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Inversion and Application of Muon Tomography Data for Cave Exploration in Budapest, Hungary

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In this contribution we present a prospecting muon-tomograph and its application for cave exploration in Budapest, Hungary.
The more than 50 years old basic idea behind muon tomography is the ability of muon particles, generated in the upper atmosphere to penetrate tens of meters into rocks with continuous attenuation before decay. This enables us placing a detector in a tunnel and measure muon fluxes from different directions and convert these fluxes to rock density data.
The lightweight, 51x46x32 cm3 size, muon tomograph containing 5 detector layers was developed by Wigner Research Centre for Physics, Budapest, Hungary. A muon passing at least 4 of the 5 detector layers along one line are classified as unique muon detection. Its angular resolution is approximately 1 degree and it is effective up to 50 degrees off zenith.
During the measurement campaign we installed the muon detector at seventeen locations along an abandoned, likely Cold War air raid shelter tunnel for 10-15 days at each location, collecting large set of events. The measured fluxes are converted to apparent density lengths (multiplication of rock densities by along path lengths) using an empirically tested relationship.
For inverting measurements, a 3D block model of the subsurface was developed. It consisted of cuboids, with equal horizontal size, equal number in every line and in every row of the model. Additionally it consisted of blocks with different heights, equal number of blocks in every column. (Block height was constant in a column, but varied from column to column.) The heights of the blocks in a column were chosen, that top face of the uppermost blocks has an elevation defined by a Digital Elevation Model. Initially the density of every model blocks was set to a realistic value.
We calculated the theoretical density length for every detector location and for a subset of flux measurement directions. We also calculated the partial derivatives of these theoretical density length values with respect to the densities of every model block. This is the Jacobian of the problem and these values were proportional to the path length in the respective block.
A regularized least squares solution returns the corrections of the densities of the blocks. If the corrected density of a block is significantly smaller than the typical rock density of the subsurface, the block is dedicated as a cave. According to our results a supposed cave exists some 7 meters above the tunnel.
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