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PATTERN RECOGNITION OF THE EARTHQUAKE NUMBERS AND ENERGY RELEASED PER MONTH IN THE EASTERN COAST OF TAIWAN

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Abstract

In this paper, the author delves into the time series of energy released by earthquakes each year (from 1995 to 2017) as well as each month (from January 1995 to June 2018) for the whole of Taiwan and especially, three eastern coast counties, Milan, Hyaline, and Tatung. The energy issued from each earthquake is transferred to the equivalent atomic bomb which was dropped on Hiroshima, Japan with the code-named Little Boy. Each year in the average sense, the total earthquakes release 34.9 atomic bombs in Taiwan - 4.48 in Milan, 7.88 in Hyaline, and 5.14 in Tatung. The energy released by earthquakes in each month is also calculated by the equivalent atomic bombs. The stationary ties for the energy released by total and labelled earthquakes are checked by the augmented Dickey-Fuller (ADF) method, and they are all stationary. The time series for monthly number of earthquakes in Taiwan and three eastern coast counties are all stationary. The patterns of the time series of labelled number of earthquakes are recognized through autocorrelation function (ACF) and partial autocorrelation function (PACF). After the parameters p, q, r of the ARIMA (Autoregressive Integrated Moving Average) method is determined, and then they can be used to forecast labelled earthquake numbers. The deviation between observed and forecasted also evaluated. The average number of deviation per month is 6.7 for the whole of Taiwan, 1.5 for Milan, 3.6 for Hyaline, and 0.9 for Tatung.

Key Words: ADF, ACF, PACF, ARIMA

Introduction

Taiwan is on the Circum-Pacific seismic zone, and people there should get along with the tremor of land in their life time. The seismic properties of this land should be understood instead of being ignored. One of a best ways is using time series, which collects important data of earthquakes from 1995 to now, to delve into the hidden properties of something not yet be explored.

In this study, the author adopted the public archive of the Central Weather Bureau (CWB) of Taiwan [1], and then extracted the total and labelled number of earthquakes and its magnitude for the whole of and three eastern coast counties of Taiwan - Milan, Hualien, and Taitung. The magnitude of an earthquake represents its energy released, and the equation proposed by Gutenberg and Richter [2,3] is used to calculate the energy issued by each earthquake. Since the energy is usually huge, it is “normalized” by the energy of atomic bomb which was dropped on Hiroshima, Japan. The atomic bomb with code-named Little Boy [5] produced 6.3E+20 ergs of energy when detonated on Hiroshima, Japan. The yearly time series collects data from 1995 to

2017 (23 years), and the monthly data assembles from January 1995 to June 2018 with a total of 282 months.

The stationary of a time series is not explosive, nor trending, and nor wandering aimlessly without returning to its mean [6,7].Whether the time series for energy released, or the number is stationary or not will be checked carefully by the augmented Dickey-Fuller (ADF) unit root method [7].The stationary evaluation for each time series is done by State and double checked by Views. All the graphs are plotted by Minitab. Two types of earthquakes, labelled and unlabeled are recorded in the CWB archive [1]. The labelled one is magnitude larger than 4.0, and the unlabeled one released less energy and affects only locally [1]. Both the time series of total (labelled plus unlabeled) and labelled earthquakes are scrutinized for the whole of Taiwan and three eastern coast counties. The monthly energy released from earthquakes and numbers are shown in Appendix A.

Time series of energy released by the whole of Taiwan and three eastern coast counties
Yearly data of energy released from all earthquakes in Taiwan and three counties on the eastern coast

Energy released by all earthquakes per year in Taiwan

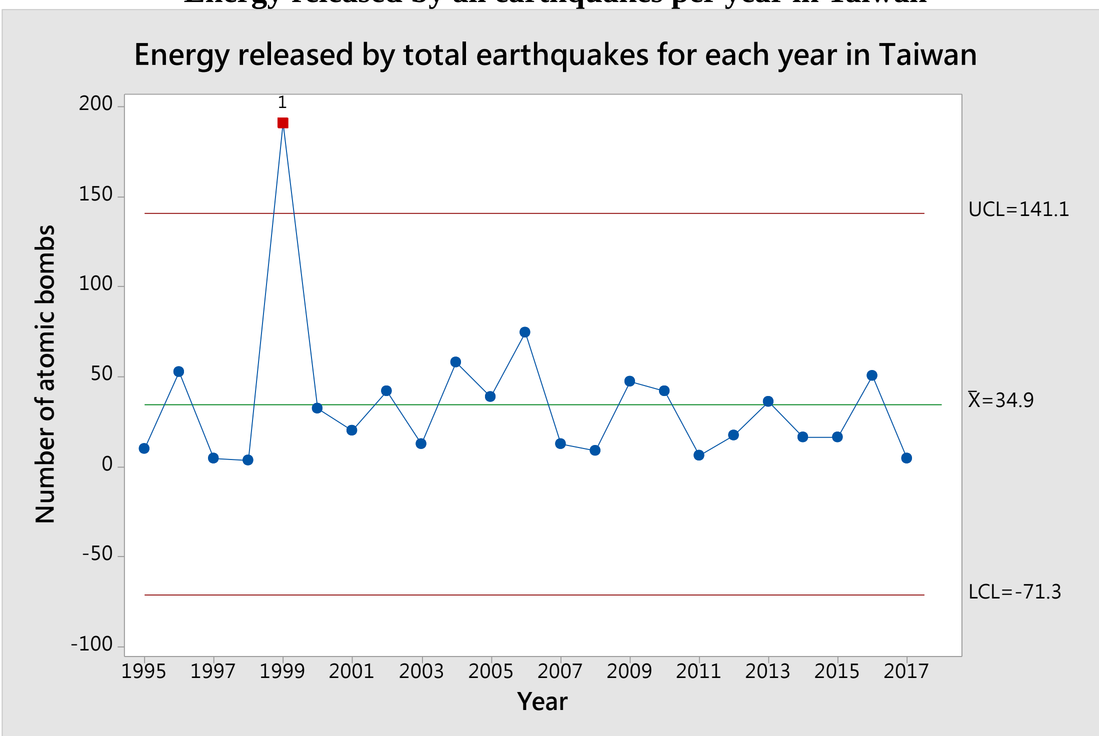

Figure 1: Energy released by all earthquakes each year in Taiwan

The average energy released by all the earthquakes in Taiwan is equivalent to 34.9 atomic bombs per year. In year 1999, the energy released is 191.46 atomic bombs [4], and that is three standard errors above the mean.

Energy released by all earthquakes per year in Milan

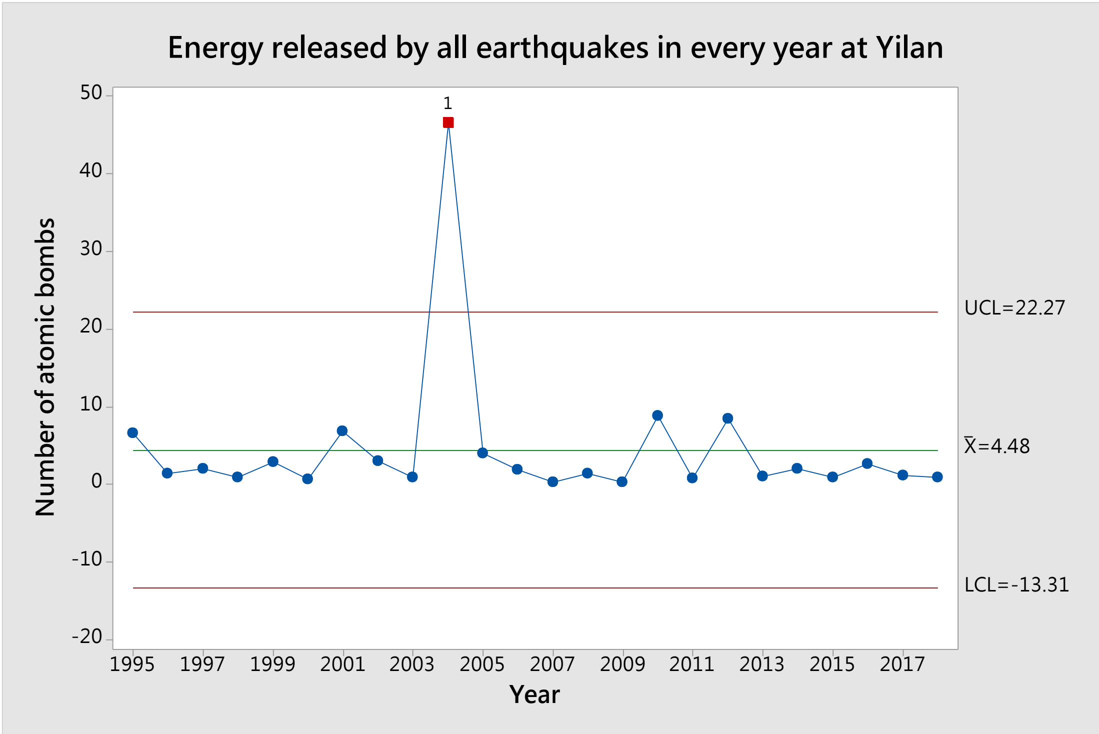

Figure 2: Energy released by all earthquakes each year in Milan

The average energy released by all the earthquakes in Milan is equivalent to 4.48 atomic bombs per year. In year 2004, the energy released is 46.56 atomic bombs, and that is three standard errors above the mean.

Energy released by all earthquakes per year in Hyaline

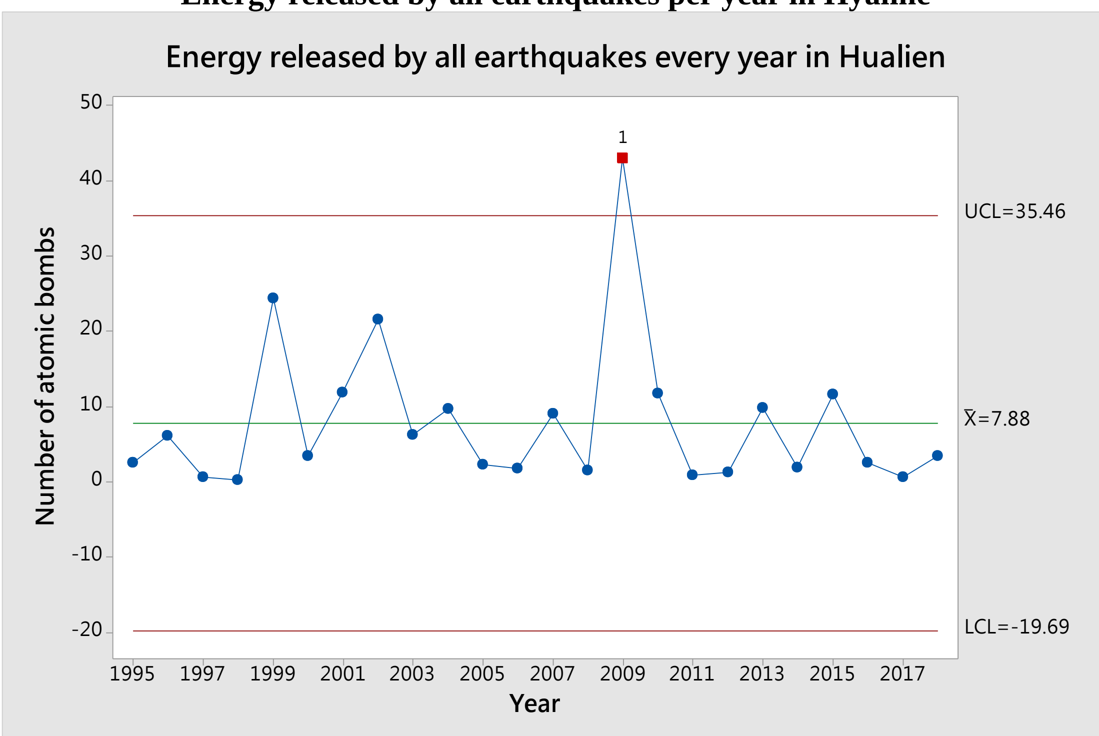

Figure 3: Energy released by all earthquakes each year in Hyaline

The average energy released by annual earthquakes in Hyaline is equivalent to 7.88 atomic bombs per year. In 2009, the energy issued reckoned to 43.09 atomic bombs, which is more than three standard errors above the mean.

Energy released by all earthquakes per year in Tatung

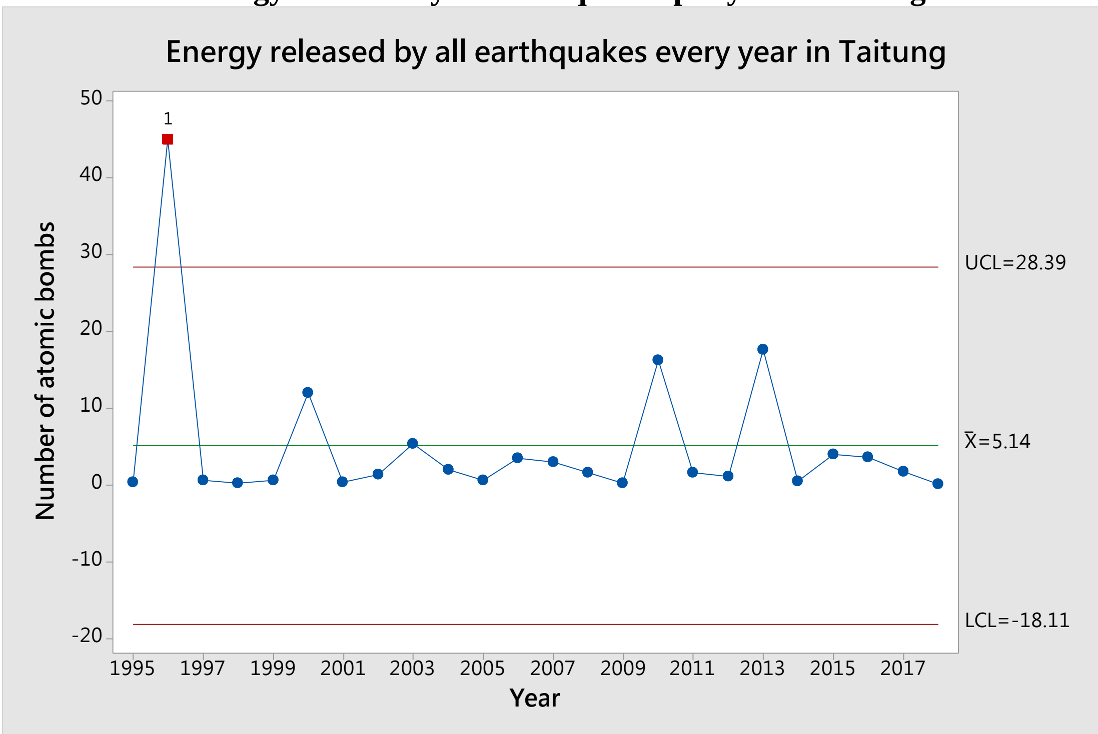

Figure 4: Energy released by all earthquakes each year in Tatung

The average energy released by annual earthquakes in Tatung is equivalent to 5.14 atomic bombs per year. In 1996, the energy issued reckoned to 45.01 atomic bombs, which is more than three standard errors above the mean.

Energy released by the labelled earthquakes per year in Taiwan and three counties on the eastern coast

Energy released by the labelled earthquakes per year in Taiwan

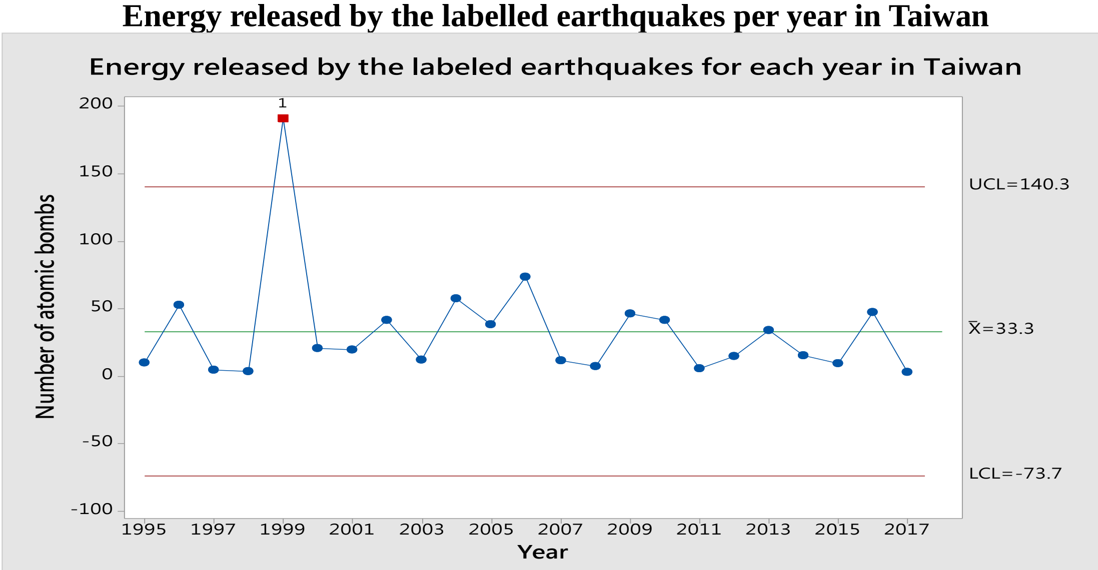

Figure 5: Energy released by the labelled earthquakes each year in Taiwan

The average energy released by the labelled earthquakes in Taiwan is equivalent to 33.3 atomic bombs per year. In year 1999, the energy released is 191.46 atomic bombs, and that is three standard errors above the mean. Note that this value is same as the total earthquakes because not until May, 2000 did the Central Weather Bureau begin to collect unlabeled local earthquakes into its archive.

Energy released by the labelled earthquakes per year in Yilan

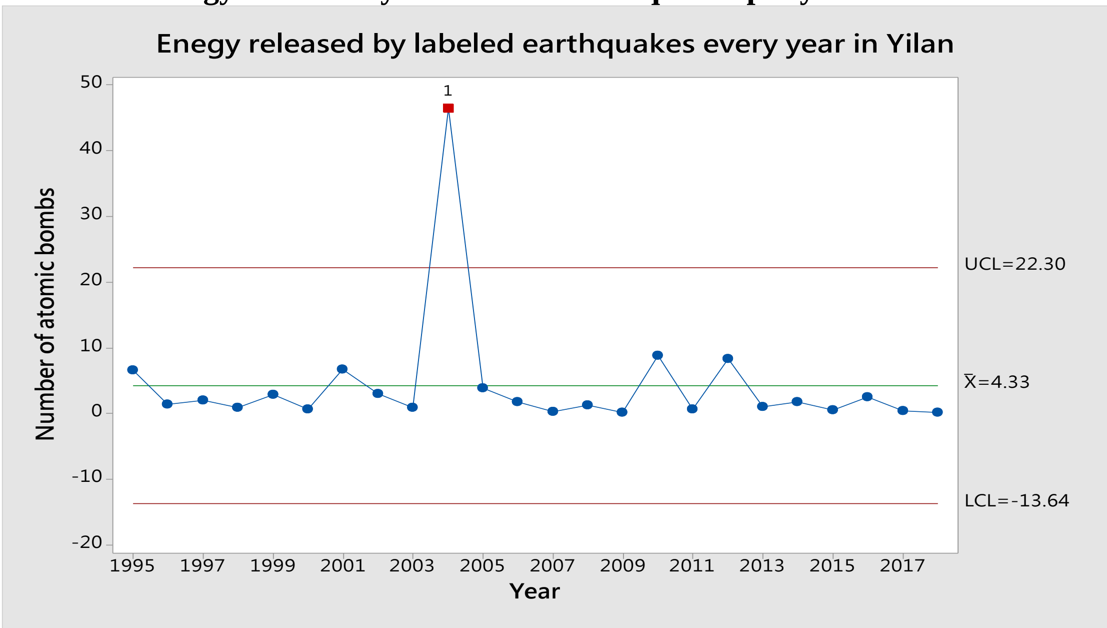

Figure 6: Energy released by labelled earthquakes each year in Milan

The average energy released by all the earthquakes in Milan is equivalent to 4.33 atomic bombs per year. In year 2004, the energy released is 46.50 atomic bombs, and that is three standard errors above the mean.

Energy released by the labelled earthquakes per year in Hyaline

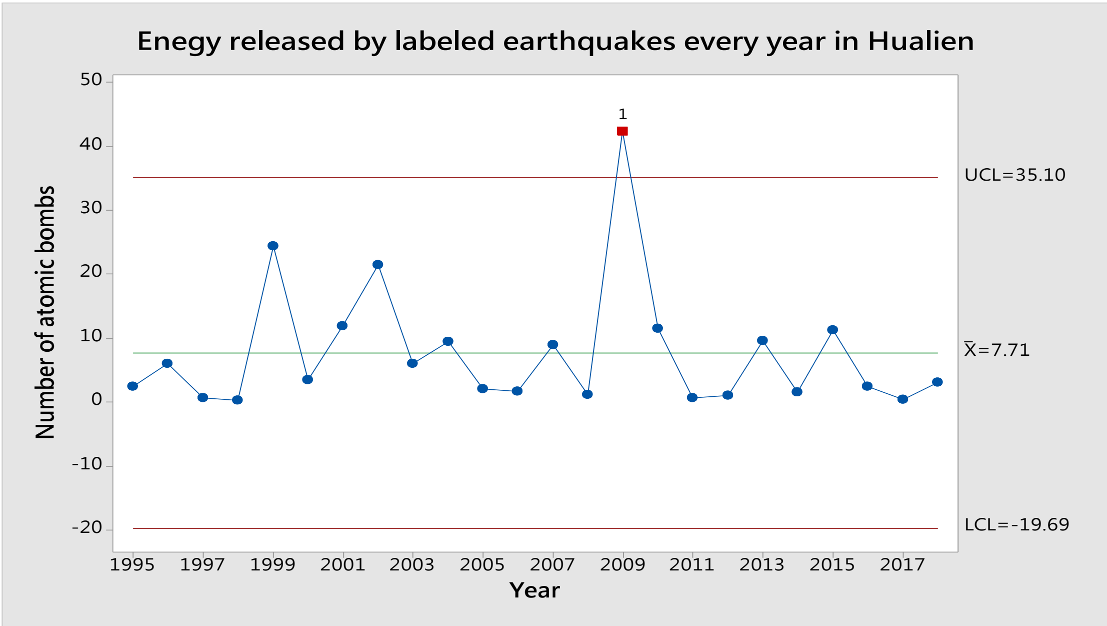

Figure 7: Energy released by labelled earthquakes each year in Hyaline

The average energy released by annual earthquakes in Haulier is equivalent to 7.71 atomic bombs per year. In 2009, the energy issued reckoned to 42.39 atomic bombs, which is more than three standard errors above the mean.

Energy released by the labelled earthquakes per year in Tantung

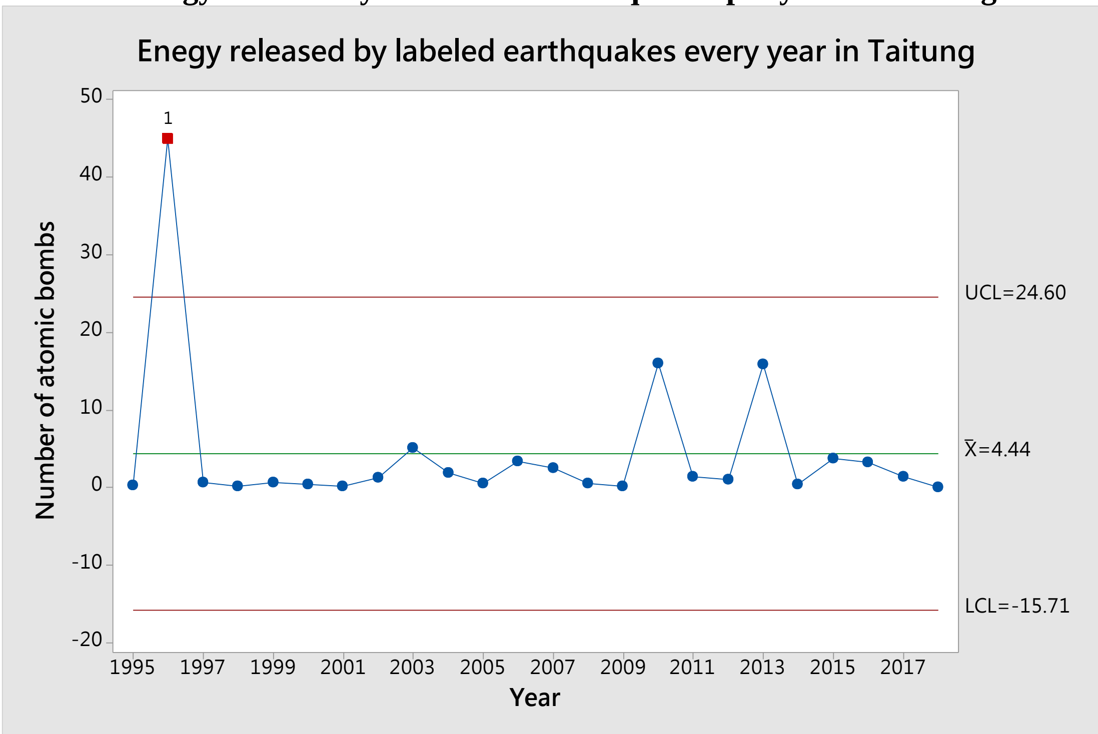

Figure 8: Energy released by labelled earthquakes each year in Tatung

The average energy released by annual earthquakes in Tatung is equivalent to 4.44 atomic bombs per year. In 1996, the energy issued reckoned to 45.01 atomic bombs, which is more than three standard errors above the mean.

Summarize the analyses of this section can get the following table.

Table 1: Mean value of the energy released yearly of earthquakes in Taiwan and three eastern coast counties (equivalent to atomic bomb numbers)

	Taiwan	Yilan	Hualien	Taitung
Total earthquakes	34.9	4.48	7.88	5.14
Labeled earthquakes	33.3	4.33	7.71	4.44

Time series of energy released by earthquakes per month and their stationary check for entire Taiwan and three eastern coast counties

Time series of energy released by earthquakes per month and their stationarity check for entire Taiwan

Time series of energy released by all earthquakes per month in Taiwan

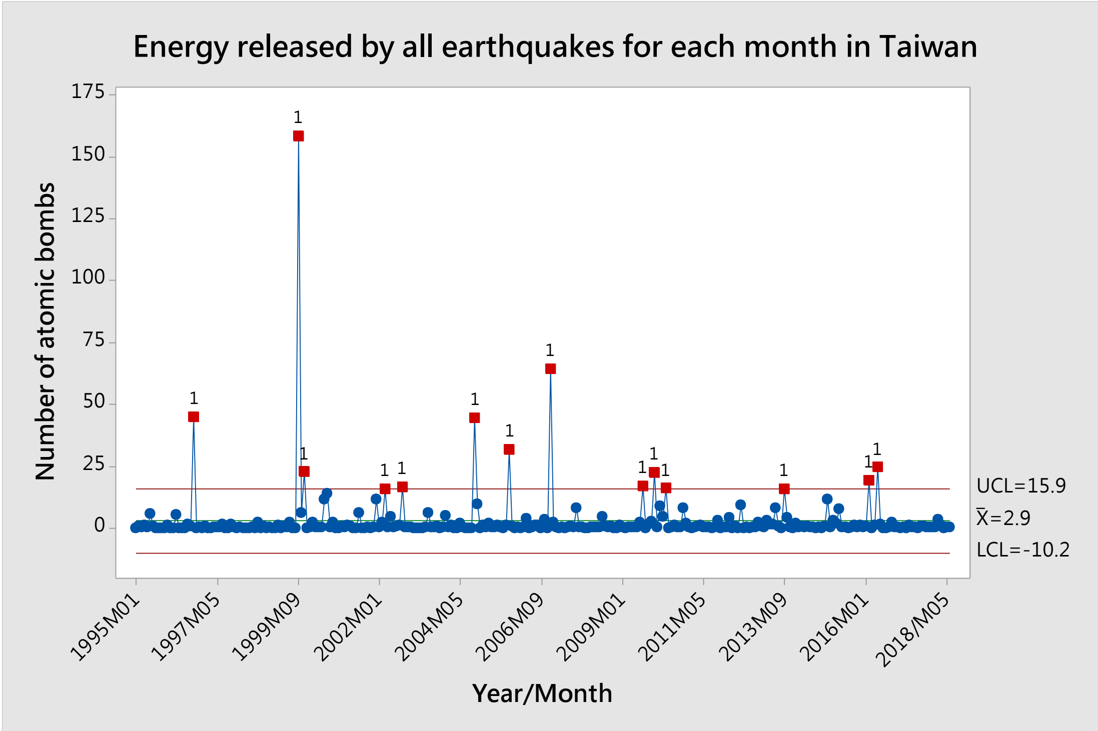

Figure 9: Energy released by all earthquakes each month in Taiwan from January 1995 to June 2018

The energy released by all (labelled plus unlabeled) earthquakes each month in Taiwan is plotted in the above figure. Averagely speaking, there are 2.9 atomic bombs equivalent energy released by all the earthquakes per month in the whole Taiwan.

The stationary check of time series of energy released by earthquakes per month in Taiwan

The stationary of the time series is checked by the augmented Dickey-Fuller (ADF) method by the famous computer program State, and double checked by Views.

Table 2: The critical values and Dickey-Fuller unit root test for monthly total earthquakes from January 1995 to June 2018 for entire Taiwan

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-16.618	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released by total earthquakes each month is stationary.

Time series of energy released by labelled earthquakes per month in Taiwan

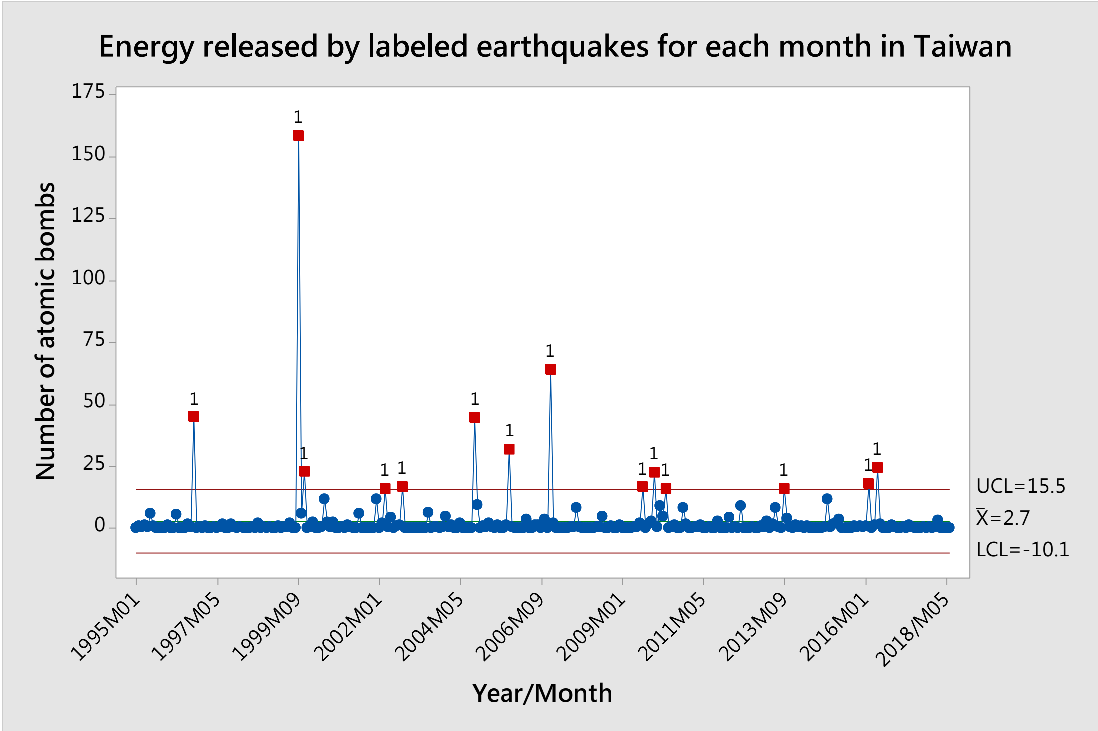

Figure 10: Energy released by labelled earthquakes each month in Taiwan from January 1995 to June 2018

The energy released by labelled earthquakes each month in Taiwan is plotted in the above figure. Averagely speaking, there are 2.7 atomic bombs equivalent energy released by the labelled earthquakes per month in the whole of Taiwan.

The stationary check of time series of energy released by labelled earthquakes per month in Taiwan

Table 3: The critical values and Dickey-Fuller unit root test for monthly labelled earthquakes from January 1995 to June 2018 for entire Taiwan

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-16.623	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly labelled earthquakes is stationary.

Time series of energy released by the earthquakes per month and its stationary check for Milan

Time series of energy released by all the earthquakes per month in Milan

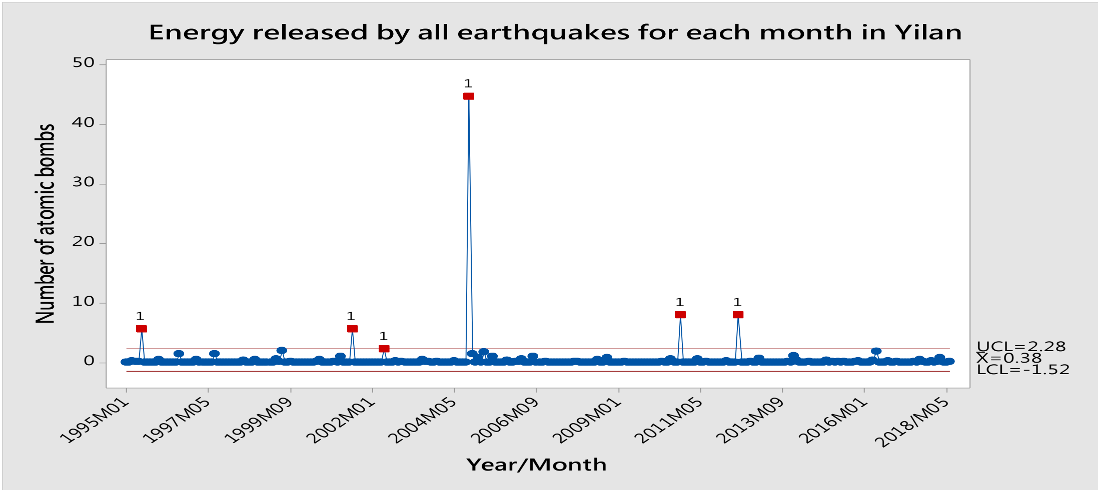

Figure 11: Energy released by all earthquakes each month in Milan from January 1995 to June 2018

Averagely speaking, there are 0.38 atomic bombs equivalent energy released by all the earthquakes per month in Milan.

The stationary check of time series of energy released by earthquakes per month in Yilan

Table 4: The critical values and Dickey-Fuller unit root test for monthly total earthquakes from January 1995 to June 2018 in Milan

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-16.484	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly total earthquakes in Yilan is stationary.

Time series of energy released by labelled earthquakes per month in Yilan

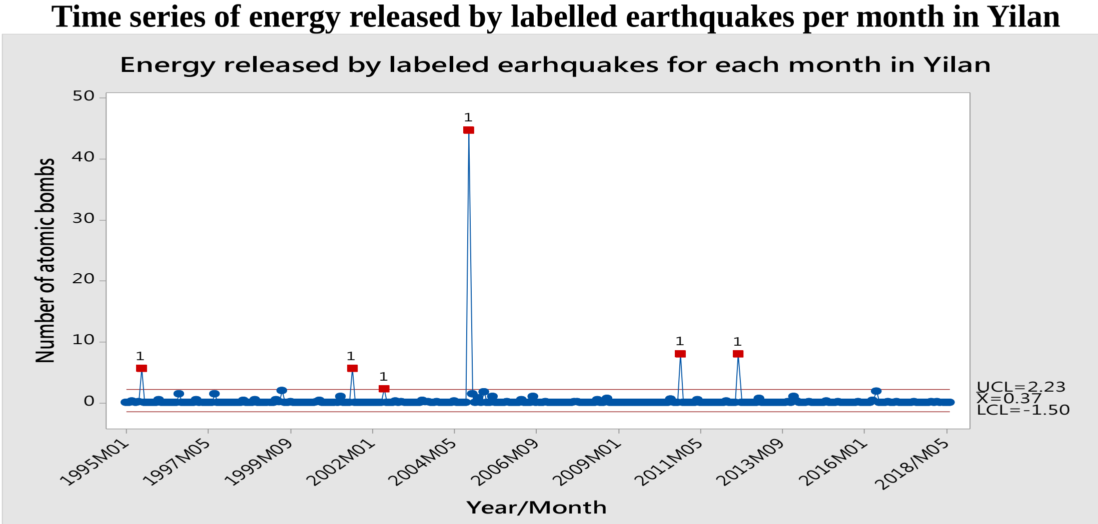

Figure 12: Energy released by labelled earthquakes each month in Yilan from January 1995 to June 2018

Averagely speaking, there are 0.37 atomic bombs equivalent energy released by the labeled earthquakes per month in Yilan.

The stationary check of time series of energy released by labeled earthquakes per month in Milan

Table 5: The critical values and Dickey-Fuller unit root test for monthly labeled earthquakes from January 1995 to June 2018 in Yilan

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-16.485	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly labelled earthquakes in Yilan is stationary.

Time series of energy released by earthquakes per month and its stationary check for Hyaline

Time series of energy released by earthquakes per month in Hyaline

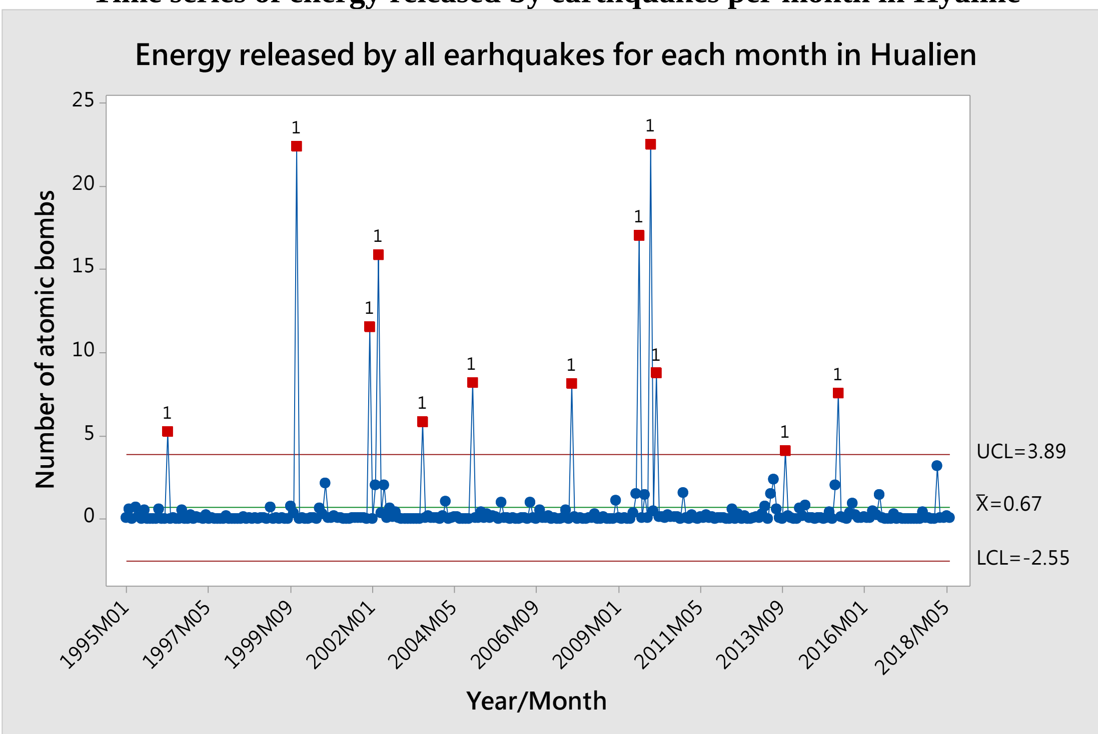

Figure 13: Energy released by all earthquakes each month in Hyaline from January 1995 to June 2018

Averagely speaking, there are 0.67 atomic bombs equivalent energy released by all the earthquakes per month in Hyaline.

The stationary check of time series of energy released by all earthquakes per month in Hyaline

Table 6: The critical values and Dickey-Fuller unit root test for monthly total earthquakes from January 1995 to June 2018 in Haulier

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-16.773	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly total earthquakes in Hyaline is stationary.

Time series of energy released by labelled earthquakes per month in Hyaline

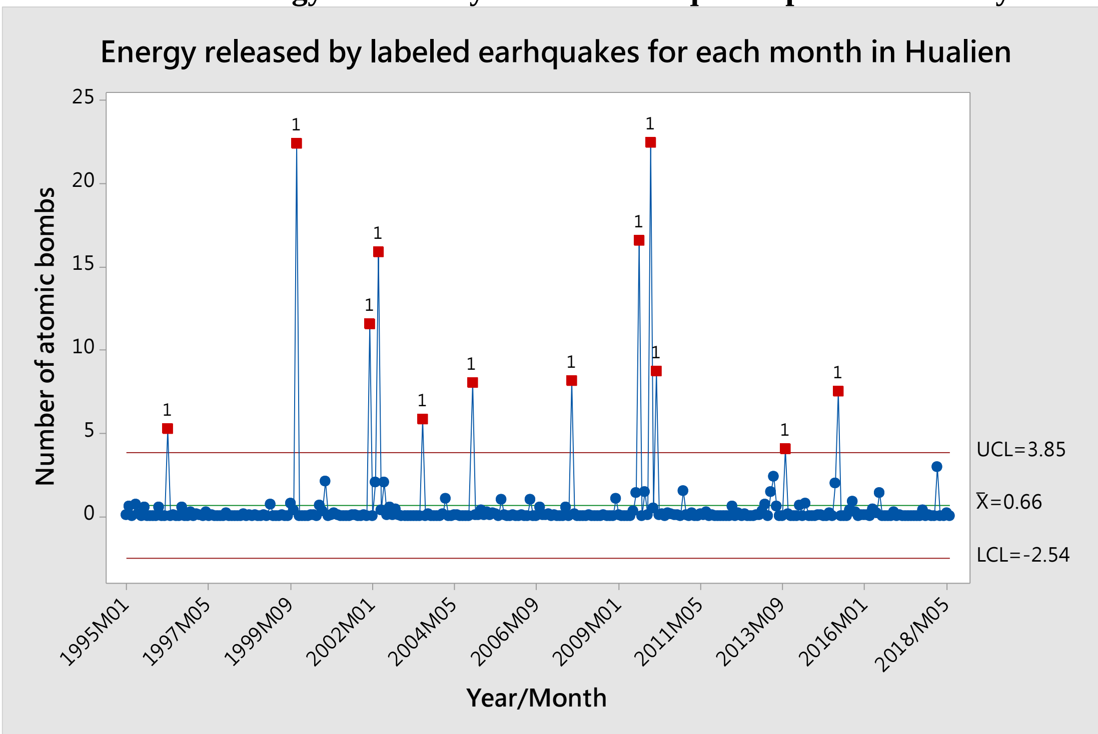

Figure 14: Energy released by the labelled earthquakes each month in Hyaline from January 1995 to June 2018

Averagely speaking, there are 0.66 atomic bombs equivalent energy released by the labelled earthquakes per month in Hyaline.

The stationary check of time series of energy released by labelled earthquakes per month in Hyaline

Table 7: The critical values and Dickey-Fuller unit root test for monthly labelled earthquakes from January 1995 to June 2018 in Hyaline

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-16.781	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly labelled earthquakes in Hyaline is stationary.

Time series of energy released by earthquakes per month and its stationary check for Tatung

Time series of energy released by total earthquakes per month in Tatung

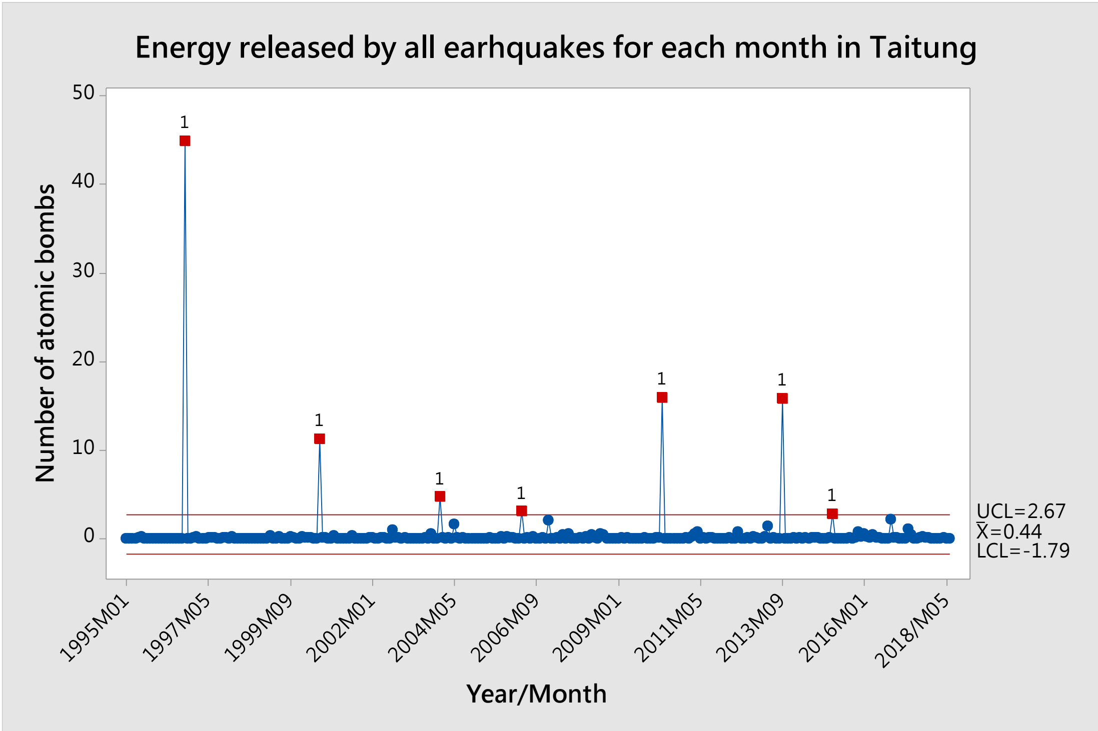

Figure 15: Energy released by all the earthquakes each month in Taitung from January 1995 to June 2018

Averagely speaking, there are 0.44 atomic bombs equivalent energy released by all the earthquakes per month in Tatung.

The stationary check of time series of energy released by all earthquakes per month in Tatung

Table 8: The critical values and Dickey-Fuller unit root test for monthly labelled earthquakes from January 1995 to June 2018 in Tatung

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-17.010	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly total earthquakes in Tatung is stationary.

Time series of energy released by labelled earthquakes per month in Tatung

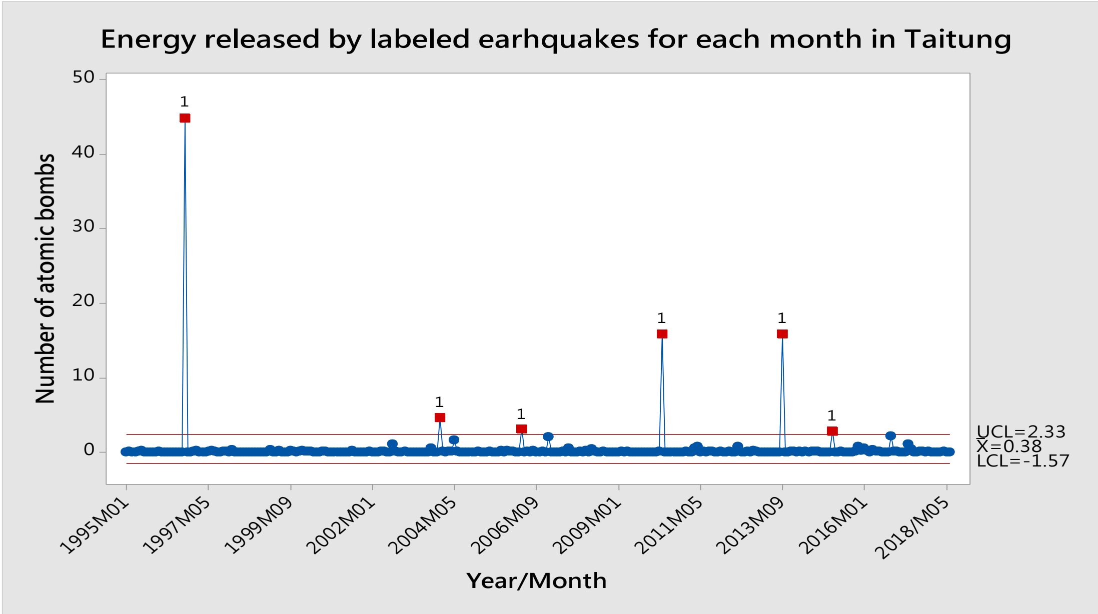

Figure 16: Energy released by the labelled earthquakes each month in Tatung from January 1995 to June 2018

Averagely speaking, there are 0.38 atomic bombs equivalent energy released by the labelled earthquakes per month in Tatung.

The stationary check of time series of energy released by labelled earthquakes per month in Tantung

Table 9: The critical values and Dickey-Fuller unit root test for monthly labelled earthquakes from January 1995 to June 2018 in Tantung

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-16.947	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly labelled earthquakes in Tantung is stationary.

Table 10: Mean value of the energy released by monthly earthquakes in Taiwan and three eastern coast counties (equivalent atomic bombs)

	Taiwan	Yilan	Hualien	Taitung
Total earthquakes	2.9	0.38	0.67	0.44
Labeled earthquakes	2.7	0.37	0.66	0.38

The stationary of the time series of monthly number of earthquakes

Monthly total number of earthquakes in Taiwan

Time series of the number of monthly total earthquakes in Taiwan

Table 11: The critical values and Dickey-Fuller unit root test for monthly total earthquakes from January 1995 to June 2018 in Taiwan

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-12.208	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly total earthquakes in Taiwan is stationary. The estimating equation is:

$$\Delta \text{MTQTAI}_t = 27.055 - 0.6961 MTQTAI_{t-1} \qquad (1)$$

$$\tau(t) \qquad (-12.208)$$

Where $MTQTAI_t$ is monthly total earthquakes in Taiwan at time t. Δ is time difference.

Time series of the number of monthly labelled earthquakes in Taiwan

Table 12: The critical values and Dickey-Fuller unit root test for monthly labelled earthquakes from January 1995 to June 2018 in Taiwan

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-10.476	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly labelled earthquakes in Taiwan is stationary. The estimating equation is:

$$\Delta \text{MLQTAI}_t = 6.5368 - 0.5640 MLQTAI_{t-1} \qquad (2)$$

$$\tau(t) \qquad (-10.476)$$

Where $MLQTAI_t$ is monthly labelled earthquakes in Taiwan at time t. Δ is time difference.

Time series of the number of monthly earthquakes in Milan

Time series of the number of monthly total earthquakes in Milan

Table 13: The critical values and Dickey-Fuller unit root test for monthly total earthquakes from January 1995 to June 2018 in Milan

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-6.870	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly total earthquakes in Milan is stationary. The estimating equation is:

$$\Delta \text{MTQY}_t = 2.676 - 0.3980 MTQY_{t-1} - 0.1787 \Delta MTQY_{t-1} \qquad (3)$$

$\tau(t)$ (-6.870)

Where $MTQY_t$ is monthly total earthquakes in Milan at time t. Δ is time difference.

Time series of the number of monthly labelled earthquakes in Milan

Table 14: The critical values and Dickey-Fuller unit root test for monthly labelled earthquakes from January 1995 to June 2018 in Milan

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-10.919	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly labelled earthquakes in Milan is stationary. The estimating equation is:

$$\Delta \text{MLQY}_t = 1.1607 - 0.5977 MLQY_{t-1} \qquad (4)$$

$\tau(t)$ (-10.919)

Where $MLQY_t$ is monthly labelled earthquakes in Milan at time t. Δ is time difference.

Time series of the number of monthly earthquakes in Hyaline

Time series of the number of monthly total earthquakes in Hyaline

Table 15: The critical values and Dickey-Fuller unit root test for monthly total earthquakes from January 1995 to June 2018 in Hyaline

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-14.155	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly total earthquakes in Hualien is stationary. The estimating equation is:

$$\Delta \text{MTQH}_t = 15.124 - 0.8356 MTQH_{t-1} \qquad (5)$$

$\tau(t)$ (-14.155)

Where $MTQH_t$ is monthly total earthquakes in Hyaline at time t. Δ is time difference.

Time series of the number of monthly labelled earthquakes in Hyaline

Table 16: The critical values and Dickey-Fuller unit root test for monthly labelled earthquakes from January 1995 to June 2018 in Hyaline

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-14.187	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly labelled earthquakes in Hyaline is stationary. The estimating equation is:

$$\Delta \text{MLQH}_t = 3.9990 - 0.8376 MLQH_{t-1} \quad (6)$$

$\tau(t)$ (-14.187)

Where $MLQH_t$ is monthly labelled earthquakes in Hyaline at time t. Δ is time difference.

Time series of the number of monthly total earthquakes in Tantung

Time series of the number of monthly total earthquakes in Tantung

Table 17: The critical values and Dickey-Fuller unit root test for monthly total earthquakes from January 1995 to June 2018 in Tantung

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-14.554	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly total earthquakes in Tantung is stationary. The estimating equation is:

$$\Delta \text{MTQT}_t = 4.8402 - 0.8641 MTQT_{t-1} \quad (7)$$

$\tau(t)$ (-14.554)

Where $MTQT_t$ is monthly total earthquakes in Tantung at time t. Δ is time difference.

Time series of the number of monthly labelled earthquakes in Tantung

Table 18: The critical values and Dickey-Fuller unit root test for monthly labelled earthquakes from January 1995 to June 2018 in Tantung

$\tau(t)$ Test statistic	1% Critical value	5% Critical value	10% Critical value
-15.485	-3.43	-2.86	-2.57
MacKinnon approximate *p*-value for $\tau(t)$ = 0.0000			

The null hypothesis H_0: no stationary is rejected at 5% level of significance. In other words, the time series of the energy released from monthly labelled earthquakes in Tantung is stationary. The estimating equation is:

$$\Delta \text{MLQT}_t = 1.4336 - 0.9236 MLQT_{t-1} \quad (8)$$

$$\tau(t) \qquad (-15.485)$$

Where $MLQT_t$ is monthly labelled earthquakes in Tantung at time t. Δ is time difference.

Pattern recognition and forecasting of monthly number of labelled earthquakes

In this section, only the time series pattern for monthly number of labelled earthquakes is recognized and used to make a short-term forecast. The time series of the total number of earthquakes can just follow the same procedure and will not be discussed in this section. The time series of the labelled number of earthquakes to be explored in this section is the whole of Taiwan and three eastern counties. From the pattern of the autocorrelation function (ACF) and partial autocorrelation function (PACF), one can make a judgement of the parameters using the ARIMA (p,q,r) method. The ARIMA (p,q,r) method (autoregressive integrated moving average) is one of the most versatile methods in forecasting algorithm [6]. As long as a set of suitable parameters (p,q,r) is determined, then one can use it to make a short-term forecast. The whole pattern recognition flow chart can be referred to in Appendix B.

Pattern recognition of time series of the number of earthquakes in Taiwan

In this subsection, only the labelled earthquakes in Taiwan are explored.

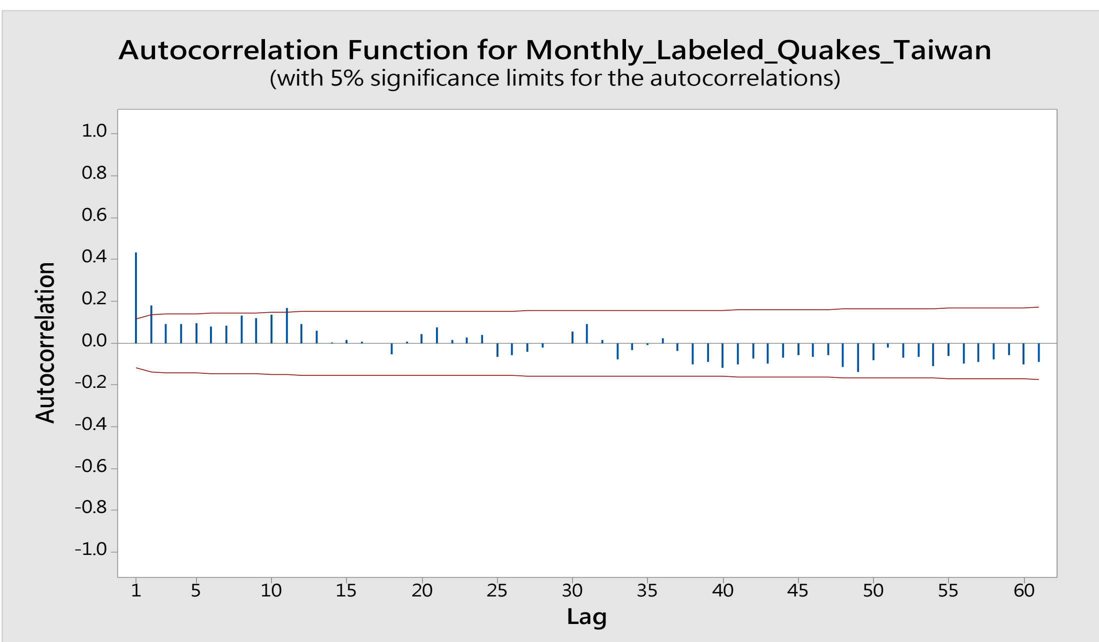

Figure 17: Autocorrelation function (ACF) of labelled number of earthquakes per month in Taiwan

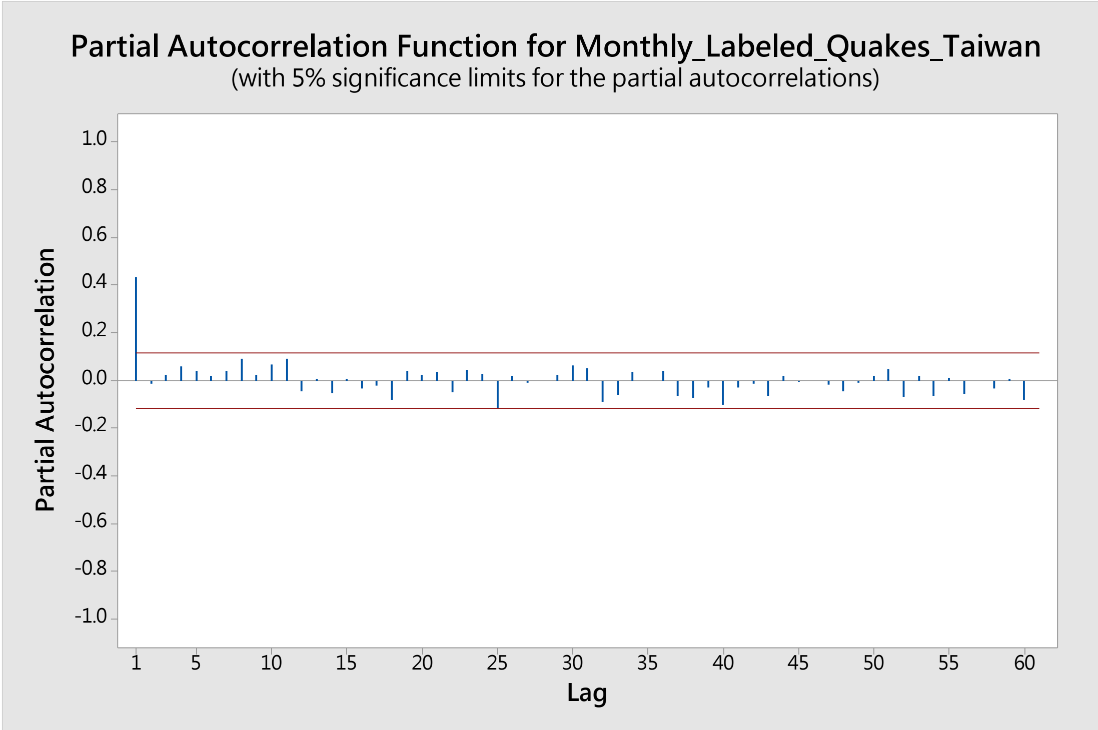

Figure 18: Partial autocorrelation function (PACF) of labelled earthquakes per month in Taiwan

After several trial and errors, the author finds the ARIMA (3,0,0) is a suitable model for the labelled number of earthquakes in Taiwan. The autocorrelation function (ACF) of the residual of ARIMA (3,0,0) is as follows:

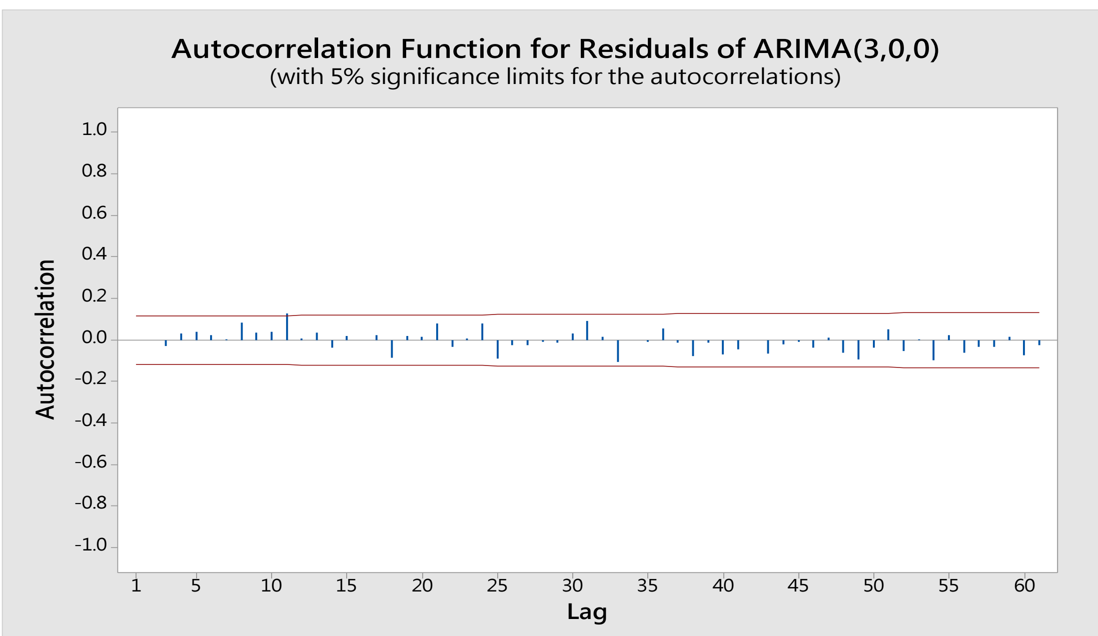

Figure 19: Autocorrelation function (ACF) of the residuals of ARIMA(3,0,0)

From the above figure, one finds the residuals of ARIMA (3,0,0) are all within two standard errors of the mean. It proves that ARIMA (3,0,0) is a suitable model for the labelled earthquakes per month in Taiwan.

Pattern recognition of time series for the number of earthquakes in Milan

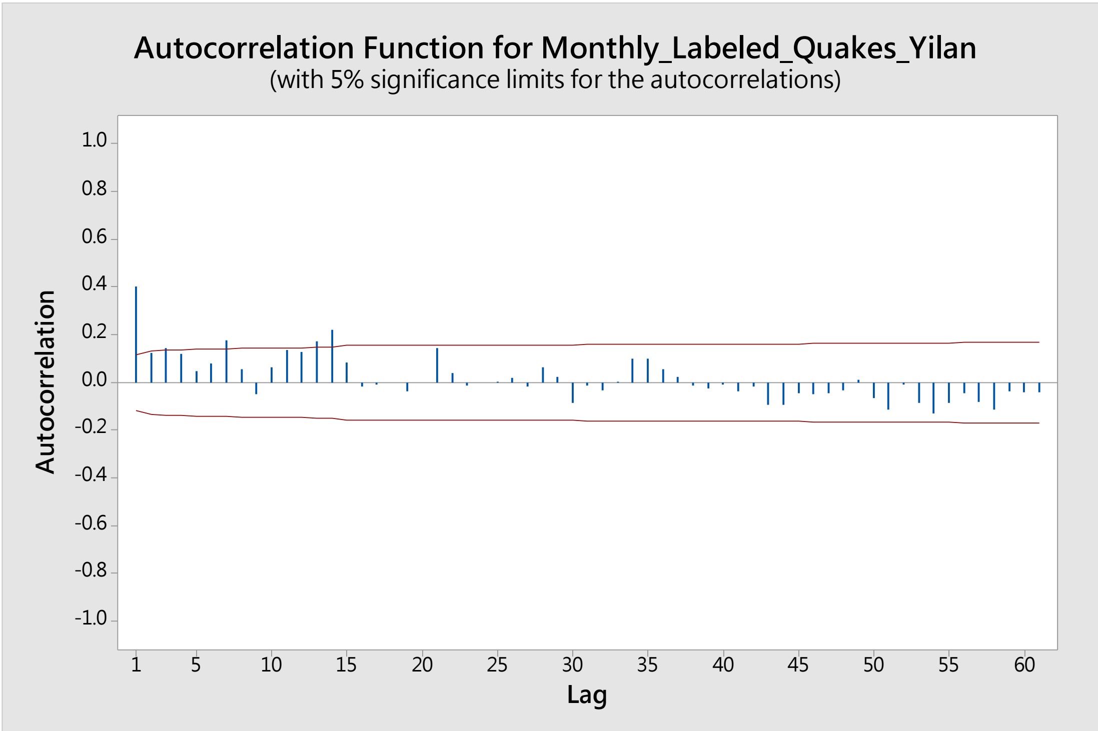

Figure 20: Autocorrelation function (ACF) of labelled earthquakes per month in Milan

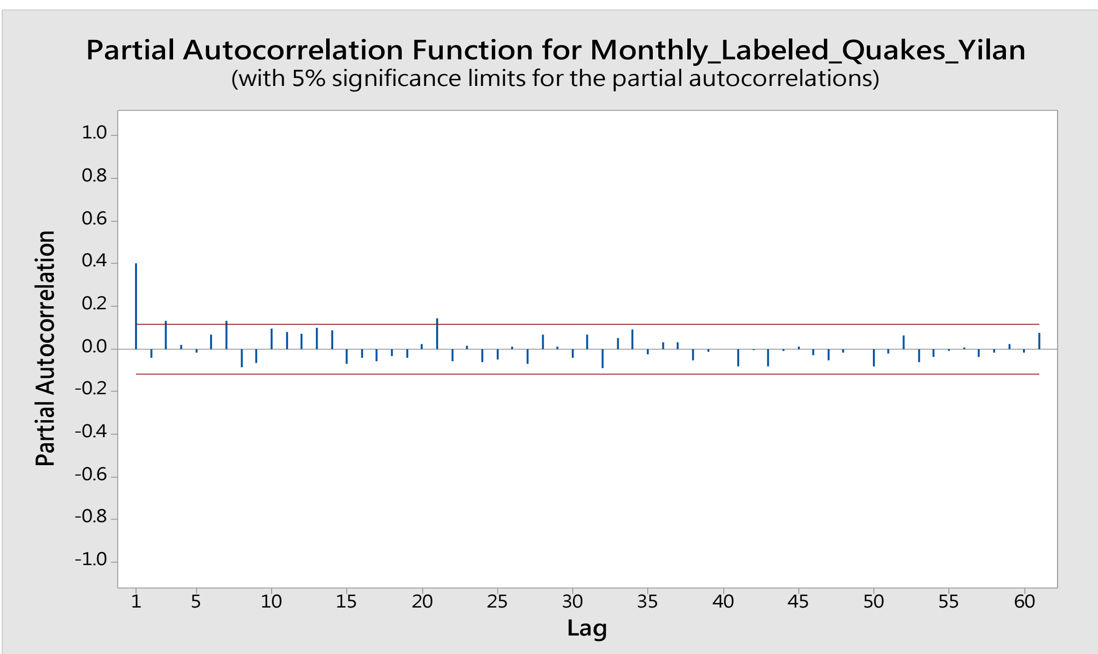

Figure 21: Partial autocorrelation function (PACF) of labelled earthquakes per month in Milan

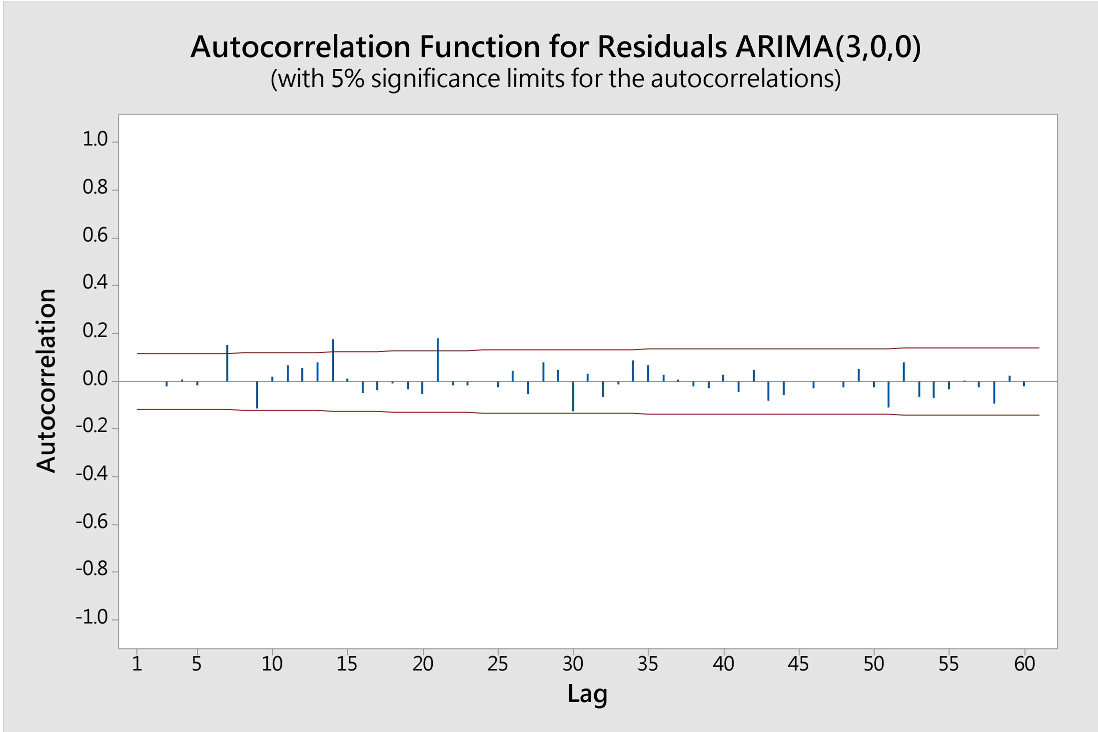

Figure 22: Autocorrelation function (ACF) of ARIMA (3,0,0) for the labelled number of earthquakes per month in Milan

The ARIMA (3,0,0) model is suitable for Milan because the autocorrelation function of the residuals is within two standard errors of mean.

Pattern recognition of time series for the number of earthquakes in Haulier

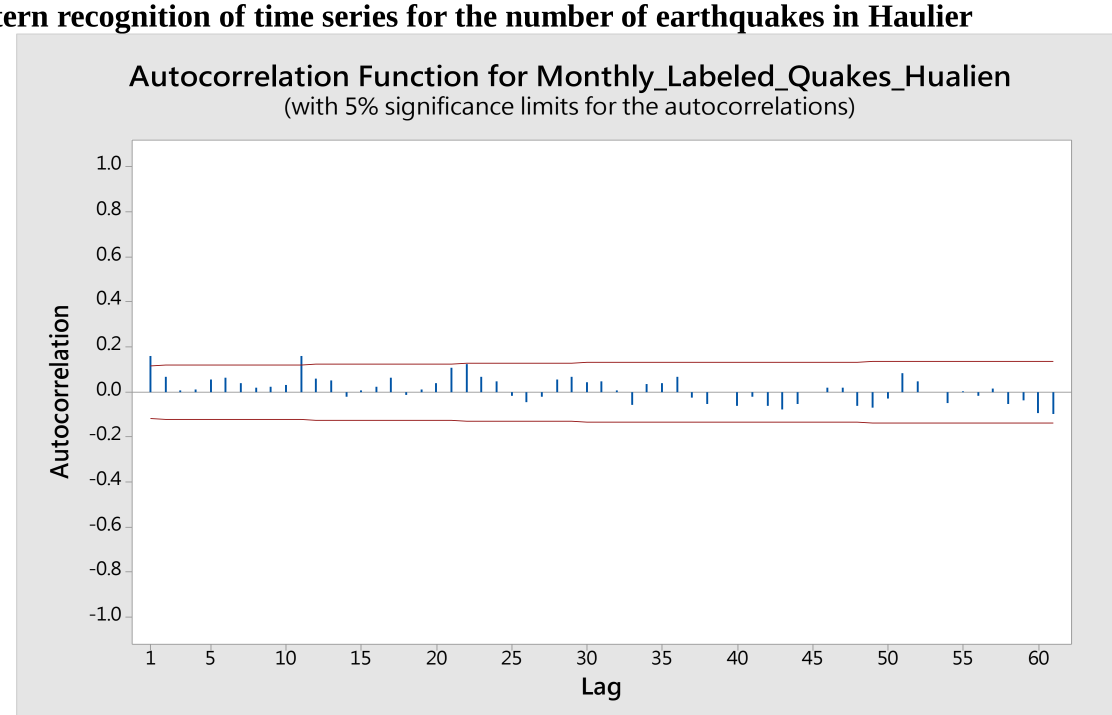

Figure 23: Autocorrelation function (ACF) of labelled earthquakes per month in Haulier

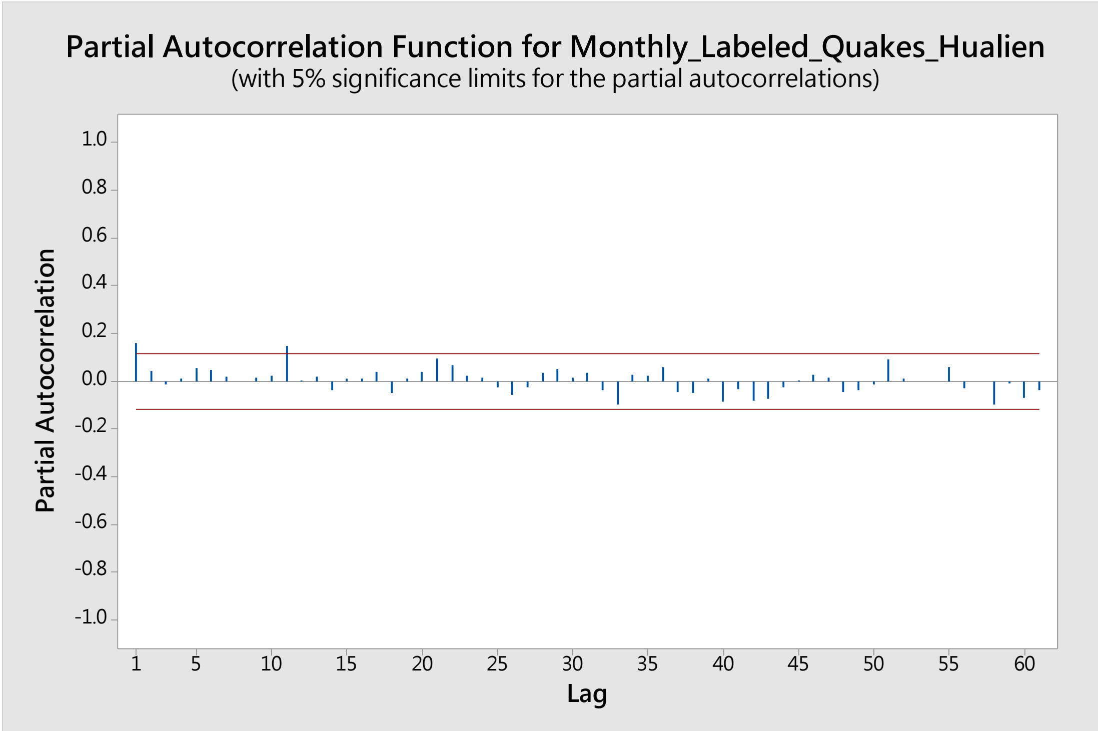

Figure 24: Partial autocorrelation function (PACF) of labelled earthquakes per month in Haulier

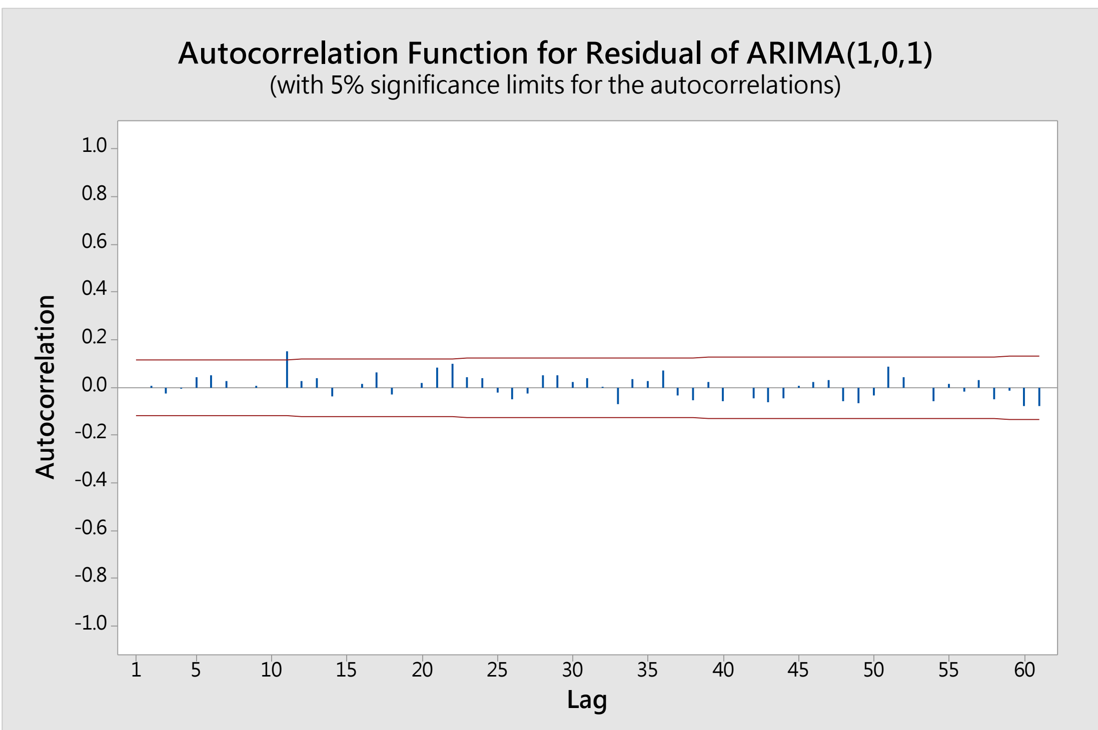

Figure 25: Autocorrelation function (ACF) of ARIMA (1,0,1) for the labelled number of earthquakes per month in Haulier

The ARIMA (1,0,1) model is suitable for Haulier because the autocorrelation function of the residuals is within two standard errors of the mean.

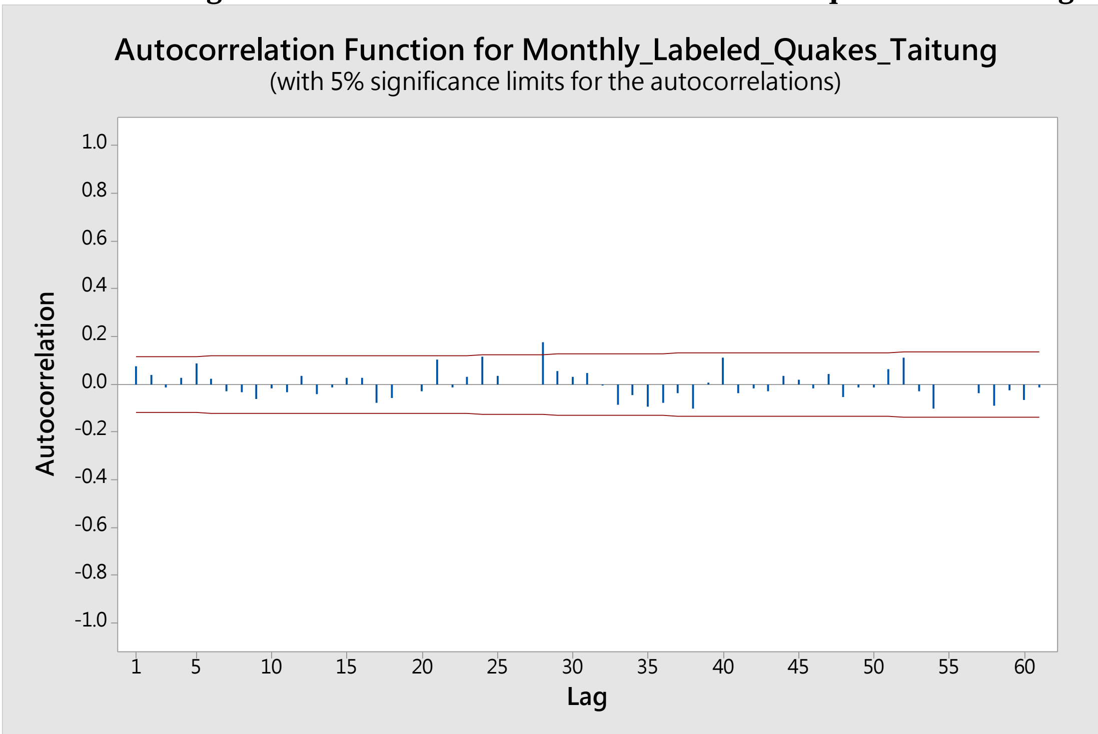

Figure 26: Autocorrelation function (ACF) of labelled earthquakes per month in Tantung

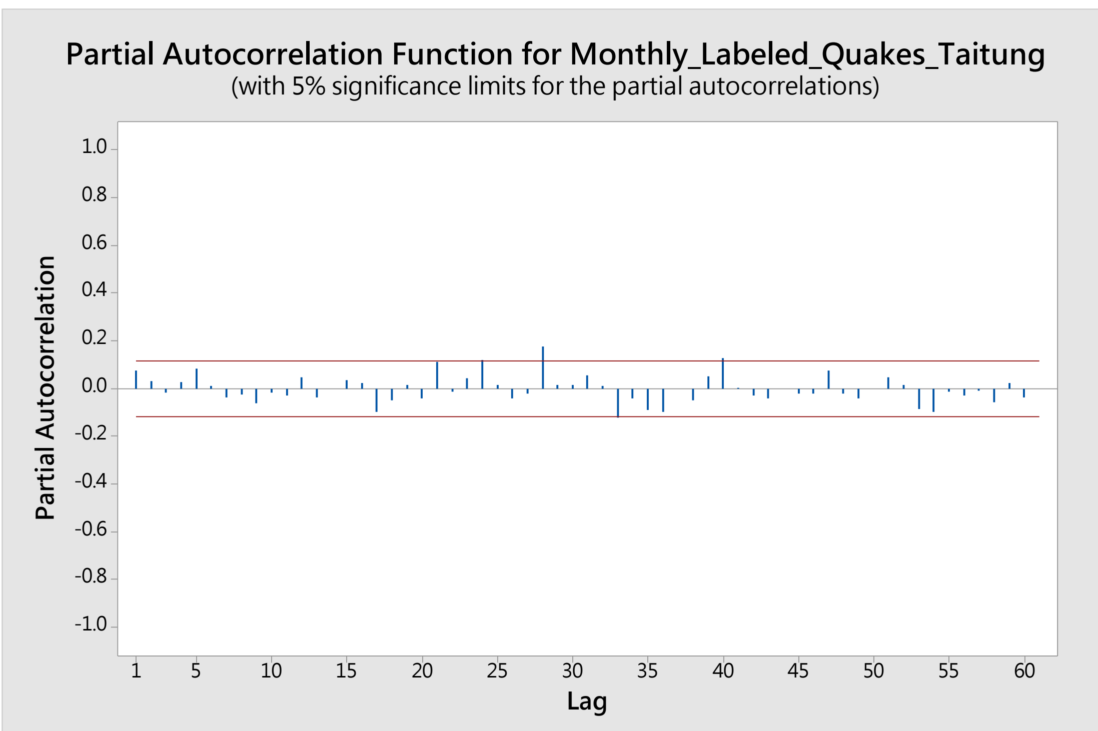

Figure 27: Partial autocorrelation function (PACF) of labelled earthquakes per month in Taitung

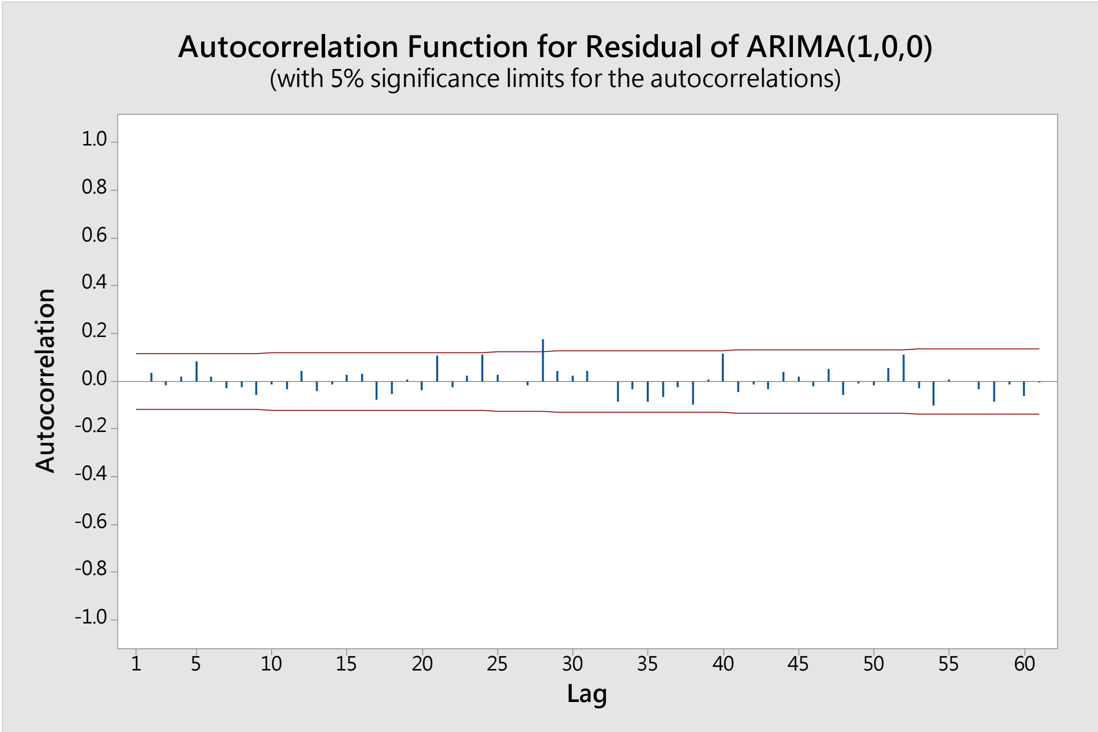

Figure 28: Autocorrelation function (ACF) of ARIMA (1,0,0) for the labelled number of earthquakes per month in Tantung

The ARIMA (1,0,0) model is suitable for Tantung because the autocorrelation function of the residuals is within two standard errors of the mean.

Deviation check of observed and forecasted labelled number of earthquakes

The mean absolute deviation (MAD) method [6] is used to check the deviation of the forecasted number of labelled earthquakes and the observed data. The mean absolute deviation method has the form:

$$\text{MAD} = \frac{1}{n}\sum_{t=1}^{n}\left|Y_t - \hat{Y}_t\right| \qquad (5)$$

Where n is the number of observed data, Y_t is the real number of labelled earthquakes at time t, $\hat{Y}_t$ is the number of forecasting labelled earthquakes at time t.

The author uses the observed real data from January 1995 December 2016 and the proposed ARIMA (p,q,r) models to check the accuracy of each area, and the following table is obtained.

Table 19: The ARIMA model and deviation checks of each area

Area	Whole Taiwan	Yilan	Hualien	Taitung
Model	ARIMA(3,0,0)	ARIMA(3,0,0)	ARIMA(1,0,1)	ARIMA(1,0,0)
Deviation	6.7	1.5	3.6	0.9

(times/month)				

The average number of deviation per month for the whole of Taiwan is 6.7, and 1.5 for Milan, 3.6 for Haulier and 0.9 for Tantung respectively.

Conclusions

From the calculation of the previous sections, the following conclusions can be obtained:

The time series of energy released from 1995 to 2017 for the whole of Taiwan and three eastern counties -Milan, Haulier, and Tantung are studied. The energy released is equivalent to 34.9 atomic bombs for Taiwan per year. And it is equivalent to 4.48, 7.88, and 5.14 atomic bombs for Milan, Haulier, and Tantung respectively.

The mean value of the energy released by the labelled earthquakes for each year in Taiwan is equivalent to 33.3 atomic bombs. And it is equivalent to 4.33, 7.71, and 4.44 atomic bombs for Milan, Haulier, and Tantung respectively.

The time series of energy released from January 1995 to June 2018 in the whole of Taiwan and three eastern counties -Milan, Haulier, and Tantung are studied. The energy released is equivalent to 2.9 atomic bombs in Taiwan per month. And it is equivalent to 0.38, 0.67, and 0.44 atomic bombs for Milan, Haulier, and Tantung respectively.

The mean value of the energy released by the labelled earthquakes for each month in Taiwan is equivalent to 2.7 atomic bombs. And it is equivalent to 0.37, 0.66, and 0.38 for Milan, Haulier, and Tantung respectively.

The stationary of time series for energy released per month for total (labelled plus unlabeled) and labelled earthquakes are checked by the augment Dickey-Fuller (ADF) method. Time series for the whole of Taiwan as well as three eastern coast counties are all stationary.

The pattern for the monthly number of labelled earthquakes has been recognized for the whole Taiwan and three eastern coast counties. Through autocorrelation function (ACF) and partial autocorrelation function (PACF), the parameters of ARIMA (p,q,r) can be determined. To forecast the labelled number of earthquakes in the near future, the ARIMA(3,0,0) model is suitable for whole Taiwan and Milan, the ARIMA(1,0,1) model is appropriate for Haulier, and the ARIMA(1,0,0) model is acceptable for Tantung.

By using the time series data from January 1995 to December 2016, and adopting their corresponding ARIMA models to forecast the number of labelled earthquakes for the whole of Taiwan and three eastern coast counties in the twelve months of 2017 are obtained. The difference between observed and forecasted is checked by the mean absolute deviation (MAD) algorithm. The average deviation (times/month) is 6.7 for the whole of Taiwan, 1.5 for Milan, 3.6 for Haulier, and 0.9 for Tantung.

References

Central Weather Bureau (CWB) of Taiwan. http://www.cwb.gov.tw. Accessed 5 July, 2018.

Kramer, S. L. *Geotechnical Earthquake Engineering*. New Jersey: Prentice Hall, 1996.

Pidwirny, M. (2011). Surface wave magnitude. http://www.eoearth.org/view/article/164453 Accessed 8 July, 2018.

921 Earthquake. https://en.wikipedia.org/wiki/921_earthquake Accessed 8 July, 2018.

Little Boy, Wikipedia, https://en.wikipedia.org/wiki/Little_Boy, Accessed 3 July, 2018.

Hanker, J. E., and Wincher, D. W. *Business Forecasting, 9th ed. (2009)*. New Jersey: Pearson Prentice Hall.

Hill, R. C, Griffiths, W. E, and Lim, G. C. *Principle of Econometrics, 4th ed. (2012).* John Wiley & Sons, Inc.

Appendices

Appendix A: Earthquake numbers and energy released in three eastern coast counties

The energy released by earthquakes in three eastern coast of Taiwan is shown in Table A1. The yearly data are collected from 1995 to June 2018, and the number of earthquakes separated into each city and county are assembled from January 1995 to June 2018.Since the monthly energy and number lists are very long, only partly data are shown in Table A2 and Table A3.

Table A1: The energy released by the total and labelled earthquakes in three eastern coast cities (Yilan, Hualien, Taitung) in Taiwan (unit=ergs)

Year	Energy_Total_Quakes_Yilan	Energy_Labeled_Quakes_Yilan	Energy_Total_Quakes_Hualien	Energy_Labeled_Quakes_Hualien	Energy_Total_Quakes_Taitung	Energy_Labeled_Quakes_Taitung
1995	4.2E+21	4.2E+21	1.61E+21	1.61E+21	2.01E+20	2.01E+20
1996	9.02E+20	9.02E+20	3.86E+21	3.86E+21	2.84E+22	2.84E+22
1997	1.3E+21	1.3E+21	4.29E+20	4.29E+20	4.13E+20	4.13E+20
1998	5.93E+20	5.93E+20	2.03E+20	2.03E+20	1.64E+20	1.64E+20
1999	1.84E+21	1.84E+21	1.54E+22	1.54E+22	4.13E+20	4.13E+20
2000	4.78E+20	4.06E+20	2.2E+21	2.18E+21	7.58E+21	2.79E+20
2001	4.32E+21	4.29E+21	7.52E+21	7.49E+21	2.08E+20	1.62E+20
2002	1.95E+21	1.89E+21	1.36E+22	1.35E+22	8.97E+20	8.27E+20
2003	6.32E+20	6.01E+20	3.93E+21	3.83E+21	3.39E+21	3.26E+21
2004	2.93E+22	2.93E+22	6.12E+21	5.98E+21	1.25E+21	1.19E+21

2005	2.58E+21	2.46E+21	1.45E+21	1.35E+21	3.49E+20	3.27E+20
2006	1.23E+21	1.14E+21	1.15E+21	1.13E+21	2.20E+21	2.14E+21
2007	2.34E+20	1.86E+20	5.76E+21	5.69E+21	1.92E+21	1.61E+21
2008	8.75E+20	8.18E+20	1.01E+21	7.79E+20	9.84E+20	3.75E+20
2009	2.35E+20	9.79E+19	2.71E+22	2.67E+22	1.37E+20	9.04E+19
2010	5.59E+21	5.56E+21	7.39E+21	7.24E+21	1.02E+22	1.01E+22
2011	5.54E+20	4.11E+20	5.65E+20	4.67E+20	1.04E+21	9.02E+20
2012	5.33E+21	5.3E+21	8.13E+20	6.55E+20	7.02E+20	6.63E+20
2013	6.63E+20	6.41E+20	6.21E+21	6.09E+21	1.11E+22	1E+22
2014	1.27E+21	1.12E+21	1.19E+21	9.92E+20	3.13E+20	2.69E+20
2015	5.69E+20	4E+20	7.37E+21	7.1E+21	2.49E+21	2.39E+21
2016	1.67E+21	1.63E+21	1.65E+21	1.53E+21	2.25E+21	2.07E+21
2017	7.91E+20	2.72E+20	3.92E+20	3.14E+20	1.11E+21	9.25E+20
2018	6.15E+20	1.18E+20	2.19E+21	1.99E+21	6.17E+19	3.15E+19
Total	6.78E+22	6.55E+22	1.19E+23	1.17E+23	7.77E+22	6.72E+22

Table A2: Monthly earthquake energy released in terms of the number of equivalent atomic bombs in Yilan, Hualien and Taitung (only partly shown)

Year/	Monthly_Total_Bombs_	Monthly_Labeled_Bombs_	Monthly_Total_Bombs_H	Monthly_Labeled_Bombs_H	Monthly_Total_Bombs_Ta	Monthly_Labeled_Bombs_Ta

Month	Yilan	Yilan	ualien	ualien	itung	itung
1995 M01	0.00	0.00	0.04	0.04	0.00	0.00
1995 M02	0.00	0.00	0.58	0.58	0.02	0.02
1995 M03	0.25	0.25	0.02	0.02	0.00	0.00
1995 M04	0.09	0.09	0.71	0.71	0.00	0.00
1995 M05	0.14	0.14	0.10	0.10	0.12	0.12
1995 M06	5.63	5.63	0.00	0.00	0.14	0.14
1995 M07	0.03	0.03	0.53	0.53	0.00	0.00
1995 M08	0.04	0.04	0.00	0.00	0.00	0.00
1995 M09	0.00	0.00	0.00	0.00	0.00	0.00
1995 M10	0.04	0.04	0.01	0.01	0.00	0.00
1995 M11	0.01	0.01	0.00	0.00	0.02	0.02
1995 M12	0.44	0.44	0.55	0.55	0.02	0.02
2017/ M01	0.01	0.00	0.04	0.04	0.00	0.00
2017/ M02	0.06	0.06	0.00	0.00	0.01	0.00
2017/ M03	0.08	0.07	0.01	0.00	0.01	0.01
2017/ M04	0.00	0.00	0.00	0.00	1.01	1.00
2017/	0.00	0.00	0.01	0.01	0.39	0.36

M05						
2017/ M06	0.16	0.16	0.00	0.00	0.00	0.00
2017/ M07	0.03	0.00	0.02	0.01	0.02	0.00
2017/ M08	0.51	0.00	0.01	0.01	0.10	0.03
2017/ M09	0.14	0.01	0.39	0.37	0.14	0.05
2017/ M10	0.06	0.00	0.05	0.00	0.06	0.00
2017/ M11	0.01	0.01	0.07	0.06	0.03	0.03
2017/ M12	0.20	0.13	0.02	0.00	0.01	0.00
2018/ M01	0.01	0.00	0.01	0.00	0.02	0.00
2018/ M02	0.16	0.15	3.16	2.93	0.00	0.00
2018/ M03	0.78	0.03	0.02	0.01	0.00	0.00
2018/ M04	0.01	0.00	0.05	0.00	0.04	0.04
2018/ M05	0.02	0.00	0.20	0.19	0.01	0.01
2018/ M06	0.08	0.06	0.04	0.02	0.02	0.00
Total	107.62	104.00	189.15	184.94	123.40	106.64

Table A3: Monthly number of total (labelled plus unlabeled) and labelled earthquakes (only partly shown)

Year/ Month	Monthly_Total_Qukes_ Yilan	Monthly_Labeled_Quakes_ Yilan	Monthly_Total_Quakes_Hualien	Monthly_Labeled_Quakes_Hualien	Monthly_Total_Quakes_Taitung	Monthly_Labeled_Quakes_Taitung

1995 M01	0	0	1	1	0	0
1995 M02	0	0	4	4	1	1
1995 M03	1	1	1	1	0	0
1995 M04	1	1	3	3	0	0
1995 M05	3	3	5	5	3	3
1995 M06	1	1	0	0	3	3
1995 M07	3	3	3	3	0	0
1995 M08	2	2	0	0	0	0
1995 M09	0	0	0	0	0	0
1995 M10	2	2	1	1	0	0
1995 M11	2	2	3	3	1	1
1995 M12	2	2	3	3	1	1
2017/ M01	9	0	9	2	6	2
2017/ M02	3	0	3	2	4	0
2017/ M03	14	3	13	0	4	1
2017/ M04	3	0	13	0	6	1
2017/ M05	4	0	3	1	5	1

2017/ M06	7	3	7	1	3	0
2017/ M07	10	1	8	1	4	0
2017/ M08	9	0	6	1	4	1
2017/ M09	7	1	13	3	8	2
2017/ M10	7	0	9	0	3	0
2017/ M11	1	1	7	1	6	2
2017/ M12	8	1	11	0	5	0
2018/ M01	5	0	14	1	16	1
2018/ M02	10	3	476	62	4	0
2018/ M03	15	3	27	1	4	0
2018/ M04	10	0	15	1	12	6
2018/ M05	9	0	13	2	12	1
2018/ M06	11	1	26	4	13	2
Total	1862	545	5082	1342	1572	436

Appendix B: ARIMA(p,q,r) Forecasting Procedures

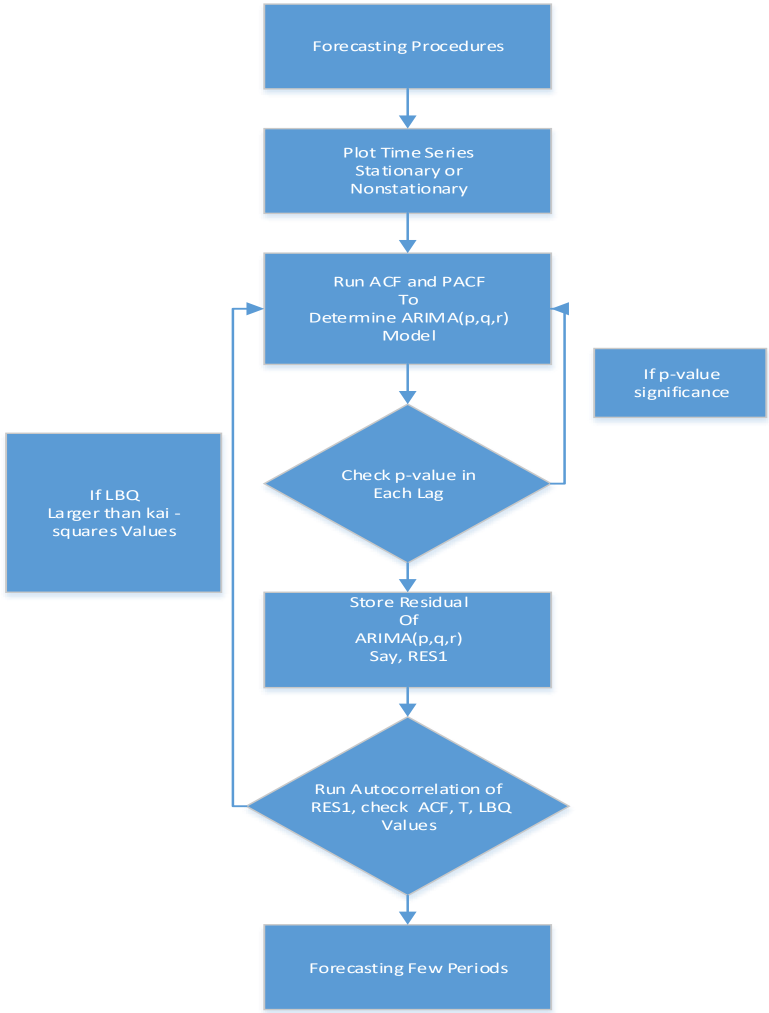

Figure B1: ARIMA (p,q,r) forecasting procedures