RE-EXAMINATION OF SURFACE WAVE MAGNITUDE ESTIMATES FOR THE NORTH KOREAN EVENT OF 25 MAY 2009

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ABSTRACT

The International Monitoring System (IMS) network of seismic stations detected the event occurring on 25 May 2009 at 00:54 UT in North Korea and corresponding bulletins were released from automatic and interactive analysis. The final Reviewed Event Bulletin (REB) for this event was made up of 72 arrivals from 59 stations being used for event location. From 45 of these recording stations body wave magnitude estimates were reported resulting in a network-averaged event magnitude of mb=4.5. Besides, 15 stations were included with surface wave magnitude estimates yielding a network-averaged magnitude of Ms=3.6. During automatic post-processing event characterization and Standard Event Screening was carried out including screening with the mb-Ms criterion based on these magnitude estimates. As a result, the event was flagged as “not screened out”, but it turned out that it was only marginally off the mb-Ms screening line. The fact that such an event considered to be a nuclear test explosion should be reasonably well discriminated prompted a study to investigate a potential bias of Ms values.

The surface wave magnitudes published in the REB show an interesting clustering of the reported magnitude estimates. Six stations had positive magnitude residuals within 0.2 to 0.5 magnitude units while another seven stations had negative residuals of equivalent size. Only two stations had smaller magnitude residuals. As Ms estimates from stations at shorter distances were found to have negative residuals and more distant stations to have positive residuals, the Ms magnitude estimation procedure applied at the IDC was checked and validated. Reviewing the magnitude estimates a few interesting facts were uncovered. First, the surface wave magnitude at one station (ATTU), even though being in the negative residual group, was determined from a marginal signal. Second, the azimuth dependence of the residuals showed clear pattern in that all positive residuals are from a narrow azimuth window between 290 and 320 degrees from the event, with a single exception (MKAR). Re-analysis of waveforms in the 20 s period range shows that surface wave trains at additional IMS stations in this azimuth range (e.g., KURK, VRAC) can be found well above the background noise. Hence, surface wave magnitude estimates obtained at these stations are relatively high, and the network-averaged surface wave magnitude reported in the REB must be considered a low estimate. Within this scenario it may have been likely that the event would have been screened out under the rules for Standard Event Screening based on the mb-Ms criterion applied at the time.

OBJECTIVES

The event detected by the IMS network occurring on 25 May 2009 at 00:54 UT in North Korea has drawn some attention because initial reports and press releases issued by the Provisional Technical Secretariat (PTS) of the Preparatory Commission for the Nuclear-Test-Ban Treaty Organization (CTBTO) have indicated that the event may have a significant earthquake signature and that it may be difficult to clearly identify it as an underground explosion. One difficulty associated with this event is that there were some observations of surface waves on the tangential component (e.g., BJT station) that are associated with Love wave-type. As it also turned out, a particular difficulty for this event arose from the fact that it was almost screened out during event characterization and standard event screening by the mb-Ms criterion as applied during automatic post-processing, similar to findings from the 2006 event. Therefore the objective of this research is concerned with the re-evaluation of surface wave magnitudes at the stations of the IMS as reported in the Reviewed Event Bulletin (REB) and the identification of any additional surface wave observations at other IMS stations, wherever possible. Furthermore it is intended to evaluate how re-examination and addition of missed surface wave magnitudes will impact on the performance of Standard Event Screening as carried out at the International Data Centre (IDC) of the PTS.

RESEARCH ACCOMPLISHED

On 25 May 2009 at 00:54 UT an event was detected by the International Monitoring System (IMS) network and automatically and interactively located in North Korea near a location of 41.311°N and 129.0464°E (REB parameters) with the depth fixed to the Earth's surface, on the basis of 72 arrivals from 59 stations (see Figure 1). As to the magnitude of the event a body wave magnitude estimate of mb=4.5 and a surface wave magnitude of Ms=3.6 were given, averaged over 45 and 15 station estimates, respectively. Results and assessments were released by the PTS within days, including the data and associated standard products such as the Standard Event Lists (SEL1-3), the REB, the Standard Event Bulletin (SEB) including event characterization parameters, and the Standard Screened Event Bulletin (SSEB) following from application of Standard Event Screening procedures. As pointed out by Selby & Bowers (2009), the set of body and surface wave magnitude values places this event between the Eurasian earthquake and explosions populations and very close to the IDC experimental event screening line, an observation similar to what they had reported for the 2006 event in the same region (Selby & Bowers, 2007; Bonner et al., 2008). This closeness of the event to being screened out during Standard Event Screening may have prompted some concerns (CTBTO, 2009a, b) expressing that the signals from this event would go along with earthquake-like characteristics.

Based on these findings this study sets out to review the published surface wave magnitude and to investigate reasons for the Ms estimate apparently biased high. The initial finding is that the reported station magnitude estimates reported in the REB cluster into two groups (Figure2): a group of six stations with magnitude residuals about 0.2-0.5 magnitude units above the average and seven stations having the same, but negative, residuals. Only two stations showed magnitude estimates that were within 0.1 units of the network average. As most stations showing high estimates were found at larger distances than the group of stations with low estimates (Figure 2a), this effect may be related to the distance correction applied at the IDC (Rezapour & Pearce, 1998). However, the case of MKAR as well as a careful review of the process argue against such a problem.

When plotting the observed station residuals according to station azimuth (Figure 2b) it is found that the group of stations showing high residuals are within a narrow azimuth range between 290° and 320°, i.e., stations to the west and northwest of the epicenter. All stations with low estimates are found at other directions – with the exception of MKAR being within the azimuth range of stations with high estimates. Ford et al. (2009) studied the 2009 event and concluded that an earthquake source is not consistent with the data at frequencies between 10 and 50 s, with the best-fit full seismic moment tensor being predominantly explosive. They argue that non-isotropic radiation is required due to observed Love waves on transverse components, but they also discuss effects from tensile failure models and anisotropic wave propagation. They refer to previous work for the 2006 North Korean explosion and the similarity of mb-Ms of this event with some Eurasian earthquakes (Bonner et al., 2008) and dissimilarity with NTS and Semipalatinsk explosions (Patton & Taylor, 2008).

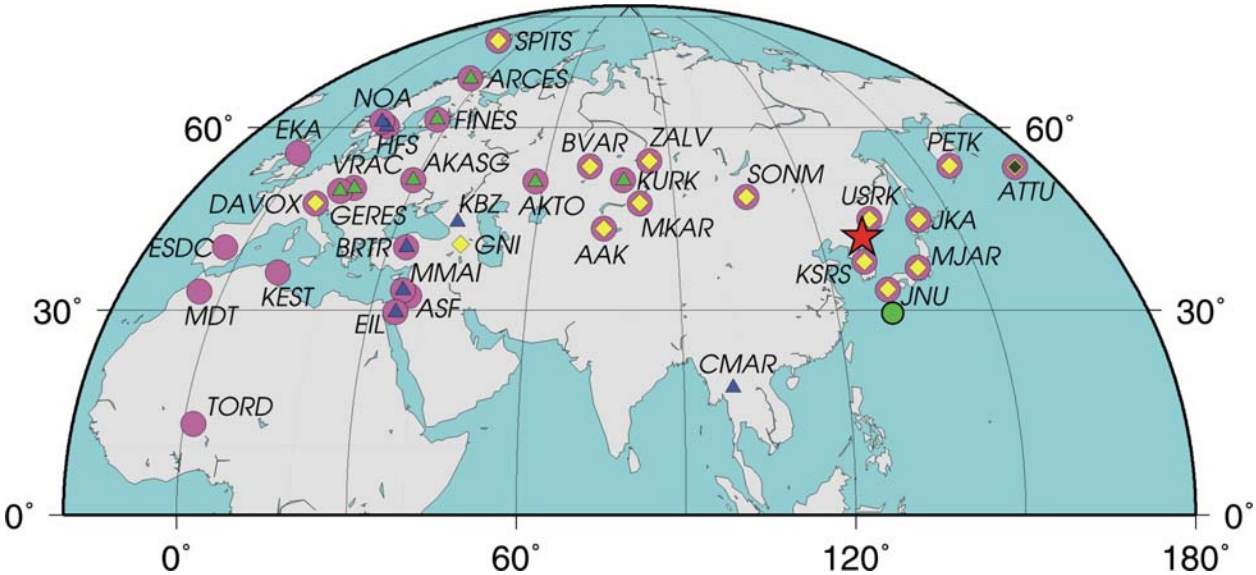

Figure 1. Geographical distribution of stations of the IMS seismic stations recording signals from the 2009 North Korean event. Red dots indicate stations providing defining phases for event location in the Reviewed Event Bulletin (REB). Yellow diamonds symbolize stations with LR observations and associated surface wave magnitude estimates. Triangles (green/blue) represent stations with LR waveforms, whereby green symbols are used for stations with additional surface wave estimates and blue symbols are used where the signals are too marginal for magnitude estimation. The green dot represents a Ryukyu Islands event occurring about 12 mins later which produced the later LR signals shown in the record sections.

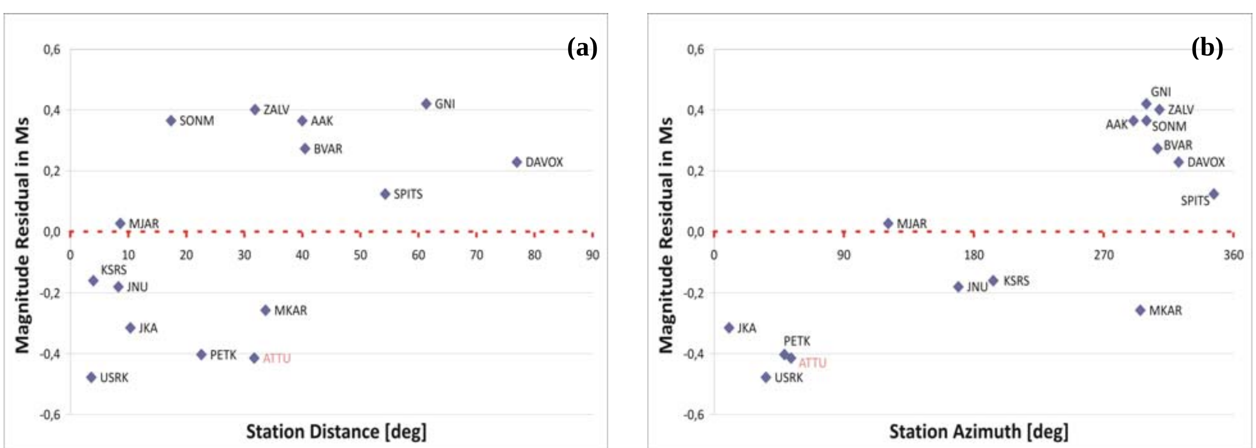

Figure 2. Station surface wave magnitude estimates for 15 IMS stations as contained in the REB and their network-average residuals plotted against epicenter-station distance (a-left) and plotted against station azimuth (from epicenter) (b-right). Note: ATTU is marked differently to indicate its spurious or invalid estimate.

Processing and Analysis Steps

Waveform data for IMS stations included in the REB were downloaded from the IDC. For analyzing the data the SeismicHandler software (Stammler, 1993), which is the standard analysis package at the German National Data Center, was used; in routine teleseismic event analysis amplitudes for surface wave estimation can be measured with this software from SRO-LP simulation records. In order to build corresponding simulation filters, the response files for those stations were requested which showed a potential for a reasonable LR signal. For stations where instrument responses were provided in poles and zeros (PAZ) representation simulation filters could readily be established, while for stations with responses given as frequency, amplitude and phase (FAP) values establishment of corresponding simulations filter is work still in progress. To validate the surface wave estimates in the REB and the procedure for the magnitude determination in this study, the broad-band channels as well as a number of short-period channels were converted to SRO-LP records (see Figure 3) and amplitude and period measurements made and checked for consistency. To calculate surface wave magnitudes the distance correction relation of Rezapour & Pearce (1998) was used, as is at the IDC. While clear surface wave trains are visible for almost all stations reported in the REB, the surface wave train for stations ATTU does not emerge from the background noise.

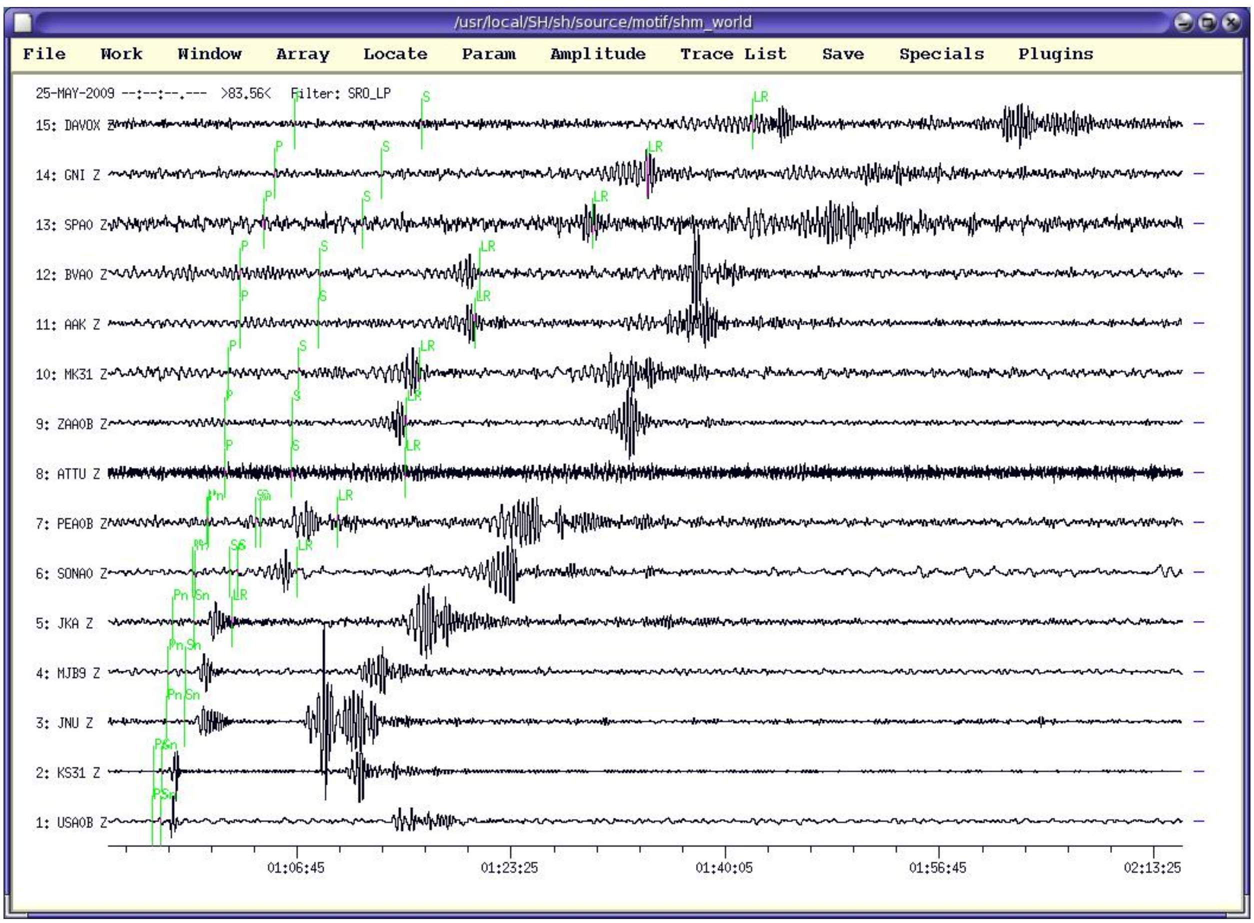

Figure 3. Simulated seismograms for an SRO-LP instrument used to read absolute ground motion amplitudes and periods for the surface wave trains. Note also the somewhat larger surface wave trains from a later event in the Ryukyu Islands region (see also Figure 1).

For stations with potential LR signals the data were initially filtered with a third-order Butterworth bandpass filter for periods between 16 and 25 sec (Figure 4a). From these filtered records it became apparent that fourteen additional IMS stations may be used to obtain additional Ms estimates. Theses stations were located mainly on the Eurasian platform including Scandinavia (see Figure 1). SRO-LP-simulations were done of these stations (Figure 4b) and for another seven stations Ms estimates could be made.

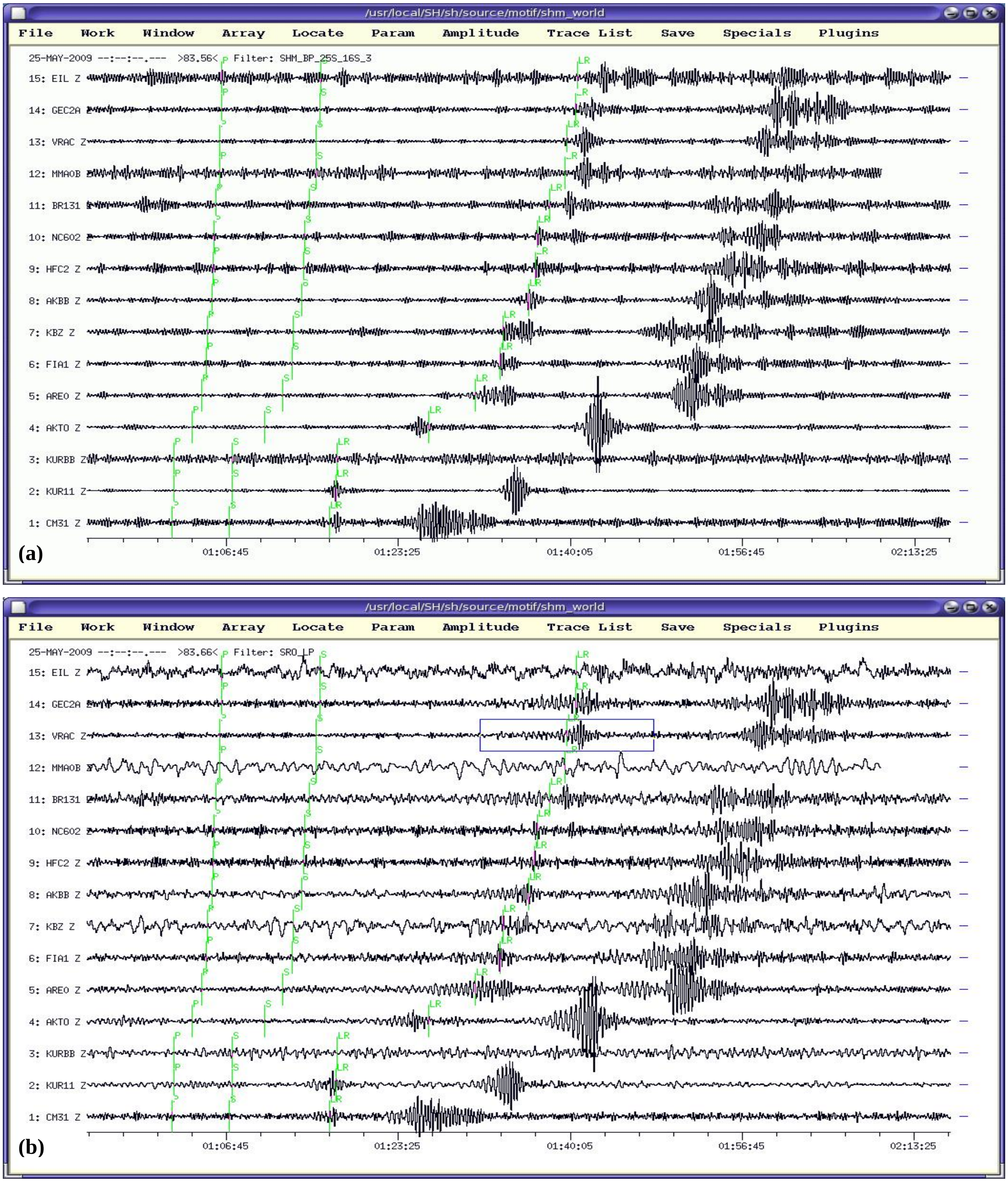

Figure 4. Band-pass filtered seismograms for another 14 IMS stations showing relevant signal levels between 16 and 25 s period (a - upper record section) at LR group velocity. For these stations SRO-LP simulated records were generated (b - lower record section). For seven stations (KURK, AKTO, ARCES, FINES, AKASG, VRAC, GERES) amplitudes can be reliably read, while signals are too marginal for the other stations (CMAR, KBZ, HFS, NOA, MMAI, EIL) (or simulation filters were not reliable from FAP representation).

Results of Surface Wave Magnitude Re-evaluation

Besides re-evaluating the measurements published in the REB (Figure 5a), additional measurements were made at IMS stations and at stations of the German Regional Seismic Network (GRSN) (Figure 5b). Each figure shows the mean Ms values for the particular data sets, plotted near the distance of 89 degrees.

Most Ms estimates of this study are very close to the REB values (Figure 5a), except for USRK. Two estimates for SONM are given: the initial (low) estimate was made on late waveform cycles and some filtering was used to get a measurement close to the signal maximum and which is consistent with the REB value. The results by Selby and Bowers (2009) show more scatter due to their estimation procedure not requiring the measurement to be done within the 18-22 s period band. While the means from the REB values and the values determined by Selby & Bowers are nearly the same, the estimate from this study given in Figure 5a shows a slightly higher value, as three below-average stations (KSRS, ATTU, MKAR) were not used.

The Ms estimates of the seven additional IMS stations, except for FINES, are all above a magnitude value of Ms=3.6 (Figure 5b). The same is found for magnitude values estimated at GRSN stations, except for one (BFO). Therefore the network-average MS values are further increasing, with the mean for all IMS stations used here resulting in Ms=3.74 and the average found for GRSN stations even 0.1 units higher. As can be seen from Figure 1, all the additional stations identified here are within the azimuth segment identified from Figure 2b. The directions are consistent with westerly directions mentioned by Bonner et al. (2008) where they found three stations with large magnitude estimates for the 2006 North Korea event.

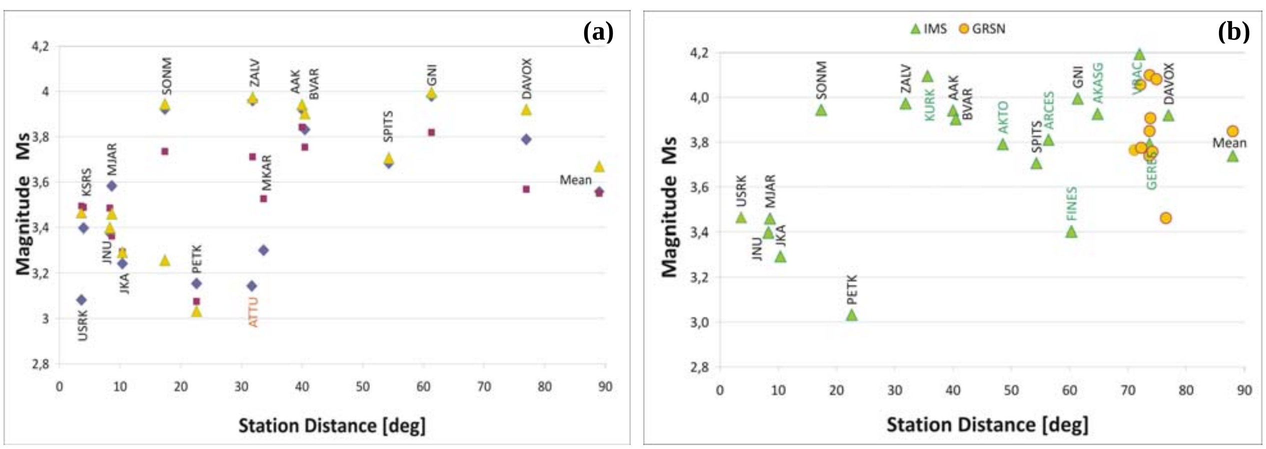

Figure 5. Results of Ms estimation for stations included in the REB with exception of ATTU (no reasonable LR) and KSRS and MKAR (FAP response) (a -left) and for additional IMS stations (lighter font) or GRSN stations (yellow dots) analyzed in this study (b – right). Ms estimates of this study (triangles) are compared to REB values (diamonds) and results by Selby and Bowers (2009) (squares).

During standard event screening carried out at the IDC all events with mb≥3.5 are considered, and if an event lies above the experimental screening line Ms=1.25 mb -2.2 (Figure 6), along with its error tolerances, it is flagged as “screened out” in relation to the mb-Ms criterion. As such the event in North Korea on 25 May 2009 was not screened out by the IDC, due to its proximity to the screening line. Similar results were also obtained by Selby and Bowers (2009). From the results obtained in this study, the event under consideration progressively moves away from the screening line as the data were reprocessed (exclusion of ATTU, KSRS and MKAR) and when including additional stations in Eurasia.

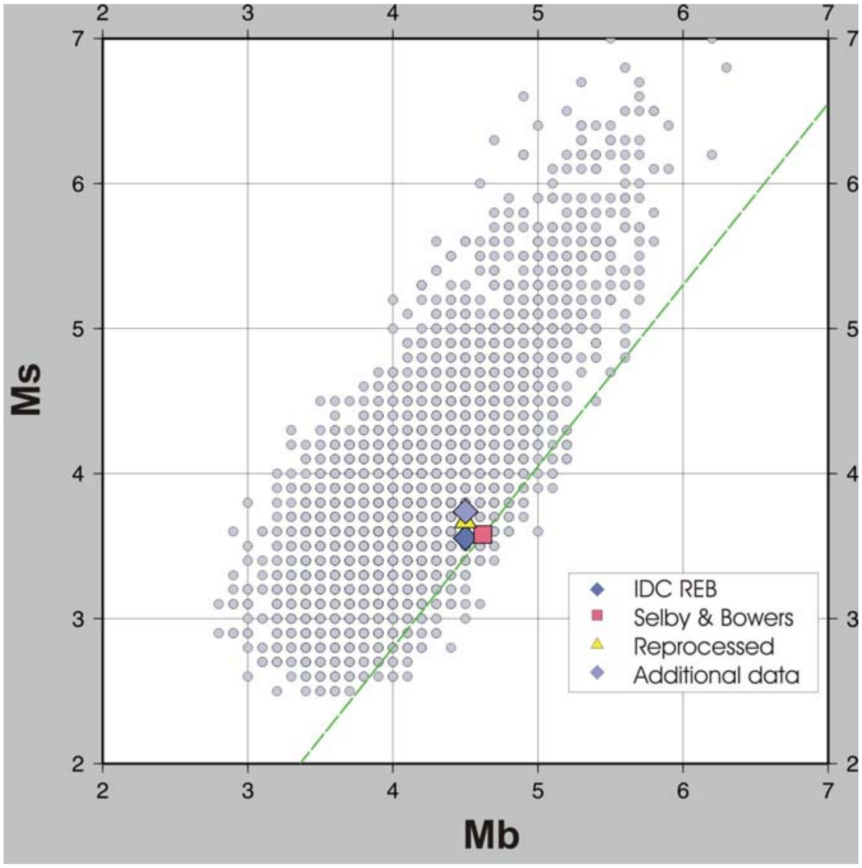

Figure 6. Results of mb versus Ms scaling for all REB events in 2009 yielding mb and Ms estimates. Also shown is the screening line (dashed green line) used in standard event screening at the IDC. Besides the REB results, those by Selby and Bowers (2009) and from this study (for REB stations and when including additional stations) are given.

CONCLUSIONS AND RECOMMENDATIONS

Surface wave magnitude estimates obtained by the IDC were revisited and, in general, the results were confirmed. However, station ATTU's estimate is based on spurious data. Furthermore there is a strong positive Ms magnitude bias for station azimuths between 290 and 320º with the stations located on the Eurasian platform. This information was used to identify additional stations showing LR signals, and corresponding magnitude estimates were made. The new estimates fit into the previously identified pattern of higher than average estimates including stations of the GRSN. The findings indicate that the event could be problematic when applying the standard event screening criterion applied at the time. Questions also arise to what extend the identified positive bias of Ms estimates for stations across the Eurasian platform are a source related effect or that propagation conditions are such that they favor high estimates. If this is the case standard event screening criteria need to be revisited, as has already begun.

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