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Simultaneous relocation of the seismicity of the Pannonian Basin using Bayesloc

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Introduction

The seismicity of the Pannonian Basin can be described as moderate. The recent seismic activity is caused by the Adriatic microplate's movement, which rotates counter- clockwise relative to Europe. Based on geophysical studies, the current stress field is typically characterized by compression. The main active tectonic structures are flower structures linked to reactivated faults, shear zones. Additional geological structural studies require the most accurate earthquake catalogue. We relocated all events in the Pannonian Basin with the iLoc location algorithm using travel-time predictions from RSTT, a global, three-dimensional velocity model of the crust and upper mantle to provide accurate single event locations, then we applied the Bayesloc algorithm.We show that the results present an improved view of the seismicity of the region.

Data sources, iLoc initial coordinates

In our work we have used all of the instrumentally registered seismic events between 1996 and 2017 in the Pannonian Basin, therefore the relevant waveforms come from a wide range of sources (Fig 1).The Bayesloc requires the coordinates of the absolute initial hypocenters. The absolute locations of the earthquakes reported in the Hungarian National Seismological Bulletin (HNSB) provided by the Kövesligethy Radó Seismological Observatory (KRSO) were relocated with the iLoc (Bondár et al., 2011). iLoc relocations were performed with RSTT 3D global velocity model (Myers et al., 2010, Bondár et al., 2018).

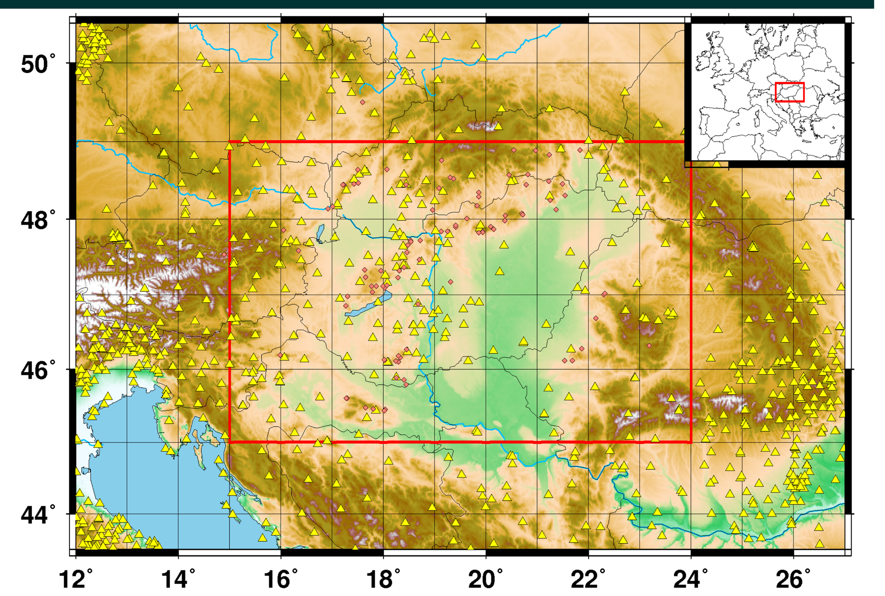

Fig 1. Local and regional stations used in the relocations.

Bayesloc algorithm

Bayesloc (Myers et al., 2007) is a statistical model of the multiple event system (developed at Lawrence Livermore National Laboratory) which includes event locations, travel-time corrections, assessments of arrival-time measurement precision, and phase labels. This algorithm does not linearize the seismic event location problem, and thus may produce better earthquake locations than standard linearized location techniques such as Geiger's method. Bayesloc uses the Monte Carlo Markov Chain method to sample the joint probability of the multiple-event system. Bayesloc also accepts probabilistic prior constraints on any of the input parameters, which can significantly tighten the distribution of all parameters. The several hundred confirmed quarry blasts and mine explosions that qualify for ground truth help to anchor the seismicity pattern to known ground truth locations. Unlike most multiple event location algorithms, bayesloc can handle not only event clusters but distributed seismicity of an entire region, thus perfectly posed for the task in hand. We used the ak135 global velocity model (Kennett et al., 1995) for all test runs. We performed data pre-processing before the Bayesloc run.

Suspicious explosions (SX) and prior constrains

Based on the day-time peak on the origin-hour distibution of the bulletin earthquakes we assume that there are antropoghenic events labeled as earthquakes in the catalogue, therefore we created a „Suspicious explosions (SX)" group. Frist, we identified all mining locations where explosions could be performed. We have used the data of Mining and Geological Survey of Hungary (MFBSZ) which contained about 900 mine polygons. To estimate the size of the polygons we take the average of the incirlcle and excircle radius and add + 5 km as error of location. Later this error was fine-tuned. This way based on the centroid-coordinates and the final radius we assume that any seismic event in the given radius of the centroid is potentially created by explosions (Fig 2B). The filtering was refined by the time frequency of the known explosions (anthropogenic events are usually carried out during the day-time, Fig 2A). The above mentioned data, coordinates and calculated average radius were exported from QGIS, and loaded in a SQL database.

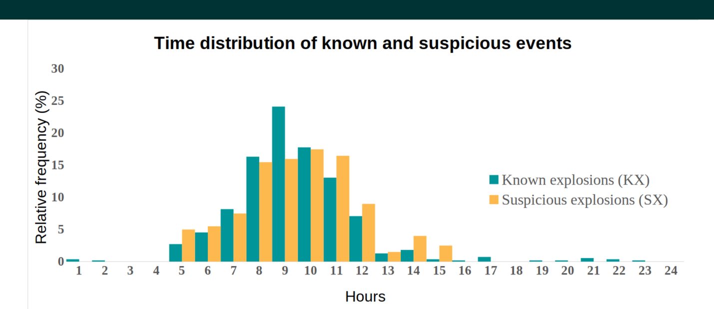

Fig 2A. Origin-hour distribution of the SX, KX events

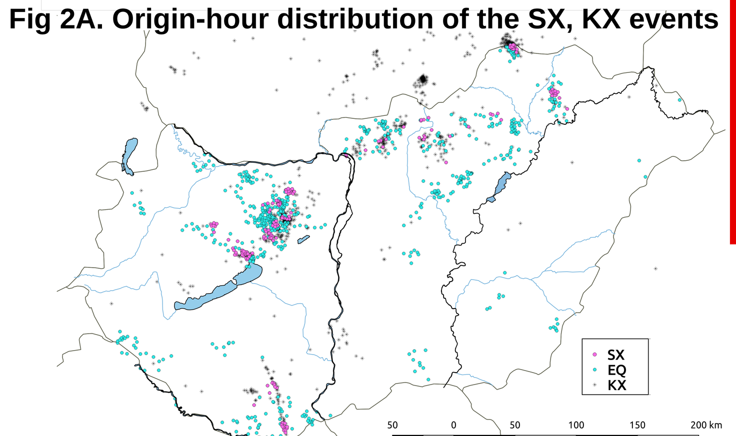

Fig 2B. Map view of suspicious (SX) and known (KX) explosions

Catalogue [number of events]	Dist SD (km)	Depth SD (km)	Time SD (sec)
Earthquake (EQ) [2142]	20	5	5.0
Known explosions (KX) [983]	10	0.1	5.0
Suspicious explosions (SX) [322]	10	3	5.0
Ground truth (GT) [391]	2	0.1	5.0

Table 1. Prior constrains of different type of events

Creating a well-connected network using graph theory

The aim of this step was to create a well-connected, "nonseparable" network before the Bayesloc run. We created a graph (Fig 3.) based on the bulletin - stations and events are the vertices, while the arrival times are the edges. We created a biconnected subgraph. An undirected graph is called Biconnected if there are two vertex-disjoint paths between any two vertices, i. e., does not contain articulation vertices. The removed articulation points are typically teleseismic stations (Fig 4.), the events are well-connected in the bulletin.

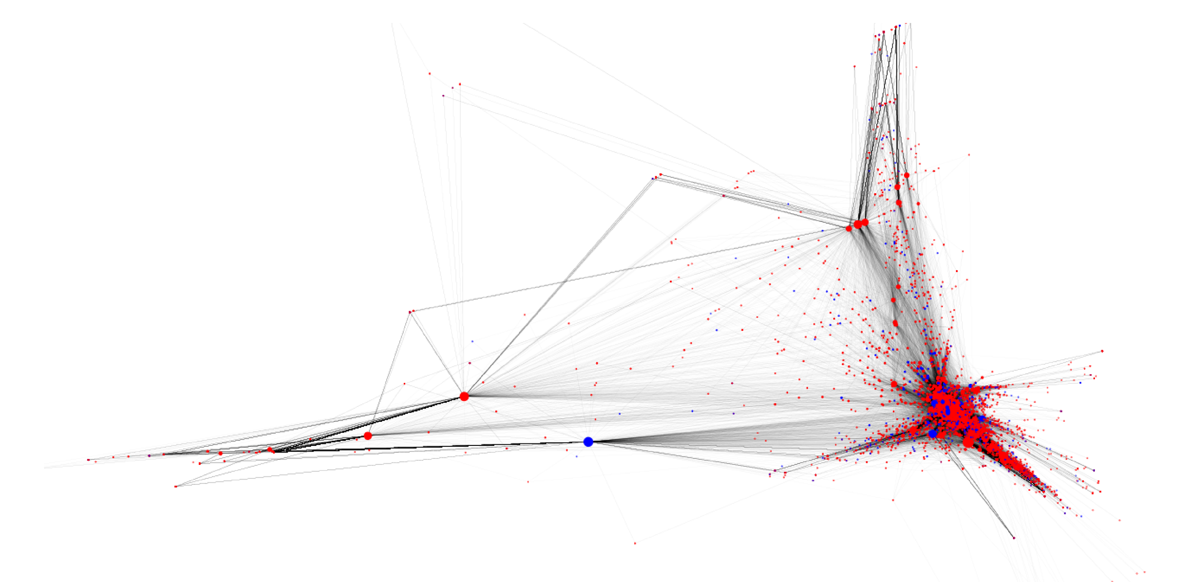
Fig 3. The biconnected subgraph based on the bulletin. Blue color: stations, red color: events (Spectral layout)

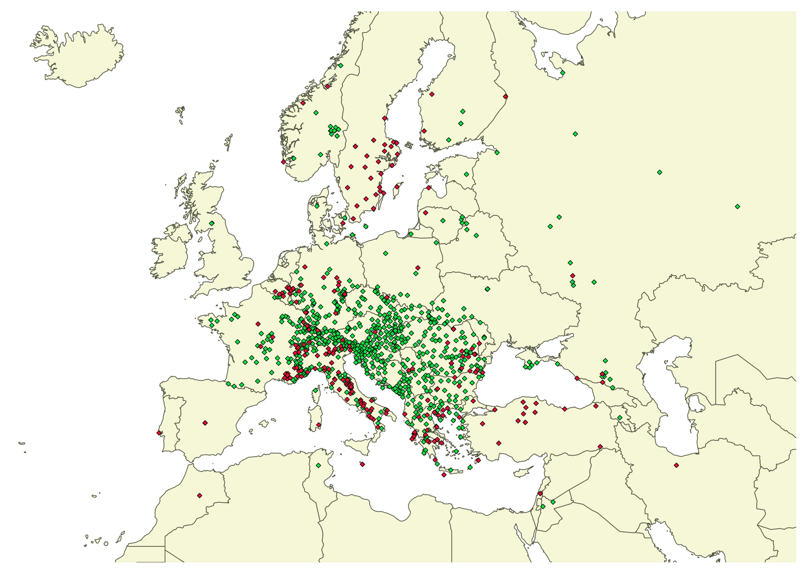
Fig 4. The red stations are the removed articulation vertices,the green stations stayed in the biconnected subgraph.

Output statistics

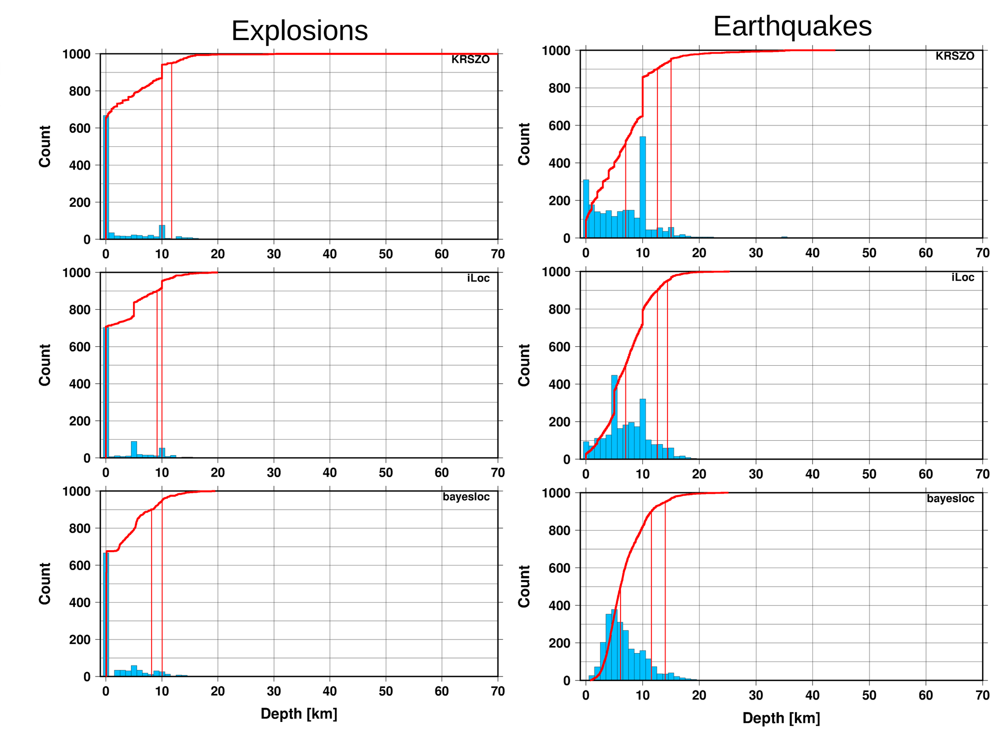

Fig 5. Histograms of the event depths. Top: KRSO, Middle: iLoc initial locations, Bottom: Bayesloc solutions.

Final results

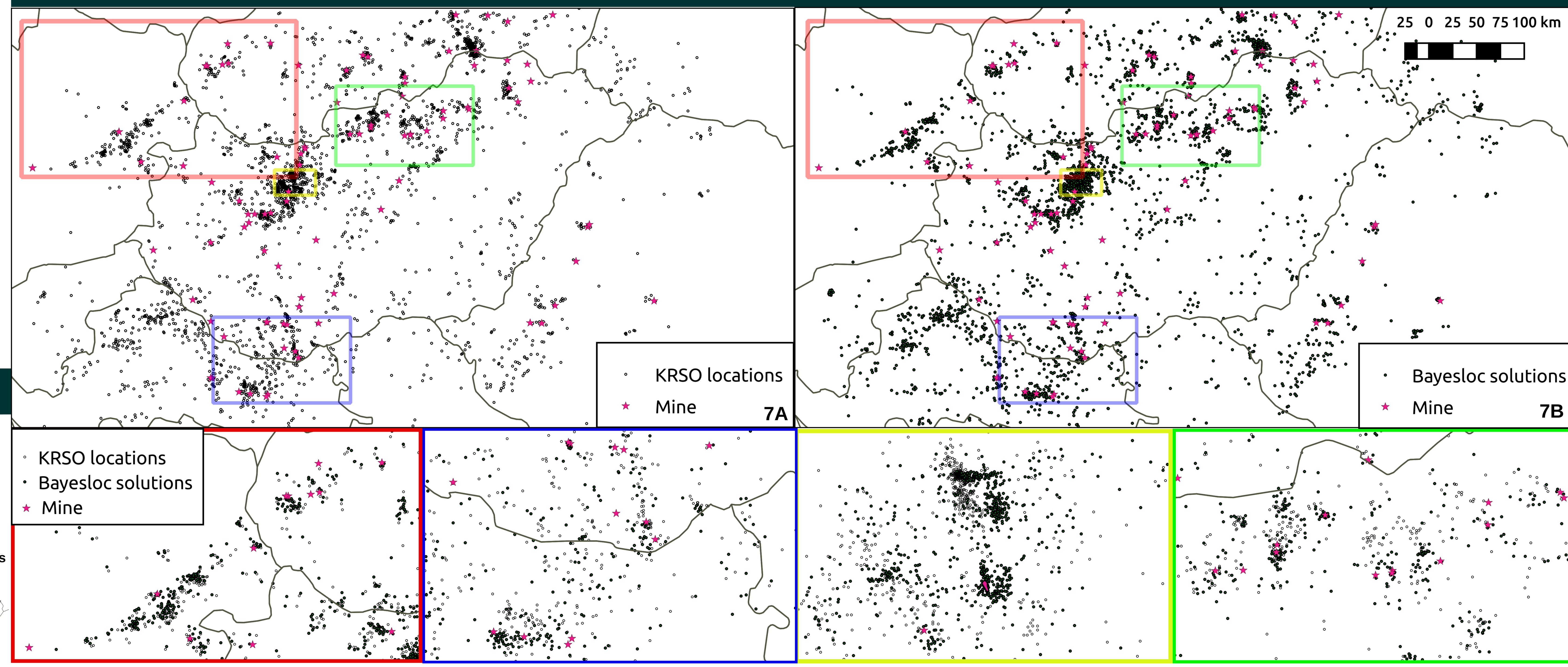

Fig 7. Original bulletin locations (KRSO, 7A) and Bayesloc final solutions (7B) . Purple stars indicate the mines. Framed areas are shown in more detail in the second line (KRSO-Bayesloc comparative figures).

The final solution of Bayesloc using ak135 velocity model (7B) is considerably more accurate than the original KRSO locations (7A). Reliable iLoc initial locations (with RSTT model) make a significant contribution to the final solutions. The events around the mines are dramatically better clustered in Hungary (yellow frame) and Croatia (blue frame), and the depth distribution has improved compared to KRSO locations (Fig 5). The prior constrainst contributed remarkably to the outcome of the relocation. We have successfully used the Suspicious Explosions (SX) event group.

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