Application of Network-averaged Teleseismic $P$-wave Spectra to Seismic Yield Estimation of Underground Nuclear Explosions

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Abstract—A set of procedures is described for estimating network-averaged teleseismic $P$-wave spectra for underground nuclear explosions and for analytically inverting these spectra to obtain estimates of $m_0$/yield relations and individual yields for explosions at previously uncalibrated test sites. These procedures are then applied to the analyses of explosions at the former Soviet test sites at Shagan River, Degelen Mountain, Novaya Zemlya and Azgir, as well as at the French Sahara, U.S. Amchitka and Chinese Lop Nor test sites. It is demonstrated that the resulting seismic estimates of explosion yield and $m_0$/yield relations are remarkably consistent with a variety of other available information for a number of these test sites. These results lead us to conclude that the network-averaged teleseismic $P$-wave spectra provide considerably more diagnostic information regarding the explosion seismic source than do the corresponding narrowband magnitude measures such as $m_0$, $M_s$ and $m_0(L_g)$, and, therefore, that they are to be preferred for applications to seismic yield estimation for explosions at previously uncalibrated test sites.

Key words: Nuclear explosions, yield estimation, $P$-wave spectra.

Introduction

One of the results of the intensive U.S. research program which was initiated to support monitoring of the Threshold Test-Ban Treaty (TTBT) was the development of a new capability to determine stable estimates of network-averaged teleseismic $P$-wave spectra for underground nuclear explosions and the subsequent development of procedures for analytically inverting these spectra to derive estimates of explosion yield and other source parameters (Murphy et al., 1989; Murphy, 1989). This constituted an important advance in that previous seismic yield estimation procedures were based on empirical correlations between narrowband magnitude measures (i.e., $m_0$, $M_s$, $m_0(L_g)$) and explosion yield, and such measures are not well-suited for resolving possible trade-offs between source and propagation path effects at uncalibrated test sites. The broader band network-averaged $P$-wave spectra, on the other hand, provide additional frequency-dependent information which can be used to quantitatively evaluate such trade-offs and their possible effects on test site

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magnitude bias estimates. Seismic yield estimation procedures based on these network-averaged spectra were subsequently developed and applied to the estimation of $m_b$/yield relations for underground nuclear explosions at the Soviet test sites at Shagan River, Degelen Mountain, Novaya Zemlya and Azgir, the French Sahara and Mururoa test sites and the Chinese Lop Nor test site. The objectives of this paper are to document these procedures and summarize the principal results of their application to this wide variety of different nuclear test sites.

**Overview of the Spectral Analysis Procedures**

Before proceeding to a consideration of specific test sites, it is appropriate to review the definition of the network-averaged $P$-wave spectra and the algorithms that have been developed to determine seismic yield estimates from these spectra. As was indicated by MURPHY et al. (1989), the basic spectral data used in the analysis are obtained by bandpass-filtering the individual short-period teleseismic recordings through a comb of Gaussian filters spaced at intervals of 0.25 Hz. In order to maintain constant bandwidth, the filter $Q$ values are taken to be linearly related to filter center frequency, $f_c$, with $Q = 12f_c$, producing frequency resolution of approximately 0.1 Hz and time resolution of approximately 2 seconds. The spectral

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![Normalized Observed vs Theoretical Spectral Amplitude](image)

**Figure 1**
Comparison of normalized observed and best-fitting theoretical network-averaged $P$-wave spectra (left) and $pP$ (right) for the NTS SLED explosion.