Ten years of seismicity in the Euro-Mediterranean region: Panorama of the EMSC bulletin 1998-2007

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Abstract

The Euro-Mediterranean Seismological Center (EMSC) is in charge since 1998 of collecting seismological parametric data recorded by local institutes of the Euro-Mediterranean region in order to improve data availability for the seismological community and to rapidly produce a comprehensive bulletin for the region. The goals are to reproduce the seismicity as imaged by the local agencies when events occur within their network and to improve event location in borders regions and off-shore.

The Euro-Med Bulletin now contains ten years of seismicity from January 1998 to December 2007. Event locations have been obtained by merging parametric data collected from 77 seismological agencies. Thanks to the many contributions, the Euro-Med Bulletin displays a high coverage of the region with the collection of data recorded by 2,465 stations. In total, 102,000 events are included for the period 1998-2007. We present here the performances of the Euro-Med Bulletin and their evolution over the years.

Willing to continuously improve its performances, the EMSC is working on further discarding non tectonic events from the current Euro-Med bulletin which could be achieved by setting up additional collection of event type information (from rockburst to mine activity) with the help of the local networks. Additionally, the currently available bulletin will be enriched with low magnitude events and will be recomputed using the global velocity model ak135 as recommended by IASPEI.

Introduction

The European Mediterranean Seismological Center (EMSC), created in 1975, is an international NGO hosted since 1992 by the LDG (Laboratoire de Détection et de Géophysique, CEA France). Its members are seismological institutes and observatories of the Euro-Med region that spans from Iceland in the North West to Yemen in the South East. Its main scientific activities are Real Time Earthquake Information services and the production of the Euro-Med Bulletin (Godey et al., 2006) accessible on the web (www.emsc-csem.org).

The Bulletin activities rely on the collection of manually revised parametric data provided by the seismological networks of the Euro-Med region. After merging the data, the Euro-Med Bulletin is reviewed then published through the internet and provided to the ISC.

The main objectives of the Euro-Med bulletin are to:

- Collect and archive bulletin data from the Euro-Med region.
- Improve data availability for the seismological community through the EMSC database collected since 1998 (including contributors and EMSC bulletins).
- Produce a regular bulletin rapidly after earthquake occurrence in the Euro-Med region with a magnitude threshold of 3.0.
- Reproduce the seismicity when occurring inside the local networks region and improve events location in border regions and off-shore.
- Compute magnitude when station amplitude/period information are provided.

Data Collection and Bulletin Production

The data collected by the EMSC are manually revised parametric information. These information can be either bulletins data which include earthquake source parameters (origin time, epicentre, depth, event type and magnitudes) with the associated arrivals or groups of arrivals for which no location is available. The groups and isolated arrivals are useful as they can be associated to a hypocenter reported by other networks and help constraining the hypocenter location. For all data types, the detailed arrivals information include station code, phase identification, arrival time and amplitude/period information when available. All station codes must be registered at the International Seismological Station Registry, maintained by the ISC and the NEIC. The EMSC has become an important relay from the local institutes helping in the registration of more than 700 stations participating for the first time to international data exchange.

The EMSC encourages data contributors to provide rapidly (weekly or mnthly) their data to ensure their full use in the EMB production. The recommended procedure to provide data to the EMSC is ascii format by email.

The production of the EMB relies on the association of the data collected from several networks and the computation of event hypocenters using the related readings (Godey et al., 2006). The software to perform the association and event location was developed by our host, the LDG and was incorporated in the Euro-Med Bulletin production in the framework of the EPSI project (Earthquake Parameters and Standardised Information for a European-Mediterranean Bulletin). The epicenter location method is based on an improved version of the Geiger algorithm (Geiger, 1910). A triangulation method is applied for local events and a classical Husebye method is performed for teleseismic events. The current location procedure uses both local and global velocity models. The crustal velocity models are provided by the contributing networks or were defined for border regions within the EPSI project. The global velocity models are based on the Jeffreys-Bullen tables for P and S phases (Jeffreys and Bullen, 1940) and Iaspei91 for the other phases (Storchak *et al.*, 2003). For each event, an automatic location is computed using phases from different networks before entering a manual review (for approximately 80% of the events).

Data Contributions and Evolution Over Ten Years

Since 1998, the EMSC has received data from 77 different data contributors from 56 countries (Appendix A). All of the institutes did not provide data continuously, some of them were temporary networks and others have merged under a unique institute. Therefore the maximum number of unique contributors is 71, reached in 2007. The evolution over ten years (Fig. 1) shows a drastic increase in the data collection, particularly in the last years. The large increase observed since 2003 reflects the combined effort of the EMSC and the network operators to establish reliable data exchange procedure. Several networks have started to make their data available to the international community by providing for the first time their data to the EMSC. Among those new contributors, we can name Tunisia, Libya, Egypt, Uzbekistan, Dubai, Latvia, Belarus and Lithuania. Those new contributions made the Euro-Med Bulletin the most complete collection of data for the region.

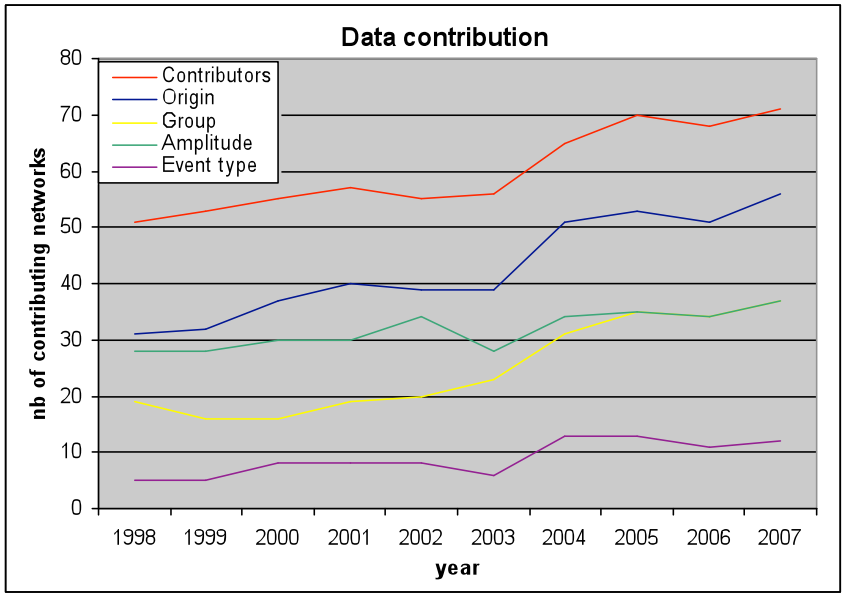

Figure 1: Evolution of the data contribution by the EMSC between 1998 and 2008.

In addition to basic parametric data, 37 networks (in 2007) provide amplitude and period information to the EMSC. These information are crucial to calculate an independent estimation of the magnitude. Since 1998, the number of networks providing amplitude/period information has increased from 28 to 37 over ten years, but still only represents 50% of all contributing networks.

Event type information is provided in the Euro-Med bulletin. It includes earthquake but also non tectonic event information such as rock burst, induced event, mine explosion, experimental explosion, nuclear explosion, landslide using the nomenclature defined in IASPEI (Bormann, 2002). It is becoming a crucial point to avoid misinterpreting the seismicity in a specific region. In particular, if a seismicity catalogue is used for seismic hazard assessment studies, draw-backs can be propagated. However, identifying induced seismicity is only possible when the contributors provide this information. Though the EMSC is devoting a large effort to collect event type description, it is often missing from the data contributions. Since 1998, a total of 15 networks (this values varying over the years) have included event type information in their data exchange (Fig. 1). Seven networks only provide

information on known earthquakes and discard non tectonic events from their contribution to the EMSC. More contributions and detailed event type policy information are needed to further discard non tectonic activity from the Euro-Med Bulletin.

A total of 2,465 stations in the Euro-Med region (Fig. 2) have reported revised parametric data to EMSC since 1998. The distribution of stations in the Euro-Med region shows a good coverage except gaps in Ukraine and parts of the Middle East (Fig. 2).

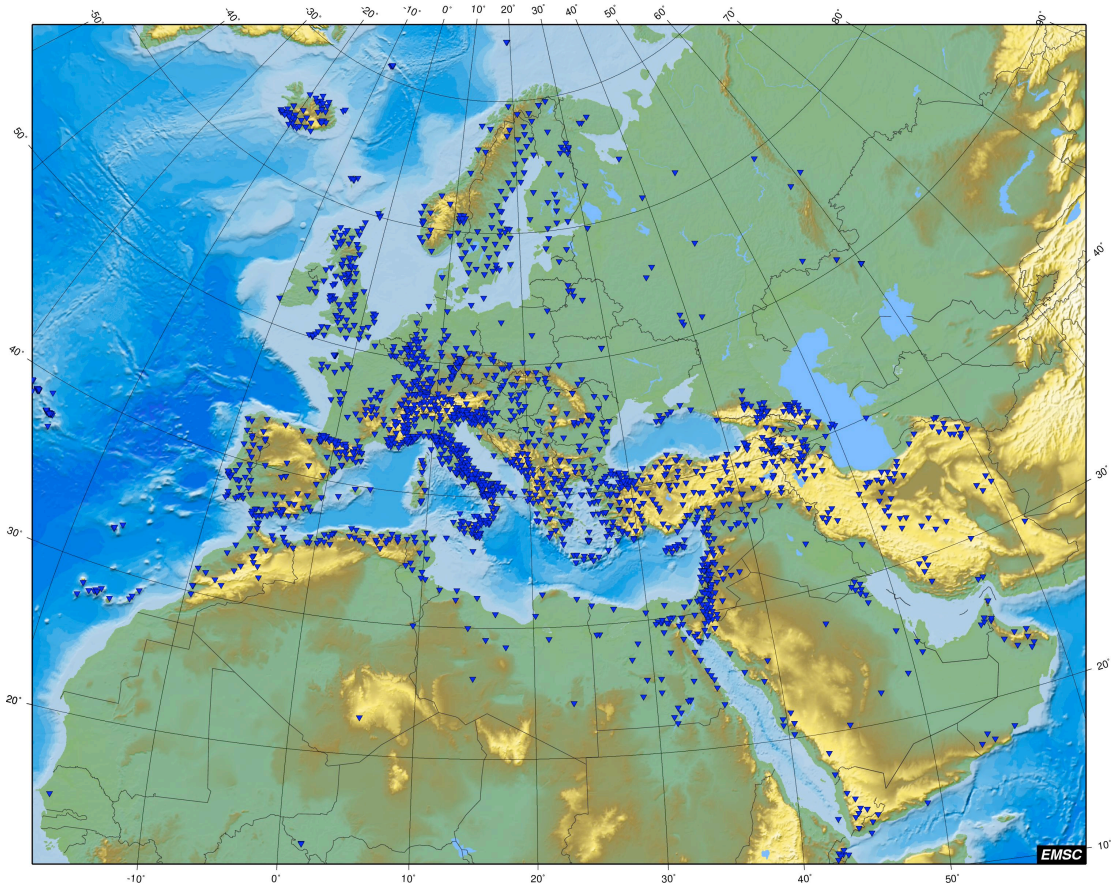

Figure 2: Location of the contributing stations to the Euro-Med bulletin.

Products and Data Access

Three classes of events are defined for the Euro-Med Bulletin.

- Associated events are events for which phase association from several networks is possible. In this case, a new location is computed.
- Reported events are events recorded by a single network in its authoritative region. This region corresponds to the network deployment area, comprising the country and extending into the sea or neighboring countries. In this case, no phase association is possible and the location of the local network is reported without relocation.
- Deprecated events are events recorded by a distant network (outside of its authoritative region). No phase association is possible and the location of the contributing network is reported without relocation and flagged as dubious. These events are discarded from the published Euro-Med Bulletin. Their access is only possible upon specific request.

The Euro-Med catalogue (list of locations) is fully available to the general public on our web site http://www.emsc-csem.org/index.php?page=data&sub=drm. Free and full access to the raw bulletins (i.e. original bulletins provided by the contributing networks) database (by autoDRM) and to the Euro-Med Bulletin is given to all data contributors and EMSC members for non commercial uses through our web site http://www.emsc-csem.org/index.php?page=data&sub=drm. The requested data are provided in GSE2.0 format. By the end of 2009, all EMB products should become available to all. Since 2006, the Euro-Med Bulletin is also integrated to the ISC bulletin.

Euro-Med Bulletin 1998-2007 Content

For the period January 1998 to December 2007, the Euro-Med bulletin encompasses 102,014 events (corresponding to above 2.5 millions phases). Since 2003, the amount of events in the Euro-Med bulletin has dramatically increased reaching 21,562 events for the year 2007 (Fig. 3). This increase is related to the additional contributions from several networks and to the change of the magnitude threshold (from 3.0 to 2.5) applied in the manual revision. The evolution of the number of phases used in the Euro-Med Bulletin over the years follows a similar trend.

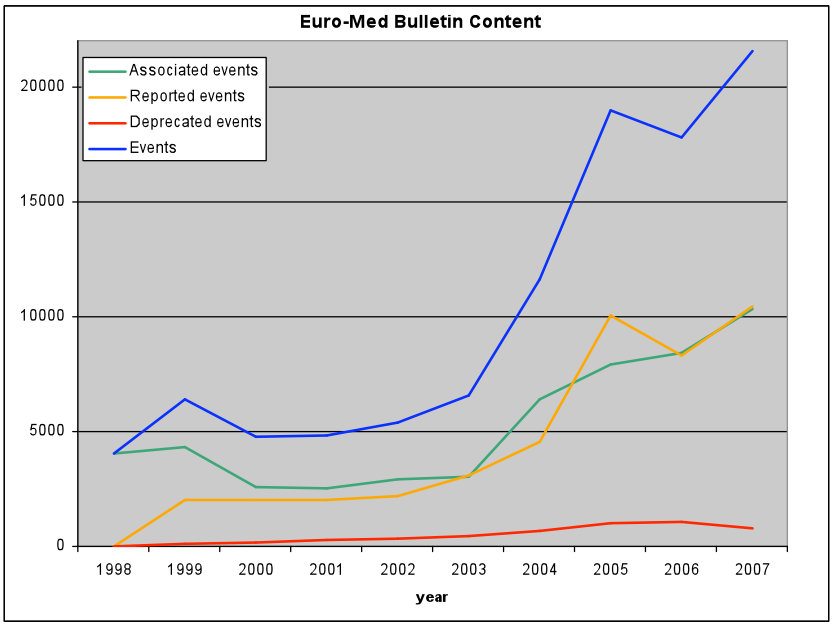

Figure 3: Evolution of the data content of the Euro-Med Bulletin from 1998 to 2007.

Fig. 3 also shows the evolution for each type of classes. The number of reported events has increased in a similar way to the number of associated events in relation with the growing contributions. Those events occurred mostly in the seismically active Aegean region. The higher number of reported events in 2005 is also mainly related to the Greek earthquake sequence of October and November for which smaller events were only reported by the National Observatory of Athens.

Seismicity in the Euro-Med Region between 1998 and 2007

The Euro-Mediterranean region is the scene of highly variable tectonic processes although the African-Eurasian plate interaction dominates the geodynamic regime. Regions with the highest seismicity are related to major faults (North Anatolian fault,

Dead Sea fault) corresponding to shallow earthquakes and subduction zones (Hellenic Arc, Calabria, Vrancea) displaying deeper events. Subcrustal seismicity is also depicted near the Gibraltar Arc and in the South of Spain. Seismicity occurs also along the Mid Atlantic and the Red Sea-Aden Gulf Ridges. Continental collision also generates high subcrustal seismicity in the Zagros region. Other areas of lower seismicity are characterized by diffuse and intermittent activity.

The maps of natural seismicity obtained in the Euro-Med Bulletin (where non tectonic events and deprecated events are discarded) are presented on Fig. 4 and 5 as a function of magnitude and depth.
Both magnitude and hypocentral distributions obtained characterised well the seismicity. Three earthquakes of magnitude greater than 7.0 are observed and 44 events of magnitude greater than 6.0 (Fig. 4). For magnitude lower than 3.5, heterogeneous distribution can be obtained as each network uses different magnitude threshold in their contribution to the EMSC. The threshold applied by the Icelandic network is set to 3.5, whereas it is set to 2.0 in Norway. Seismicity in the Sub-Saharan Africa and part of Russia is under sampled in the Euro-Med Bulletin due to little constraints available in those areas. Low magnitude seismicity may also be missing at the edges of the study areas (Mid Atlantic Ridge, Aden Gulf).

Seismicity related to subduction zones are well characterised in the Euro-Med bulletin (Fig. 5) in the Tyrrhenian Sea and in the Hellenic Arc. The Vrancea is defined by a narrow zone of large depth seismicity. Intermediate seismicity is observed in the Gibraltar, Zagros and Cyprus regions.

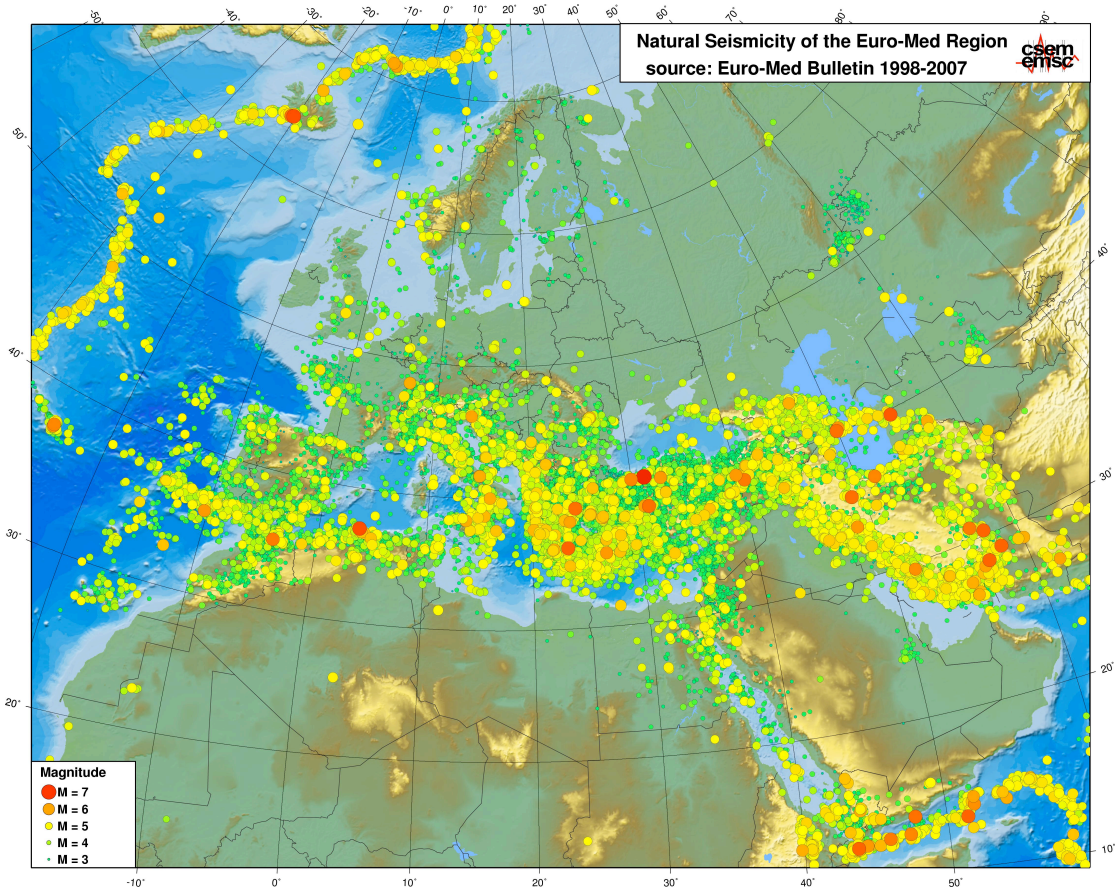

Figure 4: Earthquakes magnitude distribution in the Euro-Med bulletin between 1998 and 2007.

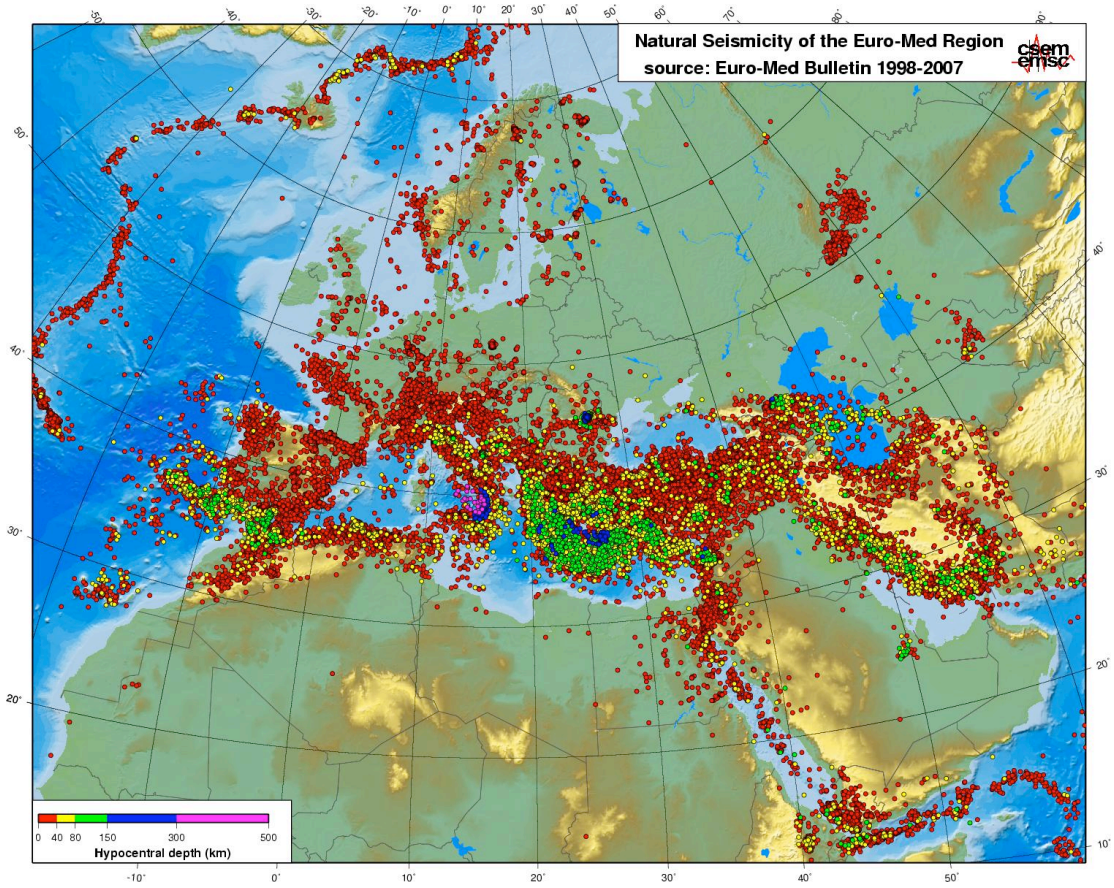

Figure 5: Earthquakes hypocentral distribution in the Euro-Med bulletin between 1998 and 2007.

Euro-Med Bulletin Performances

The Gutenberg Richter law computed for associated and reported events displays a magnitude ML completeness of 2.8 (Fig. 6). The completeness has been improved in the Euro-Med Bulletin since 2006 when the magnitude threshold for reviewing was lowered to 2.5 (Godey et al., 2006). The magnitude completeness is 4.0 for mb magnitude (Fig. 6).
The comparison of 6,266 events reported by the NEIC (PDES) for which mb magnitude are available shows a large agreement of the two bulletins (Fig. 7) with 86% of the events displaying a magnitude difference of less than 0.2. In terms of ML magnitude, 3,068 events could be compared. Again, the two bulletins are largely consistent. However, most ML values included in the EMB and PDES are not independent but reported from the same local networks.

The azimuthal gap provides a first insight on the earthquake location constraint obtained in the Euro-Med Bulletin. The results for the period 1998-2007 are provided on Fig. 8 for associated events. High resolution is observed for most of the Euro-Med region although lower azimuthal gap is obtained at the outskirt of the area and at the coasts (e.g. West of Gibraltar). The active region of Greece and Turkey is well covered, except in the Libyan and Ionian Seas. In this region, improvements are already observed since 2007 thanks to the data contribution from Libya. In the North of the Red Sea, lower resolution is also obtained which should be improved by new data contribution from Saudi Arabia and Egypt.

Over the 10 years for which the Euro-Med Bulletin has been computed, the azimuthal gap has greatly improved. 70% of the events of 2007 display a gap lower than 140° against 45% in 1998 (Fig. 9).

To further assess the accuracy of the earthquakes location included in the Euro-Med Bulletin, we have performed a search of events fulfilling the ground truth (GT)

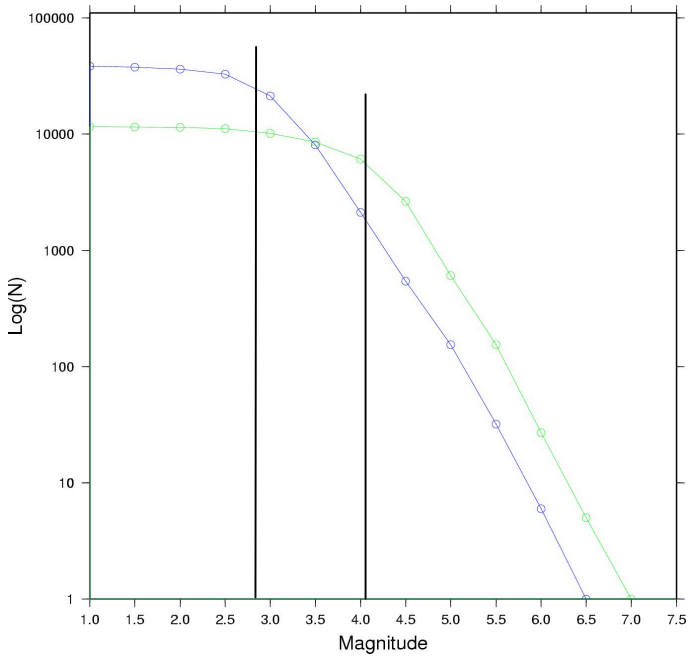

Figure 6: Gutenberg-Richter cumulative distribution for mb (Green) and ML (blue) magnitudes observed in the Euro-Med bulletin.

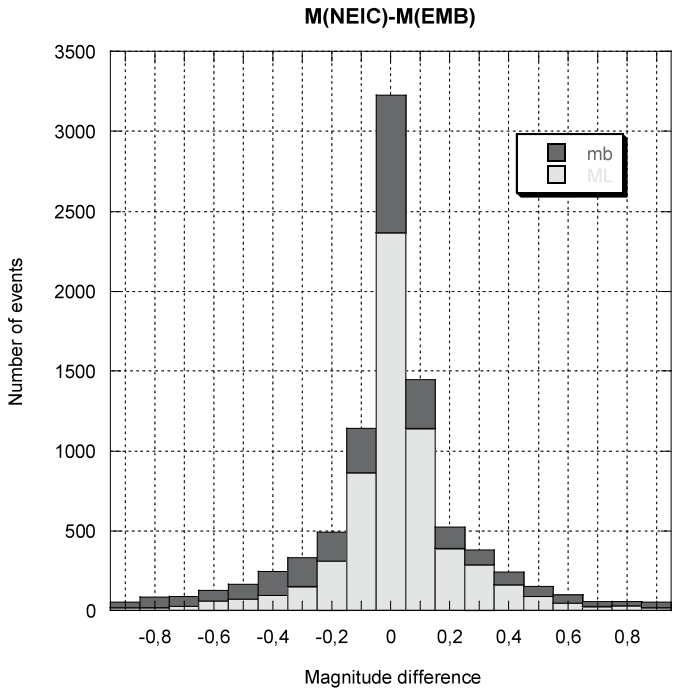

Figure 7: Comparison of mb and ML magnitudes computed at the NEIC and in the Euro-Med bulletin for all associated events. Mean values are -0.06 for mb and 0.02 for ML. Associated standard deviations are 0.49 for mb and 0.27 for ML.

criteria as defined by Bondar et al. (2004). 4,702 events of our bulletin correspond to GT5 events at 95% confidence (Fig. 10). For those events the epicenter information uncertainty is estimated to 5km. Their number has steadily increased over the years, from 200 in 1998 to 1,400 in 2007, showing the ongoing improvements in the data collection and bulletin production at the EMSC. The distribution of GT5 events mainly relies on the station distribution. Most of the GT5 events lay in Western Europe and in Turkey where the station density is the highest.

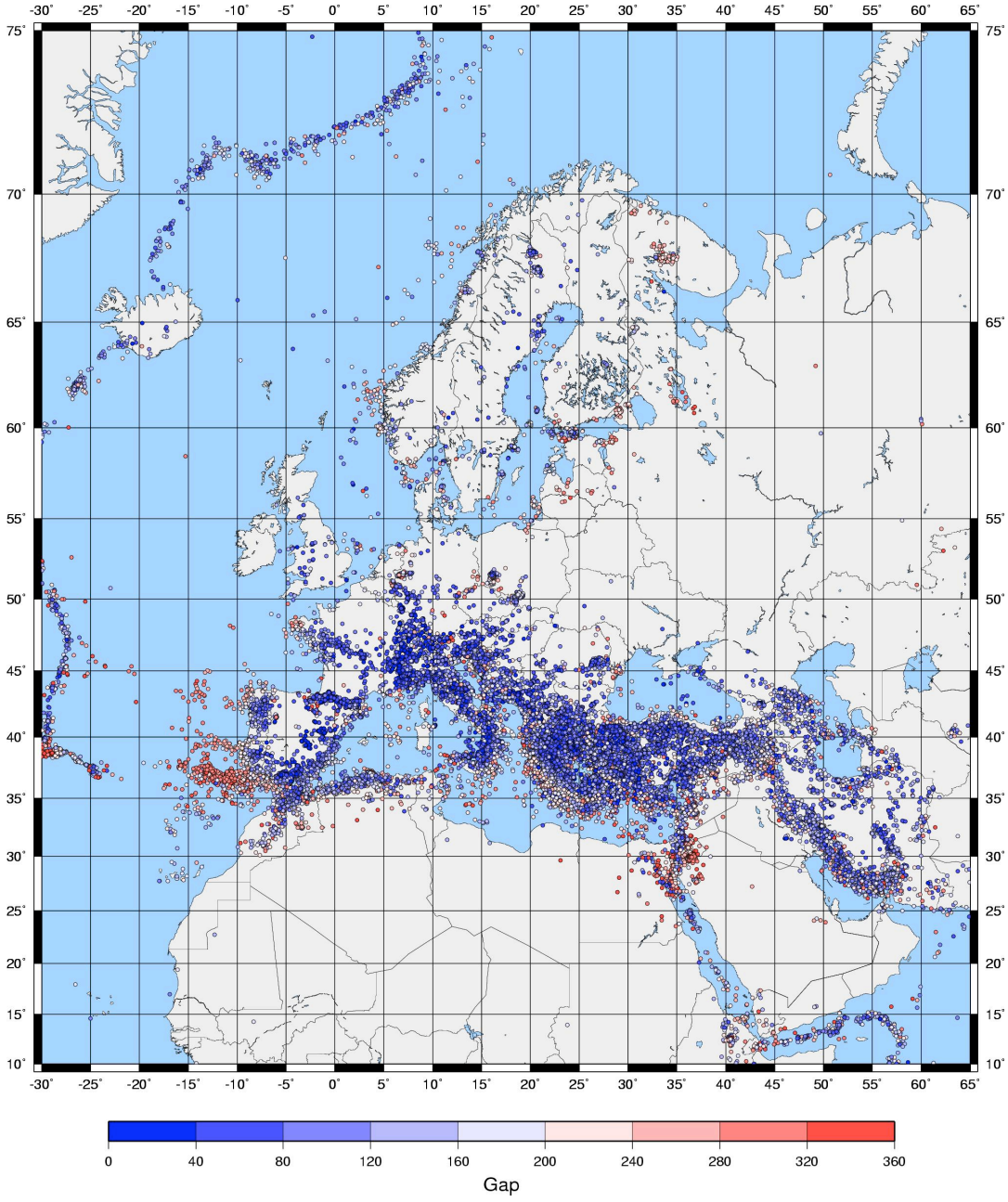

Figure 8: Azimuthal gap distribution of associated events in the Euro-Med Bulletin.

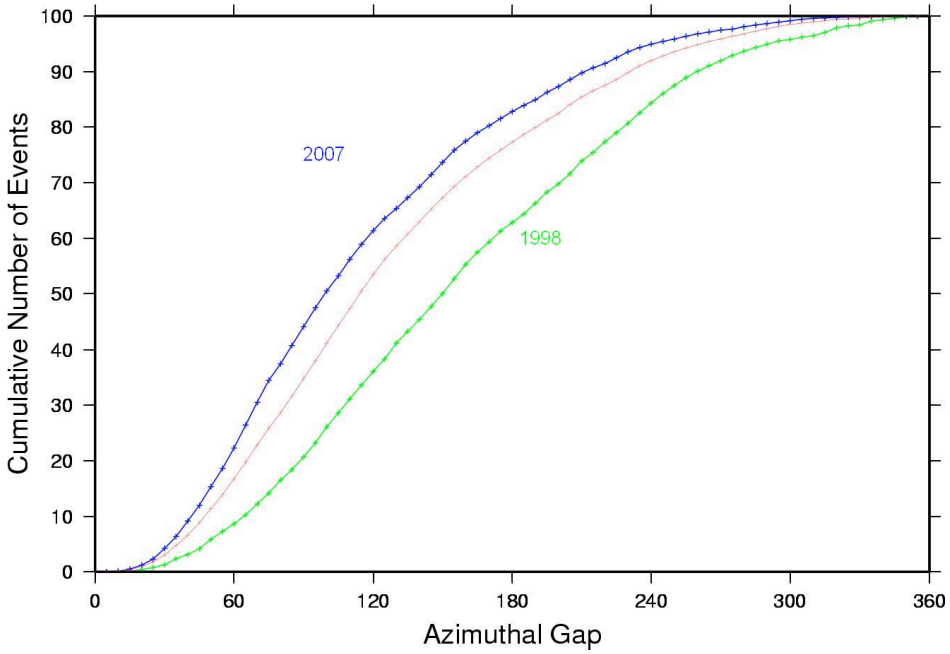

Figure 9: Azimuthal gap obtained in the Euro-Med Bulletin for all associated events. Red: average over the period 1998-2007; Blue: average over the year 2007; Green: average for the year 1998.

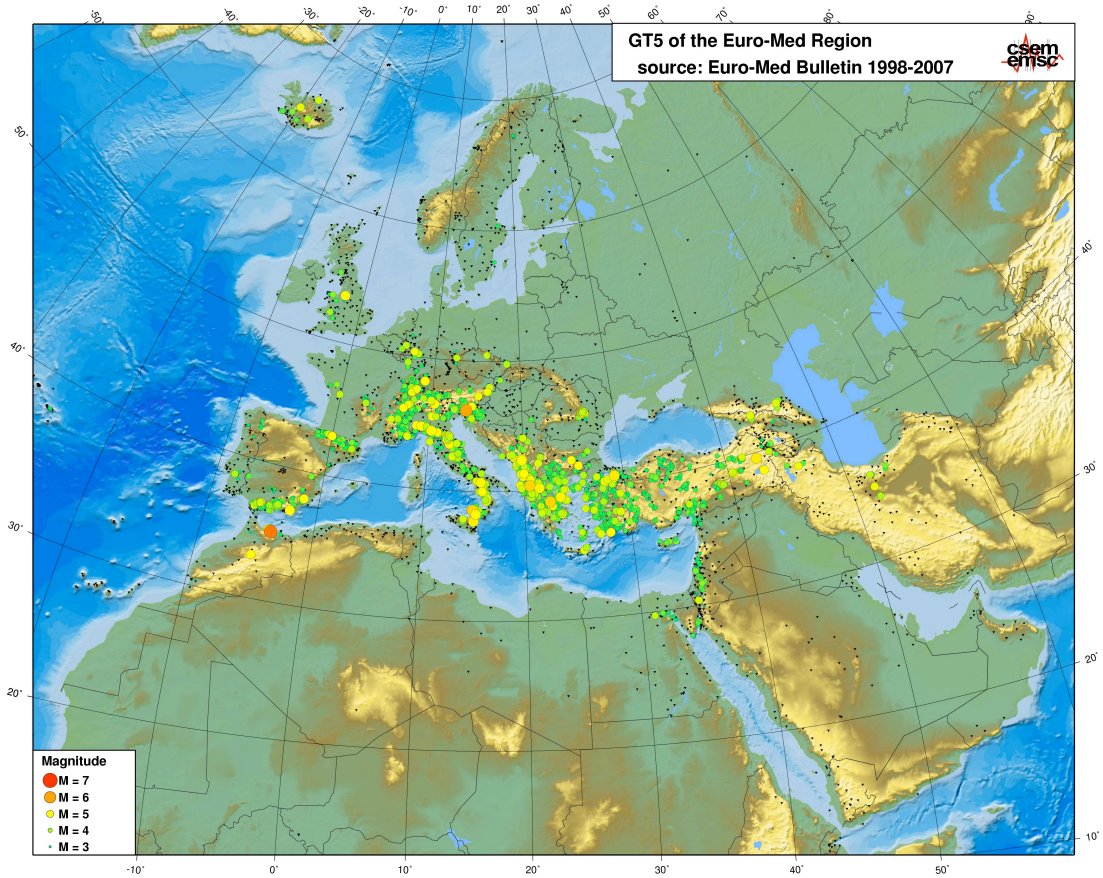

Figure 10: Events fulfilling the GT5 criteria (Bondar et al., 2004) in the Euro-Mediterranean bulletin.

Perspectives

Seeking to improve the Euro-Med Bulletin production and content, the EMSC is working on several aspects: the proper identification of non tectonic events, the inclusion of low magnitude events and the use of a more up-to-date velocity model.

For the period 1998-2007, 3,437 events are currently identified as non tectonic events. Seismicity associated with induced events is observed in Poland at the exploration sites of Lubin and Silesia. Clusters are also observed in Scandinavia, the Middle East and at the border of Germany and the Benelux. However, small clusters of seismicity can be observed in Poland in the natural seismicity map (Fig. 11) which means that identification of mine activity may not be complete. The first improvement to apply on our bulletin is therefore to work in collaboration with the data contributors to fully integrate identification of non tectonic seismicity and to promote the distribution of event type information in the international data exchange.

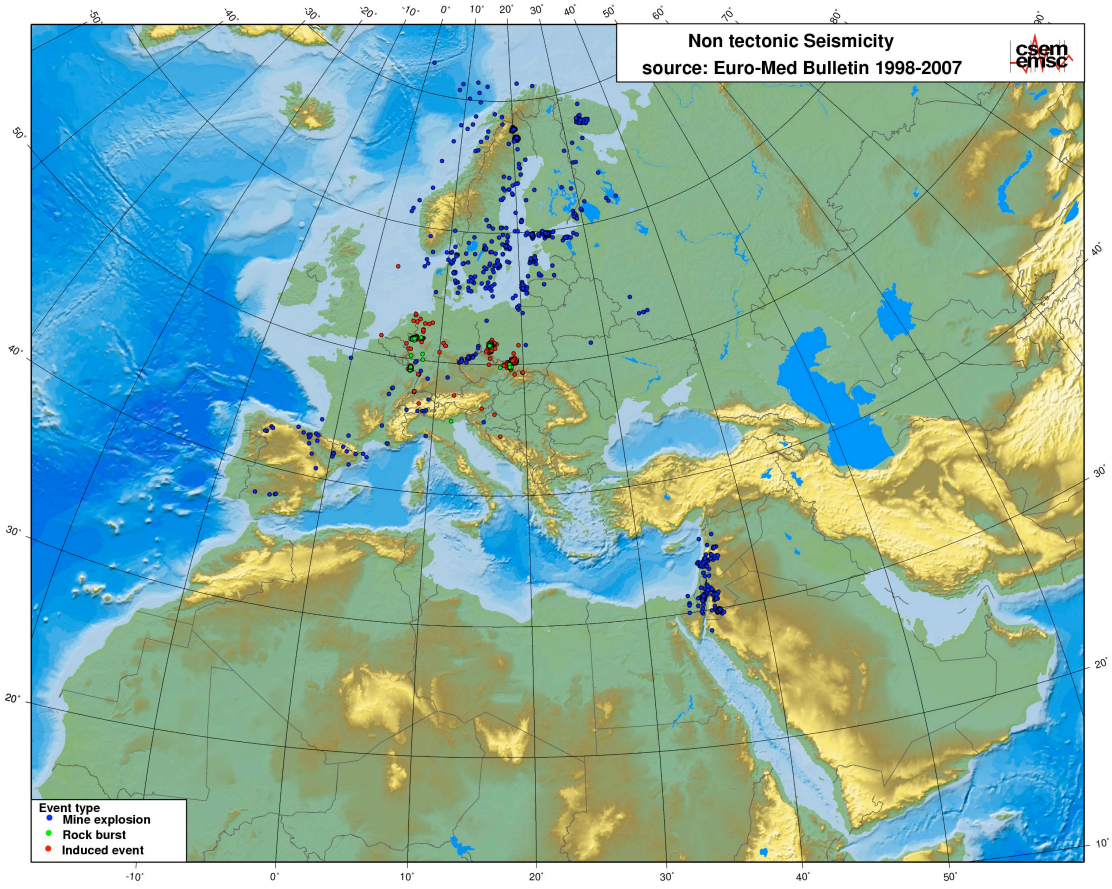

Figure 11: Distribution of identified non tectonic events in the Euro-Med Bulletin 1998-2007.

In the framework of the NERIES (Network of Research Infrastructures for European Seismology) project (http://www.neries-eu.org/), all seismological information (waveforms, parametric data, accelerograms, shakemaps, etc) for each event will be available through one single web portal. A reference catalogue of earthquakes is necessary in order to link all information related to a single event. This catalogue should include the most accurate information at any time and therefore should encompass from real time data to past information. To reach this goal, the Euro-Med

Bulletin and the Real Time Information provided by the EMSC are associated. This association not only provides the essential seed of the NERIES portal but also contributes to a detailed analysis of the real time information service based mostly on automatic data in comparison with the Euro-Med Bulletin based on reviewed and more complete information. It will enable us to identify and comment on specific events of the Real Time Catalogue: ghost events generated by local automatic procedures; artificial events or small magnitude events reported in real time but discarded from the revised contributions of the local institutes and poorly constrained real time locations.

The second main improvement to be applied in the Euro-Med Bulletin is the integration of low magnitude events, using all the bulletin data (origins and associated picks) provided by the data contributors. The initial goal of the Euro-Med Bulletin was to include earthquakes greater than magnitude 3.0. However, with the development of the NERIES portal, end-users have requested to include lower magnitude events and to dismiss this threshold. This will be performed for the whole period 1998-2007. It is important to notice that higher discrepancy in the magnitude completeness will then be observed depending on the region.

Another key point of the Euro-Med Bulletin production is the velocity models used. Tests are currently performed at the EMSC to implement the 1D reference ak135 global velocity model (Kennett *et al.,* 1995) which is recommended by the IASPEI working group on earthquake location method. The use of local velocity models will then be withdrawn. The total 10 years of bulletin will be recomputed and analyzed before being published during the year 2009.

Finally the Euro-Med Bulletin will be used to realize an educational seismicity map of the region, dedicated to a general audience, especially targeting schoolsThe goal of this informative map is to raise public awareness of the seismic risk and its prevention. The Euro-Med bulletin will be displayed in association with the regional tectonic settings and specific information on major events of the region.

Conclusions

Through regular and enhanced collaboration with the seismological institutes of the Euro-Med region, the EMSC is able to produce a comprehensive regional bulletin of the region. It led to continuously increasing data collection and more accurate results. The seismicity presented here spans the period 1998-2007. By merging data from the various local institutes, high azimuthal coverage is obtained for most of the region. The obtained catalogue is consistent with local network knowledge and improved in border regions and off-shore. The Euro-Med Bulletin is now integrated to the ISC bulletin and has become a useful reference for the seismological community, such as the NERIES project. Willing to improve its production, the EMB will be enriched with more accurate event type information and low magnitude events before being recomputed with ak135 global velocity models.

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Appendix 1: List of Contributing Networks to the Euro-Med Bulletin

Algeria: Centre de Recherche en Astronomie, Astrophysique et Geophysique
Greece: National Observatory of Athens
Republic of Azerbaijan: Center of Seismic Survey, Azerbaijan Academy of Science
Italy: Osservatorio Sismologico Universita di Bari
Belarus: Center of Geophysical Monitoring
Serbia: Seismological Survey of Serbia
Norway: University of Bergen
Germany: Bundesanstalt fur Geowissenschaften und Rohstoffe
United Kingdom: British Geological Survey
Slovakia: Geophysical Institute, Slovak Academy of Science
Romania: Romanian Seismic Network
Hungary: Hungarian Seismic Network
Morocco: Centre National de la Recherche Scientifique et Technique
The Netherlands: Koninklijk Nederlands Meteorologish Instituut
Turkey: Directorate of Disaster Affairs
Yemen: National Seismological Observatory Center
Ireland: Dublin Institute for Advanced Studies
Denmark: National Survey and Cadastre
Dubai: Dubai Seismic Network
Syria: Higher Institute of Earthquake Studies and Research
Turkey: Marmara Research Center
Italy: Rete Sismica Igg
Czech Republic: Geophysical Institute of the Academy of Sciences
Israel: Geophysical Institute of Israel
Lebanon: Centre National de Recherche Scientifique
Germany: Seismological Central Observatory
Finland: Institute of Seismology

Egypt: National Research Institute of Astronomy and Geophysics
Portugal: Instituto de Meteorologia
Czech Republic: Institute of Physics of the Earth
Turkey: Kandilli Observatory
Iraq: Iraqi Meteorological Organisation and Seismology
Jordan: Jordan Seismological Observatory
Kuwait: Kuwait Institute for Scientific Research
France : Laboratoire de Detection et de Geophysique
Libya: Libyan Center for Remote Sensing and Space Science
Lithuania: Geological Survey of Lithuania
Slovenia: Agencija Republike Slovenije za okolje
Latvia: Latvian Seismic Network, Latvian Environment, Geology and Meteorology Agency
Spain: Instituto Geografico Nacional
Moldova: Institute of Geophysics and Geology
Spain: Institut Cartografic de Catalunya
Norway: Norwegian Seismic Array
USA: National Earthquake Information Center
Cyprus: Geophysical Survey Department
Kazakhstan: National Data Center, Institute of Geophysical Research
Syria: National Syrian Seismological Centre
Armenia: National Survey of Seismic Protection
Russia: Geophysical Survey of the Russian Academy of Sciences
Oman: Earthquake Monitoring Center of Oman
Portugal: Instituto de Meteorologia, Azores University
Montenegro: Montenegro Seismological Observatory
Iceland: Department of Geophysics, Icelandic Meteorological Office
Italy: Instituto Nazionale di Geofisica e Vulcanologia
Saudi Arabia: King Saud University
Tunisia: Institut National de Meteorologie
Spain: Real Instituto y Observatorio de la Armada
Macedonia: Seismological Observatory
Saudi Arabia: Saudian National Seismological Network
Bulgaria: Geophisical Institute of Sofia
Bosnia-Herzogovina Republic: Hydrometeorological Institute
Morocco: Departement de Physique du Globe
France: Reseau National de Surveillance Sismique
Iran: Institute of Geophysics, University of Tehran
Greece: Aristocle University of Thessaloniki
Iran: International Institute for Earthquake Engineering and Seismology
Georgia: Seismic Monitoring Centre of Georgia
Albania: Albanian Seismological Network
Italy: Istituto Nazionale di Oceanografia e di Geofisica Sperimentale
Belgium: Observatoire Royal de Belgique
Sweden: Uppsala seismic network
Greece: University of Patras Seismological Laboratory
Uzbekistan: Institute of Seismology, Uzbekistan Academy of Sciences
Poland: Warsaw seismic network
Croatia: Seismological Survey
Austria: Central Institute for Meteorology and Geodynamics
Switzerland: Swiss Seismological Service