Nuclear test depth determination: global analysis of PNEs to DPRK-2016
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Introduction. Seismic event depth determination is a part of Special Studies and Expert Technical Analysis (ETA) specified in Comprehensive Nuclear Test Ban Treaty (CTBT). We have studied a number of approaches aimed at depth determination and designed a prototype software. Since the data of the first few seconds of signal of very shallow events is very sensitive to the depth phases, cross correlation between observed and theoretical seismograms can provide a basis for the event depth estimation, and an expanded approach may even cover teleseismic regions. We applied this approach mostly to events that occurred near the International Data Centre (IDC) within the first 100 seconds. The IDC contains a wide set of historical records of global seismic network for nuclear events, including so called Penelec Nuclear Explosions (PNE) with presumably known depths, and most recent PKP nuklear nuclear tests were produced for seismic stations and the regional modelling was done with the generalised low technique by Valeriy Cerveny.

Depth determination of the announced DPRK-2016 explosion and Indian Shakti-2 with synthetic modeling.

We use a synthetic modeling approach to shallow event depth determination based on theoretical simulations. Basholit program (Herrmann and Ammon, 2002) was used as it’s allowed for specific velocity models for the source and receiver as well as to the propagation model. Source and receiver velocity models are observed in the array by the method like in DPRK case, see also our paper 6620 and the global reference model ak135 is used for the teleseismic propagation path. To assess the dependency of the amplitude and frequency content of the arrival, a range of anisotropy parameters, including a) wave propagation parameters, and synthetic seismograms are calculated for a range of source depths from the surface to 4 km, every 100 meters. Synthetic seismograms with the highest cross correlation with the observed signal corresponding to the apparent depth of the event.

Figures 1a and 1b shows depth determination (ln) vs stations. Colored diamonds indicate depth corresponding to maximum cross correlation coefficient in the range of 0 and source depth. Depth histograms shown with error of figure. Depth histograms shown with standard deviation (ln). Depth histograms shown with error of figure. Depth histograms shown with standard deviation (ln).

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Depths (k, l, j) of synthetic seismograms were calculated from the theoretical phase information. Depth histograms shown with standard deviation (ln). Depth histograms shown with standard deviation (ln).

Historical nuclear tests processing with synthetic modeling

Data used for the research

Example: 2011 Virginia M5.7 Earthquake

The 2011 M5.7 Virginia earthquake was chosen as a test event for our method. Using cross correlation as the objective function, a maximum was reached at 3.8 km. Depth test was performed on the event waveform by the method, the earthquake occurred on 21 June 2011 in the city of Virginia. The epicenter was located at 38.02 latitude and 77.5 longitude. The depth was reported by the USGS as 5.5 km.

Source depths were searched 0.2 km to 3.0 km in 0.2 km increments with optimal moment tensor solution at each depth. The distribution of the maxima is shown in Figure 2.

Depth determination with synthetic moment tensor estimation

Using this method, we have chosen the depth moment tensor for each of the event in USGS catalogue. The depth moment tensor was determined at 4.0 km. The depth was confirmed by the Global CMT catalogue (ICG, 2011) which states the depth to be 5.0 km.

Conclusions. We are in a process of development of preliminary depth maps for a wide range of depths, yields and for both the weapon tests and so called ground zero testing. The Global CMT project is an additional effort and conducted as an on-demand service for the Provisional Technical Secretariat and State Parties in a routine manner after entering the Treaty into force. A number of case studies were completed and support and benefit from our approach to solve these difficult challenges. We use also our methodology for some other global seismic array stations and we will continue development of this technique.