DISCREPANCIES AMONG PIDC, ISC, AND USGS SEISMIC MAGNITUDES

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ABSTRACT

We are working to document and then to explain the well-known systematic differences between magnitudes (mb) assigned by the prototype International Data Centre (PIDC), the International Seismological Centre (ISC), and the United States Geological Survey (USGS). To do this, we first obtain "classical magnitudes" that reproduce the instrumentation and procedures associated with the Veith-Clawson magnitude scale. Though others claim to assign such magnitudes using broadband data, current practice is notably different from the actual Veith-Clawson protocol, and uses measurements made from narrow-band filtered data derived from broadband instruments. We obtain classical magnitudes by making time-domain measurements using WWSSN seismograms simulated from digital waveforms, thus allowing us to maintain consistency with the original Veith-Clawson magnitude scale.

Our first project, now submitted for publication, describes the systematic differences between PIDC mb and USGS (PDE) mb for 13 underground nuclear explosions and 10 large earthquakes (PDE mb ≥ 6.4). We have now begun to study a larger group of seismic events, spread across different depths and magnitudes, that all have USGS (PDE) mb = 5.0. For these we have obtained the Veith-Clawson mb. For 50 events, the average VC mb is 4.7, and the average Reviewed Event Bulletin (REB) mb is 4.5. Thus, the VC mb values are generally lower that the PDE mb. Our VC mb values are greater than or equal to the REB mb for all 50 events. The average discrepancy (VC mb - REB mb) is 0.2 m.u., which is less than half the discrepancy for large events (PDE mb ≥ 6.4) we studied earlier. The discrepancy is the same (0.2 m.u.) for events in the REB assigned a default depth of zero as it is for events that are assigned an actual focal depth. However, this may not continue to be the case when more events are included. For the 50 events, the VC event mb's range from 4.0-5.2, while the REB event mb's range from 4.0-5.0. We have also attempted to assign a Veith-Clawson mb for a set of events for which the USGS (PDE) mb is 4.0. For these events, there are only a few stations reporting an mb, and these overwhelmingly are array stations, for which the SNR is typically too low to permit assigning a station mb from a single reference channel. These are preliminary results, to be re-evaluated when we have examined a larger number of events.

OBJECTIVE

Our first goal with this project has been to document differences among teleseismic body-wave magnitudes, m_b, published by three different organizations that monitor global seismicity. These are the Prototype International Data Centre (PIDC), the US Geological Survey's National Earthquake Information Center (USGS/NEIC) — which publishes the Preliminary Determination of Epicenters (PDE), and the International Seismological Centre (ISC). Our second goal is to reach a quantitative understanding of at least some of the contributing causes of the observed differences.

RESEARCH ACCOMPLISHED

Introduction

Although seismic magnitudes are intended to be a measure of source strength, it is well known that in practice they are influenced by numerous additional factors such as the particular set of stations reporting individual magnitudes, the instrument responses, and the details of how each station magnitude is assigned.

Because many problems in assigning magnitude can be avoided by use of a set of fixed stations and standardization of measurements, the PIDC m_b has the potential to achieve a more consistent set of short-period magnitudes, as well as one that is more promptly available after an event than magnitudes published by other organizations. It was therefore of concern that when the PIDC began publishing seismic event bulletins daily in January 1995, it was apparent that PIDC body-wave magnitudes (m_b) were systematically lower than PDE m_b values assigned by the USGS. The amount of this discrepancy is approximately 0.4 magnitude units (m.u.), although, as we have shown in Kim *et al*. (2001) and Granville *et al.* (2002), for large magnitude earthquakes the offset is even greater. These two papers, reporting earlier work on this project, were studies of magnitudes assigned for a set of 13 underground nuclear explosions and a set of 10 large earthquakes that all had PDE $m_b \geq 6.4$. The basic methodology was to compare the PIDC values of station m_b (sometimes referred to as the Reviewed Event Bulletin $m_{b,}$ or REB m_b) with the Veith-Clawson (VC) m_b worked up from the same set of seismograms as those used by the PIDC. We have chosen the latter m_b scale as a reference, because it is a Richter-type m_b that follows a well-defined measurement protocol (Veith and Clawson, 1972), and is based on a specific instrument response — the WWSSN short-period seismometer — that was widely used for twenty years and that enabled the use of short-period magnitudes measured with greater precision than those of previous generations. Our previous work on this project concluded that the PIDC m_b and the VC m_b were in quite good agreement for the nuclear explosions; but that for large earthquakes, they gave significantly different magnitudes, due largely to choice of the time window in which maximum amplitude was measured, and to the differences in frequency band through which the broadband data were passed, prior to assigning these two magnitudes.

The present paper is in two parts. First, we document differences among PIDC, USGS, and ISC m_b values, noting that most previous studies of this general type have emphasized comparisons between just the PIDC and the USGS. The main issue here, is to see whether there is any common ground among these three m_b values, or whether they each have distinctive characteristics. Second, we extend our previous comparisons of PIDC m_b and Veith-Clawson m_b for large events, to a set of 100 earthquakes that all have PDE m_b = 5.0. Again we made measurements from the same seismograms (1521 of them) as were analyzed by the PIDC. The main issue in this latter study is whether the significant magnitude differences found for large earthquakes persist for moderate earthquakes.

Comparisons among PIDC, USGS, and ISC values of m_b

For each of the twelve quarters from 1997 to 1999, we have extracted from ISC databases the set of seismic events that were assigned m_b values by all three agencies that routinely publish bulletins of global seismicity — that is, by the PIDC, the USGS, and the ISC. Numbers ranged from a low of 2008 events in the fourth quarter of 1998, to a high of 2883 events in the fourth quarter of 1997. In this brief paper we focus on just the first quarter of 1997, for which there were exactly 2600 events assigned an m_b value by all three agencies.

Figure 1 shows four different ways to compare these magnitudes. As noted in the figure caption, there are significant differences between ISC and NEIC m_b values for magnitudes below about 5. And, these two magnitudes have different behavior with respect to the PIDC m_b at the lower magnitudes. Presumably the differences here between ISC and NEIC are due to the fact that measurements of ground amplitude *A*, and period *T*, made by the PIDC, are accepted and used by the ISC; but the USGS does not use these measurements. (In making location estimates, the USGS uses arrival times reported by the PIDC for International Monitoring System (IMS) stations. But for *A* and *T* measurements at IMS stations, the USGS either makes the measurements in-house, or in some cases accepts them from station operators.) Figure 1 also shows, in the lower right panel, a tendency for ISC magnitudes to merge with NEIC m_b for the larger events, but to become smaller than NEIC values as magnitude decreases. The question here is how much the ISC values for the smaller magnitude events are dominated by *A* and *T* measurements made by the PIDC. It is a great benefit for the ISC to have information from the PIDC on events at smaller magnitude — detected principally by the IMS array stations — but does the ISC have additional contributed magnitudes at low magnitude? Note that the bottom left panel of Figure 1 appears to show on average about the same offset (between ISC and PIDC) at lower magnitudes, as the offset at higher magnitudes. But all these magnitudes are given to one decimal place, so each point at lower magnitudes can represent many events, and it is not possible to tell from this panel where the centroid of one set of magnitudes lies, corresponding to a constant magnitude on the other scale.

The bottom right panel of Figure 1 shows the cumulative magnitude distribution of the 2600 events, for each scale. This is the number of events greater than a given magnitude. The events have been sorted in descending order separately for each scale, so that a particular order number may be associated with different events on different scales. Nevertheless, since these are the same 2600 events, the comparison in this panel is a useful device to see how the magnitude discrepancy between different scales varies as a function of magnitude. The discrepancy between PIDC and NEIC magnitudes stays approximately constant at about 0.4 m. u. over a range of about 1.5 m.u., becoming larger for the largest five events and smaller for the smallest one thousand events. The ISC magnitude distribution moves between the other two scales, being close to NEIC at large magnitudes so that there is about 0.4 to 0.5 m. u. offset from the PIDC m_b, for the few largest events, with the ISC – PIDC offset diminishing quite steadily at lower magnitudes.

In assessing the degree of dependence of the ISC on the PIDC for reported magnitudes of small events, it should be noted that discussion here is limited only to events for which there are adequate teleseismic detections to permit measurement of *A* and *T* values by all three agencies. The ISC derives a Gutenberg-Richter m_b and the PIDC uses Veith-Clawson distance corrections so the actual station magnitudes will be slightly different for any seismogram used by both the ISC and PIDC. At low magnitude, the ISC reports very large numbers of additional events for which no teleseismic m_b is available.

Figure 2 shows, for each of the PIDC, NEIC and ISC m_b scales, the number of contributing stations as a function of m_b. Although as expected the NEIC and ISC have far more stations than the PIDC at magnitudes greater than about 5, it is still difficult to tell how many stations are contributing at lower magnitudes — though the figure caption attempts to make an estimate. However the differences and dependences between the three agencies become clearer in Figure 3, which shows comparisons similar to those of Figure 1, but using just the number of stations reporting, instead of the magnitude values directly.

It is remarkable in Figure 3, how different the three panels are. The line "$x = y$" is shown (for which the two numbers would be equal). Almost all the points in the two sub-figures on the left (top and bottom) lie to the right of this line, indicating that the ISC almost always uses more stations to determine m_b than does either the NEIC (top left) or the PIDC (bottom left). This is presumably because the ISC uses almost all the NEIC's and PIDC's magnitude readings, and can only add stations in each case. From the bottom left panel, we see from the significant number of points to the right if the "$x = y$" line that indeed the ISC uses significantly more stations for determining m_b than does the PIDC, for almost all events. However, it is also clear that the actual value of the ISC event m_b at low magnitude is likely to be strongly controlled by the PIDC values, whereas the NEIC magnitudes must be quite independent because there is such a lack of correlation (between NEIC and PIDC) on the number of stations used, for the smaller events (see upper right panel).

We have results corresponding to Figures 1, 2, 3 for each of the twelve quarters in 1997 to 1999. As noted in Granville *et al*. (2002), for these years the knowledge of instrument responses at IMS stations had improved enough to avoid some of the earlier problems apparent in certain PIDC station m_b values during 1995 and 1996.

Comparisons between PIDC magnitude and a classical (Veith-Clawson) magnitude

In this project, in seeking to assess m_b values published by the PIDC, we recognize that comparisons with NEIC and ISC values, while interesting, are difficult to interpret at a basic level. The difficulties stem from various changes in the way in which USGS and ISC magnitudes have been assigned over the last ten years, and also by the uses that the USGS and the ISC have themselves made of measurements of ground amplitude A and period T reported by the PIDC (though the USGS stopped using such measurements in August 1996). As a classical or traditional standard against which to compare the PIDC m_b values, we have instead chosen to use the Veith–Clawson m_b. Specifically we have simulated Worldwide Standard Seismographic Network short-period signals from broadband records and made the Veith-Clawson measurement (Veith and Clawson, 1972). We concentrated at first on some quite large seismic sources in order to avoid the problems of using a few sensitive arrays (which can dominate the characteristics of seismicity bulletins because most events are small and such events are detected mostly by arrays). Our results in these first studies (Granville *et al*., 2002) were based on several hundred simulated WWSSN seismograms (460 for 13 underground nuclear explosions, for which the PIDC called in auxiliary stations as well as primary stations; and 200 for 10 earthquakes, for which the PIDC had no great need for auxiliary station information so most of the data came from primary stations).

Here we present preliminary results from a new study of 100 earthquakes around the world that all had PDE m_b exactly equal to 5.0. We obtained broadband seismograms for all of the 3-component stations used by the PIDC to report station magnitudes for these events, and we also obtained an appropriate single digital channel (the reference channel) for each of the array stations used by the PIDC to assign station magnitudes for these events. This study required the simulation of 1521 WWSSN short-period seismograms, from each of which we made the classical measurements of A and T and converted to m_b by procedures described by Veith and Clawson (1972). The set of VC stations magnitudes for each event were then averaged arithmetically to obtain the classical VC event m_b. Figure 4 compares the PIDC (REB) event m_b vs. the VC m_b for the 100 events with PDE $m_b = 5.0$. We found that the average PIDC event m_b was 4.49, i.e. about 0.5 m.u. smaller than the PDE m_b value. The average VC m_b was 4.65 and thus closer to the PIDC than the PDE value. Thus, the average discrepancy (VC m_b – PIDC m_b) was 0.16 m.u. This is less than half the VC – PIDC discrepancy for large magnitude (PDE $m_b \geq 6.4$) events studied earlier. The average discrepancy between NEIC and VC was 0.35 m.u., somewhat larger than expected.

The station m_b values, both PIDC (from the REB) and VC, are shown in Figure 5. Again it is clear that in most cases, the VC station m_b exceeds the PIDC station m_b. It is of some interest that the distribution of differences between these m_b values, which has a mean of 0.16 m.u., is not symmetric. This preliminary result is shown in Figure 6. Finally in this section on VC magnitudes, we note a depth effect. For those PDE m_b 5.0 events assigned the default depth of zero in the REB (36 events), the average VC event m_b is 4.8, whereas the VC event m_b for events with a non-zero focal depth is 4.6 (64 events). VC magnitudes are significantly sensitive to event depth, even with measurements made on seismograms with the passband for which this scale was designed.

In order to understand even better how the PIDC procedure for assigning body-wave magnitudes differs from the classical method by which such short-period magnitudes are assigned, we must examine events with various depth ranges separately, to see the influence of attenuation in the upper mantle near subduction zones, and the influence of depth phases.

CONCLUSIONS AND RECOMMENDATIONS

As we near the end of this two-year project, we remain convinced of the potential for PIDC magnitudes (and by extension, IDC magnitudes from Vienna) to provide stable short-period teleseismic body-wave magnitudes. Problems with calibration (instrument responses) of some stations, apparent in the first two years of PIDC operation (only after many months of effort to resolve inconsistencies), are largely solved. And it is clear that PIDC m_b values for small events are having a significant effect on ISC m_b values. However, as shown by our comparisons of PIDC m_b values with the classical Veith-Clawson values obtained from the same seismograms used by the PIDC, it is also clear that the PIDC values depart significantly from the traditional short-period magnitude scales which were developed in the 1960s through the 1980s.

Such a discrepancy has the potential to generate a number of problems, because it fundamentally undercuts the concept of any absolute reference level for a short-period magnitude. (All empirical magnitude scales imply that magnitude zero, or some other fixed magnitude, corresponds to a particular amplitude of ground motion at some fixed distance. This amplitude can be taken as a reference level.) In order to establish continuity with earlier decades in which short-period magnitude scales where developed, and became the basis for numerous quite precise studies that quantified different types of seismic sources, we advocate continued assignment of m_b values by the international monitoring community, using a traditional instrument response. Equally if not more important, we advocate use of a time window for making the measurement of ground amplitude, that is larger than the 5.5-s window used by the PIDC. Such a change would likely reduce significantly the discrepancy between PIDC and other magnitude scales, for events above magnitude 5.

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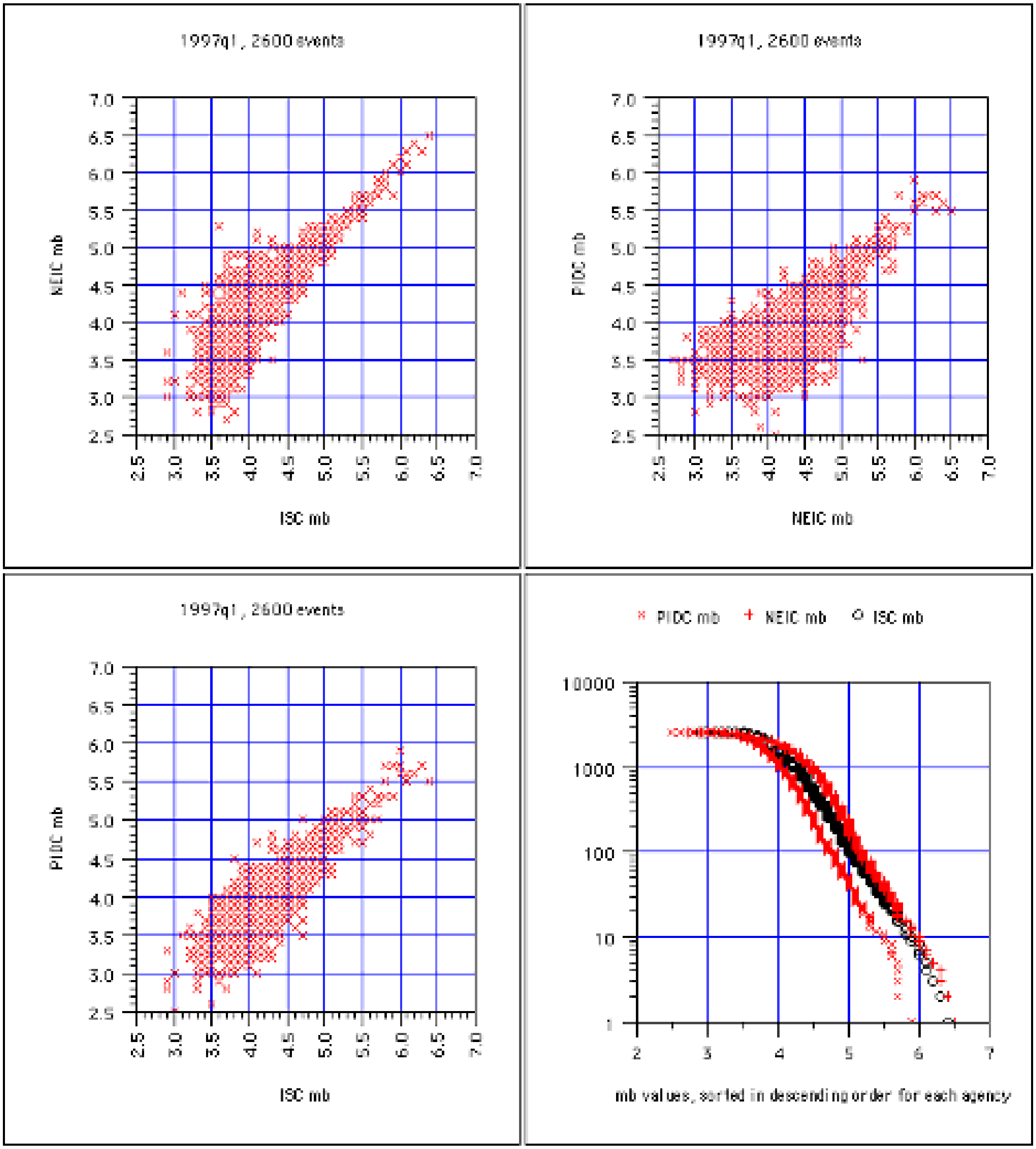

Figure 1. Four different comparisons among m_b values assigned by the PIDC, the NEIC (USGS) and the ISC, for the first quarter of 1997. The top right panel shows the familiar discrepancy, of NEIC values being typically larger than PIDC values, with considerable scatter at low magnitudes. But the upper left panel shows that NEIC and ISC values are quite poorly correlated, at least below magnitude 5. The lower left panel shows a discrepancy between ISC and PIDC, but with much less scatter than is the case between NEIC and ISC. On the bottom right, the 2600 magnitudes from each agency are sorted. Over about 1.5 m.u., there is a constant offset of about 0.4 units between PIDC and NEIC, but the ISC changes from NEIC values at high magnitude, almost to PIDC values at low magnitudes.

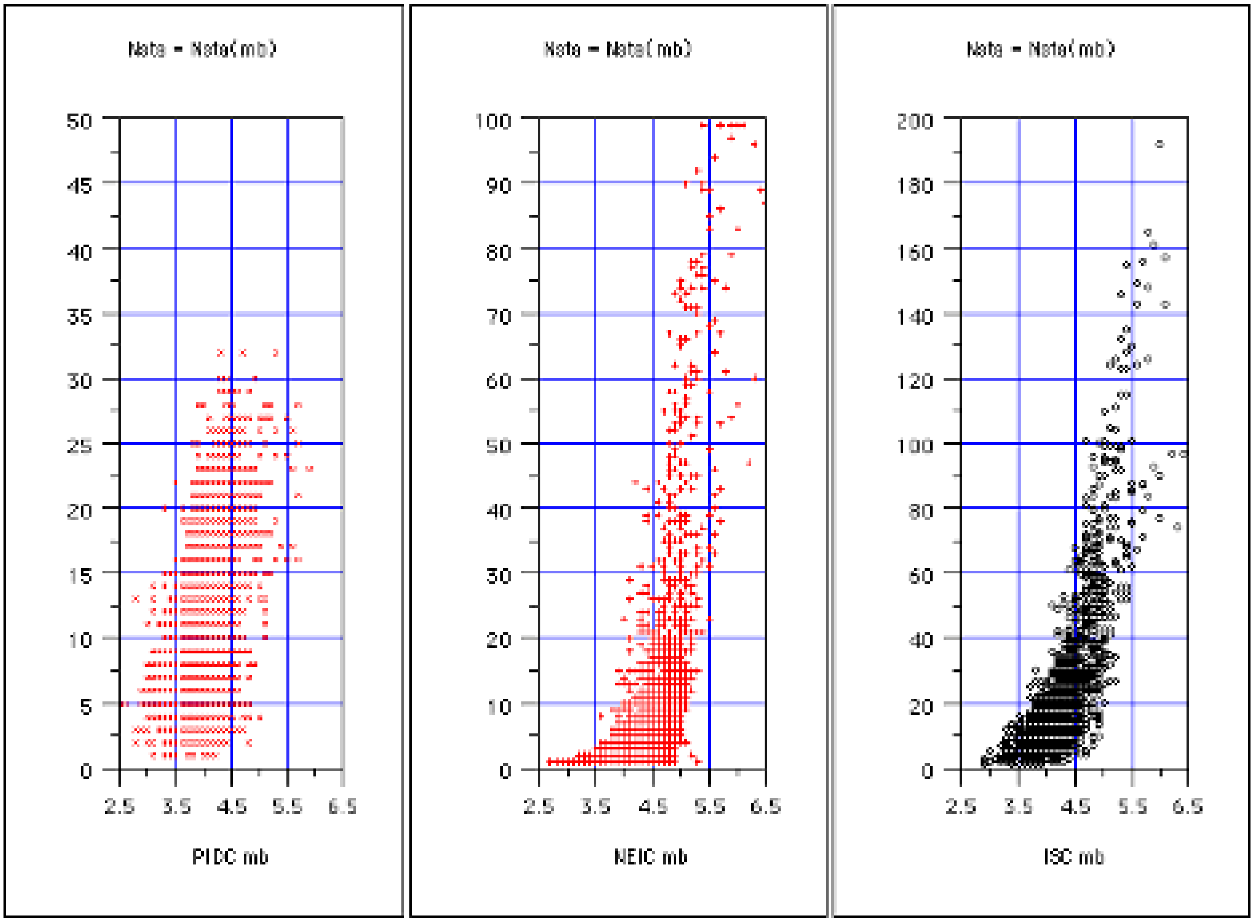

Figure 2. The number of stations contributing station magnitude values is shown for the same time period underlying Figure 1 (first quarter, 1997), and for the same set of 2600 events. Note that the scale for the number of stations doubles from PIDC to NEIC to ISC. The typical magnitude 4 event, as monitored by the USGS, has only about five station magnitudes (though considerably more for a limited number of events). But for the PIDC, as well as the ISC, the typical number is much greater.

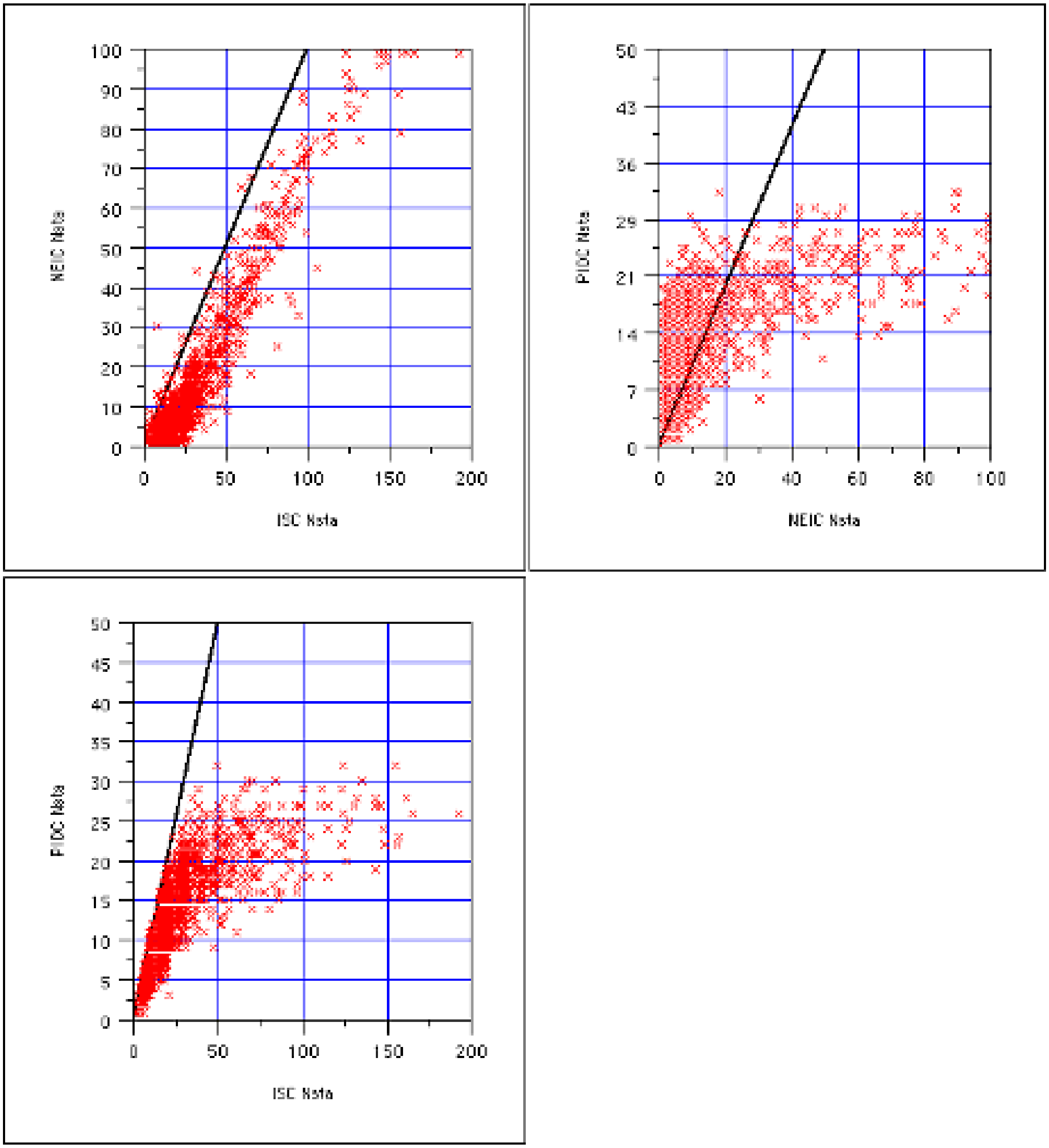

Figure 3. These three sub-figures show comparisons among the number of stations used to assign *m_b* values, just for the 2600 seismic events during the first quarter of 1997 that have *m_b* assigned by the PIDC, the USGS/NEIC, and the ISC. The comparisons are quite different in the three different panels. The upper left panel generally shows good correspondence between the number of stations used to assign *m_b*, by the NEIC and the ISC. The upper right panel shows much lower correspondence, in station numbers used by the PIDC and the NEIC. (Note that the NEIC does not use values of amplitude and period, needed to compute station magnitudes that are measured by the PIDC.) The lower left panel shows remarkably high correspondence between the number of stations used to assign *m_b*, by the PIDC and the ISC, when the number of stations is quite low. The ISC <u>does</u> use PIDC measurements of amplitude and period, which apparently, according to this sub-figure, typically provide about half the station *m_b* values used by the ISC at low magnitude.

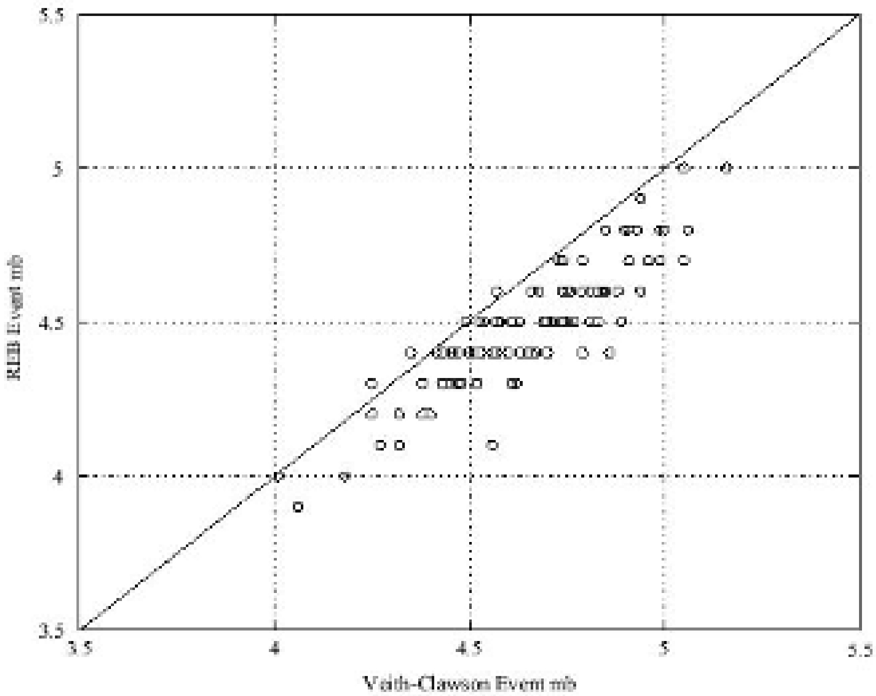

Figure 4. A comparison of mb(REB) against mb(VC), for 100 earthquakes during 1997–1998 that all had mb(PDE) = 5.

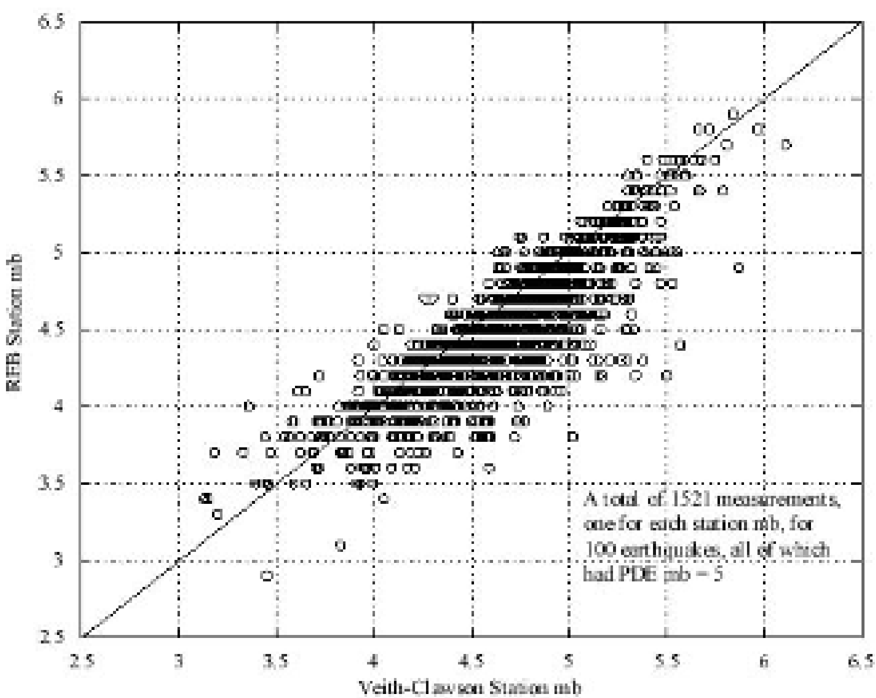

Figure 5. Similar to Figure 4, but now the individual station magnitude values are compared.

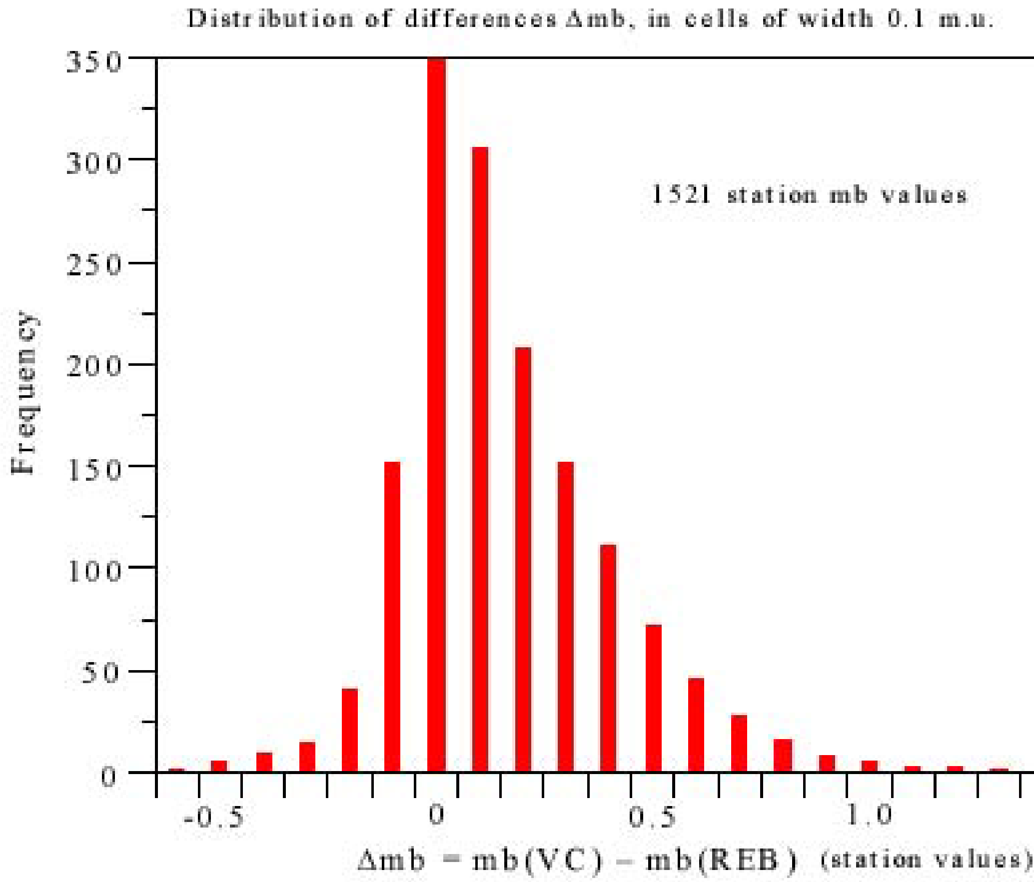

Figure 6. Histogram showing the distribution of differences between Veith–Clawson station mb and the REB station mb, for the individual station observations.