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SUMMARY

This report describes the recomputation of some 100,000 bodywave magnitudes for earthquakes occurring in the period 1964-81 inclusive. Compared with the existing conventional magnitude estimates the new values are relatively free from bias introduced by data truncation, station amplitude terms and errors in the amplitude-distance curve. The redeterminations should enable more accurate predictions of seismicity both globally and regionally and of amplitudes seen at individual recording stations.

1. INTRODUCTION

This report describes the redetermination of short-period bodywave magnitudes (m_b) of earthquakes reported by the International Seismological Centre (ISC) during the period 1964-81 inclusive. These redeterminations were made because of the presence of bias in routine estimations arising from three causes:

(a) Noise and/or an amplitude measurement threshold employed by station analysts result in a differential loss or data truncation of low values for the station magnitudes. Using the mean as magnitude estimator gives a positive bias (eg, Herrin and Tucker (1), Evernden and Kohler (2), Ringdahl (3,4)). In this report this bias will be referred to as "truncation bias".

(b) Station amplitude terms (eg, North (5) Booth, Marshall and Young (6)) are known to exist but are not routinely applied by agencies such as the ISC.

(c) Errors in the Gutenberg and Richter (7) amplitude distance correction factors routinely applied are known to exist (eg, Marshall et al (8)).

The amplitude of bias in routine magnitude estimates depends on the disposition and number of reporting stations in the network and their amplitude reporting thresholds. This bias will vary temporally as the network changes and systematically with both geographical location and magnitude itself. The redeterminations described in this report provide a data file of magnitudes relatively free from these variations for use in seismicity studies, prediction of individual station ground amplitudes and the identification of "anomalous" earthquakes.

2. SUMMARY OF METHOD AND DATA USED

Ringdal (3) describes a maximum-likelihood technique for estimating magnitudes which is intended to eliminate much of the bias introduced by data truncation at low readings. In a recent application of the technique Ringdal (4) describes the redetermination of the ISC magnitudes for the period 1970-80. The new magnitudes appear to remove many of the inconsistencies of previous magnitudes with respect to global seismicity and network capability. The method used here is similar to that of Ringdal (4) with some modifications and is described fully in appendix A. The data used are the ISC bulletin tapes for the period 1964-81 inclusive. The technique requires a knowledge of the amplitude-reporting thresholds of stations submitting data to the ISC and the station amplitude terms. Details of the estimation of these are given in appendix B. The amplitude-distance curve used is based on that of Marshall, Bingham and Young (8) and is described fully in appendix C. To reduce the effects of regional variations from the curve only data in the distance range 30 to 100 degrees are used and only the magnitudes of earthquakes with at least 1 amplitude reading within this range for the designated station network redetermined. Some 100,000 earthquakes fall into this category for the period 1964-81 inclusive.

3. DISCUSSION OF THE RESULTS

Figure 1 shows a plot of the mean differences between the ISC and recomputed magnitudes as a function of recomputed magnitude using the maximum likelihood estimator used by Ringdal (3,4) and a similar formulation given by Christoffersson et al (11). The differences result from the use of the new statistical procedure, alternative amplitude-distance curve and the application of station amplitude corrections. Apart from a baseline shift the results using Ringdal's formulation are broadly similar to those presented in his original publication (4) and shows that the difference or bias is maximum at intermediate magnitudes. The fall off in bias at low magnitudes does not occur using the Christoffersson et al (11) formulation of the likelihood equation and, as shown below, this is in agreement with predicted results. The baseline shift of the 0.05 units revealed at large ($m_b \geqslant 6.0$) magnitudes results partly from the use of an alternative amplitude distance curve (appendix C) but mainly from baselining of the station corrections as discussed in appendix B.

To check the consistency of the estimations and improve confidence in the redeterminations, a data simulation experiment was undertaken to check whether the bias observations such as in figure 1 are realistic. The procedure used, which is similar to that of Evernden and Kohler (2), is as follows:

For a simulated true magnitude and hypocentre:-

(a) Calculate the expected amplitude at each station in the designated network using the amplitude-distance curve (Δ = 30 to 100);

(b) Add normally distributed (SD = 0.35) random numbers to the amplitudes to simulate amplitude variance. The random numbers were truncated at ± 4 standard deviations;

(c) Add normally distributed random numbers to station average noise levels to simulate noise variance. In this case the standard deviation appropriate to each station was used (see table 1);

(d) Signal a detection if amplitude > noise and compute magnitude as mean for all detections. Repeat for a large sample (say 500) of simulations at each "true" magnitude.

(e) Compute the bias as the mean difference between true and calculated magnitudes.

To isolate the effect of truncation bias, station amplitude corrections were not used. The 1979-81 network was used and assumed thresholds are given in table 1.

The observational network (ie, those stations within the distance range 30 to 100 degrees of the epicentre) changes with epicentre location and therefore the bias will vary geographically. Figure 2 shows the variation of the computed bias worldwide for a source of true magnitude m_b = 5.0 for the 1978-81 network in table 1. The bias varies between 0.2 to 0.3 units with the largest values in the southern hemisphere (thus correlating with detection threshold). For m_b = 6.0 the bias drops to less than 0.05 units almost everywhere. The observed variation will result in apparently significant but spurious geographical variation in seismicity parameters such as b values if conventional magnitude values are employed.

Figure 3 shows the mean difference between conventional and maximum likelihood magnitudes for the Japan-Kuriles region as a function of the maximum-likelihood values. Since no station corrections were applied and the same amplitude-distance curve was used, the difference is the result of "truncation bias". Also plotted is the bias predicted using the simulation procedure described above. Agreement is very good for both likelihood formulations except that the fall off at low magnitudes found using Ringdal's equation is not predicted. Figures 4, 5 and 6 for the Aegean, Tonga and region of high bias south of Australia (figure 2) show the same pattern of agreement and deviation indicating that the changes from the conventional estimates are realistic. The differences between the two likelihood formulations are negligible at magnitudes normally used for seismicity statistics (m_b 4.8 to 6.0) but in order to obtain unbiased estimates over the maximum magnitude range the formulation of Christoffersson et al (11) was subsequently applied.

To illustrate the use of the new data file figure 7 shows the incremental magnitude-frequency plot for all shallow (depth < 100 km) earthquakes for the period 1964-81. The straight line fitted using the Page (9) method, indicates that the annual seismicity is represented by the incremental form:

$$\text{Log}(N) = 7.49 - 1.06\, m_b \qquad \text{.... (1A)}$$

or the cumulative form

$$\mathrm{Log}(N_c) = 8.10 - 1.06\ m_b \qquad \ldots. \quad (1B)$$

The b value of 1.06 is higher than 0.9 found by Ringdal (4) and 0.98 found by Lilwall and Douglas (10). This difference in the b value may reflect the different curve fitting techniques employed as Ringdal used the Kelly and Lacoss (19) method whilst here only data on the linear section was utilised. The predicted annual number of earthquakes with $m_b \geq 4.0$ is 7250, which is similar to the value of 7500 found by Ringdal (4) and 7900 by Lilwall and Douglas (10). Figure 6 also shows a magnitude-frequency plot for the Soviet Bloc (as defined in Lilwall and Douglas (10)) for which the linear section is described by

$$\mathrm{Log}(N) = 5.91 - 0.97\ m_b$$

$$\mathrm{Log}(N_c) = 6.56 - 0.97\ m_b$$

The b values obtained using the redetermined magnitudes (1.06 and 0.97) are lower than those obtained using the ISC magnitudes (1.43 and 1.23, see Lilwall and Douglas (10)) and the smaller difference (0.09 compared with 0.20) suggest that b values based on the new magnitude determinations may show less regional variation.

APPENDIX A

MAXIMUM LIKELIHOOD DETERMINATION OF MAGNITUDES

A1. DEFINITION OF TERMS

For ease of reference the definition of mathematical terms is as follows:

For a network of N stations let the subscript i refer to the i^{th} station. For a seismic event of true magnitude M let

D be the subset of the N station indices i for which the station reports on amplitude

a_i be the ground amplitude (Log^A/T) at i^{th} station

m_i be the associated station magnitude given by equation (3) below

B_i be the distance-depth correction for i^{th} station

σ_i be the SD of m_i about M

S_i be the station amplitude term

g_i be the average (50%) threshold for reported amplitudes at i^{th} station

γ_i be the SD of the threshold about g_i

G_i be the earthquake magnitude corresponding to noise amplitude g_i given by equation (4) below

Pa_i be the probability that a given station is inoperative

Some of the above terms are related by the following equations:

$$m_i = a_i + B_i \quad \ldots. \quad (3)$$

This is the definition of station magnitude m_i.

Also:

$$G_i = g_i + B_i \quad \ldots. \quad (4)$$

defines the "noise magnitude" threshold G_i.

A2. THEORY OF METHOD

Routine estimates of the true magnitude M are the mean of the observed station magnitudes $m_i (i \epsilon D)$

ie,

$$\bar{M} = \sum_{i \epsilon D} m_i / \sum_{i \epsilon D} 1.0 \quad \ldots. \quad (5)$$

The station magnitudes m_i are assumed to be normally distributed about the true magnitude (Freedman (12)). If the observed set m_i ($i \epsilon D$) is randomly sampled then the mean should be unbiased. Unfortunately ground noise, and thresholds applied by the analyst result in a truncation of lower m_i values and the resulting mean is positively biased. The method used to estimate magnitudes described in this report is similar to that of Ringdal (3,4) and is intended to remove this truncation bias. Simultaneously the method applies station terms S_i. The basic theory is as follows:

For a given earthquake, true magnitude M let the network of observing stations be divided into two sets namely

Set A: Stations which report an amplitude a_i (ie, $i \epsilon D$)

Set B: Stations not reporting an amplitude (ie, $i \not\epsilon D$)

For earthquakes of true magnitude M the conditional probability distributions of observations in sets A and B are as given by Christoffersson et al (11) are:

$$\text{Set A} \quad \underset{i \epsilon D}{P_i(m_i/M)} = \Phi\left[\frac{m_i - G_i}{\gamma_i}\right] \phi\left[\frac{m_i - (M+S_i)}{\sigma_i}\right] \qquad \dots. \quad (6)$$

$$\text{Set B} \quad \underset{i \not\epsilon D}{P_i(\text{no detect}/M)} = \Phi\left[\frac{G_i - (M+S_i)}{\sqrt{\gamma_i^2 + \sigma_i^2}}\right] \qquad \dots. \quad (7)$$

where ϕ and Φ are the normal and cumulative normal distributions respectively. If in addition there is a probability Pa_i of the station not operating the equation (6) is multiplied by (1-Pa) and (7) modified to

$$\underset{i \not\epsilon D}{P_i} = Pa_i + (1-Pa_i)\,\Phi\left[\frac{G_i - (M+S_i)}{\sqrt{\gamma_i^2+\sigma_i^2}}\right] \qquad \dots. \quad (8)$$

The likelihood function for the total set of observations in sets A and B is the product of the individual probabilities (6) and (8)

$$L = \prod_{i \epsilon D}^{N} (1-Pa_i)\,\Phi\left[\frac{m_i - G_i}{\gamma_i}\right]\phi\left[\frac{m_i-(M+S_i)}{\sigma_i}\right] \prod_{i/D}^{N}\left[Pa_i + (1-Pa_i)\Phi\left[\frac{G_i-(M+S_i)}{\sqrt{\gamma_i^2+\sigma_i^2}}\right]\right] \Big/ \; P1$$

$$\dots. \quad (9)$$

where

$$P_1 = 1.0 - \prod_{i=1}^{N} \left[Pa_i + (1-Pa_i)\ \Phi \left[\frac{G_i - (M+S_i)}{\sqrt{\gamma_i^2+\sigma_i^2}} \right] \right] \qquad \ldots. \quad (10)$$

The factor P_1 is necessary to make the probabilities conditional to at least one station reporting an amplitude. In Ringdal's (3,4) formulation the detection probability of the amplitude observations and P_1 in equation (9) are omitted. Both formulations were tried and compared (see section 2). The maximum likelihood estimate $\hat{M}$ of M can be found by maximising L in (9) numerically for variation in M using the observations $m_i(i \epsilon D)$ and predetermined values for σ_i, G_i, γ_i, S_i and Pa_i. Details of the estimation of these is given in appendix B.

Ringdal (4) has extended the procedure to include stations which report an arrival time (ie, detections) but give no amplitude. In this third group the probability used in his likelihood function is

$$P_i = \Phi \left[\frac{M+S_i-G_i}{\sqrt{\sigma_i^2+\gamma_i^2}} \right] \qquad \ldots. \quad (11)$$

This is so, provided the station is not also reporting amplitudes. The threshold G_i may be lower than the amplitude reporting threshold. Comparison of the mean ISC magnitude for which a station reports amplitudes to that for arrival times as suggested by Ringdal indicates that this threshold difference was most frequently 0.2 to 0.3 units. Clearly where a station reports arrival times alone, and sometimes both arrival times and amplitude during a given time, then they are adopting the reasonable practice of reporting an amplitude only where there is adequate signal to noise (ie, $\simeq$ 2.0). The difference in threshold is an unfortunate complication if this extra group of observations is used because it is difficult to estimate the lower thresholds accurately from bulletin data. In addition a further problem arises from the need to distinguish when stations are reporting detections only, in which case equation (11) holds, from when both amplitudes and detections are being reported but with differing thresholds. In the latter case the probability will be the difference of two functions of the form (11) but with the different thresholds. The simplified likelihood function (9) is therefore used here and the information content of the "arrival time" data disregarded.

A3. PRACTICAL CONSIDERATIONS

The data used are those published by the ISC for the period 1964-81 inclusive and are available on magnetic tape. Since non-reporting stations contribute to the results at a given time it is important that the observing network is selected carefully to reduce the effect of non-operating stations not fully allowed for in the probability Pa_i. To enable this and also to remove stations during periods of apparently erratic reporting, stations were flagged in or out of the network on a monthly basis. Stations were chosen if they have contributed sufficient data to permit reasonable estimates of the station correction and reporting thresholds. Many more of the less sensitive stations have beeen included here than were used by Ringdal (4). The reasons for this are twofold; firstly the inclusion of such stations reduces the bias for large magnitude ($m_b > 6.0$) that results from the loss of data from stations which have clipped recordings (von Seggern and Rivers (13), Ringdal (14)); secondly the greater geographical extent of the network should give a better baseline to the station terms.

To determine the periods when each station was used, the data submitted to the ISC by each station were displayed in terms of the number of events and the average amplitude reported each month. Periods when the station was wholly inoperative are obvious and the station was flagged out of the network during these months. Although many stations appear to show consistent performance over long time periods, others including some sensitive stations exhibit trends or even discontinuous changes with time. This variation has many possible causes including genuine changes in the background noise levels, variation in the seismogram analyst's practice, correction or introduction of errors either by the analyst or in transmission to the ISC and changes in instrument type or calibration. For these reasons the thresholds g_i and even the station terms S_i (see North (5)) may vary with time. The full time period 1964-81 was therefore divided into four sub-periods 1964-69, 1970-73, 1974-77 and 1978-81 and separate values for constants g_i, γ_i, S_i and σ_i and Pa_i estimated. Four years is about the minimum required to obtain sufficient data to enable stable estimates of these constants at the less sensitive stations. If even within these shorter time periods strong variation in reporting is apparent the station was flagged inoperative when appropriate.

Two problems not considered in the theory concern the possible interference to events whose P arrival falls in the coda of another and the loss of amplitude data resulting from clipped or saturated recordings.

The effect of overlapping coda is to temporarily raise the effective noise level and may result in a significant extra loss of amplitude data. Underestimation of the magnitude will occur if the <u>average</u> noise level is assumed. To reduce this problem, coda amplitudes from other earthquakes were predicted for the arrival time of each event. If the coda levels were similar to or greater than the average thresholds then the latter were temporarily increased assuming both coda and true noise added as random noise. Coda levels were predicted using the results of Sweetser, Cohen and Tillman (15), Sweetser and Cohen (16,17). Application of coda corrections has little impact on overall seismicity statistics but in isolated individual cases significant changes (0.2 to 0.3 m_b units) are found.

For the higher magnitudes ($m_b \gtrsim 5.5$), amplitude readings may be absent because the seismograms are clipped. This clipping results in a negative bias in routine magnitude estimates (von Seggern and Rivers (13), Ringdal (14)). This bias can be inadvertantly increased if such missed readings are assumed to result from non-detections. No attempt is made here to fully correct for clipping because clipping levels are not easily available, but the latter effect was reduced by identifying stations suspected to have clipped and not including them in the operating network. Clipping levels and reporting thresholds are well separated so the former can be identified because for such an eventuality the station only reports an arrival time for an earthquake with a predicted station magnitude well above the threshold.

APPENDIX B

ESTIMATION OF STATION AMPLITUDE REPORTING THRESHOLDS, AMPLITUDE TERMS AND THE PROBABILITIES THAT A STATION IS IN OPERATION

B1. AMPLITUDE MEASUREMENT THRESHOLDS (g_i and γ_i)

The average (50%) threshold g_i for amplitude measurements at a station together with its SD γ_i can be estimated by the method of Kelly and Lacoss (19). This technique also estimates the seismicity parameters of the well known Gutenberg-Richter (7) magnitude frequency relation:

$$\text{LogN} = a-bm \qquad \ldots. \quad (12)$$

Fortunately estimates of both g_i and γ_i are insensitive to variation in b (Lacoss and Chinnery (18)) and so in this study b was set to 1.0 (eg, Lilwall and Douglas (10)). The data required are the raw amplitude (Log^A/T) measurements for each station over a time period long enough to enable sufficient data to be collected. The data sources used were the ISC bulletin tapes for the period 1964-81. Since some temporal variation in the thresholds is likely this overall period was divided into four sub periods (1964-69, 1970-73, 1974-77, 1978-81) and separate values for g_i and γ_i estimated for each. Only data in the distance range 30 to 90 degrees and from months in which the station was flagged as operative (see section A3) were included.

Table 1 gives the thresholds g_i and their SD's γ_i. The former vary from just above 0.0 up to over 2.0 in terms of $\text{Log}(^A/T)$. These are not necessarily the lowest thresholds possible since they also reflect individual station analyst's choice of the minimum amplitude to be measured and submitted to the ISC. Values of γ_i are typically 0.2.

Thresholds for the most sensitive stations will be too large in table 1 because of the loss of data which the ISC was unable to associate with locatable earthquakes. This data loss starts at near m_b = 5.0 and progressively increases at lower m_b values (eg, Lilwall and Douglas (10)). Magnitude m_b = 5.0 corresponds to an amplitude (Log^A/T), over most of the teleseismic range Δ = 30 to 90, of 1.2. Above this the thresholds should be reliable but below this they will be progressively overestimated. Ringdal (4) assumed that little error in the magnitude estimates will be introduced by ignoring this since the sensitive stations nearly always report amplitudes and then thresholds do not enter into his likelihood function. This is not true for the full likelihood equation (9) and thresholds of less than $\text{Log}(^A/T)$ of 1.2 were therefore adjusted downwards using an empirical relation based on a few stations whose true reporting thresholds have been determined independently of the ISC data. These stations are the VELA arrays (data for 1966) CPO, BMO, TFO, UBO, WMO; NORSAR array NAO (mid 1970's), NB2 (late 1970's); Warramunga array, WRA; Gauribidanur array, GBA; and Eskdalemuir array, EKA. Thresholds for these arrays using the complete data output are given in Lilwall and Douglas (10). Figure 8 shows the true thresholds plotted against those found using the ISC data alone. Although sparse, the plot indicates that the thresholds using the latter data alone are overestimated by about 0.2 units for the most sensitive stations. The straight line:

$$g = 1.21g_{ISC}-0.25 \qquad \ldots . \quad (13)$$

is fitted to the data by least squares but constrained through the point (1.2,1.2) where we expect the difference to approach zero. Thresholds below 1.2 were adjusted using the above equation and are marked with an asterisk in table 1.

B2. STATION AMPLITUDE TERMS (S_i,σ_i) AND NON-OPERATION PROBABILITY (Pa_i)

A simple method of estimating the average amplitude terms for each station is described by North (5). Estimates of S_i are the mean difference between the observed station magnitudes $m_{ik}(k\epsilon D)$ for a set of NE earthquakes and the mean magnitudes M_k

If $$m_{ik} = a_{ik} + B_{ik} \qquad \ldots . \quad (14)$$

where a_{ik} = ground amplitude at i^{th} station for k^{th} event

B_{ik} = amplitude distance factor for i^{th} station for k^{th} event

D = set of indices for reporting stations

Then

$$S_i = \sum_{k\epsilon D}^{NE} (m_{ik}-M_k) / \sum_{k\epsilon D}^{NE} 1.0 \qquad \ldots . \quad (15)$$

These values for S_i will be reliable if the magnitudes M_k are unbiased and the station magnitude observations not truncated. In practice if ISC magnitudes are used for stations with high thresholds neither of these assumptions are valid and a truncation bias similar to that found in the mean magnitudes may be introduced. At the expense of the quantity of data used, these problems were reduced by using larger well recorded earthquakes only, and in addition the following alternative analysis was performed which parallels the maximum-likelihood technique described in section A2.

Suppose we have NE earthquakes of true magnitude M_k for the k^{th}. Suppose these are observed by a network of N stations each signalling detections with measured amplitudes or giving "no data". The overall likelihood equation for all the observations is similar to that given of Christoffersson et al (11) and is the product of the likelihoods given by equation (9) for the NE earthquakes ie,

$$L = \prod_{k=1}^{NE} \frac{1}{P_{1k}} \left[\prod_{i\epsilon D}^{N} (1-Pa_i)\Phi\left[\frac{m_{ik}-G_i}{\gamma_i}\right]\phi\left[\frac{m_{ik}-(M_k+S_i)}{\sigma_i}\right] \right.$$

$$\left. \cdot \prod_{i\epsilon D}^{N} (Pa_i+(1-Pa_i)\Phi\left[\frac{G_i-(M_k+S_i)}{\sqrt{\gamma_i^2+\sigma_i^2}}\right]\right] \qquad \ldots . \quad (16)$$

If, in addition, only relatively large earthquakes are considered then all the factors P_{1k} given by equation (10) can be set to 1.0. Given that M_{ik}, G_i, γ_i are known, the above function can be maximised to give estimates of M_k, S_i, Pa_i and σ_i. The numbers of unknowns (M+3N) to be determined is very large (> 1000) and to maximise this function the following piecewise iterative scheme was employed.

(a) Assuming approximate values of Pa_i, S_i and σ_i (eg, 0.15, 0.0, 0.35) estimates of the magnitudes M_k were obtained by maximising the likelihood in equation (9).

(b) Using these magnitude estimates M_k the likelihood (equation 16) was maximised to give new values of Pa_i, S_i and σ_i.

(c) Repeat (a) and (b) iteratively until the overall likelihood is maximised.

In practice, to allow for any temporal variations in the values for Pa_i, S_i and σ_i the analysis was repeated for the same four time periods used for the thresholds (section B1). A lower magnitude limit of m_b 5.4 was employed which gives sufficient data to enable stable estimates for the less sensitive stations. It was found that after three iterations the function was effectively maximised and variations in the estimates S_i between iterations were less than 0.01.

Approximate confidence limits on the S_i estimates were produced by exploring the likelihood with variation of S about its maximum-likelihood value and computing the ratio λ.

$$\lambda = L_1/L_2 \qquad \text{.... (17)}$$

where L_2 is the maximum likelihood value and L_1 is the likelihood maximised for variation of σ and P_a for a test value of S. Confidence limits are estimated assuming $-2\text{Log}\ \lambda$ is distributed as χ^2 (1) (Brownlee (20)) and are given in table 2 (under + or -).

The four sets of corrections so determined are baselined so that their total sum for each group is near zero. Since the network has evolved in time both in extent and geographical distribution, the effective baseline applied to the terms will vary. A common baseline was applied to the total set of station terms as follows. Let C(I,J) be the estimated station correction for the I^{th} station and J^{th} time period. Then let

$$C(I,J) = B(J) + S(I) + \epsilon(I,J) \qquad \text{.... (18)}$$

where B(J) is the unknown baseline correction for the J^{th} period and S(I) is the station term for the I^{th} station. $\epsilon(I,J)$ accounts for errors in the C(I,J) estimates and any other random cause of variation. Values of B(J) and S(I) were estimated by least squares as described by Douglas (21) under the constraint.

$$\Sigma S(I) = 0 \qquad \text{.... (19)}$$

The individual equations of condition (18) were weighted by the reciprocal of the standard confidence limit on the individual C(I,J) values. The values of S resulting from this analysis are given in table 2 and the baseline values B(J) are as follows:

1964-69 + 0.066
1970-73 + 0.052
1974-77 + 0.047
1978-81 - 0.004

Some of the apparent variation of the terms C(I,J) with time (J) may be real (eg, North (5)) and therefore for the final magnitude determinations the rebaselined values

$$S_b(I,J) = C(I,J) - B(J) \qquad \ldots. \quad (20)$$

were used rather than the overall estimates S(I). The baselined values S_b together with σ and P_a are given in table 2. The gradual change in the baseline values B with time reflects a shift of the world network from locations on sites with low amplitudes (such as W North America) to a greater number of sites on or underlain by old shield type crusts which tend to give high amplitudes. This means that published magnitudes in the period 1964-77 are underestimated by some 0.05 units compared with the most recent period (1978-81) and accounts for most of the baseline shift revealed in figure 1 at high ($m_b > 6.0$) magnitudes.

The mean value of σ in table 2 is 0.35 which is the same as that adopted by Ringdal (4). Following Ringdal this overall value was used in the estimation of earthquake magnitudes rather than individual values σ_i.

APPENDIX C

ALTERNATIVE AMPLITUDE-DISTANCE CURVE

Magnitude m_b of an earthquake is calculated using the equation

$$m_b = \text{Log}(^A/T) + B(\Delta,h) \qquad \ldots. \quad (23)$$

with A the ground amplitude (in microns) of the first few cycles of the P wave on short period instruments, T the period. $B(\Delta,h)$ corrects for epicentral distance and focal depth and allows for geometrical spreading and attenuation. Values of B were originally determined by Gutenberg and Richter (7) and are still used for routine determinations. Several possible revisions of this curve are now available (Veith and Clawson (22), Booth et al (6), Vanek et al (23), Marshall et al (8). Apart from baselines all these curves are very similar for the distance range $\Delta = 30$ to 100 degrees and indicate that many of the irregularities on the existing $B(\Delta,h)$ curve are not representative of the world average especially for shallow depths (< 100 km). The curve published by Marshall et al (8) was therefore used although any of the others would give similar results at least for shallow sources.

It is desirable that use of a new curve should not unduly change and the overall world seismicity obtained using the Gutenberg and Richter curve. For sources at depths less than 100 km the curve was therefore baselined so that the mean correction in the 30 to 90 degree distance range is equivalent to the Gutenberg-Richter (7) value. Below this depth range the original Gutenberg-Richter (7) corrections were used but as noted by Veith and Clawson (19) this probably overestimates the size of deep focus earthquakes as compared with shallow. Baseline changes resulting from use of the new curve are therefore minimised in the redeterminations but cannot allow for the removal of data in the range 20 to 30 degrees nor for uneven distributions of observations over the total distance range (30 to 100 degrees).

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TABLE 1. Values of Station Reporting Threshold g and Threshold Standard Deviation (γ) for the Four Time Periods Used in this Study.

	1964-69		1970-73		1974-77		1978-81	
	g	γ	g	γ	g	γ	g	γ
ABQ	-	-	-	-	*0.17	0.17	-	-
ABU	2.27	0.30	-	-	-	-	2.22	0.19
AD-	2.11	0.27	-	-	-	-	-	-
ADE	-	-	-	-	2.01	0.21	2.21	0.28
ADK	-	-	1.89	0.29	-	-	-	-
AFR	-	-	-	-	2.00	0.33	1.92	0.23
AKU	-	-	-	-	-	-	1.47	0.17
ALE	1.53	0.24	*1.14	0.14	*0.80	0.18	*0.81	0.21
ALQ	*0.77	0.22	*1.05	0.19	*0.98	0.23	*0.54	0.16
AMN	-	-	-	-	-	-	1.93	0.19
ANG	2.22	0.10	-	-	-	-	-	-
ANP	2.21	0.27	-	-	-	-	-	-
ANR	-	-	-	-	-	-	1.59	0.16
APA	-	-	-	-	-	-	1.80	0.29
APT	-	-	-	-	1.50	0.30	-	-
ARU	-	-	-	-	-	-	1.62	0.20
ASH	-	-	-	-	-	-	2.19	0.33
ASP	-	-	1.41	0.30	1.40	0.32	1.77	0.22
AVF	-	-	-	-	-	-	*1.02	0.21
BAG	1.88	0.31	1.89	0.24	1.86	0.19	2.02	0.22
BDT	-	-	-	-	-	-	1.60	0.34
BDW	-	-	-	-	-	-	*0.79	0.25
BER	-	-	1.53	0.17	-	-	-	-
BHA	*0.66	0.20	*0.71	0.15	*0.80	0.05	-	-
BKR	-	-	-	-	-	-	1.42	0.21
BKS	1.92	0.26	1.58	0.19	1.60	0.23	1.56	0.20
BLA	2.01	0.37	-	-	-	-	-	-
BMN	-	-	-	-	-	-	*0.73	0.25
BMO	*0.24	0.17	*0.27	0.17	*0.34	0.22	-	-
BNG	-	-	*0.63	0.17	*0.72	0.17	*0.85	0.12
BNS	1.62	0.19	1.63	0.25	-	-	-	-
BOD	-	-	-	-	-	-	*1.10	0.14
BOZ	*0.97	0.22	-	-	-	-	-	-
BRG	-	-	*0.94	0.13	*0.95	0.13	*0.98	0.08
BSF	-	-	-	-	*1.12	0.18	*1.17	0.22
BUD	-	-	-	-	1.74	0.32	1.78	0.26
BUH	1.57	0.26	-	-	-	-	-	-
BUL	*0.77	0.16	*0.81	0.11	*0.88	0.11	*0.80	0.11
CAN	1.50	0.26	1.65	0.27	-	-	-	-
CAR	1.50	0.16	1.54	0.11	1.65	0.16	1.66	0.14
CBM	-	-	-	-	-	-	1.31	0.26
CDF	-	-	-	-	*1.09	0.20	*1.03	0.20
CHG	*0.82	0.19	-	-	*0.78	0.19	*1.07	0.11
CIR	*0.66	0.16	*0.72	0.12	*0.82	0.06	*0.74	0.05
CLK	*0.67	0.16	*0.74	0.11	*0.85	0.07	*0.82	0.07
CLL	1.57	0.23	1.21	0.12	*1.16	0.11	*1.18	0.12
CMC	1.85	0.19	-	-	-	-	-	-
CNN	1.80	0.24	-	-	-	-	-	-
COL	*0.89	0.21	*0.99	0.14	*1.01	0.14	*0.97	0.13
COP	1.89	0.13	1.81	0.18	1.91	0.18	1.91	0.19
CPO	*0.61	0.21	*0.82	0.15	*0.79	0.16	-	-
CTA	-	-	-	-	-	-	1.52	0.24
CVF	-	-	-	-	1.47	0.25	1.43	0.30
DAG	-	-	-	-	*1.00	0.20	*1.00	0.15
DAR	-	-	1.63	0.19	-	-	-	-
DBN	2.80	0.18	-	-	-	-	-	-
DCN	-	-	-	-	-	-	1.83	0.28

	1964-69		1970-73		1974-77		1978-81	
	g	γ	g	γ	g	γ	g	γ
DIX	-	-	-	-	-	-	*0.87	0.21
DKM	-	-	-	-	-	-	1.72	0.21
DLE	-	-	-	-	-	-	1.77	0.27
DMU	-	-	-	-	-	-	1.78	0.27
DOM	2.15	0.25	-	-	-	-	-	-
DUG	*0.47	0.22	*1.01	0.30	*1.13	0.26	-	-
EAU	-	-	-	-	1.55	0.28	1.74	0.27
EBH	-	-	-	-	1.51	0.31	1.67	0.26
EBL	-	-	-	-	1.38	0.27	1.57	0.27
ECP	-	-	-	-	-	-	2.57	0.52
EDI	-	-	-	-	1.46	0.25	1.64	0.24
EDM	1.80	0.20	1.59	0.12	1.69	0.15	1.62	0.09
EGL	-	-	-	-	1.42	0.28	1.59	0.27
EKA	*1.07	0.26	1.39	0.22	*1.18	0.20	*1.01	0.28
ELO	-	-	-	-	1.53	0.30	1.56	0.25
ELT	-	-	-	-	-	-	1.30	0.22
EMM	-	-	-	-	-	-	1.50	0.25
EPF	-	-	-	-	-	-	1.34	0.27
ESK	1.53	0.19	-	-	2.05	0.30	1.85	0.17
EUR	*0.65	0.22	*0.80	0.36	*0.70	0.35	*0.78	0.38
FBA	-	-	-	-	-	-	*1.17	0.29
FBC	1.65	0.11	1.76	0.14	-	-	-	-
FCC	1.71	0.10	1.73	0.09	1.81	0.17	1.93	0.31
FEL	2.07	0.27	-	-	-	-	-	-
FFC	-	-	1.60	0.07	*1.02	0.26	*1.05	0.25
FLN	-	-	-	-	1.36	0.24	1.41	0.29
FLO	-	-	1.35	0.23	-	-	-	-
FRB	-	-	-	-	1.82	0.19	1.78	0.16
FRT	-	-	-	-	-	-	1.92	0.22
FRU	-	-	-	-	-	-	1.54	0.12
FSJ	2.14	0.39	1.55	0.13	1.64	0.28	-	-
FUR	1.52	0.42	1.54	0.31	1.41	0.25	-	-
GAR	-	-	-	-	-	-	1.59	0.29
GBA	1.26	0.20	-	-	*1.18	0.19	*0.87	0.30
GDH	1.67	0.25	1.43	0.34	1.49	0.36	1.48	0.26
GEO	2.14	0.35	-	-	-	-	-	-
GIL	*0.94	0.23	*0.94	0.25	*1.13	0.28	-	-
GOL	*0.67	0.23	*0.89	0.27	*0.97	0.24	*0.91	0.24
GRE	1.76	0.24	-	-	-	-	-	-
GRF	-	-	1.53	0.19	1.47	0.23	1.24	0.25
GRM	-	-	1.46	0.22	1.61	0.17	-	-
GRR	-	-	-	-	1.33	0.22	1.36	0.26
GRS	-	-	-	-	-	-	1.54	0.05
GUA	-	-	2.46	0.40	2.17	0.22	2.28	0.18
GWC	1.81	0.11	2.00	0.19	-	-	-	-
HAU	-	-	-	-	*1.18	0.18	*1.10	0.21
HDM	-	-	-	-	1.34	0.27	1.54	0.32
HFS	-	-	*0.69	0.24	*0.77	0.22	*0.79	0.23
HNR	-	-	2.00	0.27	-	-	-	-
HYB	1.38	0.15	1.55	0.21	1.54	0.21	1.41	0.17
ILG	*0.98	0.35	-	-	-	-	-	-
ILT	-	-	-	-	-	-	1.36	0.19
INK	-	-	1.58	0.12	1.53	0.10	1.55	0.13
IPM	-	-	-	-	-	-	1.55	0.15
IRK	-	-	-	-	-	-	1.24	0.19
ISQ	-	-	-	-	-	-	1.98	0.19
JAY	-	-	-	-	-	-	1.81	0.15

	1964-69		1970-73		1974-77		1978-81	
	g	ν	g	ν	g	ν	g	ν
JCT	-	-	*1.07	0.18	*1.18	0.30	*1.02	0.20
JER	1.68	0.30	-	-	-	-	-	-
JOS	-	-	-	-	1.45	0.28	1.30	0.23
KBL	1.22	0.28	*1.04	0.17	-	-	-	-
KBS	1.31	0.19	1.45	0.15	1.64	0.21	1.51	0.18
KEV	1.22	0.16	1.26	0.14	*1.18	0.13	1.20	0.13
KGM	-	-	-	-	-	-	2.18	0.17
KHC	1.26	0.20	*1.16	0.16	*1.04	0.16	*1.16	0.31
KHE	-	-	-	-	-	-	1.71	0.24
KIP	2.13	0.25	-	-	-	-	-	-
KIR	-	-	-	-	1.81	0.11	1.83	0.11
KJF	-	-	*1.13	0.14	*1.10	0.10	*1.19	0.12
KJN	*1.06	0.17	*1.05	0.14	-	-	-	-
KKM	-	-	-	-	-	-	1.93	0.19
KLG	1.41	0.30	2.05	0.31	2.32	0.28	-	-
KNA	-	-	-	-	2.31	0.29	1.92	0.27
KOD	1.35	0.21	1.61	0.17	1.56	0.20	-	-
KON	1.34	0.18	1.37	0.16	1.38	0.17	-	-
KRA	1.42	0.16	1.54	0.18	1.49	0.14	1.53	0.10
KRI	-	-	-	-	-	-	*0.76	0.05
KRK	1.62	0.16	-	-	-	-	-	-
KRL	2.37	0.22	-	-	-	-	-	-
KRP	-	-	1.79	0.17	1.97	0.19	1.87	0.18
KRR	*0.66	0.16	*0.72	0.14	*0.83	0.06	-	-
KSR	-	-	-	-	-	-	1.22	0.21
KTG	1.56	0.28	1.33	0.35	*1.12	0.28	1.21	0.22
LAO	*0.54	0.27	*0.23	0.24	*0.14	0.13	-	-
LBF	-	-	-	-	*0.96	0.19	*1.00	0.24
LEM	-	-	-	-	-	-	1.49	0.17
LFF	-	-	-	-	1.27	0.20	1.31	0.24
LGP	-	-	-	-	-	-	2.20	0.11
LHC	-	-	-	-	1.79	0.08	1.89	0.15
LHN	1.35	0.19	-	-	-	-	-	-
LJU	1.59	0.20	1.68	0.22	1.74	0.19	-	-
LMR	-	-	-	-	1.45	0.26	1.44	0.31
LON	*1.16	0.30	*1.18	0.23	*1.14	0.14	-	-
LOR	-	-	1.46	0.40	*1.04	0.21	*1.02	0.24
LPA	1.93	0.21	-	-	-	-	-	-
LPB	*1.19	0.25	-	-	1.41	0.22	1.45	0.28
LPF	-	-	-	-	1.21	0.21	1.31	0.26
LPO	-	-	-	-	1.26	0.22	1.24	0.27
LPS	1.35	0.21	1.21	0.16	1.33	0.19	-	-
LRG	-	-	-	-	1.45	0.25	1.58	0.32
LSF	-	-	-	-	1.22	0.21	*1.20	0.25
MAT	-	-	-	-	1.42	0.31	1.30	0.22
MBC	1.30	0.18	1.43	0.14	*0.78	0.22	*0.71	0.26
MBL	-	-	-	-	2.00	0.30	1.95	0.36
MEK	-	-	-	-	2.43	0.44	1.78	0.30
MFF	-	-	-	-	1.23	0.19	1.29	0.28
MHC	2.04	0.28	-	-	-	-	-	-
MIM	-	-	-	-	-	-	1.26	0.26
MIR	-	-	-	-	-	-	1.77	0.22
MJZ	-	-	2.15	0.13	-	-	-	-
MNG	-	-	1.68	0.17	1.64	0.26	-	-
MNT	-	-	1.81	0.17	1.91	0.21	-	-
MOS	-	-	-	-	-	-	1.93	0.20
MOX	1.21	0.20	*1.06	0.13	*1.10	0.13	1.21	0.13

	1964-69		1970-73		1974-77		1978-81	
	g	ν	g	ν	g	ν	g	ν
MOY	-	-	-	-	-	-	1.33	0.14
MSZ	-	-	1.72	0.17	2.08	0.24	-	-
MTD	-	-	*0.80	0.10	*0.90	0.09	*0.79	0.07
MUN	1.68	0.24	1.87	0.24	2.08	0.31	2.29	0.47
MWI	2.05	0.12	-	-	-	-	-	-
MZF	-	-	-	-	-	-	*1.10	0.23
NAI	1.50	0.25	*0.96	0.05	1.43	0.19	1.51	0.21
NAU	-	-	-	-	-	-	1.56	0.27
NAO	-	-	*0.34	0.22	*0.34	0.28	-	-
NBZ	-	-	-	-	-	-	*0.37	0.26
NCS	1.26	0.16	-	-	-	-	-	-
NDI	1.65	0.24	1.88	0.28	1.79	0.24	1.84	0.33
NEW	1.28	0.21	*1.17	0.21	1.43	0.31	1.45	0.33
NIE	*1.20	0.19	*1.07	0.14	*1.01	0.05	-	-
NOR	*1.05	0.19	*0.93	0.16	-	-	-	-
NP-	*0.86	0.26	-	-	-	-	-	-
NRI	-	-	-	-	-	-	*0.98	0.16
NUR	*1.19	0.18	1.26	0.15	*1.13	0.11	*1.19	0.12
NVL	-	-	-	-	-	-	1.70	0.31
NVS	-	-	-	-	-	-	1.52	0.29
NWAO	-	-	-	-	1.91	0.32	1.54	0.29
OBN	-	-	-	-	-	-	1.48	0.20
OIC	-	-	1.29	0.24	1.67	0.33	-	-
OIS	1.67	0.34	1.70	0.27	-	-	-	-
OTP	-	-	-	-	-	-	2.11	0.24
OTT	-	-	-	-	1.39	0.16	1.39	0.15
PAE	-	-	-	-	1.84	0.31	1.80	0.21
PAS	-	-	-	-	-	-	2.19	0.21
PCT	-	-	-	-	-	-	1.35	0.28
PET	-	-	-	-	-	-	1.75	0.23
PLP	-	-	-	-	-	-	1.86	0.29
PLV	2.43	0.24	-	-	-	-	-	-
PMG	1.45	0.18	1.62	0.17	1.79	0.20	1.93	0.23
PMO	-	-	-	-	1.76	0.31	1.68	0.26
PMR	*1.06	0.22	*1.08	0.26	1.22	0.34	*1.15	0.28
PNT	-	-	1.40	0.12	*1.19	0.17	1.21	0.14
POO	1.33	0.20	1.56	0.20	1.61	0.19	1.65	0.19
PPI	-	-	-	-	-	-	1.65	0.17
PPN	-	-	1.57	0.25	1.61	0.27	1.61	0.18
PPT	-	-	1.84	0.29	1.89	0.28	1.90	0.22
PRA	2.36	0.21	1.54	0.12	1.52	0.09	-	-
PRE	*1.16	0.23	*0.92	0.12	*0.93	0.06	1.30	0.23
PRU	1.24	0.14	1.27	0.12	1.39	0.21	1.33	0.17
PRZ	-	-	-	-	-	-	1.59	0.23
PSI	-	-	-	-	-	-	1.26	0.15
PTO	2.07	0.31	-	-	-	-	-	-
PUL	-	-	-	-	-	-	1.94	0.21
QUE	1.65	0.39	1.30	0.21	-	-	-	-
RAB	1.72	0.18	1.84	0.26	-	-	-	-
RCD	1.64	0.19	-	-	-	-	-	-
RES	1.50	0.15	1.54	0.15	*0.80	0.18	*0.77	0.12
RIV	2.06	0.23	2.01	0.24	1.92	0.24	-	-
RJF	-	-	-	-	1.28	0.24	*1.10	0.21
RKT	-	-	-	-	1.85	0.30	1.79	0.21
ROL	-	-	1.30	0.24	-	-	-	-
RUV	-	-	-	-	1.72	0.29	1.74	0.27
SAM	-	-	-	-	-	-	2.26	0.23

	1964-69		1970-73		1974-77		1978-81	
	g	ν	g	ν	g	ν	g	ν
SCH	-	-	1.93	0.17	1.92	0.21	1.56	0.25
SDV	-	-	-	-	-	-	1.84	0.14
SEO	1.47	0.21	-	-	-	-	-	-
SES	-	-	1.65	0.16	1.75	0.15	1.80	0.17
SEY	-	-	-	-	-	-	1.47	0.17
SFA	-	-	2.12	0.13	2.09	0.22	-	-
SHK	1.63	0.26	1.78	0.22	1.88	0.17	2.04	0.16
SHL	1.22	0.23	1.75	0.11	-	-	-	-
SJG	1.43	0.26	1.56	0.22	-	-	-	-
SMF	-	-	-	-	-	-	*1.03	0.21
SNA	1.47	0.29	-	-	-	-	-	-
SOC	-	-	-	-	-	-	2.12	0.29
SOP	-	-	-	-	1.62	0.25	1.43	0.23
SPA	1.95	0.36	1.73	0.36	1.22	0.30	*1.05	0.26
SPF	-	-	-	-	1.39	0.24	-	-
SPO	1.70	0.25	-	-	-	-	-	-
SSC	-	-	-	-	1.31	0.25	1.28	0.24
SSF	-	-	-	-	*0.97	0.18	*1.02	0.23
STU	1.68	0.28	1.86	0.22	1.82	0.22	-	-
SVE	-	-	-	-	-	-	1.66	0.21
SVI	1.93	0.16	-	-	-	-	-	-
SVT	1.72	0.14	-	-	-	-	-	-
TAN	-	-	2.05	0.19	-	-	-	-
TAS	-	-	-	-	-	-	1.74	0.12
TCF	-	-	-	-	*1.00	0.20	*1.09	0.26
TFO	*0.20	0.20	-	-	-	-	-	-
TIK	-	-	-	-	-	-	*1.16	0.25
TLG	-	-	-	-	-	-	*1.06	0.25
TOL	-	-	1.85	0.26	-	-	-	-
TOO	1.86	0.31	-	-	-	-	-	-
TPT	-	-	1.68	0.25	1.68	0.28	1.67	0.25
TRN	1.55	0.19	1.56	0.15	1.57	0.15	1.67	0.18
TRO	1.41	0.20	1.44	0.20	-	-	-	-
TRT	-	-	-	-	-	-	1.91	0.20
TSI	-	-	-	-	-	-	2.49	0.23
TSK	1.48	0.35	1.28	0.25	-	-	-	-
TUC	*1.08	0.20	*1.17	0.13	*1.13	0.26	-	-
TUL	-	-	1.24	0.30	*1.11	0.27	*1.06	0.25
TVO	-	-	1.78	0.25	1.87	0.25	1.89	0.21
UBO	*0.34	0.20	*0.46	0.29	-	-	-	-
UCT	-	-	-	-	1.35	0.26	1.42	0.23
UPP	-	-	-	-	-	-	1.83	0.11
UZH	-	-	-	-	-	-	*1.18	0.18
VAH	-	-	1.64	0.25	1.67	0.31	1.65	0.26
VAL	2.30	0.29	2.17	0.28	2.07	0.23	2.09	0.29
VIE	-	-	2.17	0.19	2.09	0.31	-	-
VLA	-	-	-	-	-	-	2.21	0.29
WIN	1.32	0.27	*0.93	0.10	*0.93	0.06	-	-
WMO	*0.40	0.14	-	-	-	-	-	-
WRA	-	-	-	-	-	-	*0.63	0.30
YAK	-	-	-	-	-	-	1.86	0.24
YKC	-	-	1.75	0.15	*1.15	0.20	1.24	0.24
YSS	-	-	-	-	-	-	1.56	0.22
ZAK	-	-	-	-	-	-	*0.87	0.19
ZUL	-	-	-	-	1.38	0.20	1.50	0.18

TABLE 2. Station Amplitude Terms (S), Station Magnitude Standard Deviation (σ) and Non-Operation Probability (P_a) for the Four Time Periods Used in this Study.

		1964-69				1970-73				1974-77				1978-81			
	$\overline{S}$	S	+OR-	SD	PA	S	+OR-	SD	PA	S	+OR-	SD	PA	S	+OR-	SD	PA
ABQ	-0.38	-	-	-	-	-	-	-	-	-0.38	0.04	0.39	0.24	-	-	-	-
ABU	0.31	0.30	0.06	0.51	0.16	-	-	-	-	-	-	-	-	0.31	0.04	0.32	0.40
AD-	-0.15	-0.15	0.11	0.45	0.04	-	-	-	-	-	-	-	-	-	-	-	-
ADE	0.45	-	-	-	-	-	-	-	-	0.45	0.04	0.44	0.13	0.44	0.04	0.46	0.04
ADK	0.07	-	-	-	-	0.07	0.07	0.35	0.39	-	-	-	-	-	-	-	-
AFR	-0.05	-	-	-	-	-	-	-	-	-0.04	0.03	0.33	0.11	-0.07	0.04	0.33	0.44
AKU	-0.07	-	-	-	-	-	-	-	-	-	-	-	-	-0.07	0.03	0.31	0.12
ALE	-0.10	-0.08	0.02	0.31	0.04	-0.12	0.03	0.31	0.06	-0.07	0.02	0.31	0.21	-0.16	0.03	0.34	0.28
ALQ	-0.26	-0.33	0.03	0.38	0.10	-0.17	0.03	0.32	0.19	-0.21	0.04	0.38	0.22	-0.34	0.03	0.36	0.04
AMN	-0.14	-	-	-	-	-	-	-	-	-	-	-	-	-0.14	0.07	0.43	0.43
ANG	0.14	0.15	0.10	0.40	0.47	-	-	-	-	-	-	-	-	-	-	-	-
ANP	0.32	0.32	0.04	0.40	0.28	-	-	-	-	-	-	-	-	-	-	-	-
ANR	0.57	-	-	-	-	-	-	-	-	-	-	-	-	0.57	0.03	0.32	0.09
APA	-0.07	-	-	-	-	-	-	-	-	-	-	-	-	-0.06	0.03	0.31	0.09
APT	-0.16	-	-	-	-	-	-	-	-	-0.16	0.04	0.34	0.05	-	-	-	-
ARU	0.42	-	-	-	-	-	-	-	-	-	-	-	-	0.42	0.03	0.29	0.09
ASH	0.38	-	-	-	-	-	-	-	-	-	-	-	-	0.38	0.09	0.47	0.25
ASP	0.00	-	-	-	-	-0.06	0.01	0.33	0.02	-0.16	0.03	0.39	0.03	0.17	0.02	0.34	0.07
AVF	-0.02	-	-	-	-	-	-	-	-	-	-	-	-	-0.02	0.02	0.27	0.05
BAG	0.06	-0.22	0.07	0.56	0.03	0.05	0.06	0.34	0.06	0.12	0.04	0.38	0.08	0.17	0.04	0.34	0.10
BDT	-0.13	-	-	-	-	-	-	-	-	-	-	-	-	-0.13	0.03	0.44	0.05
BDW	-0.38	-	-	-	-	-	-	-	-	-	-	-	-	-0.38	0.03	0.39	0.11
BER	-0.10	-	-	-	-	-0.10	0.05	0.26	0.21	-	-	-	-	-	-	-	-
BHA	-0.42	-0.35	0.03	0.33	0.09	-0.49	0.04	0.38	0.21	-0.44	0.03	0.29	0.33	-	-	-	-
BKR	0.37	-	-	-	-	-	-	-	-	-	-	-	-	0.37	0.04	0.35	0.29
BKS	0.02	0.18	0.03	0.36	0.02	0.02	0.04	0.37	0.06	-0.05	0.03	0.41	0.04	-0.03	0.02	0.35	0.07
BLA	-0.24	-0.24	0.05	0.51	0.10	-	-	-	-	-	-	-	-	-	-	-	-
BMN	-0.29	-	-	-	-	-	-	-	-	-	-	-	-	-0.28	0.03	0.39	0.17
BMO	-0.27	-0.30	0.02	0.36	0.05	-0.19	0.02	0.38	0.01	-0.38	0.04	0.42	0.08	-	-	-	-
BNG	-0.29	-	-	-	-	-0.56	0.05	0.50	0.17	-0.25	0.04	0.43	0.25	-0.11	0.04	0.41	0.33
BNS	0.20	0.19	0.02	0.27	0.03	0.20	0.03	0.32	0.05	-	-	-	-	-	-	-	-
BOD	-0.00	-	-	-	-	-	-	-	-	-	-	-	-	-0.00	0.04	0.38	0.13
BOZ	-0.15	-0.15	0.03	0.31	0.16	-	-	-	-	-	-	-	-	-	-	-	-
BRG	0.00	-	-	-	-	-0.02	0.03	0.31	0.10	0.07	0.02	0.27	0.02	-0.04	0.02	0.28	0.02
BSF	-0.03	-	-	-	-	-	-	-	-	-0.05	0.03	0.21	0.14	-0.02	0.02	0.23	0.05
BUD	-0.11	-	-	-	-	-	-	-	-	-0.16	0.06	0.47	0.05	-0.07	0.05	0.42	0.09
BUH	-0.04	-0.03	0.05	0.47	0.04	-	-	-	-	-	-	-	-	-	-	-	-
BUL	-0.18	-0.17	0.02	0.27	0.05	-0.15	0.03	0.33	0.01	-0.17	0.02	0.32	0.01	-0.20	0.02	0.27	0.01
CAN	-0.10	-0.18	0.03	0.38	0.13	0.01	0.04	0.32	0.10	-	-	-	-	-	-	-	-
CAR	-0.03	-0.03	0.03	0.35	0.06	-0.03	0.01	0.31	0.02	-0.03	0.04	0.39	0.03	-0.07	0.07	0.50	0.03
CBM	-0.49	-	-	-	-	-	-	-	-	-	-	-	-	-0.49	0.09	0.50	0.29

The overall value $\overline{S}$ in column 2 is determined from the other values as described in appendix B.

		1964-69				1970-73				1974-77				1978-81			
	$\bar{S}$	S	+OR-	SD	PA	S	+OR-	SD	PA	S	+OR-	SD	PA	S	+OR-	SD	PA
CDF	-0.06	-	-	-	-	-	-	-	-	-0.05	0.03	0.25	0.16	-0.06	0.02	0.28	0.09
CHG	-0.07	-0.19	0.10	0.42	0.78	-	-	-	-	-0.13	0.06	0.37	0.56	-0.02	0.02	0.33	0.08
CIR	-0.42	-0.30	0.04	0.28	0.15	-0.42	0.03	0.33	0.07	-0.41	0.03	0.32	0.22	-0.51	0.03	0.26	0.18
CLK	-0.51	-0.56	0.03	0.32	0.18	-0.53	0.03	0.31	0.12	-0.48	0.04	0.33	0.18	-0.47	0.02	0.27	0.13
CLL	0.17	0.35	0.03	0.34	0.02	0.07	0.03	0.35	0.02	0.12	0.03	0.36	0.01	0.15	0.02	0.28	0.00
CMC	0.07	0.07	0.03	0.31	0.08	-	-	-	-	-	-	-	-	-	-	-	-
CNN	0.11	0.11	0.04	0.35	0.32	-	-	-	-	-	-	-	-	-	-	-	-
COL	0.05	-0.03	0.02	0.36	0.04	0.14	0.03	0.35	0.07	0.05	0.03	0.35	0.08	0.08	0.03	0.38	0.15
COP	0.26	0.29	0.02	0.32	0.07	0.18	0.03	0.27	0.11	0.23	0.03	0.34	0.03	0.29	0.02	0.22	0.14
CPO	-0.13	-0.16	0.02	0.34	0.06	-0.07	0.03	0.32	0.09	-0.15	0.04	0.34	0.06	-	-	-	-
CTA	-0.10	-	-	-	-	-	-	-	-	-	-	-	-	-0.10	0.05	0.42	0.34
CVF	-0.04	-	-	-	-	-	-	-	-	0.00	0.05	0.32	0.48	-0.06	0.03	0.31	0.35
DAG	-0.05	-	-	-	-	-	-	-	-	-0.10	0.03	0.40	0.04	-0.02	0.02	0.32	0.06
DAR	-0.04	-	-	-	-	-0.03	0.06	0.39	0.22	-	-	-	-	-	-	-	-
DBN	0.74	0.74	0.04	0.27	0.44	-	-	-	-	-	-	-	-	-	-	-	-
DCN	0.32	-	-	-	-	-	-	-	-	-	-	-	-	0.32	0.02	0.24	0.15
DIX	-0.21	-	-	-	-	-	-	-	-	-	-	-	-	-0.21	0.03	0.34	0.12
DKM	0.18	-	-	-	-	-	-	-	-	-	-	-	-	0.18	0.03	0.25	0.19
DLE	0.26	-	-	-	-	-	-	-	-	-	-	-	-	0.26	0.03	0.30	0.07
DMU	0.28	-	-	-	-	-	-	-	-	-	-	-	-	0.28	0.03	0.27	0.06
DOM	-0.22	-0.22	0.12	0.40	0.46	-	-	-	-	-	-	-	-	-	-	-	-
DUG	-0.21	-0.24	0.03	0.42	0.15	-0.22	0.03	0.34	0.22	-0.17	0.03	0.34	0.15	-	-	-	-
EAU	0.02	-	-	-	-	-	-	-	-	-0.04	0.04	0.37	0.19	0.06	0.03	0.33	0.25
EBH	-0.02	-	-	-	-	-	-	-	-	-0.07	0.03	0.34	0.07	0.03	0.03	0.32	0.24
EBL	-0.13	-	-	-	-	-	-	-	-	-0.16	0.03	0.32	0.16	-0.10	0.03	0.30	0.27
ECP	0.18	-	-	-	-	-	-	-	-	-	-	-	-	0.18	0.02	0.32	0.05
EDI	-0.18	-	-	-	-	-	-	-	-	-0.18	0.04	0.43	0.19	-0.18	0.04	0.31	0.47
EDM	0.28	0.28	0.04	0.36	0.01	0.25	0.02	0.28	0.06	0.26	0.03	0.32	0.08	0.32	0.02	0.26	0.36
EGL	-0.11	-	-	-	-	-	-	-	-	-0.15	0.03	0.36	0.04	-0.07	0.03	0.32	0.29
EKA	-0.10	-0.09	0.03	0.36	0.07	-0.05	0.04	0.28	0.18	-0.14	0.02	0.29	0.03	-0.07	0.03	0.31	0.11
ELO	-0.12	-	-	-	-	-	-	-	-	-0.19	0.05	0.36	0.21	-0.08	0.03	0.30	0.28
ELT	0.21	-	-	-	-	-	-	-	-	-	-	-	-	0.21	0.03	0.37	0.11
EMM	-0.08	-	-	-	-	-	-	-	-	-	-	-	-	-0.08	0.05	0.35	0.62
EPF	0.04	-	-	-	-	-	-	-	-	-	-	-	-	0.04	0.04	0.38	0.18
ESK	0.13	0.28	0.03	0.31	0.05	-	-	-	-	0.05	0.02	0.37	0.10	0.11	0.02	0.20	0.30
EUR	-0.48	-0.21	0.03	0.42	0.13	-0.54	0.03	0.44	0.03	-0.65	0.04	0.53	0.03	-0.53	0.02	0.52	0.05
FBA	-0.03	-	-	-	-	-	-	-	-	-	-	-	-	-0.03	0.03	0.37	0.12
FBC	0.12	0.15	0.02	0.20	0.20	0.07	0.04	0.32	0.22	-	-	-	-	-	-	-	-
FCC	0.04	0.01	0.03	0.23	0.03	0.08	0.03	0.22	0.20	0.14	0.03	0.25	0.32	-0.23	0.06	0.52	0.53
FEL	-0.63	-0.63	0.22	0.60	0.13	-	-	-	-	-	-	-	-	-	-	-	-
FFC	0.04	-	-	-	-	0.02	0.03	0.24	0.09	0.06	0.02	0.30	0.15	0.02	0.02	0.30	0.29

	$\bar{S}$	1964-69 S	1964-69 +OR-	1964-69 SD	1964-69 PA	1970-73 S	1970-73 +OR-	1970-73 SD	1970-73 PA	1974-77 S	1974-77 +OR-	1974-77 SD	1974-77 PA	1978-81 S	1978-81 +OR-	1978-81 SD	1978-81 PA
FLN	0.14	-	-	-	-	-	-	-	-	0.13	0.03	0.25	0.27	0.15	0.02	0.23	0.07
FLO	0.27	-	-	-	-	0.27	0.05	0.34	0.34	-	-	-	-	-	-	-	-
FRB	0.14	-	-	-	-	-	-	-	-	0.11	0.03	0.28	0.20	0.16	0.03	0.25	0.35
FRT	-0.17	-	-	-	-	-	-	-	-	-	-	-	-	-0.17	0.06	0.38	0.47
FRU	0.37	-	-	-	-	-	-	-	-	-	-	-	-	0.37	0.03	0.33	0.18
FSJ	-0.11	-0.09	0.04	0.36	0.10	-0.12	0.04	0.29	0.29	-0.12	0.04	0.27	0.07	-	-	-	-
FUR	-0.02	-0.10	0.02	0.37	0.04	0.07	0.03	0.40	0.03	0.01	0.02	0.38	0.04	-	-	-	-
GAR	0.33	-	-	-	-	-	-	-	-	-	-	-	-	0.33	0.04	0.34	0.20
GBA	-0.16	-0.15	0.04	0.34	0.02	-	-	-	-	-0.01	0.05	0.40	0.07	-0.22	0.01	0.46	0.02
GDH	-0.15	-0.04	0.03	0.33	0.08	-0.22	0.03	0.34	0.03	-0.20	0.02	0.28	0.06	-0.12	0.02	0.26	0.16
GEO	-0.05	-0.05	0.06	0.39	0.32	-	-	-	-	-	-	-	-	-	-	-	-
GIL	-0.05	0.02	0.04	0.35	0.05	-0.05	0.03	0.41	0.05	-0.10	0.03	0.39	0.05	-	-	-	-
GOL	-0.40	-0.58	0.05	0.48	0.08	-0.33	0.04	0.47	0.07	-0.37	0.06	0.44	0.24	-0.33	0.04	0.39	0.26
GRE	-0.25	-0.25	0.09	0.47	0.53	-	-	-	-	-	-	-	-	-	-	-	-
GRF	0.24	-	-	-	-	0.25	0.03	0.31	0.12	0.25	0.03	0.33	0.10	0.22	0.03	0.36	0.09
GRM	-0.02	-	-	-	-	-0.08	0.04	0.34	0.22	0.10	0.07	0.30	0.65	-	-	-	-
GRR	0.17	-	-	-	-	-	-	-	-	0.17	0.03	0.21	0.18	0.16	0.02	0.22	0.08
GRS	0.08	-	-	-	-	-	-	-	-	-	-	-	-	0.08	0.06	0.37	0.37
GUA	0.15	-	-	-	-	-0.35	0.13	0.55	0.25	0.13	0.08	0.48	0.36	0.34	0.05	0.33	0.53
GWC	0.18	0.19	0.03	0.25	0.04	0.18	0.04	0.26	0.05	-	-	-	-	-	-	-	-
HAU	0.00	-	-	-	-	-	-	-	-	0.01	0.02	0.21	0.16	-0.00	0.02	0.22	0.06
HDM	-0.34	-	-	-	-	-	-	-	-	-0.26	0.04	0.35	0.10	-0.50	0.08	0.50	0.53
HFS	0.11	-	-	-	-	-0.05	0.05	0.54	0.01	0.17	0.03	0.43	0.05	0.14	0.03	0.45	0.04
HNR	-0.18	-	-	-	-	-0.18	0.17	0.46	0.21	-	-	-	-	-	-	-	-
HYB	0.15	-0.15	0.04	0.42	0.05	0.18	0.03	0.34	0.03	0.24	0.02	0.30	0.06	0.19	0.02	0.28	0.02
ILG	0.14	0.14	0.08	0.49	0.24	-	-	-	-	-	-	-	-	-	-	-	-
ILT	0.06	-	-	-	-	-	-	-	-	-	-	-	-	0.06	0.03	0.36	0.14
INK	0.09	-	-	-	-	0.07	0.02	0.28	0.09	0.08	0.02	0.29	0.12	0.12	0.02	0.28	0.36
IPM	-0.02	-	-	-	-	-	-	-	-	-	-	-	-	-0.02	0.03	0.31	0.08
IRK	-0.04	-	-	-	-	-	-	-	-	-	-	-	-	-0.04	0.03	0.30	0.11
ISQ	0.23	-	-	-	-	-	-	-	-	-	-	-	-	0.23	0.06	0.26	0.36
JAY	-0.20	-	-	-	-	-	-	-	-	-	-	-	-	-0.20	0.08	0.39	0.17
JCT	-0.24	-	-	-	-	-0.24	0.04	0.32	0.56	-0.19	0.09	0.37	0.49	-0.25	0.04	0.35	0.25
JER	0.05	0.05	0.06	0.36	0.16	-	-	-	-	-	-	-	-	-	-	-	-
JOS	-0.07	-	-	-	-	-	-	-	-	-0.15	0.02	0.41	0.10	0.02	0.01	0.30	0.05
KBL	-0.13	-0.13	0.05	0.22	0.61	-0.12	0.06	0.33	0.59	-	-	-	-	-	-	-	-
KBS	-0.10	-0.13	0.04	0.28	0.17	-0.10	0.04	0.31	0.13	-0.05	0.05	0.35	0.10	-0.10	0.04	0.35	0.20
KEV	-0.12	-0.08	0.02	0.30	0.02	-0.17	0.03	0.32	0.04	-0.16	0.03	0.33	0.02	-0.03	0.04	0.59	0.01
KGM	0.21	-	-	-	-	-	-	-	-	-	-	-	-	0.21	0.03	0.27	0.25
KHC	0.07	0.13	0.02	0.29	0.04	0.14	0.02	0.27	0.02	-0.03	0.03	0.33	0.02	-0.00	0.03	0.29	0.01
KHE	0.33	-	-	-	-	-	-	-	-	-	-	-	-	0.33	0.03	0.34	0.20

	$\bar{S}$	1964-69 S	1964-69 +OR-	1964-69 SD	1964-69 PA	1970-73 S	1970-73 +OR-	1970-73 SD	1970-73 PA	1974-77 S	1974-77 +OR-	1974-77 SD	1974-77 PA	1978-81 S	1978-81 +OR-	1978-81 SD	1978-81 PA
KIP	-0.29	-0.29	0.09	0.59	0.05	-	-	-	-	-	-	-	-	-	-	-	-
KIR	0.55	-	-	-	-	-	-	-	-	0.56	0.04	0.33	0.03	0.54	0.02	0.29	0.03
KJF	0.04	-	-	-	-	-0.03	0.03	0.35	0.02	0.07	0.03	0.37	0.01	0.06	0.02	0.36	0.01
KJN	0.02	0.09	0.02	0.31	0.02	-0.08	0.03	0.35	0.07	-	-	-	-	-	-	-	-
KKM	0.04	-	-	-	-	-	-	-	-	-	-	-	-	0.04	0.05	0.36	0.41
KLG	-0.38	-0.62	0.05	0.52	0.03	-0.02	0.08	0.51	0.04	-0.29	0.20	0.57	0.04	-	-	-	-
KNA	0.15	-	-	-	-	-	-	-	-	0.40	0.10	0.36	0.53	0.01	0.06	0.34	0.62
KOD	-0.04	-0.13	0.03	0.32	0.17	0.06	0.03	0.31	0.18	-0.05	0.04	0.44	0.05	-	-	-	-
KON	-0.05	-0.04	0.03	0.36	0.09	-0.06	0.03	0.27	0.13	-0.04	0.04	0.29	0.15	-	-	-	-
KRA	0.14	0.03	0.03	0.40	0.03	0.08	0.03	0.30	0.03	0.17	0.02	0.32	0.01	0.27	0.03	0.39	0.01
KRI	-0.40	-	-	-	-	-	-	-	-	-	-	-	-	-0.40	0.02	0.27	0.06
KRK	0.01	0.01	0.04	0.33	0.09	-	-	-	-	-	-	-	-	-	-	-	-
KRL	0.29	0.29	0.05	0.48	0.03	-	-	-	-	-	-	-	-	-	-	-	-
KRP	0.27	-	-	-	-	0.41	0.06	0.38	0.26	0.13	0.11	0.52	0.21	0.17	0.07	0.41	0.32
KRR	-0.39	-0.29	0.04	0.35	0.10	-0.42	0.03	0.35	0.04	-0.45	0.03	0.29	0.16	-	-	-	-
KSR	-0.52	-	-	-	-	-	-	-	-	-	-	-	-	-0.52	0.08	0.46	0.03
KTG	-0.11	0.00	0.02	0.28	0.07	-0.10	0.02	0.29	0.02	-0.20	0.02	0.32	0.04	-0.15	0.03	0.32	0.06
LAO	-0.23	-0.58	0.04	0.57	0.07	-0.17	0.04	0.57	0.28	0.00	0.03	0.34	0.15	-	-	-	-
LBF	-0.09	-	-	-	-	-	-	-	-	-0.08	0.03	0.24	0.15	-0.10	0.02	0.23	0.24
LEM	-0.16	-	-	-	-	-	-	-	-	-	-	-	-	-0.16	0.06	0.50	0.28
LFF	0.14	-	-	-	-	-	-	-	-	0.14	0.03	0.20	0.30	0.13	0.02	0.22	0.06
LGP	0.26	-	-	-	-	-	-	-	-	-	-	-	-	0.26	0.12	0.47	0.51
LHC	0.16	-	-	-	-	-	-	-	-	0.17	0.03	0.24	0.25	0.15	0.03	0.28	0.33
LHN	-0.03	-0.03	0.04	0.32	0.11	-	-	-	-	-	-	-	-	-	-	-	-
LJU	0.20	0.06	0.02	0.31	0.07	0.20	0.03	0.32	0.01	0.39	0.03	0.26	0.05	-	-	-	-
LMR	0.05	-	-	-	-	-	-	-	-	0.11	0.03	0.23	0.31	0.01	0.02	0.28	0.13
LON	-0.50	-0.63	0.05	0.53	0.08	-0.41	0.03	0.34	0.09	-0.51	0.03	0.38	0.18	-	-	-	-
LOR	0.01	-	-	-	-	0.02	0.01	0.47	0.05	-0.01	0.03	0.30	0.09	0.01	0.02	0.28	0.05
LPA	0.24	0.24	0.06	0.37	0.17	-	-	-	-	-	-	-	-	-	-	-	-
LPB	0.02	-0.07	0.06	0.48	0.06	-	-	-	-	0.19	0.05	0.35	0.04	-0.04	0.04	0.37	0.05
LPF	0.11	-	-	-	-	-	-	-	-	0.06	0.03	0.24	0.31	0.14	0.02	0.21	0.11
LPO	0.07	-	-	-	-	-	-	-	-	0.07	0.03	0.26	0.26	0.07	0.02	0.23	0.10
LPS	-0.16	-0.16	0.05	0.40	0.34	-0.15	0.03	0.33	0.09	-0.18	0.06	0.29	0.16	-	-	-	-
LRG	0.10	-	-	-	-	-	-	-	-	0.10	0.03	0.26	0.33	0.10	0.02	0.25	0.13
LSF	-0.03	-	-	-	-	-	-	-	-	-0.03	0.04	0.25	0.39	-0.02	0.03	0.29	0.14
MAT	0.03	-	-	-	-	-	-	-	-	0.03	0.03	0.38	0.02	0.03	0.02	0.38	0.03
MBC	0.08	-0.08	0.03	0.38	0.03	0.18	0.04	0.31	0.25	0.12	0.02	0.31	0.17	0.08	0.02	0.33	0.31
MBL	-0.12	-	-	-	-	-	-	-	-	-0.15	0.09	0.31	0.30	-0.09	0.06	0.43	0.15
MEK	-0.05	-	-	-	-	-	-	-	-	0.10	0.13	0.38	0.57	-0.12	0.07	0.46	0.39
MFF	0.11	-	-	-	-	-	-	-	-	0.10	0.03	0.21	0.30	0.11	0.02	0.24	0.07
MHC	-0.02	-0.02	0.08	0.44	0.03	-	-	-	-	-	-	-	-	-	-	-	-

	$\bar{S}$	1964-69 S	+OR-	SD	PA	1970-73 S	+OR-	SD	PA	1974-77 S	+OR-	SD	PA	1978-81 S	+OR-	SD	PA
MIM	-0.32	-	-	-	-	-	-	-	-	-	-	-	-	-0.32	0.05	0.42	0.32
MIR	0.19	-	-	-	-	-	-	-	-	-	-	-	-	0.19	0.05	0.36	0.13
MJZ	0.63	-	-	-	-	0.63	0.06	0.29	0.61	-	-	-	-	-	-	-	-
MNG	0.12	-	-	-	-	0.23	0.06	0.34	0.57	-0.05	0.09	0.38	0.54	-	-	-	-
MNT	0.11	-	-	-	-	0.11	0.04	0.33	0.18	0.12	0.05	0.34	0.23	-	-	-	-
MOS	0.49	-	-	-	-	-	-	-	-	-	-	-	-	0.49	0.03	0.23	0.18
MOX	0.07	0.08	0.02	0.36	0.02	0.00	0.02	0.29	0.01	0.08	0.02	0.26	0.03	0.11	0.02	0.24	0.05
MOY	0.16	-	-	-	-	-	-	-	-	-	-	-	-	0.16	0.03	0.33	0.23
MSZ	0.25	-	-	-	-	0.25	0.06	0.28	0.72	0.24	0.09	0.36	0.60	-	-	-	-
MTD	-0.33	-	-	-	-	-0.30	0.03	0.31	0.26	-0.31	0.03	0.27	0.20	-0.37	0.02	0.25	0.23
MUN	-0.04	-0.09	0.04	0.41	0.08	0.13	0.05	0.37	0.30	-0.23	0.09	0.49	0.44	-0.01	0.05	0.36	0.08
MWI	-0.46	-0.46	0.23	0.68	0.11	-	-	-	-	-	-	-	-	-	-	-	-
MZF	0.02	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.02	0.23	0.12
NAI	-0.12	-0.15	0.04	0.45	0.04	-0.17	0.04	0.31	0.25	-0.01	0.05	0.42	0.36	-0.15	0.06	0.46	0.17
NAU	-0.18	-	-	-	-	-	-	-	-	-	-	-	-	-0.18	0.07	0.40	0.42
NAO	-0.08	-	-	-	-	-0.12	0.00	0.35	0.15	-0.12	0.05	0.39	0.06	-	-	-	-
NB2	-0.10	-	-	-	-	-	-	-	-	-	-	-	-	-0.09	0.03	0.35	0.15
NCS	-0.22	-0.22	0.06	0.29	0.16	-	-	-	-	-	-	-	-	-	-	-	-
NDI	0.18	0.19	0.02	0.41	0.05	0.17	0.04	0.41	0.05	0.21	0.03	0.35	0.01	0.15	0.01	0.43	0.05
NEW	-0.17	0.01	0.03	0.29	0.17	-0.15	0.03	0.27	0.05	-0.35	0.06	0.70	0.06	-0.32	0.04	0.34	0.02
NIE	-0.14	-0.21	0.06	0.47	0.02	-0.14	0.04	0.39	0.22	-0.08	0.04	0.40	0.28	-	-	-	-
NOR	-0.22	-0.21	0.03	0.40	0.03	-0.24	0.03	0.33	0.05	-	-	-	-	-	-	-	-
NP-	-0.13	-0.12	0.04	0.46	0.56	-	-	-	-	-	-	-	-	-	-	-	-
NRI	0.01	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.04	0.27	0.54
NUR	0.09	0.11	0.02	0.33	0.01	0.03	0.02	0.31	0.02	0.05	0.03	0.37	0.01	0.18	0.03	0.38	0.01
NVL	0.14	-	-	-	-	-	-	-	-	-	-	-	-	0.14	0.03	0.40	0.14
NVS	0.17	-	-	-	-	-	-	-	-	-	-	-	-	0.17	0.03	0.34	0.05
NWAO	-0.18	-	-	-	-	-	-	-	-	-0.17	0.14	0.45	0.27	-0.18	0.06	0.38	0.25
OBN	0.33	-	-	-	-	-	-	-	-	-	-	-	-	0.33	0.03	0.32	0.01
OIC	-0.58	-	-	-	-	-0.63	0.06	0.46	0.12	-0.52	0.06	0.52	0.06	-	-	-	-
OIS	-0.20	-0.20	0.06	0.44	0.07	-0.20	0.07	0.45	0.04	-	-	-	-	-	-	-	-
OTP	-0.08	-	-	-	-	-	-	-	-	-	-	-	-	-0.08	0.09	0.47	0.22
OTT	-0.11	-	-	-	-	-	-	-	-	-0.07	0.03	0.30	0.12	-0.16	0.03	0.31	0.16
PAE	-0.12	-	-	-	-	-	-	-	-	-0.11	0.03	0.35	0.19	-0.14	0.04	0.35	0.48
PAS	0.14	-	-	-	-	-	-	-	-	-	-	-	-	0.14	0.06	0.36	0.14
PCT	-0.42	-	-	-	-	-	-	-	-	-	-	-	-	-0.42	0.04	0.44	0.04
PET	0.14	-	-	-	-	-	-	-	-	-	-	-	-	0.14	0.05	0.39	0.24
PLP	-0.54	-	-	-	-	-	-	-	-	-	-	-	-	-0.54	0.11	0.63	0.25
PLV	0.19	0.19	0.09	0.38	0.51	-	-	-	-	-	-	-	-	-	-	-	-
PMG	0.00	-0.10	0.03	0.39	0.04	0.01	0.03	0.29	0.10	0.06	0.07	0.42	0.35	0.11	0.05	0.35	0.19
PMO	-0.03	-	-	-	-	-	-	-	-	0.06	0.03	0.38	0.16	-0.11	0.03	0.33	0.22

	$\bar{S}$	1964-69 S	+OR-	SD	PA	1970-73 S	+OR-	SD	PA	1974-77 S	+OR-	SD	PA	1978-81 S	+OR-	SD	PA
PMR	-0.08	0.00	0.03	0.31	0.06	-0.04	0.03	0.40	0.02	-0.14	0.02	0.39	0.03	-0.10	0.02	0.38	0.04
PNT	-0.00	-	-	-	-	0.01	0.02	0.27	0.08	0.01	0.02	0.30	0.20	-0.04	0.03	0.30	0.41
POO	0.01	-0.09	0.03	0.35	0.05	0.01	0.04	0.40	0.21	0.13	0.05	0.25	0.59	0.04	0.04	0.37	0.12
PPI	-0.20	-	-	-	-	-	-	-	-	-	-	-	-	-0.20	0.06	0.44	0.09
PPN	-0.25	-	-	-	-	-0.35	0.07	0.42	0.27	-0.21	0.03	0.32	0.23	-0.24	0.04	0.34	0.40
PPT	-0.03	-	-	-	-	-0.05	0.06	0.39	0.29	0.00	0.03	0.36	0.21	-0.05	0.04	0.36	0.46
PRA	0.28	0.60	0.04	0.31	0.12	0.18	0.05	0.41	0.02	-0.09	0.06	0.37	0.39	-	-	-	-
PRE	-0.27	-0.12	0.04	0.41	0.14	-0.48	0.05	0.51	0.02	-0.37	0.04	0.50	0.03	-0.15	0.04	0.36	0.16
PRU	0.03	0.02	0.02	0.27	0.03	0.07	0.02	0.26	0.02	0.07	0.02	0.29	0.01	-0.02	0.02	0.32	0.02
PRZ	0.29	-	-	-	-	-	-	-	-	-	-	-	-	0.29	0.03	0.35	0.14
PSI	-0.13	-	-	-	-	-	-	-	-	-	-	-	-	-0.13	0.03	0.36	0.13
PTO	-0.04	-0.04	0.05	0.39	0.33	-	-	-	-	-	-	-	-	-	-	-	-
PUL	0.32	-	-	-	-	-	-	-	-	-	-	-	-	0.32	0.03	0.24	0.15
QUE	-0.07	-0.11	0.05	0.51	0.06	0.00	0.09	0.49	0.24	-	-	-	-	-	-	-	-
RAB	-0.18	-0.25	0.06	0.57	0.02	-0.04	0.10	0.54	0.12	-	-	-	-	-	-	-	-
RCD	0.16	0.16	0.05	0.36	0.42	-	-	-	-	-	-	-	-	-	-	-	-
RES	-0.06	-0.12	0.03	0.35	0.03	0.00	0.05	0.42	0.20	0.01	0.02	0.33	0.18	-0.10	0.02	0.33	0.27
RIV	0.18	0.22	0.04	0.43	0.19	0.19	0.03	0.30	0.18	0.10	0.06	0.36	0.35	-	-	-	-
RJF	0.05	-	-	-	-	-	-	-	-	0.11	0.04	0.27	0.43	0.02	0.02	0.23	0.11
RKT	-0.29	-	-	-	-	-	-	-	-	-0.24	0.05	0.31	0.47	-0.36	0.07	0.38	0.54
ROL	0.14	-	-	-	-	0.14	0.05	0.35	0.27	-	-	-	-	-	-	-	-
RUV	-0.05	-	-	-	-	-	-	-	-	0.00	0.03	0.36	0.12	-0.08	0.02	0.30	0.19
SAM	0.53	-	-	-	-	-	-	-	-	-	-	-	-	0.53	0.09	0.31	0.62
SCH	0.04	-	-	-	-	0.03	0.04	0.33	0.11	0.08	0.04	0.30	0.25	0.02	0.03	0.29	0.38
SDV	-0.09	-	-	-	-	-	-	-	-	-	-	-	-	-0.09	0.08	0.39	0.09
SEO	0.19	0.19	0.12	0.32	0.86	-	-	-	-	-	-	-	-	-	-	-	-
SES	0.21	-	-	-	-	0.03	0.09	0.36	0.12	0.24	0.03	0.28	0.25	0.24	0.03	0.34	0.35
SEY	0.18	-	-	-	-	-	-	-	-	-	-	-	-	0.18	0.03	0.26	0.23
SFA	0.07	-	-	-	-	0.06	0.05	0.27	0.44	0.08	0.06	0.27	0.15	-	-	-	-
SHK	0.03	-0.21	0.08	0.44	0.22	-0.07	0.06	0.43	0.12	0.08	0.05	0.40	0.13	0.23	0.05	0.32	0.38
SHL	0.00	-0.07	0.04	0.31	0.22	0.13	0.07	0.35	0.35	-	-	-	-	-	-	-	-
SJG	0.02	-0.05	0.05	0.48	0.04	0.10	0.05	0.35	0.10	-	-	-	-	-	-	-	-
SMF	-0.00	-	-	-	-	-	-	-	-	-	-	-	-	-0.00	0.03	0.29	0.07
SNA	-0.12	-0.12	0.11	0.48	0.56	-	-	-	-	-	-	-	-	-	-	-	-
SOC	0.26	-	-	-	-	-	-	-	-	-	-	-	-	0.26	0.04	0.27	0.35
SOP	-0.11	-	-	-	-	-	-	-	-	-0.18	0.05	0.42	0.10	-0.04	0.05	0.42	0.22
SPA	0.16	0.21	0.05	0.34	0.11	0.14	0.03	0.30	0.16	0.18	0.03	0.35	0.23	0.12	0.03	0.40	0.12
SPF	0.07	-	-	-	-	-	-	-	-	0.07	0.03	0.22	0.27	-	-	-	-
SPO	-0.19	-0.19	0.09	0.51	0.04	-	-	-	-	-	-	-	-	-	-	-	-
SSC	0.11	-	-	-	-	-	-	-	-	0.09	0.03	0.22	0.15	0.12	0.02	0.20	0.09
SSF	-0.04	-	-	-	-	-	-	-	-	-0.05	0.03	0.21	0.11	-0.03	0.02	0.28	0.02

	$\bar{S}$	1964-69 S	1964-69 +OR-	1964-69 SD	1964-69 PA	1970-73 S	1970-73 +OR-	1970-73 SD	1970-73 PA	1974-77 S	1974-77 +OR-	1974-77 SD	1974-77 PA	1978-81 S	1978-81 +OR-	1978-81 SD	1978-81 PA
STU	0.17	0.18	0.03	0.39	0.04	0.23	0.03	0.36	0.22	0.10	0.03	0.32	0.17	-	-	-	-
SVE	0.37	-	-	-	-	-	-	-	-	-	-	-	-	0.37	0.04	0.31	0.15
SVI	-0.05	-0.05	0.07	0.34	0.45	-	-	-	-	-	-	-	-	-	-	-	-
SVT	-0.31	-0.31	0.13	0.47	0.36	-	-	-	-	-	-	-	-	-	-	-	-
TAN	0.34	-	-	-	-	0.34	0.03	0.34	0.06	-	-	-	-	-	-	-	-
TAS	0.50	-	-	-	-	-	-	-	-	-	-	-	-	0.50	0.04	0.37	0.10
TCF	-0.06	-	-	-	-	-	-	-	-	-0.06	0.03	0.23	0.13	-0.05	0.02	0.25	0.03
TFO	-0.32	-0.32	0.02	0.41	0.02	-	-	-	-	-	-	-	-	-	-	-	-
TIK	0.19	-	-	-	-	-	-	-	-	-	-	-	-	0.19	0.03	0.31	0.25
TLG	-0.18	-	-	-	-	-	-	-	-	-	-	-	-	-0.18	0.04	0.40	0.04
TOL	0.16	-	-	-	-	0.16	0.03	0.45	0.08	-	-	-	-	-	-	-	-
TOO	0.01	0.01	0.03	0.30	0.13	-	-	-	-	-	-	-	-	-	-	-	-
TPT	-0.06	-	-	-	-	-0.12	0.07	0.49	0.20	0.01	0.03	0.37	0.12	-0.09	0.03	0.30	0.25
TRN	-0.10	-0.10	0.03	0.35	0.04	-0.10	0.05	0.41	0.03	-0.09	0.05	0.39	0.06	-0.10	0.05	0.33	0.31
TRO	-0.05	-0.02	0.04	0.27	0.35	-0.07	0.03	0.31	0.09	-	-	-	-	-	-	-	-
TRT	-0.00	-	-	-	-	-	-	-	-	-	-	-	-	-0.00	0.04	0.37	0.36
TSI	0.31	-	-	-	-	-	-	-	-	-	-	-	-	0.31	0.10	0.39	0.51
TSK	-0.21	-0.15	0.01	0.47	0.04	-0.33	0.04	0.40	0.02	-	-	-	-	-	-	-	-
TUC	-0.23	-0.20	0.02	0.28	0.09	-0.18	0.03	0.29	0.07	-0.36	0.04	0.39	0.03	-	-	-	-
TUL	0.20	-	-	-	-	0.25	0.02	0.29	0.05	0.23	0.03	0.34	0.11	0.10	0.03	0.34	0.11
TVO	0.06	-	-	-	-	0.01	0.05	0.36	0.38	0.10	0.03	0.32	0.27	0.04	0.03	0.32	0.41
UBO	-0.13	-0.11	0.02	0.39	0.05	-0.17	0.04	0.44	0.01	-	-	-	-	-	-	-	-
UCT	-0.24	-	-	-	-	-	-	-	-	-0.22	0.04	0.32	0.10	-0.30	0.10	0.52	0.65
UPP	0.56	-	-	-	-	-	-	-	-	-	-	-	-	0.56	0.02	0.27	0.04
UZH	0.26	-	-	-	-	-	-	-	-	-	-	-	-	0.26	0.04	0.37	0.20
VAH	-0.10	-	-	-	-	-0.07	0.05	0.41	0.29	-0.06	0.03	0.37	0.08	-0.14	0.03	0.29	0.28
VAL	0.31	0.45	0.04	0.39	0.10	0.33	0.04	0.35	0.18	0.31	0.02	0.24	0.23	0.19	0.03	0.27	0.26
VIE	0.32	-	-	-	-	0.48	0.06	0.48	0.14	0.27	0.02	0.34	0.13	-	-	-	-
VLA	0.07	-	-	-	-	-	-	-	-	-	-	-	-	0.07	0.09	0.40	0.22
WIN	-0.47	-0.17	0.10	0.57	0.35	-0.47	0.05	0.53	0.03	-0.63	0.06	0.52	0.03	-	-	-	-
WMO	-0.21	-0.20	0.02	0.32	0.05	-	-	-	-	-	-	-	-	-	-	-	-
WRA	-0.27	-	-	-	-	-	-	-	-	-	-	-	-	-0.27	0.03	0.48	0.20
YAK	0.38	-	-	-	-	-	-	-	-	-	-	-	-	0.38	0.03	0.32	0.15
YKC	-0.09	-	-	-	-	-0.01	0.05	0.29	0.34	-0.09	0.03	0.38	0.21	-0.14	0.03	0.36	0.35
YSS	0.08	-	-	-	-	-	-	-	-	-	-	-	-	0.08	0.05	0.45	0.17
ZAK	0.09	-	-	-	-	-	-	-	-	-	-	-	-	0.09	0.03	0.28	0.11
ZUL	0.29	-	-	-	-	-	-	-	-	0.18	0.03	0.37	0.01	0.37	0.02	0.29	0.03

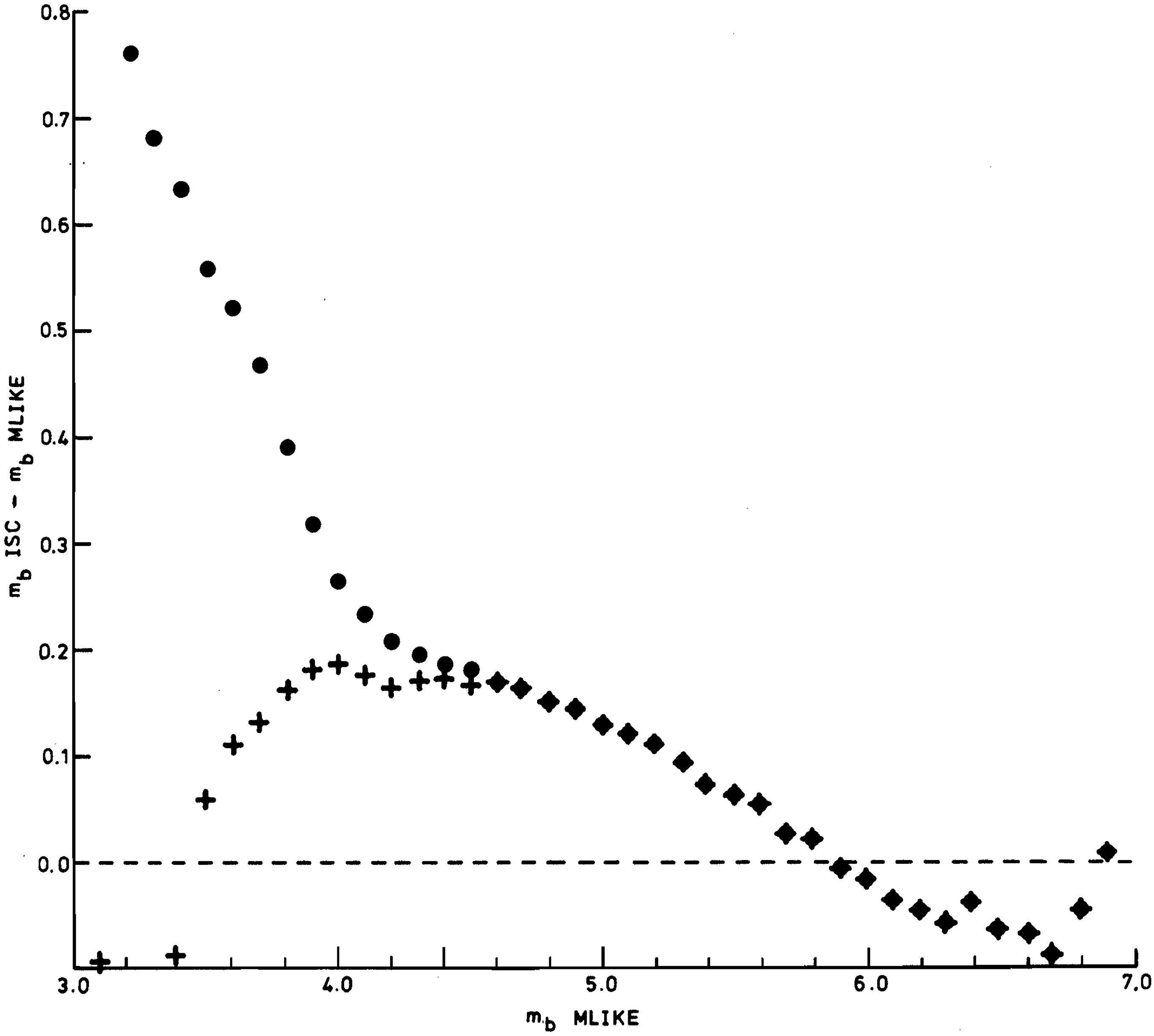

FIGURE 1. MEAN DIFFERENCE BETWEEN ISC MAGNITUDES AND RECOMPUTED MAGNITUDES AS A FUNCTION OF RECOMPUTED MAGNITUDE FOR THE PERIOD 1964-81.

Dots and crosses are for recomputed magnitude using the Christoffersson et al (11) and Ringdal (3) likelihood formulations respectively.

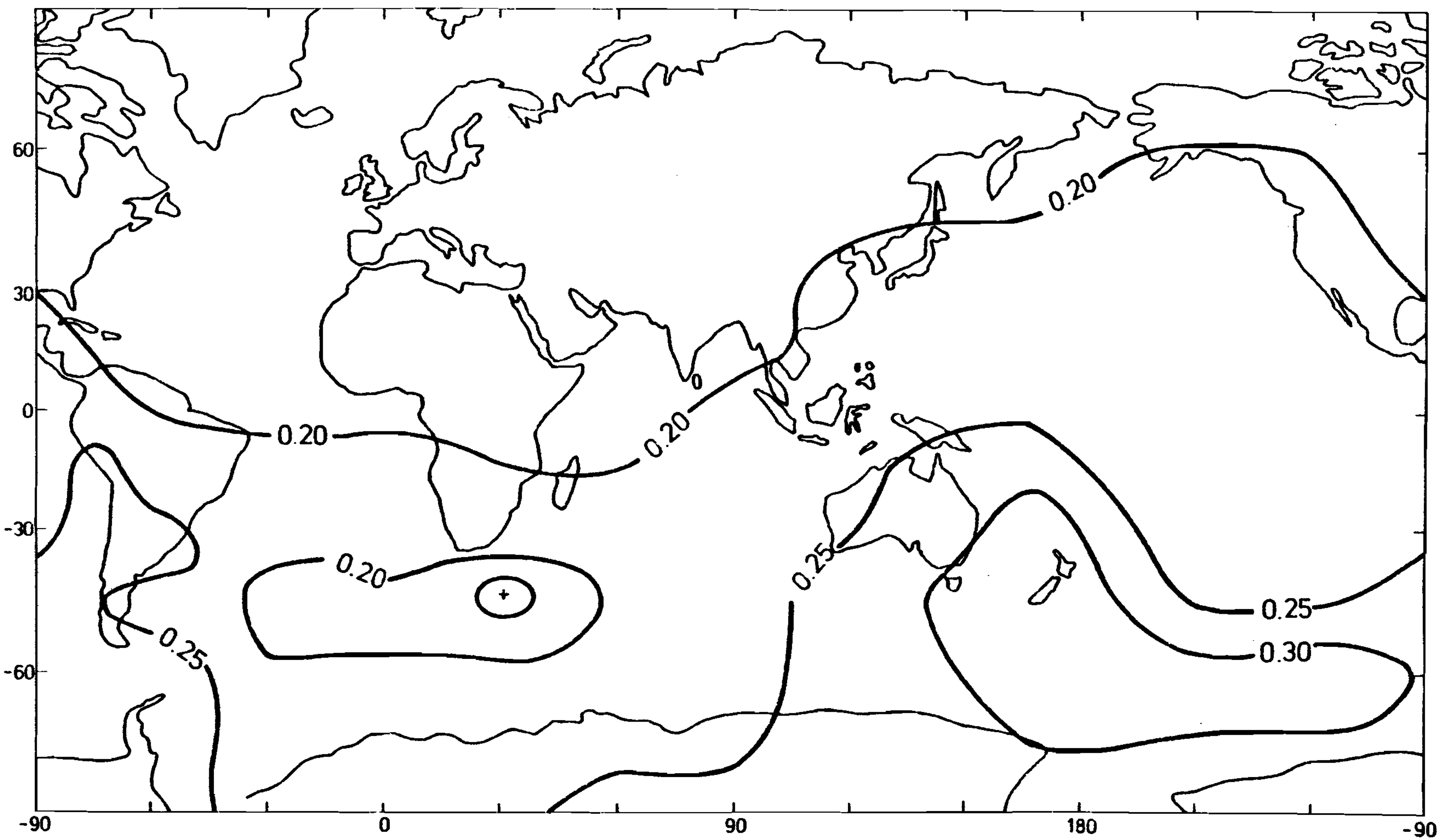

FIGURE 2. PREDICTED GLOBAL VARIATION IN BIAS IN CONVENTIONAL MAGNITUDE ESTIMATES FOR A TRUE MAGNITUDE $m_b = 5.0$.

Network operating during 1978-81 assumed (see table 1).

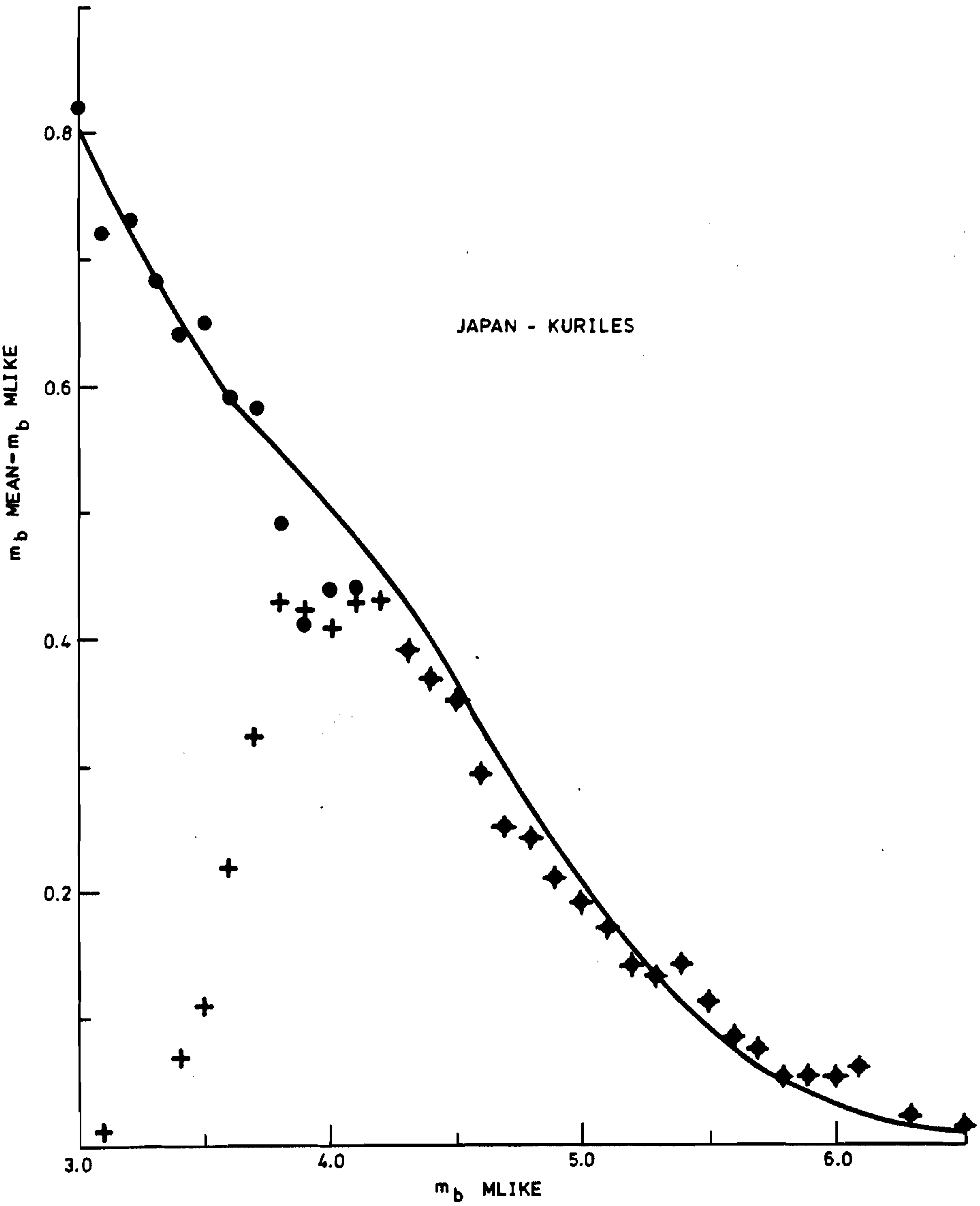

FIGURE 3. PREDICTED BIAS (LINE) FOR THE KURILES-JAPAN REGION (LAT 40 TO 50N; LONG 143 TO 157E) AS A FUNCTION OF "TRUE" MAGNITUDE.

Observed bias (dots and crosses as in figure 1) is the mean difference between the recomputed magnitudes and the conventional mean magnitude estimates using the same data and is plotted as a function of the computed magnitude.

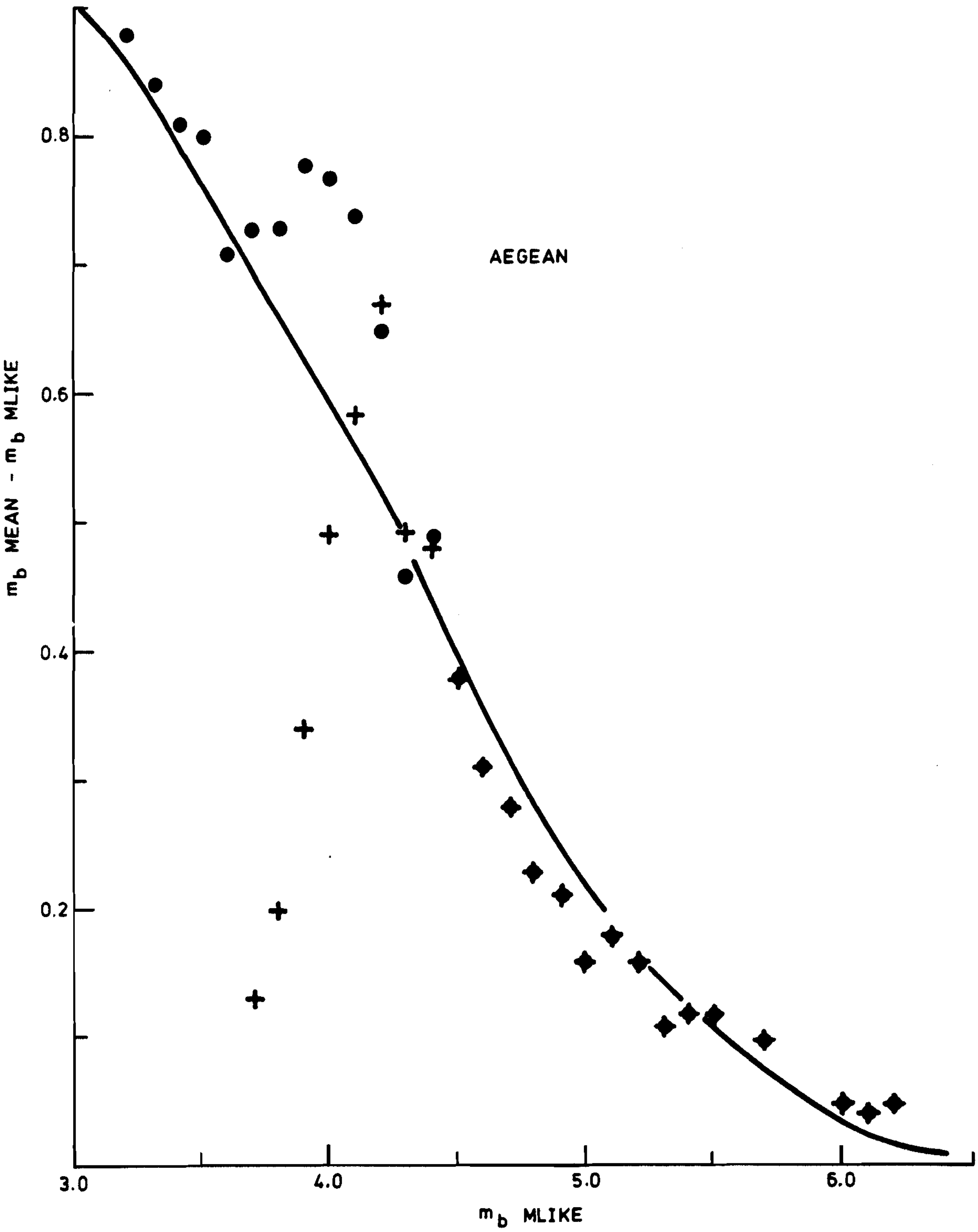

FIGURE 4. PREDICTED BIAS FOR THE AEGEAN REGION (LAT 30 TO 40N; LONG 20 TO 30E) AS A FUNCTION OF "TRUE" MAGNITUDE.

Observed bias (dots and crosses as in figure 1) is the mean difference between the recomputed magnitudes and conventional mean magnitude estimates using the same data and is plotted as a function of recomputed magnitude.

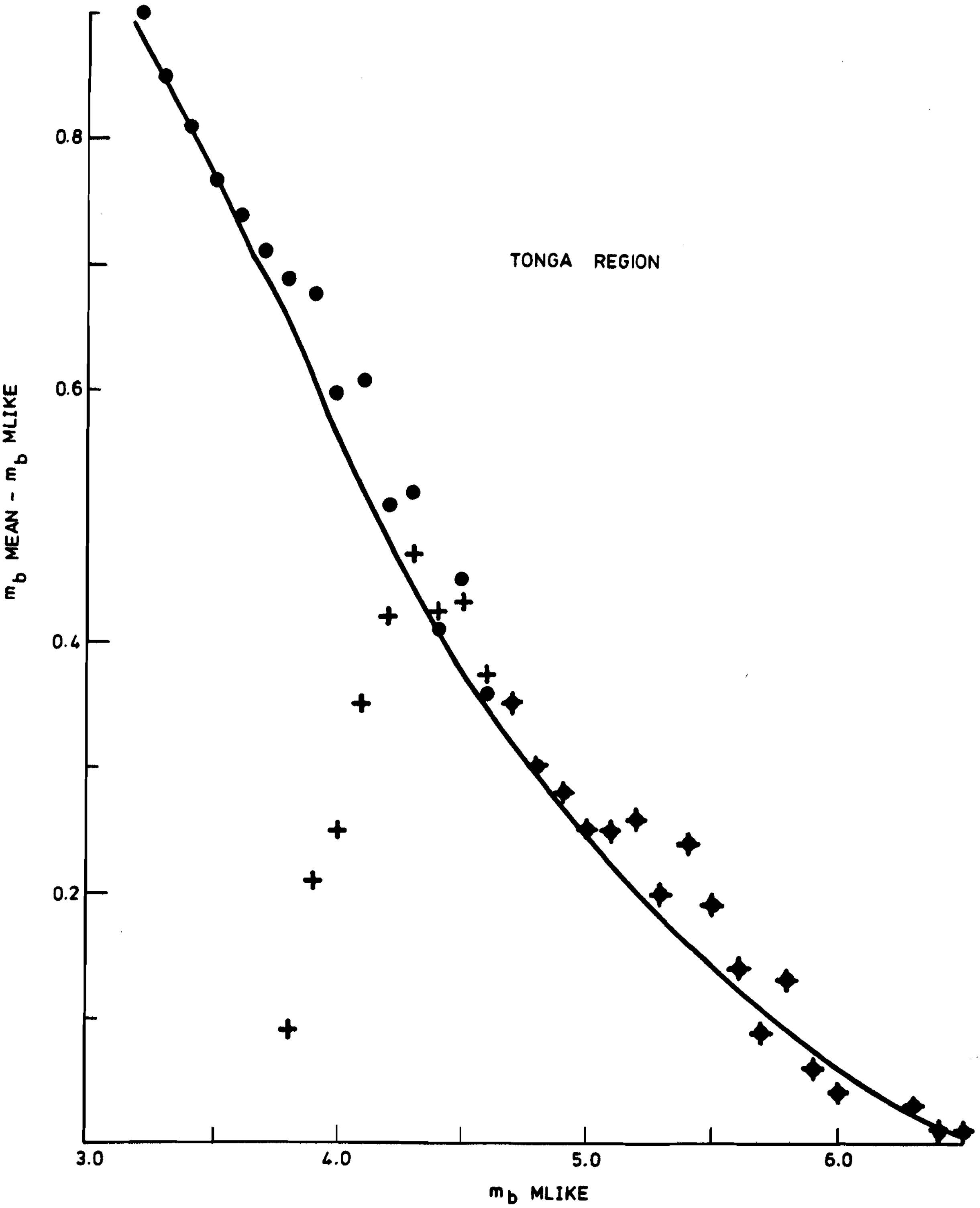

FIGURE 5. PREDICTED BIAS FOR THE TONGA REGION (LAT 14 TO 24S; LONG 170 TO 180W) AS A FUNCTION OF "TRUE" MAGNITUDE.

Observed bias (dots and crosses as in figure 1) is the mean difference between the recomputed magnitudes and conventional mean magnitude estimates using the same data and is plotted as a function of recomputed magnitude.

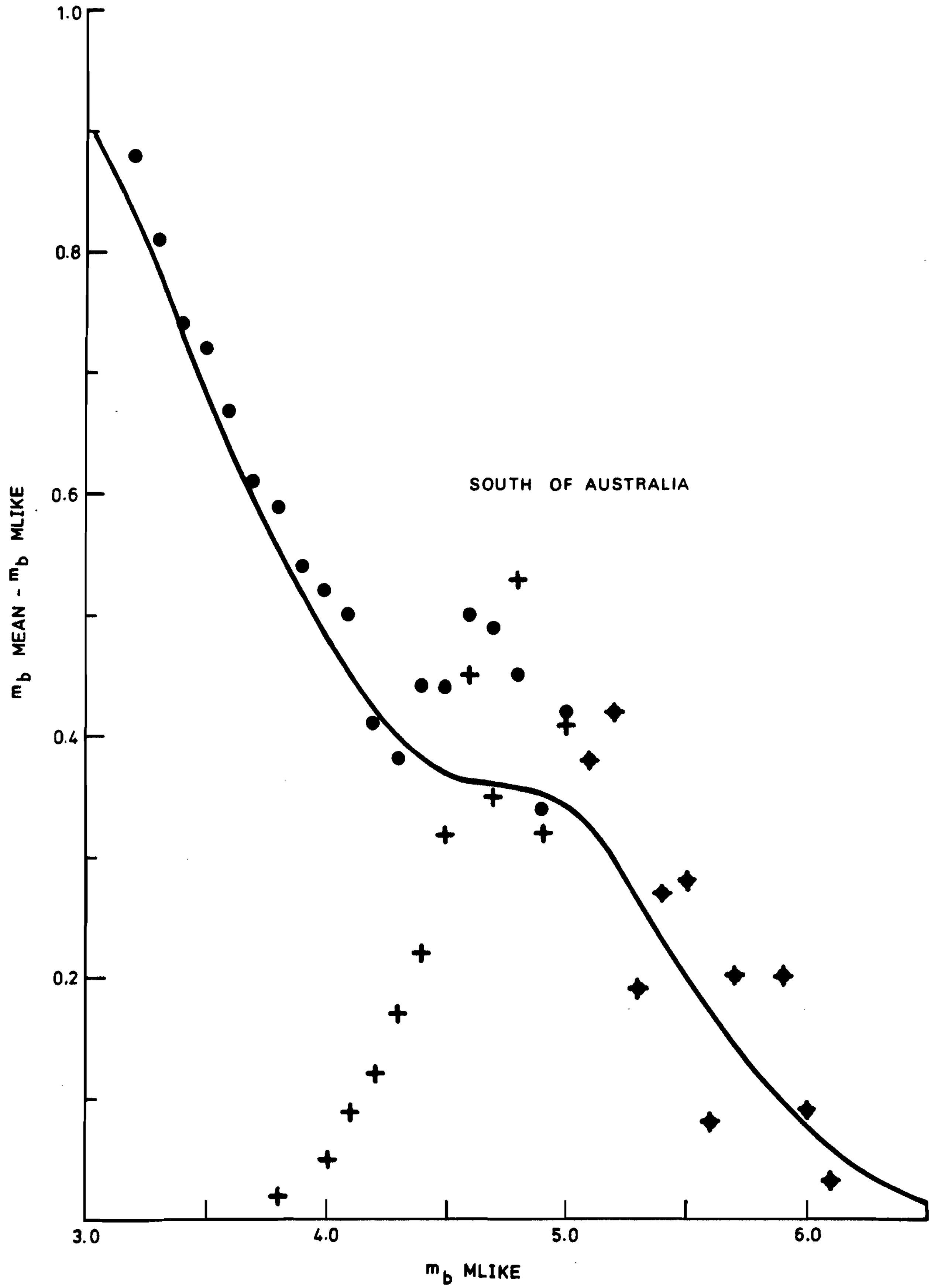

FIGURE 6. SAME PLOT AS FIGURES 3 TO 5 BUT FOR A REGION OF MAXIMUM GLOBAL BIAS PREDICTED IN FIGURE 2 IN THE REGION S OF AUSTRALIA (LAT 45 TO 65S; LONG 150 TO 180E).

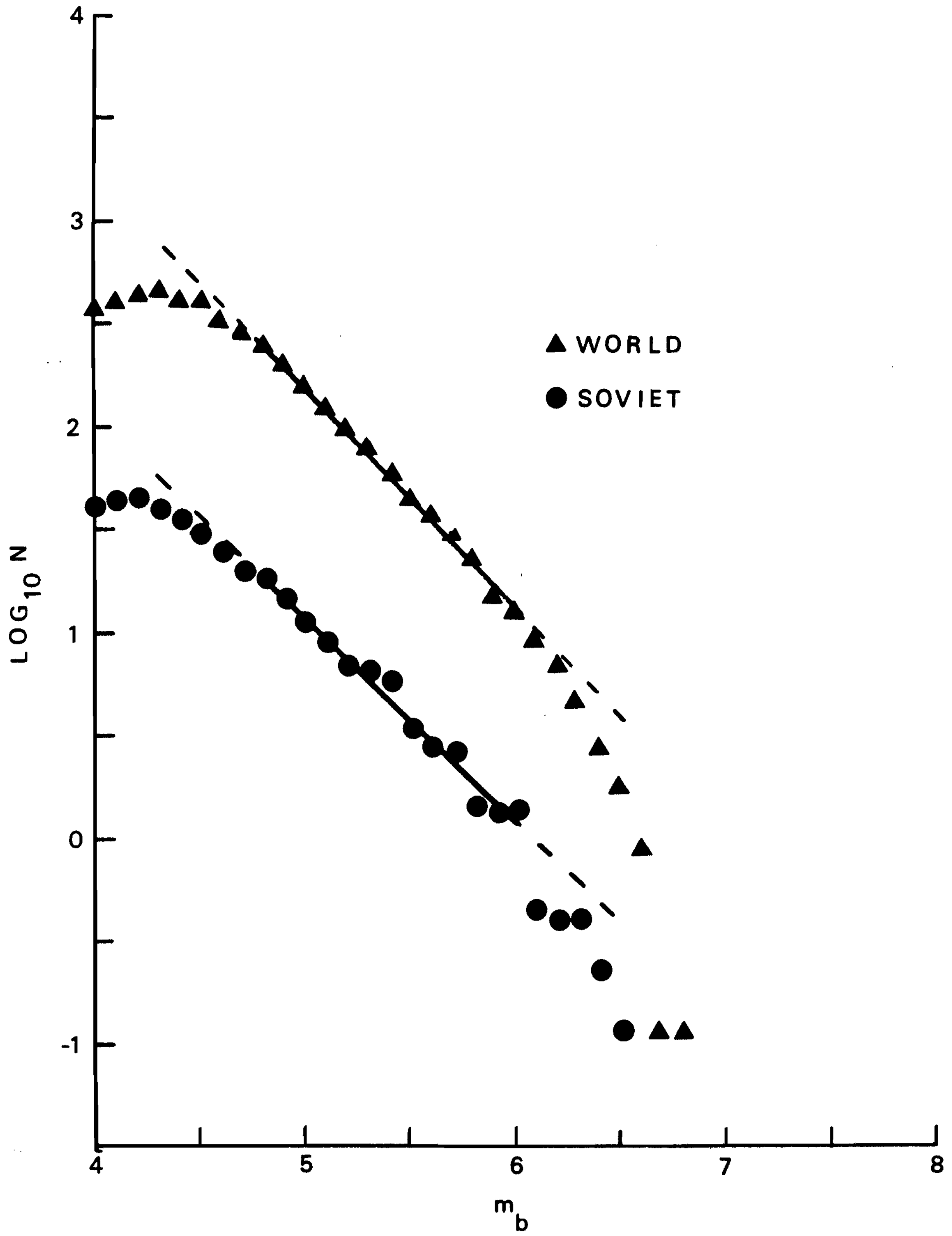

FIGURE 7. ANNUAL INCREMENTAL MAGNITUDE FREQUENCY PLOT (TRIANGLES) FOR EARTHQUAKES WORLDWIDE USING RECOMPUTED MAGNITUDES FOR THE PERIOD 1964-81 INCLUSIVE.

Straight line based on data in the interval $4.8 < m_b < 6.1$. Dots show a similar plot for Soviet Union earthquakes.

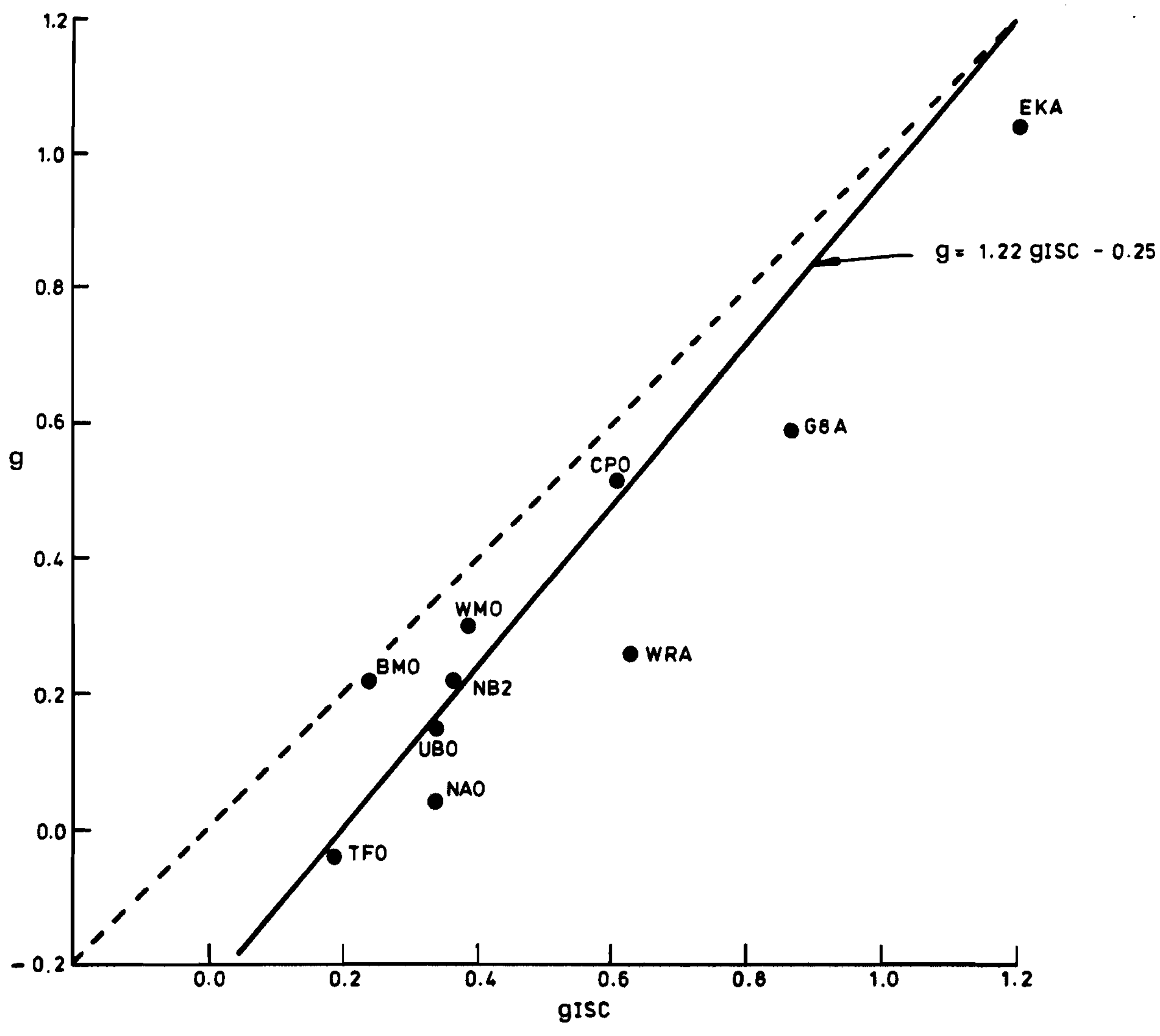

FIGURE 8. PLOT OF THRESHOLDS g DETERMINED FROM FULL STATION DATA AGAINST THRESHOLDS g_{ISC} DETERMINED USING ISC (ASSOCIATED) DATA.

Straight line fitted by least squares but constrained through point (1.2,1.2).

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Abstract This report describes the recomputation of some 100,000 bodywave magnitudes for earthquakes occurring in the period 1964-81 inclusive. Compared with the existing conventional magnitude estimates the new values are relatively free from bias introduced by data truncation, station amplitude terms and errors in the amplitude-distance curve. The redeterminations should enable more accurate predictions of seismicity both globally and regionally and of amplitudes seen at individual recording stations.

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