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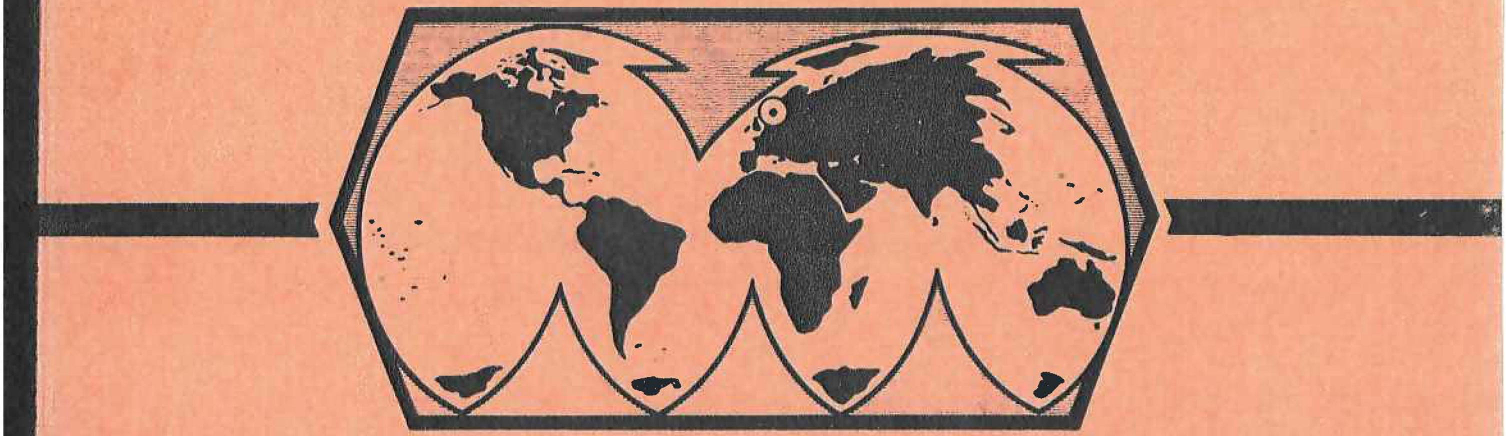

VI.2 Statistical Models for Seismic Magnitude

The concept of seismic magnitude - a measure of the kinetic energy of the elastic waves released by an earthquake - was first suggested by C.F. Richter in 1936 (see Richter, 1958). Magnitude measurements, which give an indication of the relative size of earthquakes, are today routinely made at all seismological observatories and represent an integral part of many research investigations. In the context of seismic event classification, i.e., discrimination between earthquakes and underground nuclear explosions, the magnitude parameter is of paramount importance. The reason is simply that despite extensive research efforts the so-called m_b:M_s discriminant is still considered the most reliable one and is also the most widely used. On the other hand, in certain branches of seismology like source mechanism studies the parameter seismic moment has replaced magnitude (to a large extent) for indicating the size of large earthquakes (e.g., see Kanamori and Anderson, 1975). In other parts of seismology the magnitude parameter has been somewhat discredited because of its considerable variability due to different physical factors, some of which are difficult or impossible to quantify. It must, however, be said that some of the research aimed at the magnitude problem must be rated as rather primitive.

In view of the importance of the magnitude parameter in a seismic discrimination context, NORSAR scientists have in recent years given a considerable attention to the magnitude problem. The study has been focused on:

(i) whether parts of the observed magnitude scattering was associated with inhomogeneities in the earth (forward scattering of small-scale inhomogeneities),
(ii) the magnitude estimation itself, and finally
(iii) developing discriminants having a better performance than that of the m_b:M

This section, together with section VI.3, describes some recent efforts regarding the first two factors mentioned above, namely, the scattering of the P-wave amplitude observations and in particular the proper estimation of m_b-magnitudes given the observations from a network of seismograph stations and arrays. Extensive studies show that the P-wave amplitude variations across the NORSAR array are rather large and may be clearly associated with structural heterogeneities at the bottom of the lithosphere (see Sec. VI.3). This amplitude scattering has a relatively short wavelength, i.e., varying rapidly with small changes in distance and azimuth. Also, the amplitude distribution across the NORSAR array may be approximated by a lognormal statistical distribution. This behavior has also been observed for worldwide amplitude data, and implies that the station magnitude correction term and thus the scattering term in magnitude estimation models can be considered a Gaussian variable. A novel approach to the magnitude estimation problem was the work of Ringdal (1976), who introduced a maximum likelihood technique for estimating magnitude from a network of stations, thereby taking into account information on stations being operational, but not detecting weaker events. Ignoring the latter kind of information would in most cases result in a positive magnitude bias for small events.

The mentioned maximum likelihood approach has recently been further elaborated by Christoffersson (1978). His approach differs from that of Ringdal (1976) in that it takes into account the probability that the event is actually detected by the network, whereas Ringdal (1976) considered, in statistical terms, a sample space which also included cases where an event was not seen by any of the stations in the network. The practical difference in the estimates provided by the two methods is generally small, and the relative merit of the two approaches will not be discussed here.

In summary, the statistical models presented in the paper by Christoffersson (1978) in connection with seismic magnitude deals with two main situations. The first concerns the estimation of magnitude for an event using a fixed network of stations and taking into account the detection and bias properties of the individual stations. The second treats the problem of estimating seismicity and detection and bias properties of individual stations. The models are applied to analyze the magnitude bias effects for an earthquake aftershock sequence from Japan, as recorded by a hypothetical network of 15 stations. It is found that network magnitudes computed by the conventional averaging technique are considerably biased, and that a maximum likelihood approach using instantaneous noise level estimates for non-detecting stations gives the most consistent magnitude estimates. Finally, the models are applied to evaluate the detection characteristics and associated seismicity as recorded by three VELA arrays (UBO, TFO, WMO).

While the two statistical situations discussed by Christoffersson (1978) each provide powerful techniques for eliminating the bias caused by non-detections of individual stations of a network, they are in general suited for two different estimation problems. The first (or conditional) approach is useful mainly for estimating the magnitude of individual events, and can be applied equally well to earthquakes and explosions. The second (or unconditional) approach, gives a convenient framework for joint estimation of structural parameters such as seismicity (a and b in the recurrence formula log $N=a-b\cdot M$) and station bias. It can also be used to estimate station detection characteristics. This second method is a unified approach which provides a generalization of earlier works of Kelly and Lacoss (1969) and Ringdal (1975).

Perspectives. The various maximum likelihood approaches discussed above for ensuring consistent magnitude estimates have to our knowledge only been applied to m_b-observations. The main reason for this is that this kind of magnitude data are the only ones which are easily and abundantly available. There is no reason why these novel estimation techniques should not be applicable/extended to surface wave magnitude (M_s) estimation, and also other significant problems in a discrimination context like the m_b:M_s relationship in particular for weak events. Research on these types of problems is now in progress, and our efforts here are concentrated on one hand on developing algorithms where, for example, possible correlation between the P and Rayleigh wave detectability for a given station is taken into account, and on the other hand to constructing comprehensive m_b:M_s data bases from both array and SRO-recordings. The use of advanced statistical techniques in analyzing the m_b:M_s relationship is expected to give more definite answers to a number of questions as to the nature of the relationship; e.g., the range over which it may be considered linear, the associated slope (both for explosion and earthquake populations) and most importantly, its behavior at low magnitudes where the problems due to non-detections are considered to be most significant.

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