Imaging 3d velocities from an induced earthquake swarm travel times in Bebedouro region SP

Marcelo Bianchi*[1], Andrey Jakovlev[1], Marcelo Assumpção[1]; [1]Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, São Paulo/SP, Brazil

Abstract

Between 2005 and 2010, in Bebedouro (NW of São Paulo state) thousands of small earthquakes (magnitudes up to 2.9 ML) were recorded by a temporary network with stations deployed in 22 different sites in an area of 15 km². Analyzes by many different researchers included the relocation of the main earthquakes, correlation of earthquake origin time with the rainy seasons, and analyzes of the temperature profile in water wells in the region. These analyses supported the conclusion that the activity was induced by the opening of deep water wells, with high outflow, near the center of the area that altered the flow of groundwater and thus, the stability conditions of the fractured basalt of the Serra Geral formation in the hypocentral area. Here we used the data of 8106 P-phase and 4613 S-phase travel times from the best 1789 previously located events to perform a 3D velocity inversion in the area. We use the LOTOS tomography code that searches for a possible velocity perturbation model that minimizes the travel time residues, station and event corrections in an L^1 minimization scheme. At the same time, LOTOS performed the relocations of sources. The main advantages of LOTOS are that it is designed for very local networks, uses the terrain topography information, and allows for custom distribution of stations and events. Using LOTOS we inverted for P- and S-wave 3D velocity perturbations independently, which allows us to derive also the Vp/Vs ratio, for depths ranging from surface (~ 0.6 km above sea level) to ~1.5 km below sea level. Generally anomalies were laterally distributed, we did not observe any depth variation in the distribution of anomalies. Anomaly amplitudes reach 3% and 5% for P- and S-waves, respectively. Vp/Vs values ranged from >2.0 near the surface (associated probably to less consolidated sediments) to ~1.7 at deeper parts of the model probably associated with basalts. While this was not strongly supported by the distribution of the rays, it looks like the model shows two areas, one where the Vp and Vs perturbations are in opposite directions, which is normally indicative of areas saturated with fluids in hard rock, and an area were Vp and Vs perturbations are directly correlated, like in the initial model - again this could be just an effect of ray distribution. Comparing our velocity model to the final hypocenters we observed that the events are located most of the time over high Vp and low Vs regions and thus higher than average Vp/Vs ratios. Hypocentral locations obtained after tomographic inversion also showed a trend of event hypocenters dipping to the North in the study area, also observed previously and associated with a migrating pattern of the events. The deeper events in the northern area occurred later in the event sequence and could be interpreted as resulting from pore pressure diffusion. Looking more closely at the study area topography, we could observe that the overall distribution of the events were limited by some topographic hills around the study area. Moreover, the high and low velocity anomalies of the S-wave show some correlation to the valleys inside the area. Finally, the position of high outflow wells showed a very good correlation with the positions of low Vs anomalies (high Vp) in the area that together with the observed variance reduction also supports the validity of the final model that we developed.