On the correlation of seismic activity to syzygies.

Abstract. The effect of lunar syzygies on powerful seismic events is studied.

Key words: earthquakes, volcanic eruptions, syzygies.

Introduction. A simple online search for the relationship of powerful seismic events with syzygies yields literally an enormous number of research papers going back to, at least, the 19th century, [10]; some prove the existence of such a relationship while the others disprove it. Rejections of the very existence of such correlation are plentiful both in the scientific literature, and online with any correlations attributed to mere coincidence. The existence of correlation between seismic activity and lunar motion is a seismic stand-off between those who believe that seismic activity can be predicted and those who do not. The former is best represented by the International Institute of Earthquake Prediction Theory founded by Vladimir Keilis-Borok, whose algorithm for earthquake prediction has been used to successfully predict the outcomes of numerous elections. The latter is represented by western institutions, who, after remarkably unsuccessful attempts to predict earthquakes in 1970s, have switched to complete denial of any seismic predictions. The latter argue that the increase in the tidal pull near syzygies is too small to have any effect. However, quite a few physical phenomena exhibit drastic responses to rather tiny changes in parameters. One example is provided by CO_2 which can be liquefied at $\approx 304.25K$ at a pressure of $\approx 73atm$, but not at a slightly higher temperature, even under pressures as high as $3\,000\ atm$; of course, that is because $\approx 304.25K, \approx 72.9atm$ is CO_2's critical point. If the Earth is in a critical state in some sense, it may be sensible to relatively small changes in the forces exhorted on it.

But given the relatively small change in tidal forces during syzygies, can their effect be sufficient strong to be detectable? Our research shows that it is indeed possible to detect tidal influence on Earth's seismic activity, yet it is often obscured by other, possibly more powerful, factors. In this paper we discuss the seismic activity showing correlation with lunar syzygies using data from [1, 2, 5]; specifically 1) magnitude $\geqslant 8.2$ earthquakes, 2) VEI $\geqslant 5$ volcanic eruptions, 3) earthquakes in Africa, 4) earthquakes originating below $400\ km$, 5) the year 2012 phenomenon.

The seismic data seems to be reliable from 1978 onwards; the first disagreements between major catalogs of seismic data appears as recently as 1977, e. g. [1] and [2] disagree on the magnitude of the 1977/8/19 earthquake, the earthquake is given magnitude 8.3 by [1] and magnitude 8.0 by [2]. With a considerable leap of faith we may assume that the seismic data from 1900 onwards is sufficiently reliable to draw conclusions. The pre-1900 seismic data cannot be considered reliable and may be used to draw only general conclusions.

The main ingredients of the patterns associated with the lunar motion are the synodic and anomalistic months. A *synodic month* is the time between two exactly the same adjacent phases of the Moon, e.g. two adjacent Full Moons, two adjacent New Moons, etc.; an *anomalistic month* is the time between two adjacent perigees. The exact values of synodic and anomalistic months vary, but the *average synodic month* is ≈ 29.530587981 days and the *average anomalistic month* is ≈ 27.554551. Since 14 average synodic months ≈ 413.428 days and 15 average anomalistic months ≈ 413.318 days are almost the same, the lunar motion is almost cyclical repeating itself approximately every 413 - 414 days. Thus we may define a *full lunar cycle* to be a period of ≈ 413 consecutive days which begins and ends with the same lunar phase and contains 14 New Moons, 14 Full Moons, and 15 perigees. The *closest perigee* and *2nd closest perigee* of a full lunar cycle come within less than 11 hours of New/Full Moon, and are typically separated from each other by 6-8 synodic months, [12]; e.g. the closest perigee and Full Moon were less than 2 hours apart on 2015/9/28, the 2nd closest perigee and New Moon were less than 8 hours apart on 2015/2/19. Very rarely, the 2nd closest perigee may be merely a month away from the closest perigee, e. g. in 1963 the perigees on 1963/11/2 and 1963/11/30 were at, correspondingly, $356\,958\ km$ and $356\,954\ km$ with, correspondingly 10 hours 30 minutes and 10 hours 47 minutes separating the perigees from Full Moon; the third closest perigee of $356\ 972\ km$ was on 1963/4/23 with only two hours away from New Moon. Seismic activity is influenced not only by mere proximity to a syzygy, but also by different aspects of the syzygy, e. g. the distance between Moon and Earth, proximity to perigee/apogee, proximity to perihelion, etc. In this paper, for simplicity's sake, we divide syzygies into only three types:

regular syzygy is a syzygy more than 12 hours away from the nearest perigee. (1a)

syzygy-perigee is a syzygy within 11 hours of a closest/2nd closest perigee (1b)

twin pair is a syzygy within 11 hours of a closest/2nd closest perigee coupled with an adjacent syzygy with very similar parameters, e. g. 1963/11/2 and 1963/11/30 (1c)

and define

$$\mathcal{H}_n \text{ to be the time } \begin{cases} \text{either within } 0.5+n \text{ days of a regular syzygy, or} \\ \text{within } 30+n \text{ days of a syzygy-perigee, or} \\ \text{within } 30+n \text{ days of a twin pair, where 1 day} = 24 \text{ hours.} \end{cases} \tag{1d}$$

A good example of a twin pair is provided by the already mentioned 1963/11/30 Full Moon separated from the closest perigee of $356\,954$ *km* by 10 hours 47 minutes and 1963/11/2 Full Moon separated from the 2nd closest perigee of $356\,958$ *km* by 10 hours 30 minutes; they were preceded by the 1963/4/23 New Moon separated from the 3rd-closest perigee of $356\,972$ *km* by merely two hours. For our purpose, the three events are practically indistinguishable, all three should be treated as syzygy-perigees; it is easier, however, to view the two syzygy-perigees of 1963/11/30 and 1963/11/2 as a single event of a twin-pair.

An event is in $\mathcal{H}_n$, if it is either within $0.5+n$ days of a regular syzygy or within $30+n$ days of a syzygy-perigee or a twin pair; $\mathcal{H}_n \subset \mathcal{H}_{n+1}$. The percentage of days in $\mathcal{H}_n$ is[1]

$$\approx \frac{9\,979.5+3\,992\,n}{29\,648.7} \approx \begin{cases} 74.1\%, & \text{if } n=3 \\ 60.6\%, & \text{if } n=2 \\ 47.1\%, & \text{if } n=1 \\ 33.7\%, & \text{if } n=0 \end{cases} = 74.1\%/60.6\%/47.1\%/33.7\% \tag{2}$$

If a sufficiently large group of events has $p_3\%/p_2\%/p_1\%/p_0\%$ in $\mathcal{H}_3/\mathcal{H}_2/\mathcal{H}_1/\mathcal{H}_0$, then the ratios $\boldsymbol{\kappa}_3 = \dfrac{p_3}{74.1}, \boldsymbol{\kappa}_2 = \dfrac{p_2}{60.6}, \boldsymbol{\kappa}_1 = \dfrac{p_1}{47.1}, \boldsymbol{\kappa}_0 = \dfrac{p_0}{33.7}$ are indicative of the syzygies' influence on the events.

For the sake of brevity, we shall use M for "magnitude".

M ⩾ 8.2 earthquakes in 1550 - 2017. Table 1 shows M ⩾ 8.2 earthquakes in 1938 - 2017. It was compiled by merging data from [1, 2]; fore/aftershocks are not listed.

Of the 36 earthquakes in Table 1 listed by [1] as M ⩾ 8.2, 34/29/23/18, or 94.4%/80.6%/63.9%/50%, are in $\mathcal{H}_3/\mathcal{H}_2/\mathcal{H}_1/\mathcal{H}_0$. Not only the percentages are better than (2), the ratios of these percentages to (2) $\boldsymbol{\kappa}_3 = \dfrac{94.4}{74.1} \approx 1.27, \boldsymbol{\kappa}_2 = \dfrac{80.6}{60.6} \approx 1.33, \boldsymbol{\kappa}_1 = \dfrac{63.9}{47.1} \approx 1.36, \boldsymbol{\kappa}_0 = \dfrac{50.}{33.7} \approx 1.48$ increase as n decreases. Only two earthquakes from [1] did not make it to $\mathcal{H}_3$, both rather special. The 2006/11/15

Table 1: M $\geqslant$ 8.2 earthquakes in 1938 - 2017. Fore/aftershocks are not listed, [1, 2, 12, 14].

date, time, magnitude	pertinent events	$\mathcal{H}_n, n=$	source
2017/9/8 4:49 M=8.2	2017/9/6 7:05 Full Moon, 2017/9/6 X9.3 solar flare	2	[1, 2]
2015/9/16 22:55 M=8.3	2015/9/13 6:43 New Moon 12 days before 2015/9/28 2:52 Full Moon-2nd closest perigee	 0	[1, 2]
2014/4/1 23:46 M=8.2	2 days 5 hours after 2014/3/30 18:48 New Moon	2	[1, 2]
2013/5/24 5:45 M=8.3	23 hours before 2013/5/25 4:27 Full Moon 30.3 days before 2013/6/23 11:11 Full Moon-closest perigee	1	[1, 2]
2012/4/11 8:39 M=8.6	25 days before 2012/5/6 3:36 Full Moon-closest perigee	0	[1, 2]
2011/3/11 5:46 M=9.1	7 days before 2011/3/19 18:11 Full Moon-closest perigee	0	[1, 2]
2010/2/27 6:34 M=8.8	2010/2/28 16:39 Full Moon, 2010/2/27 perigee 28 days after 2010/1/30 6:19 Full Moon-closest perigee	 0	[1, 2]
2007/9/12 11:10 M=8.4	22.5 hours after 2007/9/11 12:45 New Moon	1	[1, 2]
2006/11/15 11:14 M=8.3	Kuril Islands, 10 *km* deep	$\geqslant$4	[1, 2]
2005/3/28 16:10 M=8.6	2 days 19 hours after 2005/3/25 21:01 Full Moon	3	[1, 2]
2004/12/26 0:59 M=9.1	2004/12/26 21:31 Full Moon 15 days before 2005/1/10 12:04 New Moon-closest perigee	 0	[1, 2]
2003/9/25 19:50 M=8.3	9 hours before 2003/9/26 3:09 New Moon	0	[1, 2]
2001/6/23 20:33 M=8.4	2 days 9 hours after 2001/6/21 11:59 New Moon	2	[1, 2]
1996/2/17 6:00 M=8.2	1 day 18 hours before 1996/2/18 23:32 New Moon	2	[1, 2]
1994/10/4 13:23 M=8.3	15 hours before 1994/10/5 3:55 New Moon 30 days before 1994/11/3 13:36 New Moon-2nd closest perigee	 0	[1, 2]
1994/6/9 0:33 M=8.2	1994/6/9 8:28 New Moon	0	[1, 2]
1989/5/23 10:55 M=8.2	2 days 17 hours after 1989/5/20 18:18 Full Moon	3	[1, 2]
1977/8/19 6:09 M=8.3 (M=8.0 in [2])	1977/8/14 21:30 New Moon, 21 hours short of $\mathcal{H}_3$	$\geqslant$4	[1]
1969/8/11 21:26 M=8.2 (M=7.5 in [1])	1 day 7 hours before 1969/8/13 5:16 New Moon	1	[2]
1968/5/16 10:49 M=8.2	4 days after 1968/5/12 13:05 Full Moon-2nd closest perigee	0	[1, 2]
1965/2/4 5:01 M=8.7	1965/2/1 16:37 New Moon 18 days after 1965/1/17 13:38 Full Moon-closest perigee	 0	[1, 2]
1965/1/24 0:11 M=8.2 (M=7.6 in [2])	7 days after 1965/1/17 13:38 Full Moon-closest perigee	0	[1]
1964/3/28 3:36 M=9.2	1964/3/28 2:49 Full Moon	0	[1, 2]
1963/11/4 1:17 M=8.3	2 days after 1963/11/1 13:57 Full Moon-2nd closest perigee	0	[1, 2]
1963/10/13 5:18 M=8.5	20 days before 1963/11/1 13:57 Full Moon-2nd closest perigee	0	[1, 2]
1960/5/22 19:11 M=9.5	1960/5/25 12:27 New Moon, 1960/6/9-10 Full Moon-perigee accompanied by VEI=3 1960/5/24 eruption of Puyehue,	3	[1, 2]
1959/5/4 7:16 M=8.2 (M=7.9 in [1])	1959/5/7 20:13 New Moon 19 days before 1959/5/22 12:55 Full Moon-2nd closest perigee	 0	[2]
1958/11/6 22:58 M=8.3	24 days after 1958/10/12 20:52 New Moon-2nd closest perigee	0	[1, 2]
1957/3/9 14:23 M=8.6	23 days after 1957/2/14 16:38 Full Moon-closest perigee accompanied by VEI=2 1957/3/11 eruption of Vsevidof	0	[1, 2]
1952/11/4 16:58 M=9.0	2 days 16 hours after 1952/11/1 23:09 Full Moon	3	[1, 2]
1950/12/9 21:39 M=8.2 (M=8.0 in [2])	1950/12/9 9:29 New Moon-closest perigee	0	[1]
1950/8/15 14:10 M=8.6	2 days after 1950/8/13 16:47 New Moon	2	[1, 2]
1949/8/22 4:01 M=8.2 (M=8.1 in [2])	2 days before 1949/8/24 3:59 New Moon, 1949/8/25 perigee	2	[1]
1948/1/24 17:46 M=8.3 (M=7.8 in [1])	1948/1/26 11:17 Full Moon-closest perigee	0	[2]
1946/12/20 19:19 M=8.3	1946/12/23 13:06 New Moon 11 days after 1946/12/8 17:52 Full Moon-closest perigee	 0	[1, 2]
1946/4/1 12:29 M=8.6	16 hours before 1946/4/2 4:39 New Moon	1	[1, 2]
1943/4/6 16:07 M=8.2 (M=8.1 in [1])	1 day 19 hours after 1943/4/4 21:55 New Moon	2	[2]
1942/8/24 22:50 M=8.2 (M=8.1 in [1])	1 day 5 hours before 1942/8/26 3:45 Full Moon	1	[2]
1941/11/25 18:03 M=8.3 (M=8.0 in [1])	1941/11/19 0:04 New Moon-closest perigee	0	[2]
1940/5/24 16:34 M=8.2	3 days 3 hours after 1940/5/21 13:32 Full Moon	3	[1, 2]
1939/1/25 3:32 M=8.3 (M=7.8 in [1])	10 days before 1939/2/4 7:55 Full Moon-closest perigee	0	[2]
1938/11/20 20:19 M=8.3	28 hours before 1938/11/22 0:05 New Moon	1	[1, 2]
1938/2/1 19:04 M=8.5	1 day 6 hours after 1938/1/31 13:35 New Moon	1	[1, 2]

earthquake, followed by M=8.1 2007/1/13 aftershock, started the eleven-month season 2006/11/15 - 2007/9/29 with the most $\mathrm{M} \geqslant 8.0$ earthquakes, five in total; for comparison there were 69 $\mathrm{M} \geqslant 8.0$ earthquakes in 1938 - 2017 averaging ≈ 0.79 earthquakes per an eleven-month period. The 1977/8/19 earthquake started the 1977/8/20-1985/3/3 $\mathrm{M} \geqslant 8.0$ - earthquake drought, the longest period in 1900 - 2017 without a $\mathrm{M} \geqslant 8.0$ earthquake. Of the 39 earthquakes in Table 1 listed by [2] as $\mathrm{M} \geqslant 8.2$, 38/33/27/20, or 97.4%/84.6%/69.2%/51.3%, are in $\mathcal{H}_3/\mathcal{H}_2/\mathcal{H}_1/\mathcal{H}_0$; the ratios of these percentages to (2) $\boldsymbol{\kappa}_3 = \dfrac{94.4}{74.1} \approx 1.27, \boldsymbol{\kappa}_2 = \dfrac{84.6}{60.6} \approx 1.4, \boldsymbol{\kappa}_1 = \dfrac{69.2}{47.1} \approx 1.47, \boldsymbol{\kappa}_0 = \dfrac{51.3}{33.7} \approx 1.52$ increase as n decreases. Since the 1977/8/19 earthquake is listed by [2] as having $\mathrm{M} < 8.2$, only the 2006/11/15 earthquake is left out of $\mathcal{H}_3$. The 2006/11/15 earthquake preceded the 2006/12/5 X9.0 solar flare, [14]; whether that is pure coincidence or there is a connection between the earthquake and solar flare is not clear. The remarkable correlation shown in 1957/3/9 - 1968/5/16 happened to trail by three years the 19th solar cycle of 1954 - 1964, the most powerful solar cycle since the record-keeping began in 1700; whether that is a pure coincidence or not is not clear.

Table 2 shows $\mathrm{M} \geqslant 8.2$ earthquakes in 1900 - 1933. It was compiled exactly the same way as Table 1. Of the 12 earthquakes from [1], 5/3/2/2, or 41.7%/25%/16.7%/16.7%, are in $\mathcal{H}_3/\mathcal{H}_2/\mathcal{H}_1/\mathcal{H}_0$; the ratios of these percentages to (2) $\boldsymbol{\kappa}_3 = \dfrac{41.7}{74.1} \approx 0.56, \boldsymbol{\kappa}_2 = \dfrac{25}{60.6} \approx 0.41, \boldsymbol{\kappa}_1 = \dfrac{16.7}{47.1} \approx 0.35, \boldsymbol{\kappa}_0 = \dfrac{16.7}{33.7} \approx 0.5$. Of the 27 earthquakes from [2], 15/12/8/6, or 55.6%/44.4%/29.6%/22.2%, are in $\mathcal{H}_3/\mathcal{H}_2/\mathcal{H}_1/\mathcal{H}_0$; the ratios of these percentages to (2) $\boldsymbol{\kappa}_3 = \dfrac{55.6}{74.1} \approx 0.75, \boldsymbol{\kappa}_2 = \dfrac{44.4}{60.6} \approx 0.73, \boldsymbol{\kappa}_1 = \dfrac{29.6}{47.1} \approx 0.63, \boldsymbol{\kappa}_0 = \dfrac{22.2}{33.7} \approx 0.66$ are all less than one indicating that instead of being attracted to syzygies, the earthquakes were repelled from syzygies; we call such behavior *anti-correlation*. Both catalogs lead to $\boldsymbol{\kappa}_3 \geqslant \boldsymbol{\kappa}_2 \geqslant \boldsymbol{\kappa}_1 \leqslant \boldsymbol{\kappa}_0$. The thirteen earthquakes in Table 2 that did not make it to $\mathcal{H}_3$ may be divided in clusters: three in 1901/8/9 - 1903/6/2; three in 1905/7/9 - 1906/1/31; three in 1917/5/1 - 1918/8/15; and two in 1922/11/11 - 1924/4/14.

There is no reliable data about the pre-1900 earthquakes, the magnitude, coordinates of the epicenter, or even date of pre-1900 earthquakes often vary widely between catalogs. The reason for that is that the pre-1900 earthquake data is compiled based on historical descriptions, often very vague and subjective; the interpretations of these descriptions are also very subjective. The first glance at pre-1900 $\mathrm{M} \geqslant 8.2$ earthquakes is provided by Table 3 composed of the most-gossiped-about 1550 - 1899 $\mathrm{M} \geqslant 8.2$ earthquakes compiled from two Wikipedia articles [4]; the sheer number of non-scientists involved in Wikipedia seems to guarantee a certain degree of objectivity. Table 3

Table 2: M $\geqslant$ 8.2 earthquakes in 1900 - 1933. Fore/aftershocks are not listed, [1, 2, 12].

date, time, magnitude	pertinent events	$\mathcal{H}_n, n=$	source
1933/3/2 17:31 M=8.4	Japan	$\geqslant 4$	[1, 2]
1924/4/14 16:20 M=8.3	1924/5/18,21:52 Full Moon-closest perigee, 4.3 days short of $\mathcal{H}_3$	$\geqslant 4$	[2]
1923/2/3 16:02 M=8.4	48 hours after 1923/2/1 15:54 Full Moon	2	[1, 2]
1922/11/11 4:33 M=8.5	Chile	$\geqslant 4$	[1, 2]
1920/12/16 12:06 M=8.3	9 days before 1920/12/25 12:38 Full Moon-closest perigee	0	[1, 2]
1920/6/5 4:22 M=8.2	11 days before 1920/6/16 13:41 New Moon-2nd closest perigee	0	[1, 2]
1919/1/1 2:59 M=8.3	1 day 6 hours before 1919/1/2 8:24 New Moon	1	[2]
1918/9/7 17:16 M=8.3	2 days 7 hours after 1918/9/5 10:43 New Moon	2	[2]
1918/8/15 12:18 M=8.3	Philippines	$\geqslant 4$	[1, 2]
1917/6/26 5:49 M=8.3	Samoa	$\geqslant 4$	[2]
1917/5/1 18:26 M=8.2	Kermadec Islands	$\geqslant 4$	[1]
1908/12/12 12:08 M=8.2	Peru	$\geqslant 4$	[2]
1907/4/15 6:08 M=8.3	2 days 11 hours after 1907/4/12 19:08 New Moon	2	[2]
1906/12/12 18:21 M=8.3	1906/12/15 18:55 New Moon-closest perigee	0	[2]
1906/8/17 0:40 M=8.2	Chile 3 days 1 hour before 1906/8/20 1:26 New Moon	3	[1, 2]
1906/8/17 0:11 M=8.3	Alaska 3 days 2 hours before 1906/8/20 1:26 New Moon	3	[1]
1906/1/31 15:36 M=8.8	Equador	$\geqslant 4$	[1, 2]
1906/1/21 13:50 M=8.4	3 days 4 hours before 1906/1/24 17:11 New Moon	3	[2]
1905/7/23 2:46 M=8.3	Mongolia	$\geqslant 4$	[1, 2]
1905/7/9 9:41 M=8.3	Mongolia	$\geqslant 4$	[1, 2]
1905/1/22 2:43 M=8.4	20 hours after 1905/1/21 7:15 Full Moon	1	[2]
1904/8/27 21:56 M=8.3	13 days before 1904/9/9 20:43 New Moon-2nd closest perigee	0	[2]
1904/6/25 14:46 M=8.3	2 days 6 hours before 1904/6/27 20:22 Full Moon	2	[2]
1903/6/2 13:17 M=8.3	Alaska	$\geqslant 4$	[2]
1901/8/9 18:34 M=8.2	Japan	$\geqslant 4$	[2]
1901/8/9 13:01 M=8.4	Loyalty Islands, accompanied by 1901/8/9 eruption of Epi	$\geqslant 4$	[2]
1900/10/29 9:11 M=8.4	18 days after 1900/10/8 13:19 Full Moon-2nd closest perigee	0	[2]
1900/10/9 12:25 M=8.3	1 day after 1900/10/8 13:19 Full Moon-2nd closest perigee	0	[2]

indicates that the anti-correlation of M $\geqslant$ 8.2 earthquakes with syzygies shown in Table 2 extends all the way back to 1835, reaching its peak in 1905 - 1918 when the number of earthquakes in $\mathcal{H}_3$ was merely 3 out of 7, or 42.9% much less than predicted by (2). The 1919 - 1933 years seem to be the transition period between the 1898 - 1918 core of anti-correlation and the correlation season of 1938 - present. The 1835 - 1897 years seem to be the transition period between the 1898 - 1918 core of anti-correlation and the correlation season of 1550 - 1834.

Table 4, showing M $\geqslant$ 8.2 earthquakes from [2, 3], allows us to zoom in on the 1550 - 1833 years. The New Madrid earthquakes have been since downgraded to lower magnitudes and the 1761/3/30, 1716/2/11, 1586/7/10, 1584/3/17 earthquakes seem to be aftershocks of preceding earthquakes; hence they are moved to the bottom of the table. The 1818/11/8, 1793/2/17, 1787/3/28, 1725/2/1, 1647/5/14 earthquakes did not make it to $\mathcal{H}_3$ but were close. Over all, Ta-

Table 3: Representative set of M $\geqslant$ 8.2 earthquakes in 1550 - 1899 compiled from [4].

date, time, magnitude	pertinent events	$\lvert\mathcal{H}_n, n=$
1897/6/12 M=8.3	1897/5/16 Full Moon-2nd closest perigee	0
1896/6/15 10:32 M=8.8	1896/6/11 8:42 New Moon, 14 hours short of $\mathcal{H}_3$	$\geqslant 4$
1877/5/10 0:59 M=8.5	1877/5/13 5:30 New Moon	3
1868/8/13 M=8.5-9.0	1868/8/17-18 New Moon-2nd closest perigee	0
1861/2/16 M=8.5	1861/3/26 Full Moon-2nd closest perigee, 8 days short of $\mathcal{H}_3$ the 1859/9/1-2 Carrington solar storm	$\geqslant 4$
1854/12/23 M=8.4, 1854/12/24 M=8.4	1855/1/18 New Moon-2nd closest perigee	0
1835/2/20 M=8.5		$\geqslant 4$
1833/11/25 M=8.8	1833/11/27 7:09 Full Moon	2
1822/11/19 M=8.5	1822/11/29 Full Moon-closest perigee	0
1797/2/4 M=8.4	1797/2/11 Full Moon, 1797/1/12 Full Moon-closest perigee	0
1787/3/28 M=8.6		$\geqslant 4$
1762/4/2 M=8.8	in Bangladesh	$\geqslant 4$
1755/11/1 M=8.5	1755/11/4 New Moon-closest perigee	0
1751/5/24 M=8.5	1751/4/25 New Moon-2nd closest perigee	0
1746/10/28 M=8.6	1746/11/12 New Moon-2nd closest perigee, 1746/10/29 Full Moon	0
1737/10/17 M=8.5	1737/10/23 New Moon-2nd closest perigee	0
1730/7/8 M=8.7	1730/6/30 Full Moon-closest perigee	0
1707/10/28 4:00 M=9.0	1707/10/25 14:33 New Moon accompanied by 1707/12/16 VEI=4 eruption of Fuji	3
1703/12/31 M=8.2	1704/1/6 New Moon-closest perigee	0
1700/1/26 M=8.7-9.2	1700/1/5 Full Moon-closest perigee	0
1687/10/20 M=8.5	1687/10/20 Full Moon	0
1647/5/14 M=8.5	in Chile, 1647/5/18 Full Moon,	$\geqslant 4$
1604/11/24 M=8.5	1604/10/22 New Moon-2nd closest perigee	3
1575/12/16 M=8.5	1575/12/18 Full Moon-closest perigee	0
1556/1/23 M=8.2	1556/1/26 Full Moon	3

ble 4 confirms the correlation of M $\geqslant$ 8.2 earthquakes with syzygies in 1550 - 1780. The 1793/2/17, 1792/8/22, 1784/5/13 earthquakes cluster together; they struck in or right after the 1981-1789 season of intensive geomagnetic storms and may have been caused by them, [16]; it is also possible the beginning of the transition period of 1835 - 1897 should be extended from 1835 to 1784.

Antipodal symmetry of earthquakes. Since the tidal forces produced by the Moon, and amplified near syzygies, are almost antipodally symmetric, we may expect the regions of powerful seismic activity to show antipodal symmetry. Figure 1 shows 1900 - 2017 earthquakes with magnitude $\geqslant$ 8.2, according to [1]. They may be divided into groups based on location: 1) in or close to South America and the land antipodal to South America, marked purple; 2) close to the eastern boundary of Asia and the shallow floor of the Scotia Sea, shown in inset A, which are almost antipodal to each other, marked brown; 3) over or close to the shallow floor of Zealandia, shown in inset B, and the regions of Northern Africa and Europe antipodal to Zealandia, marked green; 4) along Kyril-Japan

Table 4: Earthquakes in 1550-1833 listed as M $\geqslant$ 8.2 in [2, 3]. Aftershocks are listed in the bottom.

date, time, magnitude	pertinent events	$\mathcal{H}_n$, n=	source
1833/11/25 M=8.8	1833/11/27 7:09 Full Moon	2	[2, 3]
1828/3/30 12:35 M=8.3	1828/3/31 10:24 Full Moon	1	[2]
1826/6/18 3:40 M=8.2	1826/6/19 22:54 Full Moon	2	[2]
1822/11/19 2:30 M=8.5	1822/11/29 4:32 Full Moon-closest perigee	0	[2, 3]
1819/4/12 3:00 M=8.5	1819/4/10 13:08 Full Moon	2	[2, 3]
1818/11/8 15:15 M=8.5	Indonesia, 1818/11/12 21:33 Full Moon, 18 hours short of $\mathcal{H}_3$	$\geqslant$ 4	[2, 3]
1797/2/4 12:30 M=8.4	listed in [3] as M<8.2 1797/1/12 Full Moon-closest perigee	0	[2]
1793/2/17 M=8.3	Japan, 1793/1/12 New Moon Moon-closest perigee, accompanied by 1793/2/ VEI=5 eruption of Alaid, 5 days short of $\mathcal{H}_3$	$\geqslant$ 4	[2, 3]
1792/8/22 M=8.4	Kamchatka	$\geqslant$ 4	[2, 3]
1784/5/13 M=8.4	Peru, listed in [2] as M=8.0	$\geqslant$ 4	[3]
1780/1/22 M=8.5	1780/1/22 Full Moon-closest perigee	0	[3]
1762/4/2 M $\leqslant$ 8.8	Bangladesh, no magnitude assigned in [2] due to uncertainty	$\geqslant$ 4	[3]
1755/11/1 9:30 M=8.5	1755/11/4 New Moon-closest perigee	0	[2, 3]
1751/5/24 5:30 M=8.5	1751/4/25 New Moon-2nd closest perigee	0	[2, 3]
1746/10/28 M=8.6	1746/10/29 Full Moon, 1746/11/12 New Moon-2nd closest perigee	0	[3]
1737/10/16-17 M=8.3-9.0	1737/10/23 New Moon-2nd closest perigee	0	[3]
1730/7/8 8:45 M=8.7	1730/6/30 Full Moon-closest perigee	0	[2, 3]
1725/2/1 $\approx$ 11am M=8.2	near lake Baikal 1725/1/28 Full Moon, 1 day short of $\mathcal{H}_3$	$\geqslant$ 4	[2]
1716/2/6 M=8.8	Peru, 1716/2/7 15:25 Full Moon	1	[2]
1707/10/28 4:00 M=8.4	1707/10/25 14:33 New Moon accompanied by 1707/12/16 VEI=4 eruption of Fuji	3	[2, 3]
1703/12/30 M=8.2	1704/1/6 New Moon-closest perigee	0	[2, 3]
1700/1/26 M=8.7-9.2	1700/1/5 Full Moon-closest perigee	0	[2, 3]
1687/10/20 10:30 M=8.5	1687/10/20 11:36 Full Moon	0	[2]
1678/6/18 1:45 M=8.4	1678/6/19 3:32 New Moon	1	[2, 3]
1668/7/25 M=8.5	1668/7/23 Full Moon, 1668/6/24, Full Moon-closest perigee	1-2	[2, 3]
1647/5/14 2:30 M=8.5	Chile, M=8 in [3] 1647/5/18 15:09 Full Moon, 1 day short of $\mathcal{H}_3$	$\geqslant$ 4	[2]
1629/8/1 M=8.5	1629/7/20, 1629/8/18 Full Moon-closest perigees	0	[3]
1619/2/14 16:30 M=8.6	listed in [3] as M=8 1619/2/14 12:58 New Moon	0	[2]
1609/10/20 M=8.6	listed in [3] as M<8.0 1609/11/11 Full Moon-closest perigee	0	[2]
1604/11/24 18:30 M=8.5	1604/10/22 21:04 New Moon-2nd closest perigee	2	[2]
1586/1/18 0:30 M=8.2	Japan, listed in [3] as M<8 1586/1/19 18:41 New Moon	2	[2]
1582/1/22 16:30 M=8.2	Peru, listed in [3] as M<8 1582/1/24 8:56 New Moon	3	[2]
1575/12/16 18:30 M=8.5	1575/12/18 Full Moon-closest perigee	0	[2, 3]
1570/2/8 $\approx$ 13 M=8.3	listed in [3] as M=8 1570/2/5 4:22 New Moon	3	[2]
1556/1/23 M=8.2	1556/1/26 15:28 Full Moon	3	[3]
1555/11/15 M=8.4	Peru, 1555/11/14 7:03 New Moon	1-2	[2, 3]

the following earthquakes from [2, 3] are not listed in the main table for the reasons provided	
1811-1812 New Madrid earthquakes have been downgraded from M$\geqslant$ 8.2 to M< 8.0	[2]
1787/3/28 M=8.6 Mexico, most likely an aftershock of 1776/4/21 of unknown magnitude	[2]
1761/3/30 M=8.5 Lisbon, most likely an aftershock of 1755/11/1 M=8.5	[2]
1716/2/11 M=8.6 Peru, 1716/2/7 Full Moon, most likely an aftershock of 1716/2/6 M=8.8	[2]
1586/7/10 M=8.2 Peru, most likely an aftershock of 1582/3/17 M=8.2	[2]
1584/3/17 M=8.4 Peru, most likely an aftershock of 1582/3/17 M=8.2, in which case the magnitude of 1582/3/17 should be greater than that of 1584/3/17	[2]

Table 5: Antipodal seismic activity for M $\geqslant$ 8.6 earthquakes in 1934-2018, [1, 12].

magnitude, date, location of M$\geqslant$ 8.6 earthquakes and pertinent syzygies	antipodal seismic activity and pertinent syzygies
M=8.6 2012/4/11 $2^o N, 93^o E$ 2012/5/6 Full Moon-closest perigee	M=7.4 2012/3/20 $16^o N, 98^o W$ 2012/3/22 New Moon
M=9.1 2011/3/11 $38^o N, 142^o E$ 2011/3/19 Full Moon-closest perigee	M=6.5 2011/3/6 $56^o S, 27^o W$ 2011/3/19 Full Moon-closest perigee 2011/3/4 New Moon
	VEI=5 2011/6/3-4 Puyehue $41^o S, 72^o W$ 2011/6/1 New Moon
M=8.8 2010/2/27 $36^o S, 73^o W$ 2010/1/30 Full Moon-closest perigee 2010/2/28 Full Moon	M=7.0 2010/2/26 $26^o N, 128.4^o E$ 2010/1/30 Full Moon-closest perigee 2010/2/28 Full Moon
M=8.6 2005/3/28 $2^o N, 97^o E$ 2005/3/25 Full Moon	M=6.0 2005/4/11 $7^o S, 78^o W$ 2005/4/8 New Moon
M=9.1 2004/12/26 $3^o N, 96^o E$ 2004/12/26 Full Moon	M=7.2 2004/11/15 $5^o N, 78^o W$ 2004/11/12 New Moon
M=8.7 1965/2/4 $51^o N, 179^o E$ 1965/1/17 Full Moon-closest perigee 1965/2/1 New Moon	M=6.0 1965/1/16 $56^o S, 27^o W$ 1965/1/17 Full Moon-closest perigee
M=9.2 1964/3/28 $61^o N, 147^o W$ 1964/3/28 Full Moon	M=7.8 1964/5/26 $56^o S, 28^o W$ 1964/5/26 Full Moon
M=9.5 1960/5/22 $38^o S, 73^o W$ 1960/5/25 New Moon, end of 1956-1960 intense season of solar storms, [15]	M=6.5 1960/5/18 $29^o N, 130^o E$ M=8.0 1960/3/20 $40^o N, 143^o E$, no close syzygies
M=8.6 1957/3/9 $51^o N, 176^o W$ 1957/2/14 Full Moon-closest perigee	M=6.0 1957/5/12 $61^o S, 24^o W$ 1957/5/13 Full Moon
M=9.0 1952/11/4 $53^o N, 160^o E$ 1952/11/1 Full Moon	M=6.5 1952/4/15 $57^o S, 26^o W$ M=6.4 1952/6/19 $54^o S, 54^o W$, 1952/6/22 New Moon
M=8.6 1950/8/15 $28^o N, 96^o E$ 1950/8/13 New Moon	M=7.1 1950/8/14 $28^o S, 63^o W$ 1950/8/13 New Moon
M=8.6 1946/4/1 $53^o N, 163^o W$ 1946/4/2 New Moon	M=6.4 1946/10/26 $60^o S, 35^o W$ 1946/10/24 New Moon

and Aleutian trenches or close to Alaska, marked yellow. Catalog [2] assigns magnitude $\geqslant$ 8.2 to additional earthquakes: 1969/8/11, 1959/5/4, 1948/1/24, 1943/4/6, 1942/8/24, 1941/11/25, 1939/1/25, 1924/4/14, 1919/1/1, 1918/9/7, 1917/6/26, 1908/12/12, 1907/4/15, 1906/12/12, 1906/1/21, 1905/1/22, 1904/8/27, 1904/6/25,1903/6/2, 1901/8/9 in Japan, 1901/8/9 Loyalty Island, 1900/10/29 and 1900/10/9; each one of them fits into either of the categories marked purple, green, brown or yellow.

We may also expect the most powerful seismic activity to be accompanied by considerable seismic activity near the antipodal location. Table 5 shows that this is indeed the case. Not only the M $\geqslant$ 8.6 earthquakes correlate with syzygies but so do their almost antipodal matches.

The strongest earthquakes of the full lunar cycle in 2009/7/21 - 2018/7/13, or the year

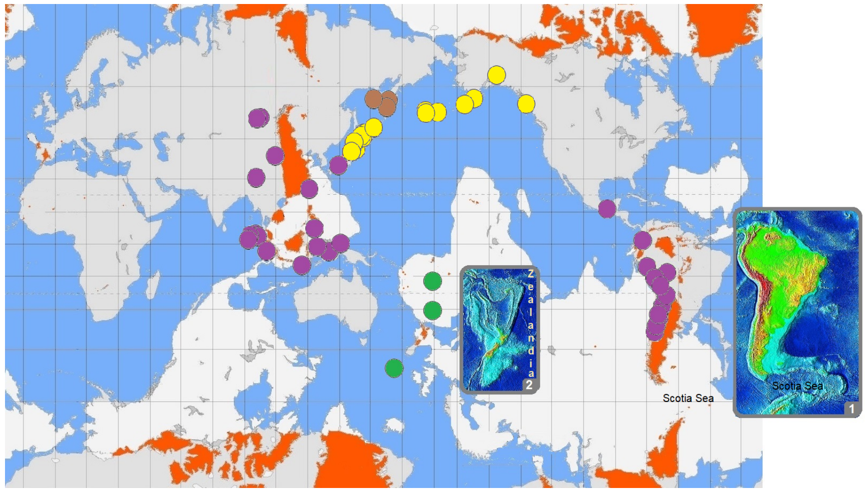


Figure 1: Magnitude $\geqslant 8.2$ earthquakes in 1900-2017 plotted on the map of antipodes in Mercator projection, [1, 11]. The land antipodal to water is shown in light gray, water antipodal to land is shown in white, land antipodal to land is shown in orange, water antipodal to water is shown in blue.

2012 phenomenon. A strong influence of the Moon was exhibited by the strongest earthquakes of the full lunar cycle in 2009/7/21 - 2018/7/13 when the strongest earthquake of the full lunar cycle struck within 33 days of Full Moon-closest perigee in six out of eight full lunar cycles, as shown in Tables 6. The correlation is, most likely, due to Full Moon coming within less than 66 minutes of the closest perigee of the full lunar cycle for five years in a row: on 2011/3/19, 2012/5/6, 2013/6/23, 2014/8/10, 2015/9/28 Full Moon and the closest perigee were correspondingly 59, 2, 23, 27, and 65 minutes apart; such an event is very rare and might be the reason why the ancient Maya used 2012 as a time stamp to mark the end of one time cycle and the beginning of another, hence we refer to the event as *the year 2012 phenomenon*. The previous sequence of Full Moon-closest/2nd closest perigees of less than an hour between Full Moon and perigee was on 1809/5/29, 1810/7/16, 1811/9/2, 1812/10/20, followed by Full Moon-closest perigees of 356 496 km on 1813/12/7 and of 356 647 km on 1815/1/25; it was followed by the 1815/4/10 VEI=7 eruption of Tambora. Would there be a powerful eruption in the next year or two?

The full lunar cycle started and ended on the day of New Moon-2nd closest perigee in 2009/7/21 - 2012/12/12, in 2014/1/30 - 2018/8/10 the full lunar cycle started and ended one synodic month after New Moon-2nd closest perigee; that may have contributed to the breakdown in the pattern causing the strongest earthquake to strike on 2014/4/1 rather than within 33 days of the

Table 6: The strongest earthquakes of the full lunar cycle in 2009/7/21 - 2018/7/13, [1, 12, 14]. The M=7.9 2017/1/22 aftershock of the M=7.9 2016/12/17 earthquake is excluded.

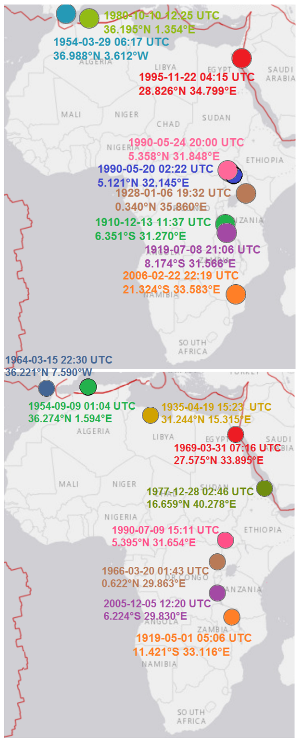
date, time, magnitude	pertinent events	$\lvert\mathcal{H}_n, n=$	antipodal activity
2009/7/21 - 2010/9/8 full lunar cycle, 406 days long			
2010/2/27 M=8.8 $36^oS, 73^oW$ near 2015/9/16	28 days after 2010/1/30 Full Moon-closest perigee, 2010/2/27-28 Full Moon-perigee	0	2010/2/26 M=7.0 $26^oN, 128^oE$
2010/9/8 - 2011/10/26 full lunar cycle, 413 days long			
2011/3/11 M=9.1 $38^oN, 142^oE$	8 days before 2011/3/19 Full Moon-closest perigee	0	
2011/10/26 - 2012/12/12 full lunar cycle, 413 days long			
2012/4/11 M=8.6 $2^oN, 93^oE$ near 2017/9/8	25 days before 2012/5/6 Full Moon-closest perigee, 2012/4/6-7 Full Moon-perigee	0	2012/4/11 M=6.5 $18^oN, 103^oW$
2012/12/12 - 2014/1/30 full lunar cycle, 414 days long			
2013/5/24 M=8.3 $55^oN, 153^oE$ near 2018/1/23	31 days before 2013/6/23 Full Moon-closest perigee, 2013/5/25-26 Full Moon-perigee	1	2013/7/15 M=7.3 $61^oS, 25^oW$
2014/1/30 - 2015/3/19 full lunar cycle, 413 days long			
2014/4/1 M=8.2 $20^oS, 71^oW$	2014/3/30 New Moon, 2014/3/29 X1.0 solar flare, **not** within 33 days of 2014/8/10 Full Moon-closest perigee	2	2014/3/2 M=6.5 $27^oN, 127^oE$ 2014/3/1 New Moon
2015/3/19 - 2016/5/6 full lunar cycle, 414 days long			
2015/9/16 M=8.3 $32^oS, 72^oW$ near 2010/2/27	12 days before 2015/9/28 Full Moon-closest perigee, 2015/9/13 New Moon	0	2015/11/13 M=6.7 $31^oN, 129^oE$ 2015/11/11 New Moon
2016/5/6 - 2017/6/23 full lunar cycle, 413 days long			
2016/12/17 M=7.9 $5^oS, 154^oE$	33 days after 2016/11/14 Full Moon-closest perigee, 2016/12/14 Full Moon	3	2016/8/29 M=7.1 $0^oS, 18^oW$ 2016/9/1 New Moon
2017/6/23- 2018/8/10 full lunar cycle, 414 days long			
2017/9/8 4:49 M=8.2 $15^oN, 94^oW$ near 2012/4/11	2017/9/6 7:05 Full Moon 2017/9/7 X9.3 solar flare	2	
2018/1/23 M=7.9 $56^oN, 149^oW$ near 2013/5/24	21 days after 2018/1/2 Full Moon-closest perigee, 20 days after 2018/1/3 perihelion	0	2018/1/28 M=6.6 $53^oS, 10^oE$

2014/8/10 Full Moon-closest perigee.

The years 2010 - 2014 produced five M $\geqslant$ 8.2 earthquakes, averaging one per year; for comparison, in 1900 - 2009 there were only 39 M $\geqslant$ 8.2 earthquakes averaging less than 0.36 earthquakes per year. Of the thirteen M $\geqslant$ 8.6 earthquakes in 1900 - 2017, three, or 23%. struck in 2010 - 2012. In the 2017/5/26 - 2018/7/13 full lunar cycle, the second strongest earthquake was 21 days after days of Full Moon-closest perigee, the strongest earthquake of the lunar cycle struck within two days of 2017/9/6 Full Moon and 2017/9/7 X9.3 solar flare.

In the 2008/6/3-2009/7/21 full lunar cycle, the strongest earthquake was of M=7.8 and it struck on 2009/7/15, 43 days after the 2009/6/3 syzygy-perigee; it was preceded by a M=7.7 earthquake on 2009/7/5, 33 day after the 2009/6/3 syzygy-perigee. Another M=7.7 earthquake

Table 7: M $\geqslant 6.6$ earthquakes in Africa in 1900 - 2016, including fore/aftershocks, [1, 12]. In bold are the earthquakes along the East African Rift Line.



Date, time, magnitude	pertinent events	$\mathcal{H}_n, n=$
2006/2/22 M=7.0	2006/2/27 New Moon-2nd closest perigee	0
2005/12/5 12:20 M=6.8	2005/12/1 15:00 New Moon 14.5 hours short of $\mathcal{H}_3$	$\geqslant 4$
1995/11/22 M=7.2	1995/11/22-23 New Moon-perigee 1995/12/22 New Moon-closest perigee	0
1990/7/9 15:11 M=6.6	1990/7/8 1:24 Full Moon	2
1990/5/20 M=7.2	1990/5/24 New Moon-2nd closest perigee	0
1990/5/24 M=7.1	1990/5/24 New Moon-2nd closest perigee	0
1980/10/10 M=7.3	1980/10/23 Full Moon-closest perigee	0
1977/12/28 M=6.6	1977/12/25 Full Moon 1977/12/10 New Moon-closest perigee	0
1969/3/31 7:16 M=6.6	1969/4/2 18:47 Full Moon	2
1966/3/20 1:43 M=6.6	1966/3/22 4:48 New Moon	2
1964/3/15 22:30 M=6.6	1964/3/14 2:16 New Moon	2
1954/9/9 1:04 M=6.7	1954/9/12 20:21 Full Moon 7.5 hours short of $\mathcal{H}_3$	$\geqslant 4$
1954/3/29 6:17 M=7.8	1954/4/3 New Moon-2nd closest perigee	0
1935/4/19 15:23 M=6.8	1935/4/18 21:11 Full Moon	1
1928/1/6 19:32 M=7.0	1928/1/7 6:08 Full Moon	0
1919/7/8 M=7.2		$\geqslant 4$
1919/5/1 M=6.7	1919/4/30 New Moon-2nd closest perigee	0
1910/12/13 M=7.3	1910/11/17 Full Moon-closest perigee	0
In addition, [2] lists the following as M$\geqslant 6.6$		
1992/9/11 M=7.0	1992/8/28 New Moon-closest perigee	0
1960/9/22 9:05 M=6.6	1960/9/20 23:12 New Moon	2
1906/8/25 M=6.8		$\geqslant 4$

struck on 2009/1/3, 22 days after the 2008/12/12 Full Moon-closest perigee. In the 2007/4/17-2008/6/3 full lunar cycle, the strongest earthquake was of M=8.4 and it struck on 2007/9/12, 44 days before the 2007/10/26 Full Moon-closest perigee. So the pattern was building up two full lunar cycles prior to 2009/7/21-2018/7/13. We may expect the pattern to wither after 2018/7/13 but it still should be felt in the 2018/7/13 - 2019/8/30 full lunar cycle suggesting a powerful earthquake of M $\geqslant 7.7$ within 45 days of the 2019/2/19 Full Moon-closest perigee, it should be one of the three strongest earthquakes of the lunar cycle.

M $\geqslant$ 6.6 earthquakes in Africa. The East African Rift Line is only a forming tectonic line, the earthquakes along it cannot be attributed to the motion of continental plates and may be expected to be more influenced by syzygies than earthquakes elsewhere. Africa's 1900 - 2017 earthquakes listed by [1] as M $\geqslant 6.6$ are shown in Table 7. Of the total of 18 earthquakes, 15/15/11/10, or 83.3%/83.3%/61.1%/55.6%, were in $\mathcal{H}_3/\mathcal{H}_2/\mathcal{H}_1\mathcal{H}_0$, the ratios of these percentages to (2) $\boldsymbol{\kappa}_3 =$

Table 8: M⩾7.4 earthquakes below 400 km in 1900 - 2017, fore/aftershocks excluded, [1, 2].

date, time, magnitude, depth	pertinent events	$\|\mathcal{H}_n, n=$	source
2015/11/24 22:46 M=7.6d=606	2015/11/25 22:45 Full Moon	1	[1, 2]
2015/5/30 11:23 M=7.8 d=664	2015/6/2 16:22 Full Moon	3	[2]
2013/5/24 5:45 M=8.3 d=598	2013/5/25 4:27 Full Moon	1	[1, 2]
2012/8/14 3:00 M=7.7 d=583	2012/8/17 15:55 New Moon	3	[1, 2]
2010/7/23 22:08 M=7.6 d=578	2010/7/22 2:35 syzygy-perigee	2	[1, 2]
2008/7/5 2:12 M=7.7 d=633	2008/7/3 2:20 New Moon	2	[1, 2]
2002/8/19 11:01 M=7.7 d=580	2002/8/22 22:30 Full Moon	3	[1, 2]
1996/8/5 22:38 M=7.4 d=550	1996/7/30 syzygy-perigee	0	[1]
1996/6/17 11:22 M=7.9 d=587	1996/6/16 1:38 New Moon	1	[1]
1994/6/9 10:33 M=8.2 d=631	1994/6/9 8:28 New Moon	0	[1, 2]
1994/3/9 23:28 M=7.6 d=563	1994/3/12 7:07 New Moon	2	[1, 2]
1984/3/6 2:17 M=7.4 d=457	1984/3/2 18:32 New Moon	0	[1]
1970/7/31 17:08 M=8 d=645	1970/8/2 5:59 New Moon	2	[1]
1968/10/7 19:20 M=7.5 d=516	1968/10/6 11:46 New Moon	1	[2]
1963/11/9 22:16 M=7.6 d=591	1963/11/2 and 1963/11/30 syzygy-perigees	0	[1, 2]
1963/8/15 17:25 M=7.7 d=550	1963/8/19 7:35 New Moon, 2 hours short of $\mathcal{H}_3$	⩾ 4	[1, 2]
1961/8/19 5:10 M=7.6 d=612	1961/8/25 syzygy-perigee	0	[1]
1961/8/31 1:57 M=7.5 d=629	1961/8/25 syzygy-perigee	0	[2]
1958/7/26 17:37 M=7.5 d=612	1958/7/30 16:46 Full Moon, 12 hours short of $\mathcal{H}_3$	⩾ 4	[1, 2]
1957/9/28 14:20 M=7.4 d=587	1957/8/25 18:11 syzygy-perigee, 12 hours short of $\mathcal{H}_3$	⩾ 4	[1, 2]
1957/4/16 4:4 M=7.5 d=600	1957/4/14 12:09 Full Moon	2	[2]
1956/5/23 20:49 M=7.6 d=419	1956/5/24 15:26 Full Moon	1	[1, 2]
1954/3/29 6:17 M=7.8 d=626	1954/4/4 syzygy-perigee	0	[1]
1937/4/16 3:02 M=8.1 d=400	1937/5/10 syzygy-perigee	0	[2]
1932/5/26 16:10 M=7.6 d=570	1932/4/20 20:14 syzygy-perigee, 2.5 days short of $\mathcal{H}_3$	⩾ 4	[1, 2]
1922/1/17 3:50 M=7.9 d=475	1922/2/12 syzygy-perigee	0	[1, 2]
1921/12/18 15:29 M=7.6 d=650	1921/12/15 2:50 Full Moon, 0.7 hours short of $\mathcal{H}_3$	⩾ 4	[2]
1919/1/1 3:01 M=7.8 d=485	1919/1/2 8:24 New Moon	1	[1]
1917/7/31 3:23 M=7.5 d=460	1917/8/3 5:11 Full Moon	3	[2]
1916/6/21 21:32 M=7.5 d=600	1916/7/15 syzygy-perigee	0	[2]
1912/12/7 22:47 M=7.5 d=620	1912/12/8 17:07 New Moon	1	[2]
1909/2/22 9:22 M=7.8 d-550	1909/2/20 10:52 New Moon, 1909/3/21 syzygy-perigee	0	[2]
1907/5/25 14:02 M=7.9 d=600	1907/5/27 14:19 Full Moon	2	[2]
1903/1/4 5:07 M=8.0 d=400	1903/1/13 syzygy-perigee	0	[2]
1902/6/11 ≈5 am M=8 d=600	1902/6/6 syzygy-perigee	0	[2]

$\frac{83.3}{74.1} \approx 1.12, \boldsymbol{\kappa}_2 = \frac{83.3}{60.6} \approx 1.37, \boldsymbol{\kappa}_1 = \frac{61.1}{47.1} \approx 1.3, \boldsymbol{\kappa}_0 = \frac{55.6}{33.7} \approx 1.65$ may be said to "almost increase" as n decreases. Of the ten earthquakes along the East African Rift Line, shown in the Table in bold, 8/8/6/6, or 80%/80%/60%/60%, were in $\mathcal{H}_3/\mathcal{H}_2/\mathcal{H}_1\mathcal{H}_0$; the ratios of these percentages to (2) $\boldsymbol{\kappa}_3 = \frac{80.}{74.1} \approx 1.08, \boldsymbol{\kappa}_2 = \frac{80.}{60.6} \approx 1.32, \boldsymbol{\kappa}_1 = \frac{60.}{47.1} \approx 1.27, \boldsymbol{\kappa}_0 = \frac{60}{33.7} \approx 1.78$ may be said to "almost increase" as n decreases. The 1990/7/9 earthquakes was 107 minutes short of $\mathcal{H}_1$, had it struck 107 minutes earlier, both ratios would have been increasing as n decreases. Three more earthquakes listed as M ⩾ 6.6 by [2] are shown at the bottom of Table 7.

Powerful earthquakes at great depths. Most earthquakes strike in or near the crust and/or upper mantle with the focal depth in the range of $0 - 400\ km$; yet some have focal depth up to $700\ km$, striking in the transition zone separating the upper mantle from the lower mantle. The high temperature and pressure in the transition zone should make them more susceptible to tidal forces.

Table 8 shows $\mathrm{M} \geqslant 7.4$ earthquakes of the focal depth $\geqslant 400\ km$ according to [1, 2] in 1900 - 2018/8/1. Of the 22 earthquakes from [1], 18/16/12/7, or 81.8%/72.7%/ 54.5%/31.8% are in $\mathcal{H}_3/\mathcal{H}_2/\mathcal{H}_1/\mathcal{H}_0$; of the 28 earthquakes from [2] 23/19/14/9, or 82.1%/67.9%/ 50%/32.1%, are in $\mathcal{H}_3/\mathcal{H}_2/\mathcal{H}_1/\mathcal{H}_0$; both distributions are somewhat similar to (2). A bit more careful examination of Table 8 shows that all earthquakes that did not make it to $\mathcal{H}_3$, almost did so.

VEI $\geqslant 5$ volcanic eruptions in 1600 - 2017. Unlike earthquakes, most powerful volcanic eruption leave long-lasting traces letting us determine their magnitudes and dates. Although the dates and magnitudes of powerful eruptions can be determined sufficiently well, it is hard to determine when the seismic activity associated with such eruptions actually started as powerful eruptions are often preceded by earthquakes and less powerful eruptions; with that in mind, Table 9 shows all VEI $\geqslant 5$ eruptions in 1600 - 2017 with syzygies, with the date and time selected or estimated to be those of the strongest blast, unless otherwise stated.

The number of eruptions in $\mathcal{H}_3/\mathcal{H}_2/\mathcal{H}_1/\mathcal{H}_0$ in 1600 - 1815 was 14/12/10/8 or 82.4%/70.6%/ 58.8%/47.1% of the total of 17; the ratios of these percentages to (2) $\boldsymbol{\kappa}_3 = \dfrac{82.4}{74.1} \approx 1.11, \boldsymbol{\kappa}_2 = \dfrac{70.6}{60.6} \approx 1.165, \boldsymbol{\kappa}_1 = \dfrac{58.8}{47.1} \approx 1.25, \boldsymbol{\kappa}_0 = \dfrac{47.1}{33.7} \approx 1.4$ increase as n decreases.

The number of eruptions in $\mathcal{H}_3/\mathcal{H}_2/\mathcal{H}_1/\mathcal{H}_0$ in 1913 - 2017 was 8/7/5/4 or 72.7%/63.6%/45.5%/ 36.4% of the total of 11; which is almost identical to (2) and the the ratios of these percentages to (2) $\boldsymbol{\kappa}_3 = \dfrac{72.7}{74.1} \approx 0.98, \boldsymbol{\kappa}_2 = \dfrac{63.6}{60.6} \approx 1.05, \boldsymbol{\kappa}_1 = \dfrac{45.5}{47.1} \approx 0.97, \boldsymbol{\kappa}_0 = \dfrac{36.4}{33.7} \approx 1.08$ are all close to one. Yet the three eruptions that did not make it to $\mathcal{H}_3$ were close, so $\boldsymbol{\kappa}_3 \approx \boldsymbol{\kappa}_2 \approx \boldsymbol{\kappa}_1 \approx\approx 1$ might be due to lack of refinement of the method employed in this paper rather than due to lack of correlation. The 1963/3/17 eruption of Agung occurred right in the midst of the 1957/3/9/,-/,1965/1/2/24 period which had nine $\mathrm{M} \geqslant 8.2$ earthquakes, most likely caused by the 19th solar cycle, the most powerful solar cycle known since the record-keeping started in 1700. The 1956/3/30 eruption of Bezymianny was the peak of a prolonged 1956 - 1963 seismic activity that almost coincided with the 19th solar cycle.

Table 9: All known VEI $\geqslant 5$ volcanic eruptions in 1600 - 2017 with the month known, [5, 12, 14].

date, volcano, VEI	pertinent events	$\lvert\mathcal{H}_n, n=$
2012/7/18-19 Havre VEI=5	2012/7/19 4:25 New Moon, coincided with a considerable drop in cosmic ray activity and preceded powerful 2012/7/23 CME	1
2011/6/3-4 Puyehue VEI=5 seismic activity started 2011/6/2	2011/6/1 21:03 New Moon	2
1991/8/8-12 Hudson VEI=5	1991/8/10 New Moon, 1991/7/11 New Moon-closest perigee	0
1991/6/15 Pinatubo VEI=6	1991/6/12 New Moon, 1991/7/11 New Moon-closest perigee; 1991/6/1 -1991/6/15 five X12.0 solar flares	0
1982/5/27-28 El Chichon VEI=5 and 1982/4/3-4, 1982/3/29	1982/6/21 New Moon-2nd closest perigee; 1982/4/8 Full Moon, 1982/3/25 New Moon	0
1980/5/18 8:32 St.Helens VEI=5 seismic activity started 1980/3/15	1980/5/14 12:02 New Moon, 22 hours short of $\mathcal{H}_3$; 1980/3/16 New Moon-2nd closest perigee	$\geqslant 4$
1963/3/17 Agung VEI=4-5	37 days before 1963/4/23 New Moon-2nd closest perigee, 4 days short of $\mathcal{H}_3$	$\geqslant 4$
1956/3/30 5:10 Bezymianny VEI=5	1956/3/26 13:11 Full Moon, 6 hours short of $\mathcal{H}_3$	$\geqslant 4$
1933/1/8 Kharimkotan VEI=5	1933/1/11 20:36 Full Moon	3
1932/4/10 Cerro Azul VEI=6	1932/4/20 Full Moon-closest perigee	0
1913/1/20 Colima VEI=5	1913/1/22 Full Moon, 1913/2/21 Full moon-closest perigee	2
1912/6/6 Novarupta VEI=6	38 days before twin pair of syzygy-perigees on 1912/7/14 and 1912/8/12, 5 days short of $\mathcal{H}_3$	$\geqslant 4$
1907/3/28 Ksudach VEI=5	1907/3/29 Full Moon	1
1902/10/24 Santa Maria VEI=5-6		$\geqslant 4$
1886/6/10 Tarawera VEI=5		$\geqslant 4$
1883/8/27 Krakatoa VEI=6	1883/9/1 New Moon; 1882/11/ powerful geomagnetic storm	$\geqslant 4$
1875/3/29 Askja VEI=5		$\geqslant 4$
1854/2/18 Shiveluch VEI=5		$\geqslant 4$
1835/1/20 Cosiguina VEI=5		$\geqslant 4$
1822/10/8 Galunggung VEI=5	1822/11/29 Full Moon-closes perigee	$\geqslant 4$
1815/4/10 Tambora VEI=7	1815/4/9 18:23 New Moon	0-1
1808/12/ exact date is unknown but was prior to 1808/12/11, exact location is unknown, VEI=6, 1 - 25 days after 1808/11/17 New Moon-2nd closest perigee		0
1793/2/ exact date is unknown, Alaid VEI=5, 19 - 47 days after 1793/1/12 New Moon-closest perigee, the average of 19 and 47 is 33, which gives $n = 3$ as the most likely value		3
1783/6/8 Laki VEI=4-5	1783/6/15 Full Moon-closest perigee	0
1755/10/17 Katla VEI=5	1755/11/4 New Moon-closest perigee	0
1739/8/19 Tarumai VEI= 5	1739/7/20 Full Moon-closest perigee	0
1721/5/11 Katla VEI=5	1721/6/10 Full Moon-closest perigee	0
1707/12/16 Fuji VEI=5	1707/12/9 Full Moon-closest perigee	0
1673/5/20 Gamkonora VEI=5	1673/5/16 11:09 New Moon	4
1667/9/23 Tarumai VEI=5	middle of Maunder Minimum	$\geqslant 4$
1663/8/16 Usu VEI=5	1663/8/18 20:15 Full Moon	2
1640/12/26 Parker VEI=5	1640/12/28 7:24 Full Moon	2
1640/7/31 Komaga-take VEI=5	1640/8/1 20:48 Full Moon	1
1631/12/16 Vesuvius VEI=5		$\geqslant 4$
1630/9/3 Furnas VEI=5	1630/9/7 New Moon-2nd closest perigee	0
1625/9/2 Katla VEI=5	1625/9/1 New Moon, 1625/8/18 Full Moon-2nd closest perigee	0
1600/2/17 Huaynaputina VEI=6	1600/2/14 17:31 New Moon	3

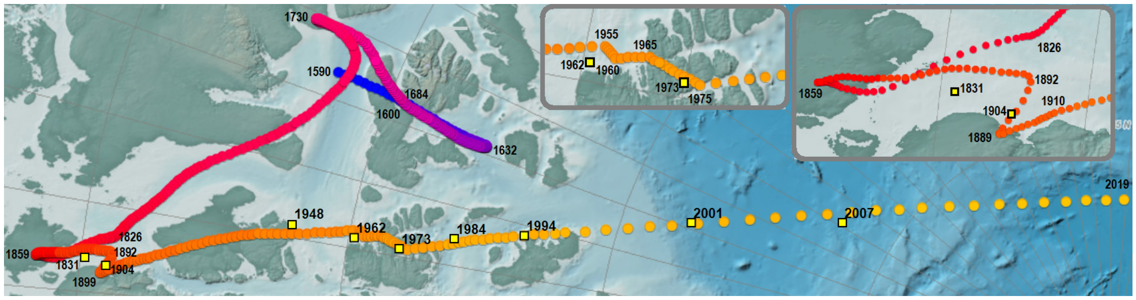


Figure 2: Modelled path of the magnetic North Pole; yellow squares indicate observed locations. The gUFM model was used for 1590-1890, the IGRF model was used for 1900-2020, a smooth transition was imposed for 1890-1900 to connect the models. The modelled path often significantly deviates from the observed locations, and thus should be viewed only as a rough approximation of the real path, [8]. The 1859 turn in the path coincided with the Carrington solar storm of 1859/9/1-2; the 1730 turn in the path coincided with the Boston solar storm of 1730/10/22.

During the anti-correlation season of 1822 - 1912, out of 9 volcanic eruptions 8, or 88.9% were outside of $\mathcal{H}_3$; that is $\dfrac{88.9}{100-74.1} \approx 3.4$ times more than what a random distribution of eruptions would have produced.

All but one known M $\geqslant$ 8.2 earthquakes in 1687 - 1755 and all but two known VEI $\geqslant$ 5 volcanic eruptions in 1707 - 1815 occurred within 30 days of a syzygy-perigee; all of them occurred within 3.5 days of a regular syzygy or within 33.5 days of a syzygy-perigee.

The correlation pattern and the Earth's magnetic field. The worsening of correlation of earthquakes to syzygies in 1835 - 1933 in Tables 1 - 3 (or 1784 - 1933, if we use Table 4) and the worsening of correlation of volcanic eruptions to syzygies in 1822 - 1912 in Table 9 are chronologically close to the twist in the path of the magnetic North pole in 1826 - 1910 and the110-year long secondary solar cycle of 1810 - 1920 shown in Figure 3.

Several more aspects of the magnetic North Pole seem to mirror seismic activity: 1) the 1647/5/14 earthquake and 1631/12/16 eruption occurred close to the 1632 sharp turn in the path of the magnetic North pole at the beginning of the Maunder minimum; 2) the 1977/8/19 earthquake in Table 1 and the worsening of correlation of volcanic eruptions to syzygies in 1956 - 1980 in Table 9 were chronologically close to the change in the direction of motion of the magnetic North pole around 1955 - 1975 shown in the inset; 3) the 1684 - 1755 angle in the path of the North magnetic pole coincides with a period of extremely good correlation in Tables 3, 9.

Figure 4 shows M $\geqslant$ 8.2 earthquakes and VEI $\geqslant$ 5 volcanic eruptions in 1958 - 2016 ver-

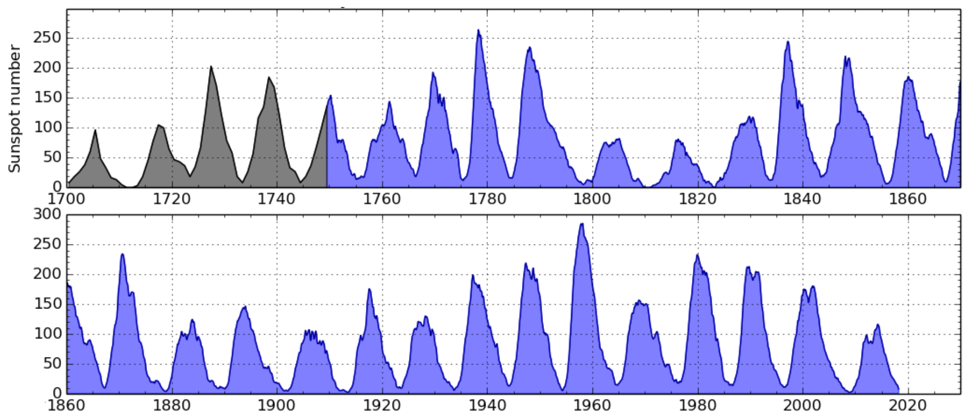


Figure 3: Yearly mean sunspot number (black) up to 1749 and monthly 13-month smoothed sunspot number (blue) in 1749 - 2017, [14].

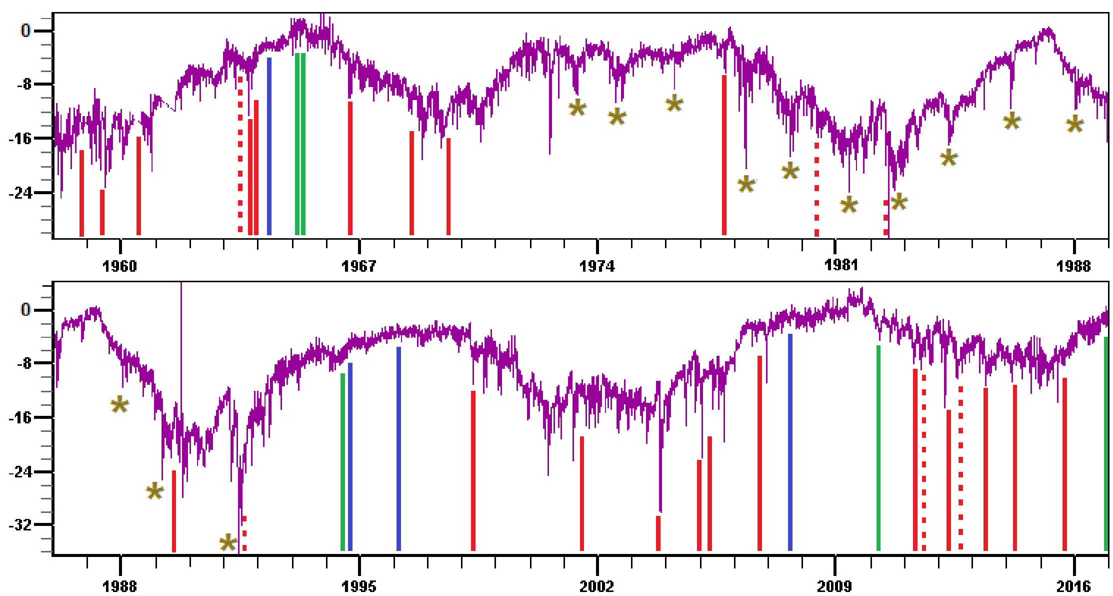


Figure 4: M $\geqslant 8.2$ earthquakes and VEI $\geqslant 5$ volcanic eruptions versus cosmic ray intensity (CRI) in 1958 - 2016. Daily average of CRI is shown in purple, [6]. M $\geqslant 8.2$ earthquakes are marked by solid vertical lines, red lines indicate earthquakes near considerable drop-downs in CRI, green lines indicate earthquakes near insignificant drop-down, blue lines indicate earthquakes far away from any drop-downs. VEI $\geqslant 5$ volcanic eruptions are marked by dotted vertical lines, all of them are near drop-downs in CRI. The recurring drop-downs in 1973/5/17 - 1991/6/15 are marked by asterisks.

sus cosmic ray intensity (CRI). All the eruptions and most of the earthquakes occurred close to drop-downs in CRI; one may be tempted to conclude that the drop-downs contributed to the powerful seismic events. However, the most pronounced drop-downs in CRI recurred in 1973/5/17 -

1991/6/15 approximately every 600 days, yet only two M $\geqslant$ 8.2 earthquakes and only two VEI $\geqslant$ 5 volcanic eruptions occurred at that time. The drop-downs in CRI are usually caused by solar flares, yet some drop-downs follow earthquakes rather than precede them suggesting that there might be a third agent affecting both the earthquakes and the solar activity leading the solar flares. That certain terrestrial activities seem to precede solar activities was also pointed out in [9].

Drop-downs in CRI may also be due to changes in the geomagnetic field. The existence of correlation between powerful seismic activity and drastic changes in the geomagnetic field is supported by other observations, e.g. 1) the eruption of Pinatubo, the most powerful eruption of the past 60 years coincided with a drastic increase of solar flares, [14], which certainly affected the Earth's magnetic field; 2) 2004/12/27 powerful $\gamma-$ ray burst practically coincided with the 2004/12/26 M=9.1 earthquake; 3) powerful solar flares in March-April of 1950 preceded the 1950/5/22 M=9.5 earthquake; 4) the only two earthquakes in Table 6 that did not strike within 31 days of perigee-syzygy, struck 1-3 days after considerable solar flares.

Is there a deep-rooted relationship between the seismic and geomagnetic activities? The geophysicists of today do not believe so and attribute any correlation between the geomagnetic and seismic activities to be mere coincidence. The Earth's magnetic field is generated by the dynamo in the liquid core; which, as a liquid, is affected by the tidal forces. Thus the correlation between the tidal forces and the Earth's magnetic field is quite plausible even though it goes against the grain of modern Geophysics. If the tidal forces affect the seismic activity on Earth, then they should be correlated with geomagnetic activity.

Ultra-powerful seismic events. Since regular syzygies affect seismicity within 3.5 days and syzygy-perigees affect seismicity within 30 days, we may ask ourselves whether there are events that may affect seismicity within longer periods of time. Table 10 shows that all VEI $\geqslant$ 6 eruptions from Table 9 and the only known M=9.5 earthquake were preceded by events which may amplify the Moon's effect on Earth.

Could such events have affected the break-down in correlation of M $\geqslant$ 8.2 earthquakes in 1835-1934 and VEI $\geqslant$ 5 eruptions in 1822-1912 with syzygies and what exactly the events were? One possible contributor could be the three perigees of 1893/12/23, 1912/1/4, 1930/1/15 at, correspondingly, 356 396 km, 356 375 km, 356 397 km which were the closest perigees of 1500-2018; preceded by three perigees of 1789/2/10, 1831/12/19, 1875/12/12, all under 356 460 km;

Table 10: VEI $\geqslant 6$ volcanic eruptions in 1600 - 2017 and M=9.5 earthquake in 1900 - 2017.

VEI$\geqslant 6$ eruptions & M=9.5 earthquake	additional terrestrial and/or celestial events which may amplify the power of eruptions and earthquakes
1991/6/15 Pinatubo VEI=6	Preceded in 1991/6/1 - 1991/6/15 by five X12.0 solar flares and many more less powerful ones. Preceded by 1992/1/19 Full Moon-closest perigee with $\leqslant$ an hour between Full Moon and the perigee of 356 548 km.
1932/4/10 Cerro Azul VEI=6	Preceded by 1930/1/15 Full Moon-closest perigee, with perigee of 356 397 km being the second closest perigee of the century; its effect was further amplified by proximity to perihelion. Preceded by 1931/3/4 Full Moon-closest perigee with only 13 minutes between Full Moon and perigee.
1912/6/6 Novarupta VEI=6	Preceded by 1912/1/4 Full Moon-closest perigee with only 6 minutes between Full Moon and perigee, at 356 378 km the perigee was the closest perigee of 1500-2018. Preceded by a twin pair of 1912/7/14–1912/8/12 New Moon-perigees.
1902/10/24 Santa Maria VEI=5-6	Preceded by 1902/6/6, 1901/4/18, 1900/3/1 New Moon-closest perigees with, correspondingly, 79, 42, 40 minutes between New Moon and perigee.
1883/8/27 Krakatoa VEI=6	
1815/4/10 Tambora VEI=7	Preceded by 1812/10/20, 1811/9/2, 1810/7/16, 1809/5/29 Full Moon-closest/2nd closest perigees with $\leqslant$ an hour between Full Moon and perigee, all perigees $\leqslant$ 356 995 km. Preceded by 1815/1/25 and 1813/12/7 Full Moon-closest perigee with perigees correspondingly 356 647 km and 356 496 km.
1600/2/17 Huaynaputina VEI=6	Preceded by 1598/1/7 New Moon-closest perigee with perigee of 356 623 km only 10 minutes from Full Moon. Preceded by three twin pairs of 1599/9/5 –1599/10/3, 1598/7/18–1598/8/16, 1597/5/3–1597/5/31 Full Moon-perigees.
1960/5/22 M=9.5	The earthquake was accompanied by 1960/5/24 VEI=3 eruption of Puyehue. Two years earlier, the maximum smoothed sunspot number (SIDC formula) of 285.0 was observed in March 1958, it is the highest on the record in 1700 - 2017, [13]. In 1956 - 1960 geomagnetic storms were at all time high, [15]. 1960/5/4 solar flare accelerated particles to cosmic ray energies briefly increasing cosmic ray intensity.

for comparison, all perigees in 1931 - 2033 exceed 356 460 km.

Another contributor could be the pair of the 1859/9/1 and 1882/11/18 powerful solar flares.

Discussion. The ratios $\boldsymbol{\kappa}_3/\boldsymbol{\kappa}_2/\boldsymbol{\kappa}_1/\boldsymbol{\kappa}_0$ might be the first, albeit rudimentary, tool to study the effect of tidal forces on seismic activity. Except for the values 0.98/1.05/0.97/1.08 for VEI $\geqslant 5$ eruptions in 1913 - 2017, the rest of the values 1.27/1.33/1.36/1.48; 1.27/1.4/1.47/1.52; 1.12/1.37/1.3/1.65; 1.08/1.32/1.27/1.78; 1.11/1.165/1.25/1.4 consistently show that during correlation seasons $\mathcal{H}_3, \mathcal{H}_2, \mathcal{H}_1, \mathcal{H}_0$ receive more than their fair share of seismic activity with $\mathcal{H}_0$ receiving as much as 1.4 -1.78 times more than it would have had there been no correlation. That VEI $\geqslant 5$ eruptions in 1913 - 2017 do not show any correlation must be more due to the imperfection of the tolls employed rather than lack of correlation. During anti-correlation periods, the seismic activity not only was not attracted to syzygies, it seemed to be repelled from syzygies most likely due to other factors affecting seismic activity and overshadowing syzygies' influence. The weather forecast involves work with numerous factors affecting the weather, the seismic forecast should also be based on numerous factors. Yet a number of researchers persistently fix on syzygies alone in their attempts to show lack of correlation of seismic activity with syzygies. Seismic activity clearly depends on whether it is intraplate or interplate, shallow or deep, in ocean or on land; it is affected by cosmic rays, solar flares and coronal mass ejections, as well as lunar syzygies. The syzygies themselves are not the same and affect seismic activity differently, depending on the distance from Earth, time to the nearest perigee, the subsolar and sublunar points, and many more. A very rudimentary and simplistic attempt to account for these differences is the separation of syzygies into regular syzygies and syzygy-perigees employed in this paper. Failure to differentiate between regular syzygies and syzygy-perigees leads to the seismic events within $30+n$ days of syzygy-perigees, spread out more or less uniformly over different lunar phases, overshadowing any correlation between regular syzygies and seismic events. To develop a better tool, one needs to study the patterns of seismicity; yet with only 50 years of totally reliable seismic data and another 50 years of relatively reliable seismic data available, only few patterns of seismic activity are easily detectable.

The seismic activity appears to be sensitive to both the tidal forces exhorted by Moon and Sun and the electromagnetic forces exhorted by solar flares and cosmic rays. There is only one part of Earth sensitive to both, and that is the liquid core, suggesting that, at least some, powerful earthquakes draw their power from the liquid core. Recent work [7] suggests that, at least some, earthquakes may be caused by pulses of deep fluids. We believe the fluid is coming from the liquid core.

Notes

1. To derive estimate (2) we consider the period of 1004 average synodic months $\approx 1004 \times 29.530587981 \approx 81$ years 63.46033 days or 1076 average anomalistic months $\approx 1076 \times 27.554551 \approx 81$ years 63.446488 days, with a year taken to be 365.25 days. The difference between 81 years 63.46033 days and 81 years 63.44688 days is ≈ 0.01345 days or slightly more than half an hour so for any practical purposes we may consider the two periods to be equal to 81 years 63.5 days or 29 648.7 days and contain 2008 syzygies. The period will contain $\frac{1004}{14} \times 2 = 144$ full lunar cycles, almost each cycle has two syzygy-perigees, but some cycles may have a syzygy perigee and a twin pair of syzygies which consists of two syzygy-perigees separated by a synodic month, e.g. 2002/2/27 and 2002/3/28. As a sample of such a period we may take 1921/1/1 - 2002/2/4, it contains 2008 syzygies comprising 1851 regular syzygies, 133 syzygy-perigees, 12 twin pairs of syzygy-perigees. The number of days of 1921/1/1 - 2002/2/4 in $\mathcal{H}_n$ is given by the formula $1851\,(0.5+2n)+133\,(60+2n)+12\,(89.5+2n)=9979.5+3992n$. Thus the days in $\mathcal{H}_n$ make $\frac{9\,979.5+3\,992\,n}{29\,648.7}$ portion of 1921/1/1 - 2002/2/4; we take it as a reference formula for all periods of time.
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