Earthquake Prediction Model III-A

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Abstract

The objective of this research is to further continue[1,2,3,4,5] analyzing and investigating correlations between astronomical data and the significant earthquakes of magnitude seven and higher by developing the model using the 110 years (1900-2009) of earthquake data and then predicting the earthquakes for 2011-2017, with the intended goal of predicting future earthquakes with a greater advanced warning and higher degree of accuracy than current technology. Up to this point in research, the Model III[3] seems to perform better than other models. This paper focuses on further exploring the possibility of improving the Model III by analyzing an additional case of the Model III that includes the selection of the angle pairs as independent variables employed in linear regression. As a part of this ongoing research, further research is necessary to build a useful, predictive model that can assess the probability of a given earthquake occurring during a certain time period at a given geographical location on earth. Predicting earthquakes well in advance of the state of the art will promote, protect, and enhance the world economy, potentially saving millions of lives.

Introduction

There is absolutely no precedent in predicting an earthquake solely based on planetary configuration. An occurrence of an earthquake is a random event and it can sometimes occur more frequently than other times. This research began with the idea that planetary positions along the ecliptic, and therefore, their apparent (geocentric) positions as viewed from earth, may potentially correlate with the occurrence of earthquakes. Based on planetary characteristics and a large amount of earthquake data, several hypotheses were tested to see if these correlations actually exist. The results of this exercise indicated that certain planetary configurations seem to correlate reasonably well with earthquakes. This research has evolved from 15-degree multiple angles (Model I) to 12 degree multiple angles (Model II) to the top 16 most frequently occurred longitudinal (Model III) and declination (Model IV) angles.

The intent of this paper is to highlight the initial findings of the extension to the Model III with an additional case of Model III-A, and compare their (Model III and III-A) predictions performance against the actual earthquakes of seven and higher values for 2011-2017.

Independent Variables versus Dependent variables

As pointed out in the earlier papers[1,2,3,4] , one of the challenges involved in developing a correlation between the earthquakes and the corresponding astronomical planetary data is to accurately select the independent variables for developing the model.

In order to avoid confusion, the word angle here when used as "angle pair" refers to the description of planets involved in forming that angle (such as Saturn-Jupiter pair as Sa-Ju), and when it is used as just "angle", it refers to the "value" of the angle for that angle pair (such as Sa-Ju30 for Sa-Ju forming 30 degree angle).

An angle between any two planets is the angle (value) formed by them with respect to the earth. For example, while Jupiter is rising on the eastern horizon and Mars is at the zenith (just above in the sky) are said to form a square aspect (approximately a ninety degree angle) between them. In other words, it is the angle formed by Jupiter and Mars with respect to the earth. And it exactly equals the geocentric longitudinal difference between them along the ecliptic. In the models presented here, the dependent variable is the earthquake magnitude, and the independent variables are the angles of the planetary angle pairs

To further clearly explain this in detail, consider a simple case. Assume that only three planets Saturn, Jupiter and Mars are responsible for an earthquake of significant magnitude M (seven or higher) to occur when they make certain angles between them. Let us assume that their geocentric longitudinal positions to be Sa, Ju and Mr. The respective angle pairs thus formed are Sa-Ju, Ju-Mr and Sa-Mr.

The correlation between M (earthquake magnitude) and the angles is assumed linear, and therefore, mathematically, it can be expressed as:

$$M = a_1 \text{ x } (Sa\text{-}Ju) + a_2 \text{ x } (Ju - Mr) + a_3 \text{ x } (Sa\text{-}Mr) + a_4$$

In the above equation a_1, a_2, a_3 and a_4 are constants. M which is on the left hand side of the equation is a dependent variable while the angles (values of the angles) on the right side are independent variables. It is the variation or change in the angle value of these independent variables dictates the variation in the earthquake value M.

However, it can be shown that information about any two pairs of these angles is sufficient to know the third pair. For example, if we know the angles of Sa-Ju and Ju-Mr then by adding these two angles the angle of Sa-Mr is known. In other words, there are truly only two independent variable angle pairs in the above equation. The challenge then becomes is to decide which of these two variable angle pairs are truly independent or which one is to discard so that the above equation represents the accurate correlation between the earthquake M and the angle pairs.

In general, in theory, for N number of planets, there can be no more than N-1 independent pairs of angles for a given earthquake. In statistical term, one degree of freedom is removed when planets are paired from the list of N number of independent planets. The Model III[3] is based on 11 planets (6 outer planets: Pluto, Neptune, Uranus, Saturn, Jupiter and Mars; 2 inner planets: Venus and Mercury; Sun, Moon and the north lunar node, Rahu). For 11 planets, therefore, a total of 55 angle pairs are possible. However, for a given earthquake, theoretically a maximum of 10 pairs out of these 55 pairs are truly independent.

For each planetary angle pair, the original model III uses the top 16 most frequently occurred angles for the earthquakes of magnitude seven and higher that occurred during the 1900-2009. Consider a typical earthquake that occurred on January 17, 1903 at 16:05 GMT of Magnitude 7.0[7].

The sidereal longitudinal planetary positions on the scale of 0 to 360 degrees for that moment are shown in Table-1. Since our interest is in planetary angles, the difference between the longitudinal positions of the respective planetary pair, the value of planetary angles for any given moment will be the same regardless of the zodiac (tropical or sidereal) used. The planets are listed in the order from the slowest moving planet Pluto to the fastest moving Moon (note that average motion of Venus, Mercury and Sun is about the same as Mercury and Venus always appear closer to Sun from the earth, and therefore are listed in the order: Venus, Mercury and Sun).

Table-1

Sidereal longitudinal planetary positions for Jan 17, 1903 16:05 GMT

1	Pluto	55.61685
2	Neptune	69.26068
3	Uranus	241.0694
4	Saturn	277.3226
5	Rahu	177.8804
6	Jupiter	299.6127
7	Mars	168.5378
8	Venus	285.8416
9	Mercury	292.7295
10	Sun	273.9801
11	Moon	149.7972

In Table-2, all 55 angle pairs along with their respective values are listed for this earthquake. The first two letter mnemonics are used for planets. For example, Pl for Pluto, Ra for Rahu, Ju for Jupiter, Mn for Moon, and so on are employed. The value of angle (difference between the longitudinal positions of the respective planetary pair) is always positive and lies between 0 to 180 degrees. The angle pairs are listed with the the slowest moving planet (such as Pluto) first making angles to other planets, then Neptune with other planets, and finally Sun with the Moon.

Table-2

Fifty five planetary angle pairs along with their respective values

1	Pl-Ne	13.64382	11	Ne-Ur	171.8087	20	Ur-Sa	36.25318
2	Pl-Ur	174.5474	12	Ne-Sa	151.9381	21	Ur-Ra	63.18903
3	Pl-Sa	138.2942	13	Ne-Ra	108.6197	22	Ur-Ju	58.5433
4	Pl-Ra	122.2635	14	Ne-Ju	129.6479	23	Ur-Mr	72.53161
5	Pl-Ju	116.0041	15	Ne-Mr	99.27714	24	Ur-Ve	44.77222
6	Pl-Mr	112.921	16	Ne-Ve	143.419	25	Ur-Mc	51.6601
7	Pl-Ve	129.7752	17	Ne-Mc	136.5312	26	Ur-Su	32.91064
8	Pl-Mc	122.8873	18	Ne-Su	155.2806	27	Ur-Mn	91.27223
9	Pl-Su	141.6368	19	Ne-Mn	80.53652			
10	Pl-Mn	94.18034						

28	Sa-Ra	99.44221	35	Ra-Ju	121.7323	41	Ju-Mr	131.0749
29	Sa-Ju	22.29012	36	Ra-Mr	9.342578	42	Ju-Ve	13.77108
30	Sa-Mr	108.7848	37	Ra-Ve	107.9612	43	Ju-Mc	6.883201
31	Sa-Ve	8.519033	38	Ra-Mc	114.8491	44	Ju-Su	25.63266
32	Sa-Mc	15.40692	39	Ra-Su	96.09967	45	Ju-Mn	149.8155
33	Sa-Su	3.342546	40	Ra-Mn	28.0832			
34	Sa-Mn	127.5254						

46	Mr-Ve	117.3038	50	Ve-Mc	6.887883	53	Mc-Su	18.74946
47	Mr-Mc	124.1917	51	Ve-Su	11.86158	54	Mc-Mn	142.9323
48	Mr-Su	105.4422	52	Vn-Mn	136.0444			
49	Mr-Mn	18.74062						

55	Su-Mn	124.1829

Earlier it was explained that for three planetary angle pairs, information (angle values) about any two angle pairs is sufficient to know the angle of the third pair. In that example we used Saturn, Jupiter and Mars. From Table-2, the angle Sa-Ju equals 22.29; Ju-Mr equals 131.07. Then the third pair, Sa-Mr, can be computed by subtracting 22.29 from 131.07, which equals 108.78. And it agrees with the value in Table-2 for Sa-Mr listed as 108.78.

According to the top 16 most frequently occurred angles for each pair of angles for the earthquakes of magnitude seven and higher during the 1900-2009[3,8], the following 15 angle pairs are involved for this earthquake (Note that 0.5 orb was employed to calculate the top 16 most frequently occurred angles for each pair) as listed in Table-3.

Table-3

Fifteen angle pairs, based on the top 16 most frequently occurred angles for each angle pair

1	Ne-Ur	172
2	Ne-Sa	152
3	Ne-Ra	109
4	Ne-Ju	130
5	Ne-Mr	99
6	Ne-Mn	81
7	Ur-Ra	63
8	Ur-Mr	73
9	Ur-Su	33
10	Sa-Mr	109
11	Sa-Su	3
12	Ra-Mn	28
13	Mr-Mn	19
14	Ve-Mc	7
15	Mc-Su	19

It is important to note that out of possible 55 angle pairs, only15 angle pairs comes from the list of the top 16 most frequently occurred angles for each pair.

Now as stated earlier, for a given earthquake, only 10 angle pairs out of these 55 pairs are truly independent if 11 planets are involved. However, Table-3 lists 15 pairs of angles. But with close inspection, for instance, among the three pairs: Ne-Ur, Ne-Ra and Ur-Ra, one of them is dependent and therefore, must be removed.

In order to establish a criterion for removing a dependent pair of angle, an assumption is made that the planets that are closer to the earth are considered more important in contributing to earthquake than the others. With that assumption, the slowest moving planet among the three pairs, Ne-Ur, Ne-Ra and Ur-Ra is Ne-Ur, and it is treated as a dependent variable angle pair. Therefore, it is removed. This criterion is termed here as Top Discard, since the slowest moving planet appears at the top in the list shown in Table-1.

In Table-3, except Pluto (Pl) all other ten planets are involved. Therefore, there cannot be more than nine independent angle pairs. However, by successively applying the dependent angle pair discarding procedure from top, eleven independent angle pairs are obtained, and they are listed in Table-4.

Table-4

, Eleven independent angle pairs after applying the Top Discard procedure

1	Ne-Ju	130
2	Ne-Mn	81
3	Ur-Ra	63
4	Ur-Mr	73
5	Ur-Su	33
6	Sa-Mr	109
7	Sa-Su	3
8	Ra-Mn	28
9	Mr-Mn	19
10	Ve-Mc	7
11	Mc-Su	19

The explanation for the eleven independent angle pairs while theoretically only nine independent angle pairs were expected is as follows.

For each angle pair, there can be a maximum of 180 angles possible, and since the model only selects the top 16 frequently occurred angles for each variable of angle pair, some of the angle pairs do not get picked up by the model.

To further explain this, in Table-4, the top two angle pairs are Ne-Ju130 (meaning one of the top 16 angles for the Neptune-Jupiter angle pair is 130 degrees) and Ne-Mn81. The third angle in this case would be Ju-Mn150. However it does not appear in Table-4 since it is not in the list of top 16 angles for the variable angle pair Ju-Mn.[3] It is in fact listed as the 23rd angle in the list of most frequently occurred angles for that pair. Therefore, it doesn't show up in the selection. As a result, the Ne-Ju does not get discarded.

Thus, instead of selecting N-1 angle pairs for N number of planets involved, for some earthquake data points, the number of independent variable angle pairs can exceed N-1 for N number of planets. And because of this limitation, as it will be shown later, despite the theoretically better approach, the performance of this Top Discard based model is somewhat degraded. There are about 400 data points out of 1672 (about 22 percent) which exceed theoretically expected N-1 independent variables.

Since the only major difference between the Model III and the Model III-A is discarding of angle pairs which are deemed to be dependent variables from the list of independent variables, the development of Model III-A is very similar to that of the original Model III. Therefore, a review of the original Model III is presented here before presenting the Model III-A.

Review of the original Model III

The original Model III[3] was developed to predict earthquakes of magnitude 7 and higher by accounting the influence of each individual angle pair of planets and weighing them differently. The weighted model was developed using a simple linear regression technique. Thus, in theory, there are 55 different pairs of planets (6 outer, 2 inner, Sun, Moon and the North lunar node) and 16 distinct angles (from 0 degrees to 180), making a total of 880 maximum possible unique variables that can influence the earthquake occurrence.

Since the Moon's average daily variation is about 13 degrees it can form almost equal number of angles with every other planet during a daily twenty-four hour period. Nonetheless to test the influence of Moon, two sets of models, one with the inclusion of Moon and the other without were developed.

The earthquakes of magnitude 7 or higher that occurred during January1900 – December 2009 were obtained from the USGS[6,8] website. Two data sets of 1900-1972 and 1973-2009 were combined to create one large data set of 1672 points. To avoid the co-linearity in data employed, if there were more than one earthquake of magnitude 7 or higher occurred in one day, the only one with the highest magnitude was selected for that day for this analysis. The accuracy of the data sets was verified against the Centennial Earthquake Catalog[6]. The first step of the analysis was to determine the top sixteen frequently occurred angles during the 1900-2009. Then computations of angles for all the 55 planetary angle pairs were performed. Using an orb of one half degree the planetary data pertaining to the top 16 angles were extracted for all 55 planetary angle pairs for the model. Thus, there are 880 unique variables. A linear model is assumed as follows.

$$\text{Earthquake Magnitude} = \Sigma\, Cn * (\text{angle pair})n + \text{constant} \qquad \text{for } n = 1 \text{ to } 880$$

where Cn is the coefficient of the nth angle pair; and the nth angle pair equals unity when true and zero otherwise.

For example, Neptune-Saturn 152 degree angle is represented by the X_{184}th variable which becomes unity only when the angle between Uranus and Saturn lies between 151.5 and 152.5 degrees. For all other angles between Uranus and Saturn, X_{184}th variable equals zero.

Linear regression was performed and all the coefficients were estimated by generalized least squares. A number of coefficients were so small in magnitude that their influence on the model was deemed negligible. The corresponding variables were omitted one at a time and the regression was repeated to confirm that their influence on the model indeed was negligible. As mentioned earlier two sets of the model were developed, one with the inclusion of Moon (referred here as with-Moon model) and the other without Moon (referred here as without-Moon Model). For each of these two sets, two cases were obtained as follows:

The first case for each of these two sets includes all the variables (880 variables for with-Moon Model and 720 variables for without-Moon model)

The second case where the insignificant variables were omitted subject to the criteria of t>=1 where “t” is statistical test that measures the significance of the coefficient. For this case there were 410 variables for with-Moon model and 280 variables for without-Moon model.

The value of the constant in the linear equation of these cases as calculated by robust linear regression ranged between 7.27and 7.30. The simulation results showed that the two cases of each set were almost identical in their performance as the successive omission of coefficients of insignificant magnitude did not seem to degrade the model performance while allowing the data noise reduction.

It must be noted that one of the limitations of these models is that they only apply over a narrow range of seven and higher earthquake magnitude. Therefore, all predicted values for earthquakes below magnitude seven are irrelevant and meaningless since they can be applicable for the entire lower range of earthquake magnitudes from zero to 6.9. The other important limitation to these models is that they are based on only 1672 data points (since earthquakes of magnitude seven and higher occur about a dozen time per year). Thus, for example, for the model of 410 variables, the ratio of data points to model variables is just above four. Consequently, the R-square term, which is a measure of model fit, varied with decreasing amount of variables from 0.51 to 0.45 indicating a fit not so perfect.

Using Greenwich noontime daily planetary positions, each model was then used to predict the earthquakes for the year 2011-2017. A summary of assumptions reflecting the limitations described above form the basis for the model and are listed below:

1. The predicted earthquakes of magnitude less than 7 are ignored since the model is based on the earthquake data set of magnitude 7 and higher. Thus, the prediction dates of an earthquake of magnitude less than 7 also apply for the dates when earthquake did not occur.

2. As pointed out earlier, in order to determine the angles for each angle pair of two sets of models, with-Moon and the without-Moon were developed. The determination of the angles used for each pair of planets was based on the top 16 most frequently occurred angles for earthquakes of seven and higher magnitude during 1900-2009. Thus for each pair of planets, a unique set of 16 angles were used in the models.

3. One half of degree orb is applied for all angles.

4. Since the predictions (or simulations) were computed on a daily basis corresponding to Greenwich noon, prediction is assumed to apply for the entire date (12 AM to the next 12 AM of Greenwich Time).

5 The minimum number of angles required to meet the criteria of realizing the earthquake of magnitude seven or higher must be higher than the daily average number of angles for that year.

6 The model cases thus obtained when applied to the daily Greenwich Noon geocentric planetary longitude for 2011 -2017 for earthquake predictions, the predicted resulted seem to overestimate the actual earthquakes about by the amount of their corresponding root mean square errors. Therefore, the predictions were corrected with the lower end of the root mean square errors which ranged from 0.28 to 0.33.

7 Out of the four model cases only two, 410-variable with Moon and 720-variable without Moon model cases, were selected as they seem to correlate well with the actual data. In other words, the prediction dates are based on the simulated results provided by these two model cases.

Top Discard based Model III (Model III-A)

Identically following the steps involved in developing the Model III, the Model III-A was developed where linear regression was performed and all the coefficients were estimated by generalized least squares. But before the linear regression was performed the angle pairs which were deemed to be dependent variables from the list of independent variables were discarded by applying the "Top Discard" procedure as described earlier. Thus, two sets of the model were developed, one with the inclusion of Moon (referred here as with-Moon model) and the other without Moon (referred here as without-Moon Model). For each of these two sets, two cases were obtained as follows:

The first case for each of these two sets included all the variables (880 variables for with-Moon Model and 720 variables for without-Moon model)

The second case where the insignificant variables were omitted subject to the criteria of t>=1 where "t" is statistical test that measures the significance of the coefficient. For this case there were 364 variables for with-Moon model and 284 variables for without-Moon model.

The value of the constant in the linear equation of these cases as calculated by robust linear regression ranged between 7.20and 7.298. The R-squared term, which is a measure of model fit, varied with decreasing amount of variables from 0.5 to 0.43. The simulation results showed that the two cases of each set were almost identical in their performance as the successive omission of coefficients of insignificant magnitude did not seem to degrade the model performance while allowing the data noise reduction.

The assumptions involved are identical to the ones that apply for the Model III as listed above. Additional assumptions for the Model III-A are:

1. In order to establish a criterion for removing a dependent pair of angle, an assumption is made that the planets that are closer to the earth are considered more important in contributing to earthquake than the others. This criterion is termed here as Top Discard, as the slowest moving planet in the angle pair is discarded first.

2. The number of angle pairs for N number of planets involved can exceed theoretical limit of N-1 due to the limitation of frequently occurred top 16 angles for each variable angle pair. There are about 400 data points out of 1672 (about 22 percent) which exceed theoretically expected N-1 independent variables.

Results

The Model III which is based on the top 16 most frequently occurred angles for each pair of planetary angle with four different cases was employed for prediction of earthquakes of significant (seven or higher) magnitude for 2011-2017. The prediction days and the corresponding actual dates on which earthquakes occurred are summarized in Table-5 for 2011-2017.

Table-5

Model III Results for 2011-2017

	Model Cases	**No. of Days (P days)**	**Number of Hits**	**Actual No. of Earthquakes**	**P days/Total**	**Probability Binomial**
1	880 Variables	618	31	99	0.24169	0.06433
2	410 Variables	826	36	99	0.32303	0.22313
3	720 Variables	707	34	99	0.27650	0.08628
4	280 Variables	882	33	99	0.34494	0.63255
	Combined 410/720 variables	1086	55	99	0.42472	0.00593

Note: Total Number of days for 2011-2017 is 2557

In the column 2 of Table-5 the four cases of the model III are listed. The first and the second case are for with Moon set. The first case includes all 880 variable angles while the second one 410 variable angles subject to the criteria of t>=1 where "t" is statistical test that measures the significance of the coefficient. Similarly the third and the fourth are for without Moon set, with all 720 variables angles for the third case and 280 variable angles for the fourth case subject to t>=1.

In the column 3 of Table-5, the corresponding total number of prediction dates for 2011-2017 are listed. Note that total number of days for the entire 7 year period is 2557.

The corresponding successful earthquake hits or predictions for all cases are listed in the next column, the column 4, and the actual number of earthquakes that occurred during the seven year period is listed in column 5.

In the column 6, the respective ratio of the prediction dates and the total number of dates are shown for all cases. Using the Binomial probability distribution, the last column lists the calculated probability (p-values) for each of these four cases. The lower the probability, the better the performance. When p-value approaches unity, the model performance approaches the total randomness or zero correlation. Usually when the p-value is less than 0.1, the model performance is considered significant enough.

Thus, for 880 variable case (out of four cases), the p- value (probability) as listed in Table-5 is 0.06433 or 6.4 percent. In other words, the case-1 correctly predicts 31 earthquakes out of 99 earthquakes by picking 618 predicted days out of 2557 days of the seven year period. It also means the probability for predicting 31 or higher earthquakes out of 99 earthquakes by picking 618 days out of 2557 days is 6.4 percent.

At the bottom of the Table-5, a combined case of the 410 and 720 variables is listed. This case successfully predicts 55 out of 99 earthquakes by picking 1086 days out of 2557 days and that translates to the p-value of 0.00593 or 0.6 percent probability. Thus the combined case being one order of magnitude better (from 6.4 to 0.6 percent) is very significant.

The performance of Model III-A which is based on the top 16 most frequently occurred angles for each pair of planetary angle and employs the top discard procedure to discard the angle pairs that are deemed not truly independent, is highlighted similar to Model III, with four different cases for predicting earthquakes of significant (seven or higher) magnitude for 2011-2017. The prediction days and the corresponding actual dates on which earthquakes occurred are summarized in Table-6 for 2011-2017.

Table-6

Model III-A Results for 2011-2017

	Model Cases	No. of Days (P days)	Number of Successful Hits	Actual No. of Earthquakes	P days/Total	Probability Binomial
1	880 Variables	588	29	99	0.22996	0.08791
2	391 Variables	686	25	99	0.26828	0.67476
3	720 Variables	635	31	99	0.24834	0.08674
4	287 Variables	642	19	99	0.25108	0.93321
	Combined					
	391/720	990	41	99	0.38717	0.32504

Note: Total Number of days for 2011-2017 are 2557

As shown in Table-6, for 880 variable case (the case 1), the p- value (probability) as listed in Table-6 is 0.08791 or 8.8 percent. In other words, the case-1 correctly predicts 29 earthquakes out of 99 earthquakes by picking 588 predicted days out of 2557 days of the seven year period. It also means the probability for predicting 29 or higher earthquakes out of 99 earthquakes by picking 588 days out of 2557 days is 8.8 percent.

At the bottom of the Table-6, a combined case of the 391 and 720 variables is listed. This case successfully predicts only 41 out of 99 earthquakes by picking 990 days out of 2557 days and that translates to the p-value of 0.32504 or 32 percent probability. Thus the combined case in this case is worse than the case-1 of 880 variables or case-3 of 720 variables. The best case for Model III-A is either 880 variable or 720 variable case.

Conclusions

When compared the results from Table-5 and Table-6 for Model III and Model III-A respectively, it is clear that all the cases of the Model III show better performance of predicting earthquakes against the corresponding cases of the Model III-A.

As explained earlier, the poor performance of the Model III-A can be attributed to the fact that for about 22 percent of the earthquake data points, the number of independent variable angle pairs exceed N-1 for N number of planets. This was due to the limitation that the angle pairs that deemed as not truly independent variables could not be discarded as they were not included in the top 16 frequently occurred angles for those angle pairs.

Furthermore, the limit of number of angles for the top frequently occurred angles cannot be increased since it would worsen the already poor ratio of 880 variables for 1672 data points for linear regression. Thus despite the theoretically better approach, the performance of this Top Discard based model is degraded due to unsuccessful discarding of the angle pairs that were deemed not independent.

Additionally, the assumption of “Top Discard”, the criterion for removing a dependent pair of angle, may sometimes remove the truly independent variable instead of dependent one.

The better performance of the Model III over the Model III-A can also be attributed the fact that the degradation due to retaining the dependent variables for Model III may not be as significant as that due to degradation of the Model III-A where inadverantly the a true independent variable might be removed.

It is important to recognize that model performance varies from one year to the next. The performance of Model III is significantly enhanced for 2014 by correctly predicting 11 out of 12 earthquakes by picking 148 days out of 365 for that year. However, the performance of Model III was severely degraded by predicting only 3 out of 7 earthquakes by picking 200 predicted days out of 365 for 2017.

Therefore, the performance of the Model III and Model III-A as well may need to be observed over a long period of time to confirm the consistency of their performance.

For the improvement of the Model III-A more research is warranted, perhaps by effectively discarding the unwanted angle pairs for each of the earthquake data point, and also perhaps by redistributing the number of top angles among all the angle pairs instead of 16 top angles for all angle pairs.

Finally, for the model to be applied for earthquakes of magnitude 7 and higher to predict over a narrower range of days and locations would require further research work.

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