*REPORT*
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# Could planet/sun conjunctions be used to predict large (moment magnitude ≥ 7) earthquakes?

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## Introduction

Following the recent moment magnitude (Mw) 7.8 and Mw 7.5 Kahramanmaraş, Türkiye, earthquake sequence on 6 February 2023 (U. S. Geological Survey, 2017), an assertion that planet/sun alignments and lunar phases may help to predict an earthquake occurrence became widespread in some news outlets and on social media (Chappell, 2023). In the following, we call this alignment of three celestial bodies a conjunction, although the correct word in astronomy would be a syzygy.

Usually, the assertion that planet/sun alignments and lunar phases may predict an earthquake occurrence is promoted by choosing carefully a period of time at which these alignments occur and showing specific earthquakes that occurred at the same time. Such assertions usually do not mention that these conjunction events do happen extremely frequently, and that most of the time, they are not followed by significant earthquakes. By making a large number of predictions (Garcia, 2017; Service Checknews, 2019), some of them may come true, but that does not mean that the method has any predictive power. The only literature available arguing that conjunctions can be used to predict earthquake occurrence either calls into question fundamental physics without any proof (Omerbashich, 2011; Safronov, 2022), or does not show the background rate of conjunctions (Awadh, 2021). The major logical flaw in these analyses is showing only events that are associated with conjunctions while not paying attention to the total quantity of conjunctions (see Khalisi, 2021; Zanette, 2011). Indeed, if conjunctions are very common, it is easy to associate them with earthquakes, but it may not help in any way to predict future earthquakes.

The assertion that planet/sun alignment may predict an earthquake can be seen as a more evolved version of the theory that the moon phase has a strong influence on earthquakes. The moon phase theory has been debated for a long time by seismologists (e.g., Schuster, 1897), and the question is still not completely answered yet (Ide et al., 2016; Hough, 2018; Kossobokov and Panza, 2020; Zaccagnino et al., 2022). In some regions, slow-earthquakes like tremors (Nakata et al., 2008; Rubinstein et al., 2008) or low frequency earthquakes (Thomas et al., 2012) are influenced by tides. Depending on the area, the considered period in the seismic cycle (Tanaka, 2010, 2012; Peng et al., 2021), and the focal mechanism (Tsuruoka et al., 1995), the moon phase may have some influence or not. Overall, it seems to have an influence (Yan et al., 2023), at least for some regions/period or time, that may be incorporated in long term probabilistic earthquake forecasting (Ide et al., 2016); however, this effect is too small to be used as a way to predict earthquakes (Witze, 2016). A rigorous attempt to perform short term prediction, with the idea that before a large earthquake, smaller earthquakes would be more tide-sensitive as the crust is approaching critical strength, proved the method to be ineffective for prediction (Hirose et al., 2022).

While for the moon/earth/sun alignments, there exists a physical mechanism by which the stresses are

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changing in the crust via gravity change which may weakly influence earthquake occurrence (Ide et al., 2016), there is no such mechanism for planets/sun alignments because the electromagnetic and gravity fields due to celestial bodies other than the Sun and moon are usually extremely small when they reach the Earth.

This paper aims to test whether the planet/sun alignment, along with the moon phase, can be used to predict earthquakes. For this purpose, we are systematically comparing the percentage of earthquakes linked with conjunction(s) with the percentage of the time that conjunction(s) are happening over a 69-year period of time using a global catalog of earthquakes. In the future, more detailed analyses can be conducted to examine whether there is an effect of other planets on the occurrence of earthquakes, for example by calculating the gravitational effects on the tractions of differently oriented faults (e.g., Cochran et al., 2004; Ide et al., 2016).

This assertion that planet/sun alignment is strongly promoting earthquakes would be valid only if the rate of earthquakes associated with conjunctions was higher than the conjunction rate. We evaluate the significance of our results by calculating the p-value, making the null hypothesis that earthquakes follow a binomial distribution during the period of our catalog with the probability given by the probability of conjunctions.

## Method

We first chose the ISC-GEM catalog (Storchak et al., 2013, 2015; Di Giacomo et al., 2018) and selected earthquakes of Mw ≥ 7 over the period 1950/01/01-2018/12/31. The reason for starting at the year 1950 is because the catalog starts to be complete for shallow events (>60km) and for Mw ≥ 7 at years 1918–1939 (Michael, 2014). We chose the 10 years delay as a margin to be sure not to flaw the analysis by missing any Mw 7 earthquakes.

To calculate each planet/sun alignment, we took advantage of the Astropy package in python (The Astropy Collaboration et al., 2018, 2022) that allows us to calculate the position of any planets in the solar system, the Sun, and the moon at any time. For each day covering the period of the earthquake catalog, we calculated if there was a conjunction or not. We used the NASA JPL ephemerides model "DE430" (Folkner et al., 2014). We did not take into account leap seconds in the calculation of the day, because the offset is less than a minute for the considered period.

The celestial bodies included are: the Sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

For each triplet of given three celestial bodies $A$, $B$ and $C$ in the solar system, we calculated their positions in International Celestial Reference System (ICRS).

We then calculated each vector $\overrightarrow{AB}$, $\overrightarrow{BC}$, $\overrightarrow{AC}$ and the associated norms $\left\|\overrightarrow{AB}\right\|$, $\left\|\overrightarrow{BC}\right\|$ and $\left\|\overrightarrow{AC}\right\|$. The vector that has the longest norm shows the greatest distance between two bodies, hence we can find the body that is in the middle. For example, if $\left\|\overrightarrow{AC}\right\|$ is the greatest distance, we can guess that the celestial body $B$ is in the middle. Finally, we can calculate the angle between $\overrightarrow{AB}$ and $\overrightarrow{BC}$ as:

$$\theta = \frac{180}{\pi} \cos^{-1}\left(\frac{\overrightarrow{AB} \bullet \overrightarrow{BC}}{\left\|\overrightarrow{AB}\right\| \left\|\overrightarrow{BC}\right\|}\right), \quad (1)$$

in degrees.

When the angle $\theta$ was smaller than a threshold $\theta_{\text{thr}}$, we set that there was an alignment of the celestial bodies for the day. In the following paper, we used the threshold $\theta_{\text{thr}} = 3°$ unless stated otherwise.

For the moon phase, we calculated the projection of the moon on the ecliptic plane (the plane that contains the orbital of the Earth). Then, we tried to find if the projection on this plane was in opposition (full Moon) or in conjunction (new Moon) with the Sun from the Earth. A threshold of $6.5^{\circ}$ was used, and this threshold is chosen because the average orbital of the moon around the Earth during one day is around $12^{\circ}$.

## Results

The results are presented in Table 1 for the threshold $\theta_{\text{thr}} = 3^{\circ}$. The total time period consists of 25202 days, among which 19565 days are associated with conjunctions, so that 78% of the time, there is at least one conjunction on the day. For the same period, there are 813 earthquakes, among which 640 are associated with conjunctions, so that 79% percent of earthquakes are associated with conjunctions.

We did the same study for earthquakes associated with full or new moon, as well as for earthquakes associated with both full or new moon and at least one conjunction. The percentage of days associated with either full or new moon is 7% (1743/25202), very much the same as the number of earthquakes that happened during full or new moon 7% (58/813). Finally, there are 5% (1349/25202) of days, and 6% (52/813) of earthquakes associated with both full or new moon and at least one conjunction.

We can formulate the null hypothesis that earthquakes follow a binomial law with the probability $p$ given by the number of days that are associated with conjunctions:

$$P\left[k\,|n|\,p\right] = \binom{n}{k} p^k (1-p)^{n-k}, \quad (2)$$

where $P$ is the probability to observe $k$ earthquakes that are associated with at least one conjunction in the total number of earthquakes $n$. Because $n$ is large in our sample, we can approximate the binomial distribution by a normal law:

$$P[k|n|p] \approx \frac{e^{-\frac{1}{2}\left(\frac{k-np}{\sqrt{np(1-p)}}\right)^2}}{\sqrt{2\pi np(1-p)}}. \quad (3)$$

Finally, the single-side p-value will be:

$$p_{\text{value}} = \frac{1}{2} - \frac{1}{2}\text{erf}\left(\frac{k-np}{\sqrt{2np(1-p)}}\right), \quad (4)$$

| | |
|---|---|
| **Number of days associated with conjunction(s)** | 19565/25202 (77.63%) |
| **Number of earthquakes associated with conjunction(s)** | 640/813 (78.72%) $p_{\text{value}} = 0.23$ |
| **Number of days associated with full/new moon** | 1743/25202 (6.92%) |
| **Number of earthquakes associated with full/new moon** | 58/813 (7.13%) $p_{\text{value}} = 0.40$ |
| **Number of days associated with both full/new moon and conjunction(s)** | 1349/25202 (5.35%) |
| **Number of earthquakes associated with both full/new moon and conjunction(s)** | 52/813 (6.40%) $p_{\text{value}} = 0.09$ |

**Table 1** Comparison of the frequency of a particular event (for example a conjunction), and the frequency of an earthquake that can be associated to the event during the period 1950/01/01-2018/12/31. The threshold used here to define a conjunction is $\theta_{\text{thr}} = 3^{\circ}$. The calculated p-value is one-sided, for the null hypothesis that the earthquakes follow a binomial law with the probability given by the frequency calculated with the number of days.

if $k > np$, where erf is the error function.

The p-value represents the probability of obtaining a value worse than or equal to the calculated value. Usually, a value $p_{\text{value}} < 0.05$ is taken to indicate that we can reject the null hypothesis, meaning that there is only 5% chance that the null hypothesis could be true given the data.

We choose a single-side p-value because this will favor the rejection of the null hypothesis (the single side p-value is lower than the two-side p-value), hence it is providing an initial advantage to the hypothesis that conjunctions are linked to earthquakes. Given that the p-value for earthquakes associated with conjunction(s) is 0.23 (Table 1), we cannot reject the null hypothesis, hence the difference between the observed value of earthquake linked with conjunction(s) and the total number of conjunctions is not significant. The same analysis can be done for earthquakes associated with full/new moon ($p_{\text{value}} = 0.40$, Table 1), or earthquakes that are associated with both full/new moon and at least one conjunction ($p_{\text{value}} = 0.09$, Table 1). In these two cases, the p-value is also high enough ($p_{\text{value}} > 0.05$) that we cannot reject the null hypothesis.

## Discussion and conclusion

The frequency of earthquakes associated with conjunction(s) and the frequency of conjunctions are pretty much the same, and the difference is statistically non-significant (all the p-values are larger than 5%). This means that we cannot reject the hypothesis that earthquakes are occurring following a binomial law during the time period of the earthquake catalog.

The fact that the null hypothesis cannot be rejected does not mean that it is the true hypothesis. It just means that given this earthquake catalog, we do not have a scientific basis to reject it.

It is known that earthquakes are not completely random, especially because of aftershocks, and aftershocks have not been removed from the catalog here. However, trying to remove aftershocks and foreshocks does not change the conclusion of the paper (see Supplementary Text and Supplementary Tables S1-S2).

The assertion that earthquakes are linked with conjunctions is unlikely based on our results. For such a strong claim that earthquakes can be predicted using conjunctions and moon phase, because it would have extremely important societal implications, it would need very significant results associated with very low p-value. This is far from being the case here.

We also tried to find if a planet was more often that the others associated with conjunctions (Figure 1). This seems not to be the case because the p-value for every planet (except Neptune) is quite large ($p_{\text{value}} \geq 0.1$). For Neptune, the p-value is small, which means that the probability to observe this result or more extreme results was only 1%. Given the earthquake catalog and the period of time, we cannot statistically rule out that Neptune has some influence. However, it still does not mean that it can be used for earthquake prediction because conjunctions including Neptune are very common and 97% of the time are not followed by a large earthquake (there are 8344 days with at least one conjunction including Neptune, and 266 earthquakes are associated with at least one conjunction including Neptune).

Finally, we tried to see if a conjunction was more often than others associated with earthquake occurrence (Figure 2). The results are less clear, because for a given conjunction, the percentage of one particular conjunction during the whole period is small (<2% for the conjunction that is the most frequent), so that the number of earthquakes sampling this conjunction is also very small. This leads to a large variability. However, we can

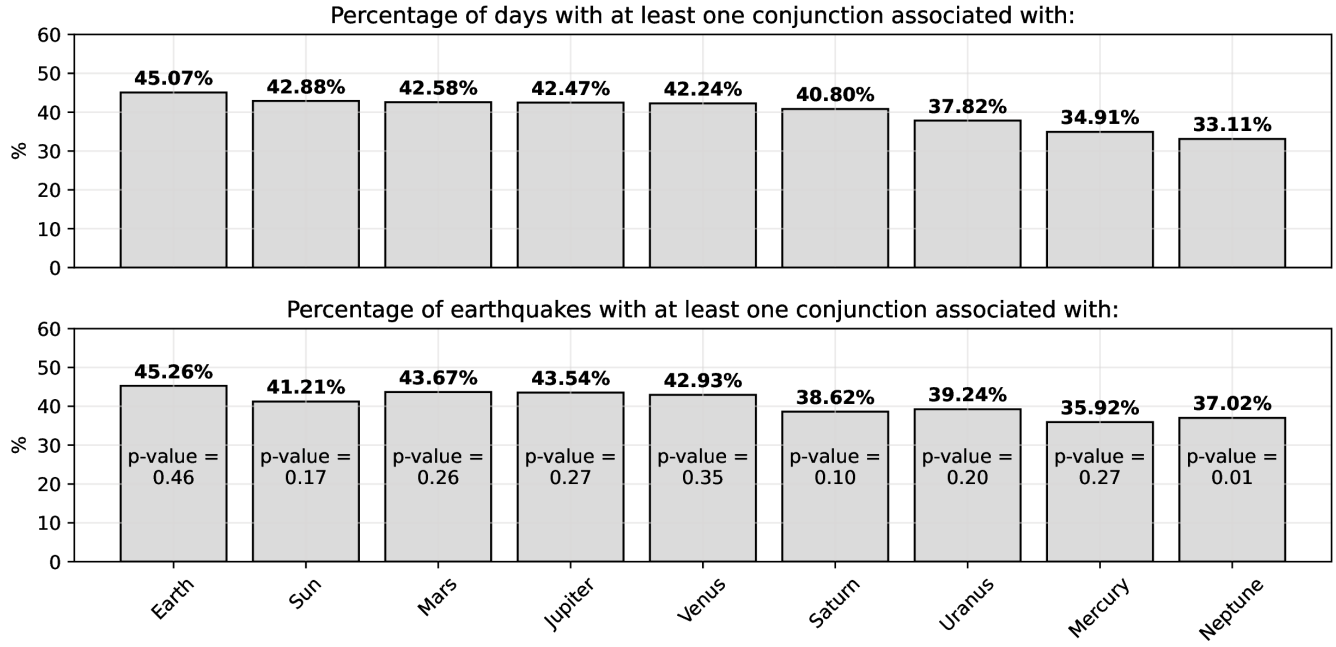


**Figure 1** Comparison of the percentage of days involving at least one conjunction associated with a given planet, and the percentage of earthquakes linked with at least one conjunction associated with a given planet. The threshold angle to define a conjunction is $\theta_{\text{thr}} = 3^{\circ}$.

still say that the overall trend is respected, such that the conjunctions that are the most frequent are most often associated with earthquakes.

Changing the threshold for conjunction does not change the results, and the same conclusion can be made. If the threshold angle is too small, we may miss some conjunctions because the orbital plane is not exactly the same for each planet. For example, the results with the threshold of $2^{\circ}$ are given in Supplementary Table S3. Reducing the threshold angle mainly reduces the percentage of time conjunctions are happening and reduces in the same way the percentage of earthquakes that are associated with conjunctions.

Persons defending the assertion of planet/sun conjunctions may continue arguing that I still did not look at a particular association of conjunctions, or association with only full moon. This is true. But given the number of possible associations, it is impossible to test them all. Rigorous and scientific tests of any such specific associations are welcomed.

The alignment of three planets/sun is actually something extremely ordinary in the solar system that is happening close to every day (for the threshold $3^{\circ}$, it happens 78% of the time). Finding a conjunction on the day of an earthquake is therefore normal, and if we start looking at time windows including some days before and after an earthquake it becomes even more likely that a conjunction will have occurred. We showed that the percentage of earthquakes associated with at least one conjunction is actually very similar to the percentage of the time where there is at least one conjunction, and that the difference between the two is not statistically significant. Hence, there is no significant effect of planet/sun alignment or moon phase on the occurrence of large earthquakes, and it can certainly not be used to provide short term prediction of earthquakes.

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## Data and code availability

The catalog of earthquake is available at the following link: http://www.isc.ac.uk/iscgem/request_catalogue.php

The software used to create the figures and perform the calculation is available on Zenodo (DOI: 10.5281/zenodo.7859401) at the following link: https://zenodo.org/badge/latestdoi/612635356. It uses python, with the Astropy package.

## Competing interests

The author has no competing interests.

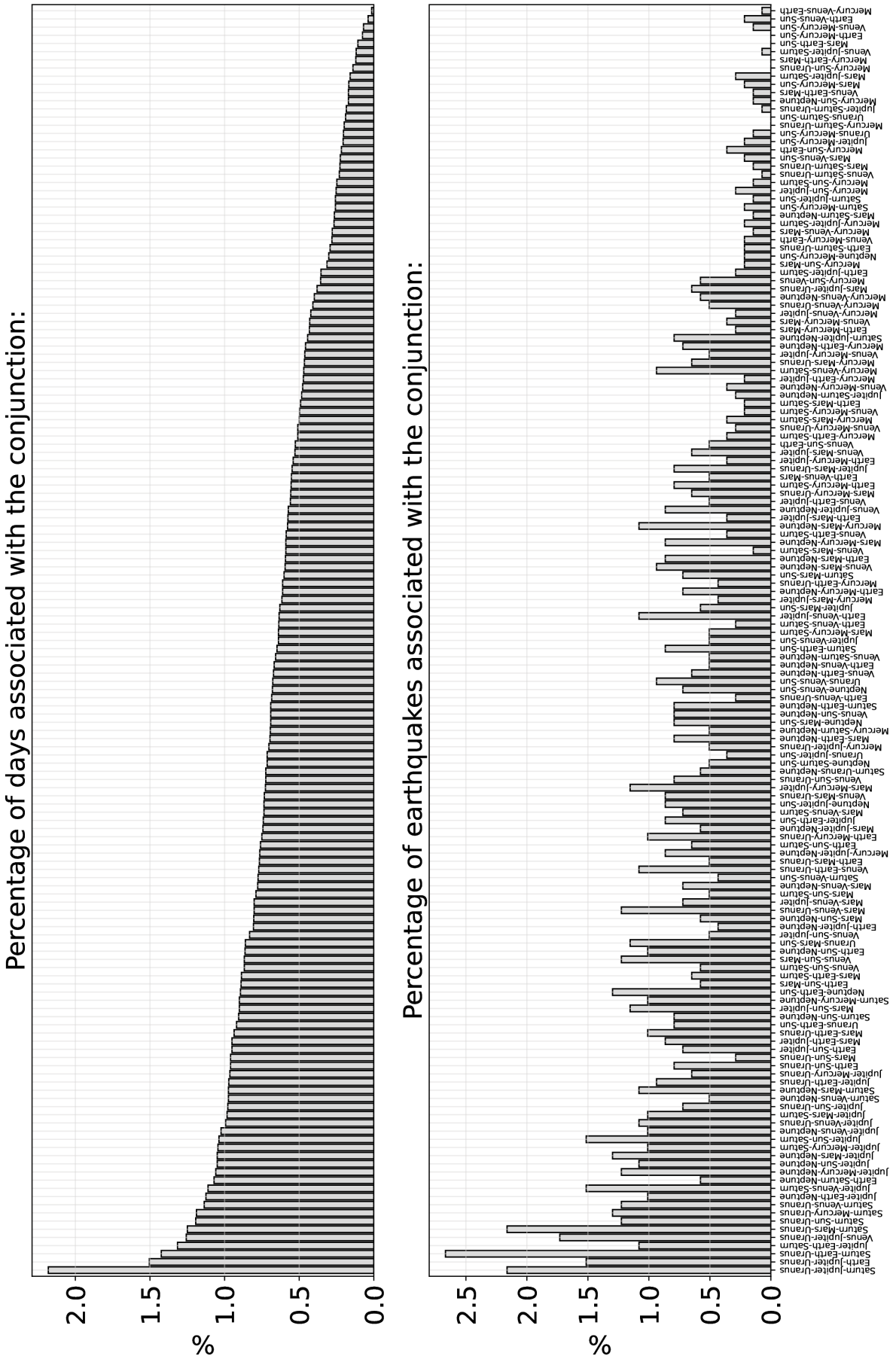


**Figure 2** Comparison of the percentage of days that a specific conjunction happens, with the percentage of earthquakes that can be linked with the same specific conjunction. The threshold angle to define a conjunction is $\theta_{\text{thr}} = 3^{\circ}$).

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