Operational Procedures of Agencies Contributing to the ISC

Seismological Central Observatory (SZO) of BGR, Germany

Gernot Hartmann, Thomas Plenefisch and Klaus Stammler

Federal Institute for Geosciences and Natural Resources (BGR), Hanover

Germany

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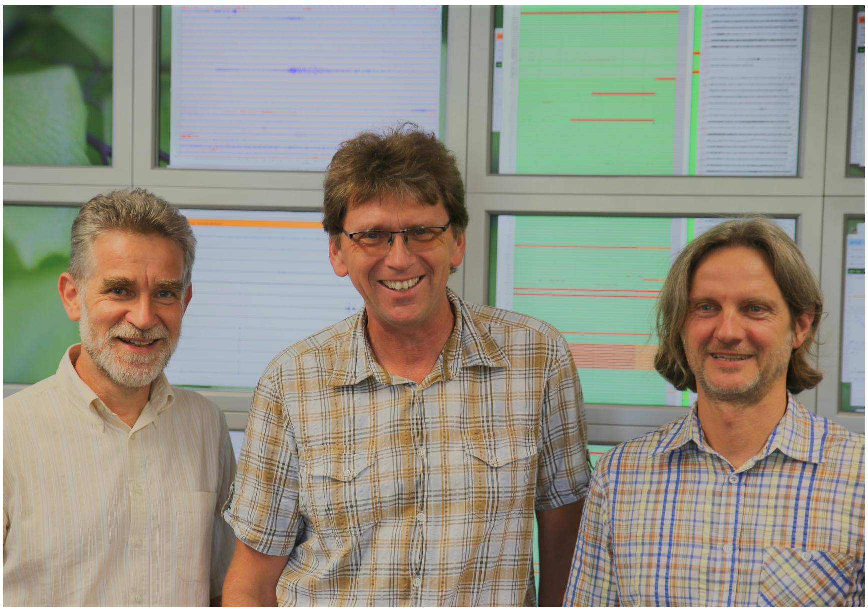
Gernot Hartmann, Thomas Plenefisch and Klaus Stammler
Federal Institute for Geosciences and Natural Resources (BGR), Hanover, Germany



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5.1.1 Introduction

The Seismological Central Observatory (SZO) is a department of the Federal Institute for Geosciences and Natural Resources (BGR) in Hanover (Germany). The three main tasks of the SZO are to observe and analyse earthquakes mainly focused on Germany and adjacent regions, to consult the government and national industry in the field of induced seismicity and to fulfill the German commitments for the verification of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). In order to meet these requirements the SZO runs a considerable amount of seismic stations and hosts the date centre for seismological broadband data in Germany. It also supports the open data policy in seismology and therefore all waveform data are available to the public.

5.1.2 Station Network and Data Management

Station Network

The GRSN (German Regional Seismic Network) currently consists of 45 stations (Figure 5.1). They are all equipped with broadband sensors, mostly Streckeisen STS-2 and STS-2.5. The data are recorded continuously and transmitted via DSL connections or cellphone networks (GPRS, LTE) into the data centre of the Federal Institute for Geosciences and Natural Resources (BGR) in Hanover. The core of the GRSN, consisting of eight stations, was installed in 1991 in addition to the previously existing Gräfenberg array (see next paragraph). The number of stations was increased stepwise since then until today's configuration was reached. The available sample rates are usually 100 Hz and 20 Hz, at some stations also 1 Hz. The station sites have been carefully selected in order to approximate an even distribution over the area of Germany and to obtain optimum locations concerning noise conditions. The network serves as a backbone for the German seismological community and is used for the observation and analysis of local, regional and teleseismic events.

A unique subset of these stations is formed by the Gräfenberg array (GRF) situated in the Franconian Jura region in the South-East of Germany (see Fig. 5.1). The 13 stations of the array were installed between 1975 and 1980 and since then we record continuous digital broadband data from all stations. The stations are located in an area of about 50 x 100 km. The main purpose of this array has been, and still is, the observation and analysis of teleseismic signals. In the beginning the stations were equipped with the first generation of Streckeisen STS-1 instruments with a bandwidth of 20 s to 5 Hz at a sampling rate of 20 Hz. At ten sites there existed vertical channels only and at three sites three component systems were installed. As digitisers we used our own developments, since no suitable devices for high resolution seismic records were available at that time. These instruments were replaced by STS-2 seismometers and Reftek 130 digitisers in 2006 resulting in three component recordings and 20 and 100 Hz sampling rates at each station site. This GRF data set contains the longest history of digital broadband array data worldwide.

In addition to the backbone network GRSN, denser and mostly short-period networks are operated by a number of state agencies, but only a fraction of them is publicly accessible and technically compatible with the GRSN. The data of a large part of these open and technically compatible stations is also collected by the BGR and hosted by its data centre. The stations are provided mainly by universities, state agencies and some long-term monitoring projects. Due to their main task of monitoring specific areas, some of them are installed at locations with limited recording capabilities and only a small number of these stations is equipped with broadband instruments, the others have mid- or short-period seismometers.

A third group of dedicated stations is operated by the BGR within the frame of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), consisting of a 25 element short-period seismic array with an aperture of 4 km (GERES) and two infrasound arrays in the Bavarian Forest (IS26, 8 elements) and Antarctica (IS27, 9 elements) as well as some additional infrasound training stations in Germany (see Section 5.1.4).

All three station groups together (GRSN, local networks and CTBT stations) total about 180 seismic stations from within Germany plus about 20 infrasound stations that are currently transmitted to the data centre in Hanover.

Data Archive

The seismic and infrasound data archive of the BGR consists of permanently archived continuous data of the stations described in the section above. As already mentioned, the oldest data in this archive are GRF array data from 1975 (only a few data segments of one station, the continuous operation started in 1976). In 1991 the GRSN was installed and started operation at eight sites and was extended many times up to the current number of stations. At the beginning, in 1975, the archive media was 800 bpi (bytes per inch) reel tapes written in a self-designed data format. After several time consuming recopy operations using 1600 bpi tapes, WORM disks and CDs the complete data set of the archive is now stored on RAID systems using miniSEED as storage format. The total size is about 30 TB. Currently it is growing by about 10 GB a day. All data are openly available through various interfaces, the most common interface currently is via FDSN webservices (see Section 5.1.2).

Data Flow

All stations described above are connected to the data centre in Hanover via the seedlink protocol (`https://www.seiscomp3.org/doc/applications/seedlink.html`). Their continuous data arrive in the data centre a few seconds after they have been recorded. There the data are collected, quality checked and processed by event detectors (Figure 5.2). After some weeks at temporary disk locations the data are permanently archived and several backup copies are created. The storage media used are RAID systems, for the backups a redundant RAID system, a tape robot system and removable hard disks are used. The tape robot handles three copies automatically, together with the two redundant RAID systems and two copies on external disks our data reside on seven physically different media in order to minimise the probability of data loss due to media failure. Time segmented subsets of the data get checksums and are regularly checked for integrity including all backup copies.

Quality Checks

Automatic processes (own Python software) are running to analyse the data streams for quality issues. The routines check for data gaps, timing problems (using correlation and array features) and irregular amplitude deviations in comparison to the mean of all other traces. Additionally the log channels of the digitizers are scanned for state-of-health (SOH) parameters reported. The parameters are extracted and statistically analysed, unusual deviations produce warning or error messages. All information gathered (i.e. status messages) is collected in a database connected to an automatic alarm system to activate station operators on duty to fix hardware and software issues in the data centre or at the station site as soon as possible.

Integration in EIDA

The BGR is part of the virtual European data centre EIDA (European Integrated Data Center, `https://www.orfeus-eu.org/data/eida`). There, under the umbrella of ORFEUS, a number of European data

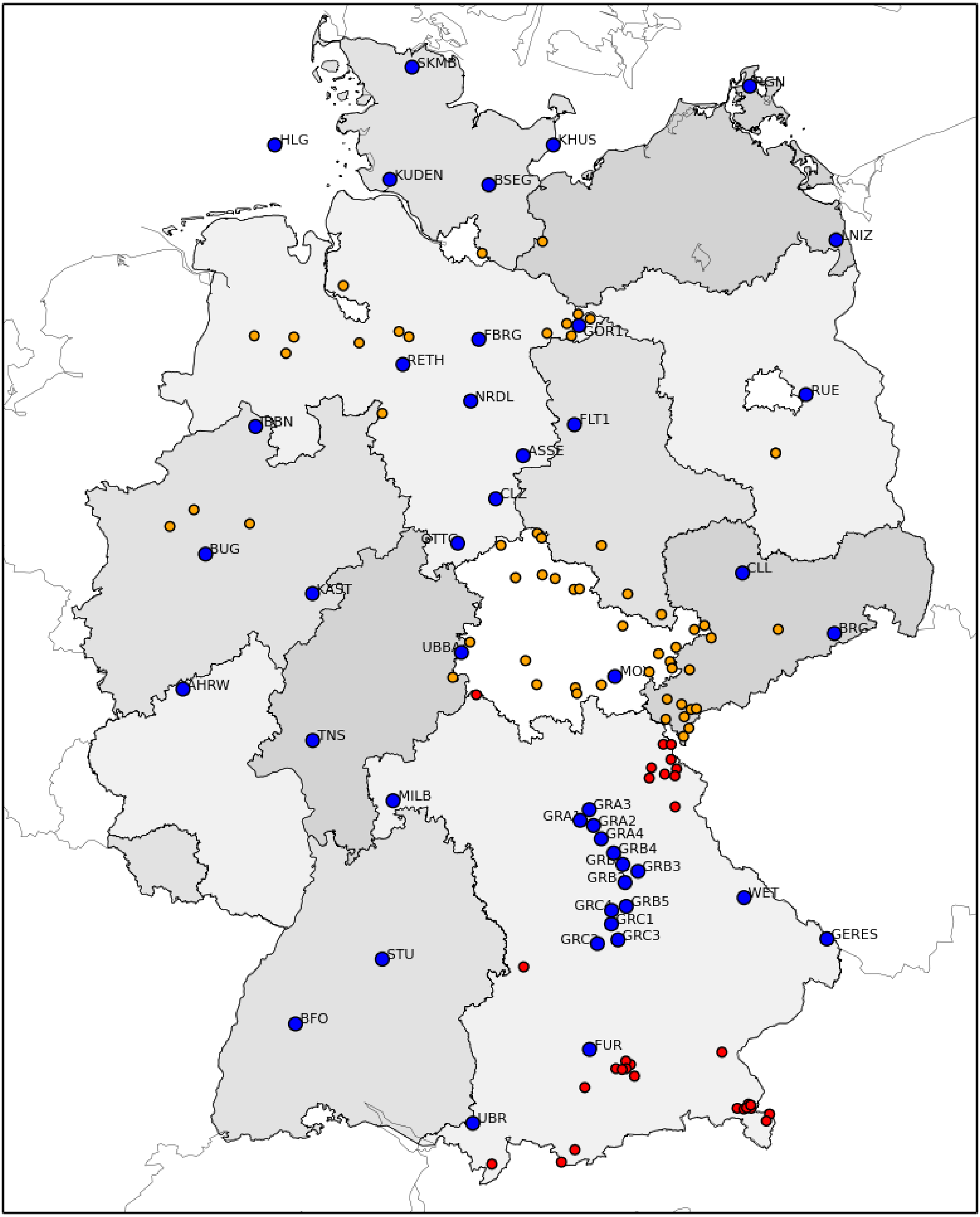

Figure 5.1: *Map of open stations in Germany. The labeled, blue circles show the locations of the GRSN stations, the unlabeled, orange circles indicate local networks and long-term project stations hosted by the BGR and the red circles show the Bavarian network hosted at a separate server. All stations are available through EIDA (see Section 5.1.2). The gray shaded areas indicate the federal states within Germany.*

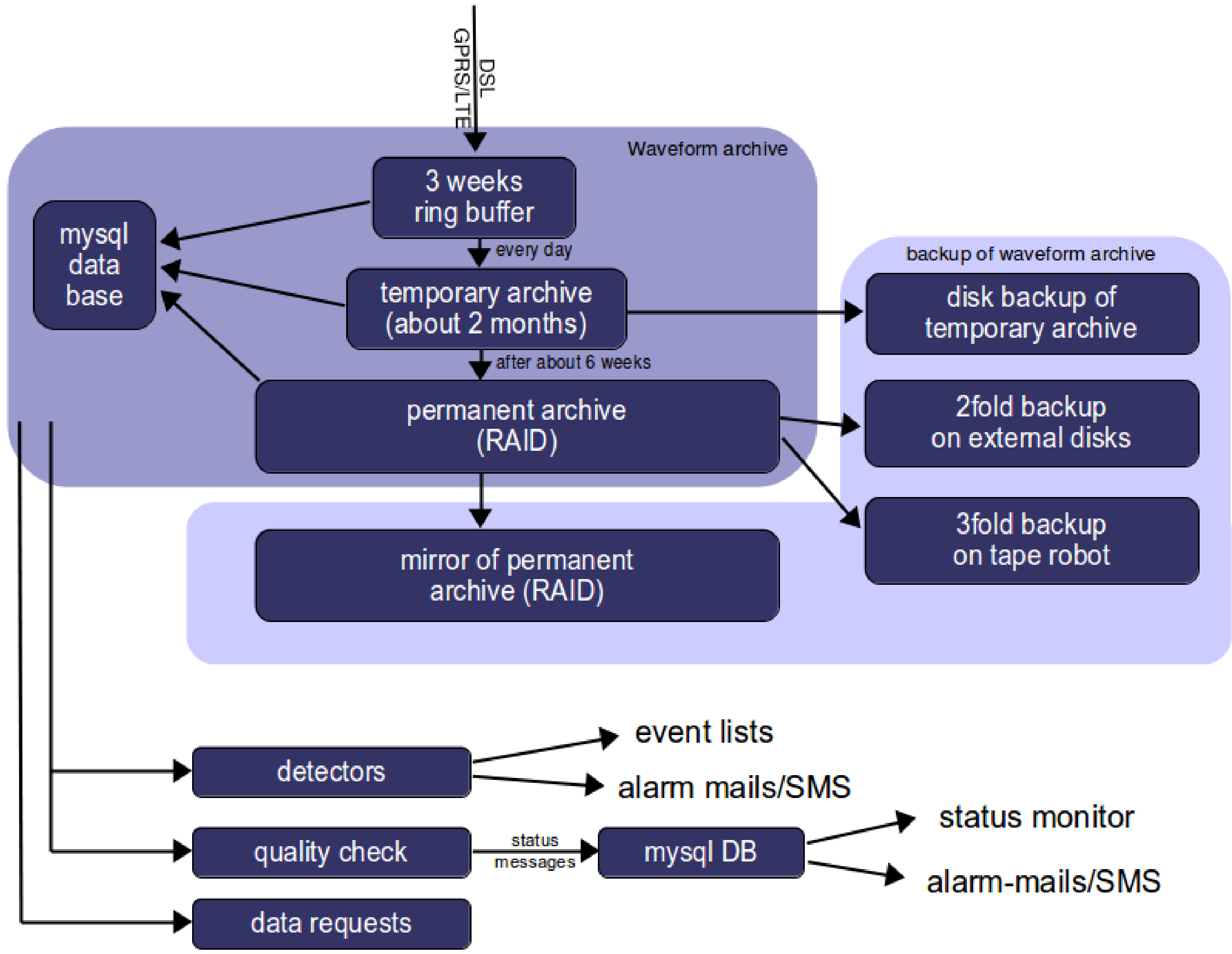

Figure 5.2: *Schematic data flow inside the data centre. The data flow in online and are stored in ring buffers on seedlink servers. Full day files are copied into a temporary archive. After about 6 weeks the data are permanently archived on large RAID systems. For all storage systems backups exist, the permanent archive has in total 6 backup copies on different media. All data access is managed by a database, feeding data into detectors, data requests and quality check routines. A second database handles status messages connected to a viewing interface and alarm triggers.*

centres agreed to standardise their data format, the access to their waveform data as well as procedures for quality checks. A common platform enables the user to access waveforms of thousands of stations in Europe with a few clicks or to integrate EIDA waveforms in their data processing algorithms using standard retrieval software, currently arclink (about to be retired) and FDSN webservices (as offered by IRIS).

5.1.3 Routine Data Analysis

After the GRSN went in operation in 1991 and a continuous online transmission of the waveform data to the BGR was settled, a processing pipeline for regular analysis of seismic events in Germany and adjacent areas was developed. The analysis procedures evolved since that time as well as the number of stations were steadily increased. Nowadays, the seismological analysis makes use of more than 200 stations in and around Germany. The near real time digital waveform data as well as data from the past are permanently available in the seismic waveform data archive of BGR (see Section 5.1.2).

Automated Detection Process and Manual Event Review

We employ a number of detection algorithms to scan the continuous data streams for seismic events. We implemented simple STA/LTA detectors, an FK-array detector, run Seiscomp3 (`https://www.seiscomp3.org`) on the data traces and developed a self-made grid search detector analyzing summation signals along phase travel time curves. The results of all detectors are grouped and combined into a detection list with preliminary locations. Relevant events trigger an alarm to the analyst on duty. The interface to the detection list is implemented as an internal web site offering preview waveform figures and resolution diagrams.

In a daily routine the analyst on duty reviews this list of detection manually and verifies or rejects the events. The analysis is performed with the Seismic Handler software package (*Stammler*, 1993). We focus on seismic events in Germany as well as on regional and teleseismic events, for which signals were recorded at German stations. For detection and analysis of events close to the national borders we receive online waveform data of about 50 stations from Germany's neighbouring countries to complement our data set. In case of strong earthquakes, a quick epicenter determination can be provided some minutes after the alert of the near real time detector.

Analysis of Local Seismic Events

In general, seismic events in Germany with magnitude 2 and above are located, the magnitudes are estimated and the source is classified as tectonic, induced or man-made. Furthermore, events in neighboring countries with magnitudes larger than 3 are analyzed, if clear phases on GRSN stations are observed. The results are stored in an event data base and are retrievable from the BGR website. A simplified velocity model for Germany is used if a large number of stations in a wide distance range are incorporated. This model is based on mean travel time curves derived from phase readings at GRSN stations for the past 25 years. For specific regions we make use of locally defined velocity models, e.g. in Vogtland or Northern Germany (see Section 5.1.5). The epicenter parameter and the phase readings are sent to the European-Mediterranean Seismological Centre (EMSC) after finishing the daily routine analysis.

Earthquake Catalogue for Germany

The event database at BGR contains all estimated parameters of the manually reviewed local seismic events. Besides the event determination of BGR, the results of seismological agencies of the federal states of Germany and universities are collected and associated in this data base. These agencies operate small-scale local station networks and can provide precise location results for events within their monitoring area. They are marked as preferred solutions. Additionally, epicenter data from earthquake catalogues of neighboring countries will be included and associated to events in the data base, when such publications becomes available. Customized compilations of bulletins are provided regularly or on request. The main product is the "Data Catalogue of Earthquakes in Germany and Adjacent Areas". Since the beginning of regular earthquake analysis with GRSN at the BGR, the catalogue is published monthly.

The information is given in the international standardized format ISF/IMS1.0 (`http://www.isc.ac.uk/standards/isf`). The catalogue is made available at the BGR website (`http://www.bgr.bund.de/erdbebenkatalog-deutschland`). Furthermore, the catalogue is sent to a number of recipients, e.g. to the ISC for their integration in the final ISC Bulletin.

Since 1974 the German earthquake catalogue was published yearly, until 1997 as printed matter, more recently electronically only. The monograph "Erdbebenkatalog für Deutschland" by *Leydecker* (2011), contains historical earthquakes before that time, wherein the first entry dates back to the year 813. The German earthquake catalogue has a magnitude of completeness of 2. It mainly contains tectonic earthquakes. However, since increasing mining activities triggered a higher rate of seismic stress release, more so-called mining induced events were detected and included in the event data base. Last but not least, explosions mainly in quarries and opencast mines are seismically recorded. Some of them are larger than magnitude 2, and therefore they are analyzed and included in the event data base as well.

Figure 5.3 shows the seismicity in Germany in the past 20 years. On average about 500 seismic events with magnitude above 2 are analysed every year. Of these 30% are tectonic earthquakes, 14% induced events, and 56% quarry blasts and explosions. However, no blast exceeded a magnitude of 3. Whereas, one earthquake per year on average is larger than magnitude 4. The tectonic active regions are the Lower Rhine area, the Upper Rhine Graben, Lake Constance area, Swabian Jura, the Alps area, and the Vogtland region. The occurrence of swarm quakes in the Vogtland is of special interest (see Section 5.1.5). The mining induced events are concentrated in the different mining areas: Coal mining caused the events in the Ruhr coal mining district and the Saar mining district. After abandoning mining in the Saar district in 2008 and the closing of all mines but one in the Ruhr district, the seismic activity was almost completely eliminated. Induced events by potash mining are registered in the Werra potash mining district and the South Harz mining district. Natural gas production caused an increasing number of seismic events in Northern Germany in the past 10 years (see Section 5.1.5). The utilization of geothermal energy is also accompanied by the risk of occurrence of seismic events as seen near Landau and Munich.

Analysis of Teleseismic Events

Besides investigations of local seismic events there is also a routine analysis of regional and teleseismic events at the SZO. Following the definition in the New Manual of Seismological Observatory Practice (NMSOP) (*Bormann*, 2012) we define as regional seismic events those occurring in the distance range up to 15 degrees (dominated by crustal and uppermost mantle phases) while events above 15 degrees distance are regarded as teleseismic. At the SZO teleseismic events are solely located with stations in Germany and in some cases supplemented by stations from neighbouring countries. The procedure is based on a detection list automatically created by several distinct trigger algorithms. Since only stations in Germany and surrounding countries are involved - which are far away from the seismic events - we apply array methods to identify distinct seismic phases and to locate the events. Either by f-k analysis of the data of the densely spaced Gräfenberg array sites or by coherent phase picking at waveforms of the large aperture GRSN stations we retrieve slowness and azimuth values for teleseismic phases. This direction information is used for backtracking the raypaths to estimate the epicenter. For events in the distance range below 100 degrees the first arriving P-phase is used for location. Figure 5.4 shows an example of the f-k analysis for a magnitude 8 event offshore Mexico (08.09.2017, 04:49:21 UTC, Ms 8.3)

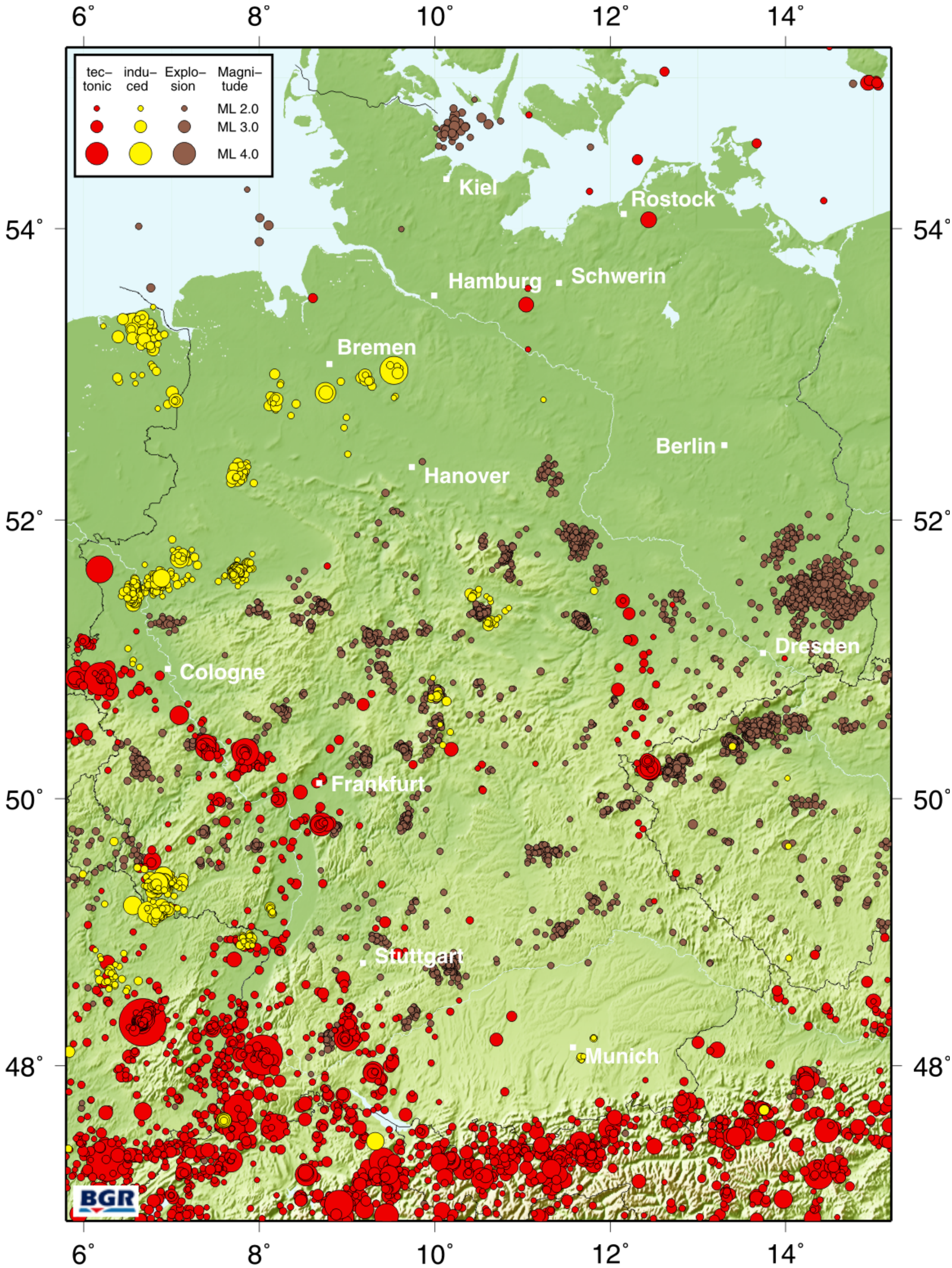

Figure 5.3: *Seismic events with magnitude 2.0 and above in Germany and adjacent regions in the recent 20 years (1998-2017). The tectonic events, induced events, and explosions are colour coded. The different magnitudes of the events correspond to the size of the circles.*

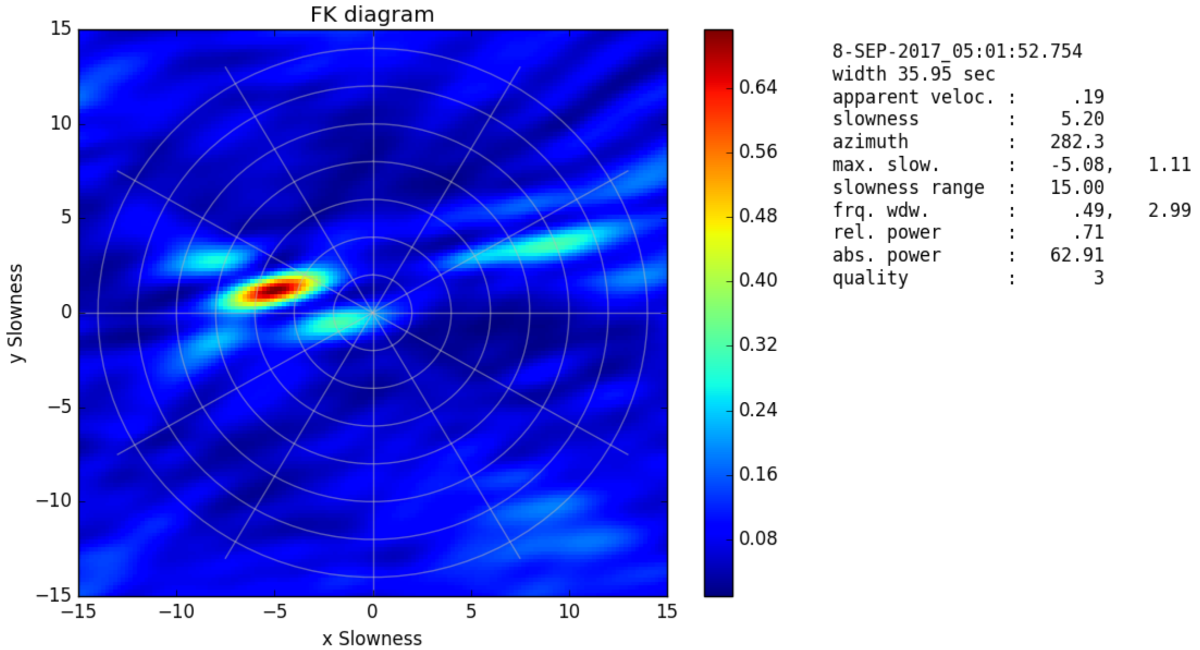

Figure 5.4: *Result of the f-k analysis for the P wavetrain of an event offshore Mexico (08.09.2017, 04:49:21 UTC, Ms 8.3) recorded at the Gräfenberg array. The inferred slowness and azimuth can be used to backtrack the ray and determine the epicenter.*

recorded at the Gräfenberg array. The inferred slowness is 5.20 and the azimuth 282 degrees.

For all P phases the body wave magnitudes are calculated and for events with a source depth shallower than 50 km the surface magnitude Ms is determined at stations GRA1 and MOX. Beside such common parameters as hypocenters, magnitudes, onset times and phase amplitudes, slowness and azimuths, which are important for teleseismic events, are also stored in a teleseismic database. As for the local events the data are transmitted to the EMSC immediately after manual analysis and monthly bulletins are sent to the ISC. Figure 5.5 shows all teleseismic events of 2017 that had been analyzed by the SZO with stations in Germany. Altogether, these are 1089 events. 837 events were located with our own algorithms. For the other 252 events we provide phase picks but no reasonably precise locations were found. In these cases locations from other agencies, mostly from NEIC or EMSC, were associated.

Depth Phases, Secondary Phases and Core Phases

In the routine analysis a special emphasis is also given to later phases. On one hand this is related to the detection and analysis of depth phases like pP or sP which appear after the P phase. Such a depth phase is comparably easy to identify as its slowness is identical or at least very similar to its related direct phase. Only when a prominent depth phase is visible, is the depth of the event determined, otherwise a fixed depth (e.g. 10 or 33 km) is chosen and assigned to the event. On the other hand, later phases like S, PcP, PP, SS, SKS etc. are also picked in the case of a stronger event, mostly for events above magnitude 6. We use so-called ”phase maps“ in order to identify later phases which may be worthwhile for further analysis. For a set of phases it shows a comparison between the theoretical values of travel time and slowness and a possibly corresponding occurrence of signal energy derived

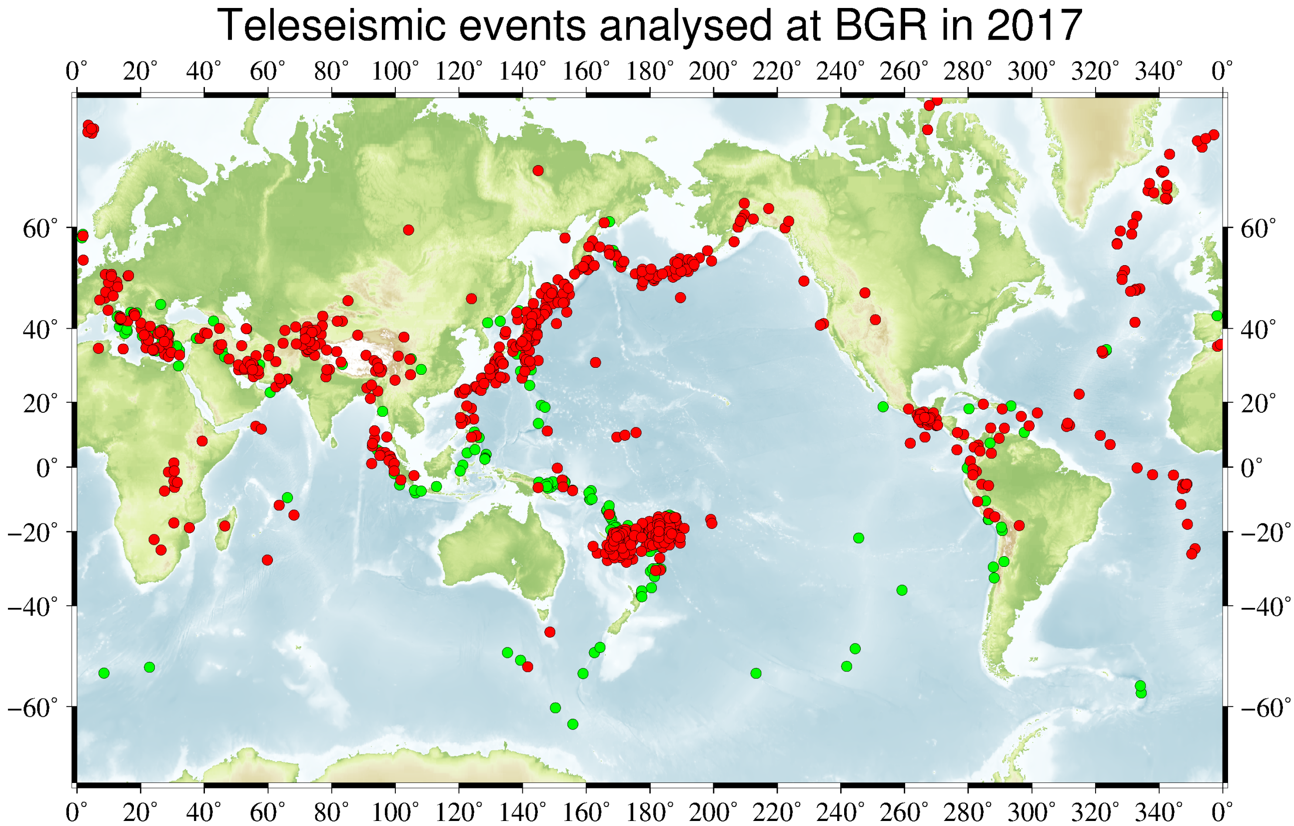

Figure 5.5: *World map showing epicenters of all teleseismic events that had been analyzed at the Central Seismological Observatory (SZO) of BGR for the year 2017. Red circles depict the events with epicenter location of BGR, green circles those for which only phase readings at German stations are associated to epicenter locations from other agencies.*

from array data of GRF and GRSN. Thereby, the plot helps the analyst to find those secondary phases which may be analysable. An example of this procedure is given in Figure 5.6 for the Mexico event of 08.09.2017 mentioned above. Figure 5.7 shows the three-component seismograms of the offshore Mexico event recorded at GRA1 comprising body and surface waves as well as the identified and picked direct phase (P) and later phases (S, SS, L).

Nearly 40% of our located events contain core phases generated at sources in the distance range greater than 140 degrees. These events are mostly located within the subduction zone at Fiji and Tonga, one of the most seismically active regions in the world. Since the epicentral distance between Fiji/Tonga and stations in Germany ranges between 142 degrees and 150 degrees, our stations are in most cases in or close to the caustic of the PKP branches in about 144 degrees. At the caustic the PKP phases (PKPdf, PKPbc and PKPab) are of comparably strong amplitude and can be easily identified by traveltime and slowness on short period filtered records. Especially, the PKPbc is dominant from 146 degrees to about 153 degrees. Due to the strong variation of the PKPbc slowness with distance, the phase is very suitable to locate the events. Therefore, and with respect to the caustic, we are sometimes able to locate events down to a magnitude of 4. Depending on the hypocenter and the radiation it is sometimes possible to identify and pick all three PKP branches and moreover in some cases also the corresponding depth phases. For deep Fiji events we are able in numerous cases to locate them and their depths in comparable accuracy to NEIC, GFZ and EMSC.

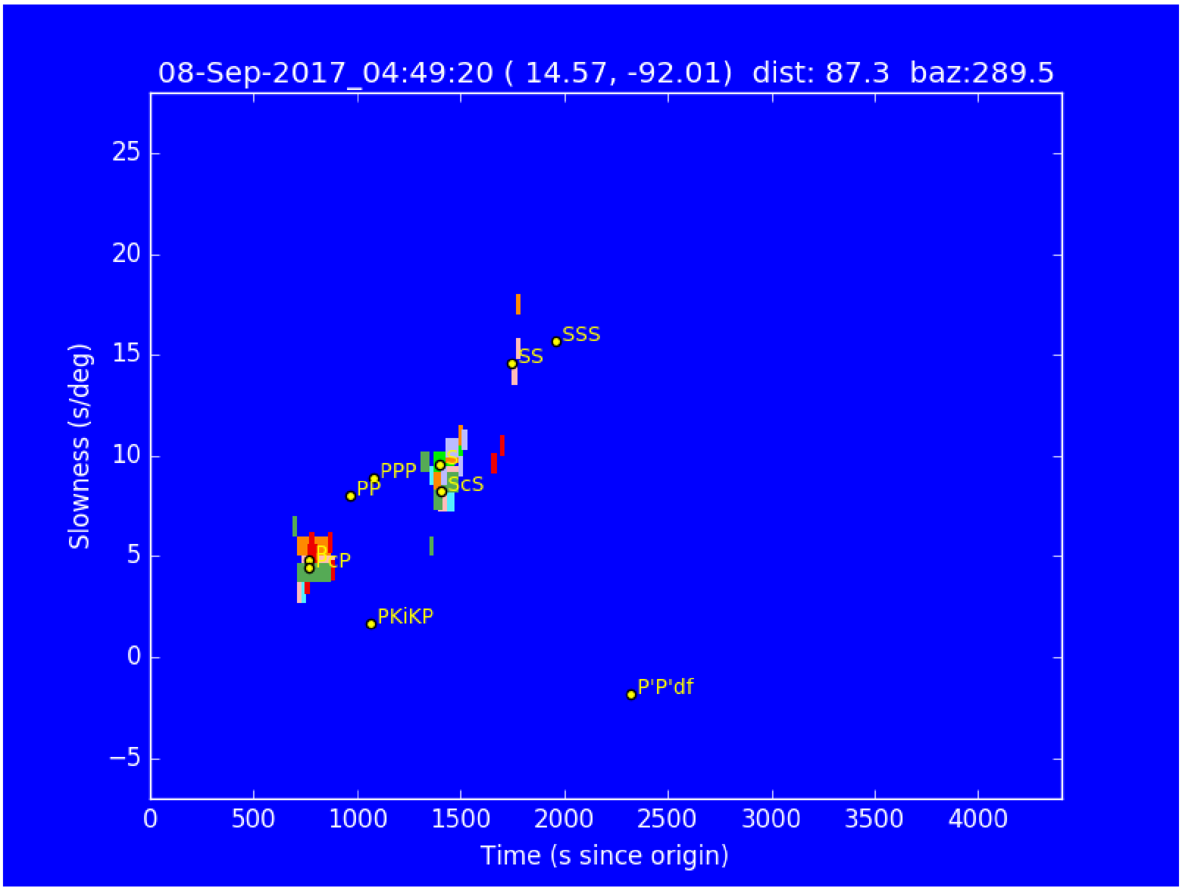

Figure 5.6: Phase map calculated for the magnitude 8 event offshore Mexico (08.09.2017, 04:49:21 UTC, Ms 8.3). The theoretical onset times and slowness of distinct phases are given by labeled circles. Coloured bars denote times for which coherent energy is found in the "real" seismograms either for the Gräfenberg array or for the GRSN (different colors are related to different filters, components or arrays not explained here). In case theoretical values coincide with a coloured bar an analysis of the phase may be worthwhile.

Table 5.1: Quantity of particular picked phases in 2017. PKP are PKP phases which could not be unequivocally assigned to one of the three PKP branches.*

Direct Phases	Quantity
P	10844
pP	1139
sP	61
Pdif	280
sPdif	26

PKP Phases	Quantity
PKPdf	1237
PKPbc	5655
PKPab	733
pPKPdf	82
pPKPbc	685
pPKPab	11

Later P Phases	Quantity
PP	341
PcP	18
PKP*	117
PKiKP	72

S + L Phases	Quantity
S	217
SS	27
ScS	1
SKPdf	11
SKPab	1
L	1437

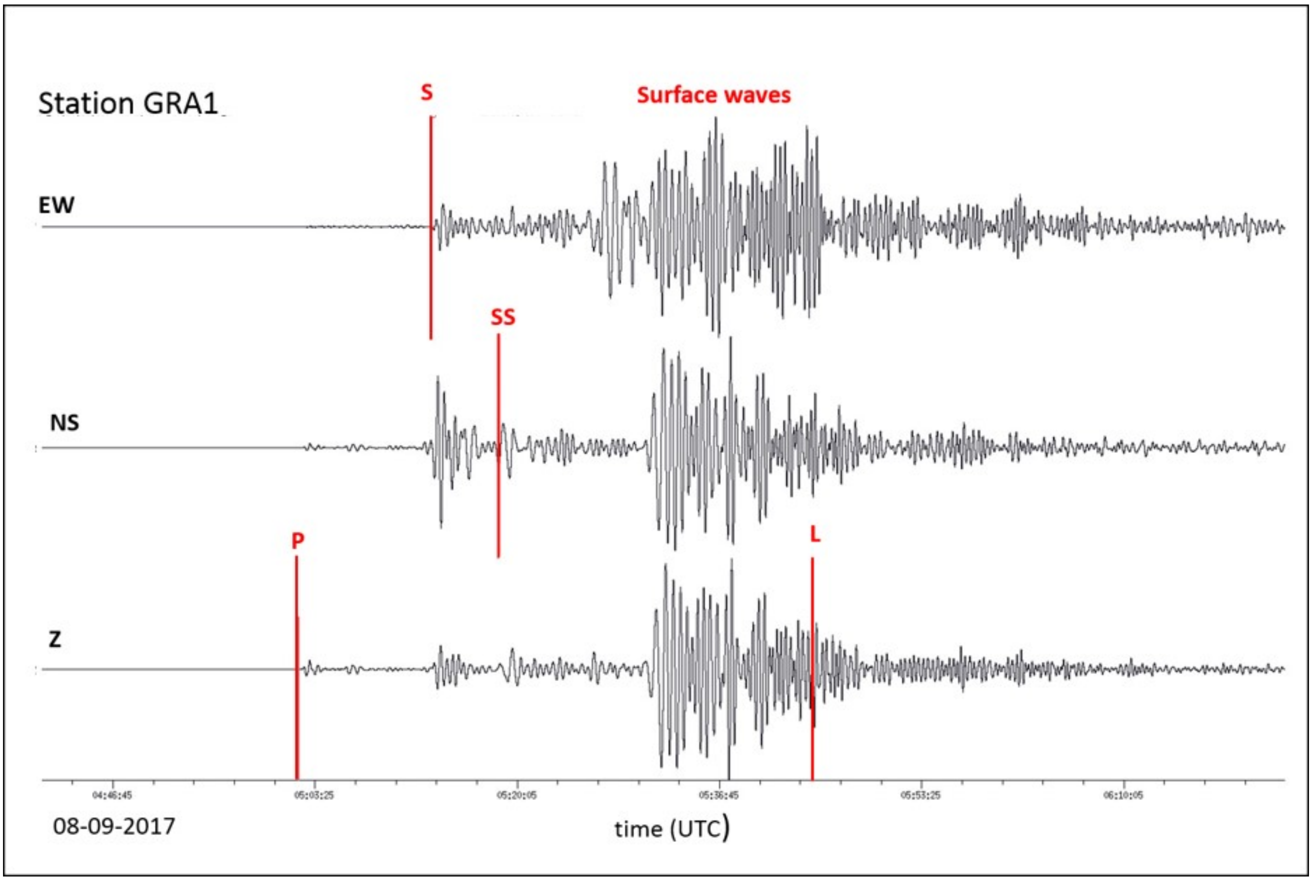

Figure 5.7: *Three component seismogram of the magnitude 8 event offshore Mexico (08.09.2017, 04:49:21 UTC, Ms 8.3) recorded at station GRA1 of the Gräfenberg array. The SRO-LP filtered seismograms show the body and surface waves as well as identified and picked phases.*

In summary, altogether 10844 P phases, 306 Pdif phases, 1888 later phases and 8403 PKP phases including depth phases have been determined in the year 2017 and incorporated in our database (Table 5.1). In case of a strong and/or important earthquake, like the Tohoku earthquake 2011, the Amatrice earthquake 2016 or the recent Lombok event 2018 we create special websites, give information and interviews to the media and respond to questions from the public.

5.1.4 Operating the German National Data Center for the Verification of the CTBT

The development of nuclear weapons is attended by the necessity for nuclear tests, most of them are conducted beneath the surface. Seismological stations are predestined for the monitoring of underground explosions. Consequently, the BGR with its Central Seismological Observatory was requested to host the German national data center (NDC) for the verification of the CTBT. After the Partial Test Ban Treaty was signed in 1963, the initial Gräfenberg array (GRF) was installed by the Advanced Research Projects Agency (ARPA) of the United States of America in order to register nuclear explosions mainly in the former Soviet Union. In the 1970s the array was reconfigured and modernized and became the world's first broad band digital seismic array (see Section 5.1.2). Thus, the data archive at BGR provides seismic GRF recordings for nearly all nuclear tests at the different test sites for more than 40 years.

Small aperture arrays for better detection capability of nuclear tests in regional distances were installed in the 1980s in Norway, Finland, and Germany. The GERES array is part of those stations. The geological conditions and distance from urban areas made it a highly sensitive station, which became one of 50 primary seismic stations (PS19) in the International Monitoring System (IMS) of the CTBT. The BGR assumed the responsibility as station operator in 1997. The array was upgraded to fulfill the requirements of the IMS.

Since the CTBT prohibits not only underground nuclear tests but also explosions in the ocean and in the atmosphere, hydroacoustic and infrasound techniques are necessary for the verification of the treaty. In this regard, the BGR established the infrasound array IS26, which is co-located to the seismic PS19 array. In 2001, it became the first certified infrasound station of the IMS. Another infrasound station (IS27) at the instigation of BGR was installed at the German Antarctic research station Neumayer. Finally, BGR equipped the seismic station SNAA at the South African Antarctic research base SANAE in co-operation with the Council for Geosciences in South Africa. This is a three component station and acts as an auxiliary seismic IMS station (AS035).

Ensuring the reliable operation of the German IMS stations is one task of the German NDC for the verification of the CTBT. Main criteria are a data availability of at least 98 % per annum with a maximum transmission latency of 5 minutes to the international data center (IDC). The second important NDC task is to provide the German government with the scientific expertise in monitoring nuclear explosions. Moreover, the NDC is located at the interface between CTBTO and the German verification community and supports research activities on verification-related issues. The German NDC benefits very much from the integration with the Central Seismological Observatory (SZO) at BGR. For the analysis of suspicious events, the NDC makes use of all IMS data complemented by data of international seismic networks, which are freely available through international data centres (e.g. IRIS). This allows independent processing, aimed at improving detection capability, localization and source identification. For example, the set of six nuclear explosions in North Korea within the recent 12 years allows a comprehensive assessment with precise results of relative location and source mechanism. Figure 5.8 shows the recordings of the six North Korean nuclear explosions at the German IMS station PS19 (GERES).

5.1.5 Analysis of Special Seismic Events

Induced Seismicity at the Natural Gas Fields in Northern Germany

The Northern German basin is a tectonic region of relatively low seismic activity with only singular and weak tectonic events. However, during recent decades seismicity rose in the vicinity of natural gas fields in that area with continuous gas gathering. Due to the spatial vicinity of the earthquakes to the operated gas fields and their occurrence starting after the beginning of extraction they are ranked as induced seismic events. The area of epicenters of these events extend 50 km NS and 400 km EW from the border to the Netherlands in the West to Altmark region in the East (Figure 5.9).

Altogether, more than 80 events with ML 0.5 to 4.5 were detected and analyzed between 1977 and 2017. Many of them were felt by some of the inhabitants up to 15 km from the epicenter whereas the strongest one, the magnitude 4.5 event close to the village of Rotenburg on 20th October 2004, was felt in Hamburg as far as 65 km from the epicenter. Whereas epicenters could be determined precisely, other

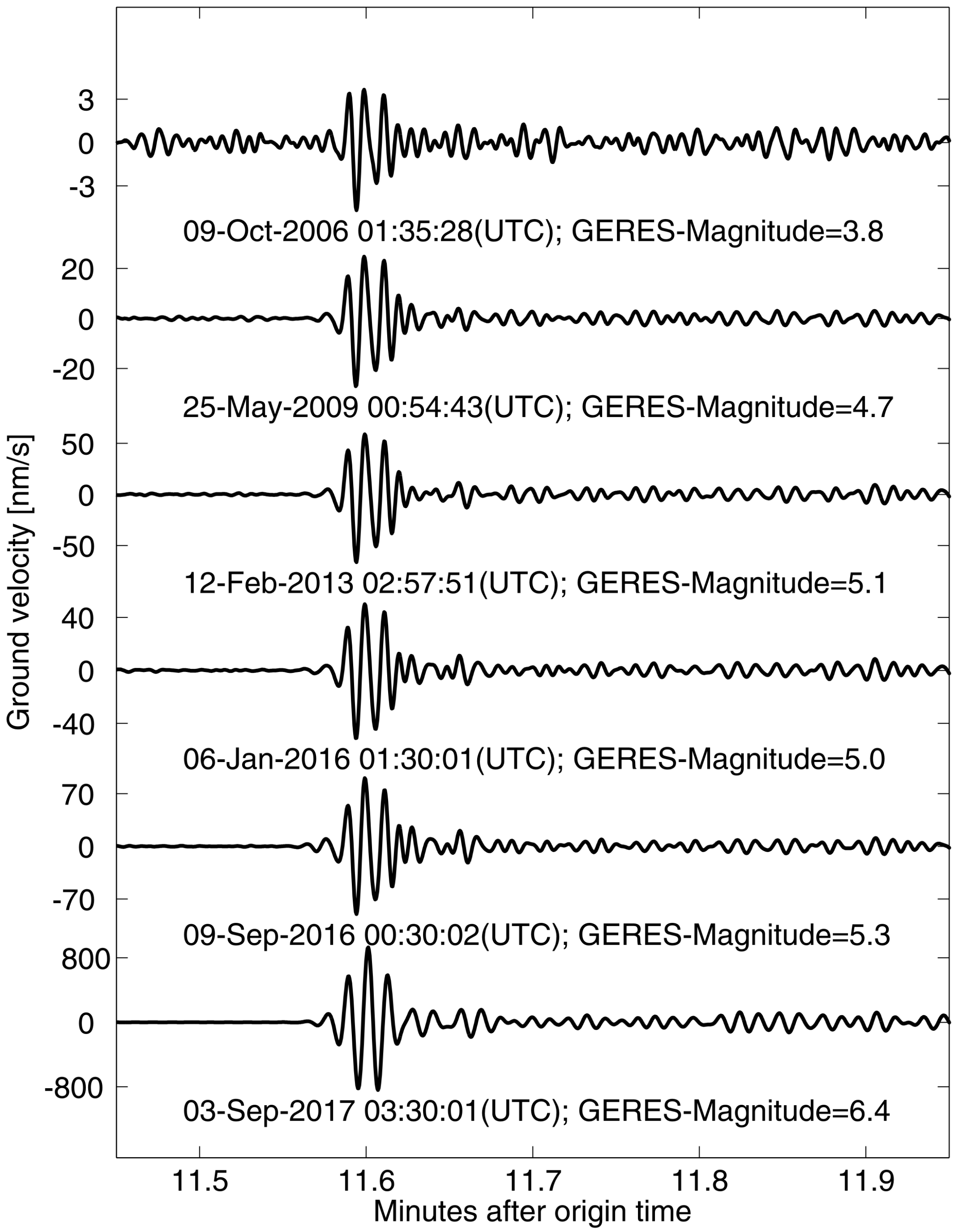

Figure 5.8: *Recording of nuclear explosions: The six North Korean nuclear explosions were recorded at the German IMS station PS19 (GERES) about 11.58 minutes after origin time. The seismic beams are displayed, which are estimated from the filtered traces (Bandpass 1.2-2.8 Hz) of the 25 array elements. The signals of the P wave are highly correlated due to the similar source conditions of the individual nuclear explosions. They differ mainly in the amplitudes, from which the GERES magnitude is calculated.*

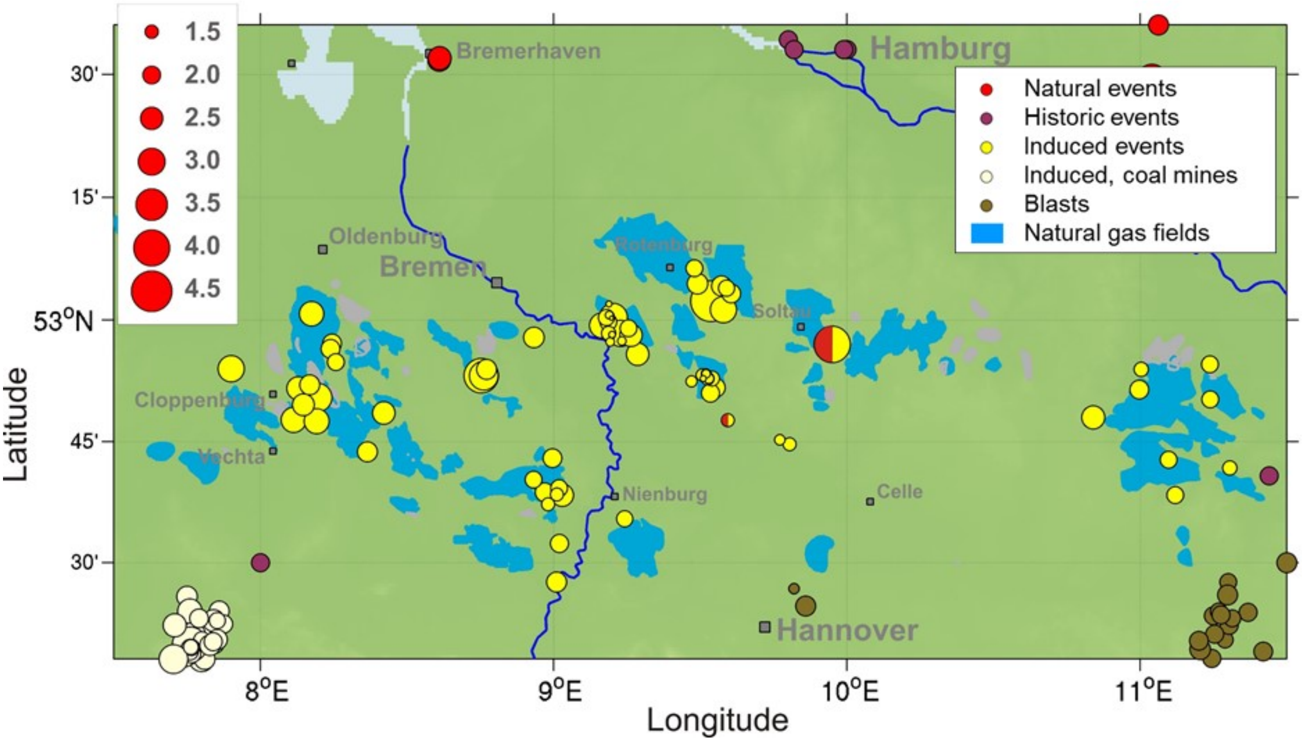

Figure 5.9: *Seismicity in the vicinity of the natural gas fields (blue) in Northern Germany of the years 1977 to 2016. Events are divided into induced events (yellow), natural events (red), blasts (brown) or historical events (purple). The bicolored event is the Soltau earthquake of 1977 for which it is still not clear if it is induced or natural. (Source: Nicolai Gestermann)*

source parameters, such as focal depths and focal mechanisms, were of lower accuracy. This was mainly caused by the sparse station coverage in the area, at least until 2010, and unfavourable signal-to-noise conditions as a result of thick sedimentary layers. The situation changed when the SZO installed some permanent and temporary stations in the area from 2010 onwards and the gas production companies also started to renew and extend their monitoring networks. On the basis of the enlarged networks focal depths are now more precisely determined for the recent events. It became apparent that most of the events have focal depths close to the reservoir horizon, a further indication for their classification as induced events.

The process of earthquake generation is still not well understood. Trigger mechanisms have not systematically been investigated. However, it is commonly accepted that there is a pressure reduction in the reservoir as a consequence of the gas extraction which leads to heterogeneous compaction within the reservoir and variations in the local stress field. The majority of the focal mechanisms calculated so far represents normal faulting and orientations of nodal planes being in quite good agreement with the strike direction of tectonic faults limiting the natural gas fields.

Knowledge and competence in the field of induced seismicity is of great importance for the SZO as division of BGR. As a subordinated agency of the federal government BGR has a duty to inform and advise the government as well as the public in any issues of energy supply as well as of protection of the civil population. In this context the expertise of BGR in the field of induced seismicity and its aftermath is steadily demanded during recent years.

Swarm Earthquakes in Vogtland/NW-Bohemia

An interesting area exhibiting natural seismicity in Germany is the Vogtland/NW-Bohemia area at the border between Germany and the Czech Republic. It is known as one of the most famous earthquake swarm regions in Europe. The special type of seismicity - called swarms - is expressed by the accumulation of a huge number of events of similar magnitude and their episodic reoccurrence. During a swarm hundreds or thousands of earthquakes without a distinct main shock occur spatially and temporally clustered.

The most recent swarm in Vogtland/NW-Bohemia occurred between the 10th of May and the beginning of August 2018. With more than 1000 detectable events and magnitudes up to 3.9 it is one of the most prominent swarms in last decades succeeding the big swarms of 2011, 2008, 2000 and 1985/86. The swarm is located close to the small village of Novy Kostel on Czech territory close to the border with Germany. The events were felt by a huge number of inhabitants on the Czech and German side and numerous requests were posed to the SZO. The SZO launched a press release and several interviews were given to the media. During the routine analysis at the SZO more than 100 events with magnitude above 2 were located and incorporated in our database as well as in the German earthquake catalogue where our analysis supplements the analysis of the universities, in this case the analysis of Collm Geophysical Observatory of the Leipzig University (for more information on Collm observatory and their analysis of events in Vogtland region see article in Summary of the Bulletin of the ISC by *Wendt and Buchholz* (2017)) and the TSN (seismic network of Thuringia) of the Jena University. The epicentres of the new swarm as well as those of the preceding swarms are given in Figure 5.10. The new swarm is located in the more northern part of the NNW-SSE oriented cloud of epicentres formed by preceding swarms. Primarily, all epicentres follow the strike of the Marianske Lazne fault zone and parallel striking fault systems and are located close to the crossing with the Eger rift.

The detailed analysis of the distinct swarm events is not only of statistical interest and to hold a complete catalogue. The analysed Vogtland events are also a basis for scientific investigations with respect to the physical and tectonic reasons and processes of the swarms, which are still under debate. There are many indications for some kind of volcanic phenomena as reasons for the swarms and some recent scientists have formulated the hypothesis that the swarms may be a kind of precursor for the formation of a volcano.

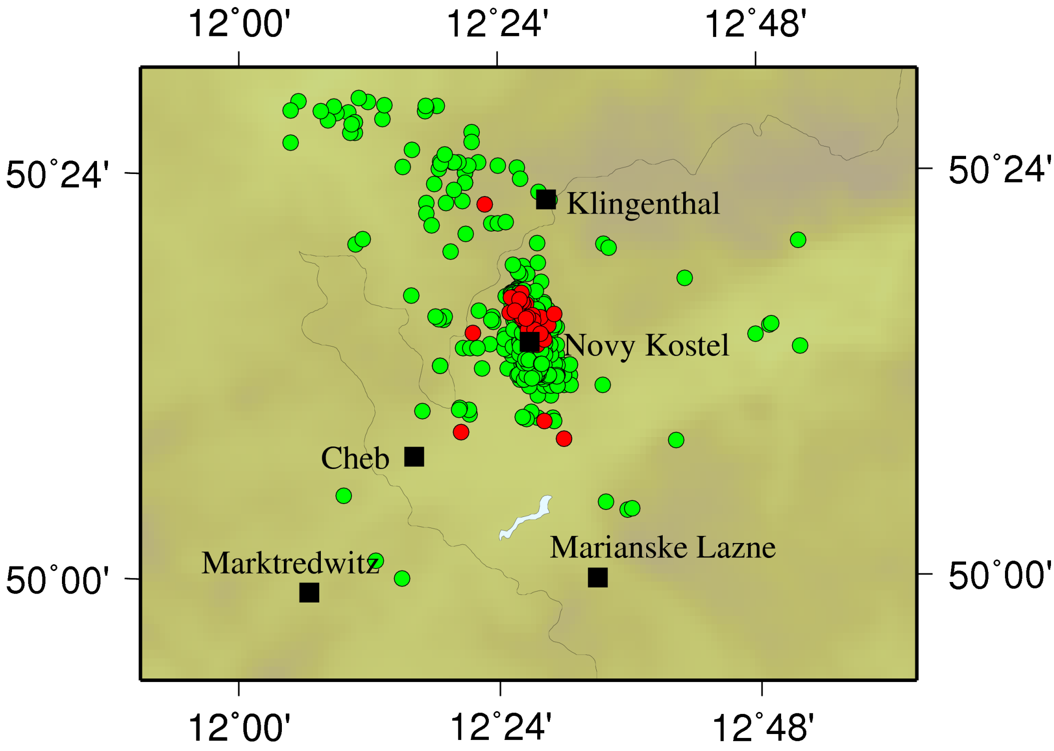

Figure 5.10: *Epicenters of earthquakes recorded and analysed at the SZO for the broader region of Vogtland/NW-Bohemia. Green circles denote the events since 1990, red circles the events of the recent swarm in 2018.*

5.1.6 References

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