Review of “100+ years of recomputed surface wave magnitude of shallow earthquakes” by Drs. D. Di Giacomo and D. A. Storchak

With the recent advent of high-quality seismic networks, the database of observational seismology has expanded significantly, yet the availability is relatively short, about 3 to 4 decades, and it is desirable to relate the results of modern seismology to those obtained prior to the 1980s. As the authors state, the surface-wave magnitude M_S is among the key parameters that would allow us to compare the modern and old events, thereby allowing us to better understand the long-term seismicity of the Earth. Unfortunately, the historical data of M_S is incomplete and often confusing, and we encounter many difficulties. This paper describes the results of impressive efforts to establish a more complete historical M_S database, and is a welcome contribution to seismology and merits formal publication in Earth System Science Data. As the authors state, this is not meant to be a completed product, and future developments are planned and proposed. Thus, this review consists of some questions on the procedures used, but more importantly, I would like to make some suggestions and caveats with the hope that this database can be made more useful for serious users including myself.

I will make some detailed comments below, and I recommend publication of this manuscript, after the authors consider my comments at their discretion.

<u>Comments and questions on specific points.</u>

Line 25. Please comment on A and $(A/T)_{max}$. Is the component specified? Does $(A/T)_{max}$ literally mean the maximum of A/T, or can (A_{max}/T) be used as a proxy?

Line 31 to 36. I thought that the basis of Abe’s (1981) catalog is Gutenberg’s notepad (Goodstein et al., 1980). Also, I thought that Rothé (1969) is the continuation of Gutenberg and Richter’s (1954) Seismicity of the Earth. As far as I understand, most magnitudes published in Gutenberg and Richter (1954) and Rothé are M_S but some are based on m_B. It appears that Gutenberg’s idea of “unified magnitude” had some influence on the magnitudes in these publications. Some explanations here would be helpful. Richter (1958) would be most useful on this subject.

Line 44. What does “digitize” mean here? Does it mean to convert printed materials to computer-accessible format?

Line 63. $\sqrt{\left(2*\frac{A}{T}\right)^2_{N|E}}$ is an ambiguous notation. Please clarify.

Line 70. Can you elaborate on “median absolute deviation (SMAD) of the a-trimmed station magnitude”?

Line 198. I agree with the statement “It is of paramount importance that datasets are well-documented and that users know how they are created in order to properly use them for research”

Line 227 to 232. Although I do not have strong objection to the statement here, I think this section reads somewhat strange. Although “Saturation” and “Under-estimation” can be used in a qualitative statement, it is important to emphasize here that M_S and Mw are different parameters representing an earthquake "measure" at different periods. Both measures are equally important.

Line 248. I am glad to know that development of the M_S dataset will continue. Although the current database is very useful, for the events before 1970, the number of stations is often very limited with a large azimuthal gap, and it would be extremely helpful to include as many stations as possible. The plans summarized in this manuscript to "digitize" as many more station bulletins as possible are very impressive. Although I can understand the ISC's desire to go back to the original station bulletins, other amplitude data from various secondary sources (e.g., BCIS, Gutenberg notepad (Goodstein et al. 1980), Abe's note (this apparently exists at the Earthquake Research Institute), database used for Rothé (1969), and Lienkaemper (1984)) can be useful, and can be also utilized. Although there could be some small differences in the measuring method of amplitude, period etc in these secondary sources, it seems to me that the biggest uncertainties in the event Ms values come from the limited azimuthal coverage rather than the small differences in the amplitude measurements, and it would be useful to include Ms data from the secondary sources with an appropriate flag, if desired.

Line276 to 292. Conclusions

While I admire the ISC's efforts for establishing a good M_S data base, many investigations have been made using some standard catalogs like Gutenberg and Richter (1953), Richter (1958), Rothé (1969), Duda (1965), Abe (1981), etc. Although there are some differences in details such as the method of amplitude measurements, the method of picking the phase (A vs A/T), attenuation relation (Gutenberg vs. IASPEI formula), the component used, station corrections, and the averaging scheme etc (some of these differences are covered in this manuscript), it would be useful if the authors make some comparisons of magnitude between the new ISC M_S and that from these catalogs. It can be done by some simple figures and by some tables for important events. Again, some of the comparisons may have been already made elsewhere, but it would be useful to show them together in this paper.

There are a few questions myself, and if the authors can provide some insight on them, it will be useful for many serious researchers to fully utilize the ISC catalog.

<u>Questions</u>

The most important material is the "Ms_Dataset" that accompanies this document. Many of the issues raised below are related to the content in "Ms_Dataset".

1) I vaguely remember that Gutenberg and Richter used some station corrections (e.g., Gutenberg, 1944), but I have not seen the list of the station corrections. It is possible that the station corrections include not only the path effects (different attenuation and focusing and defocusing of energy due to multi-pathing), but also some effects of different station practices for measuring the amplitude and applying the instrument gain corrections (static magnification vs. magnification at the period of the waves being measured.)
2) Did any of the stations apply corrections for the depth? It appears that Gutenberg attempted to apply some corrections (Gutenberg, 1944), but I wonder if it is documented somewhere. I am almost certain that excitation of 20s surface waves can be significantly affected by the depth even for the relatively small depth ranges from 0 to 60 km.

3) Are any considerations given to whether the measured waves are Rayleigh type waves or Love type waves. This must have significant effects when M_S from vertical and horizontal components are mixed. Geller and Kanamori (1977) discussed some of the issues.
4) I noticed a few cases in which 2 successive events which are very close in time are given separate M_S. It will be helpful if the authors offer some explanations for these cases. Following are just 2 examples related to the 1960 Chilean earthquake.
   (i) Event 879134 and 879136.

   Event 879134 occurred about 15 min before the M_S=8.58 Chilean mainshock (#879136), and is given M_S=8.44. Judging from the difference in the amplitude of body waves, it would be very difficult to pull out the surface waves from Event 879134 which are buried in much larger waves of Event 879136.

   (ii) Event 879127 and 879128

   These events occurred just 2 minutes apart (Ms=7.18 for #879127 and M_S=7.0 or #879128), and again how the surface waves from these 2 events were separated is unclear.

5) For events after 1990 when the large number of modern global stations were used, a new problem emerged. This topic is closely related to the discussion from line 235 and Table A1. Comparison of M_S and Mw is often very important for understanding the nature of earthquakes. Large differences between M_S and Mw, and M_S between different catalogs can be due to many causes. 1) The real physical characteristics of the event (e.g., slow earthquakes), 2) very limited Mw data (e.g., single measurement), 3) large differences in M_S from different sources.

   Here, the issue is the difference in M_S from different sources. We occasionally see a very large difference ($\Delta M_S > 0.5$) between M_S from different sources. For old events (e.g., before 1970), often the difference is due to a very limited azimuthal coverage. This is to some extent inevitable because simply the number of global stations was relatively small. However, it would be important to assemble as many station Ms data as possible, even if the measurement practice is slightly different at different stations. Even if some measurements do not meet the strict ISC standard, that can be added, with appropriate flags if necessary, to the M_S basic catalog. As I will show later, I think that the variation of M_S with azimnuth is often much larger than that due to the difference in the measuring practice (amplitude, period, attenuation function, etc), and for many research purposes it is important to have a good azimuthal coverage.

   Now going back to modern events (e.g., 1970), we have the luxury of having many and many stations, and often have an opposite problem. Occasionally, we have too many stations in a small azimuthal range with "anomalous" path effects, and this can bias the final station M_S (either some sort of average or median). Since the azimuthal variation of M_S due to the path effect can be as large as ΔM_S=2 unit, this azimuthal bias can produce very confusing results. Of course, this is more of a research subject than catalog-related subject, but it will be helpful if some caveats are given in this paper. I have seen many problematic and questionable cases in the literature, and wish that some more careful discussions are made in this paper so that users are aware of this problem.

Following are some examples from old and modern events.

Event #878564 1960-03-20 Off east coast of Honshu

The ISC M_S is 7.92, but JMA magnitude M_{JMA} is 7.0. Although M_{JMA} is not exactly M_S, it was calibrated against Gutenberg and Richter's M, and generally believed to be close to M_S. For many Japanese events, M_{JMA} is indeed close to M_S (e.g., Utsu, 2001, Relationships between magnitude scales). Thus, this large difference caught my attention. Figure 1 compares the azimuthal variation of M_S taken from "Ms_Dataset" and that computed for a nearby Mw=7.3 event (3/9/2011) using the global data. The azimuthal variation patterns of M_S for the 2 events are very similar, and large. The range is almost 2 magnitude unit (6.5 to 8.5) for the 1960 Sanriku event, and 1.5 unit for the 2011 event. Since the number of stations for the 2011 event is very large (what are shown on the figure represent only a subset), and the azimuthal coverage is uniform, the median appears to be well defined. On the other hand, for the 1960 event, the data set is dominated by the stations in the azimuthal range from 300 to 360 deg. Although there is some evidence that the 1960 event was a slow earthquake, it should not affect M_S, and the users should be aware of this strong azimuthal variation of M_S.

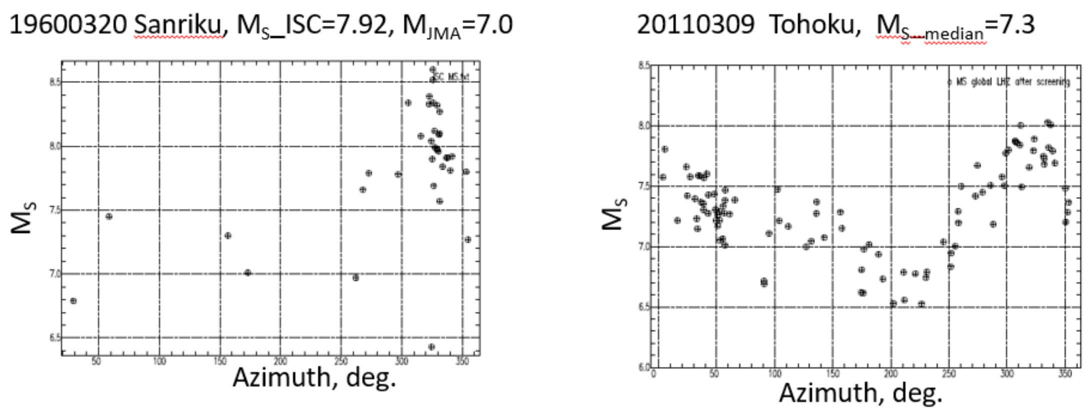

Fig. 1

Figure 2 is an example given in Table A1 of this manuscript: the 3/7/1927 event with an ISC M_S of 7.82. To compare this event with a recent event in the same area, the M_S data of the 2016 Tottori earthquake (M_S=6.2) are shown. Again the 1927 case is strongly influenced by the stations in the azimuth range of 300° to 360°. A somewhat similar pattern is seen for the 2016 Tottori earthquake, but since the azimuthal coverage is uniform, the median (M_S=6.2) seems to be fairly stable, and in fact this value agrees well with the value quoted in GCMT catalog .

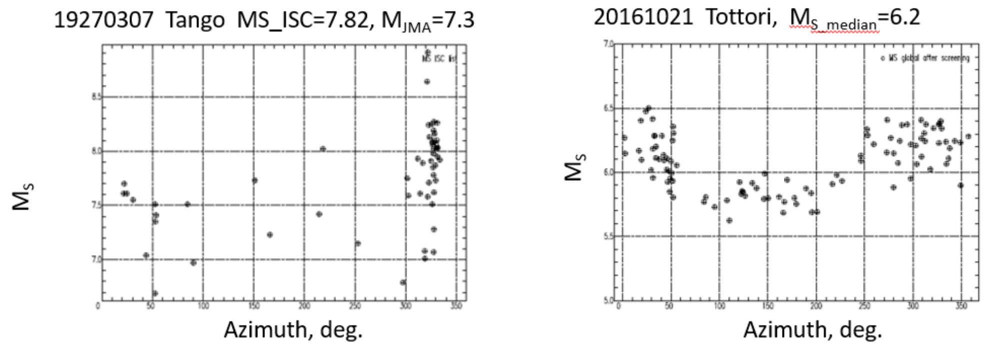

Fig. 2

Figure 3 shows an example of the 2002 Denali earthquake (Mw=7.8). The M_S value given by NEIC and listed in the GCMT catalog is 8.5, presumably an average of more station data than those shown in Figure 3. The existing global stations are far more than those shown in Figure 3, especially in the azimuth of about 100°, and an average can become very large. I do not know exactly what an averaging scheme is used. In this particular case, if we take a bin-average, we get the following:

Azimuth range	number of stations	bin average
0-45	20	7.536
45-90	4	8.468
90-135	14	8.539
135-180	8	8.273

The average of the bin average is 7.85, very close to the ISC value of 7.82. This is a new problem with recent events with so many stations, and the averaging scheme is very important.

20021103 Denali MS_ISC=7.82, M_{S_GCMT}=8.6

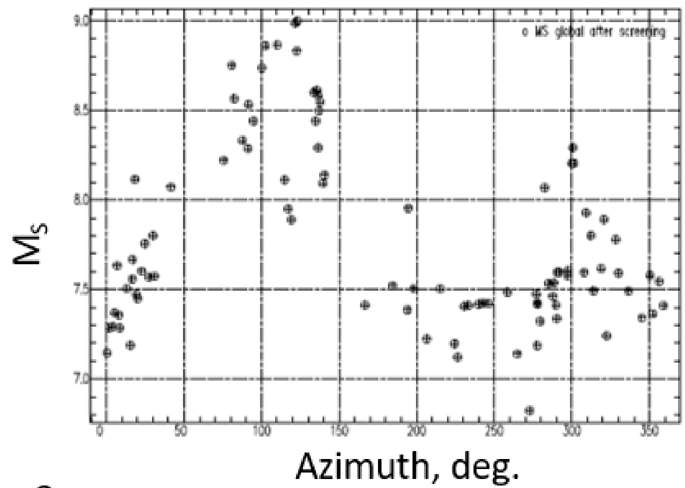

Fig. 3

This bring us to a problem with old events again. As discussed on line 238 and illustrated in Table A1 of this manuscript, the famous 1906 San Francisco is given M_S_ISC=8.61. However, as shown in Figure 4, only 6 stations are used, with 4 stations essentially in the same azimuth, and it is hard to assess the uncertainty of the assigned M_S value. Since the Gutenberg notepad lists station M_S values from some 16 stations, and Gutenberg and Richter (1954) gave MS= 8 ¼. I like this notation which probably implies an uncertainty of ¼ magnitude unit. Unfortunately, many journals demand that it should be written as 8.25 which has a very different implication for the uncertainty. Also, I suspect that Gutenberg and Richter's assignment of "quality, A, B, and C, or a, b, and c is somewhat subjective on the basis of their experience, but in case of this kind of data to which rigorous statistical method is hard to apply, I believe that it is a very reasonable practice. Actually, Lienkaemper (1984) examined Gutenberg's notepad data, and came up with M=8.3. Although I did not follow exactly what he did, he did use the 16 stations. I suspect that the data listed in the Gutenberg's note pad did not meet the strict criterion of ISC, and were not adopted in "M_S_Dataset" (I may be wrong.). However, as shown in the examples presented in Figures 1 to 4 in this review, the azimuthal station coverage is so important for obtaining a reasonable average that I would like to see as many station data as possible in the ISC catalog, even if the measurement procedure was slightly different. Overall, my experience is that the difference caused by the limited azimuthal coverage is far greater than that caused by the difference in the station practice.

190604 San Francisco M_{S_ISC}=8.61, $M_{\_GR}$=8 ¼, M_{LK}=8.3

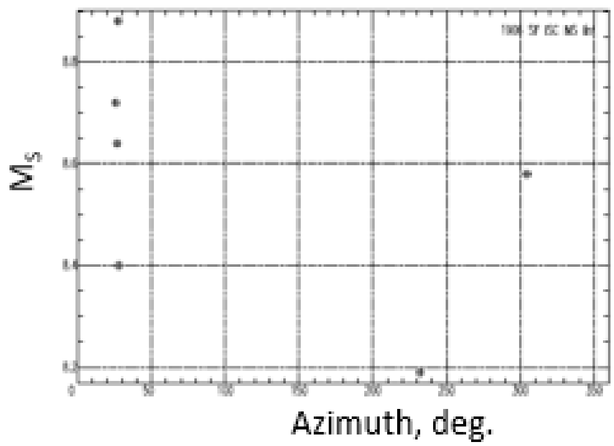

Fig. 4

My comments above are in no way the criticism of the ISC practice and catalog, but they represent my hope that the ISC catalogs will be used most effectively and properly by serious users. The historical data are important but they can have all kinds of problems and uncertainties, and very often rigorous handling is not possible. Nevertheless, these data do contain historical information which we cannot get otherwise. After all, how to use the data base and interpret it is ultimately the responsibility of the users, rather than the catalog producers, but it is most important that the catalog producers provide adequate caveats to the users so that the catalogs can be carefully used for understanding the Earth's seismicity.