

Earthquake Prediction Model V

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Abstract

The objective of this research is to further continue^{1,2,3,4} analyzing and investigating correlations between astronomical data and earthquakes, with the intended goal of predicting future earthquakes with a greater advanced warning and higher degree of accuracy than current technology. Specifically, it focuses on severe earthquakes that occurred during the last century, with special emphasis on earthquakes of magnitude 7 or higher. This research work had already shown^{1,2,3,4,6} a correlation between certain inter-planetary configurations (encompassing the relative geocentric positions and angles of all planets) and the occurrence of strong earthquakes. Building on the work done since the last publication³⁻⁶, which focused on the validation of data employed from other resources³ wherever possible, and extending the data set to include the earthquakes of magnitude 7 or higher from January 1900 to December 2010, this research includes comparison of three different data sets: 7 and higher (1672 data points), 6.7 and higher (2751 data points) and 6.6 and higher (3629 data points). The model based on the 6.7 and higher data set of 2751 data points seems to perform better than other two including the Model III. However, 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), 12 degree multiple angles (Model II), top 16 most frequently occurred angles for each pair of planetary longitudinal (Model III) and declination based (Model IV) angle. The intent of this paper is to highlight the initial findings of the next model (the model V) on prediction of earthquakes.

Beginning in 2006, the research of the natural calamities was more focused on the occurrence of earthquakes. One reason for this was the availability of accurate data on

earthquakes from National Earthquake Information Center, United States Geological Survey⁵.

Research Basis - Methodology

As pointed out earlier the bases for this research are the unique planetary positions (geocentric sidereal or tropical longitude measured along the ecliptic) surrounding earth. Astronomical data provides planetary positions as a function of time. It was observed that the geocentric angles of certain magnitudes between some pairs of planets with respect to the earth appear to correlate reasonably well with earthquakes. Correlations between earthquakes of the past and the corresponding planetary angles during those respective periods occur in a statistically significant way.

The Model

The objective for model development is to predict earthquakes of magnitude 7 and higher. First a simple model was developed based on the assumption that the earthquake severity depends on the total number of angles ranging from zero degree to 180 degrees for the top 16 most frequently occurred angles for each pair of planets during 1900-2010. In other words, the more the number of angles the higher the severity of the earthquake. However, it was found that the severity of the earthquake is not necessarily proportional to the number of angles formed. As a result, it became necessary to account for the influence of each individual angle for each pair of planets by weighing them differently. The weighted model is 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. While the previous models dealt with the fifteen and twelve-degree angle multiples, these models (Model III and up) differ from previous models and deal with the top 16 most frequently occurred angles during 1900-2010 for each pair of planets as the planetary data correlated better with the earthquakes.

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 are developed.

The earthquakes of magnitude 7 or higher that occurred during January 1900 – December 2010 were obtained from the USGS^{3,5} website to develop Model III using a total of 1672 earthquake data points. However, one of the limitations of Model III is a low number of observations (1672 earthquake data points) for variables ranging from 300 to 880. Therefore, additional two data sets, dataset-2 (Model V) and dataset-3 (Model V-A) are employed, representing 6.7 and higher earthquakes with 2571 data points and 6.6 and

higher earthquakes with 3629 data points respectively from January 1900 – December 2010 period.

To avoid the co-linearity in data employed, if there were more than one earthquake of magnitude 6.7 or higher for dataset-2 (and 6.6 or higher for dataset-3) 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 Catalog³.

As pointed out³ for Model III, the predicted results seemed to overestimate the actual earthquakes about by the amount of their corresponding RMSE (root mean square errors). And therefore, the predictions were corrected with the lower end of the RMSE which ranged from 0.28 to 0.33. Therefore, the more important reason for including two additional data sets (dataset-2 and dataset-3) for this analysis is to capture the earthquakes which lie closer to magnitude of 7 either without having to correct them with lower end of RMSE or correct them with a lower value than the lower end of the RMSE.

As with Model III, the first step of the analysis was to determine the top sixteen frequently occurred angles during the 1900-2010 for the dataset-2 and dataset-3.

An example of Neptune-Saturn pair is shown in Figure 1 for Model V. The top 16 angles for this pair are: 152, 19, 42, 20, 74, 130, 30, 57, ----- 11. And the corresponding frequency of the occurrences of these angles are: 36, 33, 31, 30, 29, 29, 27, 27,----- 23 respectively. 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 both datasets 2 and 3. The calculations and model development for these additional datasets procedure is similar to that employed for Model III as below:

Thus, for fifty five planetary angle pairs with top 16 angles each, there are 880 unique variables. A linear model is assumed as follows.

$$\text{Earthquake Magnitude} = \sum C_n * (\text{angle pair})_n + \text{constant} \quad \text{for } n=1 \text{ to } 880$$

where C_n is the coefficient of the n^{th} angle pair; and the n^{th} angle pair equals unity when true and zero otherwise.

For example, for dataset-2 (Model V), 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. Therefore, 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.

For dataset-2 (Model V) two sets of models 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). Further for the first set with-Moon model, two cases and for the second set without-Moon model one case were obtained as follows:

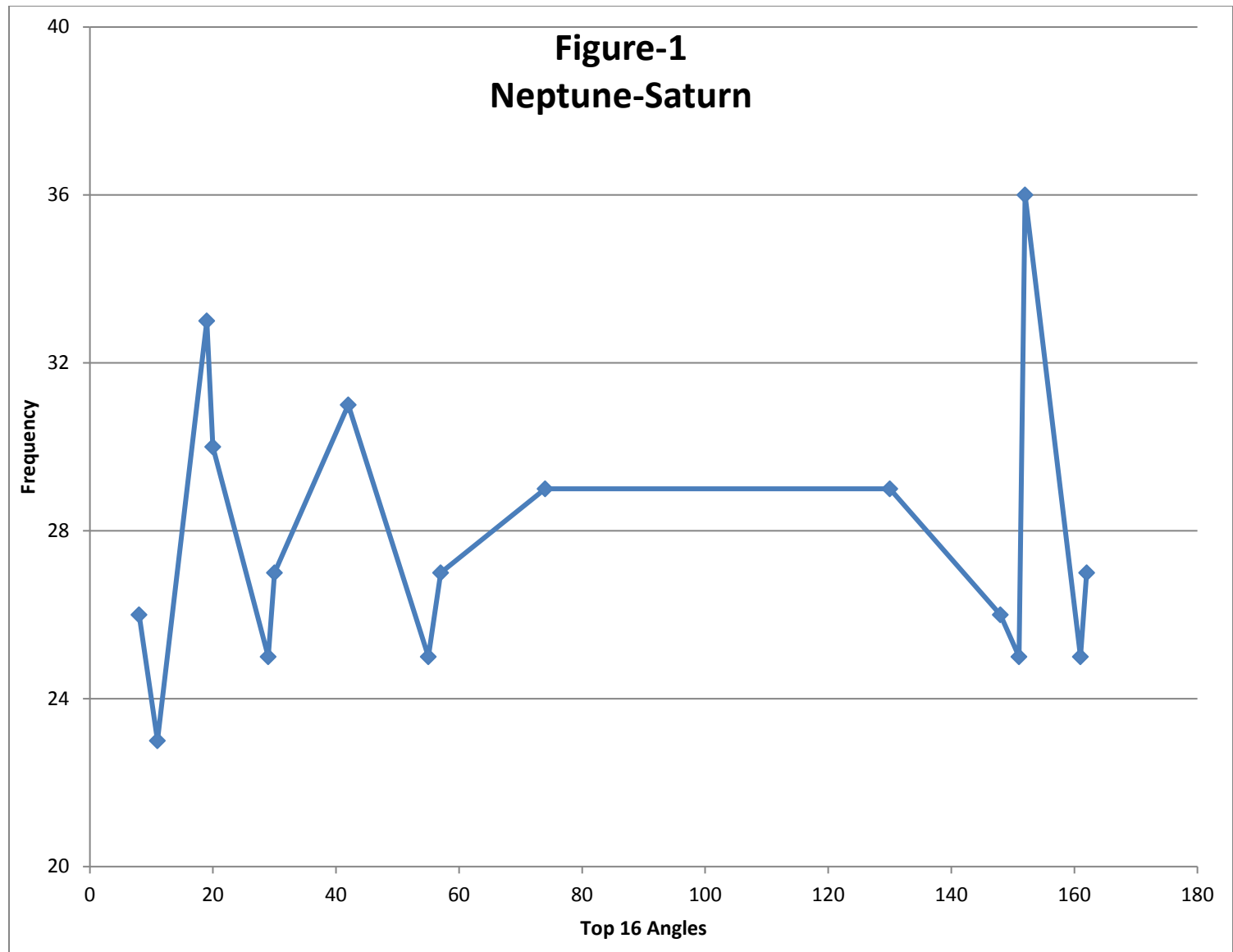
The first case of the first set includes all 880 variables for with-Moon Model, and the first case of the second set includes 720 variables without-Moon model.

The second case of the first set where the insignificant variables were omitted subject to the criteria of $t \geq 0.5$ (where “t” is statistical test that measures the significance of the coefficient), yields 570 variables for with-Moon model.

Similarly for dataset-3 (Model V-A) which include 3629 earthquakes of 6.6 and higher magnitudes, two sets of models were developed; the first case of the first set is with-Moon model (880 variables) and the second case of the first set is without-Moon Model of 720 variables.

The second case of the first set where the insignificant variables were omitted subject to the criteria of $t \geq 0.5$ (where “t” is statistical test that measures the significance of the coefficient), yields 549 variables for with-Moon model.

Although the procedure below provides model development details for dataset-2 (Model V), the same procedure is employed for dataset-3 (Model V-A) to obtain the corresponding models.



A typical set of coefficients of model variables are shown in Table-1 for the 570-variable with-Moon model of Model V. There are 55 rows representing planetary pairs and 16 columns for the corresponding angles. Naming of the planetary pairs employ characters Pl, Ne, Ur, Sa, Ra, Ju, Mr, Ve, Mc and Su for Pluto, Neptune, Uranus, Saturn, Rahu (the North lunar node), Jupiter, Mars, Venus, Mercury and Sun respectively. Thus, Pl-Ne represents the planetary pair Pluto and Neptune, and Sa-Ra represents the planetary pair Saturn and Rahu (the North lunar node).

The value of the constant in the linear equation of these cases as calculated by robust linear regression ranged between 7.08 and 7.11. The simulation results showed that the first two cases 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 2751 data points. Thus, for example, for the model of 570 variables, the ratio of data points to model variables is just around five. However, this limitation is less important compared to 1672 data points employed for the Model III. The R-square term, which is a measure of a model fit, varied with decreasing amount of variables from 0.30 to 0.29 indicating that the first two cases 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.

						Table - 1										
						570 Variable (t>=0.5) with Moon Model										
Angle-->	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Angle Pair																
PI-Ne	-0.033	-0.030	-0.074	-0.044			-0.080			-0.041	-0.154		0.042			
PI-U	0.042			0.097	0.117	-0.083	-0.074	0.085			-0.127	0.071	0.130	0.089		-0.128
PI-Sa	0.045			-0.140	0.122	-0.111		-0.090	-0.039	-0.129	0.056		0.131	0.066	0.097	-0.083
PI-Ra				0.100	-0.166		-0.079			-0.082	0.090	0.219	0.054		0.211	
PI-Jup				-0.069	-0.119		-0.069	-0.223	-0.079	0.086			-0.186	-0.209	0.092	0.059
PI-Mr	0.041		0.128			-0.197			-0.106						0.161	0.137
PI-Ve	0.107		0.148		0.060		0.214	-0.069	-0.059		-0.048	0.072	-0.134	0.059	-0.168	0.121
PI-Mc	0.045		0.046	-0.075	-0.141	-0.121		0.062	0.062	0.180		0.107	0.094	0.110	-0.104	
PI-Sun		0.054	0.123	-0.076		-0.087	0.181	0.058	-0.131	-0.074		0.062			-0.098	0.053
PI-Mn	0.088	0.078	0.132	-0.071	-0.077			0.071	-0.040	-0.119		0.067	0.146			-0.169
Ne-U	-0.053				-0.213			-0.072	-0.116	0.147	-0.095		0.048		-0.057	0.081
Ne-Sa	0.115	0.053			-0.084	0.083		0.077		0.062	0.111	-0.068		0.131	0.125	-0.059
Ne-Ra	-0.082	-0.097		-0.048		-0.047	-0.077			-0.054	-0.089	0.135	0.081	0.062	0.055	-0.064
Ne-Jup		0.167		0.083	-0.087	0.056	0.073		-0.063				0.131		-0.048	-0.082
Ne-Mr	-0.088	-0.118	-0.144		0.062	0.072		-0.189	0.080	-0.091			-0.149	-0.125	0.112	
Ne-Ve	0.049	-0.070	-0.060	0.041		-0.077	-0.185	-0.095		-0.140	-0.116		0.051		-0.130	0.049
Ne-Mc	-0.042	0.134			0.051					-0.115	-0.185		0.087		0.094	
Ne-Sun			0.249		-0.067	-0.064	0.042	0.068	-0.157		-0.098	-0.095	-0.064	0.080	-0.185	-0.053
Ne-Mn			-0.098	-0.054		0.117		0.112	-0.141	-0.067	-0.055	0.069	-0.149		0.144	
Ur-Sa	-0.080	-0.127		0.099		0.050	-0.036	-0.098		-0.102	-0.086	0.063		0.058	-0.141	-0.136
Ur-Ra	-0.090	-0.064	0.070	0.097	0.069	0.195		0.102	-0.111		0.077		-0.128	0.072		0.132
Ur-Jup	-0.122	-0.052			0.041				-0.064		0.077	-0.068		-0.100		-0.079
Ur-Mr		0.092	0.138		0.130			-0.105	-0.155		-0.073	-0.055	0.201	0.109	0.059	
Ur-Ve	0.083	0.062		-0.209	0.043	0.135	0.233		0.082		-0.039		0.088	-0.057		
Ur-Mc	-0.144			0.195	-0.115		0.058	-0.050		0.077	0.109			-0.057		0.126
Ur-Sun		0.045	0.262	0.182	-0.080	-0.048			0.094			-0.149	0.078	-0.090		
Ur-Mn		-0.073	-0.100	-0.120	0.075	0.099	-0.168	-0.187	-0.189				0.045		-0.159	-0.054
Sa-Ra		0.045	0.100	-0.087	-0.152	-0.110		0.130	0.125	0.034	-0.070		-0.116		-0.096	-0.047
Sa-Jup	0.057		-0.099	0.066	-0.054		0.048	-0.097		0.122	0.143	0.067	0.042		0.100	0.070
Sa-Mr	-0.195		0.073	-0.118	-0.143	-0.096	0.073	-0.161	-0.102				0.059			
Sa-Ve		0.053	-0.157	-0.071	0.111	-0.042	-0.073	0.071		0.150	0.152	0.112	-0.076	0.073	-0.118	
Sa-Mc	0.095	0.104				0.057	-0.101		-0.117	0.075	-0.123			-0.089	0.071	
Sa-Sun		0.173		-0.167	-0.099	0.076	0.147	0.055	0.081	0.094	0.144	-0.124	-0.081	-0.188	-0.160	-0.046
Sa-Mn		0.065	0.070				0.050	0.094	0.190	-0.138	-0.073	-0.094		-0.201		0.103
Ra-Jup	-0.043	-0.074	-0.106	0.095	-0.087		-0.062	-0.139		-0.099	0.164		-0.107	0.114		-0.120
Ra-Mr	0.053		-0.077	-0.060		0.114		0.117				-0.043		-0.086		
Ra-Ve	0.106	-0.089	0.185			0.105	0.120	0.149	-0.066	0.169	0.116	0.070		-0.163	-0.196	-0.085
Ra-Mc		0.094			0.135	-0.045		-0.117	-0.071		0.184	-0.207	0.083	0.060	0.153	0.123
Ra-Sun	-0.063		-0.123	0.056	-0.112	-0.059	-0.078			0.120		-0.087				-0.148
Ra-Mn	0.177	-0.174	0.044	0.095	-0.082	0.142		-0.080			-0.083	0.099	-0.046			
Ju-Mr				-0.161	0.094		0.103	-0.043	-0.123	-0.069	-0.074	-0.097	-0.171	-0.084	-0.068	-0.074
Ju-Ve		-0.060	0.055	-0.149	-0.118		-0.075	0.051	-0.086	0.135	0.063	0.057	0.072			
Ju-Mc	0.094	-0.154	-0.138		-0.114		0.124		-0.037	-0.200	-0.097	-0.099		-0.152		
Ju-Sun	0.160		-0.103	-0.039	0.098				-0.070			0.119	0.144		0.121	
Ju-Mn			0.079		-0.083		-0.133		-0.083		-0.124	-0.144		0.249	0.120	-0.073
Mr-Ve	0.117	0.157	-0.117	0.067	-0.117			0.240		-0.068	0.074	-0.102				0.099
Mr-Mc	-0.070	-0.108	-0.045		0.124		0.206		0.082		0.083	0.075	0.103	0.049	-0.074	
Mr-Sun		-0.151		-0.070		0.149	-0.070	0.069					-0.057			0.044
Mr-Mn			0.116	-0.045		-0.191	0.092	-0.105	-0.094	0.110			-0.108	0.205		0.086
Ve-Mc	0.041	0.054	0.029	0.052	-0.076	-0.052	-0.090		-0.081	-0.042	0.245	0.086	-0.152	-0.131	0.052	0.050
Ve-Su		0.027	0.069	0.072		0.049	-0.047				-0.033		-0.049	0.044		-0.036
Vn-Mn	0.140		-0.160	-0.127	0.072	0.127	-0.177	0.059			-0.090	-0.107	0.103			
Mc-Su		0.064			0.051	0.055			0.049			-0.054	0.054		0.065	0.049
Mc-Mn	-0.067		-0.071	0.138	0.115	-0.100		-0.104	-0.081	0.215	0.113		-0.044	0.055		0.150
Su-Mn		-0.067		0.076	-0.081	0.209	-0.079		0.097	0.081	0.090	-0.166	0.191		-0.218	-0.090

Using Greenwich noontime daily planetary positions, each model was then used to predict the earthquakes for years 2011-2017. A summary of assumptions reflecting the limitations described above form the basis for the models 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 6.7 and higher with RMSE of 0.34. 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 degree 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 6.7 and higher magnitude during 1900-2010. 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. As described earlier and illustrated in figure 1, where an example of Neptune-Saturn is used. Thus for that pair the most frequent occurred angle was 152 degrees occurring 36 times during 1900-2010 period for seven and higher magnitude earthquakes. In this case with one half degree orb, for the 152 degree, the applicable range is 151.5 – 152.5 degrees.
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 model cases thus obtained when applied to the daily Greenwich Noon geocentric planetary longitudes for 2011- 2017 period for earthquake predictions, the predicted resulted seem to overestimate the actual earthquakes about half of their amount of their corresponding root mean square errors. Therefore, the predictions were corrected with half of the lower end of the root mean square errors which ranged from 0.165 to 0.17.

For the Model III, the overestimation of predicted earthquakes was even higher (equal to the RMSE value of that model). The reason for this perhaps might be attributed to the value of the constant term in the linear equation for the model. For the Model III which has 1692 observations of earthquakes of magnitude seven and higher has the value of the constant term equals 7.25.

Therefore, in absence of angle pairs involved, the model yields an earthquake of magnitude 7.25. This defies the basis on which the model was developed. The reason the constant term is high because the assumption of linear dependency of earthquakes on angle pairs; and in order to fit the data to provide a best possible correlation where the lowest value for the observation is 7.0 obviously yields the value for the constant higher than 7.0. This is precisely the reason the predicted results overestimated the actual earthquakes as noted above and the RMSE correction was applied to compensate the overestimation. Therefore, to minimize or eliminate the influence of RMSE correction term, other datasets (dataset-2 and dataset-3) were developed by lowering their value of the threshold from 7 to 6.7 and 6.6 respectively to see if the improvement in the Model III can be realized.

The values of constant term for all three Models with all 880 variables are listed in Table-2. With increasing number of observations (number of earthquakes of magnitudes above 7, 6.7 and 6.6) the constant term decreases from 7.25 to 7.1 to 7.0. As a result, the need to apply the low end of the RMSE correction reduces from the full value of the RMSE (dataset-1 for Model III) to half of its value (dataset-2) and zero correction for the dataset-3 respectively.

Table-2

Model	Constant Term	+/- RMSE	Correction Term
Model III (1672 data pts) 7 and higher	7.25 (all 880 variables)	0.3349	-0.3349 (all)
Model V (2751 data pts) 6.7 and higher	7.1 (all 880 variables)	0.3654	-0.1827 (half)
Model V-A (3629 data pts) 6.6 and higher	7.00 (all 880 variables)	0.3830	0.0 (none)

- 6 Furthermore, for the models with the angle correction, 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.
- 7 Thus, there are three (880-variables with Moon, 570-variable with Moon subject to $t \geq 0.5$ criteria, and 720-variable without Moon model) cases were developed for the RMSE correction based only and three more for RMSE with angle corrections as they sometimes might seem to correlate better with the actual data. In other words, the prediction dates are based on the simulated results provided by these six model cases.

Results and Conclusions

The dataset-2 (Model V) which is based on the top 16 most frequently occurred angles for each pair of planetary angle with three different cases was employed for prediction of earthquakes for 2011-2017. The prediction results are summarized in Table-3 for 2011 – 2017. Similarly the results for dataset-3 (Model V-A) were obtained and are included along with the Model III and dataset-2 (Model V) in Table 3 for 2011-2017.

The results for III, V and V-A are presented in Table-3 as follows:

Column two lists all cases: the first three are based only on RMSE correction, followed by next three with both RMSE and angle correction (410 variables for Model III, 570 variables for Model V and 549 variables for Model V-A are subject to criteria of $t \geq 0.5$); and the last two are combined cases of with-Moon case where the variables which deemed insignificant subject to the statistical test criteria of $t \geq 0.5$ were eliminated and the without-Moon case, for both RMSE only and RMSE with angle correction criteria. Thus there are a total of 8 cases for each of the three models.

The next column, the “Prediction Days”, show the simulated number of predicted days for each of these 8 cases for the entire 7 year (2011-2017) period. The column four lists the corresponding number of successful predictions and the column five the actual number of earthquakes occurred for the respective cases.

Table-3

Model III

	Cases	Prediction Days	No. of hits	No. of Earthquakes	P-days/2557	P-value
1	RMSE -880	1064	49	101	0.4161126	0.0962
2	RMSE -410	1240	55	101	0.4849433	0.13585
3	RMSE -720	1100	51	101	0.4301916	0.07875
4	W/Angle-880	618	30	101	0.2416895	0.11972
5	W/Angle-410	826	35	101	0.3230348	0.34129
6	W/Angle-720	707	33	101	0.2764959	0.15447

Combined 410/720

7	RMSE	1455	69	101	0.5690262	0.01247
8	w/angle	1086	54	101	0.4247165	0.01688

Dataset-2 (Model V)

	Cases	Prediction Days	No. of hits	No. of Earthquakes	P-days/2557	P-value
1	RMSE -880	865	47	101	0.33828706	0.005478
2	RMSE -570	933	47	101	0.36488072	0.024296
3	RMSE -720	797	38	101	0.31169339	0.099341
4	W/Angle-880	500	32	101	0.19554165	0.002583
5	W/Angle-570	411	24	101	0.16073524	0.028911
6	W/Angle-720	483	20	101	0.18889323	0.446974

Combined

570/720

7	RMSE	1084	55	101	0.4239343	0.009688
8	w/angle	651	31	101	0.25459523	0.137768

Dataset-3 (Model V-A)

	Cases	Prediction Days	No. of hits	No. of Earthquakes	P-days/2557	P-value
1	RMSE -880	1165	53	101	0.45561205	0.09782
2	RMSE -549	1211	56	101	0.47360188	0.06337
3	RMSE -720	1152	49	101	0.45052796	0.27388
4	W/Angle-880	579	31	101	0.22643723	0.03816
5	W/Angle-549	659	32	101	0.2577239	0.10824
6	W/Angle-720	642	25	101	0.25107548	0.57079

Combined

549/720

7	RMSE	1411	60	101	0.55181854	0.22608
8	w/angle	902	36	101	0.35275714	0.50657

The last two columns show the corresponding calculations for the ratio of predicted days with total number of days (2557) of the seven year period and the corresponding P-values (calculated probability) for all 8 cases.

The probability calculations are based on Binomial probability distribution. 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.

The highlighted lowest p-values for each Model cases are the best case for that model.

Thus, the best case for model III is the combination of RMSE 470 variables case and RMSE 720 variable without-Moon case with a p-value of 0.01247. In other words, this best case of the Model III correctly predicts 69 out of 101 earthquakes of seven and higher magnitude by picking 1455 out of 2557 of the seven year period. It also means the probability of predicting 69 or higher earthquakes out of 101 earthquakes by picking 1455 days out of 2557 days is 1.247 percent. It must be noted that the next best case for the Model III is the combination of RMSE with angle correction for 470 variables with Moon case and RMSE with angle correction for 720 variable without-Moon case, yielding a p-value of 0.01688 is very close to the best case.

Similarly the best case for Model V (dataset-2) is RMSE with angle correction case of 880 variables yields a p-value of 0.002583 or 0.26 percent by correctly predicting 32 out of 101 earthquakes by selecting 500 days out of 2557 of the seven year period, and that for Model V-A (dataset-3) is also RMSE with angle correction case of 880 variables yielding a p-value of 0.03816 or 3.86 percent by correctly predicting 31 out of 101 earthquakes by selecting 579 days out of 2557 of the seven year period

For the seven year period (2011-2017), the best cases of all of the three models yield p-value less than 0.1 or 10 percent seem to indicate a significant enough performance. Furthermore, the Model V seems to perform about an order of magnitude better than the other two models.

It is also important to note that the deviation in performance of these models from RMSE only correction case to RMSE with angle correction case is not very significant. For instance, for Model V, the best case, 880 variable RMSE with angle correction yields 0.26 percent probability while the 880 variable with RMSE correction alone yields 0.5478 percent probability. However, the important distinction between these two cases is whereas the RMSE with the angle correction case performs better from the p-value standpoint giving a better statistically significant result, the RMSE correction only case predicts fifty percent more earthquakes (at the expense of picking more than fifty percent more days).

In Table-4, results of the best cases as described above for all the three models are summarized to show their annual performance. Note that all of them do not perform well in years 2012, 2015 and 2017 as reflected in their corresponding p-value much higher than 0.1.

Table 4

Model III Summary

RMSE Combined 410/720 (1672 EQ data)

Year	Prediction	No.	Number of	P days/Total	Probability
	Days	of Hits	Earthquakes		Bionomial
2011	209	15	17	0.5726	0.0068
2012	190	10	15	0.5191	0.1886
2013	229	12	17	0.6274	0.3452
2014	205	11	12	0.5616	0.0102
2015	203	10	17	0.5562	0.4950
2016	161	7	16	0.4399	0.6026
2017	258	4	7	0.7049	0.8803
Overall	1455	69	101	0.5690	0.0125

Model V (dataset-2) Summary

RMSE with Angle 880 variables (2751 EQ data)

Year	Prediction	No.	Number of	P days/Total	Probability
	Days	of Hits	Earthquakes		Bionomial
2011	94	8	17	0.2575	0.0474
2012	72	3	15	0.1967	0.5896
2013	59	7	17	0.1616	0.0125
2014	54	2	12	0.1479	0.5485
2015	77	2	17	0.2110	0.9012
2016	73	7	16	0.1995	0.0263
2017	71	3	7	0.1940	0.1378
Overall	500	32	101	0.1955	0.0026

Model V-A (dataset-3) Summary

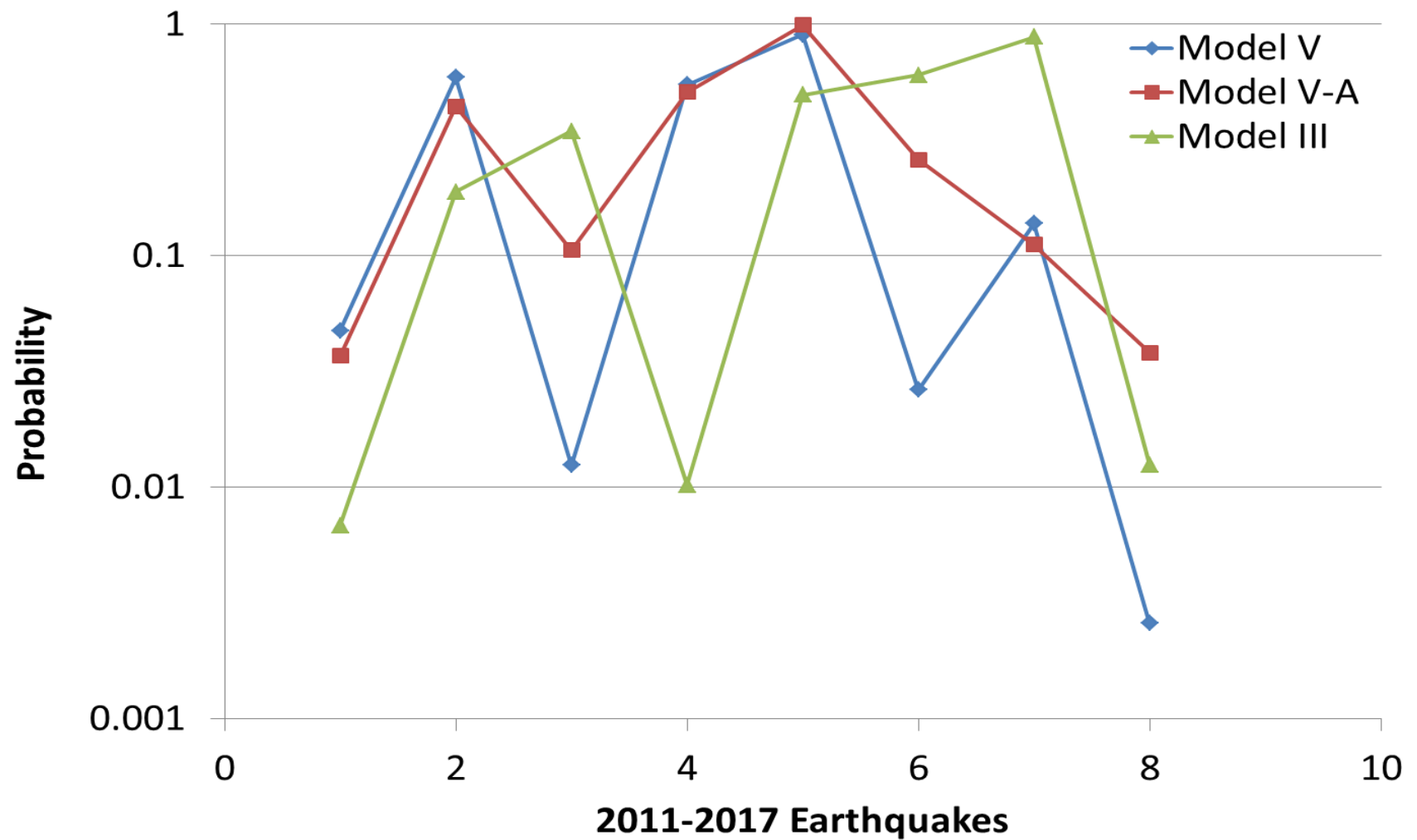
RMSE with Angle 880 variables (3629 EQ data)

Year	Prediction	No.	Number of	P days/Total	Probability
	Days	of Hits	Earthquakes		Bionomial
2011	108	9	17	0.2959	0.0370
2012	82	4	15	0.2240	0.4426
2013	73	6	17	0.2000	0.1057
2014	80	3	12	0.2192	0.5085
2015	91	1	17	0.2493	0.9924
2016	80	5	16	0.2186	0.2605
2017	65	3	7	0.1776	0.1117
Overall	579	31	101	0.2264	0.0382

The same results are depicted in figure-2 to compare their annual performance. Along the x-axis the years 2011 through 2017 are indicated by number 1 through 7, and the last number, 8 along the x-axis represents the overall performance for these three models. The y-axis shows the probability values on logarithmic scale.

The plot clearly shows that the Model V performs much better than other two with p-value ranging between 0.1 and 0.01 for 3 out of 7 years (2011, 2013 and 2016) and for 2017 almost near 0.1. The overall performance is indicated in figure-2 for the x value of number 8, and it shows the Model V performs by an order magnitude better over the other two models.

Figure-2 Model Performance Comparison



It is important to recognize that the model performance for all these models may change year over year, and the true picture is likely to emerge over a long period of time. However the expected trend is likely to prove that the performance of Model V is better than the other two. Furthermore, for Model V, the best performing case may be different from one year to the next, and the most likely that might be either 880 or 570 variable RMSE only case or 880 or 570 RMSE with angle case.

Clearly, for the model to be applied for earthquakes of magnitude 7 and higher to predict over a narrower range of days would require further improvement and therefore, more research work is warranted. In addition, further research is necessary regarding the locations of earthquakes.

Acknowledgements:

Author wishes to acknowledge US Geological Survey Website for availability of downloading the earthquake data. In addition, author wants to acknowledge suggestions from Kyosti Tarvainen for probability calculations.

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