Operational Procedures of Agencies Contributing to the ISC

China Earthquake Administration: Chinese Seismic Network

Guanghui Dai and Yanru An

China Earthquake Networks Center (CENC)

China Earthquake Administration (CEA), Beijing

China

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Operational Procedures of Contributing Agencies

5.1 China Earthquake Administration: Chinese Seismic Network

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China Earthquake Networks Center (CENC), China Earthquake Administration (CEA), Beijing, China

Guanghui Dai

Yanru An

The State Seismological Bureau (SSB) was established in China in 1971 and renamed China Earthquake Administration (CEA) in 1998. In 2018, the Ministry of Emergency Management of the People's Republic of China (PRC) was put in charge of CEA. As a government agency, CEA is mandated by the Law of the PRC on Protecting Against and Mitigating Earthquake Disasters to enforce earthquake administration in China. During the past 50 years, CEA has made great efforts on the construction of the Chinese Seismic Network (CSN) and on earthquake research to minimize earthquake disasters. In 2004, CEA authorized the China Earthquake Networks Center (CENC) to take charge of the CSN and earthquake monitoring. To meet the requirements of public concern and scientific research, CENC releases rapid earthquake notifications, archives seismic waveforms, provides seismic catalogues and phase reports. CENC provides data from 34 stations to the ISC (agency code BJI) on behalf of CEA.

5.1.1 Seismicity and Seismic Hazard

China and adjacent regions frequently suffer from severe earthquake disasters. As seen in Figure 5.1, strong earthquakes are prone to occur in the western part of the mainland, where the main driving force of tectonic deformation comes from the collision of the Indian and the Eurasian plates forming the Tibetan Plateau (*Zhang*, 2008). Another seismically active area is the Taiwan region which is located at the boundary between the Philippine Sea Plate to the East and the Eurasian Plate to the West.

Figure 5.1: *Epicentre distribution of earthquakes with* $M \geq 5.0$ *in China and the border area from 1970 to 2019.*

Since the PRC was founded in 1949 it has been hit by several strong earthquakes, including the Tangshan 7.8 earthquake in 1976, the Jiji 7.6 earthquake in 1999, the Wenchuan 8.0 earthquake in 2008, the Yushu 7.1 earthquake in 2010, the Lushan 7.0 earthquake in 2013 and the Jiuzhaigou 7.0 earthquake in 2017. Huge casualties resulted from these events, as the Tangshan earthquake killed more than 240,000 people, and the Wenchuan earthquake led to nearly 70,000 deaths and 18,000 missing.

5.1.2 History and Outlook of CSN

In the 1950s, the first Chinese analogue seismic network consisting of 20 stations in the northern region was established by the Institute of Geophysics, Chinese Academy of Sciences, the predecessor of the Institute of Geophysics, SSB. With the data from this seismic network, moderate and strong earthquakes could be observed. Then in 1966, the first telemetric seismic network was constructed with 8 stations around Beijing and the station number was expanded to 21 after the Haicheng earthquake in 1975 (*Sun and Wu*, 2007). Since the establishment of SSB in 1971, the network construction, instrument design and production and data processing software have been greatly improved. From the 1980s, most seismic stations were equipped with domestic equipment and the data was transmitted by telemetry.

However, during the Tangshan earthquake in 1976, many stations were damaged due to the short epicentral distance, as a result the hypocentre location and magnitude could not be rapidly measured at the time. Therefore, in order to cope with these huge earthquakes, establishing a dense network throughout China has become an important task of SSB. With the funding of the Chinese government, more regional networks were established, and accelerometers were also installed besides the seismometers at some stations. Through China-U.S. cooperation, 11 stations of the China Digital Seismograph Network (CDSN) were deployed between 1983 and 1987. After about 20 years of development, the seismic observation technology and seismic network construction of CSN completed a comprehensive transformation from analogue to digital in the 2000s. Meanwhile, with the innovation and improvement of transmission technology, the data transmission method gradually shifted to satellite transmission, and nowadays depends on the IP network. In the year of 2007, 1021 seismographic stations distributed over 31 provinces realized real-time transmission to CENC. Based on the evolving network, CENC and 31 provincial centres coordinate to monitor seismic activities in China and strong earthquakes worldwide.

When the Wenchuan earthquake occurred in 2008, it took only 12 minutes to release the rapid earthquake notification which is an important reference for earthquake emergency rescue. However, CEA was still unable to prevent huge casualties and decided to explore earthquake early warning and intensity rapid notification. Finally, in the year of 2018, the implementation of the National Earthquake Intensity Rapid notification and Early Warning Project began, and CENC was appointed as the legal entity by CEA. It is estimated that by 2022, the CSN will have 15,391 stations (Figure 5.2), including 1,928 seismographic stations, 3114 strong motion stations and 10349 intensity instrument stations with the aim of saving more lives in earthquake disasters.

The chronological list below summarises the development of CSN.

1950s	The first analogue seismic network consisting of 20 stations equipped with 51 seismometers in northern China was established to monitor moderate and strong earthquakes.
Early 1960s	The elementary seismic network with 12 stations equipped with SK seismometers all over China was built, and the station number was increased to 26 in the mid to late 1960s.
1966	The first telemetric seismic network consisting of 8 stations around Beijing was constructed after the occurrence of Xingtai 7.2 earthquake, and the station number was expanded to 21 after the Haicheng 7.3 earthquake in 1975.
1980s	The elementary seismic network was renewed, and the station number was expanded to 86, including 27 class I stations mainly equipped with SK or DK-1 seismometers and 59 class II stations mainly equipped with DD-1 seismometers.
1982-1985	Another 5 telemetric regional seismic networks were built.
1985-1995	More than 10 wireless-transferred local seismic networks were built.
1983-1987	Through China-U.S. cooperation, 11 stations of the China Digital Seismograph Network (CDSN) were deployed.
1996-2000	The elementary seismic network and 21 provincial seismic networks were undergoing digital transformation. The basic seismic network was renamed the National Digital

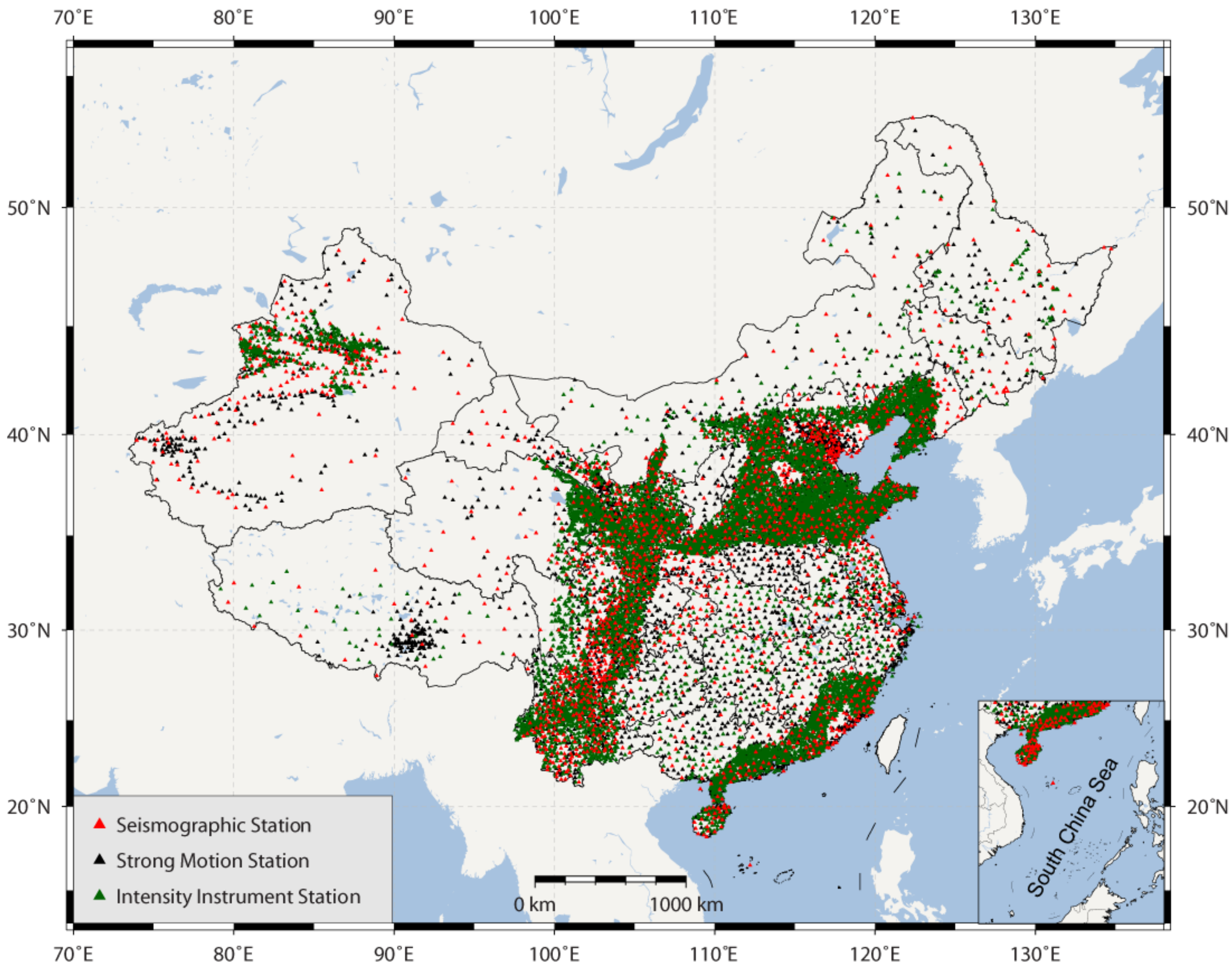

Figure 5.2: *Outlook of CSN in 2022.*

Seismic Network, of which 48 digital stations were equipped with broadband or ultra-broadband seismometers and 24-bit data acquisition units. The data was transmitted to the network centre via satellite.

1998-2001 The Capital Area Seismic Network of 107 stations was built, including broadband seismometers or borehole short period seismometers and 24-bit data acquisition units. Data is transmitted to the network centre through a DDN network.

2001-2007 1025 seismographic stations were updated or newly built. The data is transferred in real-time through the IP network. 148 national stations were equipped with ultra-broadband seismometers and 2g accelerometers, while 821 regional stations, 33 volcanic stations and 19 small aperture array stations were installed, mainly with broadband seismometers.

1154 free-field strong motion stations were newly built or updated, and 2g accelerometers and 12 structural seismic response observation arrays were installed. The stored event data was transmitted in non-real time through telephone lines.

A working system coordinated by CENC, 31 provincial centres and 107 national stations was established.

2011-2016	Very-broadband seismometers were installed in 18 national seismic stations, and broadband seismometers were installed in 68 regional seismic stations. 76 non-real-time strong motion stations and 160 real-time stations with 2g accelerometers were built.
2015-2018	1010 intensity instrument stations were built to carry out rapid intensity reports and earthquake early warning tests.
2018-2022	15391 stations are being upgraded or newly built for the project of rapid intensity reports and earthquake early warning, including 1928 seismographic stations, 3114 strong motion stations, and 10349 intensity instrument stations.

5.1.3 Current Status

The CSN is composed of the seismographic network, the strong motion network and the intensity instrument network, with 4082 stations in total (Figure 5.3). The seismographic network is distributed all over mainland China, while the other two networks are located around earthquake hazard zones. All stations are maintained by the 31 provincial centres in their jurisdiction under the management of CENC.

The Seismographic Network

The seismographic network has 1107 seismographic stations, including 166 national stations and 941 regional stations (Figure 5.4). National stations are mainly equipped with 120 s ultra-broadband seismometers (some stations with 360 s very-broadband seismometers) which are used to monitor global seismicity. Regional stations are mainly installed with 60s broadband seismometers for monitoring regional seismic activities. The density of stations in different regions is related to the degree of economic development and population density, so station distribution in eastern China is denser than in the west.

The real-time waveform data with a sampling rate of 100 Hz is transmitted to CENC via the provincial centres through a SDH network. At the same time, each provincial network centre receives waveform data from neighbouring provinces from CENC.

The Strong Motion Network

The strong motion network consists of 1965 strong motion stations with accelerometers (2g) installed to monitor the acceleration in the near field and serve for the estimation of intensity and engineering seismology (Figure 5.5). After an earthquake has occurred event waveform data sampled at 200 Hz for all the stations is stored in the data acquisition unit and then collected through a dedicated telephone line. Only 393 sites transmit the real-time data with a sampling rate of 100 Hz via the provincial network centre to CENC. Meanwhile, the real-time data is shared with the neighbouring provincial centres. Next year, about 786 non-real-time sites will be upgraded to real-time mode.

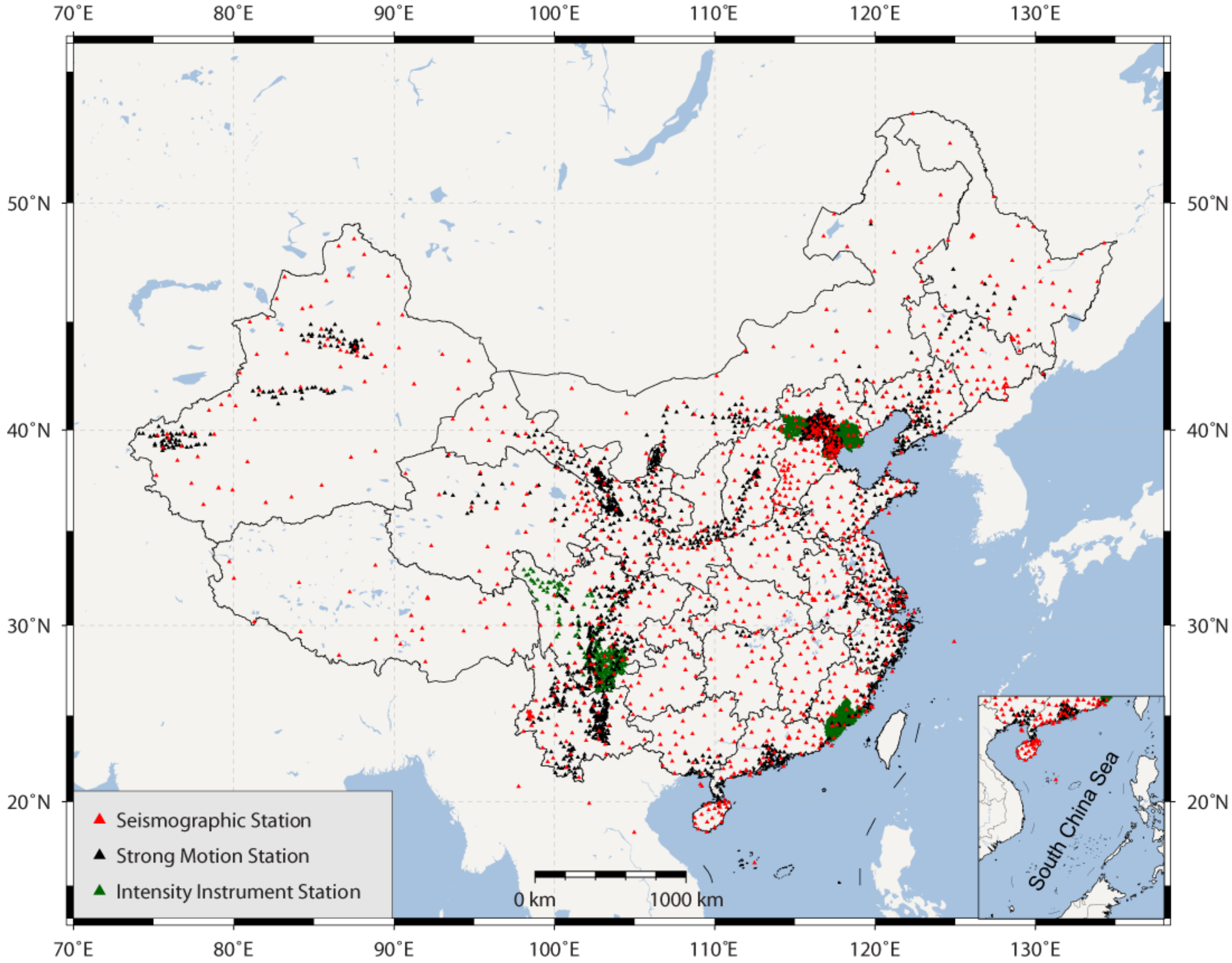

Figure 5.3: *Current status of CSN*

The Intensity Instrument Network

The intensity instrument network is composed of 1010 stations equipped with intensity meters. These stations are distributed in parts of six provinces, Beijing, Tianjin, Hebei, Sichuan, Yunnan and Fujiang (Figure 5.6). Combined with seismographic stations and strong motion stations, the intensity instrument stations are used for the rapid intensity reports and earthquake early warning testing. The continuous waveform with a sampling rate of 100Hz is transmitted via the provincial network centres in real time to CENC, and shared by the adjacent provincial centres.

Data Sharing With Other Organisations

To improve the capacity of monitoring strong earthquakes in China's border areas and worldwide, CENC shares near real-time seismic data from 99 stations from the Global Seismic Network (GSN). In addition, CENC and Korea Meteorological Administration (KMA) both share data from five stations with each other in near real time via the Internet. When a global earthquake above magnitude 5.0 occurs, CENC will send event waveform data from 20 national stations to the IRIS FTP server.

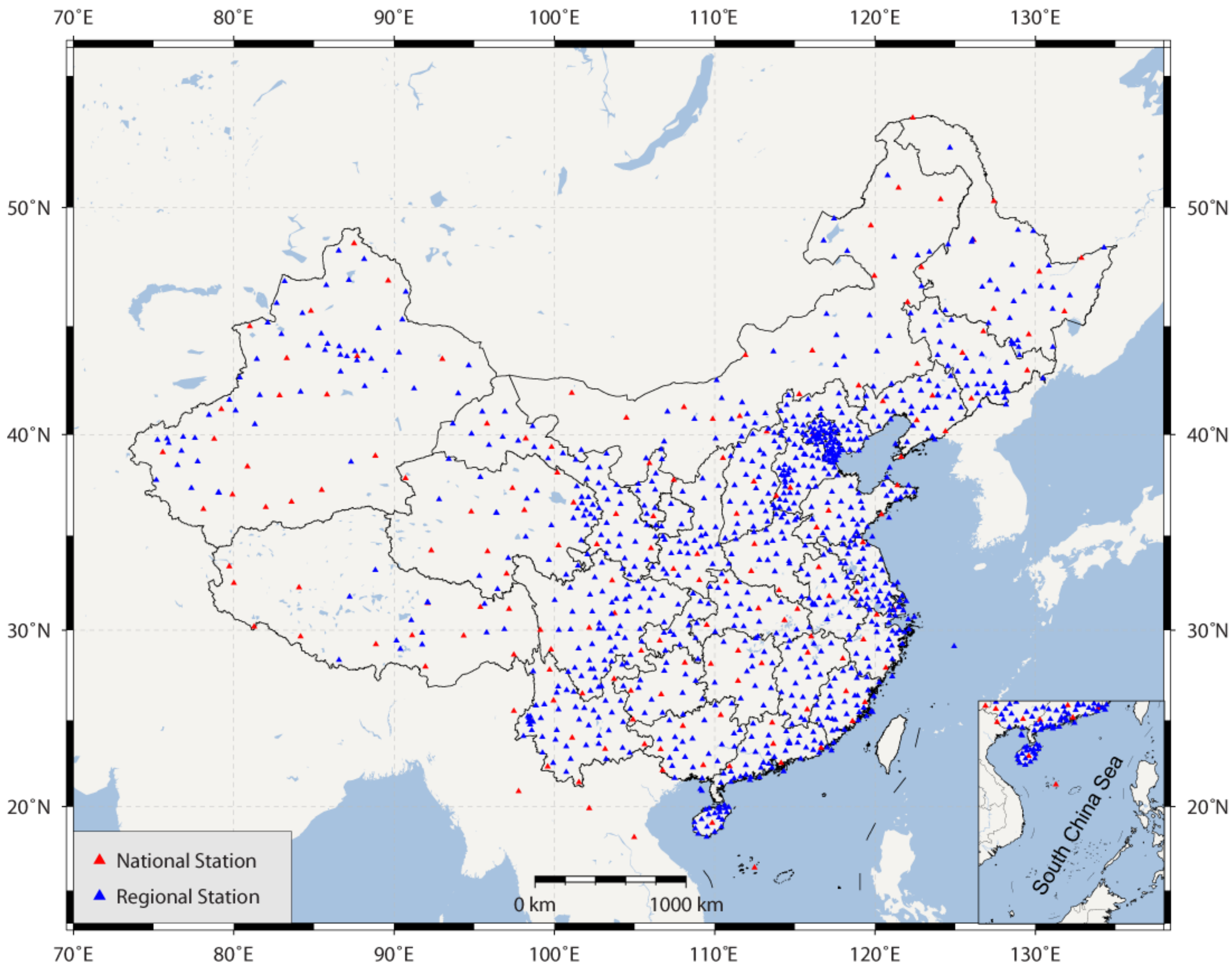

Figure 5.4: *Distribution of the Seismographic Network.*

5.1.4 Routine Data Analysis

In order to meet different requirements, e.g. public concern, rescue, forecast and research, the routine data analysis of CSN is organized in two modes: rapid analysis and precise analysis. The publication timeline is summarised in Table 5.1.

Rapid Analysis

Rapid analysis provides the rapid reports for emergency relief after an earthquake. In order to release information immediately and accurately, the rapid analysis is coordinated by CENC and 31 provincial centres. In the end, CENC releases the rapid reports.

Automatic Processing - Automatic Rapid Report (ARR)

After the Wenchuan 8.0 earthquake, CEA began to implement the automatic processing system. Three automatic systems have been developed successively and have their own specialities in handling small, medium and large earthquakes. Receiving seismic data in real time, the automatic processing systems

Figure 5.5: *Distribution of the Strong Motion Network*

Time after earthquake	**Title**	**Output**
Within 2-3 minutes if in China and adjacent areas, 7-15 minutes if in other regions abroad	Automatic rapid report (ARR)	Earthquake catalogue (Origin time, latitude, longitude, depth, magnitude, event type and place name)
Within 8-15 minutes if in China and adjacent areas, 30 minutes if in other regions abroad	Formal rapid report (FRR)	Earthquake catalogue (Origin time, latitude, longitude, depth, magnitude, event type and place name)
Within 2 days worldwide	Preliminary uniform report (PUR)	Earthquake catalogue and phase report (arrival-time, amplitude, period) of most CSN stations
Within 1 month worldwide	Final uniform report (FUR)	Earthquake catalogue and phase report (arrival-time, amplitude, period) of all CSN stations

Table 5.1: *Publication timeline of routine data analysis.*

Figure 5.6: *Distribution of Intensity Instrument Network*

detect and locate events according to the preset magnitude threshold. In order to reduce the possibility of earthquake mislocation, the results of the three systems are weighted average to produce the ARR. At present, the ARR will be released within 2-3 minutes for events M≥3.0 in China and adjacent area, and within 7-15 minutes for events M≥5.0 in other regions abroad.

Manual Processing - Formal Rapid Report (FRR)

The manual processing system will immediately issue a warning after detecting an event that exceeds the preset trigger threshold. Based on the automatic location result, the staff will check the accuracy of the phase arrival time and reduce the azimuthal gap to get a better location result. Then, more stations are used to calculate the magnitude, and the FRR is prepared to be released.

During this process, the provincial centres are only responsible for handling events in their own provinces and neighbouring areas, while CENC is dealing with global earthquakes and releases FRR final results. All information is shared among the provincial centres and CENC via the exchange platform. For events M≥3.0 in China and surrounding areas, FRR will be released within 8-15 minutes, and for events M≥5.0 in other regions abroad, FRR will be released within 30 minutes.

Precise Analysis

In contrast to the rapid analysis, the precise analysis will take more time but will be more complete and accurate. All the identified seismic events should be located and finally presented in the form of an earthquake catalogue and seismic phase report. Due to the heavy workload, the precise analysis is implemented by CENC, 31 provincial centres and the national stations together. Finally, CENC compiles and publishes the preliminary uniform report daily and the final uniform report monthly. These catalogues and seismic phase reports are widely used for disaster relief, earthquake forecasting and scientific research. In addition, CENC is trying to provide the focal mechanism, Mw, stress drop, Q factor, corner frequency and other additional parameters for events M≥3.0 in China.

Daily Processing - Preliminary Uniform Report (PUR)

Every day, 31 provincial centres analyse the data from all stations in the jurisdiction and neighbouring regions of the previous day, then submit the catalogues and phase reports to CENC. Later, CENC will process all the data to form the PUR. For this CENC will relocate events M≥4.0 in China and M≥5.0 worldwide as well as merge the provincial results for events M<4.0 in China. If the catalogues from two or more provinces are significantly different for the same event, CENC will relocate it and confirm the final results. The PUR is to give earthquake forecasters and scientific researchers a quick and precise result for analysing the development trend of earthquakes. It is possible that not all events and phases are included in PUR, especially for some events that are too small to be analysed.

Monthly Processing - Final Uniform Report (FUR)

As the final bulletin, the FUR is widely used in earthquake forecasting and scientific research. It lags one month behind real-time and is jointly accomplished by CENC, 31 provincial centres and 107 manned national stations. For global events M≥4.0 the period, amplitude and arrival time of all identifiable phases recorded by national stations are sent to CENC weekly. Then, CENC will associate these phases to locate events and generate the national network bulletin including the magnitude types M_L, M_S, M_{S7}, m_B and m_b. On the basis of the PUR, 31 provincial centres review the continuous waveform again to modify or supplement phases to ensure that all identifiable events are involved accurately, even events recorded by a single station. In the end, CENC compiles results from all sources to output the FUR using the rules similar for the PUR. The earthquake distribution from the FUR of CSN in 2009-2019 is presented in Figure 5.7 which is showing that the majority of the Earth's earthquakes occur along plate boundaries.

5.1.5 Methodology

Determination of Hypocentres

A hypocentre is constrained by the arrival-time of P phase and S phase. In order to determine the accurate location, data from any station with a large arrival time residual will not be used for calculation. For deep focus earthquakes, the depth phases, such as pP and sP will be taken into account in determining

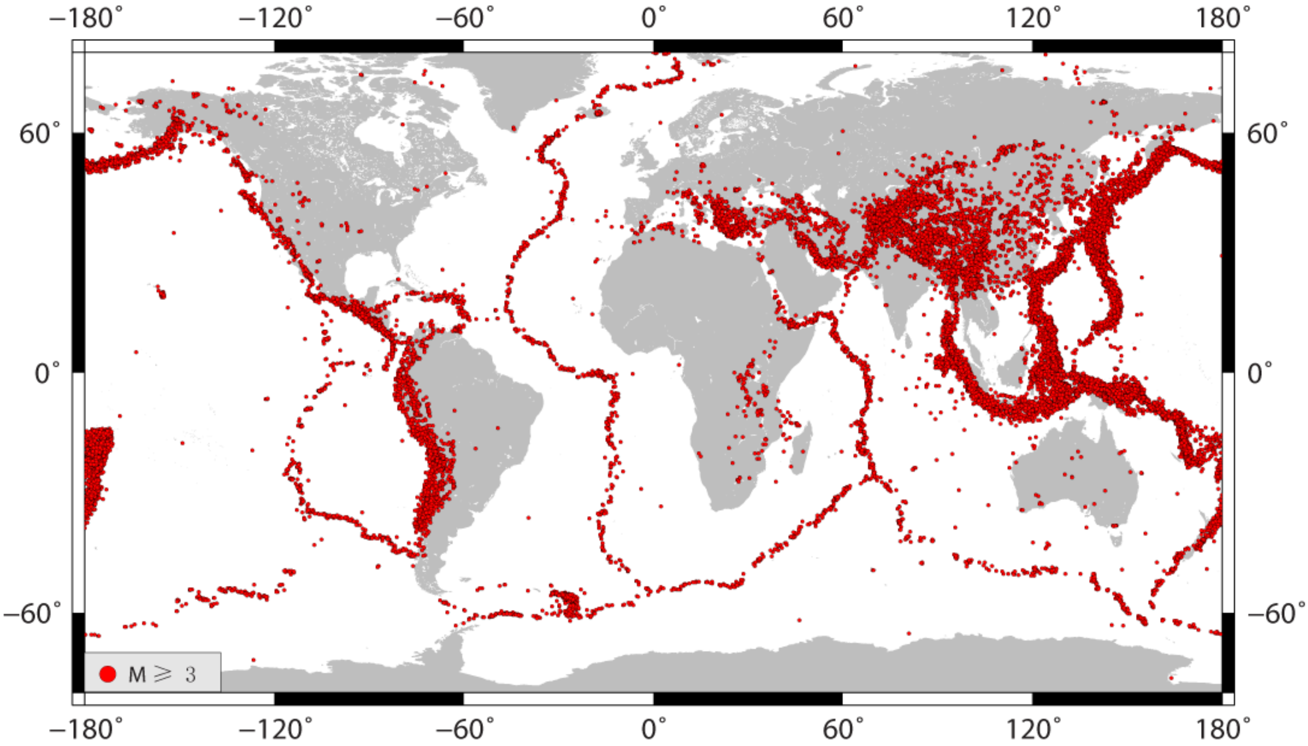

Figure 5.7: *Earthquake distribution from FUR of CSN in 2009-2019.*

the focal depth.

Different centres are using different location methods. In CENC, a self-made gird search method is used in FRR and PUR, and the Geiger's method (*Geiger*, 1910; *Bormann*, 2012) is used in FUR. In the provincial centres, there are several methods to be used in different situations. For example, the simplex algorithm (*Nelder and Mead*, 1965) is always used for locating shallow earthquakes, while the Hyposat algorithm (*Schweitzer*, 2001) is used for the moderate-deep focal earthquakes and the Locsat algorithm (*Bratt and Bache*, 1988) for earthquakes that occurred on the brim or outside of the network. Similarly, the choices of velocity models are also different. In CENC, AK135 and IASP91 models are used for FRR, PUR and FUR, while each provincial centres are using regional models.

Calculation of Magnitudes

In the provincial centres, M_L, M_S and m_b are calculated. In CENC M_L, M_S and m_b are determined for FRR and PUR, and all magnitudes(M_L, M_S, M_{S7}, m_b and m_B) are presented in FUR. Each type of magnitude is the mean of the magnitudes of all the stations involved in the calculation.

M_L

For local and regional earthquakes the magnitude M_L is given according to the following formula (*Bormann et al.*, 2007)

$$M_L = \log A_\mu + R(\Delta) \qquad \text{for } 0 \text{ km} < \Delta < 1000 \text{ km},$$

where A_μ is the arithmetical mean value of the maximum S-wave amplitude of two horizontal components in µm. $R(\Delta)$ is the calibration function of epicentral distance. The broadband velocity record should be simulated to the short period displacement record of a DD-1 or WA seismometer before the magnitude is calculated.

M_S and M_{S7}

For regional and remote earthquakes, magnitude M_S and M_{S7} are given according to the following formulas (*Bormann et al.*, 2007)

$$M_S = \log\left(\frac{A}{T}\right)_{max} + 1.66\log(\Delta) + 3.5 \qquad \text{for } 1^\circ < \Delta < 130^\circ,$$

where A is the vector average of maximum displacement of surface wave of two horizontal components in µm, T is the period in seconds and Δ is the epicentral distance in degrees. The broadband velocity record should be simulated to the medium long period displacement record of a SK seismometer before the magnitude is calculated.

$$M_{S7} = \log\left(\frac{A}{T}\right)_{max} + \delta_{763}(\Delta) \qquad \text{for } 3^\circ < \Delta < 177^\circ,$$

where A is the maximum displacement of surface wave of the vertical component in µm, T is the corresponding period of the maximum displacement in seconds, and $\delta_{763}(\Delta)$ is the calibration function of epicentral distance. The broadband velocity record should be simulated to the long period displacement record of a model 763 seismometer before the magnitude is calculated.

m_B and m_b

For all earthquakes, magnitudes m_B and m_b are given according to the following formula (*Bormann et al.*, 2007)

$$m_B \text{ or } m_b = \log\left(\frac{A}{T}\right)_{max} + Q(\Delta, h),$$

where A is the maximum displacement of the P wave of the vertical components in µm, T is the corresponding period of maximum displacement in seconds and $Q(\Delta, h)$ is the calibration function of epicentral distance and focal depth.

For m_b it should be noted that the broadband velocity record must be simulated to the short period displacement record of a DD-1 or WA seismometer and the maximum displacement should be measured within 5 seconds after the P wave arrival. For m_B the broadband velocity record should be simulated to the medium long period displacement record of a SK seismometer and the maximum displacement should be measured within 20 seconds (for large earthquakes it should be extended to 60 seconds) after the P wave arrival.

5.1.6 Data Availability

All the output of CSN is to serve the public, government and scientific research. Therefore, there are many convenient ways to get the reports and seismic data. After an earthquake has occurred, the ARR and FRR will be quickly released through SMS messages, microblog (`https://weibo.com/ceic?refer_` flag=100808&is_all=1), apps and a data-share website (http://data.earthquake.cn/). When the PUR, FUR and seismic data are ready for publication, they will be available on the same data-share website above. An exciting feature of the current rapid report service is its capability to reach hundreds of millions of users within one minute.

5.1.7 Acknowledgements

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