OPTIMUM APPROACHES TO MAGNITUDE MEASUREMENTS

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ABSTRACT

Conventional magnitude estimates from a seismic network are based on measurements from only those stations which actually detect a given event, thus ignoring the data from stations where the signal amplitude is below the detection threshold. The topic of this paper is to review some recent developments in magnitude estimation methods, using information from both detecting and non-detecting stations, and it is shown that this leads to significant improvements in magnitude estimates for small events. The method is applied to study the linearity of the $m_b:M_s$ relation of earthquakes, and it is found that the apparent curvature of observed $m_b:M_s$ relationships can be explained through detectability considerations alone. Thus, from the available data, there is no need to assume a change of the $m_b:M_s$ slope at low magnitudes. Finally, the method is used to obtain a separation curve between earthquakes and explosions on the $m_b:M_s$ diagram which represents an improvement compared to conventional approaches.

1. INTRODUCTION

The basic problem addressed in this paper is related to the fact that no seismic station has a 'perfect' detection capability. Traditionally, seismologists have been working only with seismic phases that can be seen on any given seismogram, while ignoring stations where the phases are not detectable. As has been amply demonstrated in the literature, this procedure may easily lead to biased estimates of event magnitudes and amplitude ratios of different phases, e.g., $P:PCP,$ $P:LR$ (the $m_b:M_s$ criterion), etc.
A typical example of the importance of this problem in earthquake-explosion discrimination is the use of so-called 'negative evidence' in the $m_b$:$M_s$ criterion, i.e., classification of small events for which P-waves are detected, whereas surface waves cannot be seen because of low $M_s$ magnitude.

A proper statistical treatment of the above problem requires the introduction of advanced estimation methods, such as maximum likelihood estimation, where the information from detecting as well as non-detecting stations is included in the model. Maximum likelihood estimation relating to these problems has been applied by Vinnik and Dashkov (1) to determine the P:PCP amplitude ratio, by Kelly and Lacoss (2) to estimate seismicity and detection potential, by Ringdal (3,4) for estimating magnitude and detection thresholds, by Christoffersson (5,6) to obtain a unified approach to model the entire seismic field thereby synthesizing and expanding a number of the above approaches and by Elvers (7) to develop methods for reducing false associations of phases from a global network.

Related problems have also been addressed by Elvers (8) regarding the use of 'negative evidence', by von Seggern and Blandford (9) in establishing models for event detectability, and by Pirhonen et al (10) and Ringdal et al (11) in estimating the detection potential of existing seismological stations.

Seismic magnitude has long been accepted as the most reasonable measure of the 'size' of an earthquake. However, there are large variations up to one magnitude unit in measurements at different stations for the same event. These variations are caused by various factors: focal radiation patterns, variation in attenuation, focusing, etc. To improve the magnitude measurements, single stations are usually combined into networks and the 'network magnitude' is estimated as the average magnitude of the individual stations. This procedure works well for larger events, but for events around and smaller than the 50% detection threshold it tends to overestimate the magnitude as shown by, for example, Herrin and Tucker (12). The reason for this bias is that information from non-detecting stations is ignored. To improve the magnitude measurements, it is necessary to use information on detecting properties (thresholds, etc.) and region-station bias for both detecting and non-detecting stations in the network.

In this paper we will mainly review some method-development aimed at improving the accuracy of network magnitude determinations and also discuss some recent developments concerning the classical $m_b$:$M_s$ relation for discrimination between earthquakes and explosions.