Operational Procedures of Agencies Contributing to the ISC

Servicio Sismológico Nacional
Mexico

Xyoli Pérez-Campos et al.

Instituto de Geofísica, Universidad Nacional Autónoma de México, Mexico City
Mexico

Excerpt from the
Summary of the Bulletin of the International Seismological Centre:

Xyoli Pérez-Campos et al. (2019), Servicio Sismológico Nacional, Mexico, *Summ. Bull. Internatl. Seismol. Cent.*, July - December 2017, *53*(II), pp. 29–40, https://doi.org/10.31905/SZ7RYBTM.

5

Operational Procedures of Contributing Agencies

5.1 Servicio Sismológico Nacional, Mexico

Xyoli Pérez-Campos, Víctor Hugo Espíndola, Jesús Pérez, Jorge A. Estrada, Caridad Cárdenas Monroy, Betty Zanolli Fabila, Delia Bello, Adriana González-López, Daniel González Ávila, Rafael Maldonado, Edgar Montoya-Quintanar, Reynaldo Vite, Luis D. Martínez, Yi Tan, Iván Rodríguez Rasilla, Miguel Ángel Vela Rosas, José Luis Cruz, Arturo Cárdenas, Fernando Navarro Estrada, Alejandro Hurtado and Antonio de Jesús Mendoza Carvajal

Instituto de Geofísica, Universidad Nacional Autónoma de México, Mexico City, Mexico

Team of the Servicio Sismológico Nacional, Mexico

5.1.1 History

The seismic instrumentation in Mexico started at the end of the 19th century when a Secchi and a Palmieri seismograph were installed in down town Mexico City. In 1903 Mexico participated in the 2nd conference of the International Association of Seismology and committed to the establishment of a national seismic network (*Rubinovich et al.*, 1991). The first network station was installed in Tacubaya, Mexico City; two more were installed in Oaxaca and Mazatlán (Fig. 5.1). The first was the central station which consisted of several Wiechert seismographs and Bosch-Omori pendulums. The other two stations were considered of second order, given the number and sensitivity of the instruments installed, and consisted of a horizontal 200 kg and a vertical 80 kg Wiechert seismograph. The initial plan for the Mexican network consisted of a central station, five first-order stations and 52 second-order stations (*Secretaría de Industria, Comercio y Trabajo*, 1919). By the time the Mexican Servicio Sismológico Nacional (SSN, National Seismological Service) was established in 1910, only the three mentioned stations were operating. In the same year, the Mexican Revolution ignited. Despite this, in the following three years, one more first-order station (Mérida) and three second-order stations (Zacatecas, Guadalajara, Monterrey) were installed (Fig. 5.1). The revolution lasted seven years, during which there were few hiatus on the monitoring activities. After the revolution, only four stations were operational: Tacubaya, Mérida, Mazatlán, Oaxaca (*Secretaría de Industria, Comercio y Trabajo*, 1919). In 1920, one more first-order station was installed in Colima, one second-order station, in Veracruz, and one third-order, in Puebla (Fig. 5.1). By 1925, the network consisted of seven stations distributed mainly in central and southern Mexico. By the end of the 1920s, two more stations were installed to cover the north of the country, one in Guadalajara, and the other in Chihuahua (Fig. 5.1).

Originally the SSN was under the umbrella of the Instituto Mexicano de Geología (the Mexican Institute of Geology), which was a government organisation. In 1929 the institute, including the SSN, was transferred to the Universidad Nacional Autónoma de México (UNAM, National Autonomous University of Mexico). In 1949, the Instituto de Geofísica (Institute of Geophysics) was founded and received the SSN in 1953, where it has been since then.

The history of the network can be divided into three epochs (*Pacheco*, 2001). The first one is from its beginnings to the late sixties when electromagnetic seismographs were installed. Telemetry started around 1988, 13 stations formed the Conventional Network (Figure 5.1), the instruments consisted of vertical short period seismometers. In the early nineties, the broadband network was born (Figure 5.1), telecommunication was improved and the central Station was modernised. The network was mainly concentrated in central and southern Mexico (Fig. 5.1), until 2006 when the network expanded to the north of the country. Also, by the mid 90's the Seismic Network of the Valley of Mexico was established with eight stations and continued to densify within Mexico City (Fig. 5.1).

5.1.2 Current Network Status

Currently, the SSN operates the National Network, for which the FDSN code is MX. It consists of 63 stations (Fig. 5.2) which include a broadband seismometer (120 s to 50 Hz) and an accelerometer; 43 of those stations also have a GPS/GNSS receiver and plans are to include a GPS/GNSS receiver in most of the stations. More details on the network, stations installation, and noise levels can be found in *Pérez-Campos et al.* (2018).

The SSN also operates and maintains the Valley of Mexico Seismic Network which currently has 34 operating stations (Fig. 5.2). They include a broadband seismometer (30 s to 50 Hz), and an accelerometer. The network has been described by *Quintanar et al.* (2018). Furthermore, SSN also maintains a three-station array at the Tacaná volcano at the border of Mexico and Guatemala.

The SSN also operates a hydroacoustic station (HA06) located at Socorro Island in the Pacific for the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO). This is integrated with three seismic stations within the island. Furthermore, the SSN also operates

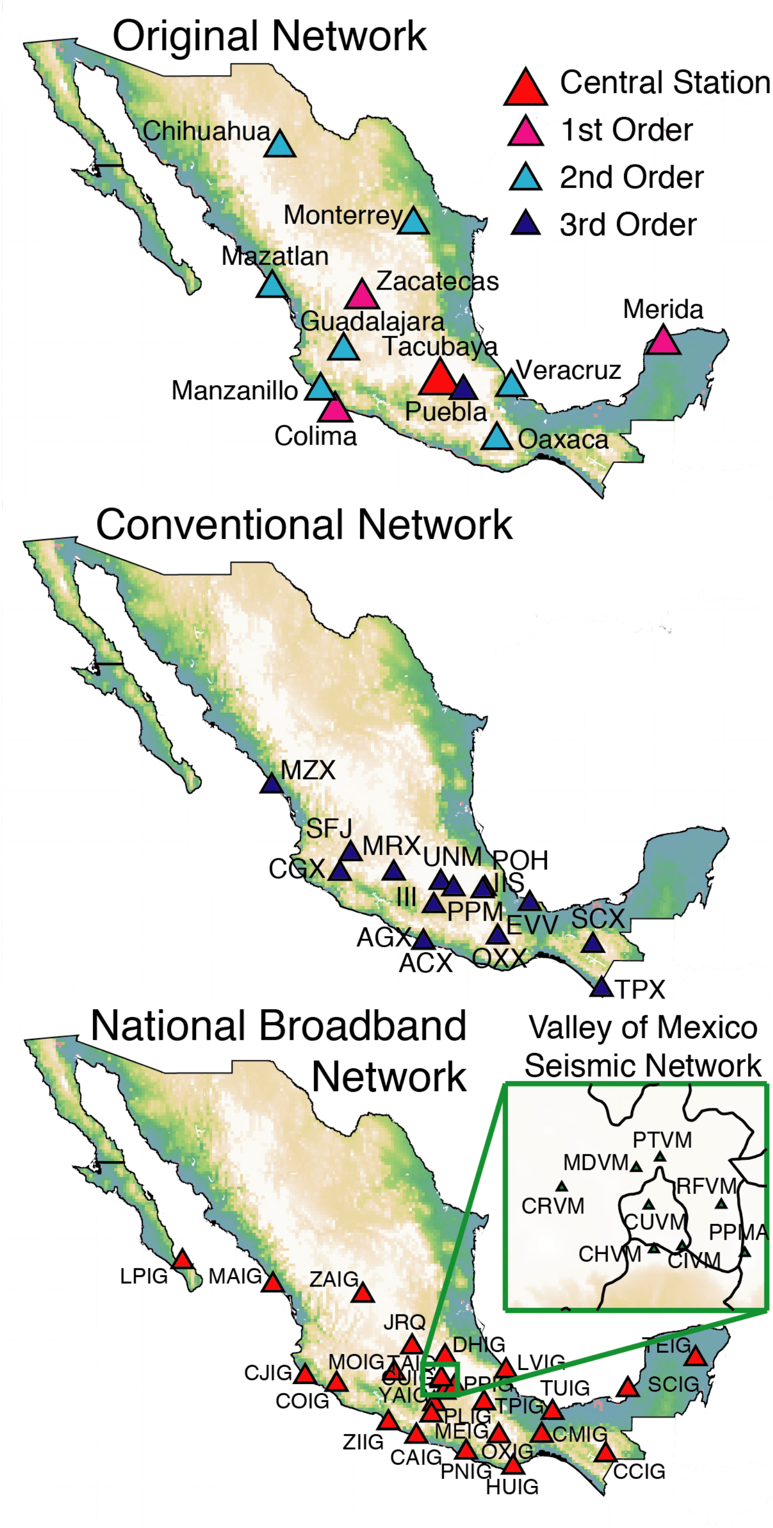

Figure 5.1: *Evolution of the network. Top: Original network, from the beginning of the SSN up to late sixties. Middle: Conventional Network, first time telemetry was implemented in the late eighties. Some stations operated until 2015. Bottom: National Broadband Network. It started with nine stations, the map corresponds to its configuration in 2005.*

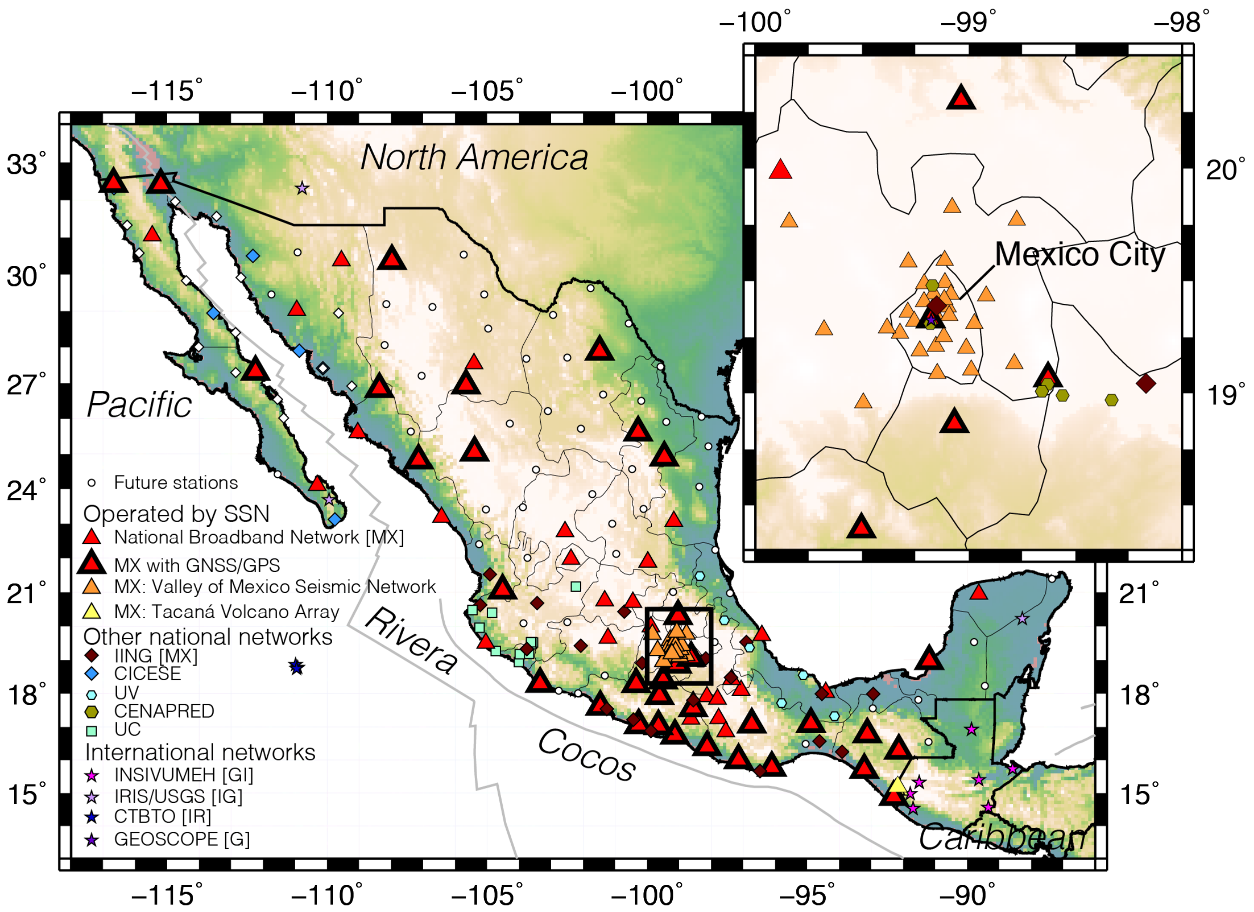

Figure 5.2: *Stations that contribute with data to the location of earthquakes within Mexico. Codes in brackets correspond to network codes in the FDSN.*

a GEOSCOPE station (UNM) located within Mexico City and a Global Seismograph Network station (TEIG) located in the Yucatán peninsula.

Future plans involve the installation of 52 new stations in the country (Fig. 5.2), mainly in those places where the current coverage is limited; this is northern Mexico and the Yucatán peninsula.

5.1.3 Data Exchange with Other Agencies

In order to improve detection and coverage capabilities nationwide, SSN exchanges data with other national and international monitoring agencies. Nationally, it exchanges data with the following institutions (see Fig. 5.2):

1. Instituto de Ingeniería, Universidad Nacional Autónoma de México (IING). The Institute of Engineering operates the largest accelerographic network (`http://aplicaciones.iingen.unam.mx/AcelerogramasRSM/Default.aspx`) in the country and is the institution responsible for generating the intensity maps for the country and for Mexico City. Most of their stations operate in stand-alone mode but twenty-four of them transmit their data in real time and are shared with the SSN. In return, the SSN sends the IING all the data from its accelerometers in the country. This contributes to the real-time national intensity map.

2. Centro de Investigación Científica y de Educación Superior de Ensenada, Baja California (CICESE). This centre operates several seismic and accelerographic networks focused on the northwest side of the county. These networks are described by *Vidal-Villegas et al.* (2018). The SSN receives data from six of its broadband stations and sends back data from 10 stations from its Broadband Network to help with regional monitoring.

3. Universidad Veracruzana (UV). This university installed, in collaboration with the government of the state of Veracruz, the Broadband Seismological Network of Veracruz, which consists of six broadband stations located along the Gulf of Mexico. A description of the network can be found in *Córdoba-Montiel et al.* (2018). The SSN receives data from all the UV stations and sends back data from SSN stations located within the state of Veracruz and in the neighbour states.

4. Centro Nacional de Prevención de Desastres (CENAPRED). The CENAPRED operates three small networks (*Gutiérrez et al.*, 2005). One is a five accelerograph array that serves as an attenuation line from Acapulco, Guerrero, to Mexico City. The second one is an accelerographic network located within Mexico City that consists of 12 stations, some of them are borehole stations. The third network is for monitoring the Popocatépetl volcano (*Guevara et al.*, 2003). Those stations consist of nine seismic stations, which have been recently updated from short period to broadband seismometers. The SSN receive data from two stations within Mexico City and four stations at the Popocatépetl volcano. In turn, the SSN sends the CENAPRED all its data in real time.

5. Universidad de Colima (UC). This university oversees the Colima volcano, and the seismicity in the region. For that purpose, it has the Red Sísmica Telemétrica del Estado de Colima (RESCO, Telemetric Seismic Network of the State of Colima; `https://portal.ucol.mx/cueiv/Sismico.htm`). Such network includes 11 broadband and four short-period stations, plus four acoustic sensors. Furthermore, the UC has a regional network that consists of four broadband and one short-period station. The SSN receive data from 15 broadband stations and in turn, sends data back from six stations in real time.

Internationally, the SSN receives data from 12 stations from the Red Sismológica Nacional (GI) of the Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH) from Guatemala (Figure 5.2) and sends back data from nine stations. For manual processing, the SSN further incorporates data from stations TEIG, TUC and SLBS from network IU (Figure 5.2) using the real-time streaming of the Incorporated Research Institutions of Seismology (IRIS) Data Management Center (DMC), and includes the data from the CTBTO stations at Socorro Island into the analysis. On the other hand, the SSN sends data in real time from seven stations to IRIS-DMC and 11 to the Pacific Tsunami Warning Center.

Moreover, for proper real-time automatic discrimination of regional earthquakes from teleseismic ones, the SSN incorporates the real-time feed from 178 stations of networks GT, II, IU, NU, and US into SeisComP3.

Depth km	Velocity km/s
0.0	6.00
16.0	7.76
33.0	7.95
100.0	8.26
200.0	8.58
413.0	8.97

Table 5.1: *Velocity model for national earthquake location.*

5.1.4 Data Flow

All data from stations described above are received at the central facility in Mexico City. The SSN data is collected with the acquisition software specific for each model of the digitiser and transferred to Earthworm. Data from the other organisations, national and international, are received in real time through the import and seedlink modules of Earthworm. Then the data follows two paths (Fig. 5.3). The first one is via a seedlink protocol to SeisComP3 for the automatic event detection, ending with the publication of the event parameters. These parameters are also fed to a W-phase inversion to estimate the moment magnitude. The second path is for manual processing by the analysts. This is done with SEISAN (*Havskov and Ottemöller*, 1999). The earthquake information is then published on the SSN webpage, the RSS feed and SSN social networks (Twitter, @SismologicoMX and Facebook, /SismologicoMX). It is also sent by e-mail and SMS to selected authorities. Twitter has become the SSN main distribution channel with more than 3.76 million followers.

5.1.5 Data Analysis

Earthquake location is done with HYPOCENTER (*Lienert and Havskov*, 1995) within SEISAN. The velocity model is a modified version of the model of *Jeffreys and Bullen* (1940) to include a mid-crust discontinuity at 16 km depth (Tab. 5.1). Along with the hypocenter location, the SSN reports magnitudes, which are estimated using different methodologies, mainly depending on the earthquake size.

Magnitude Estimation

For earthquakes with magnitudes smaller than 5.2, the SSN gets the following estimates for magnitudes.

$\mathbf{M_A}$ Magnitude estimated from the amplitude of long period waves (15 - 30 s), based on *Singh and Pacheco* (1994):

$$M_A = \frac{1}{1.5}\left[\log_{10}(M_0) - 16.1\right],$$

where $M_0 = \left(\frac{A}{A_0}\right) \times 10^{23}$ dyn-cm, and $A = \sqrt{A_E^2 + A_N^2 + A_Z^2}$, where A_Z, A_N, A_E are the maximum amplitudes in m/s measured on vertical, north-south, and east-west components, respectively; and A_0 is the theoretical amplitude given a theoretical attenuation curve.

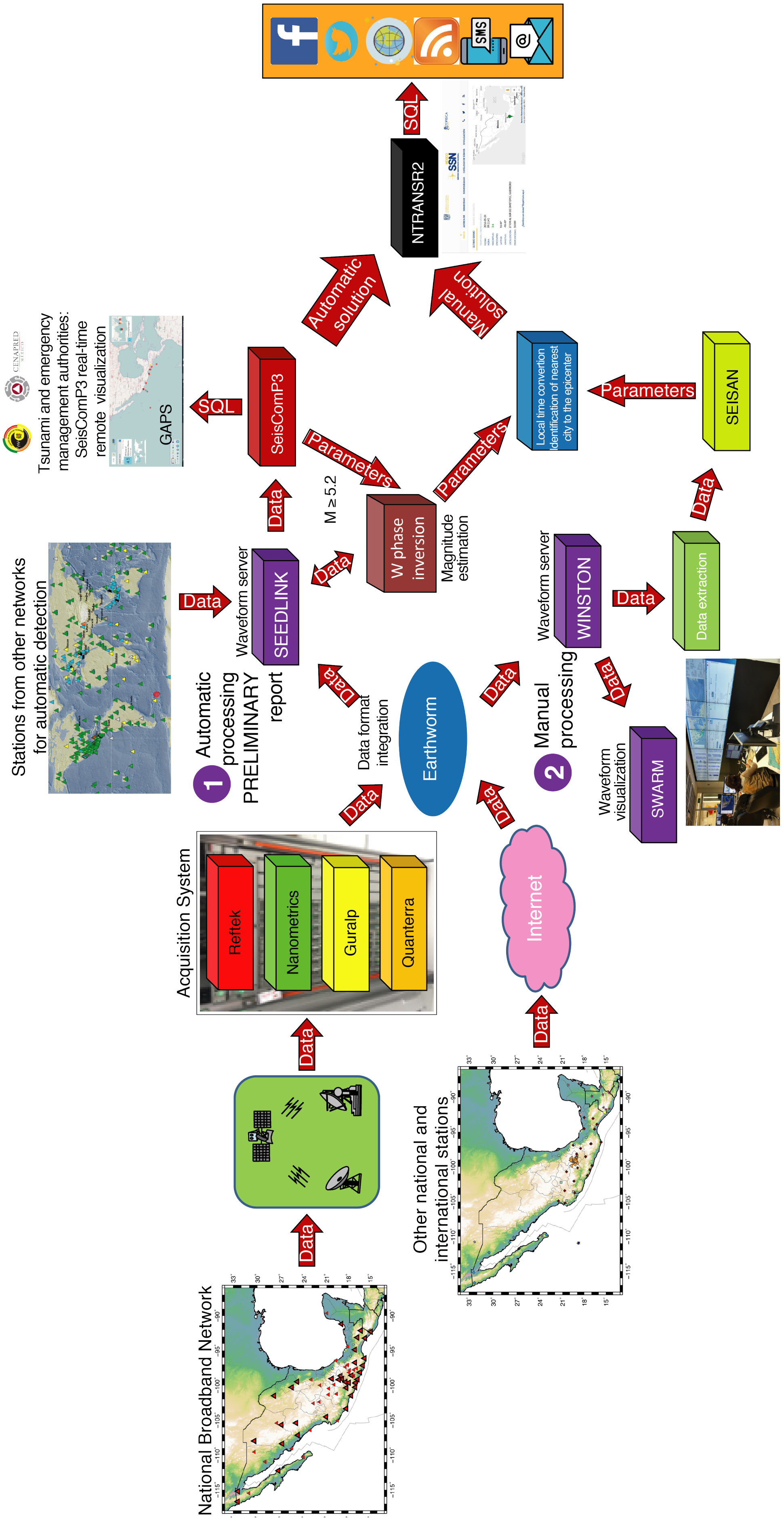

Figure 5.3: Data flow, from the stations to the public.

M_E Energy magnitude estimated following *Singh and Pacheco* (1994):

$$M_E = \frac{2}{3}\log_{10}(E_S) - 8.45,$$

where E_S is the seismic energy estimated, following *Singh and Ordaz* (1994), from the record of station CUIG located a few meters away from the SSN monitoring center.

M_A and M_E are single-station estimates. *Singh and Pacheco* (1994) only calibrated them for subduction earthquakes recorded at station CUIG. Given the close distance of this station to the SSN monitoring center these magnitudes represent a backup estimate in the event of losing communication with the network since data can be accessed manually.

M_C Coda duration magnitude calibrated by Jens Havskov in 1979 during a research visit to the Institute of Geophysics and the SSN:

$$M_C = 0.09 + 1.85\log_{10}(T) - 0.0004(D),$$

where T is the coda duration in seconds from the P wave onset and D is the epicentral distance in km. This magnitude has been reported by the SSN since 1986. This is the preferred magnitude for small earthquakes.

M_{w1} Amplitude magnitude calibrated with moment magnitude. It only uses stations that have STS-2, Trillium 120 and Trillium 240 seismometers. The methodology and calibration was reported by *Espíndola Castro and Valdés González* (2011). The expression is:

$$\log_{10}(M_{w1}) = -0.01295 + 0.0719\log_{10}(A_{max}) + 0.1543\log_{10}(D),$$

where A_{max} is the maximum amplitude of the record in counts measured from zero to peak and D is the hypocentral distance in km. The SSN has reported this magnitude since 2012 and it is the preferred value for earthquakes with magnitude above 4.0 but below 5.2.

For earthquakes larger than 5.2, the SSN estimates the moment magnitude M_w from a regional W-phase inversion (*Kanamori and Rivera*, 2008; *Hayes et al.*, 2009; *Duputel et al.*, 2012). This was implemented in real time in 2014. Also, the SSN estimates M_w from an inversion scheme that follows the procedure by *Dreger* (2003) and uses regional Green's functions and regional data.

Catalogue

Despite the first monthly seismic bulletin being from 1917, the information of the bulletins has not been incorporated in the current online catalogue yet (`http://www2.ssn.unam.mx:8080/catalogo/`). This is an ongoing task. Locations of earthquakes from 1900 to 1974 were taken from a compilation made by *Kostoglodov and Pacheco* (1999) based on various studies for such earthquakes. The instrumental history, network coverage and the processing capabilities are reflected in the catalogue. Figures 5.4a-d show some of these effects with four maps with the minimum magnitude reported by the SSN within 10x10 km^2 cells. Figure 5.4e shows the minimum magnitude reported in the whole catalogue which is

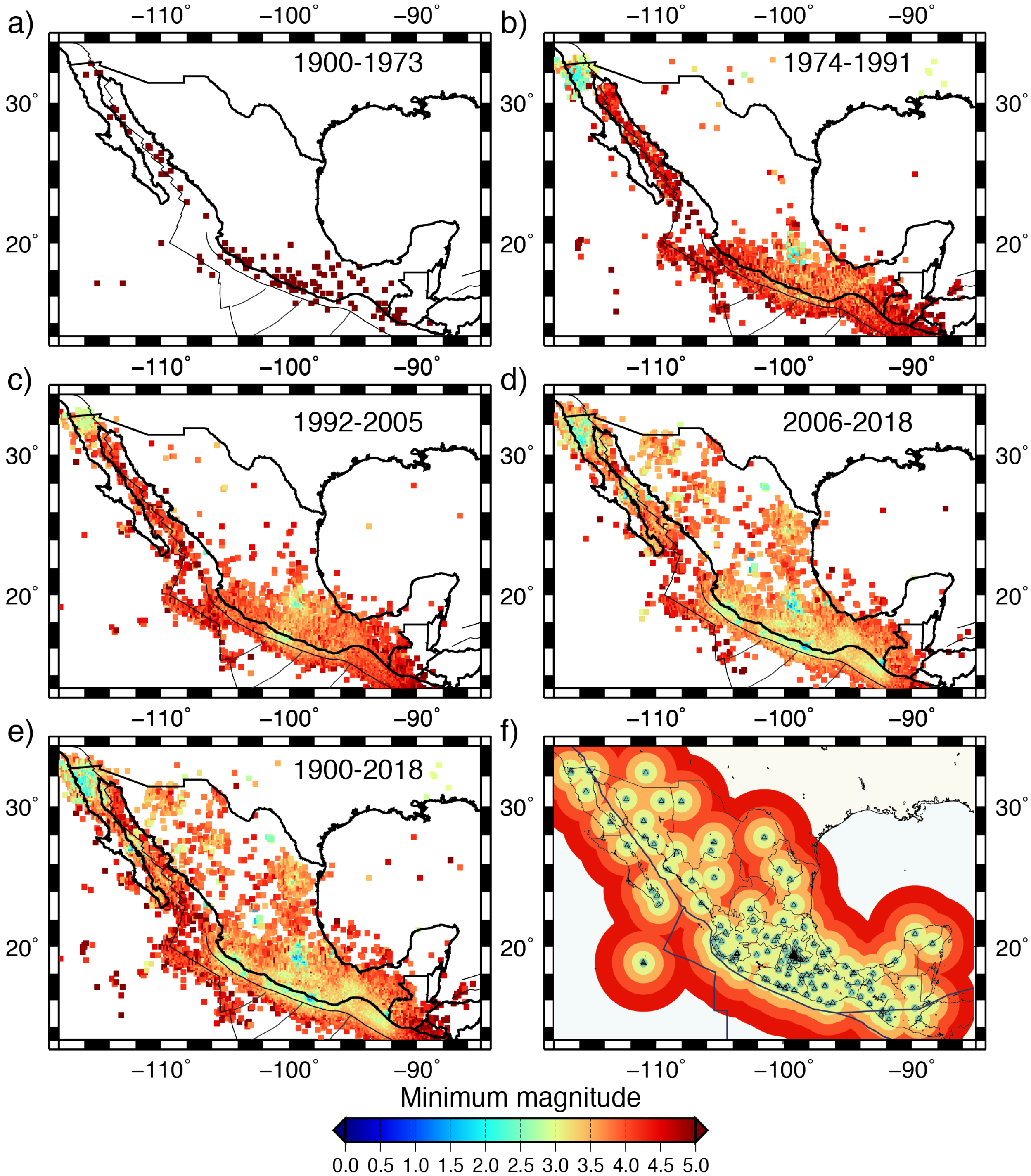

Figure 5.4: *Minimum magnitude reported and able to detect by the current network. a) Period 1900-1973, the location and magnitude information was taken from the compilation by* Kostoglodov and Pacheco *(1999). b) Period 1974-1991. The conventional network with telemetry operated during this epoch, computers were incorporated to location and magnitude estimates and magnitudes of coda duration and local magnitudes were started to be used. c) Period 1992-2005. The first stations of the National Broadband Network were installed in 1992. By 2005 the network distribution was as in Figure 5.1. d) Period 2006-2018. The broadband network expanded to other regions of the country and other national and international networks started exchanging data with the SSN. e) Minimum magnitude reported in the SSN catalogue. The area is divided into squares of 10x10 km^2. f) Minimum magnitude that the current network can detect by a single station. It includes stations from other institutions that share data with the SSN.*

clearly related to Mexico's tectonics and station density. Furthermore, Figure 5.4f shows the minimum-magnitude event that can be detected by a single station in the network. This is assuming the same noise level at all stations, given by the 95 percentile of the level for all the SSN stations as reported by *Pérez-Campos et al.* (2018). For the magnitude, we use M_{w1} as stated above. As can be seen, there are still regions within Mexico where a magnitude 4.0 might go undetected by the current network. Therefore, the SSN is trying to expand the network to those regions.

5.1.6 Data Availability

An important collection of data is all the paper records accumulated since the first instrument was installed. These are stored at the Joint Library of Earth Sciences at UNAM (`http://www.sismoteca.unam.mx`). Scanned records can be requested by email (`SSNdata@sismologico.unam.mx`). The collection will be available online at `http://www.sismoteca.unam.mx`. For the digital data, as mentioned previously, seven SSN station are available through IRIS-DMC. All continuous velocity data from the broadband national network is currently available through a Seismic Transfer Protocol (STP) client, which can be requested following instructions at `http://www.ssn.unam.mx/doi/networks/mx/`. Acceleration and GPS data are available upon request by email (`SSNdata@sismologico.unam.mx`) with a moratorium of four months.

The agency code for the SNN at the ISC is MEX.

5.1.7 Acknowledgements

Figures 5.1, 5.2, and 5.4 were generated using the Generic Mapping Tools (*Wessel and Smith*, 1998).

References

Córdoba-Montiel, F., A. Iglesias, X. Pérez-Campos, K. Sieron, Grupo de Trabajo del Servicio Sismológico Nacional, C. Valdés-González, S. K. Singh and J. F. Pacheco (2018), The Broadband Seismological Network of Veracruz, Mexico: Toward a Regional Seismotectonic Interpretation, *Seismol. Res. Lett.*, *89*(2A), 345–355, `https://doi.org/10.1785/0220170195`.

Dreger, D. S. (2003), TDMT_INV: Time domain seismic moment tensor inversion, In W.H.K. Lee, H. Kanamori, P.C. Jennings and C. Kisslinger (Eds.), *International Geophysics*, *81*(B), p. 1627, Academic Press, `https://doi.org/10.1016/S0074-6142(03)80290-5`.

Duputel, Z., L. Rivera, H. Kanamori and G. Hayes (2012), W-phase fast source inversion for moderate to large earthquakes (1990–2010), *Geophys. J. Int.*, *189*(2), 1125–1147, `https://doi.org/10.1111/j.1365-246X.2012.05419.x`.

Espíndola Castro, V. H. and C. Valdés González (2011), Calibración de magnitudes para sismos mexicanos utilizando la Red Nacional de Banda Ancha, *GEOS: Boletín de la Unión Geofísica Mexicana*, *31*(1), p. 115.

Guevara, E., R. F. Quaas, J. G. Castelán, J. Ortiz, J. Vázquez, C. Morquecho, A. M. Alarcón, A.

Martínez, A. Gómez, G. Espitia, P. Alonso and L. Cárdenas (2003), In Informes Técnicos: Instrumentación y Monitoreo del Volcán Popocatépetl, México D.F., Centro Nacional de Prevención de Desastres, https://www.cenapred.gob.mx/es/Publicaciones/archivos/119-INFORMETCNICOINSTRUMENTACINYMONITOREODELVOLCNPOPOCATPETL.PDF.

Gutiérrez, C. A., R. F. Quaas, M. Ordaz, E. Guevara, D. Muriá and S. Singh (2005), Instrumentación Sísmica. In Fascículos: Sismo, 28–36, México D.F., Centro Nacional de Prevención de Desastres, https://www.cenapred.gob.mx/es/Publicaciones/archivos/163-FASCCULOSISMOS.PDF.

Havskov, J. and L. Ottemöller (1999), SEISAN earthquake analysis software, *Seismol. Res. Lett.*, *70*(5), 532–534, https://doi.org/10.1785/gssrl.70.5.532.

Hayes, G. P., L. Rivera and H. Kanamori (2009), Source inversion of the W phase: real-time implementation and extension to low magnitudes, *Seismol. Res. Lett.*, *3*, 800–805, https://doi.org/10.1785/gssrl.70.5.532.

Jeffreys, H. and K.E. Bullen (1940), Seismological Tables, British Association Seismological Committee, London.

Kanamori H. and L. Rivera (2008), Source inversion of W phase: speeding tsunami warning, *Geophys. J. Int.*, *175*, 222–238, https://doi.org/10.1111/j.1365-246X.2008.03887.x.

Kostoglodov, V. and J. Pacheco (1999), Un catálogo de sismos moderados y grandes ocurridos en México durante el siglo XX, Poster “100 años de sismicidad en México”. D.F., México, Instituto de Geofísica, UNAM.

Lienert, B. R. and J. Havskov (1995), A computer program for locating earthquakes both locally and globally, *Seismol. Res. Lett.*, *66*(5), 26–36, https://doi.org/10.1785/gssrl.66.5.26.

Pacheco, J.F. (2001), Servicio Sismológico Nacional, Red Sismológica Nacional, Serie: Infraestructura Científica y Tecnológica, Instituto de Geofísica, Universidad Nacional Autónoma de México, México, 29 pp.

Pérez-Campos, X., V. H. Espíndola, J. Pérez, J. A. Estrada, C. Cárdenas Monroy, D. Bello, A. González-López, D. González Ávila, M. G. Contreras Ruiz Esparza, R. Maldonado, Y. Tan, I. Rodríguez Rasilla, M. A. Vela Rosas, J. L. Cruz, A. Cárdenas, F. Navarro Estrada, A. Hurtado, A. J. Mendoza Carvajal, E. Montoya-Quintanar and M. A. Pérez-Velázquez (2018), The Mexican national seismological service: An overview, *Seismol. Res. Lett.*, *89*(2A), 318–23, https://doi.org/10.1785/0220170186.

Quintanar, L., A. Cárdenas-Ramírez, D. I. Bello-Segura, V. H. Espíndola, J. A. Pérez-Santana, C. Cárdenas-Monroy, C., A. L. Carmona-Gallegos and I. Rodríguez-Rasilla (2018), A seismic network for the Valley of Mexico: Present status and perspectives, *Seismol. Res. Lett.*, *89*(2A), 356–362, https://doi.org/10.1785/0220170198.

Rubinovich, K., R. M. Levy Aguilera, C. L. Moreno and C. Block Iturriaga (1991), José Guadalupe Aguilera Serrano (1857-1941): datos biográficos y bibliografía anotada, ed. Raúl Rubinovich, UNAM, Instituto de Geología, Universidad Autónoma de Hidalgo, Instituto de Investigaciones en Ciencias de la Tierra.

Secretaría de Industria, Comercio y Trabajo (1919), Descripción histórica de la Red Seismológica Nacional, *Boletín del Instituto Geológico de México*, *18*.

Singh, S. K. and M. Ordaz (1994), Seismic energy release in Mexican subduction zone earthquakes, *BSSA*, *84*(5), 1533–1550.

Singh, S. K. and J. F. Pacheco (1994), Magnitude determination of Mexican earthquakes, *Geofísica Internacional*, *33*(2), 189–198.

Vidal-Villegas, J. A., L. Munguía, J. A. González-Ortega, M. A. Nuñez-Leal, E. Ramírez, L. Mendoza, R. R. Castro and V. Wong (2018), The Northwest Mexico Seismic Network: Real-Time Seismic Monitoring in Northern Baja California and Northwestern Sonora, Mexico, *Seismol. Res. Lett.*, *89*(2A), 324–337, https://doi.org/10.1785/0220170183.

Wessel, P. and W. H. Smith (1998), New, improved version of Generic Mapping Tools released, *Eos, Transactions American Geophysical Union*, *79*(47),579–579, https://doi.org/10.1029/98EO00426.