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Triggering of the 2003-2004 Ubaye seismic swarm, France, by pore-pressure build-up

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We study changes in effective stress that occurred during the 2003-2004 Ubaye earthquake swarm in the French Alps. Two complementary datasets are used. First, a set of 974 relocated events allows us to characterize finely the shape of the seismogenic area and the spatial migration of seismicity during the crisis. Relocations are performed by a double-difference algorithm. We compute difference in traveltimes at stations both from absolute picking times, and from cross-correlation delays of multiplets. The resulting catalogue is aligned preferentially along a single planar structure striking N130°E, and dipping 80°W. We show that this relocated activity is consistent with a triggering by a diffusive fluid overpressure front. This observation argues in favor of a deep-seated fluid circulation, responsible for a significant part of the seismic activity in Ubaye. Second, we also analyze time series of earthquake detections at a single seismological station, located just above the swarm. This time series of +16,000 events forms a dense chronicle of the swarm temporal evolution. We use it to isolate the part of fluid-induced seismicity, and to estimate the effective stress change history of this sequence. For this purpose, we model the rate of events by an ETAS model added of a non-stationary background rate $\lambda_0(t)$. We make the hypothesis that background events are directly triggered by fluid circulation at depth. Then, using the rate and state constitutive laws of *Dieterich (1994)*, we deliver an estimate of changes in effective stress for the observed rate of background events. We assume that changes in effective stress occurred under constant shear stressing rate conditions. We finally obtain a maximum change in effective stress of -3.23 MPa. Under constant normal stress conditions, this would correspond to a maximum fluid overpressure of 3.23 MPa. This estimate is in good agreement with values obtained from numerical modeling of fluid flow at depth, or with direct measurements during fluid injection experiments.