Teleseismic Loss Estimates in Near-Real-Time After the M8 Wenchuan Earthquake of May 12, 2008

Max Wyss, Philippe Rosset, and Goran Trendafiloski
World Agency of Planetary Monitoring and Earthquake Risk Reduction, 2 rue de Jargonnant, 1207 Geneva, Switzerland, wapmerr@maxwyss.com

Abstract: After large earthquakes, the true extent of losses is not known for days and weeks. In the Wenchuan case, the sum of fatalities and missing persons reported by news agencies began to reflect the true disaster only from the 6th day on. Therefore, it is important to estimate losses quantitatively in near-real-time, based on world data sets on population, building stock, attenuation, and soil properties, and near-real-time input on earthquake source parameters. In the case of the Wenchuan earthquake, our first quantitative estimate of fatalities, 21 minutes after the event, was larger by a factor of about 200 than first news reports, but smaller than the ultimate toll be a factor of 30. An hour later, our quantitative estimate of fatalities was 20,000 to 90,000, which contained the ultimate death toll of 87,476. The initial underestimate was due to an underestimate of the magnitude by 0.5 units. Other main factors that contributed to the large range in this loss estimate were uncertain attenuation, and uncertain depth. New methods may come on line, which reduce errors in initial magnitude and uncertainties in depth. By estimating losses automatically, one gains only about 10 minutes, but often introduces order of magnitude errors in addition to the large uncertainties already inherent in manual loss estimates.

Introduction

The World Agency of Planetary Monitoring and Earthquake Risk Reduction (WAPMERR) has the mission to estimate losses after earthquakes in near-real-time as rapidly and as accurately, as possible, and to report disasters immediately to the Swiss Agency for Development and Cooperation (SDC) and the United Nations Office for the Coordination of Humanitarian Affairs (OCHA). Similar efforts are planed to be implemented by other institutions because the world's exponential population growth rapidly increases the seismic risk throughout the world. Many countries do not have regional seismograph networks that allow accurate locations and magnitude estimates within seconds to minutes. Therefore, teleseismic information must be used for loss calculations. The motivation for supplying rescue and recovery organizations with quantitative estimates of expected losses within less than an hour is that information from devastated areas does not flow freely. In major disasters, it invariably takes several days until the extent of it becomes known, based on eye witness reports.

WAPMERR maintains an email and telephone service for anyone interested in loss estimates after earthquakes with $M \geq 6$ worldwide within 30 minutes on average (Wyss, 2004; Wyss and Zibzibadze, 2009). These messages contain a range of likely numbers of fatalities and of injured. In addition, a map is posted on WAPMERR's web page (www.wapmerr.org/user_quake.htlm) showing the mean damage expected in the settlements of the affected area. A list of settlements with the calculated intensities of the strong ground motion and the mean damage can be obtained upon request.

The effects of errors are considered, and are sometimes discussed in these messages. Order of magnitude errors are possible, if input parameters are inaccurate. Nevertheless, we succeed to distinguish disastrous earthquake consequences from minor ones in about 95% of the cases in near-real-time.

As input, we need accurate parameters for the earthquake source as well as world data for population, building stock, transmission properties for seismic waves, and local soil conditions in settlements. Events like the Wenchuan earthquake offer an opportunity to improve the regional data in the world data sets and to identify weaknesses in the process to estimate losses in near-real-time. For example, data on the quality of the built environment are difficult to obtain for many parts of the world and are therefore estimated by expert opinion. Also, attenuation functions differ regionally, but are not well constrained by data for some parts of the world. Finally, local soil conditions can modify the strong ground motions, but are generally not known for settlements in the developing world.

It is important to deliver reliable loss estimates as fast as possible because the chances of rescuing injured people diminish rapidly with time. Heavily and moderately injured are unlikely to survive more than two and three days, respectively (Coburn and Spence, 2002). Therefore, the purposes of this paper are: (1) to review the sequence of calculations that lead to an estimate of the likely losses, (2) to document the quality and rate at which estimates of earthquake parameters, damage to the built environment, and human losses became available outside of China in the case of the Wenchuan earthquake, and (3) to identify means by which the speed and quality of these estimates could be increased.

Method

Currently, our computer tool and data set (QLARM) to calculate losses is in reconstruction, a project carried out jointly with the Swiss Seismological Service (SED) of the Federal Institute of Technology, Zurich. The software architecture of this second generation tool for estimating losses, and sample runs, can be viewed at http://qlarm.ethz.ch. The results reported in this paper are still calculated by the program QUAKELOSS that is based on the work of Shakhramanian, *et al.*, (2000).

The strong ground shaking is calculated as a function of epicentral distance using the equation by Shebalin (Shebalin, 1968) in which constants may be adjusted for different regions. Using fragility curves for five classes of buildings, the probable damage is calculated for each class (Trendafiloski, *et al.*, 2009). Based on the distribution of buildings in the fragility classes in the epicentral area, the mean damage of each settlement is calculated and displayed by a color code on the map posted on WAPMERR's web site. From the expected damage, the effect on occupants is estimated in each settlement, using a casualty matrix (Trendafiloski, *et al.*, 2009). Given the many uncertainties in input parameters, we rely on averaging of local over- and under-estimates when many settlements are involved. Therefore, we have most confidence in the sum of human losses in all affected settlements and we do not estimate damage to single structures. Even this sum can only be regarded as an approximate estimate.

The earthquake source parameters we use are those distributed by the US Geological survey (USGS), based on teleseismic records (Wyss and Zibzibadze, 2009). As soon as reviewed calculations of the hypocenter and magnitude of a large earthquake become available, an SMS is sent from a server at the SED to WAPMERR's duty person, who then calculates the expected losses. The range of calculated values for human losses is derived from the uncertainties in building damage and in the casualty matrix. It is often expanded by expert judgment, in which the possible effects of input errors in depth, location, magnitude, and attenuation are modeled manually in near-real-time. The minimum and maximum of the human losses so obtained are used to estimate the range of possible results.

Data Flow

The first information on the Wenchuan earthquake of May 12, 2008, that reached WAPMERR was an email from the GeoForschungsZentrum (GFZ), Potsdam, 7 minutes after the origin time, giving source parameters calculated automatically (Table 1). Although this information was generated automatically, WAPMERR calculated a preliminary estimate of the losses right away because the estimated magnitude of 7.7 required immediate action. Normal practice by WAPMERR is to wait until a reviewed estimate of source parameters is available before alerts are issued. In this case, WAPMERR made an exception because reviewed source parameters took unusually long to be distributed. WAPMERR's duty person informed the SDC by telephone that a major earthquake disaster has happened in Sichuan 21 minutes after the event (Table 1).

The first reviewed magnitude calculation was 7.5, based on which WAPMERR sent an email estimating the number of fatalities in the range of 1,000 to 4,000. After a revised magnitude estimate of 7.8 was distributed by the USGS, WAPMERR called the SDC to announce a revised estimate of the losses amounting to 20,000 to 90,000 fatalities. By this time 100 minutes had elapsed since the earthquake occurrence (Table 1). News media announced that 107 people had been killed in this earthquake.

Subsequently, the possibility of the magnitude being as high as 8 was communicated by the Obninsk Observatory of the Russian Academy of Sciences (RAS) and by the Chinese Institute of Geophysics, CEA, Beijing (IG-CEA; H.-S. Peng, personal communication be telephone and email), which prompted WAPMERR to post a final estimate of fatalities in the range of 40,000 to 100,000 on their web site, along with a revised damage map about 10.5 hours after the event.

Loss Estimates as a Function of Time

The median delay with which the USGS distributes reviewed source parameters has been shortened to 19 minutes since the beginning of 2007, compared to 26 minutes before that time (Wyss and Zibzibadze, 2009). In the case of the Sichuan earthquake, the delay was close to the earlier median (Table 1).

The European Mediterranean Seismological Center (EMSC) currently delivers reviewed source parameters within 34 minutes (median), compared to 41 minutes before 2008 (Wyss and Zibzibadze, 2009). In the case of the Sichuan earthquake, their parameters were distributed with average speed. The median delay for delivery of RAS source parameters is 83 minutes, unchanged for several years. For the Sichuan earthquake they took an extra 27 minutes to distribute source parameters.

Automatic estimates of source parameters can be generated faster, but there is a question of reliability. Since mid 2008, we have monitored automatic solutions by the Geoforschungszentrum, Potsdam (GFZ), finding that they become available worldwide after 7 minutes (median and mean). In the case of the Wenchuan earthquake, their magnitude estimate was closer to the final value than any other estimate for about 1.5 hours (Table 1). This good result, together with their high quality epicenter estimate, suggests that the new service of source parameter estimates by GFZ may become useful for loss estimates.

There are three organizations currently offering estimates of impacts of earthquakes in near-real-time; the Joint Research Center (JRC), the USGS and WAPMERR. In the case of the Wenchuan earthquake, the JRC distributed an automatic “red alert”, based on automatically calculated source parameters 15 minutes after the event. In this alert, they reported the number of people within several radii ranging from 1 to 200 km and the distance of airports from the automatic epicenter.

The PAGER website of the USGS contains the following information concerning the Wenchuan earthquake. A map showing expected intensities, a list of population numbers exposed to strong ground motion of intensities IV to X, and a list of cities with the expected intensity of shaking between IV and X. The first information on PAGER appears usually about 3 minutes after the reviewed source parameters are calculated. That would have been about 30 minutes after the origin time. However, we have no record of that time, or of the content that was first posted. The final data posted on PAGER for the Sichuan earthquake is version 11.

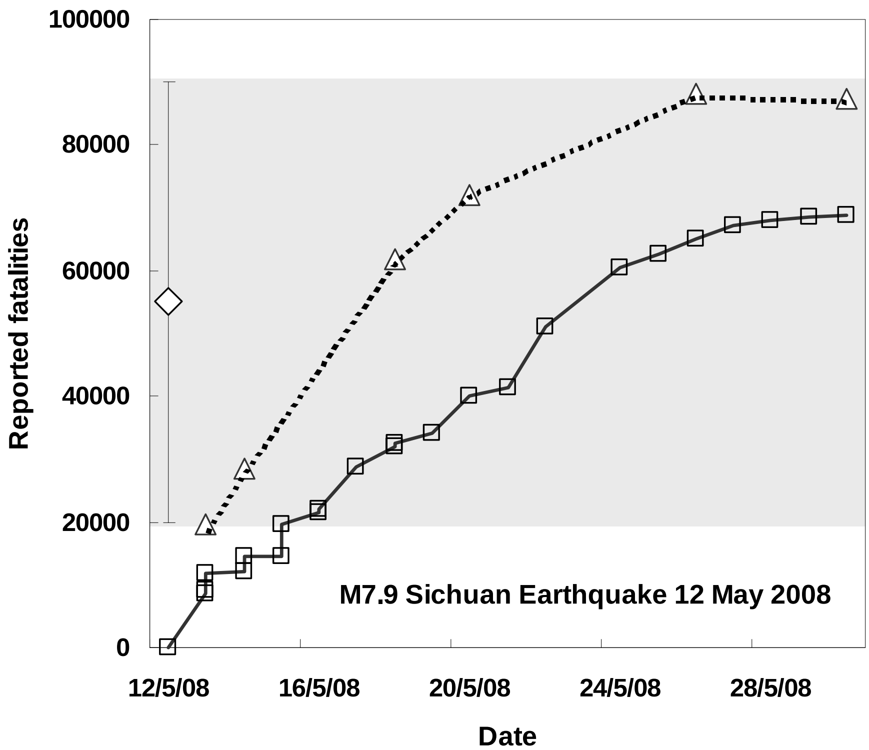

Figure 1: Reported fatalities due to the Wenchuan earthquake of 12 May 2008 (squares) as a function of time after the earthquake, compared to the quantitative estimate by WAPMERR, based on M7.9, 100 minutes after the occurrence time (diamond with error bars). The triangles show the sum of fatalities and missing, which in the end equaled the total number of fatalities.

The numbers of fatalities and the sum of fatalities plus missing, as reported by the Xichuan News Agency of China, is shown as a function of time for the 18 days following the earthquake in Figure 1. The first report on May 12 of 107 fatalities was followed by a value of 8,533 on May 13. Four days after the earthquake, the reported numbers of fatalities were still near 20,000. Only on May 18 (day 6) did the sum of fatalities plus missing (61,895) begin to reflect the disaster in a realistic way. The comparison of WAPMERR's estimate after 100 minutes (55,000 ± 35,000, diamond in Figure 1) with the final death toll of 87,476 shows that the estimate was correct. However the error associated with that estimate is large.

Distribution of Population Into Vulnerability Classes of Buildings

We are interested in evaluating the reliability of the regional data on building stock. One way to verify the approximate validity of the building data is to compare the calculated damage with the observed one. The data for this work are not yet available.

Alternatively, on may compare different expert judgments on regional distribution of people into building classes in order to identify which parts of the world data may be weak and may need to be replaced. We find that the distribution for urban settlements we used in our real time calculations of losses shows negligible differences to the distribution given by PAGER (Jaiswal and Wald, 2008) (Figure 2). For rural settlements, the differences are also small. They are 7% and 12% for classes A and B, respectively.

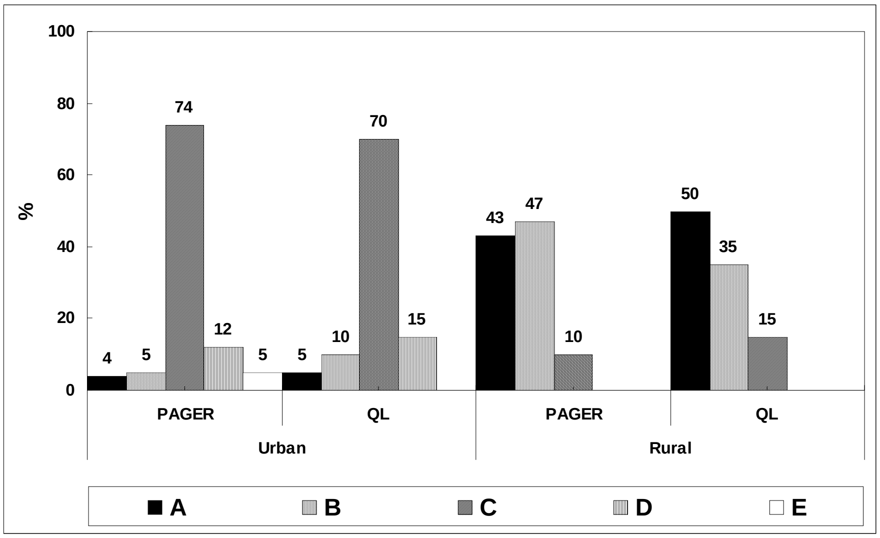

Figure 2. Distributions of population into vulnerability classes for urban and rural settlements in China as given in the PAGER and QUAKELOSS (QL) databases. Capital letters refer to building type according to the EMS-98 scale (Gruenthal, 1998), with A the weakest and F the strongest in resisting ground shaking.

The calculated mean damage grades that result using the two models for distribution in building classes are shown in Figure 3 as a function of intensity. The differences are hardly discernible.

Attenuation of Seismic Waves

In real time, we calculate the expected intensity at each settlement near the epicenter, using the Shebalin relation (Shebalin, 1968). This equation has three parameters *A*, *B*, and *C* that we may tune regionally. *A* is a linear magnitude-dependant offset, *B* stands for the distant-dependent attenuation capacity and *C* is a linear offset. The standard values for these parameters are $A = 1.5$, $B = 4.5$ $C = 3.5$. In areas where low attenuation is suspected, we use $C = 4.0$.

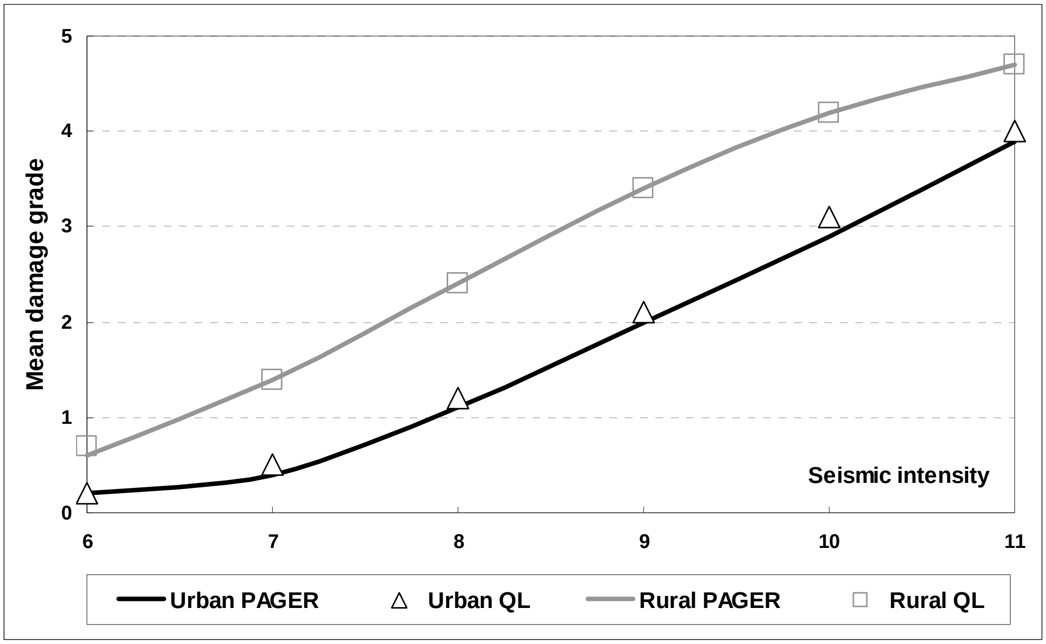

Figure 3. Mean damage grade as a function of intensity, calculated using PAGER and QUAKELOSS databases for urban and rural settlements in the Sichuan region.

The intensities calculated, using the two choices for the constant *C*, are compared in Figure 4 to observed intensities. For low intensities the data come from the ShakeMap Archive of the USGS reporting data from the Community Internet Intensity (CII) service (Allen, *et al.*, 2008) and for the high intensities distances were read off the isoseismal map of the CEA (Yifan, *et al.*, 2008). Intensities collected by the USGS are available for 41 settlements at distances from 40 to 2000 km of the epicenter and ranging from VIII to II. Intensities derived from Peak Ground Motion (PGM) as calculated by the ShakeMap program and the ones calculated from the regional attenuation relationship HH92 (Huo and Hu, 1992) are also shown in Figure 4.

For intensities higher than VI, the Shebalin relation with $C = 4.0$ matches the observed values and fits the epicentral intensity of XI. For lower intensities at larger distances, they are underestimated, but these locations are irrelevant for loss calculations. The constant $C = 3.5$ appears to be more appropriate at the short distances that matter for loss estimates. The HH92 relation is not suitable for high intensities (VIII and above) and fits the observations better at large distances. Intensities derived from peak ground motion and used to produce the ShakeMap model are lower than the observed ones.

Local Soil Conditions

Because local soil conditions can amplify strong ground motions we construct models for important cities in seismogenic areas that include microzonation data (Rosset, *et al.*, 2008; Trendafiloski, *et al.*, 2009). However, for most cities such data are not available to us, including for settlements in China. In cases without geological or other input on soil conditions, we calculate average Vs30, using the worldwide Vs30 grid of values derived from topography made available by the USGS (Allen and Wald, 2007).

The latter are selected within a radius around each site based on the population and the density of population.

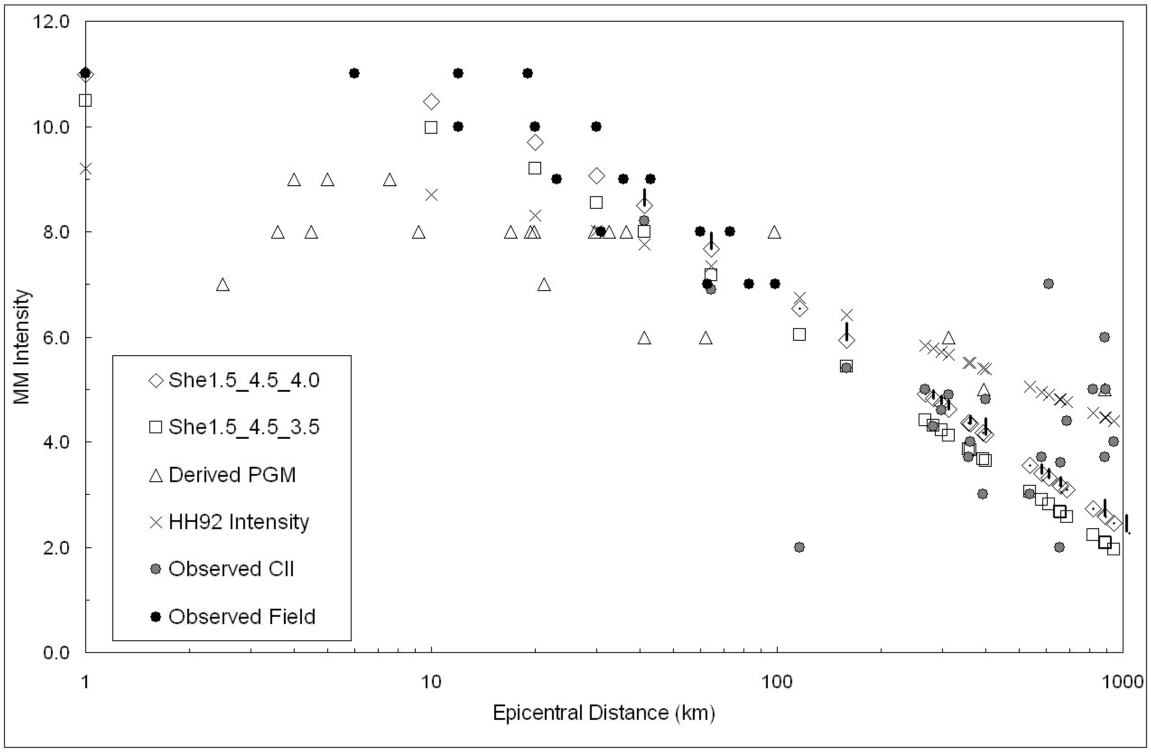

Figure 4. Intensity as a function of distance. Observations, given by the ShakeMap Atlas of the USGS (grays dots) and estimated from the isoseismal map of the CEA (black dots), are compared to the calculated intensities for the same sites using the Shebalin relationship (squares and diamonds) and a regional (HH92) relation (crosses). Derived PGM are values estimated by the ShakeMap program. Vertical bars indicate the influence of soil condition on the calculated intensity at each site derived from averaged Vs30 values by the method of (Wald and Allen, 2007).

Here we estimated how much approximately the intensities calculated may be increased due to soil properties. The amplification factors based on the average Vs30 are shown by vertical bars in Figure 4. These amplification factors typically increase the intensity values by 0.2-0.3 degree.

Discussion

Because we are aware of the many and large uncertainties inherent in loss estimates, we gave the range shown in Figure 1 in our near-real-time estimate of the number of fatalities. How could this uncertainty be decreased? To work toward an answer to that question, the influence on the estimate of human losses by input factors in general and for the Wenchuan earthquake in particular are reviewed in the following.

(1) The magnitude of the earthquake has to be known accurately for reliable loss estimates. For medium size earthquakes, the uncertainty usually does not exceed 0.2 units. However, for large and great earthquakes, magnitudes are almost always underestimated, at first. The reasons for this problem are well known and not reviewed here. In the case of the Wenchuan earthquake, the initial underestimate by 0.5 units lead to an initial underestimation of the human losses by a factor of about 20. Efforts to avoid underestimating the magnitude include integration of the long period P-wave signal, a method developed by GFZ (Di Giacomo, *et al.*, 2008) and the discovery of a new phase called W (Kanamori and Rivera, 2008).

(2) It would be desirable to have an accurate epicenter available right away. In most parts of the globe where the USGS epicenters are the best information for several days, their errors are approximately 13 to 15 km. This uncertainty could be decreased by nearly an order of magnitude, if regional network data could be distributed rapidly. Such a reduction in epicenter error could mean a tenfold reduction in the error of loss estimates in cases of medium magnitude earthquakes ($5.4 < M < 6.6$) because the distance to a single large city can be the critical factor. For the Wenchuan earthquake, the estimate of the over all extent of the disaster did not critically depend on the epicenter input, because numerous settlements were affected. Only the distribution of losses into communities depended on the exact position of the rupture.

(3) The depth from which most of the energy is released is critical for loss estimates, in large and small earthquakes. A clear example is that of the Bam M6.6, 2003 event, where modeling based on InSAR revealed an unusually shallow energy release (Wyss, *et al.*, 2006); a fact that was not known in near-real-time. However, the depth is difficult to estimate teleseismically. Regional and local data, or InSAR anamyses, would be helpful to refine the depth estimate. The effect on the loss estimates by a depth error of 15 km can be an order of magnitude for a moderate sized event close to a medium to large poorly built city. In the case of the Wenchuan earthquake, the estimated number of fatalities is about 20% larger, if a depth of 10 km is assumed, compared to 20 km depth.

Because of the inherent limitations in teleseismic depth estimates WAPMERR and PAGER are working on establishing regional 'most probable depth' values, based on previous seismicity located accurately and on tectonic fault models.

(4) The choice of attenuation influences the estimated human losses by approximately factors of 4 to 6 in the case of the Sichuan earthquake. Knowing the regional attenuation is important for all earthquakes, but the geographical setting of the Wenchuan earthquake generated an especially large increase in estimated fatalities with decreasing attenuation. This was the case because the calculated strong shaking is mostly restricted to the mountainous source area with its moderate sized settlements, if high attenuation is assumed. Assuming low attenuation, the strong shaking reaches large urban cities outside the mountains, where many victims must be expected.

Calculated intensities using the Shebalin relation (Shebalin, 1968) with $C = 4.0$ fits the epicentral intensity and observed intensities higher than VI and it also fits the reported number of fatalities, using M8 as determined by Chinese sources. The regional relation proposed by (Huo and Hu, 1992) does not predict the observed high intensities correctly. Up to now, we have not found a published attenuation relationship appropriate for this part of China. Regional differences in attenuation are well documented for only few regions. In many areas, differences seem to exist, but are statistically not well enough documented to be accepted as fact. High quality regional attenuation data would help reduce uncertainties in worldwide loss estimates.

(5) Accurate information on the regional properties of the built environment and on the casualty matrix is of course also important for accurate loss estimates. Comparison between the model we used for the distribution of people into building classes with the model proposed by (Jaiswal and Wald, 2008) shows little difference. The resulting mean damage grades are practically the same. We conclude that the data set on buildings is not likely to have been a major source of errors in the case of the Wenchuan earthquake.

(6) Local soil conditions are important when a single large city with varying soil types is the main object of interest (Rosset, *et al.*, 2008; Trendafiloski, *et al.*, 2009). For estimating the over-all extent of the losses in the Wenchuan case, this factor was less important because it averages out in the large numbers of settlements affected (approximately 200 to 500 at intensity VII and higher, depending on the attenuation function assumed). We are collecting microzonation data for large cities in seismogenic areas to be included in detailed models that will allow separate loss estimates for sub-parts of large cities.

Another question regards cost-benefit considerations in the tradeoff of quality versus delivery speed of impact assessments. Considering that the chances of rescuing a person trapped decrease rapidly with time, rescue organizations are preoccupied with speed. This is justified because there are many steps necessary to rescue a person. If in each step the minimum time is used to execute it, the sum of the saved time is significant. It follows that our loss estimates should be delivered as rapidly as possible.

On the other hand, the affected people and the rescue community are ill served, if errors are introduced because of attempts to be fast, at the cost of accuracy of the information. For example, the automatic impact assessment by JRC that gives the number of people within several radii of the epicenter, without estimates of the intensity of shaking, is about 10 minutes faster than the detailed, quantitative loss estimates by WAPMERR. The faster delivery of alerts by JRC comes at the following price. The JRC alerts do not contain evaluations of damage to the built environment, or human losses. The average error in hypocenter is 26 km, comparing the earthquake parameters used by JRC to the reviewed parameters distributed by the USGS. This error can translate into an order of magnitude of difference in the number of fatalities expected. In addition the average error in magnitude used by JRC is 0.2 units, with about 10% of the cases in the range of 0.5 to 0.7 units. These latter magnitude errors typically translate into an order of magnitude errors in estimates of fatalities. The errors of the input parameters given above were derived from the orange and red alerts JRC have distributed between January 2007 and October 2008.

Conclusions

The impact assessments and loss estimates distributed by JRC, PAGER, and WAPMERR in the first hour after the Wenchuan earthquake clearly indicated that a major disaster had taken place. However, the extent of the disaster was underestimated because the calculated magnitude was too small at first. An hour and a half after the event, WAPMERR gave a range of fatalities (20,000 to 90,000) that encompassed the final number (87,476). This information contrasted strongly with the news and government releases that began with 107 fatalities, at first, increasing to only 20,000 during the following four days. Therefore, we conclude that the loss estimates based on teleseismic data and world data sets on population and the built environment are useful.

The range of uncertainty was large in the near-real-time estimate of human losses. The most obvious way to reduced it is to develop a method to correctly and rapidly estimate magnitudes of great earthquakes. It appears that new methods are coming on line to reduce this error.

The second most important seismological input parameter that should be improved is regional attenuation relationships. New data are needed to make progress in establishing regional differences in attenuation.

The important problem of depth of energy release can be tackled by using preexisting tectonic information. An alternate method would be to receive near-real-time depth estimates from regional networks.

Regarding the question of cost-benefit of automatic versus reviewed loss estimates, the choice is clearly the reviewed procedure that delivers results 10 minutes later than automatic ones, but is typically 10 times more accurate.

Establishing a network among experts by which information could be exchanged and error sources evaluated during the few hours after disastrous earthquakes could be helpful for rendering loss estimates more precise. In the case of the Wenchuan earthquake, discussions by telephone and email between staff of the IG-CEA and WAPMERR served this purpose.

Acknowledgements: This work was carried out with the support of the Swiss Agency for Development and Cooperation, but does not necessarily reflect the opinion of this agency.

Hour (GMT)	Min	Agency	Lat (deg)	Lon (deg)	Dep. (km)	**M**	Action	Loss Estimate	Delay (min)
06	28	Origin Time							0
06	35	GFZ	31.08	103.15	43	**7.7**	automatic		7
06	43	JRC					automatic	red alert	15
06	49	WAPMERR					preliminary warning by phone to SDC, based on automatic solution	major disaster	21
06	55	USGS	31.08	103.27	10	**7.5**	reviewed parameters		27
06	57	WAPMERR	31.08	103.27	10	**7.5**	email, first quantitative loss estimate based on M7.5, reviewed	fatalities 1,000 to 4,000 injured 3,000 to 9,000	29
07	03	EMSC	31.12	103.25	10	**7.5**	reviewed parameters		35
08	07	USGS	31.08	103.27	10	**7.8**	revised magnitude		99
08	08	WAPMERR					revised loss estimate, based on M7.8, phone call	fatalities 20,000 to 90,000	100
08	17	GSR	31.1	103.4	10	**8.0**	reviewed parameters		109
08	42	EMSC	31.12	103.24	10	**7.8**	revised parameters		134
17	03	WAPMERR					final, revised loss estimate based on M7.9, low attenuation	fatalities 40,000 to 100,000	635

Table 1: Source parameter and loss estimates for the Sichuan earthquake of 12 May 2008 as a function of time.

References

Allen, T. I., and D. J. Wald (2007), Topographic slope as a proxy for global seismic site conditions (vs30) and amplification around the globe, 69 pp.

Allen, T. I., D. J. Wald, A. J. Hotovec, K. Lin, P. S. Earle, and K. D. Marano (2008), An atlas of shakemaps for selected global earthquakes, 34 pp.

Coburn, A., and R. Spence (2002), *Earthquake protection*, Second ed., John Wiley & Sons, Ltd.

Di Giacomo, D., S. Parolai, J. Saul, H. Grosser, P. Bormann, R. Wang, and J. Zschau (2008), Rapid determination of the enrgey magnitude me, paper presented at European Seismological Commission 31st General Assembly, Hersonissos.

Gruenthal, G. (1998), European macroseismic scale 1998, Conseil de l'Europe, Luxembourg.

Huo, J., and Y. Hu (1992). Study on attenuation laws of ground motion parameters, *Earthquake Engineering and Engineering Vibration* **12** 1-11.

Jaiswal, K., and D. J. Wald (2008). Creating global building inventory for earthquake loss estimation and risk management, *Earthq. Spectra*.

Kanamori, H., and L. Rivera (2008). Source inversion of w phase: Speeding up seismic tsunami warning, *Geophys. J. Int.* **175** 222-238.

Rosset, P., G. Trendafiloski, and M. Wyss (2008), Use of seismic wave propagation data for loss estimates in quakeloss2: From regional to local, paper presented at European Geosciences Union, General Assembly, Vienna, A-02459, 13-18 April.

Shakhramanian, M. A., V. I. Larionov, G. M. Nigmetov, and S. P. Sutschev (2000), *Assessment of the seismic risk and forecasting consequences of earthquakes while solving problems on population rescue*, Moscow.

Shebalin, N. V. (1968), Methods of engineering seismic data application for seismic zoning, in *Seismic zoning of the ussr*, edited by S. V. Medvedev, pp. 95-111, Science, Moscow.

Trendafiloski, G., M. Wyss, P. Rosset, and G. Marmureanu (2009). Constructing city models to estimate losses due to earthquakes worldwide: Application to bucharest, romania, *Earthq. Spectra* **in press**.

Wald, D. J., and T. I. Allen (2007). Topographic slope as a proxy for seismic site conditions and amplification, *Bull. Seism. Soc. Am.* **97** 1379-1395.

Wyss, M. (2004), Real-time prediction of earthquake casualties, paper presented at Internat. Conf. on Disasters and Society – From Hazard Assessment to Risk Reduction, Logos Publishers, Univ. Karlsruhe, 165-173, 26-27 July.

Wyss, M., R. Wang, J. Zschau, and Y. Xia (2006). Instability of loss estimates after earthquakes: Bam, 26 december 2003, *EOS* **87** 477-478.
Wyss, M., and M. Zibzibadze (2009). Delay times of worldwide global earthquake alerts, *Natural Hazards* in press.
Yifan, Y., S. Baitao, and e. al. (2008). General introduction of engineering damage of wenchuan ms 8.0 earthquake, *Journal of Earthquake Engineering and Engineering Vibration* **28** 1-118.