

Comment on "Empirical determination of depth-distance corrections for m_b and M_W from Global Seismograph Network stations" by Guust Nolet, Steve Krueger and Robert M. Clouser

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Abstract. In their recent article, Nolet *et al.* (1998) presented an analysis which led them to conclude that the epicentral distance and focal depth correction factors for m_b which were previously published by Veith and Clawson (1972) are not accurate for events with focal depths greater than 100 km. In this brief commentary, we present some independent evidence which has led us to conclude that the Veith/Clawson (V/C) corrections are in fact quite accurate, at least for seismic events having focal depths of less than about 400 km.

Nolet *et al.* (1998), hereafter called NKC, have reported on a study in which they used analyses of broadband GSN data to assess the accuracy of previously published m_b corrections for epicentral distance and focal depth (which they denote as Q_b). We have also been investigating these corrections through direct statistical analyses of large, homogeneous samples of short-period, teleseismic P wave amplitude data which have recently become available, and have reached somewhat different conclusions. Although NKC did not consider events with depths less than 100 km, it is appropriate to begin by assessing the V/C corrections for such events, since they were used by V/C as a basis for extrapolating to corrections for deeper events. For this purpose, we compared the V/C and Gutenberg/Richter (G/R) distance corrections through a statistical analysis of a large sample of over 100,000 single station m_b values determined from recordings of 15,000 shallow focus ($h < 40$ km) earthquakes which have been analyzed at the Prototype International Data Center (PIDC) which began operations at the Center for Monitoring Research in Rosslyn, Virginia on January 1, 1995. In this analysis we employed a general linear model of the form

$$m_b(i,j,k) = m(i) + sta(j) + db(k) + e(i,j,k) \quad (1)$$

where $m(i)$ denotes the event magnitudes, $sta(j)$ the station correction factors, $db(k)$ the corrections to the $B(\Delta)$ distance factor (either V/C or G/R) and $e(i,j,k)$ is the error term. In this case, the required minimization was carried out subject to the constraints that the station correction factors sum to zero and that the distance corrections sum to zero over the 30 to 80 degree distance range. The resulting distance corrections to the V/C and G/R $B(\Delta)$ factors are plotted as functions of epicentral distance over the teleseismic range extending from 23 to 90 degrees in Figure 1. It can be seen from this figure that the corrections to the V/C $B(\Delta)$ factors are remarkably small over this range (i.e. ± 0.1) and, more specifically, that they are significantly smaller than the corresponding corrections to the G/R $B(\Delta)$ factors determined using the same data set. We conclude

from these results that the V/C corrections for epicentral distance are remarkably accurate on average and superior to those of G/R for shallow focus events. In particular, we agree with NKC that many of the distance dependent details of the G/R corrections are not well-supported by the large worldwide data sets that are currently available for analysis.

While the average differences in the V/C and G/R Q_b factors are quite small for shallow events, they become progressively larger with increasing focal depth. In fact, for the deepest events in the 600-700 km depth range, the m_b values obtained using the V/C corrections are more than 0.6 magnitude units smaller, on average, than those obtained by applying the G/R corrections to exactly the same large data set of PIDC events. Now, while Veith and Clawson (1972) demonstrated using a small sample of earthquake data that their proposed distance corrections at several different focal depths are somewhat more consistent than those of G/R, that by no means validated these large differences in absolute value. In fact, an independent measure of source size is required to fully assess the effects of focal depth on m_b . We have used the Harvard moment tensor solutions as this independent measure of source size.

The Harvard moment tensor solutions have been systematically determined on a continuous basis since 1977 and have been obtained using a consistent set of data processing and analysis procedures which are based on a physical model of the earthquake source. Moreover, we have found that the source moment estimates (M_0) associated with these solutions correlate remarkably well, on average, with conventional m_b and M_s magnitude measures. To establish this fact, we analyzed a data set consisting of 5259 shallow ($h < 50$ km) earthquakes in the magnitude range $4.5 \leq m_b \leq 5.5$ for which both

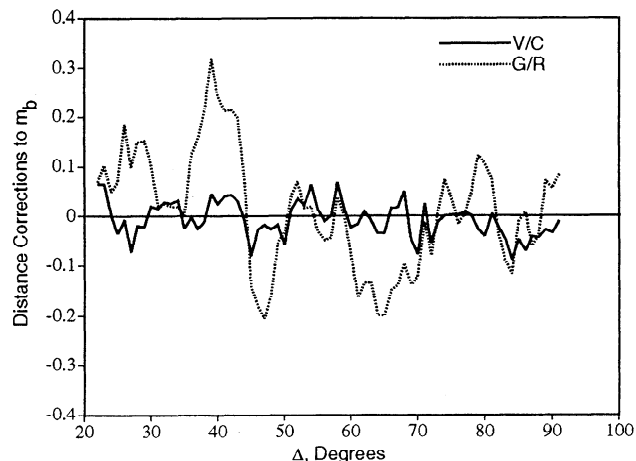


Figure 1. Average distance corrections to the V/C and G/R $B(\Delta)$ factors inferred from a statistical analysis of a large sample of data recorded from shallow focus PIDC events.

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Harvard moments and NEIS m_b and M_s values have been published. For each of the 20 years between 1977 and 1997, we computed the differences between the logarithms of the Harvard M_0 values and the corresponding NEIS m_b and M_s values and averaged the results. The resulting average differences are plotted as a function of time in Figure 2, where it can be seen that they are remarkably stable between 1982 and 1994, showing variations of less than ± 0.05 magnitude units about the mean values represented by the dotted lines on this figure. In fact, the results are so stable that it is easy to identify the 0.1 magnitude unit decrease in the NEIS m_b values associated with the incorporation of PIDC data into the NEIS m_b determinations in 1995. These results confirm the existence of a strong average correlation between m_b and M_0 , for shallow events.

In order to assess the dependence of Q_b on focal depth, we assembled a second sample of 2006 earthquakes for which Harvard moment tensor solutions and both PIDC and NEIS m_b values have been published. The normalized average differences between logarithms of the Harvard event moment estimates (M_0) and the corresponding IDC and NEIS PDE m_b values determined from this sampling of earthquakes are plotted as functions of focal depth in Figure 3. The normalization in this case consisted of subtracting the shallow focus (i.e., 0-20 km) average values from the values obtained from the sample bins at greater depths. It can be seen from this figure that the source size estimates obtained using the V/C corrections are significantly more consistent with the corresponding Harvard moment estimates than those obtained using the G/R corrections for focal depths less than about 400 km. That is, if it is assumed that the Harvard moments provide unbiased estimates of source size, then the V/C corrections are to be preferred to those of G/R over this range of focal depths. Moreover, in absolute terms, it can be seen that, on average, the PIDC m_b values based on V/C correlate remarkably well (i.e., variations $< \pm 0.1$) with the Harvard moments over this depth range. While these results don't directly validate the V/C distance correction factors at different focal depths, they do strongly suggest that they must be accurate on average, at least for focal depths less than about 400 km, which encompasses about 50% of the depth range considered by NKC and over 95% of all reported seismic events. The dashed lines on this figure corresponds to the average differences in the m_b values obtained using the V/C and G/R corrections, again shown relative to the value at shallow depth (0-20 km). It can be seen that this line tracks

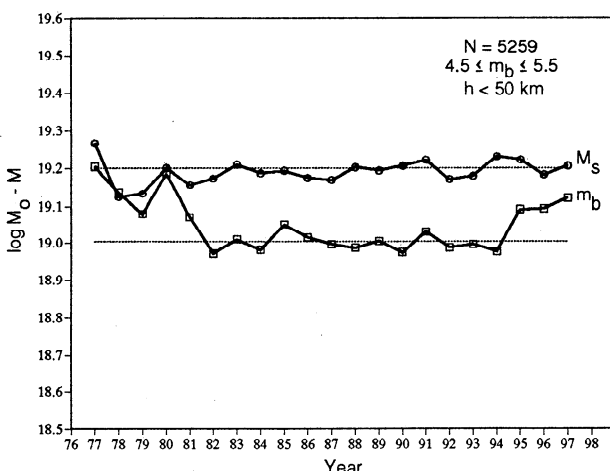


Figure 2. Time dependent average differences between the logarithms of the Harvard event moment estimates (M_0) and the corresponding NEIS m_b and M_s estimates for the same shallow earthquakes.

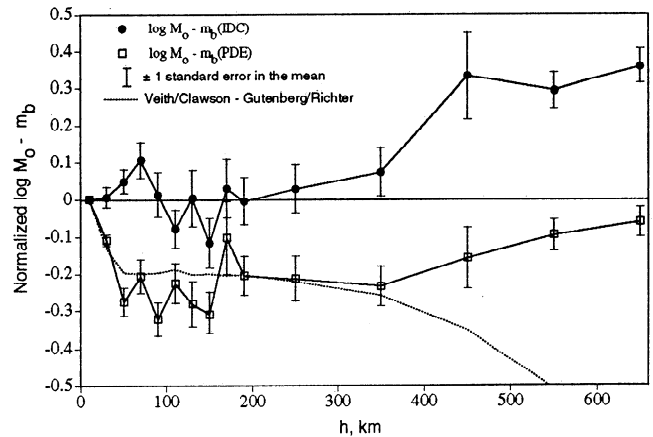


Figure 3. Average differences between the logarithms of the Harvard event moment estimates (M_0) and the corresponding PIDC and NEIS m_b values as a function of event focal depth.

the normalized $\log M_0 - m_b$ (PDE) values very closely to a depth of around 400 km, below which the differences with respect to both the PIDC and PDE m_b values drift off in a parallel manner to larger values. This suggests that there is some inconsistency between the Harvard long-period attenuation model and the short-period attenuation models implied by both the V/C and G/R corrections at depths greater than about 350 km. In their reply to this commentary, NKC present some preliminary evidence which suggests that, for events having focal depths greater than 400 km, their revised m_b estimates may indeed correlate better with Harvard moment than do the m_b values computed using V/C. While such differences in attenuation models might be expected at shallower depths, it is somewhat surprising to find them at these depths and this discrepancy deserves to be investigated in greater detail in future studies.

In summary, we conclude that the V/C Q_b corrections to m_b being employed at the PIDC provide very consistent measures of relative source size on average, at least for events having focal depths of less than about 400 km. In particular, they seem to be significantly better than the corresponding G/R corrections currently being used by NEIS and ISC in their determinations of m_b . While it is not yet entirely clear why our results differ from those of NKC over the 100 to 400 km depth range, it seems likely that it is associated with their use of broadband peak particle velocities as surrogates for the A/T values traditionally used in the determination of m_b . As those authors noted in the referenced article, their measurements were generally made at significantly lower frequencies than those typically associated with m_b determinations and our results seem to indicate that these differences negate any simple, direct correlation between the two magnitude measures.

References

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