On the relationship of seismic activity to lunar motion.

Mikhail Kovalyov *

Abstract. We discuss the correlation of seismic activity on Earth with the closest/2nd closest perigees and New/Full Moon. We show that the time and nature of correlation depend on the type of earthquakes and on the time interval considered.

Key words: Earthquakes, New/Full Moon, lunar perigee, correlation of earthquakes to lunar motion.

A simple online search for the relationship of seismic activity on Earth to lunar motion yields literally an enormous number of research papers; some prove the existence of correlation between seismic activity on Earth and syzygies and/or perigees while the others disprove it. To draw their conclusions, the authors apply statistical analysis to sufficiently large sets of earthquakes from global or local catalogues. Here we consider three relatively small but significant groups of earthquakes: 1) all $M \geqslant 7.9$ earthquakes in 1900 - 2016; 2) strongest earthquakes in Africa and New Zealand; 3) the strongest earthquakes of the year in periods of 1941- 2016. We will show that the correlation exists but is *seasonal* in the sense that it is more pronounced during certain periods of time which we shall call *correlation seasons*; outside of correlation seasons, it is obscured by other, possibly more powerful, factors. The correlation season depends on the type of earthquakes under consideration. The seasonality of correlation is one of the reasons of disagreement between the researchers who prove the existence of correlation and those who disprove it; the former, e. g. [1], use data from a time interval significantly overlapping with a correlation season, while the latter, e. g. [2, 3, 4, 5, 6], use data from a time interval only slightly overlapping with a correlation season. Another reason is how the correlation is defined and measured; here we define correlation with the help of sets $\mathcal{K}_n$. Our approach is very rudimentary and simplistic, and certainly needs a lot of refinement; yet it allows us to examine the correlation of $M \geqslant 7.9$ earthquakes with New/Full Moon and perigees and its seasonality. The correlation of seismic activity with the lunar motion may be obscured by the presence of other factors like solar flares, cosmic rays, collision

*Email: mkovalyo@ualberta.ca

with bolides. There may also be a considerable delay between the cause of a seismic event and the seismic event itself, e. g. the eruption of Pinatubo in 1991 was preceded by a powerful, most likely precursor, earthquake a year earlier; the eruption of Vesuvius in 79 AD was preceded by a powerful, most likely precursor, earthquake 17 years earlier.

Another important thing to keep in mind is the use of differently derived magnitudes, a simple look at [7] reveals that even adjacent earthquakes like 2003/7/15 M=7.6 and 2003/1/22 M=7.6 use differently derived magnitudes; the former's magnitude was derived from a centroid moment tensor inversion of intermediate- and long-period body- and surface-waves, while the latter's was based on moment tensor inversion of long-period body-waves. Although different derivations lead to very close results, in our case of considering the strongest earthquakes of the year even the magnitude difference of 0.1 may affect which earthquake is considered to be the strongest.

A *full lunar cycle* is 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[1]. The *closest perigee* and *2nd closest perigee* of a lunar cycle typically come within 10 hours of New/Full Moon, and are typically separated by approximately half of the lunar cycle; e.g. in 2015, the closest perigee and Full Moon were less than 2 hours apart on September 28, the 2nd closest perigee and New Moon were less than 8 hours apart on February 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 356956 ± 2 km with 10 hours 50 minutes $\pm$ 15 minutes separating the perigees from Full Moon; the third perigee of 356,972 km was on 1963/4/23 with only two hours separating the perigee and New Moon; all three perigees had almost identical tidal pull.

For $n = 3/2/1/0$, define *correlation sets*[2]

$$\mathcal{K}_n = \left\{ \begin{array}{l} \text{the period within } 30+n \text{ days of the day of the closest/2nd} \\ \text{closest perigee or within } n \text{ days of the day of New/Full Moon} \end{array} \right\} \tag{1}$$

So-defined $\mathcal{K}_n$ puts the synodic months before and after New/Full Moon-closest/2nd closest perigees on equal footing with the day of New/Full Moon.

The percentage of days in $\mathcal{K}_n$ is given by[3]

$$\approx \frac{140+40n}{413} \approx \begin{cases} 63\%, \text{ if } n=3 \\ 53.3\%, \text{ if } n=2 \\ 43.6\%, \text{ if } n=1 \\ 33.9\%, \text{ if } n=0 \end{cases} = 63\%/53.3\%/43.6\%/33.9\% \tag{2}$$

Since the number of days between adjacent syzygies is $\leqslant 15$, any event is always within 6-7 days of the nearest New/Full Moon making it i pointless to consider $n \geqslant 4$ to draw any conclusions about correlation of earthquakes to New/Full Moon. A sufficiently large group of earthquakes randomly distributed over a sufficiently long interval of time should have more or less the same distribution as (2), i. e. the percentage of earthquakes in $\mathcal{K}_n$ should be close to the percentage given by (2); a significant increase in the percentage of earthquakes in $\mathcal{K}_n$ for at least one value of n indicates the existence of correlation between earthquakes and lunar events.

The most powerful earthquakes of 1900 - 2016. Tables 1 - 3 show correspondingly all $\mathrm{M} \geqslant 8.6/8.6 > \mathrm{M} \geqslant 8.2/\mathrm{M} = 8.1$ earthquakes in 1900 - 2016. The distribution of earthquakes in Tables 1, 2, 3 is higher than (2) pointing towards a correlation in 1900 - 2016. The correlation was exceptionally good for $\mathrm{M} \geqslant 8.1$ earthquakes in 1946 - 2016. There was no correlation whatsoever for $\mathrm{M} \geqslant 8.1$ earthquakes in 1900 - 1945; nor was there any correlation for the M=8.0 earthquakes, listed in Table 4. Correlation returned to the M=7.9 earthquakes, listed in Table 5, but disappeared again for the $\mathrm{M} \leqslant 7.8$ earthquakes. The number of $\mathrm{M} \geqslant 7.9$ earthquakes in $\mathcal{K}_n$ in 1900 - 2016 was 89/76/68/55 or 72.4%/61.7%/55.3%/44.7% of the total of 123 exceeding the percentages of (2); the number of $\mathrm{M} \geqslant 7.9$ earthquakes in $\mathcal{K}_n$ in 1946 - 2016 was 61/55/48/38 or 78.2%/70.5%/61.5%/48.7% of the total of 78 considerably exceeding the percentages of (2).

In Tables 1, 2, 3 the difference between 1946 - 2016 and 1900 - 1945 is considerable. 1900 - 1945 was the time of civil unrest and many wars, e. g. the 1917 - 1921 Russian civil war, two world wars; it is possible that the earthquakes in 1900 - 1945 were simply not measured properly, the recent changes to USGS data base of earthquakes confirm the uncertainty in the pre-1950 earthquake data.

However, there may have been natural factors which skewed the correlation of earthquakes with closest/2nd closest perigees and New/Full Moon. As shown in Figure 1, a new maximum of the Earth's magnetic field formed north of lake Baikal some time in 1880 - 1930; it was followed by a drastic increase in the rate of change of the geomagnetic field in 1938 - 1947, [8]. The changes in the Earth's magnetic field reflect the changes in the motion of electric charges in the liquid core, which could have affected seismic activity. Figure 2 shows $\mathrm{M} \geqslant 7.6$ earthquakes in 1900 - 2016, only sixteen of them struck inland far from water and all sixteen struck close to the new location of the geomagnetic maximum near lake Baikal; twelve struck in 1905 - 1937, and only 4

Earthquake date and magnitude	Nearest New/Full Moon, perigee, etc.	Proximity to the closest or 2nd closest perigee	n
2012/4/11 M=8.6	25 days before 20012/5/6 Full Moon-closest perigee		0
2011/3/11 M=9.1	7 days before 2011/3/18-19 Full Moon-closest perigee		0
2010/2/27 M=8.8	2010/2/27-28 Full Moon-perigee	28 days after 2010/1/30 Full Moon-closest perigee	0
2005/3/28 M=8.6	2005/3/25 Full Moon		3
2004/12/26 M=9.1	2004/12/26 Full Moon 2005/1/2 perihelion	15 days before 2005/1/10 New Moon-closest perigee	0
1965/2/4 M=8.7	1965/2/1 New Moon	18 days after 1965/1/17 Full Moon-closest perigee	0
1964/3/28 M=9.2	1964/3/28 Full Moon		0
1960/5/22 M=9.5	1960/5/25 New Moon	16 days before 1960/6/9-10 Full Moon-2nd closest perigee	0
1957/3/9 M=8.6	23 days after 1957/2/14 Full Moon-closest perigee		0
1952/11/4 M=9.0	1952/11/1 Full Moon		3
1950/8/15 M=8.6	1950/8/13 New Moon		2
1946/4/1 M=8.6	1946/4/2 New Moon, 1946/4/3 perigee		1
1906/1/31 M=8.8	Proximity to 1905/12/26 New Moon, 1905/12/23 perigee, to 1906/1/3 perihelion may have contributed to the earthquake		$\geqslant 4$

Table 1: $M \geqslant 8.6$ earthquakes in 1900 - 2016, [7]. Fore/aftershocks, regardless how powerful they were, are not listed. The number of $M \geqslant 8.6$ earthquakes in $\mathcal{K}_n$ was 12/10/9/8 or 92.3%/76.9%/69.3%/61.5% of the total of 13 earthquakes. In the correlation season of 1946 - 2016, the number of $M \geqslant 8.6$ earthquakes in $\mathcal{K}_n$ was 12/10/9/8 or 100%/83.3%/75%/66.7% of the total of 12 earthquakes.

in 1938 - 2016. The periodic recurrence of the maxima in solar activity shown in Figure 3 may have also contributed to triggering powerful earthquakes in 1905 -1906; the frequency of the peaks in solar activity in Figure 3 averaged 212 days, and may have resonated with the frequency of the closest/2nd closest perigees which recur on average every 205 - 208 days. That of the six *extreme perigees*, i. e. perigees closer than 356,425 km, in 1548 - 2016, three occurred in 1893 - 1930, namely on 1893/12/23, 1912/1/4, 1930/1/15, also may have affected the seismic activity in 1900 - 1945. We may only speculate as to the true nature of whatever affected the seismic activity in 1900 - 1945 since there are precious little data to make any definitive conclusions. It looks like in period of 1900 - 1910 earthquakes were especially prone to non-lunar factors, any studies from that time are going to show utter lack of correlation, e. g. [6].

Since $\mathcal{K}_n$ are the periods of increased high tide and high tide usually appears at two almost antipodal locations, we may expect the earthquakes correlated with New/Full Moon and closest/2nd closest perigees to exhibit almost antipodal symmetry. Indeed, each of the $M \geqslant 8.6$

Earthquake date and magnitude	Nearest New/Full Moon, perigee, etc.	Proximity to the closest or 2nd closest perigee	n
2015/9/16 M=8.3	2015/9/13 New Moon	12 days before 2015/9/28 Full Moon-2nd closest perigee	0
2014/4/1 M=8.2	2014/3/30 New Moon		2
2013/5/24 M=8.3	2013/5/25 Full Moon 2013/5/26 perigee	30 days before 2013/6/23 Full Moon-closest perigee	0
2007/9/12 M=8.4	2007/9/11 New Moon		1
2006/11/15 M=8.3			$\geqslant 4$
2003/9/25 M=8.3	2003/9/26 New Moon, 2003/9/28 perigee		1
2001/6/23 M=8.4	2001/6/21 New Moon, 2001/6/23 perigee		2
1996/2/17 M=8.2	1996/2/17-18 New Moon-perigee		1
1994/10/4 M=8.3	1994/10/5 New Moon	30 days before 1994/11/3 New Moon-2nd closest perigee	0
1994/6/9 M=8.2	1994/6/9 New Moon		0
1989/5/23 M=8.2	1989/5/20 Full Moon		3
1977/8/19 M=8.3			$\geqslant 4$
1968/5/16 M=8.2	4 days after 1968/5/12 Full Moon-2nd closest perigee		0
1965/1/24 M=8.2	7 days after 1965/1/17 Full Moon-closest perigee		0
1963/10/13 M=8.5	20 days before 1963/11/2 Full Moon-2nd closest perigee		0
1958/11/6 M=8.3	24 days after 1958/10/13 New Moon-2nd closest perigee		0
1950/12/9 M=8.2	1950/12/9 New Moon-closest perigee		0
1949/8/22 M=8.2	1949/8/24 New Moon, 1949/8/25 perigee		0
1946/12/20 M=8.3	1946/12/23 New Moon	11 days after 1946/12/9 Full Moon-closest perigee	0
1940/5/24 M=8.2	1940/5/21 Full Moon		3
1938/11/20 M=8.3	1938/11/22 New Moon		2
1938/2/1 M=8.5	1938/1/31 New Moon		1
1933/3/2 M=8.4			$\geqslant 4$
1923/2/3 M=8.4	1923/2/3 Full Moon		0
1922/11/11 M=8.5	1922/10/19 New Moon-perigee		$\geqslant 4$
1920/12/16 M=8.3	10 days before 1920/12/26 Full Moon-closest perigee		0
1920/6/5 M=8.2	11 days before 1920/6/16 New Moon-2nd closest perigee		0
1918/8/15 M=8.3	1918/9/20 Full Moon, 1918/9/19 perigee		$\geqslant 4$
1917/5/1 M=8.2			$\geqslant 4$
1906/8/17 M=8.2 in Chile	1906/8/20 New Moon		3
1906/8/17 M=8.3 in Alaska	1906/8/20 New Moon		3
1905/7/23 M=8.3			$\geqslant 4$
1905/7/9 M=8.3			$\geqslant 4$

Table 2: $8.5 \geqslant \mathrm{M} \geqslant 8.2$ earthquakes in 1900 - 2016. Fore/aftershocks, regardless how powerful they were, are not listed. The number of earthquakes in $\mathcal{K}_n$ was 25/21/18/14 or 75.8%/63.6%/54.5%/42.4% of the total of 33, which is just somewhat better than (2). In the correlation season of 1946 - 2016, the number of $8.6 > \mathrm{M} \geqslant 8.2$ earthquakes in $\mathcal{K}_n$ was 17/16/14/11 or 89.5%/84.2%/73.7%/57.9% of the total of 19 earthquakes.

Earthquake date and magnitude	Nearest New/Full Moon, perigee, etc.	Proximity to the closest or 2nd closest perigee	n
2017/9/8 M=8.1 struck after 2016, hence it is not counted, presented only for information purposes	2017/9/7 Full Moon and X9.3 solar flare		
2009/9/29 M=8.1			$\geqslant 4$
2007/4/1 M=8.1	16 days before 2007/4/17 New Moon-2nd closest perigee		0
2007/1/13 M=8.1	10 days after 2007/1/3 New Moon-perihelion		$\geqslant 4$
2004/12/23 M=8.1	2004/12/26 Full Moon	18 days before 2005/1/10 New Moon-closest perigee	0
1998/3/25 M=8.1	3 days before 1998/3/28 New Moon-2nd closest perigee		0
1971/7/26 M=8.1	1971/7/22 New Moon		$\geqslant 4$
1966/10/17 M=8.1	1966/10/14 New Moon	33 days after 1966/9/14 New Moon-2nd closest perigee	3
1963/11/4 M=8.1	26 days before 1963/11/30 Full Moon-closest perigee 2 days after 1963/11/2 Full Moon-2nd closest perigee		0
1960/5/21 M=8.1	20 days before 1960/6/10 Full Moon-2nd closest perigee		0
1957/12/4 M=8.1	1957/12/7 Full Moon		3
1952/03/4 M=8.1	18 days after 1952/2/14 New Moon/2nd closest perigee		0
1945/11/27 M=8.1	37 days after 1945/10/21 Full Moon-closest perigee 1945/11/19 Full Moon-perigee		$\geqslant 4$
1944/12/7 M=8.1	1944/12/29 Full Moon, 1945/1/1 perihelion		$\geqslant 4$
1943/4/6 M=8.1	1943/4/4 New Moon		2
1942/8/24 M=8.1	1942/8/26 Full Moon		2
1939/12/21 M=8.1	1939/12/26 Full Moon, 1939/12/29 perigee 1940/1/2 perihelion		$\geqslant 4$
1932/6/3 M=8.1	1932/6/4 New Moon		1
1929/6/27 M=8.1	20 days before 1929/7/6 New Moon-closest perigee		0
1923/9/1 M=8.1			$\geqslant 4$
1920/9/20 M=8.1			$\geqslant 4$
1919/4/30 M=8.1	1919/4/30 New Moon-2nd closest perigee		0
1918/9/7 M=8.1	1918/9/5 New Moon		2
1914/5/26 M=8.1	1914/5/25 New Moon		1
1910/4/12 M=8.1	2 days after 1910/4/10 New Moon-2nd closest perigee		0

Table 3: M=8.1 earthquakes in 1900 - 2016, [7]. Fore/aftershocks, regardless how powerful they were, are not listed. The 2007/1/13 earthquake struck 10 days after 2007/1/3 New Moon-perihelion, when the effect of New Moon was amplified by perihelion, making it similar to closest/2nd closest perigee when the effect of New/Full Moon is amplified by perigee; however, it is not counted as the days close to perihelion are included in (2). In 1900 - 2016 the number of M=8.1 earthquakes in $\mathcal{K}_n$ was 16/14/11/9 or 66.7%/58.3%/45.8%/37.5% of the total of 24, which is slightly better than (2). In the correlation season of 1946 - 2016, the number of M=8.1 earthquakes in $\mathcal{K}_n$ was 8/6/6/6 or 72.7%/54.5%/54.5%/54.5% of the total of 11.

earthquakes in 1900 - 2016 shown in Table 1 was accompanied by a powerful earthquake at an almost antipodal location, usually within two months' time, except for 1952, 1946 and 1906. The antipodal matches, at least for the M $\geqslant$ 8.6 earthquakes, also correlated with closest/2nd closest

Earthquake date and magnitude	Nearest New/Full Moon, perigee, etc.	Proximity to the closest or 2nd closest perigee	n
2013/2/6 M=8.0	2013/2/10 New Moon		$\geqslant 4$
2007/8/15 M=8.0	2007/8/12 New Moon		3
2006/5/3 M=8.0			$\geqslant 4$
2000/11/16 M=8.0			$\geqslant 4$
1995/10/9 M=8.0	1995/10/8 Full Moon		1
1995/7/30 M=8.0	1995/7/27 New Moon		3
1986/5/7 M=8.0	7 days before 1986/5/24 Full Moon-2nd closest perigee		0
1985/9/19 M=8.0	1985/9/14 New Moon, 1985/9/16 perigee		$\geqslant 4$
1985/3/3 M=8.0	1985/3/7 Full Moon, 1985/3/8 perigee		$\geqslant 4$
1976/1/14 M=8.0	1976/1/17 Full Moon		3
1972/12/2 M=8.0	11 days before 1972/11/21 Full Moon-closest perigee		0
1970/7/31 M=8.0	1970/8/2 New Moon	14 days after 1970/8/17 Full Moon-2nd closest perigee	0
1960/3/20 M=8.0			$\geqslant 4$
1946/9/12 M=8.0	1946/9/11 Full Moon		1
1942/11/10 M=8.0	1942/11/8 New Moon		2
1941/11/25 M=8.0	6 days after 1941/11/19 New Moon-closest perigee		0
1934/1/15 M=8.0	1941/1/15 New Moon-2nd closest perigee		0
1924/4/14 M=8.0	35 days before 1925/5/19 Full Moon-2nd closest perigee		$\geqslant 4$
1917/6/26 M=8.0			$\geqslant 4$
1906/9/14 M=8.0	1906/9/18 New Moon		$\geqslant 4$

Table 4: M=8.0 earthquakes in 1900 - 2016, [7]. Fore/aftershocks, regardless how powerful they were, are not listed. In 1900 - 2016 the number of M=8.0 earthquakes in $\mathcal{K}_n$ was 11/8/7/5 or 55%/40%/35%/25% of the total of 20, which is worse than (2). The M=8.0 earthquakes do not seem to have a correlation season. Typically, the number of earthquakes increases as the magnitude goes down; the M=8.0 earthquakes seem to be an exception to the rule as the number of M=8.0 earthquakes is smaller than the number of M=8.1 earthquakes.

perigees and New/Full Moon, except for 1960, as shown in Table 6. Of the five $8.4 \leqslant M \leqslant 8.5$ earthquakes, only three had clearly defined almost antipodal matches correlated with the closest/2nd closest perigees and New/Full Moon.

Regional correlations. In some regions the most powerful earthquakes also correlate with New/Full Moon and closest/2nd closest perigees. One such region is Africa where most powerful earthquakes strike either along the East African Rift Line or along the north shore. The eighteen $M \geqslant 6.6$ earthquakes in Africa in 1900 - 2016 are shown in Figure 4. The correlation is very strong. The earthquakes in the Mediterranean Sea do not seem to correlate with the lunar motion; any extension of the region to include the Mediterranean Sea with its numerous earthquakes would not show any correlation.

Another region of correlation is New Zealand, correlation of seismic activity with closest/2nd

Earthquake date and magnitude	Nearest New/Full Moon perigee, etc.	Proximity to the closest or 2nd closest perigee	n
2016/12/17 M=7.9	2016/12/14 Full Moon	28 days after 2016/11/14 Full Moon-closest perigee	0
2014/6/23 M=7.9	2014/6/27 New Moon		$\geqslant 4$
2008/5/12 M=7.9	22 days before 2008/6/3 New Moon-2nd closest perigee		0
2007/9/12 M=7.9	2007/9/11 New Moon		1
2002/11/3 M=7.9	2002/11/4 New Moon -perigee	28 days after 2002/10/6 New Moon-2nd closest perigee	0
2000/6/18 M=7.9	2000/6/16 Full Moon	14 days before 2000/7/1 New Moon-closest perigee	0
2000/6/4 M=7.9	2000/6/2 New Moon	28 days before 2000/7/1 New Moon-closest perigee	0
1996/6/17 M=7.9	1996/6/16 New Moon		1
1996/6/10 M=7.9 1996/6/10 M=7.9	1996/6/1-3 Full Moon -perigee		1
1996/1/1 M=7.9	10 days after1995/12/22 New Moon-closest perigee		0
1995/12/3 M=7.9	19 days before 1995/12/22 New Moon-closest perigee		0
1987/11/30 M=7.9			$\geqslant 4$
1980/7/17 M=7.9			$\geqslant 4$
1979/9/12 M=7.9	6 days after 1979/9/6 Full Moon-2nd closest perigee		0
1976/8/16 M=7.9			$\geqslant 4$
1975/7/20 M=7.9	1975/7/23 Full Moon		3
1975/5/26 M=7.9	1975/5/25 Full Moon		1
1970/5/31 M=7.9	1970/6/4 New Moon		$\geqslant 4$
1968/5/16 M=7.9	4 days after 1968/5/12 Full Moon-2nd closest perigee		0
1959/5/4 M=7.9	18 days before 1959/5/22 Full Moon-2nd closest perigee		0
1953/11/25 M=7.9	1953/11/20 Full Moon, 1953/11/18 perigee		$\geqslant 4$
1950/12/2 M=7.9	7 days before 1950/12/9 New Moon-closest perigee		0
1941/11/18 M=7.9	1 day before 1941/11/19 New Moon-closest perigee		0
1932/12/25 M=7.9	1932/12/27New Moon	28 days after 1932/11/27 New Moon-2nd closest perigee	0
1931/10/3 M=7.9	8 days before 1931/10/11 New Moon-2nd closest perigee		0
1931/8/10 M=7.9	1931/8/13 New Moon		3
1928/6/17 M=7.9	1928/6/19 New Moon	29 days after 1928/5/19 New Moon-2nd closest perigee	0
1922/1/7 M=7.9	36 days before 1922/2/12 Full Moon-closest perigee 1921/12/29 New Moon, 1922/1/3 perihelion		$\geqslant 4$
1917/1/30 M=7.9	7 days after 1917/1/23 New Moon-2nd closest perigee		0
1916/1/1 M=7.9	1916/1/4-5 New Moon -perigee	25 days after 1915/12/7 New Moon-closest perigee	0
1911/6/15 M=7.9	11 days before 1911/6/26 New Moon-closest perigee		0
1905/4/4 M=7.9	1905/4/4 New Moon	14 days after 1905/3/21 Full Moon-2nd closest perigee	0
1901/8/9 M=7.9			$\geqslant 4$

Table 5: M=7.9 earthquakes in 1900 - 2016, [7]. Fore/aftershocks are not listed. In 1900 - 2016 the number of M=7.9 earthquakes in $\mathcal{K}_n$ was 25/23/23/19 or 75.8%/69.7%/69.7/%/57.6% of the total of 33. All of 1900 - 2016 may be considered as correlation season.

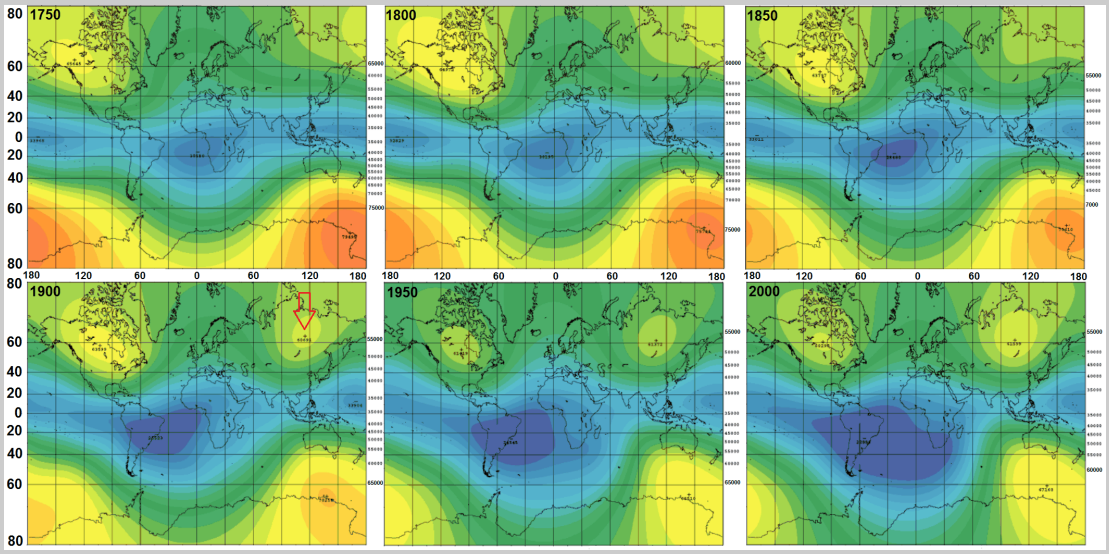


Figure 1: Total intensity of the Earth's magnetic field in nT for 1750 - 2000, [9]. In 1750 - 1850 there were two maxima of total intensity of the Earth's magnetic field: one near Antarctica and one in North America. A third maximum in Asia just north of lake Baikal, pointed to by an arrow in frame '1900', appeared some time in 1850 - 1900 and by 2015 superseded the maximum in North America.

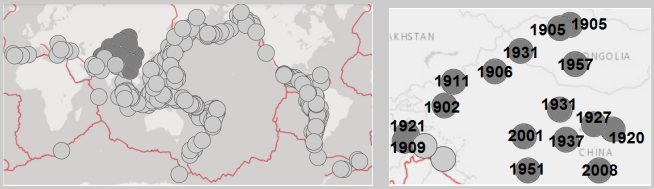


Figure 2: The left frame shows earthquakes of $M \geqslant 7.6$ in 1900 - 2016; almost all, shown in light gray, struck in/close to water. A few, shown in dark gray, struck far from water and off tectonic lines. The right frame zooms in on the latter showing the year of each of them. Of the 16 $M \geqslant 7.6$ earthquakes that struck far from water, 6 struck in 1902 - 1911, 6 in 1920 - 1937, and only 4 in 1932 - 2016.

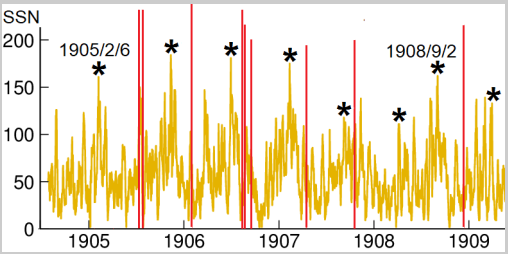


Figure 3: Sunspot numbers in 1905 -1908, [10]. The peaks, marked by asterisks, recurred on average every 212 days. The earthquakes of $M \geqslant 7.9$, shown by vertical lines, are clustered into groups: 1) 1905/7/9, 1905/7/23; 2) 1906/1/31, 3) 1906/8/17, 1906/8/17, 1906/9/15, 4) 1907/4/15; 5) 1907/10/21; 6) 1908/12/12; [7]; the average time between groups 1-5 is 208 days. The time between groups 5 and 6 is 419; there was no $M \geqslant 6.0$ earthquake between 1907/10/21 and 1908/12/12.

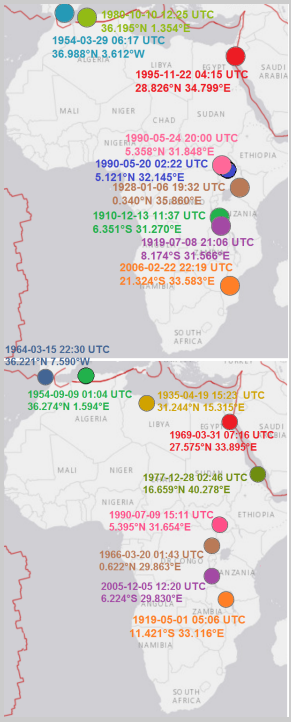
closest perigees is shown in Table 7.

The strongest earthquakes of the year in 2010 - 2016. The years 2010 - 2014 may be

Magnitude, date, location of M$\geqslant$ 8.5 earthquakes	Magnitude, date, location of the almost antipodal earthquakes	Lunar events near the almost antipodal earthquakes	n
M=8.6 2012/4/11 $2^\circ N, 93^\circ E$	M=7.4 2012/3/20 $16^\circ N, 98^\circ W$	2012/3/22 New Moon	2
M=9.1 2011/3/11 $38^\circ N, 142^\circ E$	M=6.5 2011/3/6 $56^\circ S, 27^\circ W$	2011/3/19 Full Moon-closest perigee	0
M=8.8 2010/2/27 $36^\circ S, 73^\circ W$	M=7.0 2010/2/26 $26^\circ N, 128.4^\circ E$	2010/1/30 Full Moon-closest perigee	0
M=8.4 2007/9/12 $4^\circ S, 101^\circ E$	M=6.8 2007/9/10 $3^\circ N, 78^\circ W$	2007/9/11 New Moon	1
M=8.6 2005/3/28 $2^\circ N, 97^\circ E$	M=6.0 2005/4/11 $7^\circ S, 78^\circ W$	2005/4/8 New Moon	3
M=9.1 2004/12/26 $3^\circ N, 96^\circ E$	M=7.2 2004/11/15 $5^\circ N, 78^\circ W$	2004/11/12 New Moon	3
M=8.4 2001/6/23 $16^\circ S, 74^\circ W$	M=5.9 2001/8/5 $12^\circ N, 93^\circ E$	2001/8/4 Full Moon	1
M=8.7 1965/2/4 $51^\circ N, 179^\circ E$	M=6.0 1965/1/16 $56^\circ S, 27^\circ W$	1965/1/17 Full Moon-closest perigee	1
M=9.2 1964/3/28 $61^\circ N, 147^\circ W$	M=7.8 1964/5/26 $56^\circ S, 28^\circ W$	1964/5/26 Full Moon 1964/6/10 New Moon-2nd closest perigee	0
M=8.5 1963/10/13 $45^\circ N$,$149^\circ E$	M=6.0 1963/10/3 $59^\circ S, 25^\circ W$	1963/10/3 Full Moon	0
M=9.5 1960/5/22 $38^\circ S, 73^\circ W$	M=6.5 1960/5/18 $29^\circ N, 130^\circ E$ M=8.0 1960/3/20 $40^\circ N, 143^\circ E$		$\geqslant 4$
M=8.6 1957/3/9 $51^\circ N, 176^\circ W$	M=6.0 1957/5/12 $61^\circ S, 24^\circ W$	1957/5/13 Full Moon	1
M=9.0 1952/11/4 $53^\circ N, 160^\circ E$	M=6.5 1952/4/15 $57^\circ S, 26^\circ W$ M=6.4 1952/6/19 $54^\circ S, 54^\circ W$	1952/6/22 New Moon	3
M=8.6 1950/8/15 $28^\circ N, 96^\circ E$	M=7.1 1950/8/14 $28^\circ S, 63^\circ W$	1950/8/13 New Moon	1
M=8.6 1946/4/1 $53^\circ N, 163^\circ W$	M=6.4 1946/10/26 $60^\circ S, 35^\circ W$	1946/10/24 New Moon	2
M=8.5 1938/2/1 $5^\circ S, 132^\circ E$	none		$\geqslant 4$
M=8.4 1933/3/2 $39^\circ N 145^\circ E$	M=6.5 1933/3/18 $59^\circ S, 15^\circ W$		$\geqslant 4$
M=8.5 1922/11/11 $28^\circ S, 70^\circ W$	M=7.0 1922/10/14 $25^\circ N, 121^\circ E$	1922/9/21 New Moon-2nd closest perigee	0
M=8.8 1906/1/31 $1^\circ N, 79^\circ W$	M=7.8 1907/1/4 $2^\circ N, 94^\circ E$	1907/1/3 perihelion 1906/12/15 New Moon-closest perigee	0

Table 6: The first column shows M $\geqslant$ 8.4 earthquakes from Tables 1, 2 with their coordinates; the second column shows almost antipodal seismic activity corresponding to these earthquakes. Coordinates are rounded off to the nearest degree. The third column shows the closest/2nd closest perigee within 33 days or New/Full Moon within 3 days of the almost antipodal earthquake. Not only the earthquakes correlate with New/Full Moon and closest/2nd closest perigees but so do their almost antipodal matches; of the five $8.4 \leqslant M \leqslant 8.5$ earthquakes, only three had clearly defined almost antipodal matches correlated with the closest/2nd closest perigees and New/Full Moon. The correlation set for the antipodes of M $\geqslant$ 8.6 earthquakes is all of 1900 - 2016, while the correlation set for the antipodes of M=8.5 earthquakes is 1946 - 2016.

called the years of $M \geqslant 8.2$ earthquakes, there were five of them, averaging one per year; for comparison, in 1900 - 2009 there were only 39 earthquakes of $M \geqslant 8.2$ averaging merely 0.3578 per year. As Table 1 shows, of the twelve M $\geqslant$ 8.6 earthquakes in 1900 - 2016, three, or 25%. struck in 2010 - 2012. Even more interestingly, in 2010 - 2016 the strongest earthquakes of the year showed remarkable correlation with Full Moon-closest perigee; the particulars are shown in Tables 8, 9. In 2010 - 2016, the number of the strongest earthquakes of the year within $\mathcal{K}_n$ was



Date, magnitude	Nearby New/Full Moon and perigees	n
2006/2/22 M=7.0	2006/2/27 New Moon-2nd closest perigee	0
2005/12/5 M=6.8	2005/12/5 perigee, 2005/12/1 New Moon	$\geqslant 4$
1995/11/22 M=7.2	1995/11/22-23 New Moon-perigee 1995/12/22 New Moon-closest perigee	0
1990/7/9 M=6.6	1990/7/8 Full Moon	1
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 M=6.6	1969/4/2 Full Moon	2
1966/3/20 M=6.6	1966/3/22 New Moon	2
1964/3/15 M=6.6	1964/3/14 New Moon	1
1954/9/9 M=6.7	1954/9/12 Full Moon	3
1954/3/29 M=7.8	1954/4/3 New Moon-2nd closest perigee	0
1935/4/19 M=6.8	1935/4/18 Full Moon	1
1928/1/6 M=7.0	1928/1/7 Full Moon	1
1919/7/8 M=7.2	none, but the 1919/5/1 one was a fore-shock to this earthquake so the seismic activity must have started on 1919/5/1	$\geqslant 4$
1919/5/1 M=6.7	1919/4/30 New Moon-2nd closest perigee	0
1910/12/13 M=7.3	1910/12/15-16 Full Moon-perigee 1910/11/17 Full Moon-closest perigee	0

Figure 4: The top/bottom frame shows magnitude $\geqslant 6.9$ /6.6-6.8 earthquakes in Africa in 1900 - 2016, including magnitude $\geqslant 6.6$ fore/aftershocks; the table on the right shows all magnitude $\geqslant 6.6$ earthquakes in Africa, [7]. The number earthquakes in $\mathcal{K}_n$ was 16/15/13/9 or 88.9%/83.3%/72.2%/50% of the total of 18, which is better than (2).

7/6/6/4 or 100%/85.7%/85.7%/57% of the total of 7, pointing towards a strong correlation.

Figure 5 shows the most powerful earthquakes of 1958 - 2016 superimposed on the graph of cosmic ray intensity. In 2010 - 2016, the M $\geqslant$ 8.1 earthquakes are seen recurring almost periodically close to drop-downs in cosmic ray activity. Typically such drop-down are either due to solar flares/storms or changes in the Earth's magnetic field; since there seem to have been no significant solar stroms/flare corresponding to the almost-periodically recurring drop-downs in cosmic rays, the only explanation is that the earthquakes are correlated with Earth's magnetic activity. One may speculate that the Full Moon-closest perigees stirred the liquid core which in turn produced both the earthquakes and changes in the magnetic field reflected in the cosmic ray graph. The period of 1972 - 1988 shows a similar almost-periodic recurrence of drop-downs from 1973/5/17 to 1991/6/15 approximately every 600 days, the periodicity is discussed in detail in [13]. Unlike 2010 - 2016, the period of 1972 - 1989 is devoid of M $\geqslant$ 8.1 earthquakes and less powerful earthquakes

Date, magnitude	Closest/2nd closest perigees	n
2016/11/13 M=7.8	1 day before 2016/11/14 Full Moon-closest perigee	0
2009/7/15 M=7.8	6 days before 2009/7/21 New Moon-closest perigee	0
1979/10/12 M=7.4	36 days after 1979/9/6 Full Moon-2nd closest perigee	$\geqslant 4$
1945/9/1 M=7.5	50 days before 1945/10/21 Full Moon-closest perigee 20 days before 1945/9/21-23 Full Moon-perigee	$\geqslant 4$
1931/2/13 M=7.3	15 days before 1931/3/4 Full Moon-closest perigee	0
1931/2/2 M=7.3	30 days before 1931/3/4 Full Moon-closest perigee 1 day before 1931/2/3 Full Moon-perigee	0
1929/6/16 M=7.3	25 days before 1929/7/8 Full Moon-closest perigee	0
1914/11/22 M=7.3	33 days before 194/10/19 Full Moon-closest perigee	3
1863/2/23 M=7.5	64 days after 1862/12/21 New Moon-closest perigee 35 days after 1863/1/18-19 New Moon-perigee	$\geqslant 4$
1855/1/23 M=7.5	5 days after 1855/1/18 New Moon-closest perigee	0
1848/10/16 M=7.4	27 days before 1848/11/11 Full Moon-closest perigee	0
1843/7/8 M=7.6	27 days before 1848/7/11 Full Moon	3

Table 7: $M \geqslant 7.3$ earthquakes on the two main islands of New Zealand in 1843 - 2016, [7, 11]. The number of earthquakes in $\mathcal{K}_n$ in 1900 - 2016 is 5/5/5/5 or 71.4%/71.4%/71.4/%/71.4% of the total of 7. The number of earthquakes in $\mathcal{K}_n$ in 1843 - 2016 is 9/7/7/7 or 75%/58.3%/58.3/%/58.3% of the total of 12. The 1979/10/12 earthquake was 36 days away from Full Moon-2nd closest perigee, merely three days from qualifying for correlation.

were less frequent, e. g. of the 199 $M \geqslant 7.8$ earthquakes in 1900 - 2016, with the average of 1.7 earthquakes per year, only 15 struck in 1972 - 1988, with the average of 0.9375 earthquakes per year, [7].

The 2010 - 2016 situation makes it reasonable to check for correlation the strongest earthquakes of the year or strongest earthquakes of the full lunar cycle. One problem that arises here is whether to consider the former or the latter, another problem is how to define where a year/full lunar cycle begins and where it ends. Different derivations of magnitude used for different earthquakes and already mentioned earlier also poses a problem as the difference in magnitude of merely 0.1 may affect which earthquake is considered to be the strongest. Here we consider the strongest earthquakes of the year and assume that each year begins on January 1 and ends on December 31.

Tables 10A - shows the strongest earthquakes of the year in 1941- 2010, correlation with New/Full Moon and closest/2nd closest perigee is present but rather week. In 1941 - 2016, the strongest earthquake of the year struck within $\mathcal{K}_n$ in 58/47/38/31 years or 76.3%/61.8%/50%/40.8% of the total of 76 years.

Every 54 years, lunar phases, perigees, perihelions and 11-year solar cycles "almost' repeat

Earthquake date and magnitude	Nearest New/Full Moon, perigee, etc.	Proximity to Full Moon-closest perigee of the year	n
2010/2/27 M=8.8	2010/2/27-28 Full Moon-perigee	21 days after 2010/1/30 Full Moon-closest perigee	0
2011/3/11 M=9.1		8 days before 2011/3/19 Full Moon-closest perigee	0
2012/4/11 M=8.6	2012/4/6-7 Full Moon-perigee	25 days before 2012/5/6 Full Moon-closest perigee	0
2013/5/24 M=8.3	2013/5/25-26 Full Moon-perigee	31 days before 2013/6/23 Full Moon-closest perigee	1
2014/4/1 M=8.2	2014/3/30 New Moon		1
2015/9/16 M=8.3	2015/9/13 New Moon	12 days before 2015/9/28 Full Moon-closest perigee	0
2016/12/17 M=7.9	2016/12/14 Full Moon 2016/12/12 perigee	33 days after 2016/11/14 Full Moon-closest perigee	3

Table 8: The strongest earthquakes of the year in 2010-2016, [7]. The strongest earthquake of the year struck within $\mathcal{K}_n$ in 7/6/6/4 years or 100%/85.7%/85.7%/57% of the total of 7 years.

2010/1/30	2011/3/19	2012/5/6	2013/6/23	2014/8/10	2015/9/28	2016/11/14
2010/2/27			2013/2/6			
	2011/3/11					2016/3/2
2010/4/6		2012/4/11		2014/4/1	2015/4/25	2016/4/18
			2013/5/24		2015/5/30	
				2014/6/23		
	2011/7/6					
					2015/9/16	
2010/10/25		2012/10/28				
						2016/11/13
						2016/12/17
8.8,7.8,7.8	9.1, 7.6	8.6, 7.8	8.0, 8.3	8.2, 7.9	7.8,7.8,8.3	7.8,7.8,7.8,7.9

Table 9: Above the horizontal line are the dates of the closest perigees of the year, all coincided with Full Moon. Below the horizontal line are the dates of the earthquakes of the two highest magnitudes for each year shown; fore/aftershocks are not shown, [7]. Underlined are the strongest earthquakes of the year. The strongest earthquake of the year struck within 33 days of the Full Moon-closest perigee every year but 2014. An earthquake of the highest/2nd highest magnitude struck in March - May every year. The only strongest earthquakes of the year that was more more than 33 days away from Full Moon-closest-perigee occurred on 2014/4/1, right after 2014/3/30 New Moon and 2014/3/29 X.1 solar flare, it was part of the March - May pattern.

themselves[4]; we may expect a period starting with 1956 to be somewhat similar to 2010 - 2016. Indeed, as shown in Table 10C, in 1956 - 1968, the number of strongest earthquakes of the year within $\mathcal{K}_n$ was 13/11/10/9 or 100%/84.6%/76.9%/69.2% of the total of 13, pointing towards strong correlation of the earthquakes to New/Full Moon and closest/2nd closest perigees. One

Earthquake date and magnitude	Nearby New/Full Moon, perigee, etc.	Full/New Moon-closest/2nd closest perigee of the year	n
2010/2/27 M=8.8	2010/2/27-28 Full Moon-perigee	21 days after 2010/1/30 Full Moon-closest perigee	0
2009/9/29 M=8.1			$\geqslant 4$
2008/5/12 M=7.9		22 days before 2008/6/3 New Moon-2nd closest perigee	0
2007/9/12 M=8.4	2007/9/11 New Moon		1
2006/11/15 M=8.3			$\geqslant 4$
2005/3/28 M=8.6	2005/3/25 Full Moon		3
2004/12/26 M=9.1	2004/12/26 Full Moon 2005/1/4 perihelion	14 days before 2005/1/10 New Moon-closest perigee	0
2003/9/25 M=8.3	2003/9/26 New Moon, 2003/9/28 perigee		1
2002/11/3 M=7.9	1 day before 2002/11/4 New Moon-2nd closest perigee		0
2001/6/23 M=8.4	2001/6/21 New Moon, 2001/6/23 perigee		2
2000/11/16 M=8.0			$\geqslant 4$
1999/9/20 M=7.7	1999/9/17 solar flare		$\geqslant 4$
1998/3/25 M=8.1	1998/2/26-27 New Moon-perigees	3 days before 1998/3/28 New Moon-2nd closest perigee	0
1997/10/14 M=7.8	1997/10/15-16 Full Moon-perigee	29 days after 1997/9/16 Full Moon-2nd closest perigee	0
1997/12/5 M=7.8	1997/11/6-27 X9.4, X2.6 solar flares		
1996/2/17 M=8.2	1996/2/17-18 New Moon-perigee	29 days after 1996/1/19 New Moon-2nd closest perigee	0
1995/7/30 M=8.0	1995/7/27 New Moon		3
1995/10/9 M=8.0	1995/10/8 Full Moon		1
1994/10/4 M=8.3	1994/10/5-6 New Moon-perigee	28 days before 1994/11/3 New Moon-2nd closest perigee	0
1993/8/8 M=7.8			$\geqslant 4$
1992/12/12 M=7.8	1992/12/9 Full Moon		3
1991/12/22 M=7.6	1991/12/22 Full Moon-perigee	28 days before 1992/1/19 Full Moon-closest perigee	0
1991/4/22 M=7.6			
1990/4/18 M=7.8	36 days before 1990/5/24 New Moon-2nd closest perigee		$\geqslant 4$
1989/5/23 M=8.2	1989/5/20 Full Moon		3
1988/3/6 M=7.8	1988/3/3 Full Moon		3
1987/11/30 M=7.9			$\geqslant 4$
1986/5/7 M=8.0	1986/5/8 New Moon	19 days before 1986/5/24 Full Moon-2nd closest perigee	0
1985/3/3 and 1985/9/19, both M=8.0			$\geqslant 4$
1984/2/7 M=7.6	10 days before 1984/2/17 Full Moon-closest perigee		0
1983/3/18 M=7.6			$\geqslant 4$
1982/12/19 M=7.2	11 days before 1982/12/30 Full Moon-closest perigee		0
1981/9/1 M=7.7	1981/8/29 New Moon		3

Table 10A

Earthquake date and magnitude	Nearby New/Full Moon, perigee, etc.	Full/New Moon-closest/2nd closest perigee of the year	n
1980/7/17 M=7.9			$\geqslant 4$
1979/9/12 M=7.9	6 days after 1979/9/6 Full Moon-closest perigee		0
1978/11/29 M=7.7	1978/11/30 New Moon		1
1978/6/12 M=7.7	37 days before 1978/7/19 Full Moon-closest perigee		$\geqslant 4$
	average of the two values is counted as $n = 3$		3
1977/8/19 M=7.9			$\geqslant 4$
1976/1/14 M=8.0	1976/1/17 Full Moon		3
1975/7/20 M=7.9	1975/7/23 Full Moon		3
1975/5/26 M=7.9	1975/5/25 Full Moon		1
	average of the two values of n		2
1974/10/3 M=7.6	1974/10/1 Full Moon		2
1973/6/17 M=7.7	1973/6/15 Full Moon	16 days after 1973/6/1 New Moon-closest perigee	0
1972/12/2 M=8.0	1972/12/5 New Moon	11 days before 1972/11/21 Full Moon-closest perigee	0
1971/7/26 M=8.1 1:21 am	1971/7/22 New Moon		$\geqslant 4$
1970/7/31 M=8.0	1970/8/2 New Moon	17 days before 1970/8/17 Full Moon-2nd closest perigee	0
1969/2/28 M=7.8	1969/3/4 Full Moon		$\geqslant 4$
1968/5/16 M=8.2	4 days after 1968/5/12 Full Moon-2nd closest perigee		0
1967/7/22 M=7.4	1967/7/21 Full Moon		1
1966/10/17 M=8.1	1966/10/14 New Moon 1966/10/13 perigee	33 days after 1966/9/14 New Moon-2nd closest perigee	3
1965/2/4 M=8.7	1965/2/1 New Moon	18 days after1965/1/17 Full Moon-closest perigee	0
1964/3/28 M=9.2	1964/3/28 Full Moon		0
1963/10/3 M=8.5	30 days before 1963/11/2 Full Moon-2nd closest perigee		0
1962/5/21 M=7.5	1962/5/19 Full Moon		2
1961/8/19 M=7.7	6 days before 1961/8/25 Full Moon-2nd closest perigee		0
1960/5/22 M=9.5	1960/5/25 New Moon		3
1959/5/4 M=7.9	1959/5/7 New Moon	18 days before 9/5/22 Full Moon-closest perigee	0
1958/11/6 M=8.6	23 days after 1958/10/23 New Moon-2nd closest perigee		0
1957/3/9 M=8.6	23 days after 1957/2/14 Full Moon-closest perigee		0
1956/7/9 M=7.7	1 day after 1956/7/8 New Moon-closest perigee		0
1955/2/27 M=7.5			$\geqslant 4$
1954/3/29 M=7.8	5 days before 1954/4/3 New Moon-2nd closest perigee		0
1953/11/25 M=7.9			$\geqslant 4$
1952/11/4 M=9.0	1952/11/1 Full Moon		3
1951/11/24 M=7.8	34 days before 1951/12/28 New Moon-2nd closest perigee		$\geqslant 4$
1950/8/15 M=8.6	1950/8/13 New Moon		2
1949/8/22 M=8.2	1949/8/24 New Moon, 1949/8/25 perigee		2

Table 10B

Earthquake date and magnitude	Nearby New/Full Moon, perigee, etc.	Full/New Moon-closest/2nd closest perigee of the year	n
1948/1/24 M=7.8	2 days before 1948/1/26 Full Moon-closest perigee		0
1947/11/1 M=7.6	1947/10/29 Full Moon		2
1947/5/27 M=7.6			$\geqslant 4$
	average of the two values is counted as $n = 3$		3
1946/4/1 M=8.6	1946/4/2 New Moon		1
1945/11/27 M=8.1	1945/11/19 Full Moon -perigee	36 days after 1945/10/21 Full Moon-closest perigee	$\geqslant 4$
1944/12/7 M=8.1			$\geqslant 4$
1943/4/6 M=8.1	1943/4/4 New Moon		2
1942/8/24 M=8.1	1942/8/26 Full Moon		2
1941/11/25 M=8.0	6 days after 1941/11/19 New Moon Moon-closest perigee		0

Table 10C: The strongest earthquakes of the year for 1941-2010, [7]. The strongest earthquake of the year within $\mathcal{K}_n$ struck in 52/42/33/28 years or 74.3%/60%/47.1%/40% of the total of 70 years, somewhat better than (2) but not by much.

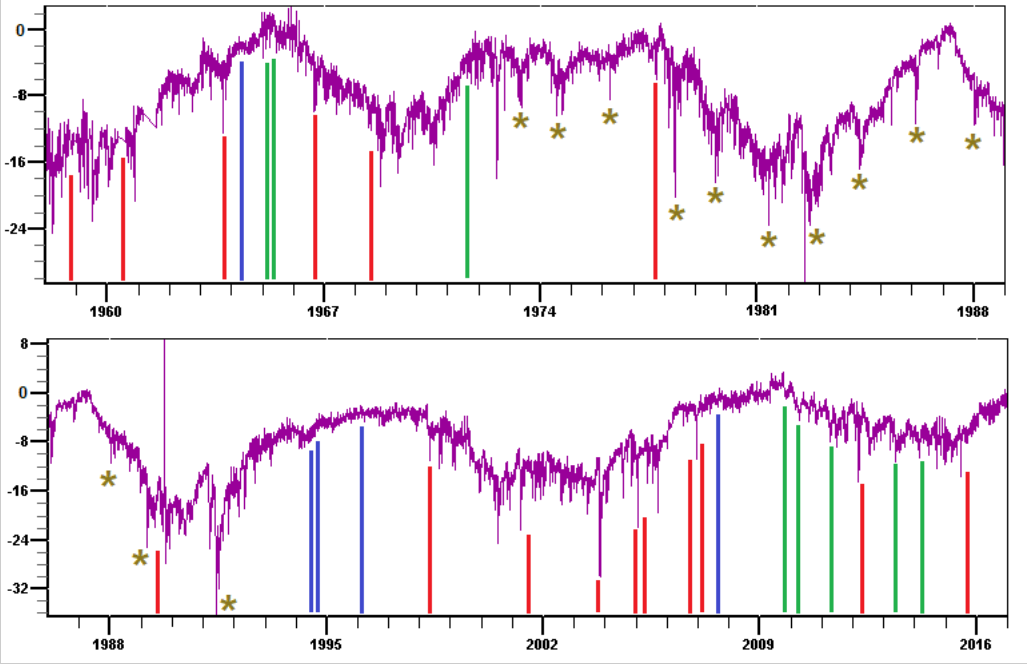


Figure 5: In purple is the graph of cosmic ray intensity with the resolution of one day, [12]. M $\geqslant$ 8.1 earthquakes are marked by vertical line; chronologically close earthquakes are denoted by a single line. Red lines indicated earthquakes near considerable drop-downs in cosmic rays, green lines indicate earthquakes near smaller drop-downs in cosmic rays, blue lines indicate earthquakes far away from drop-downs in cosmic rays. in 2010 - 2016 earthquakes recurred almost periodically near almost periodically recurring drop-downs. The period of 1972 - 1988 is devoid of M $\geqslant$ 8.1 earthquakes, during that period the drop-downs in cosmic rays, marked by asterisks, recurred almost periodically from 1973/5/17 to 1991/6/15 approximately every 600 days.

may expect a similar correlation of the strongest earthquakes of the year to New/Full Moon and closest/2nd closest perigees in 1902 - 1916, the period 54 years prior to 1956 - 1968, but there was nothing significant; the reason might be the same as the reason for lack of correlation for $M \geqslant 8.1$ earthquakes in 1900 - 1945 discussed earlier. As figure 5 shows, the season of correlation 1956 - 1968 with eight M $\geqslant$ 8.1 earthquakes was followed by the 1969 - 1990 drought with only three M $\geqslant$ 8.1 earthquakes

One contributing factor to a better correlation in 2010 - 2016 of the strongest earthquakes of the year with Full Moon-closest perigee might be the extremely low level of solar activity; with the solar activity at its lowest, the effect of the Moon on earthquakes becomes more pronounced. But that may not be the only factor. The correlation of the most powerful earthquakes to Full Moon-closest perigees may be also related to a rare event of Full Moon coming within less than 66 minutes of the closest perigee of the year for five years in a row: on 2011/3/11, 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.

Discussion. The jury is still out on how the seismic activity on Earth is affected by extraterrestrial events like solar flares and cosmic rays. There is just too little data to draw definitive conclusions. In favor of the positive answer point numerous factors, e. g. 1) the 1960/5/22 M=9.5 and 1960/3/20 M=8.0 earthquakes struck almost antipodally to each other at the end of the 1956/2/14 - 1960/11/3 solar storm swarm comprised of 19 solar storms, [14]; 2) the 1960/5/22 M=9.5 earthquake was preceded by the 1960/5/4 solar flare which accelerated particles to cosmic ray energies briefly increasing cosmic ray intensity; 3) the 1991/6/15 eruption of Pinatubo was preceded by six X10.0 - X12.0 solar flares in June 1-15, 1991 and seven X9.3 - X20 solar flares in 1989/2/6 - 1991/3/22, that is 37% of all known $\geqslant X9.0$ solar flares recorded in 1978 - 2016, [15]; 4) the 2017/9/8 M=8.1 earthquake struck right after the 2017/9/7 X9.3 solar flare; 5) the 1965/2/4 M=8.7 and 2004/12/26 M=9.1 earthquakes struck a day before the 1965/2/5 solar flare and 2004/12/27 $\gamma-$ ray burst respectively, suggesting that either the 1965/2/5 solar flare and 2004/12/27 $\gamma-$ ray burst were preceded by undetected leading fronts which contributed to the two earthquakes, or both the earthquakes and the cosmic events were caused by a third agent, possibly cosmic rays, which caused the earthquakes first and then the cosmic flare and γ -ray burst.

With the effects of so many factors tangled up, it is often hard to figure out how each one of them affects seismic activity; simple statistics only leads to confusion. Sometimes, one factor becomes dominant providing us with a window of opportunity to study how that particular factor correlates with and affects earthquakes.

That Earth's seismic activity is affected by the Moon, Sun, solar flares and cosmic rays, and seems to be related to the changes in the geomagnetic field, suggests that the most powerful seismic events draw their power from the liquid core. Indeed, since the liquid core is fluid, the Moon and Sun produce tides inside the liquid core; these tides put additional pressure on the mantle, which in turn relays the pressure to the crust leading to powerful earthquakes and eruptions. Since the liquid core contains electric currents, it is also affected by solar CME/flares and cosmic rays carrying fast-moving electric charges; the interaction of the fast-moving electric charges with the currents in the liquid core also leads to powerful earthquakes and eruptions.

Is it possible to predict earthquakes? The answer is most likely positive, yet successful forecasting needs to be based on the knowledge of patterns, which we currently do not have. All that is available is a good record of seismic activity for seven decades 1946 - 2016; a not-so-good record of seismic activity for another 50 years 1900 - 1950; and very shaky data for the years prior to 1900. Trying to forecast seismic activity with so little data is like trying to forecast winter snow based on the patterns of snowing in the fall.

The correlation of the strongest earthquakes of the year in the 2010 - 2016 correlation season may, and most likely will, continue beyond 2016. If the pattern continues, the next strongest earthquake of the year may strike within 33 days of the next January 1, 2018 Full Moon-closest perigee; Full Moon and perigee will be only four hours apart and only three days away from the January 3, 2018 perihelion. A quick look at Figure 5 reveals a more-or-less periodic recurrence of drop-downs in cosmic ray activity, most likely related to the more-or-less periodic recurrence of strongest earthquakes of the year; and the drop-downs stopped in the end of 2016.

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Notes

1. While the exact lengths of synodic and anomalistic months vary, the *average synodic month* is ≈ 29.530587981 days and the *average anomalistic month* is ≈ 27.554551. The concept of a full lunar cycle is due to the fact that 15 average anomalistic months of ≈ 413.318 days are almost the same as 14 average synodic months of ≈ 413.428 days. Back to the text.

2. Notice that $\mathcal{K}_n$ is not an ideal measure of proximity of two events. When two events occur within 24 hours, $n = 0$ if the events occur on the same date, e. g. "January 1, 2000, 1:00" and "January 1, 2000, 23:00", or $n = 1$ if they occur on separate dates, e. g. "January 3, 2000, 23:00" and "January 4, 2000, 1:00". When two events are 24 - 72 hours apart, n may be undervalue or overvalue the time between the events, e. g. "January 5, 2000, 1:00" and "January 6, 2000, 23:00" separated by 46 hours are assigned $n = 1$, while "January 7, 2000, 23:00" and "January 9, 2000, 1:00" separated by 26 hours are assigned y $n = 2$. When two events are 72 - 96 hours, they may be assigned $n = 3$, e. g. "January 8, 2000, 1:00" and "January 11, 2000, 23:00" separated by 94 hours; or may be completely dropped from the count, e. g. "January 12, 2000, 23:00" and "January 16, 2000, 1:00" separated by 74 hours. Two events separated by more than 96 hours are considered to be too far apart to be counted. The value of n is also affected by the time zone used, in this paper it is UTC. However, regardless of the time zone selected, the values of n which undervalue and overvalue the time between events should compensate for each other leading to more-or-less correct conclusions. Using "hours" to measure time between events would be better but would require resources the author does not have. Moreover, it might be impossible to determine exact time of New/Full Moon all the way back to 1900, precision within one day seems to be the best we can have. Back to text.

3. Determination of the total number of days in a full lunar cycle that are either within $30+n$ days of the closest/2nd closest perigee or within n days of New/Full Moon for $n = 0, 1, 2, 3$. The number of days within $30 + n$ days of the closest perigee is (the day of the closest perigee) + ($30 + n$ days before the closest perigee) + ($30 + n$ days after the closest perigee)= $61 + 2n$; similarly the number of days within $30 + n$ days of the 2nd closest perigee is also $61+2n$. Together the number of days within $30+n$ days of the closest/2nd closest perigee is $122+4n$; these $122+4n$ days include 5 New Moons and 5 Full Moons. The number of New Moons and Full Moons outside of these $122+4n$ days is 18, the total number of days within n days of New or Full Moon but more than $30+n$ days away

from the closest or 2nd closest perigee is $18 \times$ (the day of New or Full Moon $+$ n days before New or Full Moon $+$ n days after New or Full Moon $= 18 \times (2n+1) = 36n+18$. Thus the total number of days that fall within $30+n$ days of the closest/2nd closest perigee or within n days of a New/Full Moon is $122 + 4n + 36n + 18 = 140 + 40n$. The portion of a full lunar cycle that falls within $30 + n$ days of the closest/2nd closest perigee or within n days of a New/Full Moon is $\approx \frac{140 + 40\text{n}}{413}$, with the length of a full lunar cycle rounded off to 413. Number 30 is the rounded up length of the synodic month.

In the calculations we assumed that the adjacent closest and 2nd closest perigees are about half-a-year apart. The full lunar cycles when the closest and 2nd closest perigees are merely a month apart, e. g. 1963/11/30 and 1963/11/2, are so rare, they may be ignored in our calculation. Back to the text.

4. It is because 669 average synodic months of ≈ 19755.96336 days $\approx$ 54 years 32.5 days are almost equal to 717 average anomalistic months of ≈ 19756.61307 days $\approx$ 54 years 33.1 days. Back to the text.