

Gravitational Moon–Earth Forces Triggering Earthquakes in Subduction Zones

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Authors' contributions

This work was carried out in collaboration between both authors. Author MH designed the study, data catalogs and performed the statistical analysis. Author AA made the mathematical models and checked the analysis and the disposition of the sections. Both authors read and approved the final manuscript.

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ABSTRACT

In this paper, we investigated the possible interactions of the moon and Earth, mainly in the period 1996-2015. Initially, we considered the gravitational force of Moon vs. Earth by Newton's equation. The Moon has an elliptical orbit around the planet that reaches two points of maximum. One is the closest, the Perigee, and other the farthest is the Apogee. The Apogee and Perigee have distinct values monthly. In our study, the Perigee force was calculated during every month, year after year. This force creates an oscillation, which in, 13 – 14 months, completes a whole cycle. The wave period is 5400 hours as calculated. The energy generated by Moon on Earth from this closest position reaches a maximum during the Full or New Moon. We observed during these phases an enhancement of earthquakes near the shorelines of the Pacific. On the other hand, the wave minimum matches with the First or Third Quarter, but in this case, the effects of earthquakes are

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smaller on the same regions observed for New or Full Moon. These results indicated that external forces created by Moon- Earth system allied with internal ones are responsible for increase earthquakes in the pointed out areas. Also, the oscillating movement of Moon-Earth system provides a tool for predicting the next enhancement on earthquakes cycles.

Keywords: Earth; moon; solar cycles; perigee waves; moon phases; earthquakes.

1. INTRODUCTION

Relatively little research has been done so far about the connection between the gravitational interaction of moon-Earth system and earthquakes [1,2,3].

Investigators have doubts as to an accurate approximation of the problem. However, the evidence of an interaction between the moon and Earth are clear in studies of the ocean waves and tides, and it is well known and reviewed [4,5,6,7,8,9]. The Moon is the satellite orbiting around the Earth, in an elliptical trajectory. Its mass is eighty times less than Earth, has 27% of the earth's volume, and has no external magnetic field. The moon has a small paleomagnetic field with a magnitude of 2.5 nT. Moon's orbital movement around the Earth creates a gravitational force at the surface of the Earth, which varies every month in the extreme positions, as Perigee (closest) and Apogee (farthest). The satellite depending on its position around Sun- Earth system assumes different phases. If the moon is aligned with the Sun-Earth system, the phase is designated as the New or Full Moon. At the New Moon, it is facing the magnetic dayside of Earth, at the full Moon is on the night side of magnetosphere into the plasmasphere [10,11,12,13]. When the Moon position is 90 degrees in relation to the Sun-Earth, the phase is 1st or 3rd Quarter. These variants on the Moon position related to Earth mold different effects of the Earth as the spring and neap tides. Spring tides are the strongest tides of the moon cycle month, and the neap tides the weakest. The first step in this investigation was to calculate the variations in the gravity field of Moon- Earth system as per Newton's universal law as we see later. The result found is a gravity wave generated between the two bodies with specific values of oscillation, period, and wavelength. Then, we repeated this procedure for a complete Solar Cycle (1996-2008) to investigate how the force between Moon-Earth system varies. In this paper, we worked with two solar cycles, the Cycle 23

(1996-2008) and Cycle 24 (2008-2015) which is not complete. The reason this paper is from a series of solar variability possibly connections between the three-body system and earthquakes. The moon wave produced maximum peaks, which coincided with the Full or New Moon. The same was true for the minimum days were always, in the 1st or 3rd Quarter. After we had obtained the days for the maximum and minimum we search in the earthquakes catalog for the earthquakes location in those days, the magnitude of the earthquakes were $M \geq 4.0$. Then, we examine the Megathrust earthquakes (1700-2015) and at last the large earthquakes in the interval 1996-2016. We created Tables for those two earthquakes occurrences and discussed the influence of the moon in both of the observed events. Those data were discussed as the result of our calculations.

2. THE PERIGEE FORCE VARIATION

The following picture Fig. 1 shows the position of the sun, Earth and the moon and the moon phases for spring tides. At the new moon and full moon, the sun, Earth, and moon arrange themselves more or less along a straight line in space. The pull on the Earth, consequently on the tides increases, since the gravity of the sun, reinforces the moon's gravity. Then, at these phases, the tide's range is at its maximum and is the definition of spring tide: the highest (and lowest) tide. The weaker forces happen at the 1st or 3rd Quarter named neap tides. It is when the sun and moon are at right angles as seen from Earth. Therefore the sun's gravity works against the moon's gravity. Therefore the moon's effect on the tides is smaller, defining a neap tide; the range of those tides is at its minimum.

Fig. 1 displays the moon positions related to sun and Earth. The moon trajectory around the Earth is elliptical, with one side closer to the Earth is the perigee and the other farthest from the Earth is the apogee. Both happen once by month in one year, but in some months there can be 2 perigees or 2 apogees, [14,15].

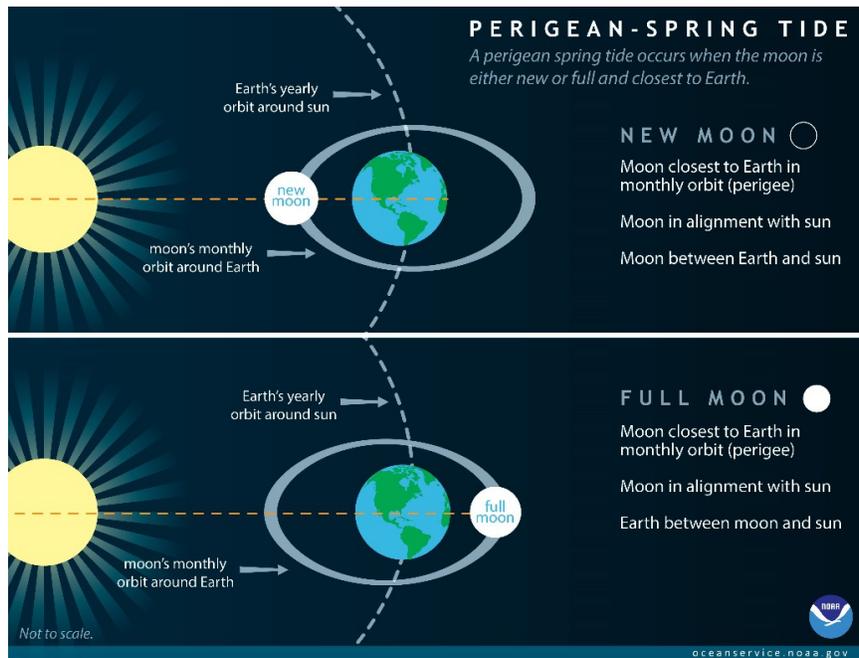


Fig. 1. Schematic diagram showing the perigee position, spring tide during the New and Full Moon. A perigee spring tide happens when the moon is either New or Full and closest to the Earth. Picture is from NOAA

As the Fig. 1 shows, at the “new moon,” the moon is between the Earth and Sun, so that the side of the moon facing toward us receives no direct sunlight, and is lit only by dim sunlight reflected from the Earth. As it moves around the Earth, the side gradually becomes more illuminated by direct sunlight. At the “full moon,” the moon is 180 degrees away from the sun, so that the Sun, Earth, and the Moon form a line. The moon is fully illuminated by the sun, so this is called “full moon”. Full or New Moon have some unusual characteristics at the “new moon,” the body receives radiation, ionized and energetic particles from the Sun, which intensifies, during solar storms. During the “full moon,” earth’s plasmasphere located at the magnetotail charges the satellite with electrons, therefore negatively.

Our first procedure in this study has been to calculate the change in gravitational force of the moon and the Earth, evident in the little difference in the perigee locations [16,17,18, 19,20].

The calculations refer to the period 1996-2008, which is a complete Solar Cycle; the objective was to observe any alteration in the moon cycle connected to the maximum or minimum of Cycle 23, [21,22,23,24,25]. The period chosen is

to detect in our calculations a possible change in the oscillatory behave of the Moon at the Perigee position. Also, we will observe any variation on earthquakes during the maxima of the solar cycles, which is connected, or not with the moon changes, [11]. The moon data positions for Perigee and Apogee during all years calculated are in the Tables in [18].

For example, on Jan15, 2016 the perigee was 369618 km. On Feb 11, 2016, it was 364357km, creating a gap between the two values of 5261 km. Therefore, an oscillation was apparent after ten months, set up by the small differences in the perigee values. Fig. 2 displays the maximum and minimum of the moon cycles against the days observed.

At the apogee locations, although the moon is further apart from earth, we followed the same method.

For the apogee locations, in this case, Jan 2, 2016, the apogee was 404,277 km, on Jan 30, 2016, was 404,552 km; the difference was only 275 km, meaning it creates a straight line if all results are considered. Therefore, we disregarded the Apogee locations in our calculations, (18) and (19).

Overall, the perigee position varied 3.5% during a year and the apogee position only 0.5% in the same period. The universal gravitational force is given by,

$$F = G \frac{mM}{r^2} \quad (1)$$

In the equation (1), the moon mass (m), earth mass (M) and $G= 6, 67 \times 10^{-11} \text{N.m}^2 \text{kg}^{-2}$ are all constants; the only variable is being r, the distance between the moon and the Earth describing an elliptical path around the earth.

The Fig. 2 displays the results for the oscillating force during Cycle 23; the period 1996-2008 was a time scale to limit our lunar wave with known data. It is also an answer to the question what happen with the variation of gravitational Moon-Earth during a solar cycle. Moreover, established how many lunar cycles are in a solar cycle. We found that there were 11 lunar cycles between the period 1996- 2008 that comprehends the Solar cycle 23. The variation and the possible connections solar cycles and moon cycles demands more calculations that we did not develop in this paper.

For the moon we found a perigee force variation, with a maximum at $F = 2.30 \times 10^{20} \text{N}$ and minimum at $F= 2.14 \times 10^{20} \text{N}$. Maximum values of F occurred at the Full or New moon and the Minimum; occurred at the First or Third Quarter. The period falls in the range of 52080 hours – 5400 hours. The moon’s speed around Earth is 3683 km/h generating a wavelength that is between $1, 94 \times 10^7 \text{km}$ - $2,05 \times 10^7 \text{km}$. The results in the Fig. 2 found a wave between the moon and the Earth, which depended on their distance variations when the satellite reaches the Perigee. The Cycle 23 took 11 moon cycles to accomplish; we took the Cycle 24 (2008-) and is in the eighth year for the possible total cycle. The Fig. 2 shows the wave with the Maximum and Minimum of the gravitational forces and the date corresponded at the horizontal axis. Fig. 3 shows the percentage of the moon phases during the maxima or minima of the gravitational force. The Full and New moon, reach the Maxima in equal percentages 25% and the minima of the force is 30 % during the First Quarter, and 20% at the Third Quarter. This result obtained between 1996- 2008.

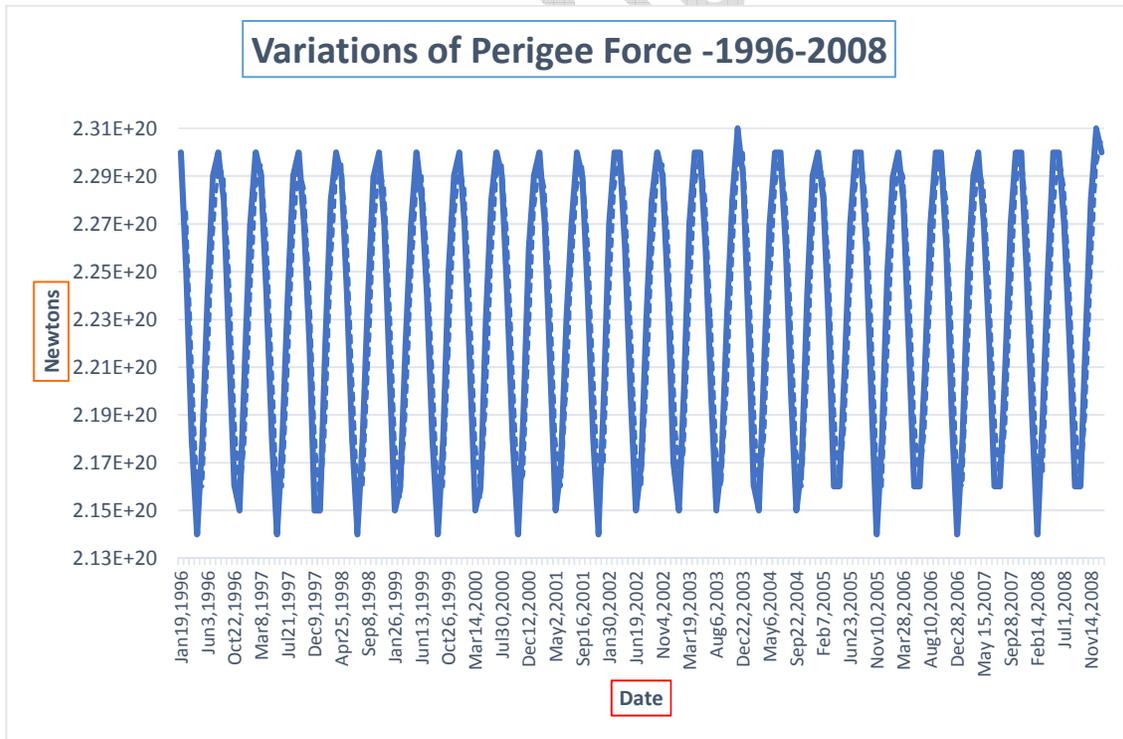


Fig. 2. Perigee force variation for the period 1996-2008. The data catalogs are in [13,16,17,18] and [19]

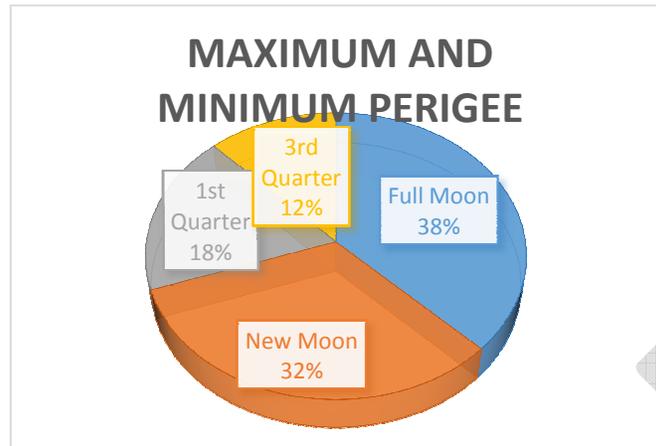


Fig. 3. The maximum or minimum perigee days distributed by moon phases

The next calculations were to consider the number of earthquakes occurred during each data of Maxima gravitational force. We took each day of the maximum force and search for the earthquakes happened at that data. Fig. 4 showing the percentage of quakes number for each maximum or minima of the perigee with magnitude $M \geq 4.0$ on each data. The evaluation showed a different result, 37% of geohazard events befall at the Full Moon, 36% of the New Moon, 19% at the First Q and only 8% at Last Quarter. The result pointed out that most earthquakes $M \geq 4.0$ observed during those phases happened in their majority at 73% during the New or Full Moon, and others 19% at the First quarter with only 8% at the Last quarter.

The results found, corroborate the assumption that during the New or Full Moon there is an enhancement of events.

The next steps are to find the link between the gravitational force variations and the events. It also tries to find out, the reason why the quakes happened more at the New or Full Moon. Most of the earthquakes occurred near the coast and subduction zones of the West Pacific area. During periods of spring tides, the gravitational pull from Sun and Moon acts jointly. Such ocean tides could create dramatic changes in the tectonic force balance in subduction zones located in the Pacific area. In an attempt to examine the regions affected by the earthquakes during the days of Maximum or Minimum perigee compilations were carried out of the different phases of the moon based on the Fig. 2. Table 1 provides a list of localities of Full Moon corresponding to the data of Maximum perigee force in the range 1996-2008. Most of the events occurred in the coastal region of the Northern Hemisphere.

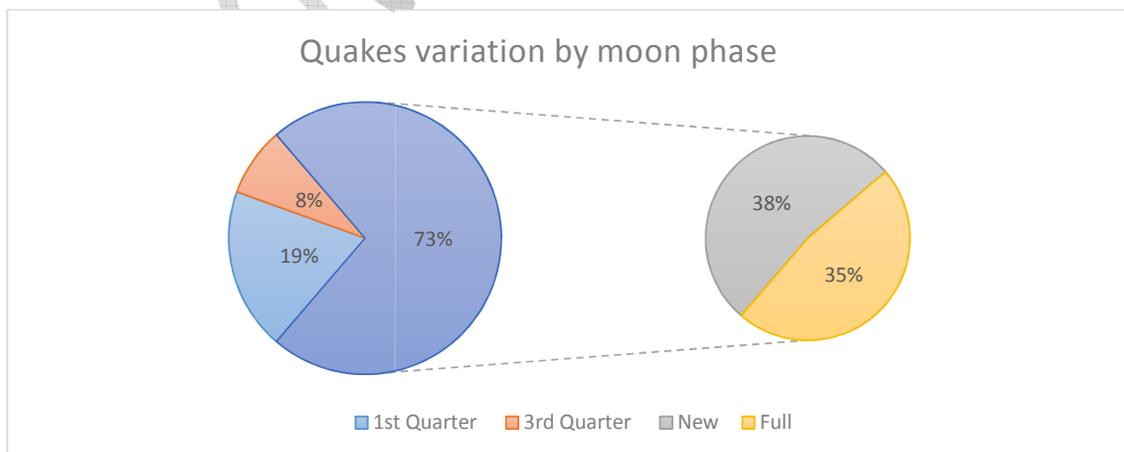


Fig. 4. Variation of the number of quakes with magnitude $M \geq 4.5$ and respective moon phase in the period 1996-2008. The locations of quakes are mainly coastlines. See Tables 1, 2, 3, 4

Table 1. Days of Maximum Perigee occurred during the Full Moon and the locations of earthquakes $M \geq 4.0$. The locations inland (intraplate) marked in red

Perigee maximum	Region - Full moon (phase)
Jul 30, 1996	East Pacific, Central Pacific, South Atlantic
Aug 19, 1997	East Pacific, Central America
Sep 16, 1997	East Pacific, South America, Iran (coast)
Oct 06, 1998	Northeast Pacific, South eastern Pacific, China, Greece
Nov 04, 1998	Tonga, Kyrgyzstan, Central Mid Atlantic, Aleutian
Dec 22, 1999	Northern Pacific, Southern Pacific, Algeria, Middle East, Russia
Jan 10, 2001	Alaska, Southeast Pacific
Feb 07, 2001	China (Intraplate), North/south eastern Pacific
Feb 27, 2002	Kuril Is, South Iran (coast), Fiji
Mar 28, 2002	North/South eastern Pacific, South America(inland) North Atlantic
Apr 17, 2003	Intraplate (Turkey, China, Utah), Pacific Ocean
May 15, 2003	All Pacific Ocean
Jun 03, 2004	Intraplate (China, Myanmar) Pacific Ocean
Jul 01, 2004	Intraplate (Turkey), Reykjanes Ridge, Indian Ocean, Pacific Ocean
Jul 21, 2005	Pacific Ocean, Indian Ocean, Atlantic Ocean, Sandwich Is
Aug 19, 2005	Myanmar (Intraplate) , Indian Ocean, Southern Pacific, South America
Sep 08, 2006	Pacific Ocean, Indian Ocean, inland (Tajikistan), Mediterranean
Oct 06, 2006	Pacific Ocean, Indian Ocean, Atlantic Ocean
Oct 26, 2007	Kashmir (Intraplate), Pacific Ocean
Nov 24, 2007	Tajikistan (Intraplate), Mediterranean, Caribe, Pacific Ocean
Dec 22, 2007	North-eastern Pacific, Southern Pacific, South America Pacific coast
Dec 12, 2008	Northern, Southern Pacific (east)
Jan 10, 2009	Southeast Pacific, South America Pacific coast

Table 2. Days of Maximum Perigee during the New Moon, and regions of earthquakes $M \geq 4$. Locations intraplate are in red. Period 1996-2008

Perigee Max.	Region - Phase new moon
Jan 19, 1996	East Pacific, Central Peru, Afghanistan, South Atlantic
Feb 07, 1997	East Pacific, Afghanistan
Mar 08, 1997	East Pacific, North Atlantic, Middle East
Mar 28, 1998	Northeast Pacific, South America
Apr 25, 1998	Northeast Pacific, Caribbean, South Atlantic
May 15, 1999	Middle East Pacific, China, California
Jul 01, 2000	Mid Atlantic Ridge, Caribbean, North-eastern Pacific, Southern East Pacific
Jul 30, 2000	Northern Pacific (Japan, Kuril Is), Southern Pacific, Atlantic
Aug 19, 2001	Iran/Iraq (coast), Southeast Pacific, Mid Atlantic
Sep 16, 2001	Southeast Pacific, Greece, Canada, Southwestern Pacific
Oct 06, 2002	Intraplate (South America), North/South eastern Pacific, Iran, North Atlantic
Nov 04, 2002	Intraplate (Alaska, Kashmir, Indonesia, Tanzania), Caribe, Japan
Nov 23, 2003	Intraplate (China, Nevada, Laos), Indian Ocean, Pacific Ocean
Dec 22, 2003	Iran, All Pacific Ocean, Mid Atlantic, North Atlantic
Dec 12, 2004	Pacific Ocean, Indian Ocean
Jan 10, 2005	Pacific Ocean, Indian Ocean, Turkey
Jan 30, 2006	Intraplate (Alaska), Pacific Ocean, Indian Ocean
Feb 27, 2006	Aleutian Is, Southern east Pacific Rise, Indian Ocean
Apr 17, 2007	Pacific Ocean (East/ West), Indian Ocean
May 06, 2008	North Atlantic, North Pacific, South Pacific
Jun 03, 2008	Intraplate (Tajikistan, Mongolia, China), Northeast, North, South Pacific, Iran

The Table 2 provides the location of quakes more earthquakes happened intraplate if occurred at the New Moon during the maxima compared with the Table 1 for the Full Moon. gravitational force days. During the New Moon,

The other Tables 3 and 4 were constructed with the minimum of gravitational force vide Fig. 2 corresponds to the First or Third Quarter. The results obtained in those Tables showed that events occurred at the coastlines in their majority.

Nevertheless, the Maxima or Minima Perigee results indicated that the earthquakes were more frequently at the Full or New Moon locating at the Pacific subduction zones [26,27,28]. To the highest Maximum (full or New Moon) events, intraplate occurred in the Middle East and far Northern (see the Tables 1, 2).

To the Minima of perigee (First or Last Quarter), there were fewer occurrences intraplate and only at the Northern Hemisphere (see the Tables 3 and 4).

During the moon's quarter phases the sun and moon at the right angles causing the bulges to cancel each other. Our results show evidence that the gravitational pull of the Moon and Earth

enhanced earthquakes in areas near the coast. It supports the claim that the tides help to trigger earthquakes. In our calculations, we considered the magnitude of events $M \geq 4.0$. The first part of this paper showed that the Moon at the Perigee created a variation in the gravitational force, which has a maximum at the Full or New Moon. The construction of this moon variation allowed to search the frequency of earthquakes during the days that the New or Full Moon reached the Maximum of the force. The events found were always near the coastlines with some few events inland. Earthquakes happen when a region under tension, pressure and, stress accumulate energy enough to a rupture point. When reaches this point it triggers an earthquake. For a quake to be correlated with external causes, we pointed some of them: flood, chemical explosion, ice quake, landslide, mine collapse, nuclear explosion, and quarry blast, among others. At this first step, we did not find an exact correlation between the Moon and earthquakes. We found during very special conditions that earthquakes would happen.

Table 3. Days of Minimum perigee corresponding to First Quarter moon phase. Earthquakes for each day are $M \geq 4$. Inland is in orange. Period is the same 1996-2008

Perigee min	Region -phase first quarter
Nov 16, 1996	Intraplate (China), East Pacific, South Africa Ocean, Caribe
Dec 09, 1997	Intraplate (Iran), north eastern/ South eastern Pacific, South America coast
Jan 3, 1998	Malawi, North -Southeast Pacific , Caribe, Southern Mid Atlantic
Jan 26, 1999	East Pacific
Mar 14, 2000	South east- western Pacific, Caribe, Middle Atlantic
Jun 19, 2002	North- South eastern Pacific, Caribe
Aug 6, 2003	North -South eastern Pacific, Mid Atlantic,
Sep 22, 2004	North-South eastern Pacific, Russia
Nov 10, 2005	Russia, China, Indian Oceans, North-South eastern Pacific
Dec 28, 2006	Rwanda, Mediterranean, South Ocean
Feb 14, 2008	South eastern Pacific, Alaska, Cornwallis Island
Apr 02, 2009	North - South Pacific

Table 4. Days of perigee minimum for the Third Quarter phase. Earthquakes recorded for each day are the less active phase, the period 1996-2008

Perigee minimum	Region - Phase third quarter
Apr 11, 1996	Atlantic, East Pacific, Indian Ocean
May 29, 1997	Intraplate (China), South Pacific. South Atlantic, Alaska
Jul 16, 1998	North- Northeast Pacific, Southeast Indian Ridge, Mediterranean
Sep 02, 1999	North- South eastern Pacific, Pacific South America coast
Oct 19, 2000	Northeast Pacific, Pakistan
Dec 06, 2001	Mid- Indian Ridge, South eastern Pacific
Jan 23, 2003	Portugal (coast) Mongolia, Indonesia Oceans
Mar 12, 2004	Afghanistan, East coast North- South Atlantic coast (Pacific)

3. DISCUSSION OF RESULTS

The results at this point are: A variation on the Perigee position created a Moon- Earth wave varying in the interval 1996- 2008. Peaks of maximum in the oscillation corresponded to the Full or New moon, peaks of minimum to the 1st or 3rd Quarter with correspondent date. The Moon can also be at the Full Moon at the apogee as well. We searched during the special days of the maximum and minimum points all the earthquakes and the regions they occurred. It coincided that the majority of earthquakes took place at the subduction or convergent zones at coastlines. The statistical calculation finds out that during the New or Full moon the higher tides doing more pressure accumulating energy at subduction regions. At the 1st or 3rd Quarter, the neap tides retract doing less tension. There is a lag time requested to trigger an earthquake not every Full or New Moon will create strain enough to trigger earthquakes. It happens when the rupture point is reached after a while the region deforming by the power of the ocean waves. If the tides are higher the deformation increase, if the tides are lower it decreases until the rupture break.

The dynamic of oceans allied to the gravitational push will trigger earthquakes. The Sun gravitational force adds the push when the moon aligned with the other two bodies. The range of time necessary to trigger large or megathrust earthquakes may be large, and we are going to see the next sections. In this paper, we are working with several data catalogs, earthquakes from Iris and USGS [29,30]. For Solar Cycles, NGDC/ NOAA [20,21,22,23,24,25], for moon data [10,17,18,19].

4. MEGATHRUST EARTHQUAKES EXTERNAL CONNECTIONS

The first part of this work demonstrated that the Moon-Earth gravitational connection is a force varying with the satellite position around the planet. This force, when located at the Perigee created a wave, which we calculated the period and the wavelength. The wave has maxima values coincident with the New or Full Moon, and the minima values with the First or Third Quarter. The Solar Cycle 23 accomplished eleven moon cycles as calculated in the Fig. 1. The Solar Cycle 24 started in 2008 and covered only eight Moon cycles so far. A possible interrelation between the lunar cycles, solar cycles, and earthquakes cycles is not feasible now.

Our next step is to examine if the Moon gravitational force is linked to the Megathrust and giant earthquakes recorded. First, we will examine Megathrust earthquakes, which had fewer events in the time interval 1700-2016, with magnitude ≥ 8.5 . Megathrust happens in subduction locations as observed before, [26,27,28].

The Table 5, displays some characteristics of those mega -events, occurrences between November- May, it also befell at the minimum of a solar cycle (we discuss this point in another paper). There was no event in the Third Quarter, which agrees with our Fig. 4 that only 8% of total events happened through this moon phase. Mega events occurred in shallow depths, near the coast, most of the Full or New Moon, with small delays in data [12].

In the examination of the events indicated there is a stress on deformed regions by the subduction stating that tides or the progression stress from gravitational forces Moon- Earth accumulates several years before the earthquake happening. The coincidence of a specific Moon phase and the event demonstrated the time when reaching the breakpoint triggers a Mega quake.

The next point it is to examine the larger earthquakes, which happens more often than the Megathrusts, in the period 1996-2016.

5. MOON PHASES CORRELATION TO LARGE EARTHQUAKES

This section amplifies the search to find possible connections between giant earthquakes and gravitational interactions between the moon and the Earth. Table 6 shows all the giant earthquakes in the period 1996-2008. It gives the data, magnitude, moon phase, and region where the event took place. Events in Indonesia during this time were in New or Full moon this is the Southern Hemisphere. Events at the 3rd Quarter happened at the Kuril Islands and Papua New Guinea in the Northern Hemisphere.

There was only one occurrence at the first Quarter in Tonga (Southern Hemisphere). Overall, large earthquakes during the Solar Cycle 23 were at the New or Full in the Pacific Coast areas. All took place at subduction localities. The Figs. 5 and 6 showing different coast areas and the giant earthquakes in a broader spectrum interval 1996-2015. Fig. 5 displays events around

Sumatra most events occurring at Full or New Moon during the period considered. The speed of the plate in this area is 70 mm/yr.

Fig. 6 illustrates the giant quakes in the same period at the South America coast, mostly at New or Full Moon. The speed of the plate is now 79mm/ yr. In both pictures, there were no intraplate occurrences, and it was rare that giant earthquakes were happening inland. Table 7 shows the largest earthquakes $M \geq 7.5$, location, data, magnitude, Main Moon Phase, Tides, Days-Moon phase difference.

As observed for the earthquakes $M \geq 8.0$ in a small interval 1996-2008, we found that larger earthquakes are more likely to happen at New or

Full Moon in the subduction margins. We marked in red the ones that are on time, delayed by one day before, or after the phase started. Our results indicated the majority of quakes happened on time, delayed, or advanced one day of the moon phase. Earthquakes most occurred at the subduction areas what indicated that the high tides are important for those interactions. Finally, we found out that few events Table 7 for $M \geq 7.5$ and $M \leq 8.0$ happened intraplate. It indicates the largest magnitude earthquakes happened in their almost totality between 1996- 2016 at the subduction locations. Connections gravitational variation, moon phase and tides increased for earthquakes with larger magnitudes most to subduction regions.

Table 5. Megathrust earthquakes ($M > 8.5$), period 1700-2016. Few events observed at the exact day Moon Phase change. Kamchatka (1952), Alaska (1964), and Indonesia (2004). The major delayed event was Chile (1960) which occurred three days before New Moon. The events happened in the interval November – May. The total of events had 89% of occurrences during the Full or 1st Quarter, 11% at the New moon. None happened at the 3rd Quarter

Date	Location	Mag- M	Depth -km	Moon -phase
1/27/1700	Cascadia sub zone	9	*	1st Q
1/31/1906	Ecuador	8.8	25	1st Q
11/4/1952	Kamchatka Peninsula	9	30	Full ○
5/22/1960	Chile	9.5	25	New●
3/28/1964	Alaska	9.2	25	Full ○
12/26/2004	Indonesia	9.1	30	Full ○
3/28/2005	Indonesia	8.7	30	Full ○
2/27/2010	Chile	8.8	23	Full ○
3/11/2011	Japan	9	29	1st Q

Table 6. Large quakes of the period 1996-2008, magnitude $M \geq 8.0$, moon phase, and region located. The percentage that a quake happened at the New or Full Moon or Third Quarter was almost the same. For the First Quarter much smaller

Date	Mag	Moon Phase	Region
12/9/2007	8.5	New	Indonesia (Sumatra)
15/08/2007	8	New	Peru
1/4/2007	8.1	Full	Solomon Is
13/01/2007	8.1	3rd Q	Kuril Is
15/11/2006	8.3	3rd Q	Kuril Is
3/5/2006	8	1st Q	Tonga
28/03/2005	8.6	Full	Indonesia (Sumatra)
26/12/2004	9.1	Full	Indonesia (Sumatra)
23/12/2004	8.1	Full	Indonesia (Sumatra)
25/09/2003	8.3	New	Macquarie Is(north)
23/06/2001	8.4	New	Hokkaido, Japan
16/11/2000	8	3rd Q	Papua New Guinea
25/03/1998	8.1	New	Balleny Is
17/02/1996	8	New	Biak region, Indonesia

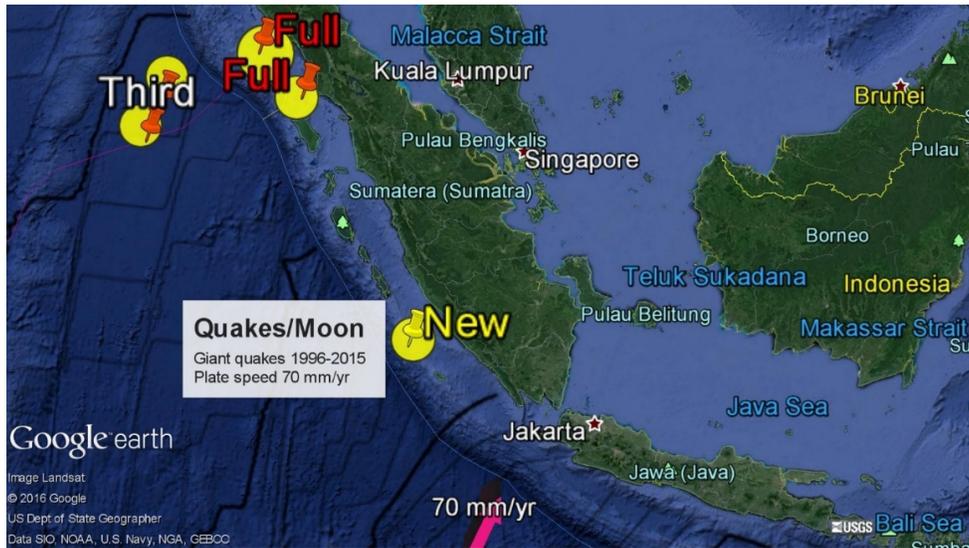


Fig. 5. Location of large earthquakes (magnitude $M \geq 8.0$) for the period 1996-2015 and, the moon phase for each of them at Indonesia. The plate speed in the region is, 70 mm/yr. (In the picture)



Fig. 6. Earthquakes $M \geq 8.0$, 1996-2015, and the moon phases, F- Full, N- New, T- Third, for the South Pacific region off the coast of South America. The plate speed at Nazca is 79 mm/yr

6. GENERAL RESULTS

We first found a gravitational wave variation with maximum values corresponding to the New or Full moon. We searched for the earthquakes $M \geq 4$ and the locations of those events, most of them occurred at subduction or convergent areas near the coastlines. The second part studied the correspondence between Megathrust events ($M \geq 8.5$), lunar phases and locations in the period

1700-2016, all happened in the subduction at the Pacific. The last two Tables 6 and 7 worked first with giant events ($M \geq 8.0$) in the period 1996-2009 and largest earthquakes ($M \geq 7.5$) in the interval 1996-2016. The results, pointed out that largest events occurred at the New or Full moon in subduction locations. Exceptions are attached for still unknown interior processes in the earth diverse from the external ones, happening at the coastlines as observed.

Table 7. Large earthquakes in the period 1996-2016, the Table gives the place, the data, magnitude, main moon phase, the number of days before or after the main phase, and the tide connections

Place	Data	Magnitude	Main Phase	Tides	Days/ Moon phase
Ecuador	16/04/2016	7.8	First Q	neap	2 before
Indonesia	2/3/2014	7.8	Third Q	neap	1 before
Brazil	24/11/2015	7.6	Full	spring	1 after
Peru	24/11/2015	7.6	Full	spring	3after
Afghanistan	26/10/2015	7.5	New	spring	1after
Chile	16/09/2015	8.5	New	spring	1after
Japan	30/05/2015	7.8	Full	spring	2 after
New Guinea	5/5/2015	7.5	Full	spring	1 before
Nepal	25/04/2015	7.8	First Q	neap	-
Alaska	23/06/2014	7.9	First Q	neap	1 after
New Guinea	19/04/2014	7.5	New	spring	1 before
Solomon Is	12/4/2014	7.6	Third Q	neap	-
Chile	3/4/2014	7.7	Full	spring	1 after
Chile	1/4/2014	8.2	Full	spring	3 after
Scotia Sea	17/11/2013	7.7	Third Q	neap	2before
Pakistan	24/09/2013	7.7	New	spring	-
Okhotsk	24/05/2013	8.3	Full	spring	1after
Iran	16/04/2013	7.7	First Q	neap	2 after
Alaska	5/1/2013	7.5	Third Q	neap	-
Canada	28/10/2012	7.8	Full	spring	1 after
Philippines	31/08/2012	7.6	Full	spring	-
Okhotsk	14/08/2012	7.7	New	spring	3 after
Sumatra	11/4/2012	8.2	Third Q	neap	2after
Sumatra	11/4/2012	8.6	Third Q	neap	2 after
Kermadec Is	6/7/2011	7.6	First Q	neap	2 after
Japan	11/3/2011	7.7	First Q	neap	1after
Japan	11/3/2011	7.9	First Q	neap	1 after
Japan	11/3/2011	9	First Q	neap	1after
Indonesia	25/10/2010	7.5	Full	spring	2 before
Philippines	23/07/2010	7.8	Full	spring	3 after
Philippines	23/07/2010	7.5	Full	spring	3 after
India	12/6/2010	7.5	New	spring	-
Sumatra	6/4/2010	7.8	Third Q	neap	-
Chile	27/02/2010	8.8	Full	spring	2after
Sta Cruz Is	7/10/2009	7.8	Full	spring	3 before
Vanuatu	7/10/2009	7.7	Full	spring	3before
Samoa	29/09/2009	8.1	First Q	neap	3 after
New Zealand	15/07/2009	7.8	Third Q	neap	-
Tonga	19/03/2009	7.6	Third Q	neap	1 after
Indonesia	3/1/2009	7.7	First Q	neap	1 before
Okhotsk	5/7/2008	7.7	New	spring	0-2 after
China	12/5/2008	7.9	First Q	neap	-
Fiji	9/12/2007	7.8	New	spring	-
Chile	14/11/2007	7.7	First Q	neap	3 after

Place	Data	Magnitude	Main Phase	Tides	Days/ Moon phase
Japan	28/9/2007	7.5	Full	spring	2 before
Indonesia	12/9/2007	7.9	New	spring	1 after
Indonesia	12/9/2007	8.5	New	spring	1 after
Peru	15/08/2007	8	New	spring	0-3 after
Indonesia	8/8/2007	7.5	New	spring	3 after
Solomon Is	1/4/2007	8.1	Third Q	neap	1 after
Molucca Sea	21/1/2007	7.5	New	spring	2 after
Kuril Is	13/1/2007	8.1	New	spring	-
Indonesia	17/7/2006	7.7	Third Q	neap	-
Tonga	3/5/2006	8	First Q	neap	2 after
Russia	20/4/2006	7.6	New	spring	2 before
Banda Sea	27/1/2006	7.6	First Q	neap	2 before
Pakistan	8/10/2005	7.6	Third Q	neap	2 before
Peru	26/9/2005	7.6	First Q	neap	1 after
New Guinea	9/9/2005	7.6	First Q	neap	2 before
Chile	13/6/2005	7.8	First Q	neap	2 after
Indonesia	28/3/2005	8.6	Full	spring	1 after
Sumatra	26/12/2005	9.1	Full	spring	1 after
Macquarie Is	23/12/2004	8.1	Full	spring	2 after
Indonesia	11/11/2004	7.5	New	spring	1 before
Alaska	17/11/2003	7.8	Third Q	neap	-
Japan	25/09/2003	8.3	New	spring	1 after
Scotia Sea	4/8/2003	7.6	First Q	neap	1 after
Carlsberg Ridge	15/7/2003	7.6	Full	spring	2 after
Alaska	3/11/2002	7.9	New	spring	1 before
Indonesia	10/10/2002	7.6	New	spring	3 before
New Guinea	8/9/2002	7.6	New	spring	1 after
Fiji	19/8/2002	7.7	Full	spring	-
Philippines	5/3/2002	7.5	Third Q	neap	1 before
China	14/11/2001	7.8	New	spring	1 before
Banda Sea	19/10/2001	7.5	New	spring	3 after
Peru	7/7/2001	7.6	Full	spring	2 after
Peru	23/6/2001	8.4	New	spring	2 after
India	26/01/2001	7.7	New	spring	2 after
Philippines	1/1/2001	7.5	First Q	neap	1 after
New Guinea	17/11/2000	7.8	Third Q	neap	2 after
New Guinea	16/11/2000	7.8	Third Q	neap	2 after
New Guinea	16/11/2000	8	Third Q	neap	2 after
S. Indian Ocean	18/6/2000	7.9	Full	spring	2 after
Indonesia	4/6/2000	7.9	New	spring	-
Indonesia	4/5/2000	7.6	New	spring	-
Japan	28/3/2000	7.6	Third Q	neap	-

The calculations indicated that the tides in the rupture points and subduction regions help in triggering earthquakes since these locations are sinking due the tides pressure and gravity. The pressure from tides makes the underneath plate which is colder, older and breakable sink, sliding

slowly under the younger continent. Therefore, two forces are acting on these points, the one from the Moon affecting tides, and one from the earth attracting the lower subducting plate and uplifting the continental one. The forces accumulating strain in the asperities under the

water and eventually disrupt these points triggering earthquakes. The external forces are the tides pressure around the shores or ocean lines that forcing cold water underneath the continental crust, which has a higher temperature, and in many cases, it breaks the lower plates and increases the tension. Generally, a straight correlation Full or New Moon and earthquakes is rare for earthquakes since it needs time to happen.

7. CONCLUSIONS

We defined external factors as the Moon- Earth gravitational variation, which can influence on the Tides especially during the New or Full Moon. Largest earthquakes and a discrete enhancement of events $M \geq 4$ observed during those phases. The results found gravitational forces between Moon and Earth acting most at the oceans and affecting the coastlines. The energy from the higher tides is pushing on the subduction regions storing strain, stress enough to disrupt the region with asperities to trigger the largest earthquakes. However, it demands a time gap to happen.

Overall, the Moon and the Earth connection have interactions that require long time intervals to affect largest seismological events. The continuation of this research is to analyze the three – body system and the consequences of the interconnections among them on earthquakes.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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