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Delay times of worldwide global earthquake alerts

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Abstract Quantitative estimates of earthquake losses are needed as soon as possible after an event. A majority of earthquake-prone countries lack the necessary dense seismograph networks, modern communication, and in some places the experts to assess losses immediately, so the earliest possible warnings must come from global information and international experts. Earthquakes of interest to us are in most areas of the world $M \geq 6$. In this article, we have analyzed the response time for distributing source parameter estimates from: National Earthquake Information Center (NEIC) of the US Geological Survey (USGS), the European Mediterranean Seismological Center (EMSC), and Geophysical Institute-Russian Academy of Science, Obninsk (RAS). In terms of earthquake consequences, the Pacific Tsunami Warning Center (TWC) issues assessments of the likelihood of tsunamis, the Joint Research Laboratory in Ispra, Italy (JRC) issues alerts listing sociological aspects of the affected region, and we distribute loss estimates, and recently the USGS has started posting impact assessment information on their PAGER web page. Two years ago, the USGS reduced its median delay of distributing earthquake source parameters by a factor of 2 to the currently observed 26 min, and they distribute information for 99% of the events of interest to us. The median delay of EMSC is 41 min, with 30% of our target events reported. RAS reports after 81 min and 30% of the target events. The first tsunami assessments by TWC reach us 18 min (median) after large earthquakes in the Pacific area. The median delay of alerts by the JRC is 44 min (36 min recently). The World Agency for Planetary Monitoring and Earthquake Risk Reduction (WAPMERR) distributes detailed loss estimates in 41 min (median). Moment tensor solutions of the USGS, which can be helpful for refining loss estimates, reach us in 78 min (median) for 58% of the earthquakes of interest.

Keywords Earthquake alerts · Tsunami alerts · Real-time earthquake loss estimates

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1 Introduction

After most disastrous earthquakes, the extent of losses does not become fully known during the first few days. Therefore, rapid and reliable estimates of likely losses, based on model calculations, are essential for adequate and timely rescue and recovery operations. The loss estimates by WAPMERR include mean damage state, number of injured and number of fatalities for each settlement, and the sum of the human losses.

Before the losses can be estimated, accurate information on the parameters of the earthquake in question must become available. For countries without dense seismograph networks, the source parameters have to be derived from global data. In this article, we examine the delay times of (1) the distribution of information on earthquake source parameters from some global agencies and (2) the distribution of estimated earthquake consequences by global means.

The earthquake parameters required for estimating event consequences are the hypocenters and the magnitude. There are several organizations that distribute all or part of this information in real time. Messages in which either magnitude or depth is absent or where the epicenter errors often exceed 100 km, are not reviewed here. In addition, automatic solutions are not used because the risk is great that losses so calculated would be incorrect because of large input errors.

NEIC, the EMSC, and the RAS are the agencies whose manually reviewed global earthquake parameters we have received by email over the last few years and their delay times are analyzed here.

The TWC issues assessments of the probability of tsunamis. At the same time, they distribute their determinations of hypocenter and magnitude. Earlier, their messages concerned the Pacific area exclusively, but were recently expanded to include the Indian Ocean. They analyze only earthquakes located under the oceans. Because of these restrictions, the TWC data are rarely available to us for loss estimates.

The USGS also distributes moment tensor solutions of earthquakes worldwide. A moment tensor describes the orientation of two perpendicular rupture planes that can account for the observed waveforms. In the case of large earthquakes, the actual plane that has ruptured can often be selected by knowledge of local tectonics. In addition, a moment tensor inversion can corroborate the initial estimation of the source depth and provide a more robust estimate of the magnitude (Mw) that is less prone to saturation than the initial magnitude estimates. Thus, moment tensor solutions can add confidence and additional detail to the initial earthquake input parameters.

The JRC issues four-color alerts (red, orange, green, and white) based mostly on automatic source parameter estimates by the USGS. They report automatically the number of people within 100 km of the epicenter and other socio-economic facts of the area. Here, their orange and red alerts are considered. We distribute loss estimates that include a map with the estimated mean damage of settlements, the number of injured, and the number of fatalities.

Recently, the USGS has begun to publish results of the impact assessment information project on their website. In it they report estimated intensity of strong ground motion in settlements near the epicenter, and they comment on the regional tectonics and nature of building construction. According to their web page, this information is posted “generally within 30 min”. Given that no alerts are distributed, we have no information to corroborate their statement.

2 Data

Since October 31, 2002, WAPMERR (World Agency for Planetary Monitoring and Earthquake Risk Reduction) has issued worldwide earthquake alerts (Wyss 2004). Since December 2003, WAPMERR has maintained records of the arrival times of emails by other agencies containing earthquake source parameter estimates. In February 2005, the USGS shortened its delay in distributing source parameters significantly. Therefore, we show graphs of delays since December 2003, but analyze only the period since February 2005 as the currently relevant data set.

The magnitude threshold for earthquakes to be analyzed by WAPMERR is defined by the Swiss Agency for Development and Cooperation (SDC) and the Swiss Seismological Service (SED). It is a function of the level of interest by the SDC in different areas. Therefore, the dataset analyzed here is subject to the restrictions shown in Fig. 1.

Alerts for magnitudes 6–6.2 are most numerous (Fig. 2) because small earthquakes occur at a higher rate than large ones, and because M6 is the threshold for most of the world. On a few occasions, we have reported earthquakes smaller than M5.5 because the magnitude estimate was above the threshold, at first, and was later reduced as we were working on the case. The epicenters are distributed over the world's regions with major seismic activity (Fig. 3).

The delay is measured by the difference between the time indicated by the email server on the email message we received, and the origin time of the earthquake. It is possible that some messages have been lost. For calculating the delay time for our own messages, we use the arrival time recorded by the same email server that receives the messages from other agencies. Our messages are distributed from a server located at the SED, a computer not connected to the server that logs in the email arrivals. Thus, we measure our own delay times in the same way as that of other agencies.

We receive messages in two computers, one at WAPMERR, and the other at SED. The messages received by SED are summarized on the web page RedPuma (http://www.seismo.ethz.ch/redpuma/), where the arrival time of the message is given as the last entry

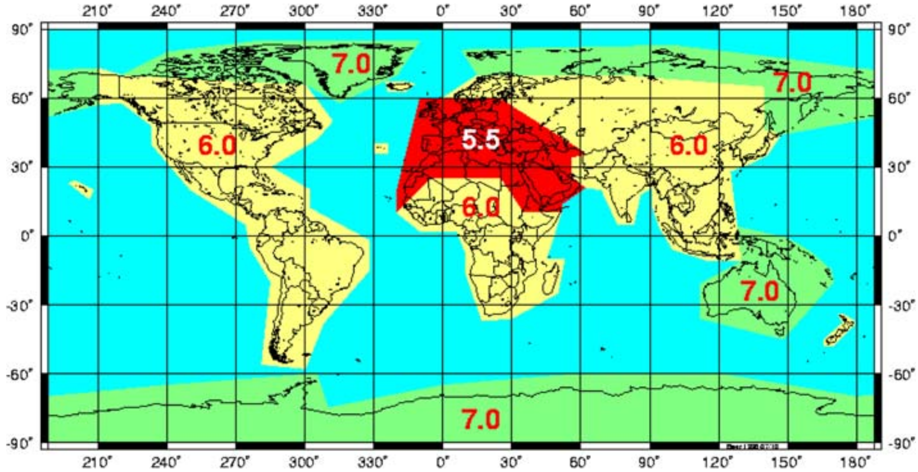


Fig. 1 Magnitude threshold ($M_{\min}$) for loss estimates in real time for which WAPMERR must estimate losses. In the blue area $M_{\min} = 8.0$

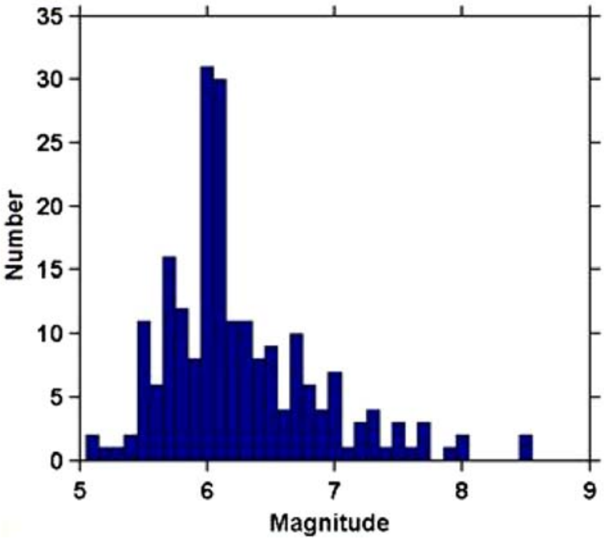


Fig. 2 Distribution of alerts as a function of magnitude

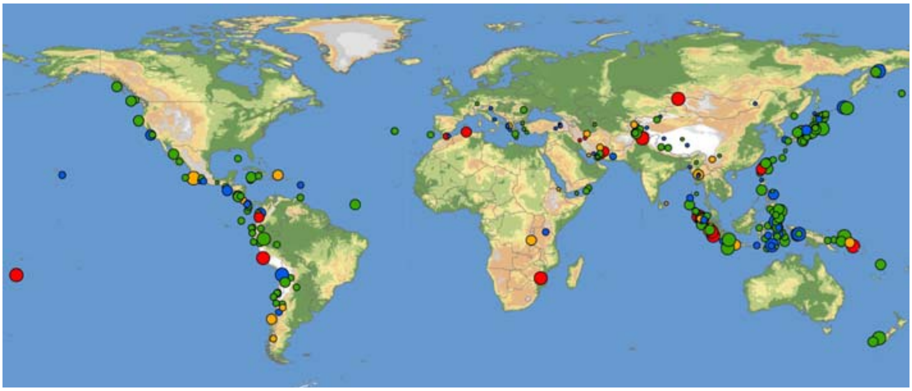


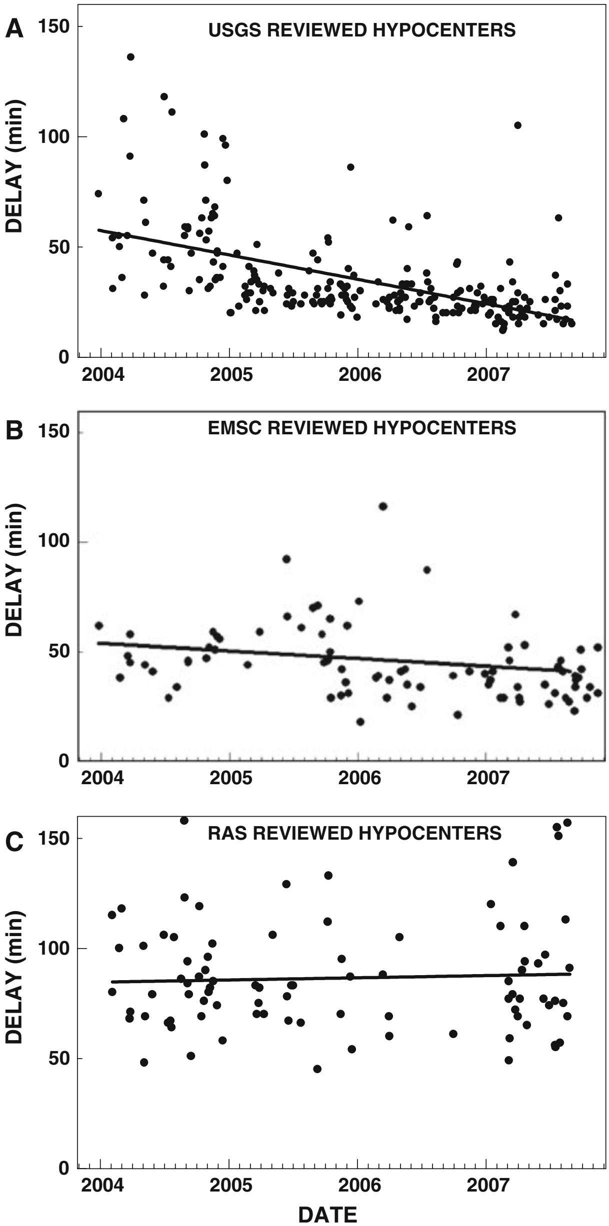
Fig. 3 Map of epicenters of the earthquakes for which WAPMERR has issued alerts since October 2002. The symbol size is proportional to magnitude, the color to estimated number of fatalities: red $\geq$1,000, 100 $\leq$ yellow < 1,000, 0 < blue < 100, green = 0

on each line. In those cases where WAPMERR did not receive a message directly, the arrival time listed by RedPuma was used. This is the case for all RAS messages analyzed herein and occasionally other messages that did not show up in WAPMERR's electronic mail box. At the request of EMSC, none of the arrival times of their messages sent only to RedPuma was used.

3 Results

The delays of reporting reviewed hypocenter and magnitude estimates by the USGS, the EMSC, and the RAS since December 2003 are compared as shown in Fig. 4. To facilitate

Fig. 4 Delays of email messages by three agencies distributing hypocenters and magnitudes of earthquakes shallower than 150 km and conforming to the filter shown in Fig. 1 between December 2003 and August 2007



comparison, the scale on the ordinate is not varied between subplots. As a result, a few data points fall outside the plot for EMSC and RAS because some messages arrived later than 160 min after the earthquake.

The trends of delays as a function of time are approximated by a straight line, although a step-like improvement occurred in the case of the USGS in approximately February 2005. The messages by the USGS are the fastest, those by the RAS the slowest. As a function of

Table 1 Reporting statistics for source parameters and consequences following earthquakes

	TWC	USGS	WAPMERR	JRC	EMSC	USGS Mo	RAS
Number of reports	32	186	187	152	56	76	57
Median delay	18	26	41	44	51	78	81
Mean delay	18	29	49	123	59	174	93
Standard deviation	8	12	33	296	37	171	38
Range	5–55	15–105	25–298	18–3,141	18–299	33–700	45–212
Percentage reported	17	99	100	82	44	58	30

time, a strong reduction of delays is seen for the USGS data, a moderate reduction for the EMSC data, and a slight increase of delays in the RAS data.

The number of reports that reached us from each agency, for the 187 earthquakes WAPMERR was interested in, were 186 (USGS), 56 (EMSC), and 57 (RAS), which corresponds to 99%, 30%, and 30% reporting, for the respective agencies (Table 1). Table 1 also gives the median delay, the mean delay, and its standard deviation, as well as the range of the delays.

The messages by the TWC are not plotted in the figures because they covered only 17% of the events of interest, being confined to the oceanic area and large magnitudes.

The messages issued by JRC and WAPMERR (Table 1), containing information on direct consequences to humans, necessarily have to be delayed longer than the information on source parameters because they are based on the latter. The delays of the automatic orange and red alerts by the JRC have decreased with time, and their spread has diminished (Fig. 5b). The delays of the reviewed loss reports by WAPMERR were strongly reduced in February 2004 (Fig. 5a), following the pattern of the USGS hypocenter messages because WAPMERR personnel wait for the reviewed USGS estimates before they calculate losses.

4 Discussion

The exact earthquake reporting requirements of each agency that distributes information on earthquake source parameters or consequences of earthquakes is unknown to us. Therefore, we do not hold an opinion on their performance; we simply evaluate the statistics of the delays in which we receive their information. Our own mission is to estimate human losses after earthquakes as rapidly, as consistently, and as accurately as possible. For this reason, the most useful source parameter reports for us are those that reach us most rapidly, most consistently, and are most accurate. The details of the question of accuracy of hypocenter and magnitude estimates will be analyzed in a different publication. Here, we deal with observed delays only. However, we have excluded from the present investigation hypocenter messages from agencies that are not able to determine location and magnitude accurately enough for the purpose of estimating losses.

The source parameter estimates of the TWC arrive first if the earthquake is large and in the greater Pacific area (Table 1). Also, the standard deviation and the spread of the delay time of their messages are the lowest. However, our mission is to cover the world, and therefore the 17% input by the TWC is not of great help to us.

The first earthquake source estimates that reach us are from the SED, our partners in the loss-estimating project. These messages (along with those of some other agencies) arrive with approximately the same delay as those from the TWC, but they are automatic and

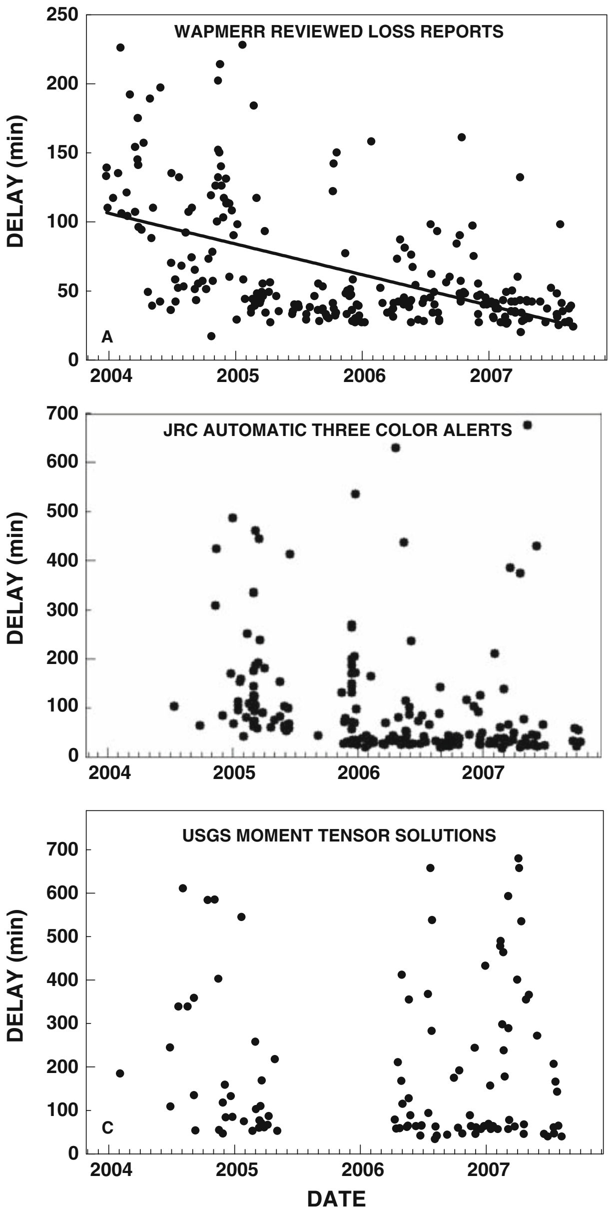


Fig. 5 Delays of WAPMERR's reviewed loss reports, JRC's automatic orange and red alerts, and USGS's moment tensor solutions as a function of time

inaccurate by necessity, as they are based on the seismograph stations in Switzerland only. However, they allow the WAPMERR duty person to get ready to compute losses as soon as the reviewed earthquake parameters from the most reliable source arrive.

From the point of view of speed and consistency, the USGS is clearly the agency that is most useful to us. Practically all earthquakes we are interested in are reported by them (99%), and their delays are short (26 min, Table 1), since they improved their reporting procedure in February 2005 (Fig. 4).

Messages by the EMSC can be useful to us, if they concern relatively small earthquakes in the European area, where the USGS may be slow in responding. However, the delays of the EMSC messages (41 min) are relatively large, and they report only 30% of the earthquakes of interest to us (Table 1). Consequently, we almost never use EMSC data. Our estimate of losses is distributed at approximately the same time as the EMSC source parameters, on average (Table 1).

The basic earthquake source parameters distributed by the RAS arrive at about the same time as the moment tensor solutions by the USGS, more than an hour after the earthquake (Table 1). Also, we receive information from RAS for only 30% of the interesting events, whereas we receive moment tensors for 58%. Thus, we cannot use RAS information for loss estimates, since we distribute our warnings on average 41 min before information from RAS arrives (Table 1).

We can use the moment tensor solutions by distributing a refined loss estimate in a second message. In the interest of near real-time loss estimates, it would be desirable if the delays of moment tensor information could be reduced. Currently, the spread of the delays is large (Fig. 5c), but the shortest delay of 33 min (Table 1) shows that moment tensors can be delivered rapidly, under favorable conditions. It would be of great help to us if a determination of the direction of rupture could be included in the moment tensor solutions, a parameter that might not be too difficult to estimate in the case of large earthquakes.

The automatic orange and red alerts of JRC show approximately the same delay as the reviewed loss estimates of WAPMERR. JRC's median delay is 44 min compared to WAPMERR's 41 min. However, if we consider JRC reports since January 2006 only (a time when an improvement of their service seems to have taken place, Fig. 5), then their median delay is 36 min. The spread of the JRC delays has also been reduced, but it is large; 13% of the data do not fit on the plot in Fig. 5b, which has been adjusted for comparison with WAPMERR's delays (Fig. 5a), where only one event exceeded the maximum value on the ordinate.

The straight line in Fig. 5a approximates WAPMERR's shortening of delay times, although a clear step-improvement occurred in February 2005, thanks to the reduction of the delays in USGS messages. The spread in delays of WAPMERR messages has also been reduced with time, but there is room for further improvement.

5 Conclusions

We conclude that for large parts of the seismically active globe, high quality local seismograph networks do not exist. Therefore, attempts to estimate losses in real time after major earthquakes must rely on source parameters derived at global distances. Because of the distances between seismographs in the worldwide network, the travel time for seismic waves to reach a sufficient number of stations to allow a stable estimate of source parameters is about 10–15 min. Approximate source parameters become available by email after this delay. Only then, can one commence preparations for loss estimates.

The first and most consistent calculation of manually reviewed source parameters are distributed by the USGS and reached WAPMERR by email 26 min (median) after major earthquakes worldwide. Source parameter messages from other agencies, including EMSC and RAS, reach us too late and are issued for too few events to be useful for estimating losses in near real time.

The moment tensor solutions distributed by the USGS, or others, could be of help in refining loss estimates, especially if they also included estimates of rupture direction and fault finiteness. Improving the speed and quantity of moment tensor messages, together with the possible inclusion of identification of the fault plane and adding fault finiteness estimates, may well be one of the most useful additions for refining loss estimates in countries without dense local seismograph networks.

The automatic orange and red alerts by JRC and the loss estimates by WAPMERR are made available to the rescue community via the webpage of GDACS (Global Disaster Alert and Coordinating System, http://www.gdacs.org/). The JRC message is meant as a first automatic alert for the rescue community 36 min after earthquakes worldwide, followed by the detailed loss estimates by WAPPMER 5 min later, on average. Together, these two services assist the rescue community and disaster managers to mount appropriate responses rapidly.

It would be very desirable if more local and regional seismograph networks would be able to distribute high-quality calculations of earthquake epicenters and especially depths electronically in real time because this could cut about 10 min in the delays analyzed here. The hypocentral errors, which are approximately 15 km for the USGS teleseismic locations, could be reduced by a factor of 3 to 4, based on local data. This in turn could influence the estimate of the number of fatalities in some cases by a factor of 10. Although we are currently able to correctly separate disastrous earthquakes from non-consequential ones in over 90% of the cases, input from well-run regional and local seismograph networks could strongly improve the accuracy of our loss estimates in near real-time.

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Note added in proofing Since May 2008, three months after submission of this manuscript, the Geoforschungszentrum, Potsdam, has begun distributing source parameters in real time by email. Their messages covered only 56% of the events of interest to us, but they arrived with a median delay of only 7 minutes.

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