Definition of Exclusion Zones Using Seismic Data

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Abstract — In verifying compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT), there is a motivation to be effective, efficient and economical and to prevent abuse of the right to conduct an On-site Inspection (OSI) in the territory of a challenged State Party. In particular, it is in the interest of a State Party to avoid irrelevant search in specific areas. In this study we propose several techniques to determine ‘exclusion zones’, which are defined as areas where an event could not have possibly occurred. All techniques are based on simple ideas of arrival time differences between seismic stations and thus are less prone to modeling errors compared to standard event location methods. The techniques proposed are: angular sector exclusion based on a tripartite micro array, half-space exclusion based on a station pair, and closed area exclusion based on circumferential networks.

Key words: CTBT, nuclear explosions, event location, seismic array, on-site inspection.

Introduction

In verifying compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT), there is a motivation to be effective, efficient and economical and to prevent abuse of the right for one State Party to call for an On-site Inspection (OSI) on the territory of another challenged State Party. This can be achieved by several means (Bartal et al., 1998), related to accurate and precise location and identification of seismic events:

1. Demonstrating that the triggered seismic event is not a nuclear explosion (different characteristics).
2. Relocating the event such that its epicenter is outside the state’s borders.
3. Relocating the event such that its epicenter is away from sensitive installations.
4. Relocating the event such that its depth is not feasible for an explosion.
5. Reducing the potential search area by minimizing the 2-D error region. This error region is usually defined as the 90% confidence error ellipse of the epicenter.

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In points 2–4 above the uncertainty associated with the epicenter and depth estimates should be included (point 5 already deals with the uncertainty). The conventional way to estimate an event’s hypocenter is to find the hypocenter’s parameters that minimize the discrepancy between measured and calculated travel times (azimuth and slowness may also be used). The error in the hypocenter determination is composed of measurement and modeling errors. The measurement error is relatively easy to estimate, however the modeling error is mostly unknown and usually has a bias factor. Moreover, there might be an error associated with local minima and with nonconvergent solutions.

In case there is significant evidence to suspect that a nuclear test has occurred, one or more State Parties could call for an OSI over an area of up to 1000 squared kilometers within the territory of another State Party. In that case, it is in the interest of the Inspected State Party (ISP) to avoid irrelevant search in general and in particular to avoid a search in specifically sensitive areas. Excluding such zones will reduce the target area. It is also in the interest of the CTBT Organization (CTBTO) to improve the cost effectiveness of the search by reducing the search area and thus reducing the manpower, equipment and time needed for the search.

In this study we propose several techniques to determine ‘exclusion zones’, defined as areas where an event could not have possibly occurred. All techniques are based on simple ideas of arrival time differences between seismic stations and thus are less prone to modeling errors compared to standard event location methods.

The techniques proposed are:

— Angular sector exclusion based on a tripartite micro array. Here we calculate the backazimuth to the event including uncertainty. This defines an angular sector where the event’s epicenter must be, and this in turn defines the complementary angular exclusion zone where the epicenter cannot be (provided any azimuth bias is properly calibrated). It should be noted that the common practice for single station backazimuth calculation is 3-component analysis. We demonstrate that the proposed technique is superior.

— Half-space exclusion based on a station pair. Here we use a pair of stations close to one another and we assume that the event must be closer to the one station which records it first than to the other station. This defines a half space where the epicenter must be and the complementary half-space exclusion zone where the epicenter cannot be. Note that this is only true in a velocity structure that is laterally homogeneous.

— Closed area exclusion based on circumferential networks. Here we surround the closed area with a network of at least three stations. If the stations are far enough from the closed area then for an event inside the area, the arrival time difference between any two stations cannot be larger than a set maximum. This maximum is based on an assumed apparent velocity and the maximum distance difference between a point inside the closed area and any two stations in the network. If it can be shown for a specific event that the time difference between