# On the Dependence of Earth's Seismic Activity on Lunar Distances

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**Abstract**

In order to explore any direct link between celestial phenomena and the seismic activity the distance between Moon and the Earth is calculated at the time of all major Earthquakes during the last 109 years. It is found that the Earthquakes (EQ) frequency is very low (4.4%) for lunar distances less than 360,000 km (close to perigee). At large lunar distances greater than 400,000 km (close to apogee), the EQ frequency (27 %) is very high. A cubic relation between the two has a high degree of goodness of fit. This leads to a major revelation that for the period of study there is found a clear dependence of EQ frequency on lunar distances.

**Keywords:** Seismic activity, Lunar distances, Dependence

## 1. Introduction

Earth quake (EQ) is one of the natural disasters on the earth. The main cause that has ever been discovered is energy release during rapid slippage along a fault. Since the middle of the19th century many seismologists and some astronomers have tried to discover the relations between the cause of the energy released and the positions of the moon and the sun in some detail.

F. Omori, Rigakushi and Rigakuhakushi (1900) have described the relation between EQ after shocks frequencies with the lunar daily distribution. The occurrence of two maxima in the curves of hourly earthquake distribution at a mean interval of 12 hrs, and approximately at, or little after, the meridian passages of the moon is found to be a common feature. G. P. Tamrazyan (1967) related syzygy zone, phase of the moon and the earthquake frequency. The study revealed that, the earthquake frequency in the new and full moon zones doesn't always increase; under certain circumstances it shows a substantial decrease. Earthquake frequency during the quadrature moon phase does not decrease; under certain circumstances it increases sharply. Besides the above facts Tamrazyan (1974) presented the evidence to support the hypothesis that the Tashkent earthquake of 1966 April 25 and the largest (intensity V or greater) earthquakes in its aftershock sequence tended to occur under similar 'cosmic' conditions. Tamrazyan (1968) related the two ranges of magnitudes of EQ, an upper magnitudes 8.4–8.9 and a lower magnitude 7.9–8.3 to (a) rotational parameters of the Earth (the so-called V numbers) and (b) lunar declination at culmination. In the last quarter of the century (1940–1964) three-fourths of all earthquake energy was released when the position of the Moon was over the northern hemisphere of the Earth (Tamrazyan, 1969). This positional relationship pertains to the seismic foci of the northern, as well as the southern hemispheres.

All the above studies are localized i.e. based on region, period and intensity of EQ, whereas, we have attempted to explore the global EQ data (more than 100 years from May, 1900 to April, 2009), to explore whether there are any links between the celestial phenomena and the seismic activity on the Earth. For this purpose in this work the EQ frequencies are studied in comparison to the lunar distances.

## 2. Earthquake frequencies and lunar distances

The raw EQ data was collected from the Centennial Catalog, the updated Engdahl, van der Hilst and Buland earthquake Catalog, The United States Geological Survey's Preliminary Determination of Epicenters (PDE), monthly listing, and Pakistan Meteorological department (Engdahl & Villaseñor, 2002; Engdahl, R. van der Hilst, & R. Buland, 1998; Sipkin, Person, & Presgrave, 2000; Utsu, 2002). The data considered includes 74 instances when the magnitude of EQ was less than 5 as compared to 1110 instances when the EQ magnitude was more. Although, more earthquakes of lower magnitudes occur, the data available appears to be biased towards the EQs of higher magnitude.

Using "ELP" (Chapront-Touzé, M. & Chapront, J., 1988) theory the lunar distances are calculated at precise time of occurrence of EQs. During the period of study the minimum lunar distance for which a significant EQ occurred (in China 26.16N, 103.171E of magnitude 5.6, on February 5th 1966 at 15:12 UTC) is found to be 356652.17 Km and 406521.31 Km as maximum one, (in India 33N, 76E of magnitude 7.8, on April 4th 1905 at 0:50 UTC).

To explore any correlation between lunar distances and the EQ frequency the whole range of lunar distances (from perigee to apogee) is divided into intervals of 5000 km. This interval size exceeds the lunar diameter and any smaller interval appears to be not well suited. These intervals along with corresponding EQ frequencies are shown in Table 1; the first column shows interval of the lunar distances (D) in $10^5$ Km, second column, the observed EQ frequencies ($y_0$) and the third column describes the relative EQ frequencies ($y_r$). The relative frequencies indicate that 10% or less EQ's occur in all selected ranges of distances, except the last interval where relative frequency is around 27%, i.e. most number of EQs occurred at or near apogee.

## 3. Modeling and statistical analysis

Table 1 clearly reveals that the EQ frequencies have a strong functional dependence on the lunar distance. As the lunar distances increase EQ frequencies increases, except around intermediate zones (from 375000 Km to 390000 Km), where some deviation can be seen. It is worth noting that, as the distance gets larger and larger (from 395000 Km to maximum), the EQ frequencies increases sharply (from 128 to 316). As mentioned earlier the data contains more instances of EQs with magnitudes 5 or more but this trend is found even if the data is divided into magnitude intervals like 2-3, 3-4, …. , 8-9 etc.

It appears that when the Moon is at its maximum distance (close to apogee) the seismic activity is much greater than when the Moon is at lower distances (near perigee). The scatter plot (Fig 1) of the data in Table 1 shows that the relation between lunar distances and the EQ frequencies is that of a cubic polynomial, as the plot has a maximum, a minimum and a strong inflexion point. For this reason to fit a 3rd degree polynomial to the data, the least square estimation from 3rd degree polynomial is employed.

The probabilistic model for the data in Table 1 is given by;

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \varepsilon$$

Where $E(y) = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3 = \Sigma\, \beta_i x^i$; i = 0,1,2,3 deterministic component;

$$\varepsilon = \text{random error component;}$$

Using Statistica 8.0 the estimation of deterministic component $\hat{y} = b_0 + b_1 x + b_2 x^2 + b_3 x^3$ hence obtained:

$$\hat{y} = 11681.2403\ x^3 - 131903.94\ x^2 + 496198.782\ x - 621746.13 \quad (1)$$

Equation (1) is the model of best fit $R^2$ = 98.96%, $R^2$adj = 98.43%, P-value <0.0001:

Fig 2 shows the fitted plot of lunar distances and EQ frequencies with 95% confidence interval (C.I) (Rumsey, 2007). The model appears to fit well because the points follow closely to the curve, but to assess the fit of the model beyond the usual suspect, scatter plot of the data, three additional items P-value, value of $R^2$-adjusted and the standardized residual plots are being analyzed.

ANOVA, one of the key features of regression analysis, shows that F = 189.9575 with P-value < 0.0001, much less than the cutoff value of, $\alpha = 0.05$ so the null hypothesis Ho: $\beta_1 = \beta_2 = \beta_3 = 0$ should be rejected against alternative hypothesis Ha: at least one of $\beta_i \neq 0$; i = 1, 2, 3: and the small P-value is statistically significant to consider it one of the criterion of best fit of model equation 1 (Stephens, 2004). $R^2$, 98.96%, and the $R^2$-adjusted, 98.43% are very high values, and these high values depict that, the cubic modal (1), fits the data of Table 1 very well (Rumsey, 2007 & Stephens, 2004).

Finally standardized residual plots, Fig 3(a) and Fig 3(b) exhibits the following features:

- The right scatter plot Fig 3(a) shows that most of the standardized residuals fall between –2 and +2 following the 68-95-99.7 Rule.
- The left plot of Fig 3(a) shows that the standardized residuals follow a linear trend which suggests that the residuals are from normal distribution.
- The left plot of Fig 3(b) demonstrates that the residuals have no pattern. They appear to occur at random.
- The right plot of Fig 3(b) shows that the residuals bear some resemblance to a normal distribution (Rumsey, 2007).

All of these plots Fig 3(a) and Fig 3(b) together suggest that the selected cubic regression model equation 1 is best fitted model (Rumsey, 2007). Estimation of EQ frequencies $\hat{y}$, using model equation (1) in the interval of $3.56 \leq D \leq 4.066$ ($10^5$ Km), residuals and standardized residuals are tabulated in Table 2.

Mean absolute percentage error (MAPE), mean absolute deviation (MAD) and root mean square deviation (RMSD) of the defined model equation 1 are shown in Table 3.

**4. Discussion**

The seismic activity of the Earth suggests that the crust is in a dynamic condition, and this dynamics is due some internal forces of the earth and is caused by the energy release during rapid slippage along a fault.

The results of Table 3 are sufficient to assume that the motion of the earth's crust is controlled by some external forces also. The scatter plot in Fig 1 indicates this situation, that there are minimum chances for occurrence of EQ at perigee (only 4-5 out of 100 EQ's), because the earth crust is strongly bound by the lunar force and hence provide resistance to plate movement. As the lunar distance increases the number of EQ's increases (from 53 to 116, Table 1) due to less lunar force on the earth crust and relative free movement of the plates. For medium lunar distances the EQ frequencies decreases and then increases again. This apparently is in disagreement of the above hypothesis, but we expect that there are some other factors affecting on the occurrence of EQ's which are needed to be further studied. The last lap of the plot follow the same behavior i.e. the EQ frequencies increases more sharply at apogee than perigee indicating that, at apogee the lunar force becomes sufficiently small that allows the moment of the earth plates with relative ease (26-27 out of 100 EQ's).

Even if the data is distributed over intervals of integral magnitudes (like 2-3, 3-4, …. , 8-9) the cubic least square fitting on each interval is found to be very good accept for lower magnitudes, i.e. 2-3, 3-4, 4-5. However, for these intervals it is only the fitness of good that depletes with $R^2 = 0.823$, 0.517 and 0.661 respectively but the trend is the same. There are only 74 instances of such magnitude EQ's that make only 6.25% of the data. If more data for these ranges is obtained the good of fit may increases to higher degrees.

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Table 1. Distribution of Lunar distances (interval of 5000 Km) during the period (May, 1900 to April, 2009) and the number of Earthquakes (EQ Frequencies) in each interval, the last column shows the relative EQ frequencies

| **Range of lunar distances (x) $10^5$ Km** | **EQ Frequencies/Count ($y_0$)** | **Relative Frequencies ($y_r$)** |
|---|---|---|
| 3.56 < D < 3.60 | 52 | 0.044 |
| 3.60 ≤ D <3.65 | 103 | 0.087 |
| 3.65 ≤ D <3.70 | 116 | 0.098 |
| 3.70 ≤ D <3.75 | 115 | 0.097 |
| 3.75 ≤ D <3.80 | 91 | 0.077 |
| 3.80 ≤ D <3.85 | 101 | 0.085 |
| 3.85 ≤ D <3.90 | 74 | 0.062 |
| 3.90 ≤ D <3.95 | 89 | 0.075 |
| 3.95 ≤ D <4.00 | 127 | 0.107 |
| 4.00 ≤ D ≤ 4.066 | 316 | 0.267 |
| Sum of EQ's | 1184 | Sum = 1 |

Table 2. Comparison between observed and calculated EQ frequencies using modal equation (1), last two columns shows the residuals of the data, and standardized residuals respectively

| **Lunar Distances (x in $10^5$ Km)** | **Observed EQ frequencies ( $y_0$)** | **Estimated EQ frequencies ( $\hat{y}$)** | **Residuals ( $y_0 - \hat{y}$)** | **Standardized Residuals** |
|---|---|---|---|---|
| 3.56 < D <3.60 | 52 | 58.140 | -6.140 | -0.826 |
| 3.60 ≤ D <3.65 | 103 | 94.363 | 8.637 | 1.163 |
| 3.65 ≤ D <3.70 | 116 | 114.301 | 1.691 | 0.228 |
| 3.70 ≤ D <3.75 | 115 | 114.282 | 0.718 | 0.097 |
| 3.75 ≤ D <3.80 | 91 | 103.045 | -12.045 | -1.621 |
| 3.80 ≤ D <3.85 | 101 | 89.358 | 11.642 | 1.567 |
| 3.85 ≤ D <3.90 | 74 | 81.982 | -7.982 | -1.074 |
| 3.90 ≤ D <3.95 | 89 | 89.678 | -0.678 | -0.0913 |
| 3.95 ≤ D <4.00 | 127 | 121.207 | 5.793 | 0.780 |
| 4.0 ≤ D ≤ 4.066 | 316 | 317.635 | -1.635 | -0.220 |

Table 3. Mean absolute percentage error (MAPE), mean absolute deviation (MAD) and root mean square deviation (RMSD) of the defined model equation 1

| S.No | APE | AD | SD |
|---|---|---|---|
| 1 | 0.118 | 6.140 | 37.698 |
| 2 | 0.084 | 8.637 | 74.593 |
| 3 | 0.0146 | 1.691 | 2.860 |
| 4 | 0.0062 | 0.717 | 0.515 |
| 5 | 0.132 | 12.045 | 145.090 |
| 6 | 0.115 | 11.642 | 135.531 |
| 7 | 0.108 | 7.982 | 63.715 |
| 8 | 0.008 | 0.678 | 0.460 |
| 9 | 0.046 | 5.793 | 33.563 |
| 10 | 0.005 | 1.635 | 2.674 |
| **Means** | **0.064** | **5.696** | **49.670** |
| **RMSD** | | | **7.048** |

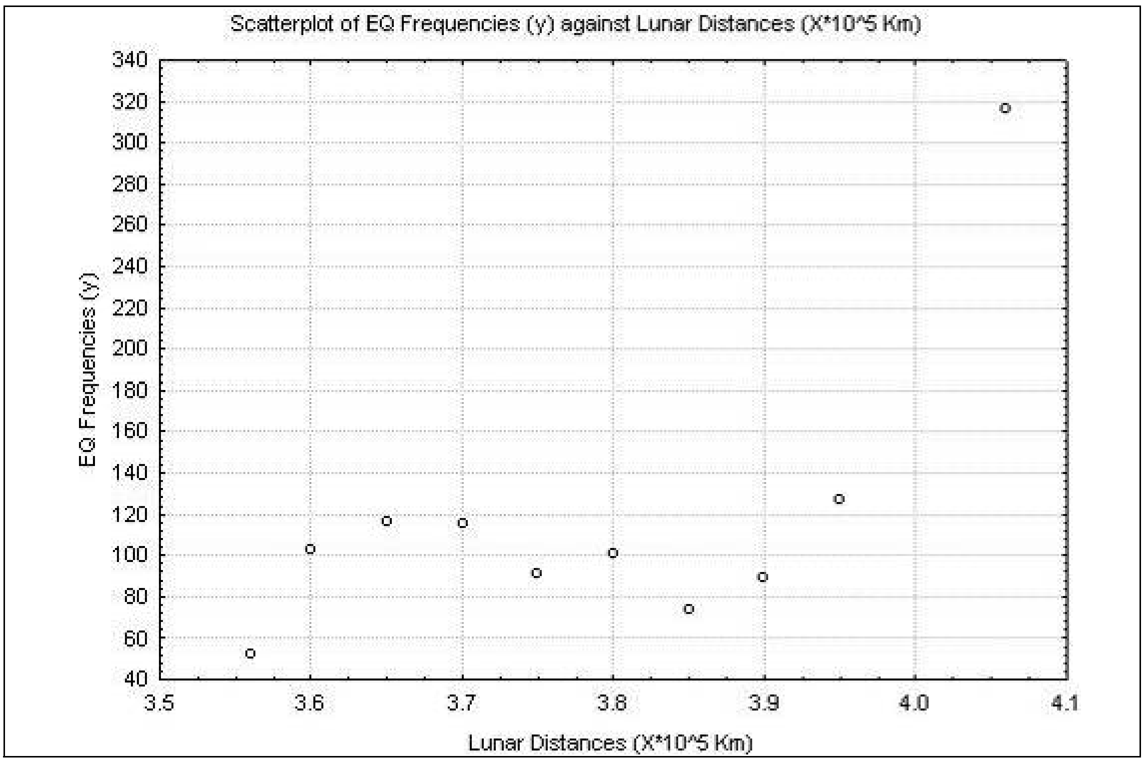


Figure 1. Scatter plot of lunar distances & EQ Frequencies, the inflation point indicates the behavior of 3rd degree polynomial relation

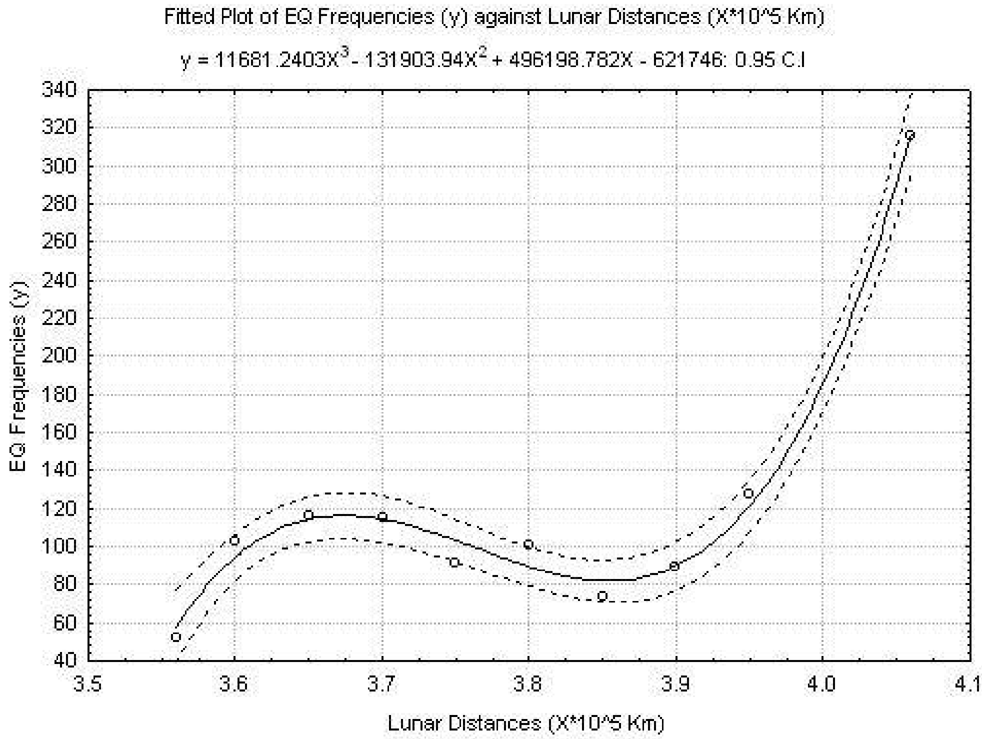


Figure 2. Fitted plot between lunar distances (x) along x-axis and EQ Frequencies (y) along y- axis

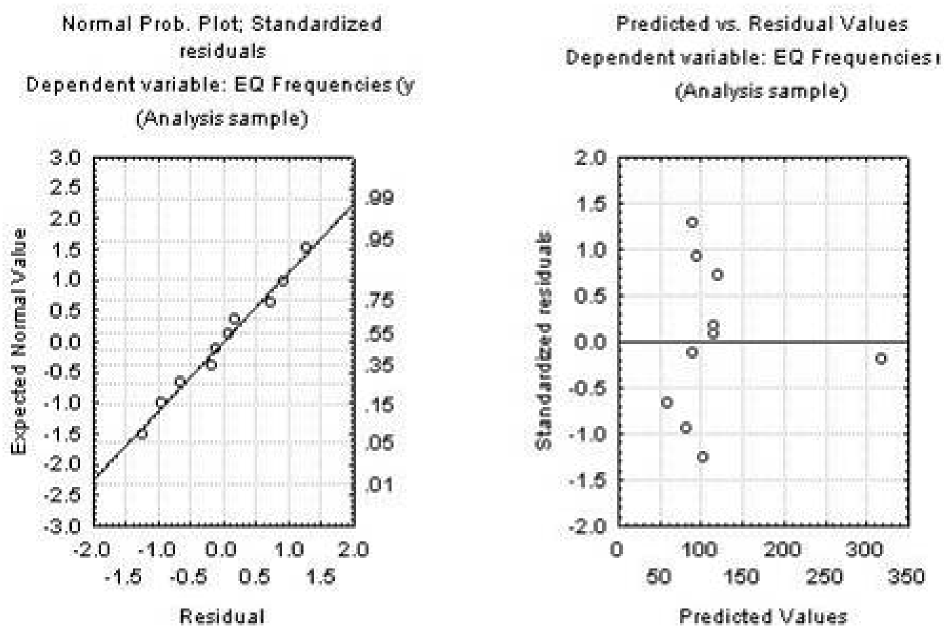


Figure 3(a). Normal probability (left) and predicted values vs. standardized residuals (right) plots of Table 2

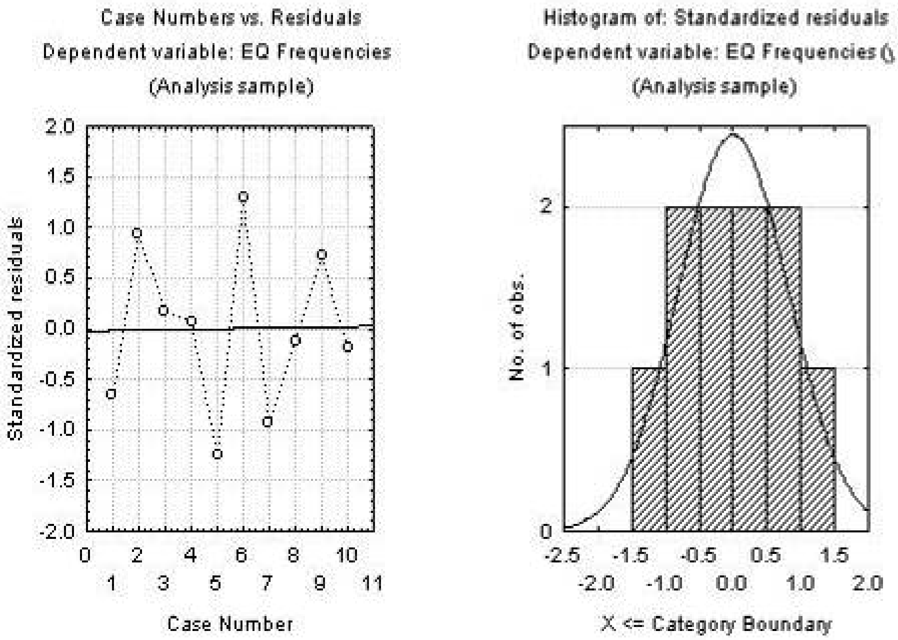


Figure 3(b). Standardized residuals by observation number (left) and histogram of standardized residuals (right) plots of Table 2