Analysis of seismic events in Malaysia using International Monitoring System (IMS) data of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)

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Abstract. The International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) is designed to be non-discriminatory and does not single out any country or region for enhanced monitoring. The seismic network, when completed, will consist of 50 primary and 120 auxiliary seismic monitoring stations in 76 countries around the world to detect and locate underground nuclear explosions. The data from the IMS stations can also be used for scientific and civil purposes. In this study, we present the results of data analysis of selected seismic events in Malaysia from 2015 to 2018 using IMS seismic stations data. Important seismicity parameters including the epicentral, magnitude distribution and seismic phases were presented in this study. We also perform comparison of the seismic events recorded by the IMS with similar seismic events detected by others seismic network at local, regional and international level. This study demonstrates that other than for nuclear explosion monitoring, the IMS data can also be used for civil and scientific applications and can make significant contribution in seismological research.

1. Introduction

Article IV of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) provides that the establishment of a verification regime shall be capable of meeting the requirements of the Treaty when it enters into force [1]. The IMS developed for this verification regime uses four modern technology, namely seismic, hydro-acoustics, infrasound and radionuclide technologies to monitor the globe for any sign of a nuclear explosion. As shown in Figure 1, the IMS consists of 321 monitoring stations and 16 radionuclide laboratories built worldwide [2]. The CTBT’s International Data Centre (IDC) in Vienna began the routine automatic and interactive processing of IMS data since June 1999 [3]. From the IDC, data and analysis are forwarded to the member states, in near real time for the automated data. For the seismic events, the detected and located events are also systematically included in the Reviewed Event Bulletin (REB). Apart of its primary mandate to monitor for any sign of nuclear test explosion, the seismicity catalog of the IDC also constitutes to a wide range of global seismological research and analyses.
Malaysia is situated on the southern edge of the Eurasian and considered to have low seismicity profile. It is closed to the most two seismically active plate boundaries, the inter plate boundary between the indo-Australian and Eurasian plates on the west and the inter-plate boundary between the Eurasian and Philippines plates on the east [4]. The tectonic framework for the whole of Malaysia covers between longitudes 90 E to 140 E and latitudes of 12 S to 20 N [5].

**Figure 1. The geographic distribution of the CTBT IMS Network.**

1.1. Seismic activity in Malaysia

Peninsular Malaysia is classified as a seismically stable as no earthquake has originated from the area [7]. However, it is still considered vulnerable as it lies close to Sumatran fault and Sumatran Subduction zone. Large earthquakes that originated from these two active areas have created considerably ground motion over western part of Peninsular Malaysia.

East Malaysia (Sabah and Sarawak) on the other hand, is classified as moderately active in seismicity [7]. Figure 3 shows the epicenter of felt earthquakes ever recorded in East Malaysia. Sabah is prone to earthquake activities compared to other parts of Malaysia, where it has suffered several earthquakes of moderate magnitude. Some of these earthquakes have caused structural damage to buildings and other infrastructures and injuries to humans [8]. In 1976, one of the worst earthquakes occurred in Sabah when a 5.8 magnitude on Richter scale earthquake shocked Lahad Datu. Later in 1991, an earthquake of magnitude 4.5 on Richter scale shook Ranau, resulting in structural damage to a school. Eastern Sabah is also exposed to tremors caused by earthquakes originated in the southern Philippines and the Straits of Macassar, Sulu Sea and Celebes Sea.

Similarly, Sarawak also has experienced several moderate-magnitude earthquakes of local origin [7]. Beside of having earthquakes of local origin, Sarawak was also affected by long-distance earthquake that originated from Southern Philippine and the Straits of Macassar, Sulu Sea and Celebes Sea.
To locate seismic epicenter and its magnitude, the seismologists require seismic data from the seismic stations. The quantity and quality of the data will determine the accuracy of the epicenter's location. The quantity of data means the number of time arrival of seismic phase used in the seismic determination, while the quality means the distribution of the station with respect to the epicenter. The Malaysian Meteorological Department (MMD) serves as national seismology information centre for the country. MMD provides information, advice and consultation related to earthquake to the Government, authorities, general public, as well as related users such as architects and planners for well-being, safety and sustainable development of the country.

Figure 2. Major tectonic in Malaysia
2. Methods
The CTBTO is operating the IDC in Vienna, Austria. Monitoring data from IMS stations are transmitted to the IDC for storing, processing and analysis. As a result, various products are produced at the IDC, including event bulletins and listings. In this study, the listing of seismic events occurred in Malaysia for the time period of January 1, 2015 to December 31, 2018 were obtained from the IDC Reviewed Event Bulletin (REB). Event bulletins produced by other seismic networks, namely the U.S. Geological Survey (USGS) and Incorporated Research Institutions for Seismology (IRIS), were also obtained for the similar time period. Such events were screened to ensure that only the detected events fall within Malaysia’s region are considered in this study. This is done by confirming the reported coordinates of each of recorded events are identical to the latitude and longitude of Malaysia’s region.

For event listed in CTBTO REB, we then retrieved the waveform data for the listing events and performed analysis using Geotool software to identify important seismicity parameters including location, depth and seismic phases. For other events listed by other seismic networks, we also perform the same step by compiling the important seismicity parameters. Lastly, we compared the seismicity parameters of events recorded by REB and other networks. The methodology used in this study is shown in Figure 4.
3. Results and discussion

As reported in the REB of seismic events in Malaysia from the period of 2015 to 2018, the CTBT IMS has recorded 16 seismic events originated in Malaysia, where all of them were in East Malaysia (Sabah and Sarawak). Out of these 16 events, only 2 were located in Sarawak, each in 2015 (Event ID 11997735) and 2018 (Event ID 15916404). The rest of the events were located in Sabah. From our further analysis on the identified waveforms utilizing the Geotool software, all of these events are classified as natural earthquakes with moderate body wave magnitude (mb) ranging from the lowest 3.4 mb to maximum magnitude of 5.2 mb. Table 1 shows the list of earthquakes recorded by the CTBT IMS network from 2015 to 2018, including its important seismicity parameters obtained from our waveform analysis.
Table 1. 2015-2018 earthquake events in East Malaysia recorded by the CTBT IMS network.

| Year 2018 | Event ID   | Date     | Time   | Latitude | Longitude | Magnitude | Depth |
|-----------|------------|----------|--------|----------|-----------|-----------|-------|
| 1         | 15530461   | 08/03/2018 | 13:06:10 | 5.8856   | 116.5306  | mb 4.4    | mbtmp 4.4 | Ms 4.3 | 0.0   |
| 2         | 15848813   | 05/04/2018 | 14:15:42 | 5.2794   | 119.0089  | mb 3.8    | mbtmp 3.8 | Ms 3.2 | 0.0   |
| 3         | 15916404   | 16/06/2018 | 21:47:58 | 1.0666   | 111.3856  | mb 3.8    | mbtmp 3.8 | Ms 2.8 | 0.0   |

| Year 2017 | Event ID   | Date     | Time   | Latitude | Longitude | Magnitude | Depth |
|-----------|------------|----------|--------|----------|-----------|-----------|-------|
| 1         | 14228945   | 06/06/2017 | 14:30:49 | 4.7966   | 118.7287  | ML 4.1    | mbtmp 4.0 | Ms 3.4 | 52.8  |
| 2         | 14888716   | 09/06/2017 | 16:25:23 | 5.9464   | 118.3581  | mb 3.5    | mbtmp 3.5 | Ms 2.7 | 0.0   |

| Year 2016 | Event ID   | Date     | Time   | Latitude | Longitude | Magnitude | Depth |
|-----------|------------|----------|--------|----------|-----------|-----------|-------|
| 1         | 13497338   | 06/06/2016 | 13:39:32 | 6.4172   | 117.3407  | mb 3.6    | mbtmp 3.6 | Ms 2.8 | 0.0   |

| Year 2015 | Event ID   | Date     | Time   | Latitude | Longitude | Magnitude | Depth |
|-----------|------------|----------|--------|----------|-----------|-----------|-------|
| 1         | 11783042   | 07/03/2015 | 21:56:00 | 5.4795   | 118.3777  | ML 3.7    | mbtmp 3.8 | Ms 2.9 | 0.0   |
| 2         | 11997735   | 14/05/2015 | 10:25:07 | 1.8141   | 110.5797  | mb 3.6    | mbtmp 3.6 | Ms 5.5 | 0.0   |
| 3         | 12047012   | 06/06/2015 | 23:15:43 | 5.0398   | 117.1911  | ML 4.4    | mbtmp 4.1 | Ms 3.1 | 0.0   |
| 4         | 12048513   | 06/06/2015 | 23:15:43 | 5.0398   | 117.1911  | ML 4.4    | mbtmp 4.1 | Ms 3.1 | 0.0   |
| 5         | 12048801   | 05/06/2015 | 15:13:32 | 6.0524   | 116.6861  | ML 4.7    | mbtmp 4.1 | Ms 3.1 | 0.0   |
| 6         | 12050340   | 06/06/2015 | 23:15:43 | 5.0398   | 117.1911  | ML 4.4    | mbtmp 4.1 | Ms 3.1 | 0.0   |
| 7         | 12068968   | 12/06/2015 | 18:25:34 | 6.0858   | 117.3888  | ML 4.1    | mbtmp 4.1 | Ms 3.1 | 0.0   |
| 8         | 12068970   | 12/06/2015 | 18:29:24 | 6.0878   | 116.8661  | mb 3.4    | mbtmp 4.1 | Ms 3.1 | 0.0   |
| 9         | 12098997   | 23/06/2015 | 09:32:34 | 6.0858   | 117.3888  | MB 4.1    | mbtmp 4.1 | Ms 3.1 | 0.0   |
| 10        | 12199515   | 26/07/2015 | 10:04:19 | 6.2731   | 117.0466  | mb 3.9    | mbtmp 4.1 | Ms 3.9 | 0.0   |

Figure 5 (a) and (b) show the snapshot of process of locating the origin location (epicenter) of 2 seismic events recorded by the CTBT IMS network. These epicenters of selected earthquakes are one of the seismic event parameters obtained from the Geotool-analysis performed in this study. Snapshot of seismic waveform analysis using Geotool software for both events are also shown in Figure 6. Figure 7 shows the epicenter of all 16 events recorded in East Malaysia by the CTBT IMS network for the period of this study. This map was tabulated based on the seismicity parameters determined from our waveform analysis.

The year of 2015 has recorded the highest number of earthquake occurrence in East Malaysia throughout the study period. The earthquake event recorded by the IMS network on June 4, 2015 23:15:43 UTC (Event ID 12047012) is consistent with the Ranau’s moderate earthquake on June 5, 2015 7:15 am local time as reported by the MMD. The MMD reported that the epicenter of this earthquake was located at 16 km northwest from Ranau with the depth of 54 km beneath the earth. Figure 8 shows the news clip reported the earthquake that shook Kota Kinabalu and other parts of Sabah’s west coast on June 5, 2015 after an earlier magnitude 5.9 earthquake hit near Ranau district [9].

In the next step, in order to compare those earthquakes recorded by the CTBT IMS network with other global networks, we compiled all the seismic events by the USGS and IRIS networks recorded in Malaysia for the same study period. Both the earthquake catalogs of USGS and IRIS reported in total 12 earthquakes were taking place in East Malaysia, slightly lower than the number of earthquakes recorded by the CTBT IMS network. Furthermore, similar with the CTBT IMS, there was no seismic event recorded took place in Peninsula Malaysia by both the USGS and IRIS networks. Table 2 and 3 show the list of earthquake events including its seismic parameters recorded and reported by the USGS and IRIS.
Figure 5 (a). Epicenter location of June 4, 2015 earthquake in East Malaysia using IMS data.

Figure 5 (b). Epicenter location of March 8, 2018 earthquake in East Malaysia using IMS data.
Table 2. 2015-2018 earthquake events in East Malaysia recorded by the USGS network.

| Year 2018 | Date     | Time   | Latitude | Longitude | Magnitude | Depth |
|-----------|----------|--------|----------|-----------|-----------|-------|
| 1         | 08/03/2018 | 13:06:13 | 6.0674   | 116.6109  | mb 5.2    | 10    |
| 2         | 08/03/2018 | 14:53:26 | 6.106    | 116.554   | mb 3.2    | 5     |

| Year 2017 | Date     | Time   | Latitude | Longitude | Magnitude | Depth |
|-----------|----------|--------|----------|-----------|-----------|-------|
| 1         | 26/03/2017 | 9:30:48 | 4.9334   | 118.7791  | mb 4.6    | 33.96 |

| Year 2016 | Date     | Time   | Latitude | Longitude | Magnitude | Depth |
|-----------|----------|--------|----------|-----------|-----------|-------|
| 1         | 04/03/2016 | 0:43:36 | 4.9182   | 118.4359  | mb 4.1    | 34.96 |

| Year 2015 | Date     | Time   | Latitude | Longitude | Magnitude | Depth |
|-----------|----------|--------|----------|-----------|-----------|-------|
| 1         | 19/03/2015 | 21:56:07 | 5.5346   | 118.6135  | mb 4.1    | 50.77 |
| 2         | 04/06/2015 | 23:15:44 | 5.9867   | 116.5409  | mww 6     | 10    |
| 3         | 05/06/2015 | 15:13:36 | 6.1402   | 116.7228  | mb 4.4    | 18.23 |
| 4         | 06/06/2015 | 5:45:15  | 6.1416   | 116.6689  | mb 4.6    | 10    |
| 5         | 12/06/2015 | 18:25:37 | 6.1504   | 116.692   | mb 4.4    | 15.01 |
| 6         | 12/06/2015 | 18:29:16 | 6.2053   | 116.6814  | mb 5.3    | 7.25  |
| 7         | 23/06/2015 | 9:32:31  | 6.1277   | 116.5537  | mb 4.5    | 15.32 |
| 8         | 26/07/2015 | 16:10:12 | 6.2782   | 116.8568  | mb 4.6    | 14.96 |

Table 3. 2015-2018 Earthquake events in East Malaysia recorded by the IRIS network.

| Year 2018 | Date     | Time   | Latitude | Longitude | Magnitude | Depth |
|-----------|----------|--------|----------|-----------|-----------|-------|
| 1         | 08/03/2018 | 13:06:13 | 6.04     | 116.61    | mb 5.2    | 10    |

| Year 2017 | Date     | Time   | Latitude | Longitude | Magnitude | Depth |
|-----------|----------|--------|----------|-----------|-----------|-------|
| 1         | 26/03/2017 | 9:30:48 | 4.93     | 118.78    | mb 4.6    | 33.96 |

| Year 2016 | Date     | Time   | Latitude | Longitude | Magnitude | Depth |
|-----------|----------|--------|----------|-----------|-----------|-------|
| 1         | 04/03/2016 | 0:43:35 | 4.92     | 118.44    | mb 4.1    | 34.96 |

| Year 2015 | Date     | Time   | Latitude | Longitude | Magnitude | Depth |
|-----------|----------|--------|----------|-----------|-----------|-------|
| 1         | 19/03/2015 | 21:56:04 | 5.6182   | 118.6962  | mb 4.1    | 35    |
| 2         | 04/06/2015 | 23:15:45 | 6.0439   | 116.6651  | Mw 6.0    | 18.1  |
| 3         | 05/06/2015 | 13:12:16 | 6.2967   | 116.6288  | mww 6.0   | 10    |
| 4         | 05/06/2015 | 15:13:35 | 6.2153   | 116.8726  | mb 4.4    | 10    |
| 5         | 06/06/2015 | 5:45:15  | 6.188    | 116.7836  | mb 4.6    | 10    |
| 6         | 12/06/2015 | 18:25:39 | 6.039    | 116.5783  | mb 4.4    | 35    |
| 7         | 12/06/2015 | 18:29:18 | 6.0674   | 116.621   | Mw 5.2    | 28.3  |
| 8         | 23/06/2015 | 9:32:33  | 6.0491   | 116.5472  | mb 4.5    | 35    |
| 9         | 26/07/2015 | 16:10:11 | 6.0664   | 116.8082  | mb 4.6    | 10    |

Again, by taking Ranau’s June 5, 2015 earthquake as an example, the parameters of seismic event detected by USGS and IRIS networks in East Malaysia on this date are also identical to the one recorded by the CTBT IMS network, as initially described above. Table 4 shows the deviation of epicenters of all earthquake events (2015 – 2018) in Sabah recorded by the USGS and IRIS networks relative to the epicenter located by the CTBT IMS detection. This deviation could be due to different number of stations used by global seismic network in locating such earthquakes in Sabah. This also owe to the fact that the more stations reporting the more accurate the epicenter location [10]. Other factor that affected the accuracy of epicenter location includes the phases used to locate the event, station distribution, and largest and secondary azimuthal gap.

Figure 9 shows a map that plots 3 three different locations of epicenter of Ranau’s June 5, 2015 earthquake calculated by the USGS and IRIS respective data as relative to the epicenter calculated by the CTBT IMS Network.
Table 4. The deviation of epicenters of all earthquake events (2015 – 2018) in East Malaysia recorded by the USGS and IRIS networks as relative to the epicenter defined by the CTBT IMS detection.

| IMS    | Year  | 2015 |        |        |        | 2016 |        |        |        | 2017 |        |        | 2018 |        |
|--------|-------|------|--------|--------|--------|------|--------|--------|--------|------|--------|--------|------|--------|
|        | No.   | 1    | 2      | 3      | 4      | 5    | 6      | 7      | 8      | 9    | 10     | 1      | 2    | 3      |
| USGS   |        | √    | √      | √      | √      | √    | √      | √      | √      | √    | √      | √      | √    | √      |
| IRIS   |        | √    | √      | √      | √      | √    | √      | √      | √      | √    | √      | √      | √    | √      |
| Deviation of epicenter relative to IMS (USGS) | Straight Length (KM) | 26.98 | 11.87  | 12.06  | 24.85  | 81.7 | 24.48  | 19.21  | 20.94  | 16.41 | 23.47  |
|        | Heading (degrees) | 75.48 | 243.4  | 19.34  | 241.3  | 250.9 | 304.3  | 358.4  | 273.5  | 19.97 | 14.58  |
| Deviation of epicenter relative to IMS (IRIS) | Straight Length (KM) | 3.24  | 71.63  | 28.08  | 11.45  | 98.02 | 27.12  | 9.8    | 34.22  | 16.12 | 19.84  |
|        | Heading (degrees) | 70.64 | 240    | 45.39  | 233.2  | 246.1 | 267.3  | 352.1  | 229.7  | 20.5  | 26.34  |

Figure 6. Snapshot of seismic waveform analysis using Geotool software.
Figure 7. The epicenters of all 16 events recorded in East Malaysia by the CTBT IMS from 2015 – 2018.

Figure 8. News clip reported the earthquake that shook Kota Kinabalu and other parts of Sabah’s west coast on June 5, 2015.
Figure 9. A Map plotting 3 three different locations of epicenter of Ranau’s June 5, 2015 earthquake calculated by the USGS and IRIS as relative to the epicenter calculated by the CTBT IMS network.

4. Conclusion
During the period of 2015-2018, the IMS network had detected 16 earthquakes in East Malaysia. From our comparison between IMS, USGS and IRIS, we found that there was slight deviation at detection in terms of epicenter location. This deviation is due to several factors including the number of stations used for locating seismic event.

This study also demonstrates that other than for nuclear explosion monitoring, the IMS data can also be used for civil and scientific applications and can make significant contribution in seismological research.

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