Operational Procedures of Agencies Contributing to the ISC

The Finnish National Seismic Network

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5.2 The Finnish National Seismic Network

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5.2.1 Introduction

The Institute of Seismology, University of Helsinki (ISUH) was founded in 1961 as a response to the growing public concern about environmental hazards caused by nuclear weapon testing. Since then ISUH has been responsible for seismic monitoring in Finland. The current mandate covers government regulatory duties in seismic hazard mitigation and nuclear test ban treaty verification, observatory activities and operation of the Finnish National Seismic Network (FNSN) as well as research and teaching of seismology at the University of Helsinki.

ISUH and its predecessor in seismic monitoring, the Department of Physics at the University of Helsinki, have actively participated in the international seismic data exchange. In the ISC Bulletin, the first phase reading from a Finnish station dates back to 1927 (HEL, Helsinki) and the earliest reported hypocentre from agency HEL to 1958. Manual analysis of teleseismic events was phased out at ISUH in 2010, but teleseismic parameter data from some of FNSN stations are still sent to the ISC through partner networks. In addition, ISUH has been submitting the monthly bulletins of local and regional seismic events to the ISC since 1998.

5.2.2 Seismicity of Finland and Surroundings

Finland is situated in the Fennoscandian shield, which is a stable continental region characterized by weak to moderate size earthquakes and a relatively low rate of natural seismicity. In an average year ISUH detects and locates roughly 16,000 local and regional seismic events, of which only 1-2% are tectonic earthquakes. The majority of events are industrial explosions for construction and mining purposes. In addition, rockbursts and other mining–induced events occur regularly in and around several large-scale mines.

Figure 5.13 shows local and regional earthquakes detected by the FNSN and partner networks since 2000. The seismicity is commonly related to both intraplate and plate margin processes; the opening of the North Atlantic Ocean, postglacial rebound, and local stress caused by e.g. gravitational or compositional variations of the crust. Diffuse seismicity arises all over the region, but a few zones of enhanced seismic activity can also be discerned. Distinct NE–SW-trending earthquake clusters extending from the western coast of the Gulf of Bothnia along the Finland-Sweden border zone to northern Norway are mostly associated with postglacial fault zones. The seismically active Kuusamo-Kandalaksha zone in eastern Finland and NW Russia is spatially associated with a major NE-SW oriented shear zone, which in turn is transected by faults and shear zones of various orientation. Enhanced seismicity in SE Finland is due to shallow earthquake swarms occurring within the Wiborg rapakivi granite batholith. The latest major swarm during 2011 and 2012 comprised more than 200 low magnitude events.

The largest known earthquake in Finland took place on 23 June 1882 in the Bothnian Bay area (see "1" in Fig. 5.13). It was scaled to Mw 4.6 and located offshore but it was still strong enough to cause minor damage to buildings in the coastal towns.

The Fennoscandian earthquakes occur generally in the uppermost 15 km of the crust and only a small portion are located in the middle and lower crust, at depths between 16 and 45 km. The focal mechanisms show mostly a combination of strike-slip and reverse faulting styles with a NW-SE direction of maximum horizontal stress. For a more comprehensive description of the regional seismicity see *Korja et al.* (2015) and references therein.

5.2.3 History of the FNSN and Present Network Status

The first seismograph station in Finland was installed at the premises of the Department of Physics, University of Helsinki in 1924. However, the mechanical Mainka seismographs had low magnification and thus the recordings were of little practical value for the study of local seismicity. The first short-period seismographs were set up between 1956 and 1963. The next significant upgrade of FNSN occurred during the late 1970's when digital tripartite arrays in southern and central Finland became fully operational, allowing for systematic use of instrumental detection, location and magnitude determination methods. By the end of the 1990's, the entire network was operating using digital telemetric or dial-up methods (*Luosto and Hyvönen*, 2001).

The FNSN has expanded significantly during the 21st Century. It now comprises 36 permanent stations and a number of portable sensors used as temporary deployments for monitoring or research purposes (Fig. 5.14). Most of the stations have Streckeisen STS-2, Nanometrics Trillium (Compact/P/PA/QA) or Guralp CMG-3T broad band sensors. Some Teledyne-Geotech S13/GS13 short period sensors are also in use. Data acquisition systems are a combination of Earth Data PS6-24 digitizers and PC with Seiscomp/Seedlink software or Nanometrics Centaurs. The stations are connected to the ISUH with Seedlink via Internet and provide continuous waveform data at 40 Hz (array) or 100–250 Hz sampling frequency. Further information about instrumentation can be found at the Institute's web site (`www.seismo.helsinki.fi`).

The FNSN is under continuous development; new station locations are being investigated and existing stations upgraded. The latest extensions include 9 stations (OBF0-8, Fig. 5.14) deployed around a planned nuclear power plant, 4 stations (RUF, RMF, NIF and KPF, Fig. 5.14) funded by FIN-EPOS to improve the overall station coverage, and 5 stations (HEL1-5, Fig. 5.14) set up in the Helsinki

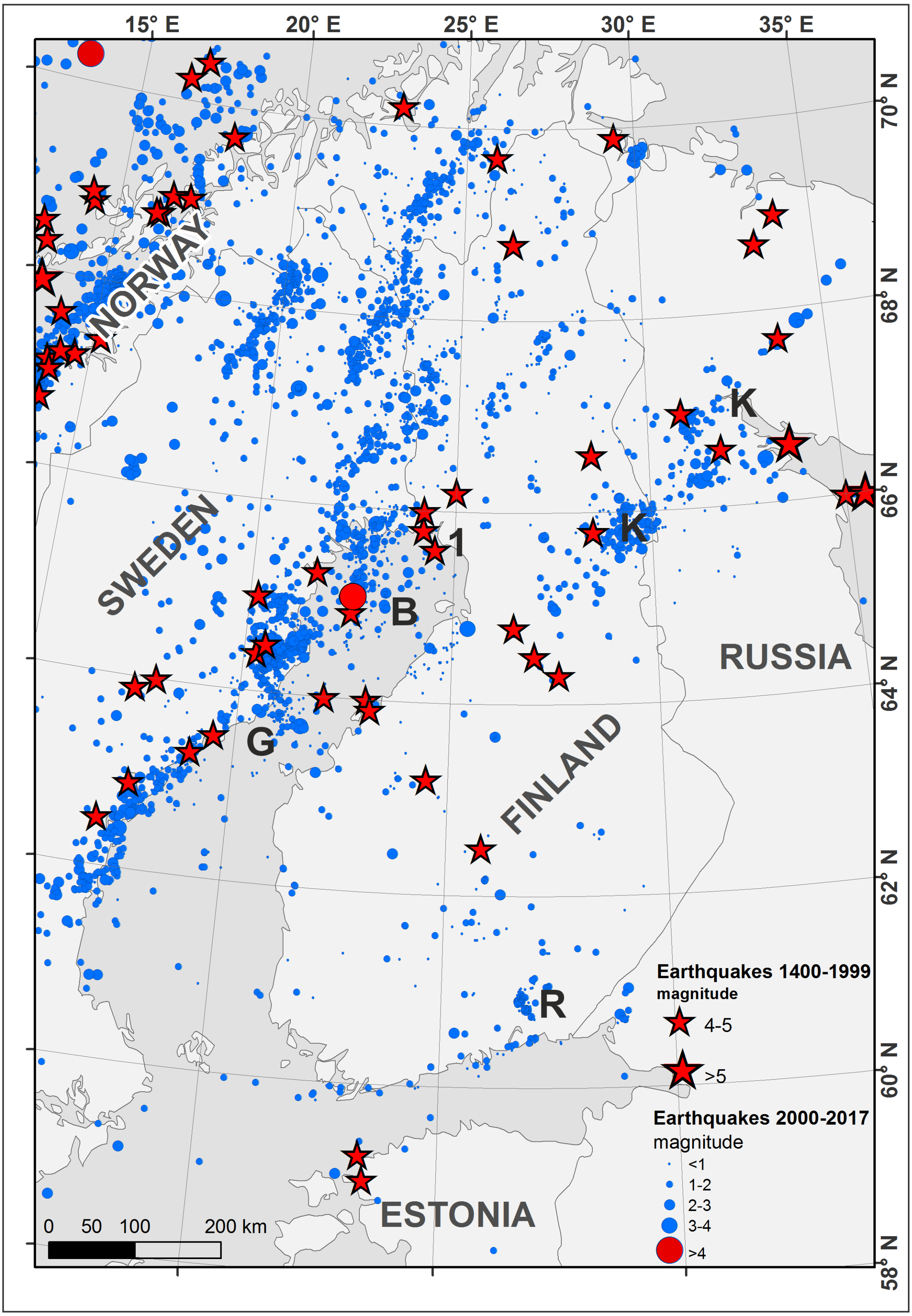

Figure 5.13: *Seismicity of Finland and surroundings. Earthquakes for 2000-2017 (dots) and M > 4 events for 1400-1999 (asterisks). 1-Bothnian Bay earthquake 23-06-1882. Seismicity zones: B-Bothnian Bay; G-Gulf of Bothnia; K-Kuusamo-Kandalaksha; R-Wiborg rapakivi area. Data sources: Fennoscandian earthquake catalogue FENCAT and ISUH preliminary earthquake data for 2014-17.*

metropolitan area to monitor induced seismicity around a deep heat geothermal pilot plant.

The regional coverage is further improved by acquiring available real time data from partner networks; the Northern Finland Seismological Network (NFSN) operated by the University of Oulu and the national seismic networks of Estonia (ENSN), Norway (NNSN) and Sweden (SNSN). In addition, data from two Russian stations (RUS) are accessed through IRIS (www.iris.edu/hq/programs/gsn) and Geofon (geofon.gfz-potsdam.de). Some of the seismic stations in Finland belong to other global seismic networks as well, transmitting data in real time to the data centres. The station KEV belongs to the IRIS global seismic network whereas FINES, a small aperture array comprising 16 substations, is one of the 50 primary monitoring stations of the Comprehensive Nuclear-Test-Ban-Treaty Organization (CTBTO; www.ctbto.org).

The permanent stations have a relatively low background noise level, as demonstrated in Figure 5.15. The examples show the probability density function of power spectral densities calculated from one year of data recorded at MEF, which is one of the noisiest urban stations, and VRF, which is a good example of low noise remote station. Analyses were made using pqlx-software (*McNamara and Boaz*, 2005). All the permanent station installations are in direct contact with bedrock, in most cases utilizing natural outcrops of bedrock.

5.2.4 Automatic Event Detection and Location System

Local and Regional Events

Since 2010, ISUH has employed an automatic system for monitoring local and regional seismic events. The system is based on network processing of three-component (3-C) and array stations and it utilizes the available on-line stations in Finland and neighbouring countries (Fig. 5.14). At a single 3-C site the detections are generated with basic STA/LTA-detector. The code used is an implementation of *Ruud and Husebye* (1992), which uses the "predicted coherence" measure of *Roberts et al.* (1989). The automatic processing of array data is done with DP/EP code provided by NORSAR (*Fyen*, 1989).

An in-house designed routine is used for event association (*Kortström et al.*, 2016a). The routine reads continuously preliminary locations from single station and array bulletins, calculates theoretical P- and S-wave travel times for each source-to-station path, and searches matching P- and S-onset times from the detection logs of other stations. An event is accepted for further analysis if a sufficient number of stations is contributing to the same preliminary origin. The associated phase data are then passed to HYPOSAT location program (*Schweitzer*, 2001). As automatic arrival times are seldom accurate enough for reliable depth estimation, the source depth is always fixed to zero during the iterations.

Finally, the event solution is forwarded to automatic event classification routine (*Kortström et al.*, 2016b). It is based on a supervised pattern recognition technique called the Support Vector Machine (SVM) and the classification relies on differences in signal energy distribution between natural and artificial seismic sources. The tool was designed to reduce work-load and the cost of manual seismic analysis by pre-filtering the fully automatic event lists. Experience gained during the operation period indicates that the SVM tool can discriminate blasts and spurious events from earthquakes with a high level of reliability.

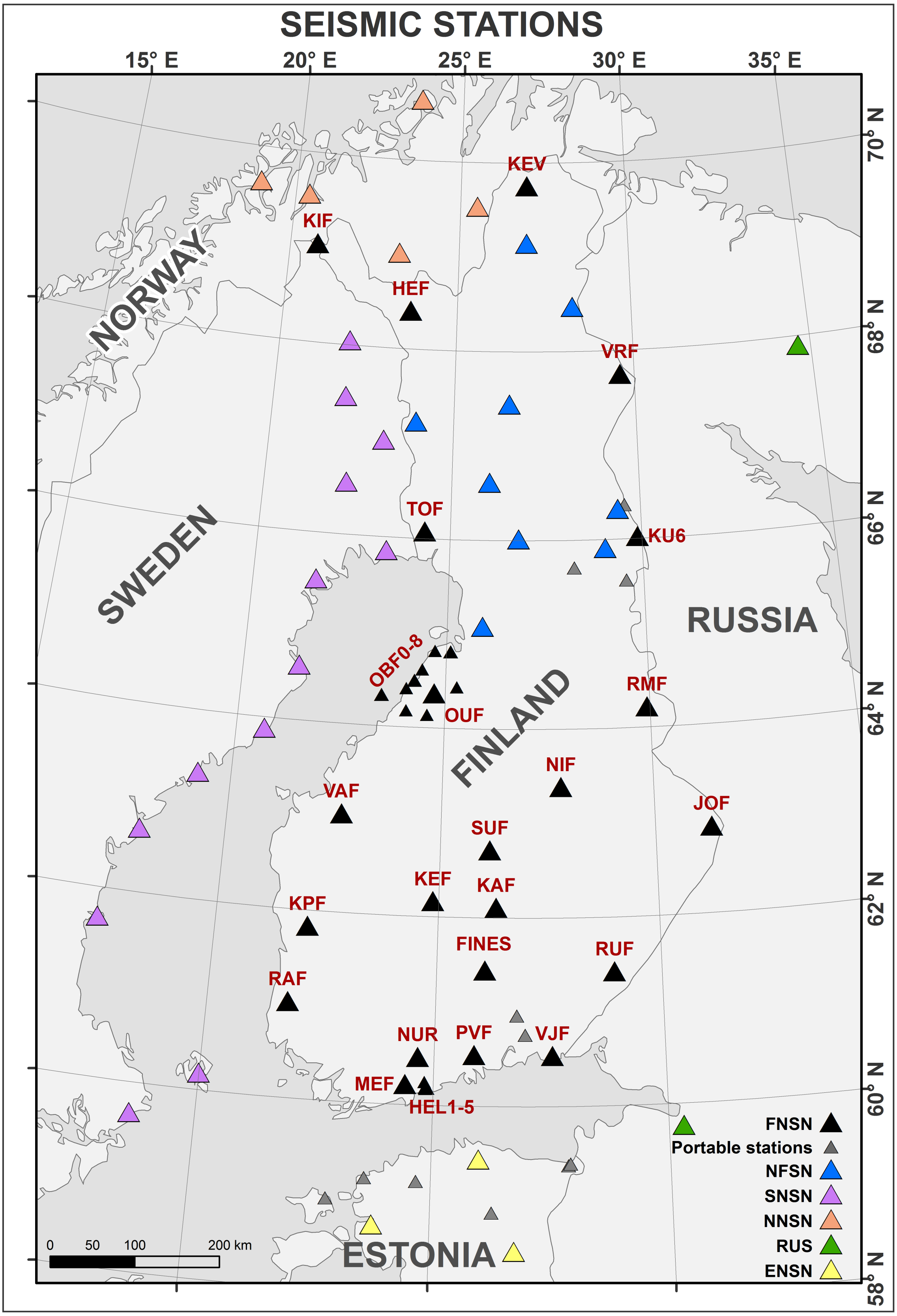

Figure 5.14: FNSN and contributing stations from partner networks. See text for network abbreviations.

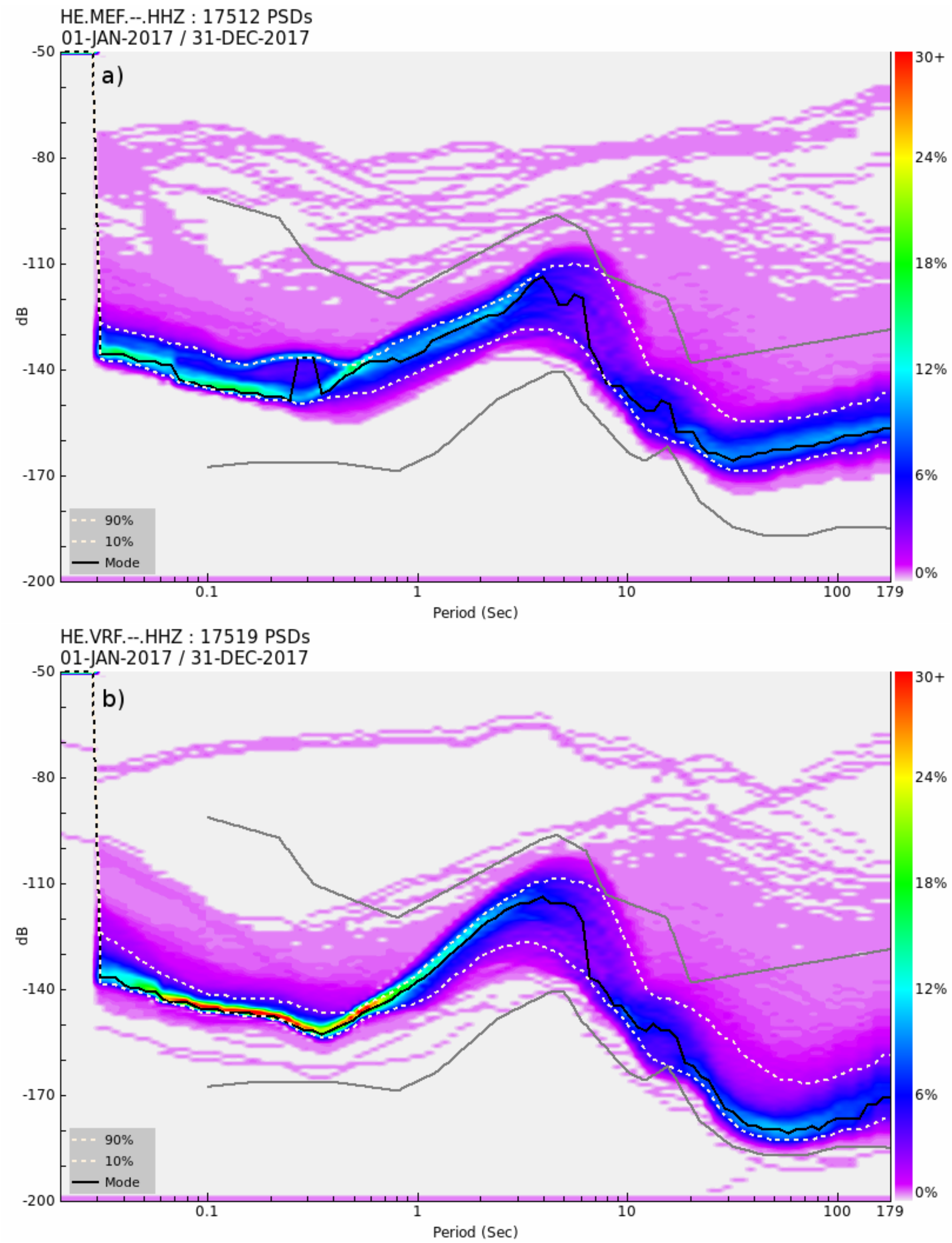

Figure 5.15: *Spectral density functions at station MEF (a) and VRF (b). Regularly observed energy levels (blue, green, yellow and red) indicate background noise and scarcer energy levels (pink and violet) sudden disturbances such as signals of seismic events. Grey lines denote the global average of low and high noise level models (Peterson, 1993).*

The output, a fully automatic event solution, includes origin time, epicenter coordinates, magnitude, event type, arrival-times of P- and S-phases at each station, and error statistics for each of the estimated parameters. The event solutions are published on the Institute's web page within 15 minutes of occurrence and, for significant events, automatic alert message is distributed to the seismologists. As is seen in Figure 5.16, the automatic data processing system provides event detection and location capabilities down to magnitude 1.0 within the network (threshold magnitude calculation method by *Valtonen et al.*, 2013).

Teleseismic Events

Due to decreasing staff resources, manual analysis of teleseismic events was terminated in 2010. However, ISUH has an implementation of SeisComP3 (`www.seismcomp3.org`) system to produce fast automatic alerts of big global earthquakes. These event solutions form the backbone of seismic monitoring in the Finnish Natural Disaster Warning System (LUOVA). LUOVA aims to provide a prompt warning and information on natural hazards and disasters for relevant authorities and emergency response centres. At ISUH there is always a seismologist on call to deliver assessed information about worldwide hazardous earthquakes or nuclear tests to LUOVA.

5.2.5 Interactive Analysis of Local and Regional Events

The precision of automatic source parameters seldom fulfils the criteria required by a good quality seismological event solution. Interactive review of automatic event solutions is therefore essential to e.g. remove spurious events and adjust the automatic phase picks. The coarse interactive analysis scheme used at ISUH is presented in Figure 5.17.

Significant events, such as strong earthquakes or widely felt seismic events are generally analysed within 12 hours of the occurrence with the event solution promptly submitted to relevant authorities, cooperative seismic agencies and media. Felt reports arriving via electronic macroseismic questionnaires or by phone are also given the highest priority in the analysis scheme.

The routine event analysis begins on the first working day after the data day by screening of the automatic event bulletin and associated digital seismograms. Additional waveform data requests are made for events missed by the automatic detector or the association routine. Event type definitions in the automatic bulletins are checked by spectral analysis methods (*Kortström et al.*, 2016b). For events identified as regular mining blasts, the automatic solution is accepted if the location and magnitude fulfil given quality criteria. The events identified as earthquakes as well as mining-induced or suspicious events are subjected to manual reanalysis: adjustment and identification of the automatic phase picks, amplitude and period measurement for local magnitude, and relocation including source depth estimation. After interactive quality-control, the daily event data are published on the web pages and stored into the parametric database.

In a monthly review, the preliminary event solutions are completed with phase readings and source parameters reported by seismic agencies in the neighbouring countries. In addition, waveform data from the offline temporary stations in Finland are screened and phase readings included in the earthquake

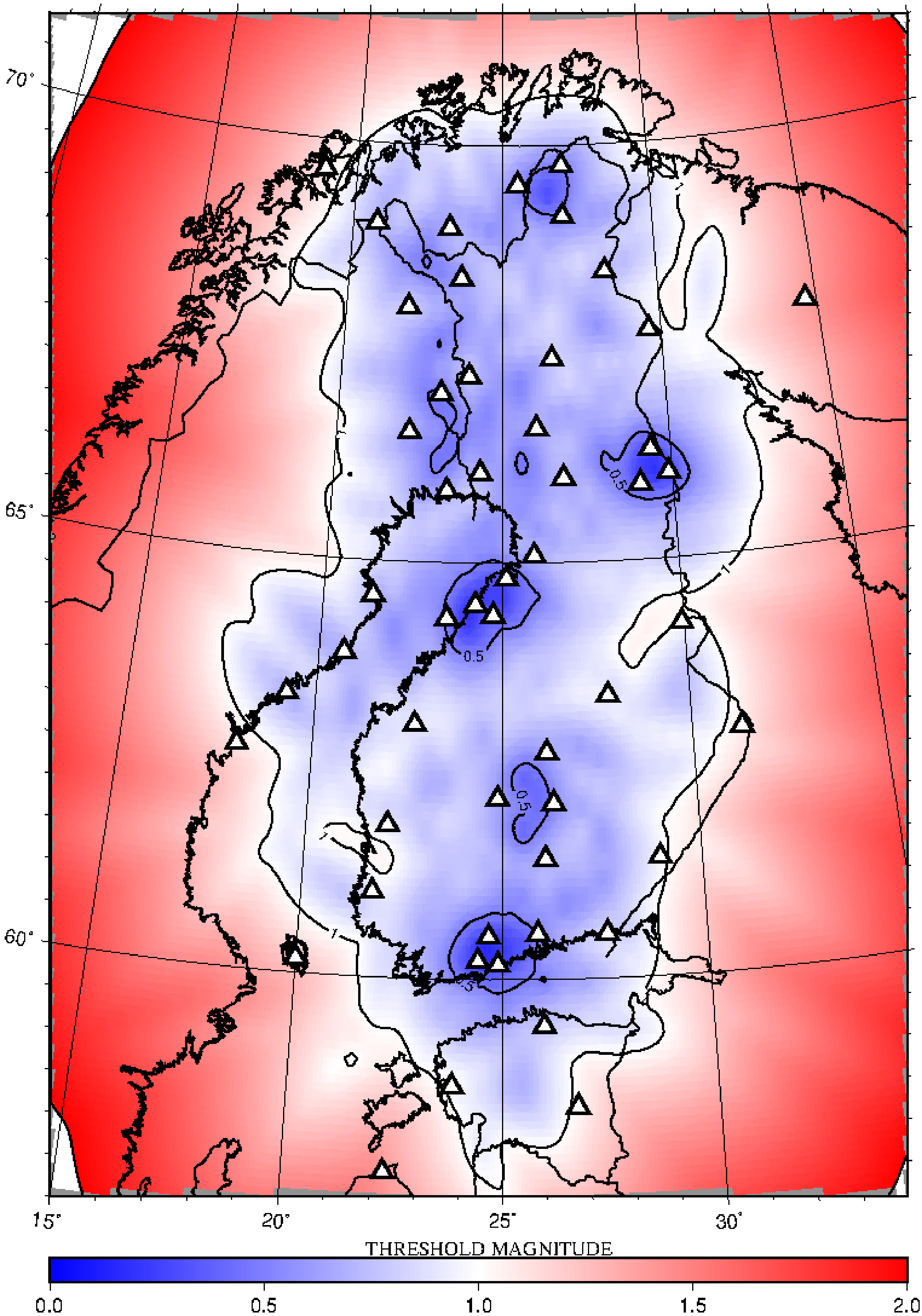

Figure 5.16: *Threshold magnitude for the current automatic detection and location system. Triangles are seismic stations that are used in the processing.*

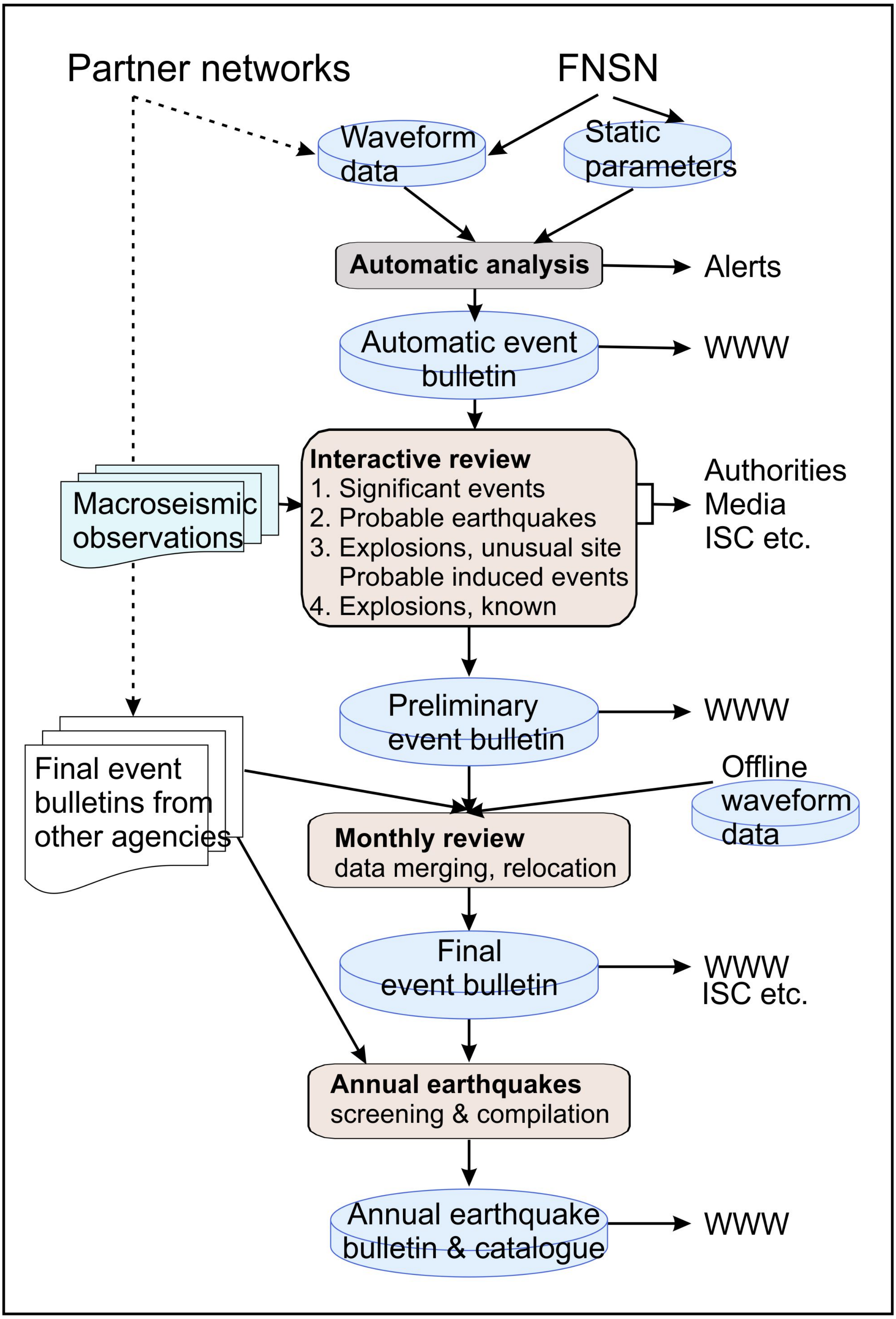

Figure 5.17: *A schematic view of local and regional event analysis at ISUH.*

reports. The final monthly bulletin is submitted to the ISC and other cooperative agencies.

For interactive seismic analysis ISUH uses the Geotool software (*Coyne and Henson*, 1995), which is available for National Data Centers of the CTBTO States Parties. The basic Geotool functions include filtering, phase picking and event location as well as several tools for spectral and array data analyses. The software can be customized and extended. As an example, ISUH has implemented its own event location routine to Geotool.

The local magnitude used at ISUH, ML(HEL), is based on synthetic Wood-Anderson amplitudes (*Uski and Tuppurainen*, 1996). For continental earthquakes the amplitudes are measured from Sg or Lg phase maxima. For offshore events, additional relations are used to estimate ML(HEL) from Sn or Pn wave maximum amplitudes. The magnitude is related to seismic moment through (*Uski et al.*, 2015):

$$\mathrm{ML(HEL)} = 0.83\log(M_0) - 7.98 \qquad \text{for } \log(M_0) \leq 13.5$$
$$\mathrm{ML(HEL)} = 0.59\log(M_0) - 4.73 \qquad \text{for } \log(M_0) > 13.5.$$

5.2.6 Annual Earthquake Bulletin

ISUH is compiling an annual report of earthquakes in Northern Europe (Fig. 5.17). The University of Bergen, the Geological Survey of Estonia and the Department of Earth Sciences, University of Uppsala are the main contributors of supplementary earthquake reports. The annual earthquake data are used to update the Fennoscandian earthquake catalogue FENCAT (*Ahjos and Uski*, 1992). The seismicity record in FENCAT spans more than six centuries and it is the most comprehensive source of earthquake data available in the region. Homogenization of the catalogue data has been a subject in recent seismic hazard studies (e.g. *Uski et al.*, 2015).

5.2.7 Data Availability

ISUH hosts a seedlink server (`finseis.seismo.helsinki.fi:18000`), from which real time data of almost all permanent stations of FNSN are freely available. The data of six stations have been forwarded to GEOFON since 2007. Our intention is to make all FNSN permanent stations available to GEOFON's EIDA data archive (`eida.gfz-potsdam.de`).

All parametric data products, i.e. local and regional event bulletins, annual earthquake bulletins as well as the FENCAT earthquake catalogue are available at the Institute's web pages (`www.seismo.helsinki.fi`).

5.2.8 Acknowledgments

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5.2.9 References

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