Topic	An operational authoritative location scheme
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1 Introduction

When an earthquake draws public and media attention, the slightest differences in published epicentral location or magnitude can lead to basic questions such as "Who is right?" As a scientist, the seismologist answers as best he can what are the uncertainties and what are their causes. And invariably the same questions come back: "OK, but who is right? Was the earthquake located 2 km or 5 km to the north of the city?"

This example – which is common for felt events affecting border regions – illustrates how the differences in earthquake parameters are often taken by journalists and citizens as proof that at least one of the publishing organisations must be wrong, thereby raising doubt in the trustworthiness of the seismological community as a whole! Improving the accuracy of earthquake parameters will not solve the problem as small differences will always persist. In essence, this is a public communications issue rather than a scientific problem. To address this issue, a scheme must be defined that specifies the conditions under which an earthquake location determined by a given agency should be considered "authoritative" and should be used as it is by other agencies.

This article describes past efforts to address this issue and the authoritative location scheme approved by the members of the European-Mediterranean Seismological Centre (EMSC) and applied in EMSC real time information services (www.emsc-csem.org) since November 2010. Not considered are the location procedures itself, the model assumptions on which they are based and their inherent errors. They are discussed in detail in IS 11.1.

2 Previous authoritative location schemes

Past efforts to define an authoritative location scheme at the EMSC and at other agencies were based on static geographical areas defined from the geographical extents of the seismic networks. A location is generally considered to be reliable when the azimuthal gap of the reporting stations is small. By definition, locations that fall within the bounds of reporting networks exhibit good azimuthal coverage. Therefore, these areas based on the network extents were supposed to identify the source for the *best* locations. Furthermore, this strategy implicitly recognises that local institutes are generally in the best position to accurately locate local earthquakes thanks to their knowledge of the local conditions.

This scheme properly addresses the majority of earthquake locations. However, it proved problematic in several cases. For example, it does not define which network should prevail in areas monitored by several networks. Such an overlap is not restricted to border regions: there are also a number of European countries in which several seismic networks are in operation. Choosing *the* authoritative network for such regions is touchy and may become a political issue: how to prevent any national institute from claiming to be authoritative over its entire national territory even when part of that territory is poorly covered by its network?

In the end, these difficulties result from the fact that the underlying assumptions – that location accuracies are uniform within network boundaries and constant over long periods of time – are not always satisfied. Location accuracies depend on both the network geometry and on the relative spatial distribution and number of stations used in the calculation of the earthquake location.

The proposed authoritative scheme described below is based on the quality of the geographical coverage of the stations which actually report the considered event. It takes into account the actual operating status of each individual station at the time of the earthquake's occurrence, and only considers those stations that reported the event and were used in the calculation of the location.

3 An operational authoritative location scheme

3.1 Assumptions

The simple and basic assumption of the proposed scheme is that locations which are both reliable and accurate must be considered to be authoritative and must therefore be published without modification for public consumption. Relocations should be restricted only to cases where a significant quality improvement can be expected. In essence, defining an authoritative location scheme amounts to the definition of the criteria for what can be considered a reliable and accurate location.

In the discussion below, we only consider the epicentral location. It is assumed that if the epicentral location is accurate and reliable, the focal depth is well constrained. Theoretically, this may not always be the case. In practice however, as we will see later, accurate and reliable locations are generally produced by local institutes which are in the best position to provide reliable depth estimates. Furthermore, as focal depth is often ignored by the public, it is a less critical element of a public communication scheme than the epicentral location or magnitude.

3.2 Criteria for accurate locations

Locations are considered to be accurate if they satisfy either of the 2 sets of criteria defined by Engdahl et al. (2001), or Bondár and McLaughlin (2009). Both criteria characterize the geometry and azimuthal distribution of the reporting stations at short distances (250 km), and were both derived from the study of explosions. The considered criteria are referred to as GT5 (for Ground Truth). If satisfied, the epicentral location is expected to be within 5 km of the actual epicentre, within a formal confidence level. For more details on the GT concept, global project and GT data base at the International Seismological Centre see section 7 in IS 11.1.

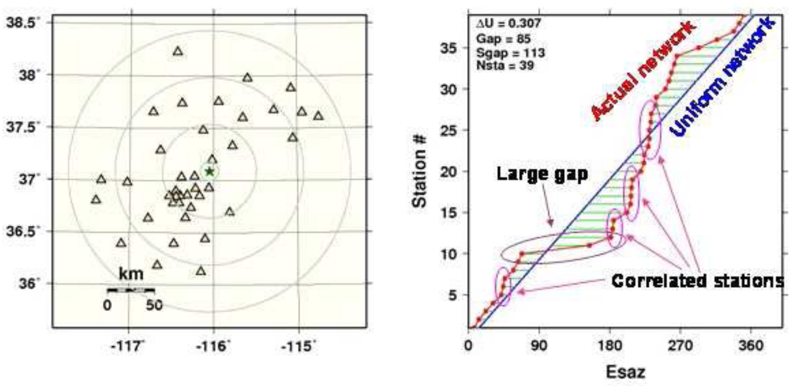
Table 1 and 2 present the GT5 criteria as defined by Engdahl et al. (2001) at a 90% confidence level and by Bondár and McLaughlin (2009) at a 95% confidence level, respectively, hereinafter referred to as GTA and GTB. The GTB criteria are more restrictive than those of the GTA, but at the same time they select events not identified previously. Allowing the choice of either of the two sets of criteria maximizes the number of potential authoritative locations. Table 2 and Figure 1 present the alternative criteria defined by Bondár and McLaughlin (2009)

Table 1 GT5 criteria at 90% confidence level for local networks, as defined by Engdahl et al. (2001).

At least 10 stations at epicentral distance ≤ 250 km
At least one station at epicentral distance ≤ 30 km
Azimuthal gap defined with stations closer than 250 km ≤ 110°

Table 2 GT5 criteria at 95% confidence level for local networks, as defined by Bondár and McLaughlin (2009). The secondary gap is the largest azimuthal gap filled by a single station. The criterion on the secondary gap implies a minimum of 5 stations. The definition of the network quality metric, ΔU, is given in Figure 1.

At least one station at epicentral distance ≤ 10 km
ΔU ≤ 0.35 when considering stations closer than 150 km
Secondary azimuthal gap defined with stations closer than 150 km ≤ 160°



$$\Delta U = \frac{4\sum \left| esaz_i - (unif_i + b)\right|}{360N}, \quad 0 \le \Delta U \le 1;$$

$$unif_i = \frac{360i}{N}; \quad b = \overline{esaz} - \overline{unif}$$

Figure 1 Definition of the network quality metric, ΔU. If the stations, ordered by event-to-station azimuth were distributed uniformly they would align along a straight diagonal line and ΔU would be zero. The dots in the right-hand panel represent the actual geometry of the network as plotted in the left-hand panel. The network quality metric is defined as the normalised area between the best fitting uniformly-spaced network and the actual network, shown shaded by grey lines in this example. The lower the ΔU value, the more uniform the network geometry. Copy of Figure 5 in Bondár and McLaughlin (2009, p. 468), with © granted by the Seismological Society of America.

The constraint on the closest station, within 30 km for GTA and 10 km for GTB, strongly restricts the geographical area where authoritative locations could potentially be found for a given network (Figure 2). In practice, less than 5% of the locations collected in real time by the EMSC satisfy these criteria.

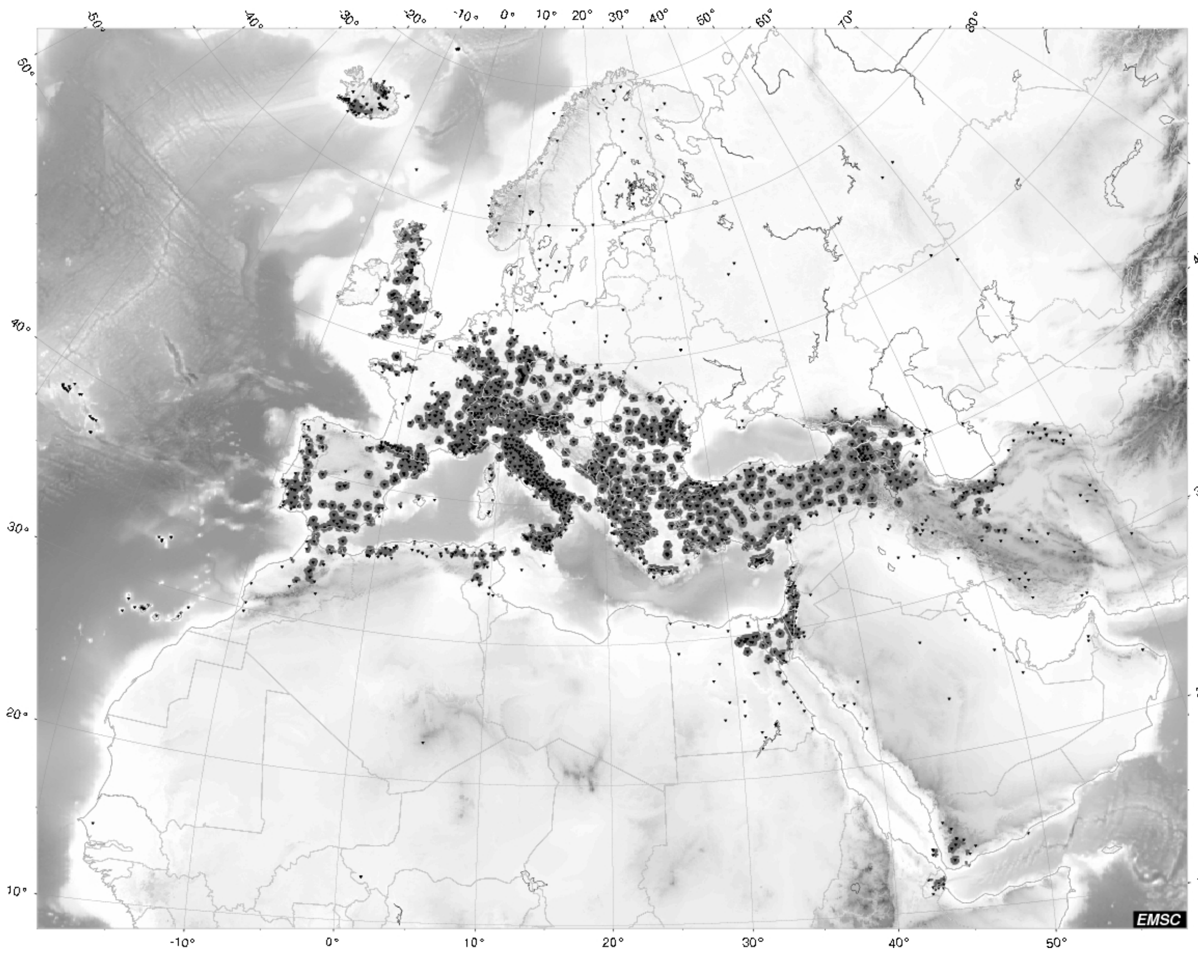


Figure 2 Geographical area where GTA or GTB criteria are satisfied when considering all the seismic stations which contribute to the EMSC real time earthquake information services. Effectively, there cannot be any GTA or GTB locations in regions where inter-station distance is greater than 30 km.

The constraint on the closest station improves the confidence in depth for crustal events, but has no significant effect on epicentral location accuracy (e.g., Bondár et al., 2004). Therefore, in agreement with our basic assumption that our authoritative scheme is based on epicentral location only, this constraint is dropped for the purposes of defining what may be considered an accurate epicentral location. It doubles to about 10% the number of locations provided in real time which are potentially authoritative. More importantly, it greatly enlarges the geographical regions where such authoritative locations could potentially be found (Figure 3).

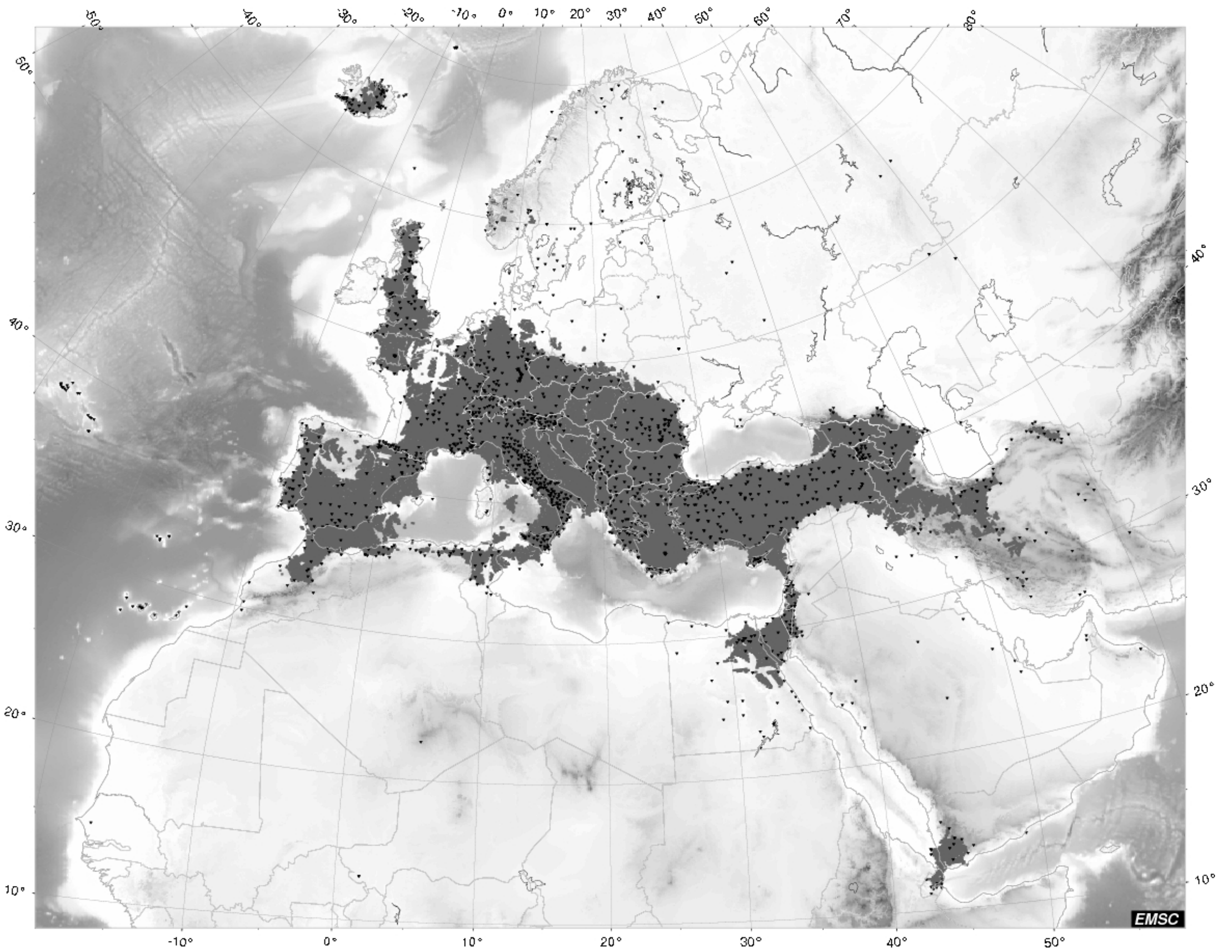


Figure 3 Geographical area where authoritative locations could potentially be found for the EMSC real time services after relaxing the closest station constraint. This result is based on the assumption that earthquakes are reported by all the stations contributing to the EMSC real time services and located within 250km of distance.

3.3 Criteria for reliable locations

As for any measurement, a location is considered to be reliable if it can be independently and consistently reproduced within its inherent uncertainties. The estimation of location uncertainties is a complex issue (e.g., Thurber and Engdahl, 2000). By taking as reference locations the final solutions produced by the local networks and published in their final bulletins, Mazet-Roux et al. (2010) show that on average the locations produced in real time by the EMSC are within 10 to 12 km of the reference locations. The location procedures currently in place at the EMSC (velocity model and algorithm) are therefore very unlikely to produce a mislocation greater than 15 km when using the same dataset. We therefore set the criterion for a reliable location as being reproducible to within less than 15 km; larger differences are assumed to indicate an unreliable location.

The vast majority (98%) of the accurate locations (per definition in section 3.2) are also effectively reproduced to within less than 15 km, and can therefore also be labelled as reliable (Figure 4). However, there are still cases in which the differences in location are significant. Potential causes for these discrepancies were investigated. In some cases, the differences in location were caused by data format or station code errors resulting in incorrect data inputs. However, in several cases no clear cause was identified. It was noted, however, that several of the submitted locations did not appear in the final bulletin of the reporting institute, or the locations in the bulletin were more than 15 km from the initially reported locations. These examples reinforce the importance of independent evaluation of location accuracy and reliability to avoid the publication of incorrect locations, even if the actual causes remain unidentified.

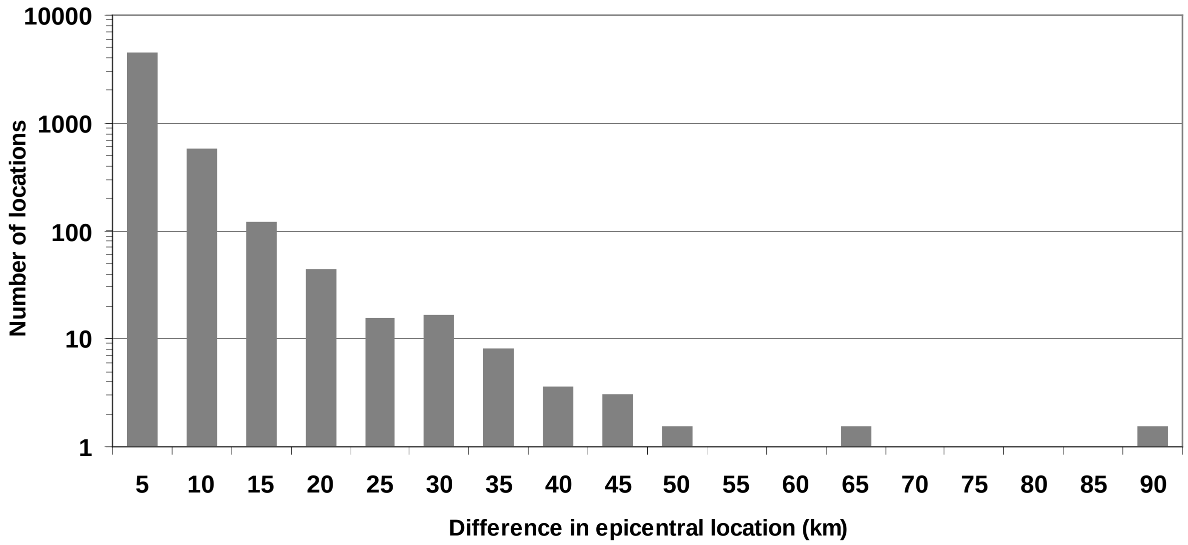


Figure 4 Distribution of the difference in epicentral location between the accurate locations (per definition in section 3.2) provided to the EMSC and EMSC relocations using the same dataset. Results obtained from the 5,265 accurate locations provided to the EMSC in real time between Sept. 2008 and Sept. 2009.

3.4 Discussion

The authoritative location scheme presented in this work defines the conditions under which a real time epicentral location provided by one of the contributing agencies to the EMSC will be published without any modification in the EMSC public real time services. It does not intend to identify the best location, nor does it address any scientific issue. The intent is to avoid possible communication difficulties with the media and the public caused by differences in published earthquake locations, even if the differences are scientifically and statistically insignificant.

In practice, we consider a location to be authoritative when it is both reliable and accurate. The accuracy criteria are derived from the GT5 criteria. An accurate location is considered to be reliable when it can be reproduced to within 15 km, using the same dataset but different location procedures (velocity model, location algorithm).

The advantages of the proposed scheme are numerous. It depends only on the spatial distribution of the stations which have been used to compute the locations. It does not require specific criteria for border regions. Each location is evaluated independently and instantaneously, which fits within the requirements of rapid information services where updates are numerous. The most significant improvement when compared to the previous procedures in place at the EMSC is that the new scheme does not depend on the magnitude of the earthquake. The old scheme, applied up through November, 2010, considered a location as authoritative if it was reported by only one network and located within the network geographical boundaries; Earthquakes reported by more than one network had not authoritative location and the published location was computed merging all available data. Larger earthquakes being recorded at larger distances are generally reported by several networks. Then, under the old scheme, the large earthquakes which typically attract public and media attention had no authoritative location.

The new scheme solves this problem. It was formally accepted by the EMSC General Assembly in September, 2010, and implemented in November of the same year in the EMSC real time information services.

Authoritative locations have also been identified within the Euro-Med bulletin (Godey et al., 2006) which merges 78 individual bulletins. Data contributors are encouraged to report, when possible, restricted data obtained through bilateral exchanges to ensure authoritative locations in border regions are identified as such. These restricted data are not published by the EMSC. We next plan to use the GT5 and possibly GT10 criteria to define the best dataset to be used to relocate earthquakes when no authoritative location is available.

4 Conclusion

The EMSC has developed and implemented a simple authoritative location scheme for its rapid earthquake information services. This development addresses a long-standing issue in public and media communications. Further improvements in the way locations are computed are also foreseen. So far, no complaints have been received from EMSC members, and the scheme seems to offer a pragmatic and satisfactory solution. The next step, and probably the biggest challenge for rapid earthquake information services, will be to propose a convincing and acceptable authoritative magnitude scheme.

Acknowledgement

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