DISCREPANCIES BETWEEN PIDC, ISC, AND USGS SEISMIC MAGNITUDES

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ABSTRACT

We seek first to document and then to explain the well-known systematic differences between magnitudes (m_b) assigned by the PIDC, ISC, and USGS. To do this, we first obtain ”classical magnitudes” that as far as possible 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 broadband waveforms, thus allowing us to maintain consistency with the original Veith-Clawson magnitude scale.

We have obtained Veith-Clawson body-wave magnitudes using simulated WWSSN short-period signals for 21 earthquakes in 1998 and 1999. All of these events have a Veith-Clawson m_b that is greater than the PIDC REB m_b. The average discrepancy is 0.5 magnitude units. The discrepancy is at least 0.4 m_b units for 71% of the station m_b observations, with several observations having an offset greater than 1 magnitude unit. Note that the same broadband seismograms underlie these discrepant magnitude values, so this is not an issue of scatter in magnitudes derived from different seismograms. The choice of Gutenberg-Richter, or Veith-Clawson, for the distance correction factor does not strongly affect the resultant event magnitude.

The depth assigned to an event by the USGS NEIC in its Preliminary Determination of Epicenters (PDE) is often greater than the depth given by the PIDC REB, especially for shallow events. This is partially due to the fact that the PIDC uses its default depth of 0 km for a significant number of events, rather than solving for an actual event depth. Since an increase in depth will result in a decrease in the magnitude [for a given measurement of log_{10}(A/T) at a given distance, where A is amplitude and T is period], it follows that the discrepancy between REB and PIDC m_b is even greater, if the REB depths are replaced by those of the PDE in the m_b calculation.

KEY WORDS: seismic magnitudes

OBJECTIVE

Main objectives of the study are to document the discrepancy between the four different magnitude scales m_b(REB), m_b(PDE), m_b(ISC), and m_b(Veith-Clawson) for the period 1995–1999 and to investigate the extent to which these discrepancies are dependent on source size, depth and event type (e.g. earthquake or explosion). We also intend to obtain *station corrections* for about 89 IMS primary and auxiliary network stations, to enable the station magnitudes reported in the REB to be used for purposes of obtaining a value on the m_b(Veith-Clawson) scale. The basis to achieve these objectives is to simulate the waveforms of a classical WWSSN instrument, measure amplitude and period of the *P* wave onset for a selected class of groundtruth events that occurred during 1995–1999, and follow the protocol for assigning a classical body-wave magnitude correctly for these events on the Veith-Clawson scale.

Introduction

Almost as soon as the GSETT-3 experiment began to produce daily bulletins of global seismicity in January 1995, it became apparent that for most seismic events the seismic body-wave magnitudes (m_b) assigned by the

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Prototype International Data Center (PIDC) were somewhat lower than those assigned for the same events by the US Geological Survey's National Earthquake Information Center (USGS/NEIC). The discrepancy between these two magnitudes extends from magnitude approximately 4 up to above magnitude 6, and has persisted from 1995 to the present day. In this section we describe how big the discrepancy is, why the discrepancy is important, and briefly review the main efforts that have been made to try and explain it.

How big is the discrepancy, and is it persistent?

To address these questions we have compared m_b values published in the Reviewed Event Bulletin (REB) of the PIDC with those published by the USGS in their Preliminary Determination of Epicenters (PDE). We have done this for the first three-month period of 1996, and for every subsequent quarter year up through the first quarter of 1999, for a total of 13 quarters. In Figure 1, we show the first quarter of 1996.

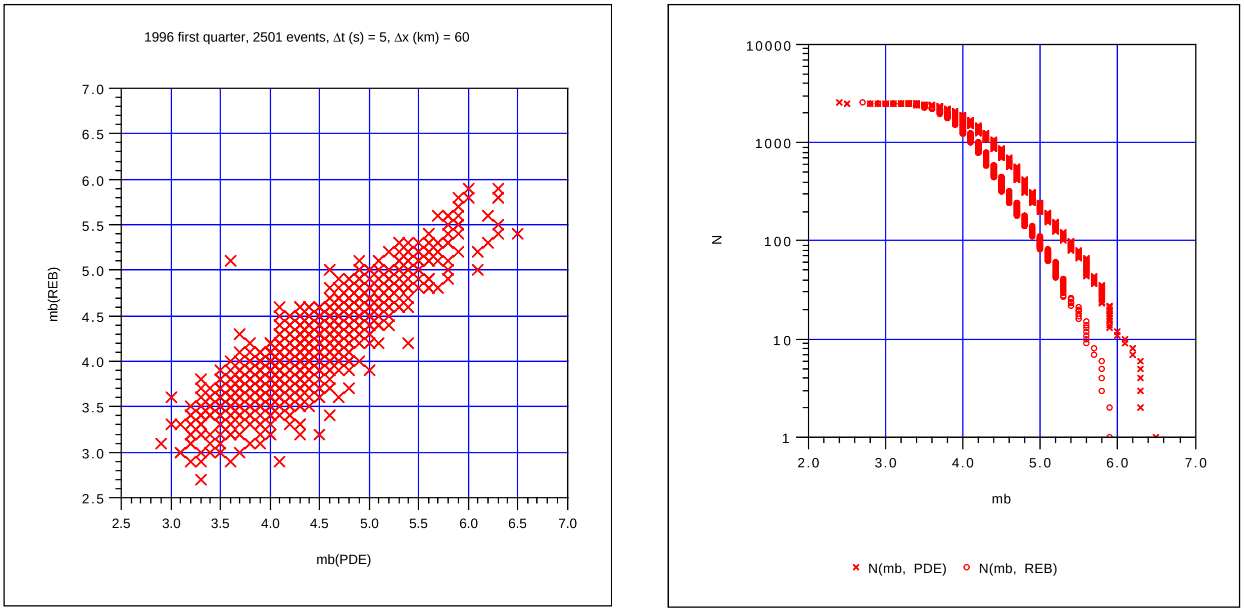

Figure 1. Comparison of m_b values for the events which are in both the REB and the PDE for the first quarter of 1996. Such events are identified by merging the two bulletins, sorting all the events by their origin times, and searching to find events pairs which are separated by not more than a specified time interval (Δt), and are also less than a specified distance apart (Δx). From the lefthand figure, it is clear that most events fall below the line of equal magnitudes, indicating that the REB value of m_b is typically lower than the PDE value. On the right, is shown the cumulative magnitude distribution for the two m_bs, in which it is apparent that the REB value is offset to lower magnitudes but by an amount that decreases at smaller magnitudes.

In Figure 1 on the left we see that most of the 2501 events for this period which are in both bulletins and have their m_b assigned by both organizations fall below the line of equality between REB and PDE magnitudes, and hence that indeed the REB value was typically lower. On the right, we see that if the separate sets of magnitude values are plotted as a display of the a cumulative magnitude distribution, in which N = N(m_b) is the number of events at and above magnitude m_b, then the REB distribution is persistently below the PDE distribution in the range m_b from about 6 down to 4. However, these magnitude distributions, at least for the first quarter of 1996, have different slopes and come together at low magnitudes. A plausible reason for the two distributions coming together at low magnitudes is that during 1995 and 1996 the USGS was accepting PIDC measurements of amplitude and period – and, at low magnitudes, the PIDC was supplying *most* of the amplitude and period measurements. Therefore, the USGS's bulletin became increasingly dominated by PIDC measurements as m_b decreased.

Similar plots for the later quarters show that m_b(REB) < m_b(PDE). But since the third quarter of 1996, the two distributions N = N(m_b) are essentially parallel for the largest 1000 events. Analysis of all the intervening 7 quarters has shown that the constant offset has been present for each quarter since, in the third quarter of 1996, the USGS stopped using PIDC measurements of amplitude and period, and made their own measurements.

How big is the discrepancy, and is it persistent? It is typically about 0.4 magnitude units, and it has stayed at this value since 1996 up through 1999 with no sign of changing.

Recently, several people (J. Murphy, J. Dewey and R. Willmann) have investigated discrepancy of m_b(REB) against m_b(PDE) and m_b(ISC), using the reported amplitude and period data. Their efforts were quite thorough, yet they could not reach solid conclusion(s) with regard to sources of such discrepancy and any clear remedy to it. It is interesting to note that a few broadband three-component stations and a dozen seismic arrays were major contributing stations to the PIDC for m_b(REB). Only six broadband stations were each reporting magnitude values for more than 10% of the events listed in the REB during January 1996 through July 1998, while 14 arrays were each reporting magnitude values for more than 10% of the events listed on REB in the same period (Murphy et al., 1999). All 89 prototype IMS stations reporting magnitude values are plotted in Figure 2 together with their station corrections determined by Murphy et al. (1999).

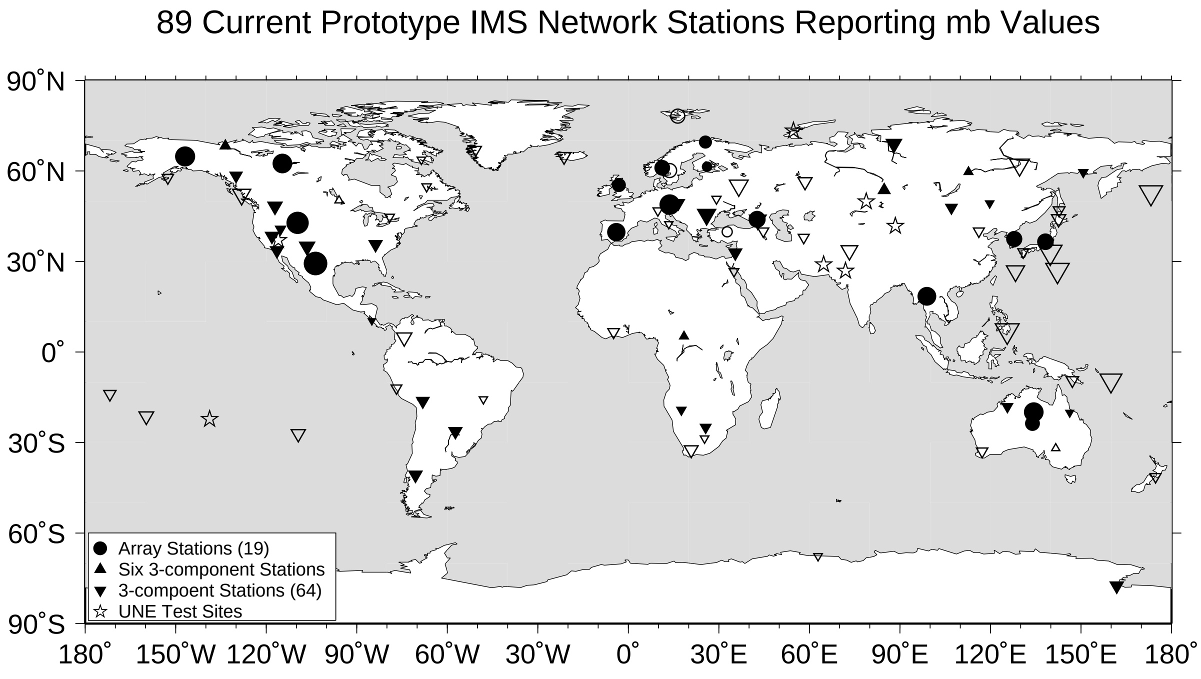

Figure 2. 89 prototype IMS network stations reporting magnitude values are plotted. The symbol size is proportional to the size of stations correction determined by Murphy et al. (1999). Filled symbols are positive station corrections, while open symbols represent negative corrections (*circle*=array stations; *triangle*=six most contributing 3-component stations; *inverted triangle*=64 3-component station).

RESEARCH ACCOMPLISHED

Magnitude of Underground Nuclear Explosions

We analyzed waveform data from underground nuclear tests at Lop Nor Chinese test site, Tuamotu Archipelago (French test site), India and Pakistan test sites. We obtained waveform data from PIDC for these UNTs used by PIDC in generating REB. Figure 3 shows record section of simulated WWSSN short-period seismograms from the Indian UNT on 05/11/1998. There are 51 station magnitudes reported in the REB for this event which has m_b(REB) = 5.0. For this explosion, teleseismic *P* waves at most of the stations in the distance ranges of 28.2 to 94.6° are quite clear and have an average period of 0.77±0.16s.

We reproduced $m_b(P)$ as determined by PIDC procedure, except for the array stations, for which we determined amplitude and period from the single reference station instead of calculating the beam trace and measure the amplitude from the beam trace. Figure 4(a) shows comparison between station m_b(REB, *circles*) and m_b reproduced in this study (*pluses*) by following the PIDC procedure. Most of the station m_bs are very close, except few m_bs from array stations. For example, reproduced single station m_bs are more than a factor of two (or 0.3 m.u.) greater than corresponding m_b values from the array beam listed on REB (KVAR, BRAR and MJAR). For other 13 array stations, m_b determined from a single reference station produced fairly consistent results as beam trace. Overall agreement between the two measurements are very close. This exercise ensures that we are using the same data and corresponding instrument responses as used by the PIDC, so that further detailed study would provide us with unequivocal evidence in finding magnitude discrepancies.

We determined Veith-Clawson m_b(VC) using the simulated WWSSN short-period records. We obtained m_b(VC)=4.96±0.35 for the Indian nuclear test. m_bs determined by other agencies are listed in Table 1. Figure 4(b) shows a comparison between m_b(VC) and m_b(REB) at each station. Arrows indicate sign and size of the m_b(REB) – m_b(VC). Though there are substantial differences at some station m_bs reported on REB and this study, the average m_b from the two methods are very close (see, Figure 4(b)).

Table 1: **Body wave magnitudes (m_b) reported by various agencies for the Indian nuclear test**

REB (m_b/N)	WWSSN/V-C (m_b/N)	PDE (m_b/N)	ISC (m_b/N)
5.0/51	4.96/51	5.2/104	5.1/149

Magnitude of Earthquakes

Magnitude determination for earthquakes introduces additional factors such as focal depth. We analyzed 21 earthquakes and excerpts results in some detail here for one of these earthquakes, the Luzon, Philippine Islands event on 12/11/1999 (18:03:36), h=19 km, m_b(REB) = 5.9/21 for detail in order to identify basic questions.

We obtained waveform data from PIDC for this earthquake used by PIDC in generating REB. We reproduced m_b(REB) as determined by PIDC procedure, except the array stations, for which we determined amplitude and period from the single reference station instead of calculating the beam trace and determining the amplitude. m_b(REB)=5.9 from 21 records from the earthquake, whereas the reproduced m_b is 5.85±0.42/21 stations. Figure 5(a) shows m_bs reported by REB (*circles*) and reproduced in this study (*pluses*). Reproduced m_b at ILAR is about 0.3 m.u. greater than REB m_b, whereas at DLBC reproduced m_b is 0.6 m.u. smaller than REB m_b. Extremely small m_b at HIA suggests that the amplitude of the *P* phase is much smaller than other stations, due to the source radiation pattern. Overall agreement between the two measurements are very close, indicating that data and instrument responses used are consistent with PIDC in most but not all cases.

We determined Veith-Clawson m_b(VC) using simulated WWSSN short-period records. We obtained m_b(VC) = 6.23±0.40, whereas USGS/NEIC reported m_b(PDE)=6.5/132. Figure 5(b) shows comparison of the station m_b(VC) and m_b(REB). Arrows indicate sign and size of the m_b(REB) – m_b(VC). The average difference between these two magnitudes is 0.33 m.u. which is somewhat smaller than the m_b(PDE) – m_b(REB) = 0.6 m.u. The mean period in REB is 0.85±0.32 s, whereas it is 1.09±0.29 s from the simulated WWSSN short-period records.

An obvious source of REB and PDE m_b discrepancies is the time window used to measure amplitude and period of *P* phases. The m_b(REB) is determined from the maximum amplitude phase in the 5.5 second time window following the *P* onset arrival. Such short time window may catch large part of seismic energy carried by sharp *P* wave signals from surface focus explosive sources, such as underground nuclear explosions. However, it is too short a window to capture major amplitudes associated with source corner frequency from larger earthquakes. For a certain class of events, mostly shallow crustal earthquake with oblique fault plane, frequently the direct arrival *P* phases have much smaller amplitude than *pP* or *sP* surface reflected depth phases due to orientation of particular source radiation pattern nodal plane. For instance, for earthquakes occurring at a depth greater than about 15 km, depth phases arrive after the 5.5 s time window used to measure amplitude of *P* onset signals to calculate m_b(REB) magnitude. Most of the amplitude measurements used to calculate m_b(ISC) and m_b(PDE) magnitudes are obtained allowing time window of up to 15 s following the onset *P* arrival.

A traditionally used protocol to measure the amplitude and associated period appears in the Manual of Seismological Observatory Practice (Willmore, 1979): ”Usually, the largest amplitude is measured within the first few cycles after the *P* onset, but not later than 15 seconds after it. The corresponding period is taken as the time difference between two neighbouring crests.”

For example, *P* phases on the vertical records from the shallow earthquake (h=19.5 km) on 12/11/1999 indicate that peak amplitude of *P* phase in the 5.5s PIDC processing window is smaller than the peak amplitude in the PDE m_b window on most of the records (Figure 6). The m_b(VC) is 6.48 and 6.42, respectively for stations FITZ (Δ =34.1°) and VNDA (Δ =96.2°), whereas m_b(VC) from the PIDC window is 6.27 and 6.38, respectively for stations FITZ and VNDA. Hence, the shorter time window used in PIDC process underestimates m_b by 0.21 and 0.04 m.u., respectively for FITZ and VNDA. Average over four stations indicates that m_b(REB) bias due to the short time window is about 0.05 m.u. m_b(REB) is 6.0 and 6.1, respectively for stations FITZ and VNDA, and indicates that m_b(WWSSN, REB window) – m_b(REB) = 0.27.

CONCLUSIONS AND RECOMMENDATIONS

We determined $m_b(P)$ (the teleseismic body wave magnitude) by using the simulated WWSSN short-period records and employing the conventional protocol (see, Willmore, 1979) to the waveform data used to generate m_b(REB) at PIDC. We believe that this is the best way to discern the sources of the known magnitude discrepancy which indicates that m_b(REB) is typically about 0.4 magnitude units smaller than m_b(PDE) or m_b(ISC). The Veith-Clawson magnitude, m_b(VC), at each station determined by using the simulated WWSSN short-period records and Veith-Clawson (1972) amplitude-distance curve for the Indian underground nuclear test on 05/11/1998 indicates that network m_b(REB) = 5.0 is very close to the network m_b(VC) = 4.96 determined in this study. This may suggest that the method used by PIDC for m_b may be suitable for shallow, underground explosions. However, the PIDC $m_b(P)$ procedure is not adequate for shallow earthquakes occurring at depth ranges 20 to 50 km. Analysis of data from the large, shallow earthquake on 12/11/1999 (h=19 km) indicates that bias due to PIDC’s short time window is about 0.05 magnitude units. This analysis also suggest that m_b(VC) – m_b(REB) is about 0.33 magnitude units for the earthquake on 12/11/1999, which is somewhat smaller than m_b(PDE) – m_b(REB) = 0.6 magnitude units.

We are continuing our effort to find sources of such m_b discrepancy and any clear remedy to it by analyzing waveform data from hundreds of events. We will also analyze m_b(single station) vs m_b(beam) for all array stations of the IMS.

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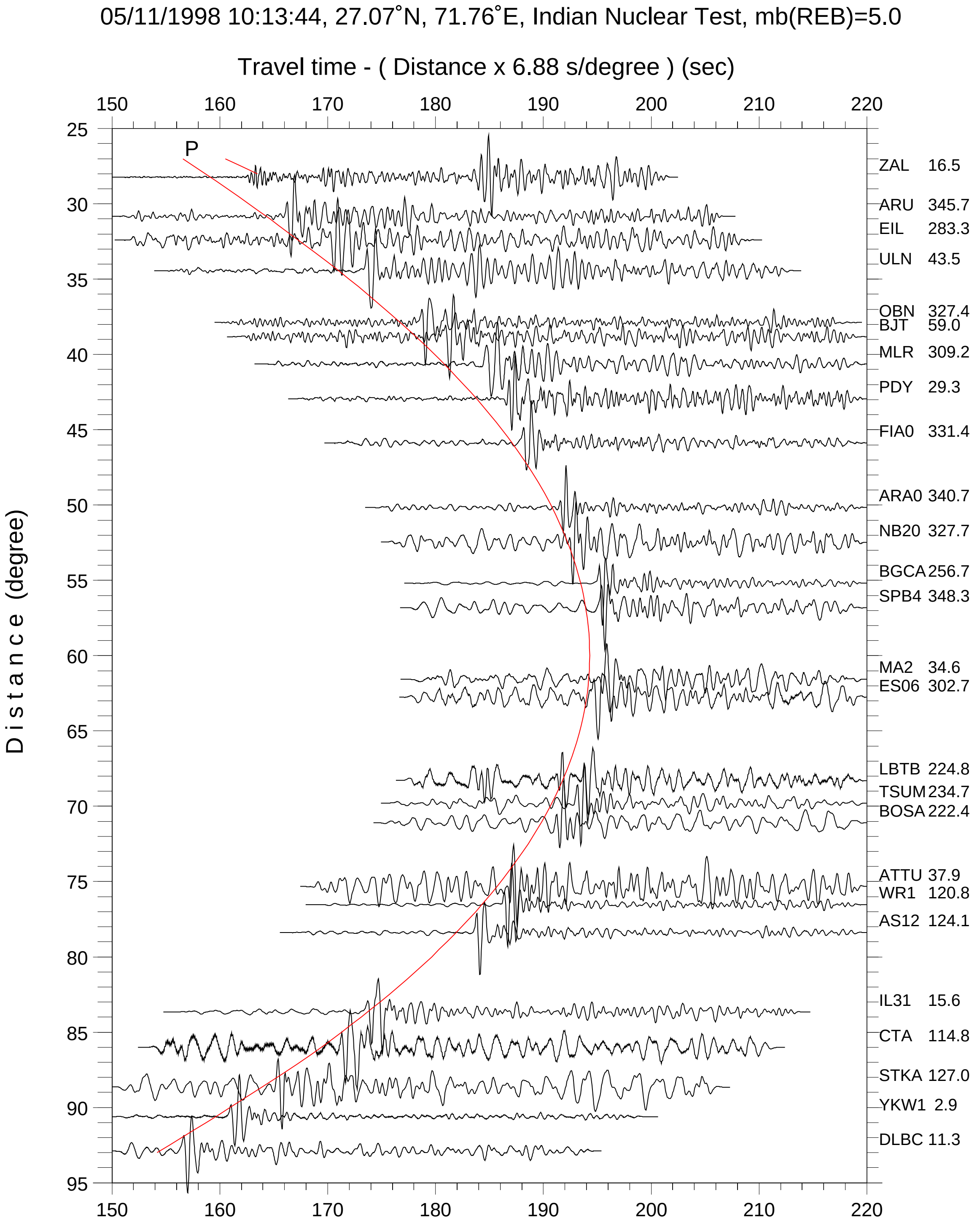
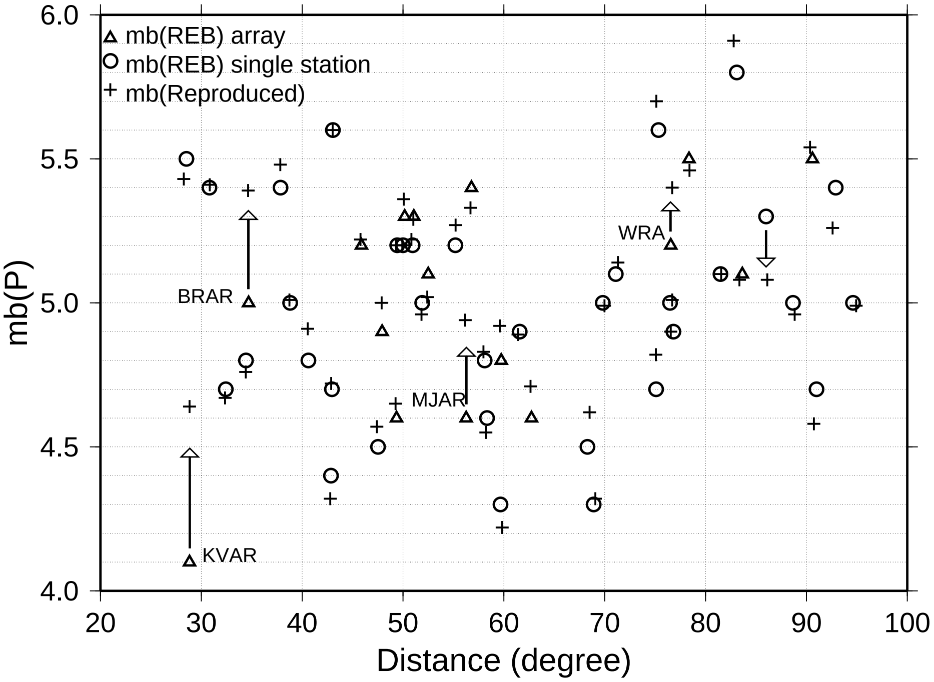


Figure 3. Record section of simulated WWSSN short-period records from the Indian UNT on 05/11/1998. Seismograms are plotted with reduced velocity of 6.88 s/degree and *P* wave arrival times from IASP91 travel time curve are indicated by red line. Station code and azimuth in degrees are indicated at the end of each trace.

(a) REB & reproduced mb, 05/11/1998, Indian UNT



(b) REB & WWSSN mb, 05/11/1998, Indian UNT

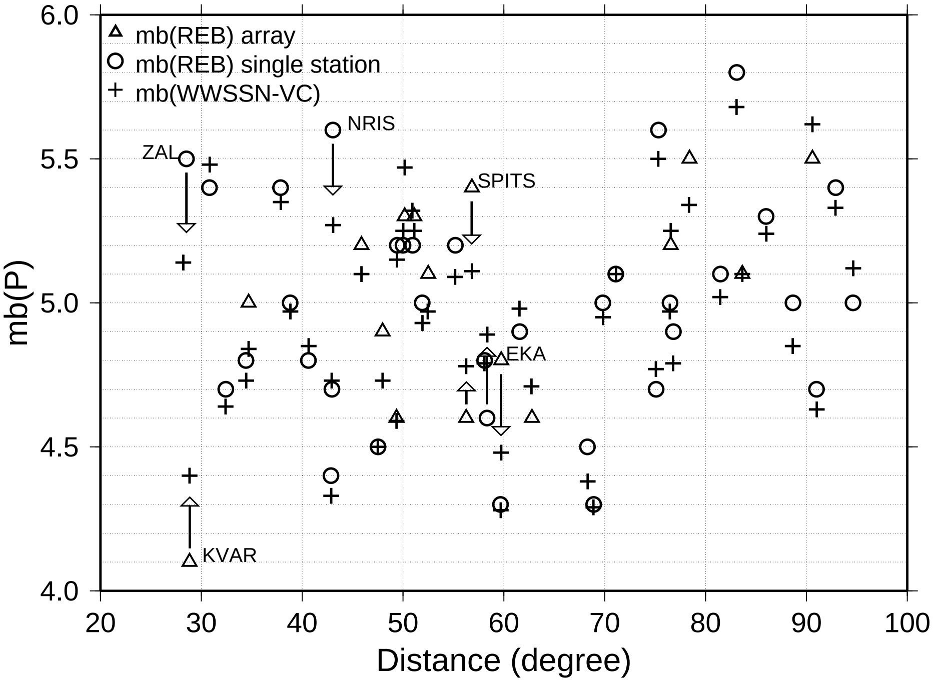


Figure 4. (a) Comparison m_bs reported by REB (*circles* and *triangles* for array stations) and reproduced in this study (*pluses*). Notice that reproduced m_b at array stations are somewhat greater than REB m_b, (b) Comparison of the station m_b(VC) and m_b(REB). Arrows indicate sign and size of the m_b(REB) – m_b(VC). The average difference between these two magnitudes is only 0.04 m.u.

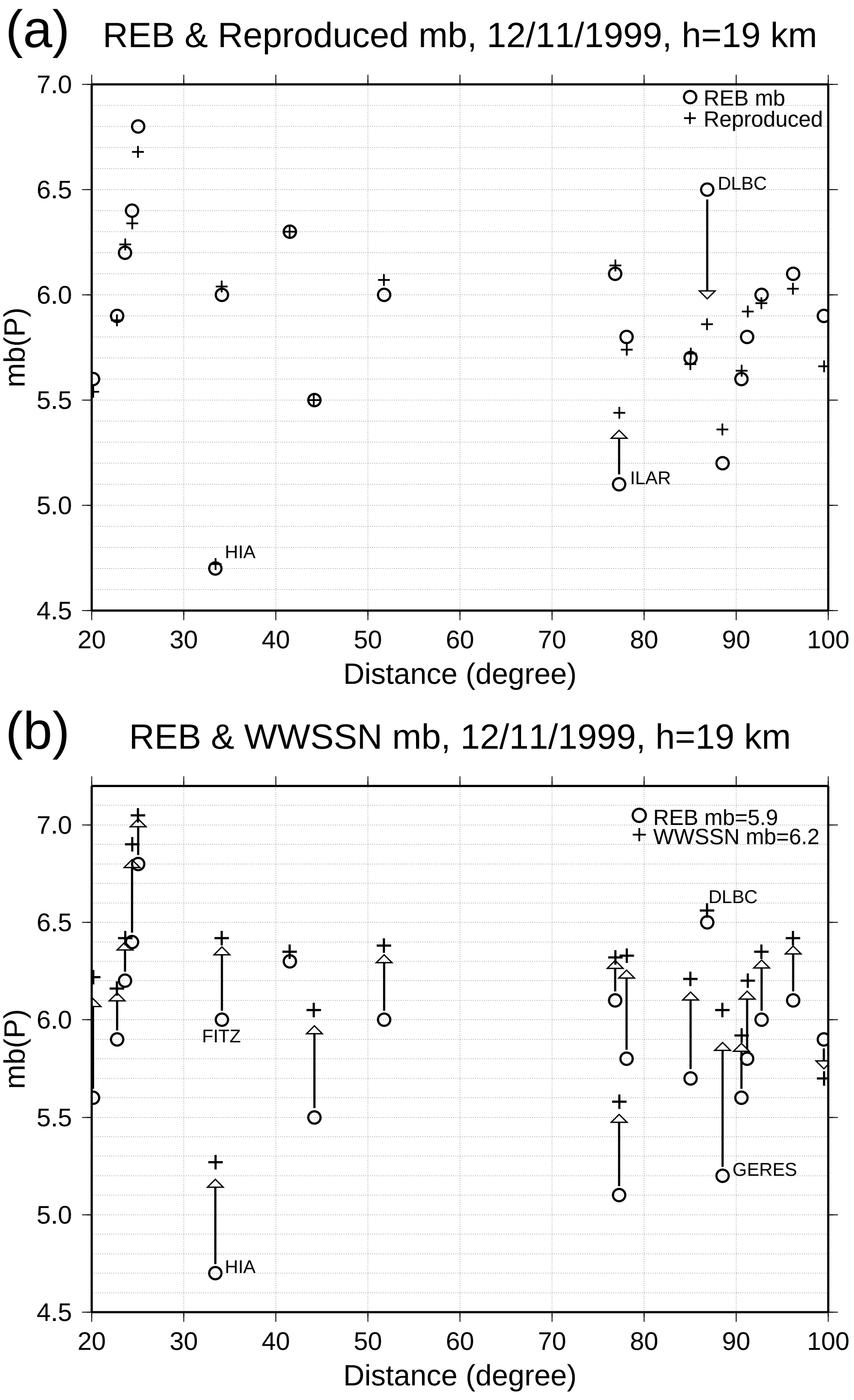


Figure 5. (a) Comparison m_bs reported by REB (*circles*) and reproduced in this study (*plus*). Notice that reproduced m_b at ILAR is about 0.3 m.u. greater than REB m_b, whereas at DLBC reproduced m_b is 0.6 m.u. smaller than REB m_b, (b) Comparison of the station m_b(VC) and m_b(REB). Arrows indicate sign and size of the m_b(REB) – m_b(VC). The average difference between these two magnitudes is 0.33 m.u.

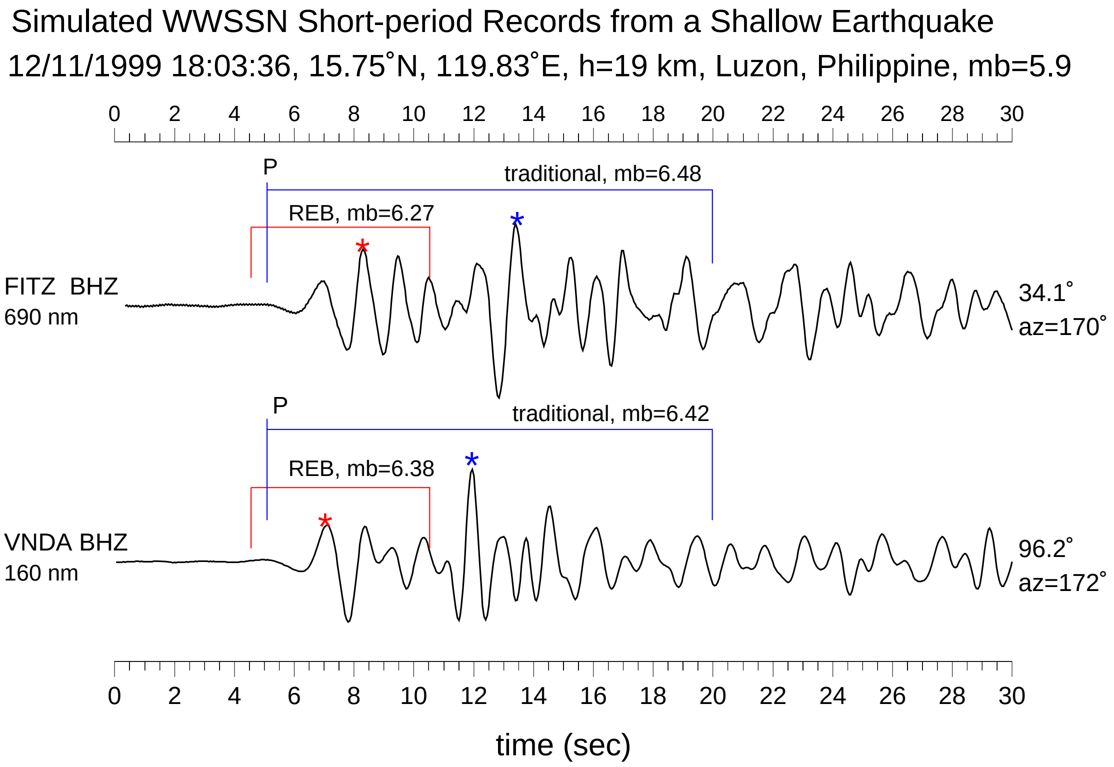


Figure 6. Simulated WWSSN records showing differences in m_b determined from 5.5s PIDC window and 15s traditional window. Largest amplitude phase on both records is *pP* phase (star).