Topic	Detectability and earthquake location accuracy modeling of seismic networks
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This information sheet focuses on the accuracy of determination of earthquake hypocenter location with respect to the locations of seismic stations in a local network and the estimation of network detection thresholds.

Contemporary methods of determination of hypocenter location and earthquake origin time are based on modeling the travel time, which is needed for seismic waves to travel from the hypocenter to the station of a seismic network. For this we need to know:

- location and height above sea level of the seismic stations;
- accurate time on all seismic stations;
- velocity structure of the Earth, through which the seismic waves propagate.

If these parameters are known, we can calculate by means of numerical methods the theoretical travel time of seismic waves from an arbitrary hypocenter to the seismic station. The calculated travel times are then applied to the actual arrival times which were picked from seismograms on all available seismic stations and thus the hypocenter location and earthquake origin time is calculated.

The accuracy of such earthquake locations depends on the three points listed above and on the accuracy of phase picking. Additionally, the theoretical accuracy of hypocenter locations is also controlled by the spatial distribution of seismic stations. Nowadays, with GPS receivers being readily available at reasonable cost, it is not difficult to know the station location and the correct time exactly. The velocity structure of the Earth is fixed, however, and often enough not well known. By studying it, the accuracy of location can be improved. Unfortunately, the determination of the velocity structure requires either extensive specialized deep seismic refraction surveys or an already operating and sufficiently dense seismic network.

Therefore, in the phase of seismic network planning, we can improve its accuracy of event location only by reasonable distribution of the stations.

A computer program LOK has been developed which estimates the accuracy of hypocenter location based on a given spatial distribution of stations. The following assumptions are made:

- station co-ordinates are known exactly;

- for locations of seismic stations an RMS value of noise in the frequency band within which the STA/LTA trigger algorithm will operate (for digital stations) or for the frequency band of the recording equipment (for analogue stations) is known;
- for both digital and analogue stations the frequency response of the seismographs is flat and proportional to ground velocity in the frequency band of interest for modeling the station and network capabilities. This bandwidth depends on the task but also on the network geometry and sensitivity. For local networks it is usually in the range between 1 and 10 Hz;
- P and S arrival times are picked with a known a priori uncertainty (e.g., 0.1 s);
- P and S velocities within the layers and the positions of layer boundaries are known with some known uncertainty;
- travel times are computed for a flat Earth model consisting of homogeneous layers;
- the size of the network area is such that flat Earth approximation can be used.

The results obtained with LOK crucially depend on these assumptions. However, even with poor choice of input parameters (e.g. velocity model) one can get relative performance of different network geometry.

In developing the program LOK we followed mainly the method described in Peters and Crosson (1972). It uses the fact, that the errors of the travel time solution depend on partial derivatives of the travel time function by the unknowns we are looking for. These unknowns are the hypocenter location and the earthquake origin time. The derivatives can be calculated for every point within the seismic network. The area is divided into squares in terms of longitude and latitude. When LOK is run, a hypocenter error ellipsoid is constructed for every grid point. The largest semi-axis of the error ellipsoid is named the hypocenter determination error while the largest of the projections of the ellipsoid semi-axes on the horizontal plane is named the epicentre determination error.

For the computation of the error ellipsoid one should include only stations on which the expected signal is above the noise threshold as defined in the station file (amplification for analogue stations and RMS noise values and STA/LTA trigger ratio for digital stations). Thus the program also gives some information on the differences in expected detectability of events for different geometries of the network. Absolute level of detectability is impossible to predict without detailed knowledge of the attenuation in the region.

Figure 1 below shows the results of respective model calculation for the Stareslo network in Slovenia. The input and output files for this example are included in the distributed version of LOK (see below). An area of 3.5 x 1.75 degree was modeled. An earthquake of Ml = 1.0 was assumed to occur at 15 km hypocentral depth. The network consists of 7 stations, denoted by red triangles in the figure. The border of Slovenia is shown in thick blue. The thin black lines, which are the actual result of the modeling, are isolines of constant hypocenter location error. The numbers in the labels are in kilometers.

As one can see, the error increases outside the network, and the network also has a few blind spots within, where the hypocenter determination error is rather large. The detectability of the network for earthquakes of Ml = 1.0 (at least 4 stations must record the event to obtain the earthquake location) can also be seen. Other examples of magnitude threshold as well as epicenter and hypocenter error calculations using an earlier version of LOK, are shown in Figs. 7.6 to 7.8. of Chapter 7.

The software enables calculation with different hypocenter depths and earthquake magnitudes. It also includes a routine that determines the stations that recorded a particular event. LOK was written in FORTAN 77 and tested under Linux. The original LOK code has recently been upgraded. A Makefile has been included, written for Intel Fortran Compiler. Users invoke the "make" command in the source directory and LOK is compiled and built. If, however, another compiler is used, the Makefile has to be modified accordingly. Yet, variables were defined in a way that the code does no longer rely on implicit Fortran definition of the variables. For downloading the source code see on the NMSOP-2 cover page in the **Overview** listing *Download Programs & Files* for **lok-sept2011.tar** and related general instructions.

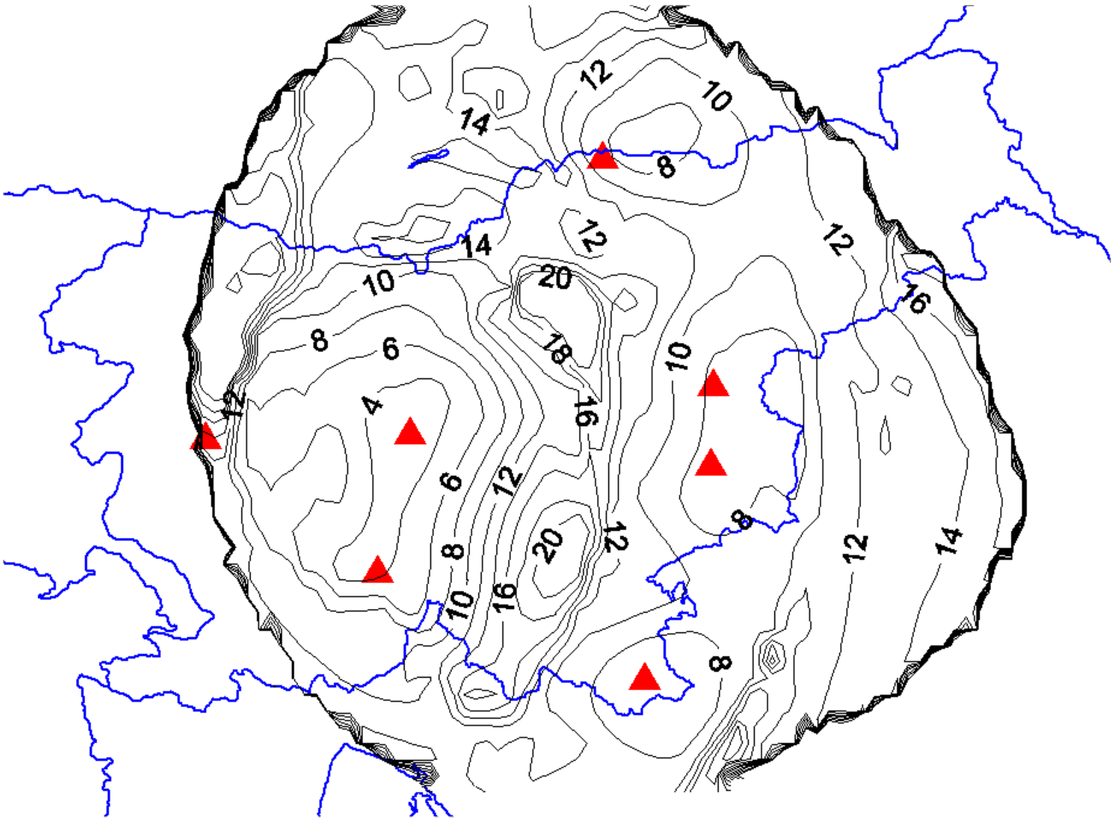

Figure 1 Result of model calculations for the Stareslo network in Slovenia for Ml = 1.0 earthquake. Red triangles: station positions, blue lines: borders of Slovenia, thin black lines: isolines of hypocenter location error in km; thick black outer boundary: outer limit of the network's location capability for earthquakes of Ml = 1.0.

Reference

Peters, D. C. and Crosson, R. S. (1972). Application of prediction analysis to hypocentre determination using local array. *Bull. Seism. Soc. Am.*, **62**(3), 775-788.