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6.1 Study of body-wave magnitudes calculated at the IDC

6.1.1 Introduction

We have initiated a study to investigate various approaches to assessing the validity of seismic events defined through automatic phase association at the International Data Center (IDC). The main idea is to develop and test various consistency measures for individual phases associated with a seismic event, using in particular the dynamic phase information (i.e. amplitudes/magnitudes). We will define ‘consistency indices’ for each phase automatically associated with a given event, and determine empirically a threshold for these indices in order to accept or reject a phase in the event definition. In this process, we will use the detection parameters of each station associated with the event as well as the information from non-detecting stations (i.e. stations not listed as associated with the event).

Our approach focuses on developing a procedure to check individual phases of events defined after the Global association (GA) process has been performed and magnitudes have been calculated. The procedure would be particularly suitable for application after the final automatic event list (SEL3) has been produced, but in principle such checks could be applied at any point in the phase association procedure, with feedback to GA for reprocessing as appropriate.

This contribution is an initial part of developing a procedure as described above, and contains a study of the various body-wave magnitudes calculated routinely by the IDC and published in the Reviewed Event Bulletin (REB) and the Late Event Bulletin (LEB). Our purpose is not to assess the quality of these magnitude calculations, nor do we intend to compare the magnitude values to those produced by other agencies, such as the ISC or USGS. Our focus in this study is to assess the usefulness of the IDC-calculated magnitudes in providing data and criteria for dynamic assessment of the automatic phase association process at the IDC. For this purpose, the important point to study is the consistency of various magnitudes calculated at the IDC, regardless of how well they correspond to external magnitude information.

6.1.2 Body-wave magnitudes calculated at the IDC and used in this study

The IDC routinely computes a number of different magnitude estimates. In this study we have compared four of them, named mb, mb1,mbmle and mb1mle. (Note that in some connections the notations mbmx and mb1mx are used instead of mbmle and mb1mle). The mb is the standard body-wave magnitude calculated by averaging the observed magnitudes at all stations in the epicentral range 20-100 degrees which detected the event. The magnitude mb1, which is denoted the ‘generalized body-wave magnitude’ by Murphy and Barker (2003) is estimated by using stations in the distance range 2-180 degrees, and includes the station corrections developed by Murphy and Barker (2003) as well as distance weighting factors. The magnitudes mbmle and mb1mle are maximum-likelihood estimates of mb and mb1, respectively, using the formulation of Ringdal (1976).

The differences in the distance correction factors between mb1 and mb are illustrated in Figures 6.1.1 and 6.1.2, which show the attenuation relations as a function of distance for the two magnitude types for events at zero depth.

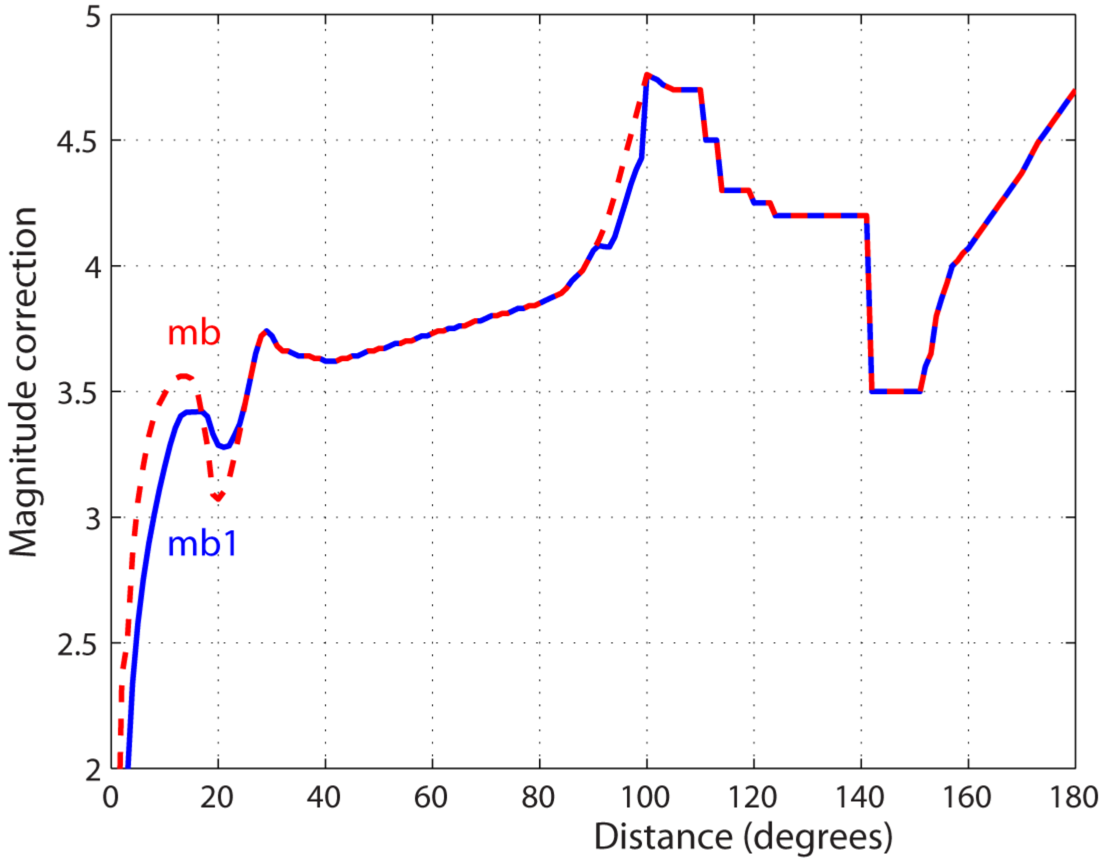

Fig. 6.1.1 Comparison of attenuation relations for mb1 and mb. Note the significant differences at distances less than 25 degrees. Also note that the IDC uses stations in the epicentral distance range 20-100 degrees for calculating REB mb values, whereas REB mb1 values are calculated for stations in the epicentral distance range 2-100 degrees.

6.1.3 Comparison of magnitudes

Figures 6.1.3 and 6.1.4 show relationships between various IDC magnitude measures as a function of event size. Figure 6.1.3 corresponds to the years 2001-2005, whereas Figure 6.1.4 covers 2006-2009. For all the plots in these and other figures in this Appendix, we have included all events in the IDC REB database satisfying the restrictions that mb has been calculated using at least five stations, and that the estimated event depth is less than 50 km.

We first note that Figures 6.1.3 and 6.1.4 are almost identical in appearance, thus indicating that the IDC processing has been very consistent over time. The increase in the IMS network and the ensuing increased number of events reported in the REB appears to have had no significant influence on this type of comparison.

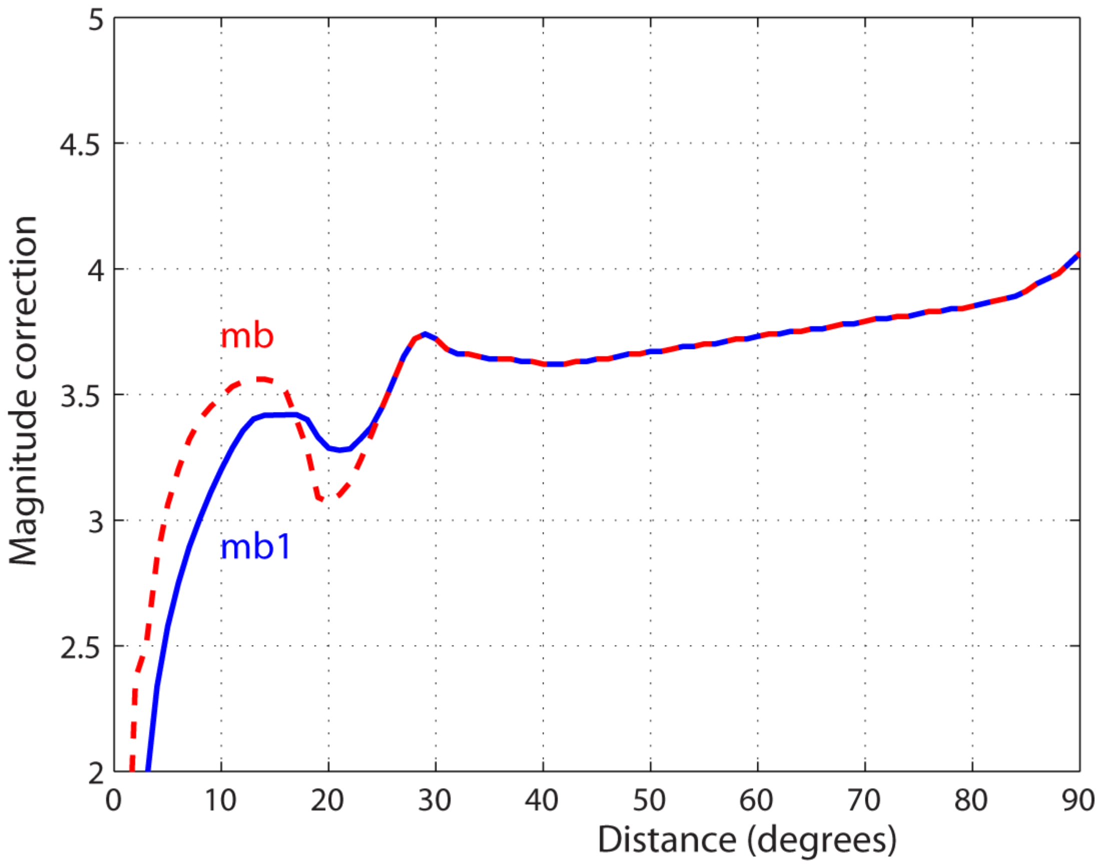

Fig. 6.1.2 Same as Figure 6.1.1, but showing an expanded view of the distance 0-90 degrees.

We further note the clear magnitude dependency, with the mb1-based magnitudes being systematically higher than the mb-based magnitudes at the low magnitude end. This would be partly due to the differences in attenuation curves shown in Figures 6.1.1 and 6.1.2, combined with the inclusion of observations at distances 2-20 degrees for the mb1 values and the weighting procedure that is part of the mb1 calculation. The station corrections could also be contributing, although they have been developed so as to retain overall consistency with the standard mb calculations. It might be interesting to compare the application of the Murphy-Baker station corrections to those developed by Zaslavsky-Paltiel and Steinberg (2008).

Figures 6.1.5 and 6.1.6 show plots similar to Figures 6.1.3 and 6.1.4, but covering only specific regions as indicated in the figure captions. In order to increase the event populations, all years (2001-2009) have been included in these plots. We note that the first of these regions is the region discussed in detail as a case study in the paper by Kværna et al. (2009).

Figures 6.1.5 and 6.1.6 show trends that are very similar to those shown in Figures 6.1.3 and 6.1.4. Other regions that we have studied show the same characteristics, so there appears to be little variation on a regional basis between the magnitude relationships.

The observed inconsistency between the mb and mb1 based magnitudes is an issue of some concern. We intend to use mb1 magnitudes in our further work since they, in contrast to the mb magnitudes, are calculated not only in the distance range 20-100 degrees, but also in the distance range 2-20 degrees. However, the current SEL3 lists include only mb and ML magnitudes, and we therefore need to consider carefully how this will influence the consistency indices.

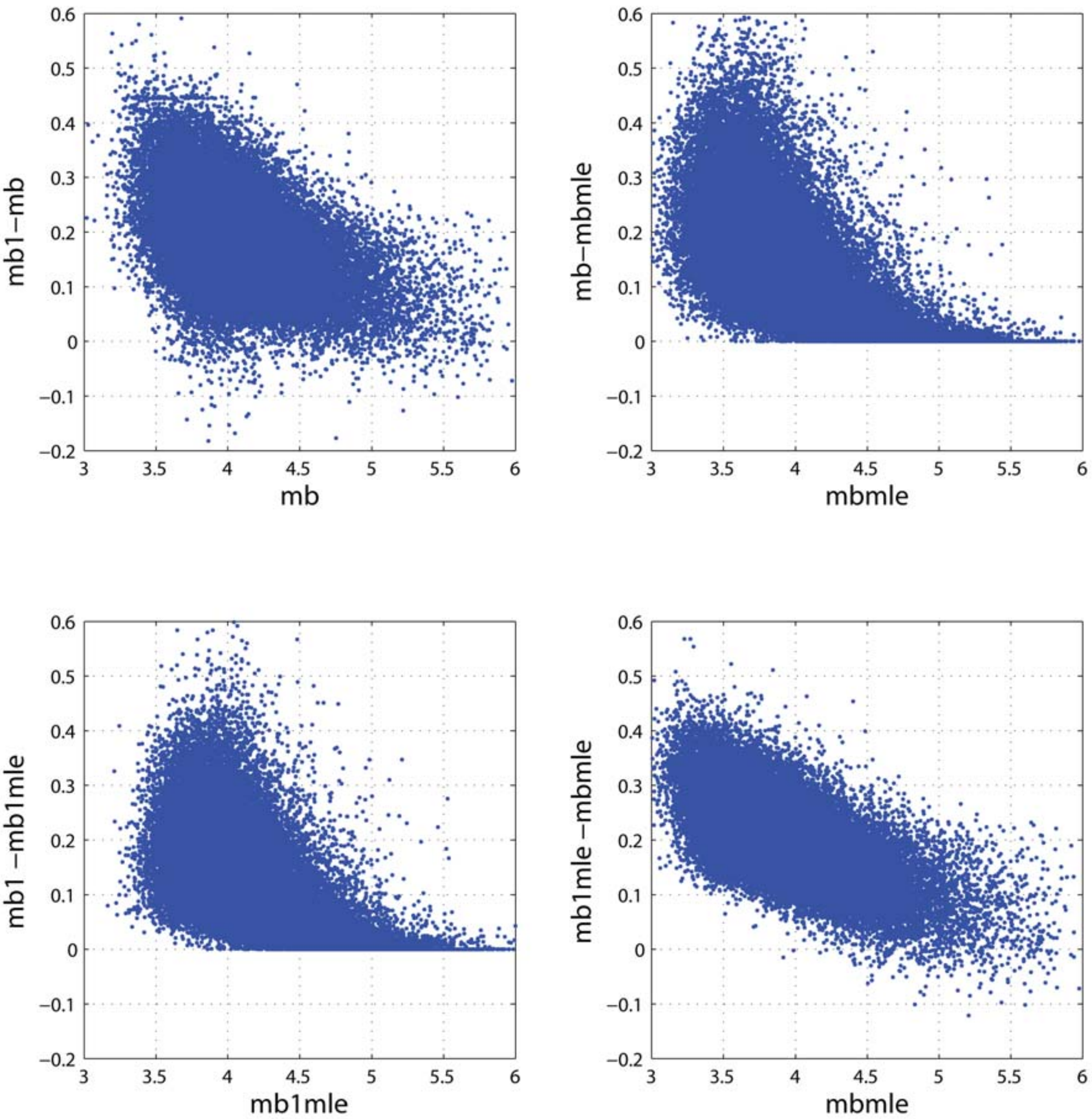

Fig. 6.1.3 Relationships between various IDC magnitude measures as a function of event size. The figure corresponds to the years 2001-2005, and covers all events in the IDC REB database satisfying the restriction that mb has been calculated using at least five stations, and that the estimated event depth is less than 50 km. Note the significant magnitude dependency, with the mb1-based magnitudes being systematically higher than the mb-based magnitudes at the low magnitude end.

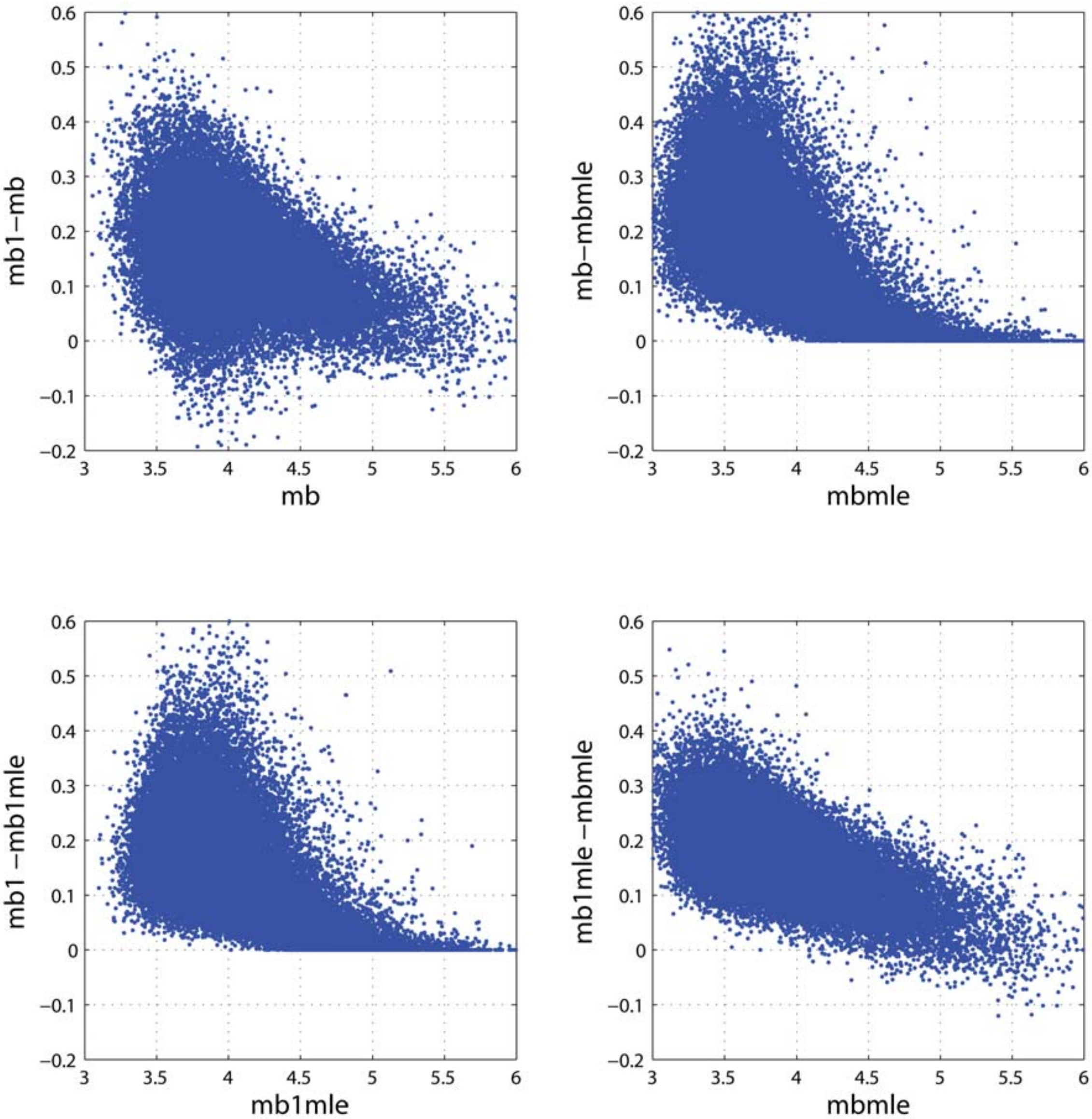

Fig. 6.1.4 Same as Figure 6.1.3, but covering the years 2006-2009. Note the very high similarity to Figure 6.1.3, indicating that the patterns are very consistent over time, even though the IMS network has expanded considerably during the years.

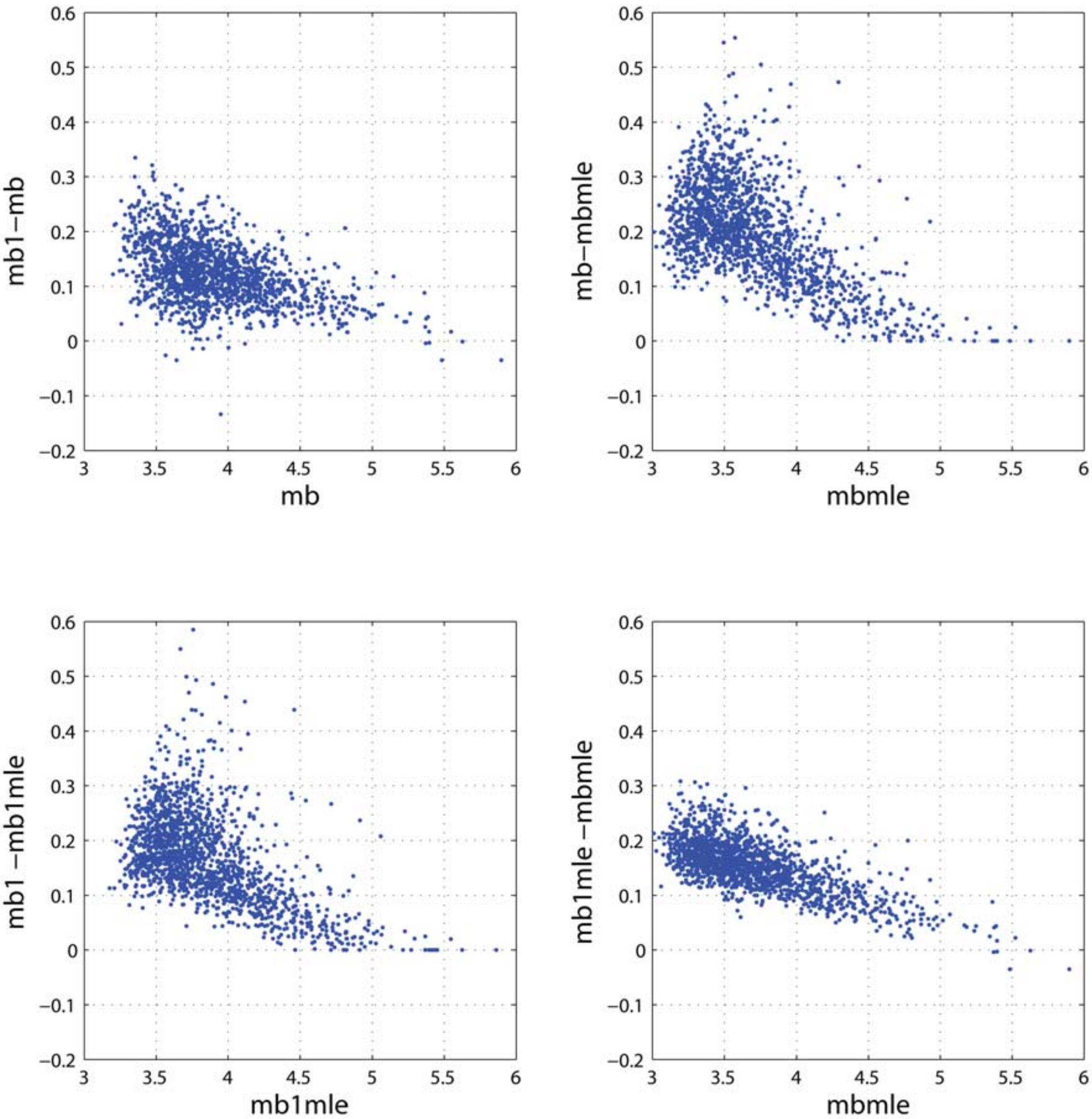

Fig. 6.1.5 Same as Figure 6.1.3, but covering all years 2001-2009 and showing only those REB events which are located within 5 degrees of 32 N, 104 E (China).

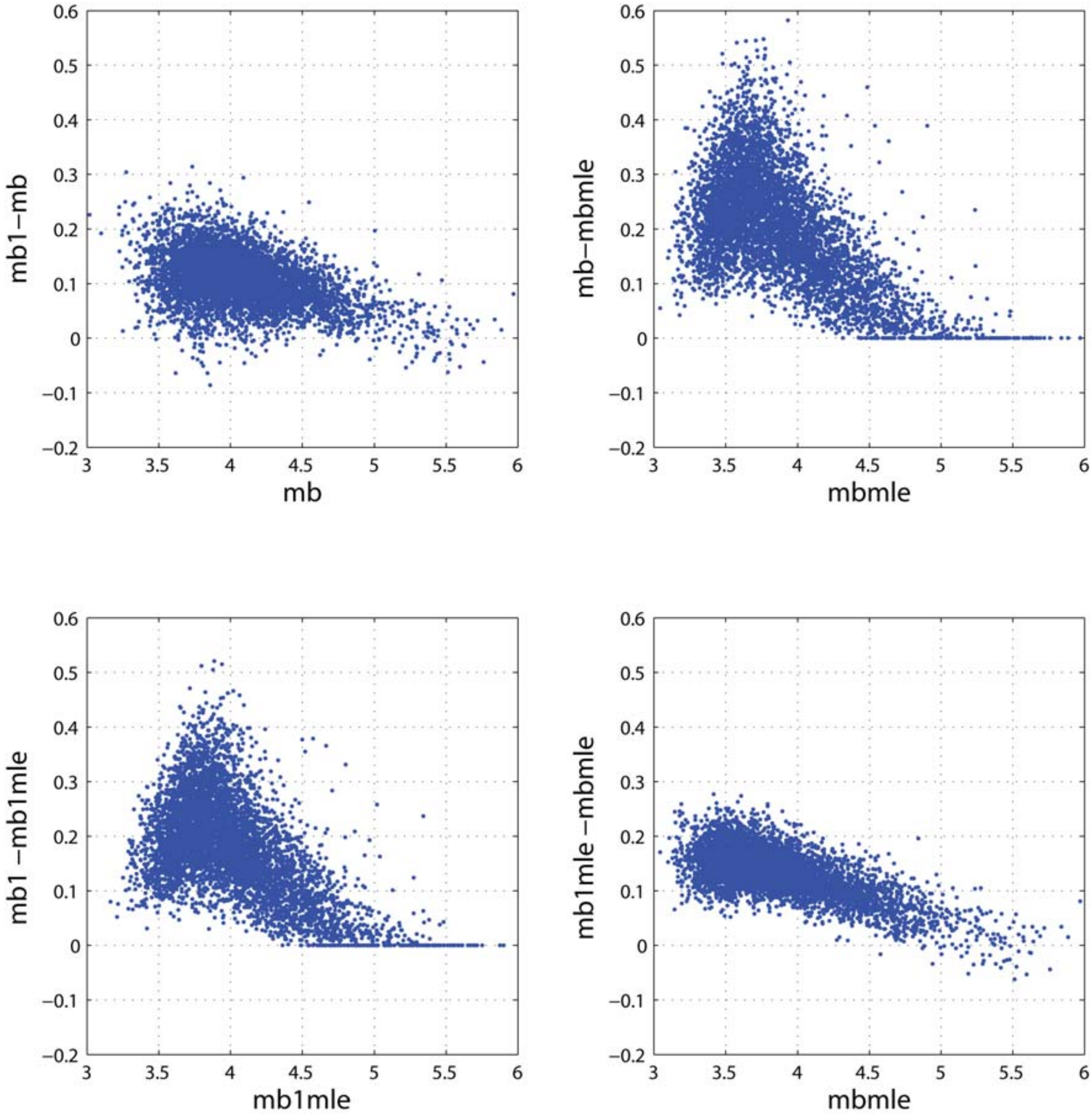

Fig. 6.1.6 Same as Figure 6.1.3, but covering all years 2001-2009 and showing only those REB events which are located within 5 degrees of 0 N, 100 E (Indonesia).

6.1.4 Linear relationships

Figures 6.1.7 through 6.1.9 show illustrations of the linear relationships between the magnitude measures. Figure 6.1.7 covers the entire database 2001-2009 with the same 5-station and 0-50 km depth restrictions as before. Figures 6.1.8 and 6.1.9 cover the two regions discussed earlier with the same restrictions.

We note that the relationships are similar for the global case and the two regions. When comparing mb-based magnitudes (x-axis) and mb1-based magnitudes (y-axis) we see that the slope is systematically less than 1.0, consistent with the previous observation of mb1 being increasingly higher than mb at low magnitudes. This is most clearly observed on the two regional plots (China and Indonesia).

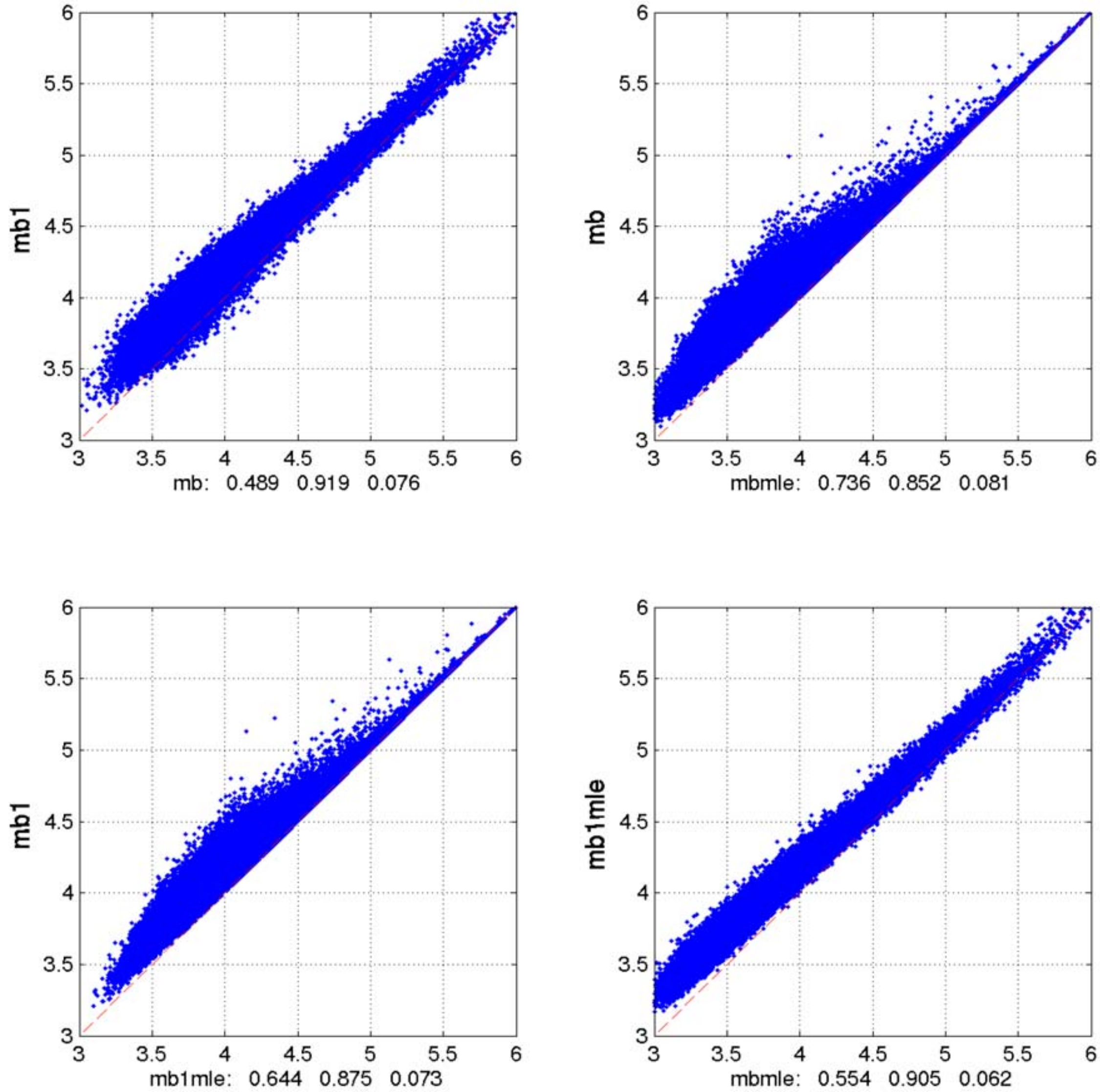

Fig. 6.1.7 Linear relations between various magnitude measures, using data from 2001-2009 from all regions (with restrictions as before). The intercept, slope and standard deviation of each least squares fit is indicated for each subplot.

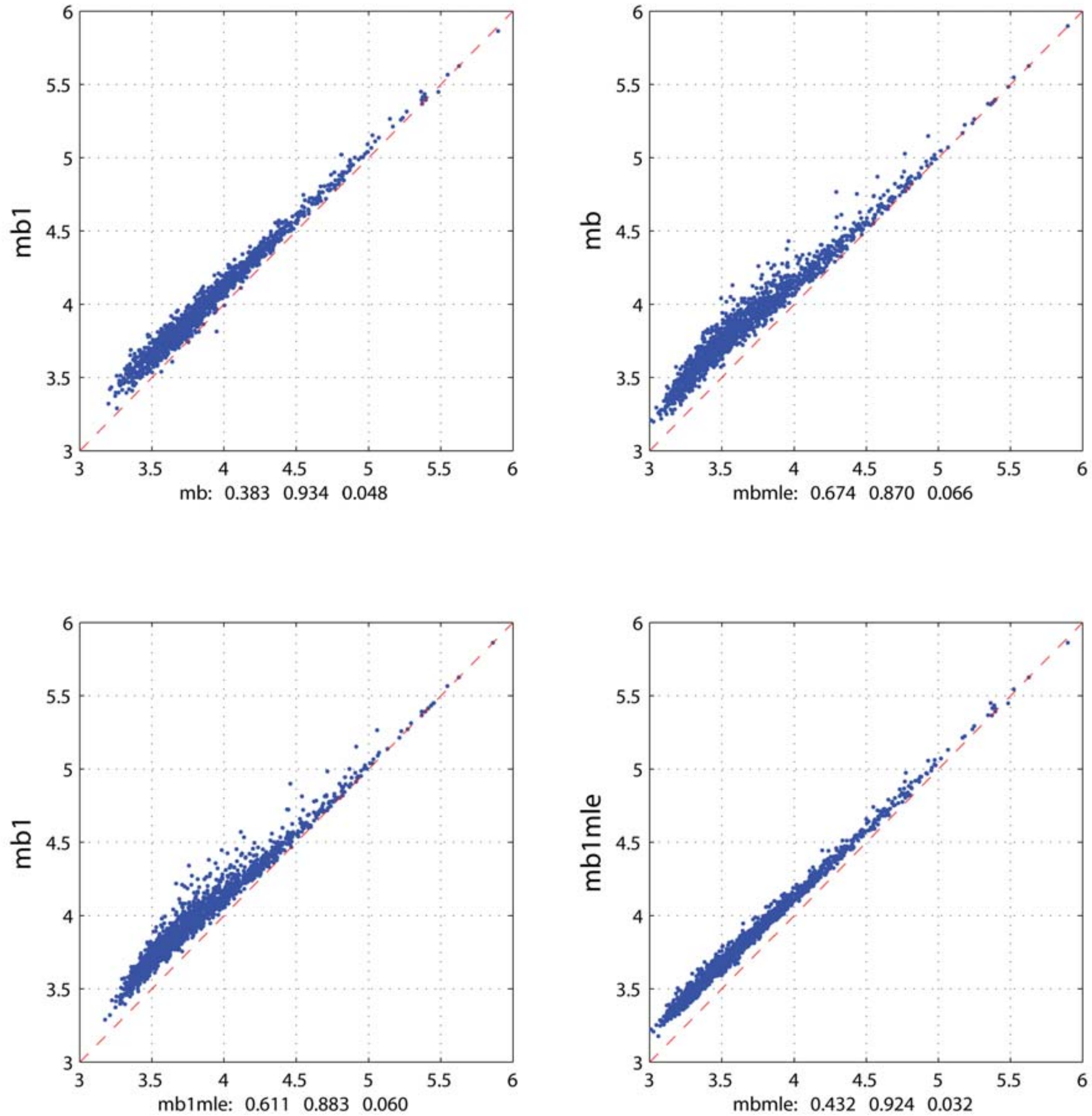

Fig. 6.1.8 Linear relations between various magnitude measures, using data from 2001-2009 (within 5 degrees of 32N, 104E, China). The intercept, slope and standard deviation of each least squares fit is indicated for each subplot.

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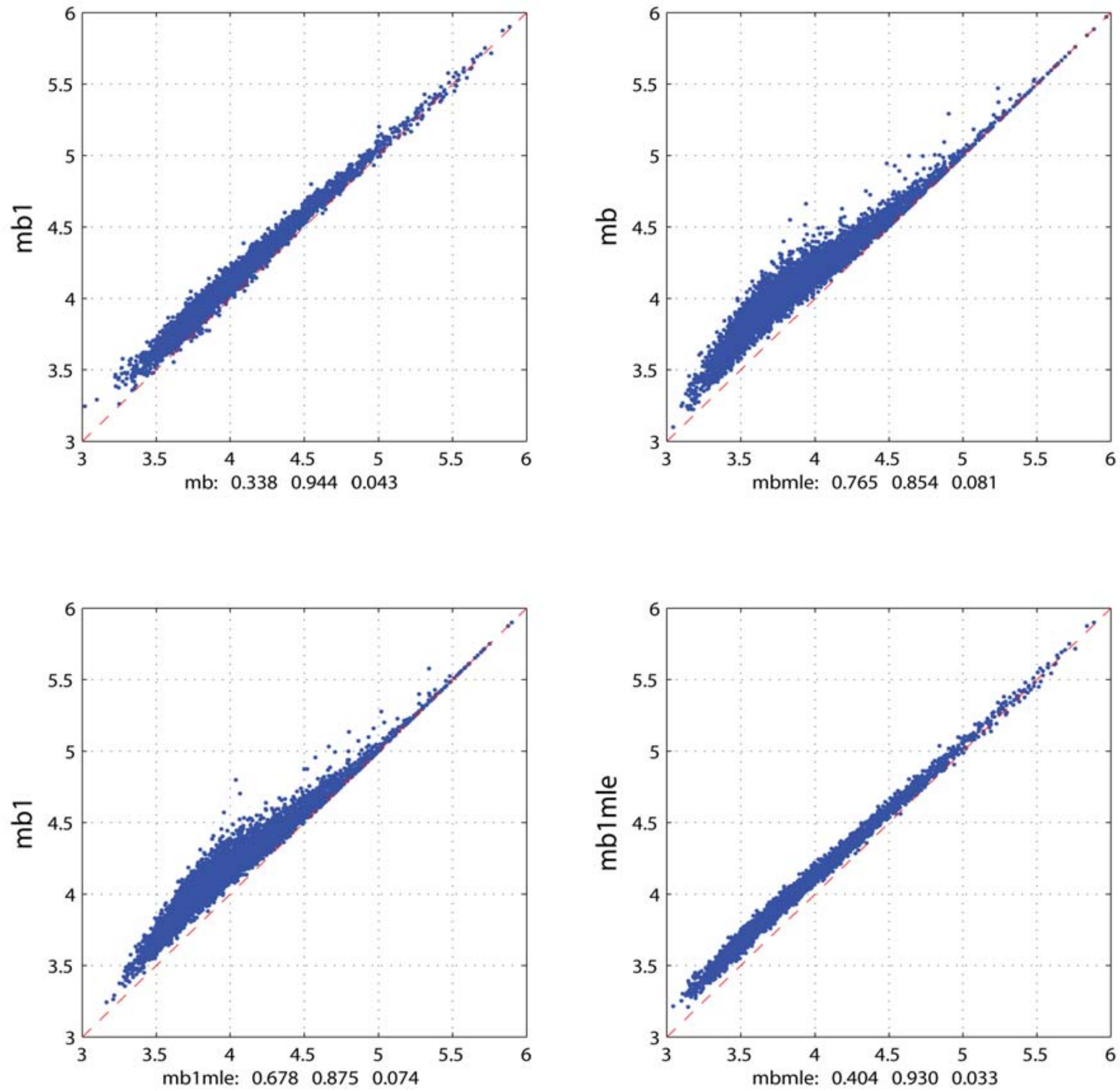

Fig. 6.1.9 Linear relations between various magnitude measures, using data from 2001-2009 (within 5 degrees of 0N, 100E, Indonesia). The intercept, slope and standard deviation of each least squares fit is indicated for each subplot.

6.1.5 Magnitude-frequency relationships

We have also studied the magnitude-frequency relationships for the various magnitude types. These relationships are shown in six figures (Figures 6.1.10-6.1.15), with Figures 6.1.10 and 6.1.11 covering all regions, while Figures 6.1.12 and 6.1.13 cover the region in China and Figures 6.1.14 and 6.1.15 cover the region in Indonesia. The restrictions on the selected events are as before.

A common feature of the plots is that the slopes of the magnitude-frequency relationships are steeper for the mb1-based magnitudes than for the mb-based magnitudes. This is clearly connected with the magnitude dependent bias effects already noted. Furthermore, we observe that (as expected) the slopes for maximum-likelihood magnitudes are less steep than those for the conventional magnitudes.

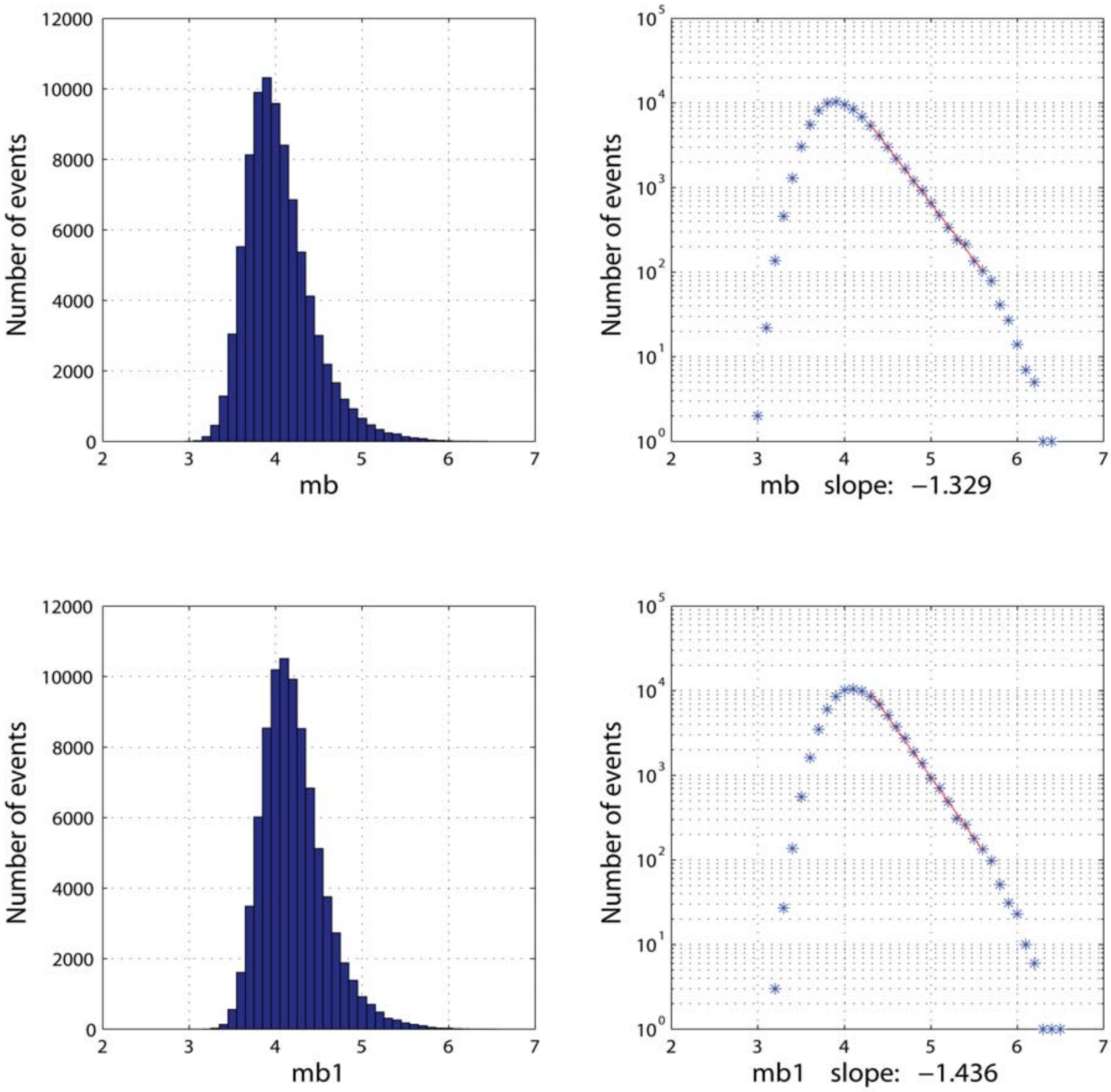

Fig. 6.1.10 Recurrence statistics for mb and mb1 for 2001-2009 (all regions). The estimated slope of the magnitude-frequency relationship (shown in red) is given for each plot.

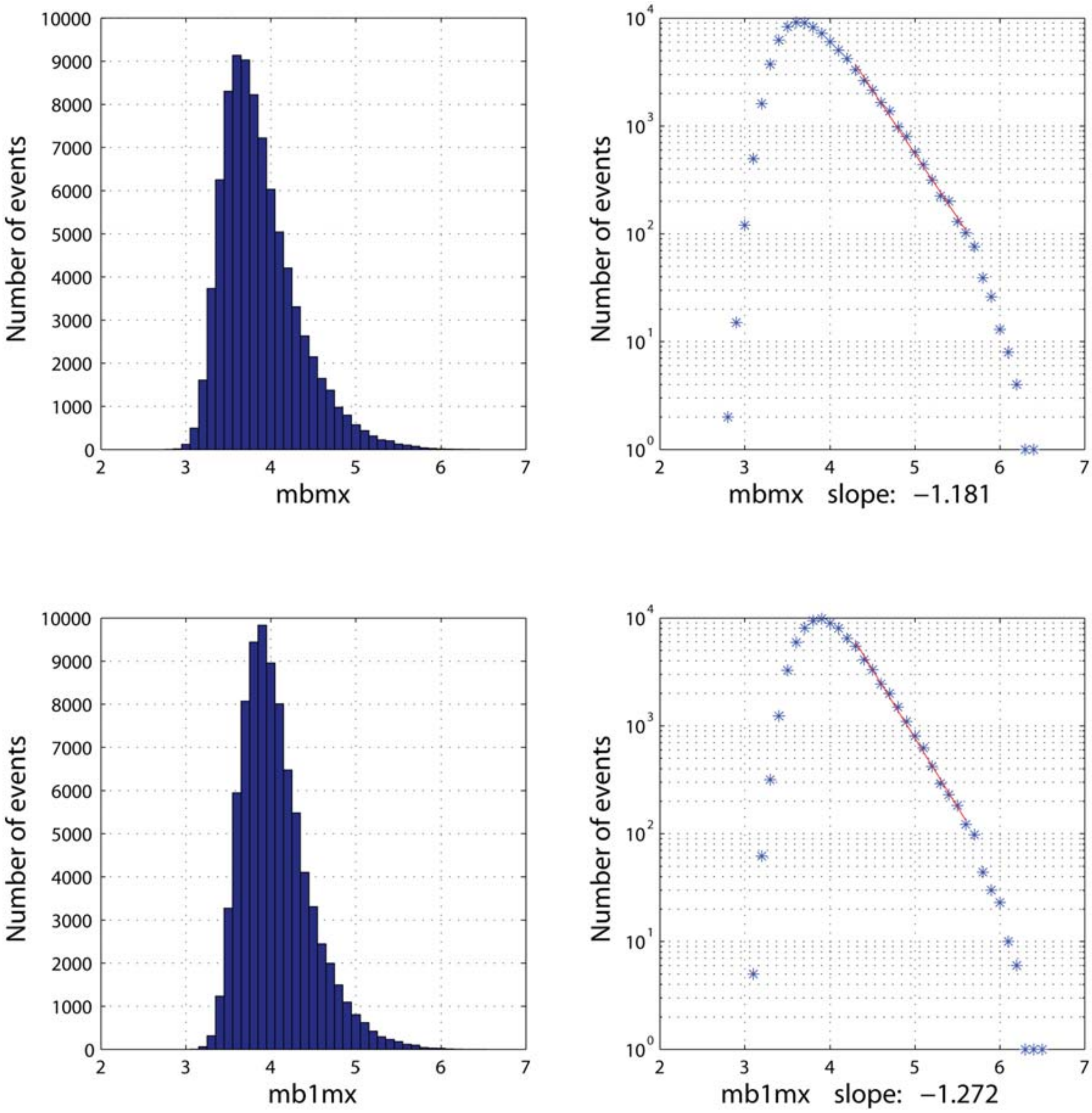

Fig. 6.1.11 Recurrence statistics for mbmx and mb1mx for 2001-2009 (all regions). The estimated slope of the magnitude-frequency relationship (shown in red) is given for each plot.

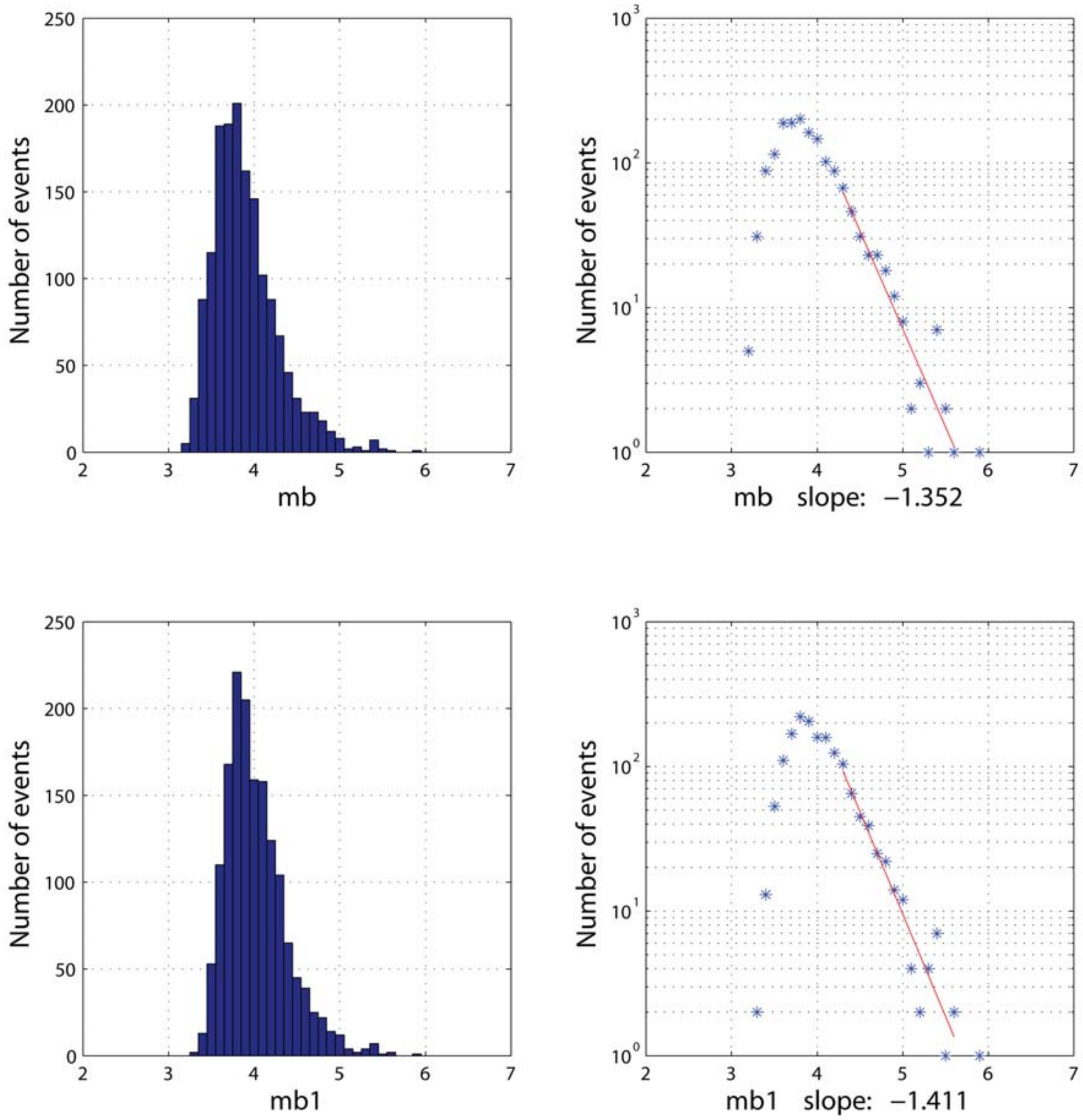

Fig. 6.1.12 Recurrence statistics for mb and mb1 for 2001-2009 (within 5 degrees of 32N, 104E, China). The estimated slope of the magnitude-frequency relationship (shown in red) is given for each plot.

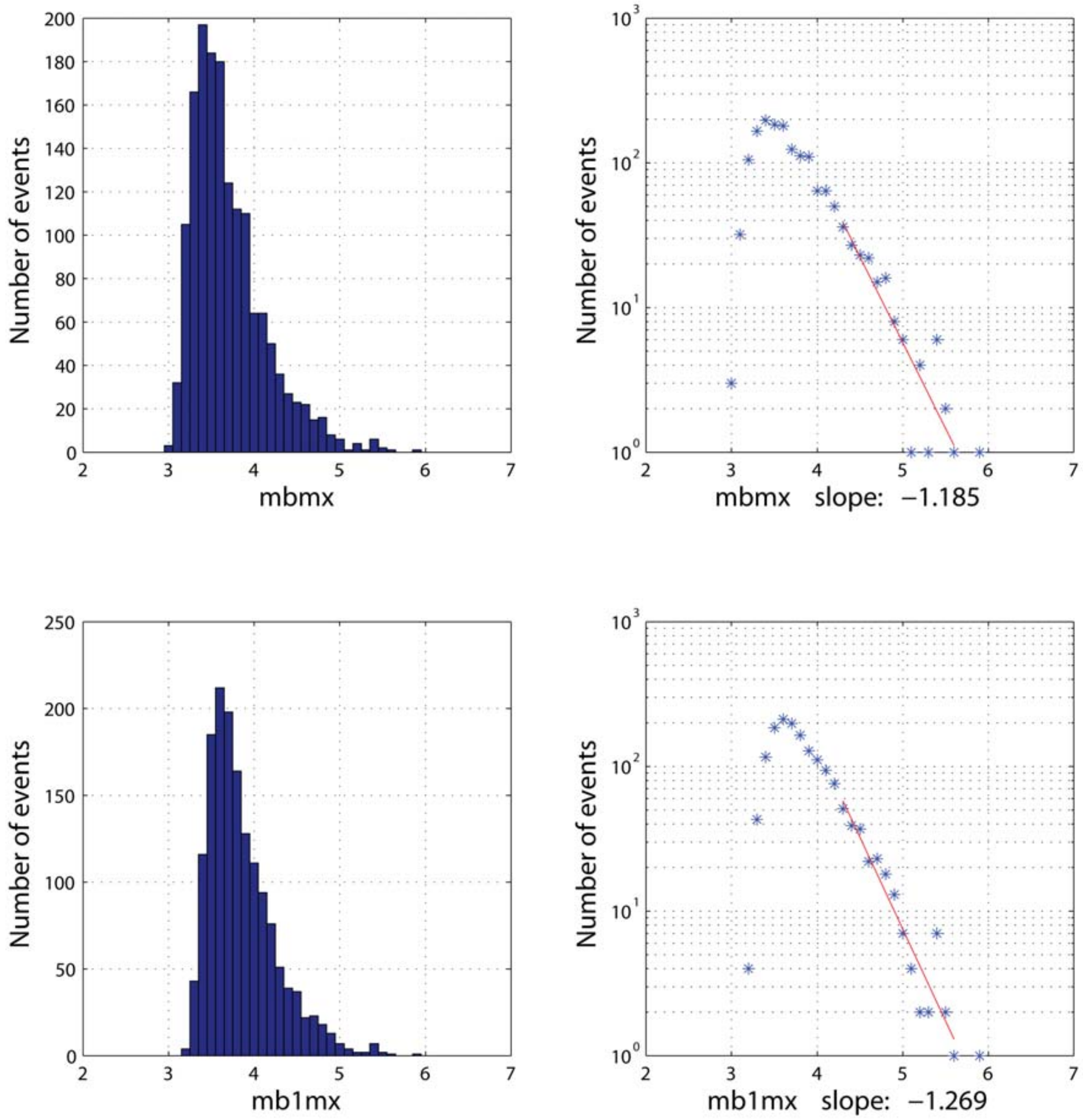

Fig. 6.1.13 Recurrence statistics for mbmx and mb1mx for 2001-2009 (within 5 degrees of 32N, 104E, China). The estimated slope of the magnitude-frequency relationship (shown in red) is given for each plot.

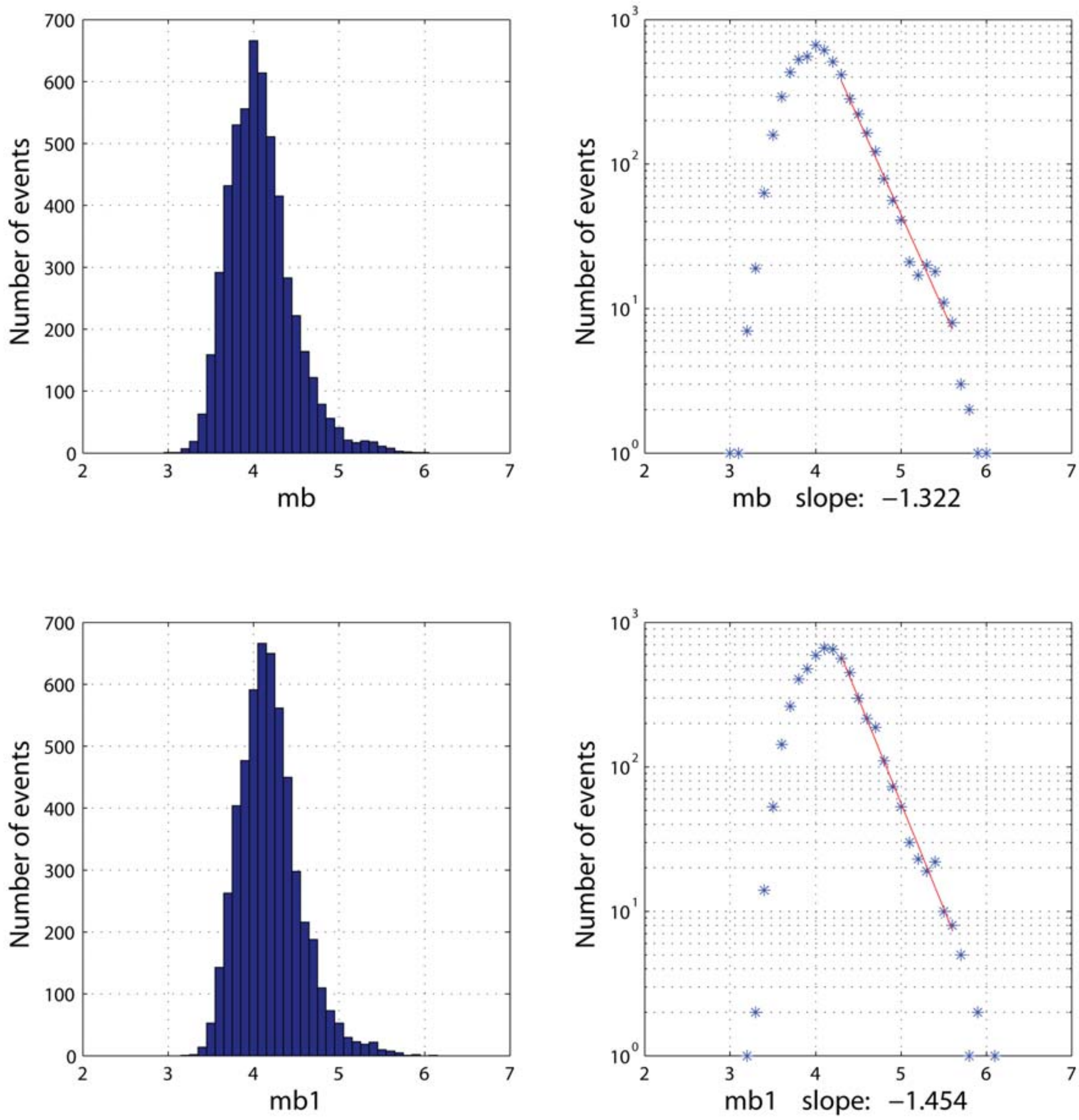

Fig. 6.1.14 Recurrence statistics for mb and mb1 for 2001-2009 (within 5 degrees of 0N, 100E, Indonesia). The estimated slope of the magnitude-frequency relationship (shown in red) is given for each plot.

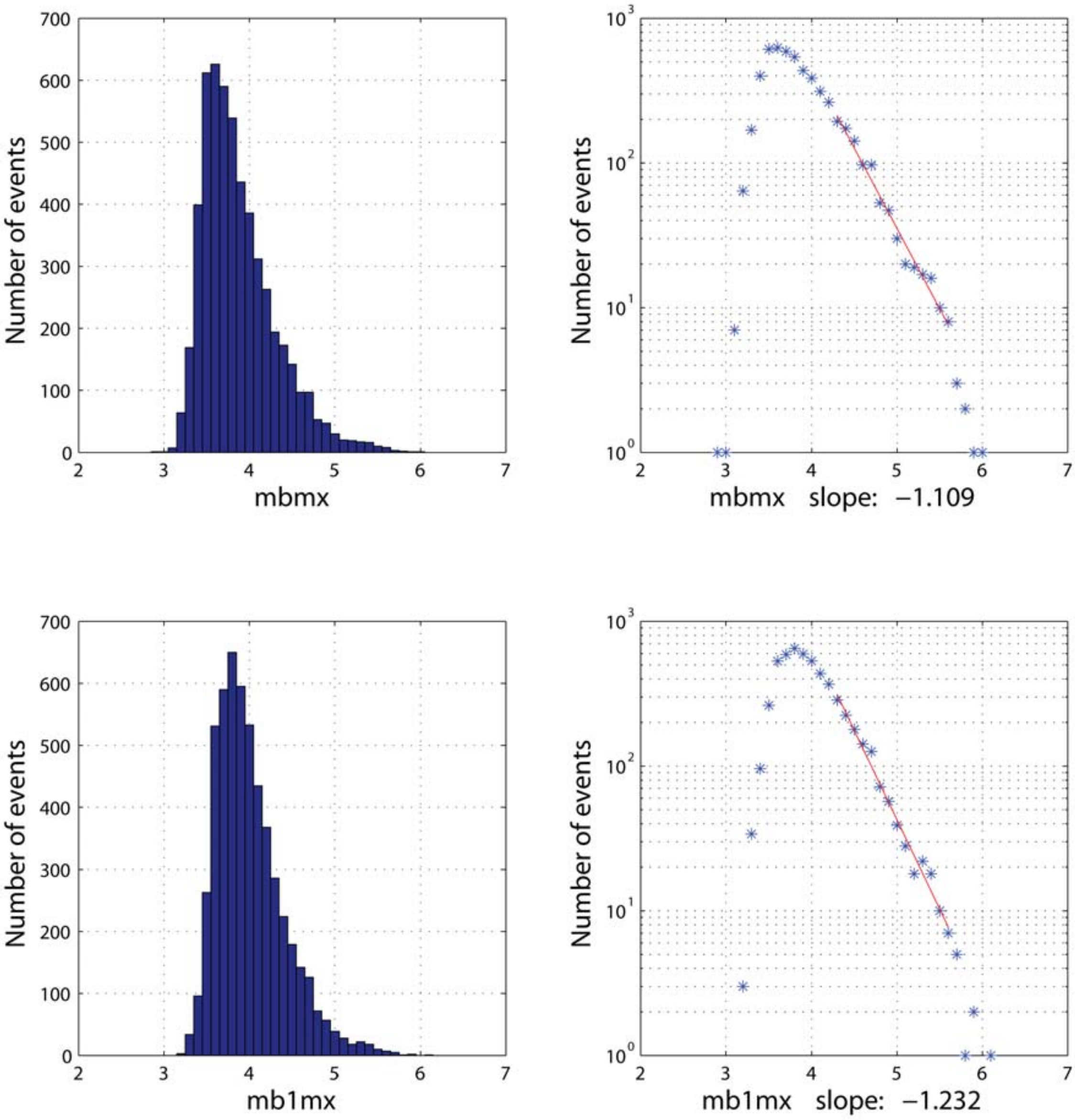

Fig. 6.1.15 Recurrence statistics for mbmx and mb1mx for 2001-2009 (within 5 degrees of 0N, 100E, Indonesia). The estimated slope of the magnitude-frequency relationship (shown in red) is given for each plot.

6.1.6 Conclusions and recommendations

We note the following observations:

- The magnitude values are fairly consistent, but the two mb1-based magnitudes are on the average about 0.1-0.2 units higher than the corresponding ones based on mb. The difference is largest at the low magnitude end.
- When comparing mb-based magnitudes (x-axis) and mb1-based magnitudes (y-axis) we see that the slope is systematically less than 1.0, consistent with the previous observation of mb1 being increasingly higher than mb at low magnitudes. This appears in all the regions we have studied. One major contributing factor here would be the significant

differences in the attenuation curves between 20 and 25 degrees (Figures 6.1.1 and 6.1.2). However, the inclusion of regional data (2-20 degrees) in the mb1 computations, the associated station corrections and the weighting procedure employed in computing mb1 would be likely to play a role as well.

- The maximum-likelihood magnitudes (mbmle and mb1mle) are more mutually consistent than the averaged magnitudes (mb and mb1). Again, this is observed in all regions we have studied.

The lower scatter for the maximum-likelihood magnitudes is attributed to the fact that the correction for non-detections reduces the standard deviation of individual network magnitude estimates.

We note that by definition the maximum-likelihood magnitudes are always lower than (or equal to) the corresponding average magnitudes. This is because the maximum-likelihood procedure is designed to eliminate or reduce positive magnitude bias due to ignoring the non-detections. In the choice between the two different types of maximum likelihood magnitudes, we plan to use the mb1mle estimates as reference event magnitude. The reason for choosing mb1mle rather than mbmle is that, for this magnitude measure, individual event magnitudes for detecting stations are included in the database also for stations within 2-20 degrees of the epicenter, which is not the case for mbmle. We note, however, that in neither case is information on non-detections reported for epicentral distances within 20 degrees, and that, for auxiliary stations, no information on non-detections is reported at any distance.

We recommend that the IDC consider the following possible actions for the near term:

1. For the dynamic validation of events and associated phases, the magnitude information should be as complete as possible, already at the SEL3 stage. Currently, the SEL3 includes only mb and ML. We suggest that mb1 be computed as well, even if the event is "unreasonable". It would also be an advantage, if practicable, to compute the maximum likelihood magnitudes (and the noise levels) for inclusion in the SEL3. In fact, in order to identify bogus events in SEL3, the most important information is precisely those magnitude values and detection/non-detection patterns that appear to be unreasonable.
2. Both previous studies and our initial studies under this project have confirmed the importance of having complete statistics on station uptimes. Clearly, it is meaningless to apply dynamic criteria if a key station is down during an event, and this station is counted as non-detecting because station downtime has not been recorded. During the further work in this study, we plan to use the Threshold Monitoring data to help identify the outages. Nevertheless, it would be an advantage to keep an independent record of the station downtimes (a downtime for a station being defined in conjunction with SEL3 as a time period for which data from that station has not been available to produce the SEL3). Note that the TM processing is not applied to auxiliary stations, so the downtime statistics for those stations must be made available by some other means – otherwise the usefulness of auxiliary stations for dynamic checking will be very limited.

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