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Seismic activity in the Ubaye Region (French Alps): a specific behaviour highlighted by mainshocks and swarm sequences

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Ubaye Region:

- One of the **most seismic active area** in France.
- Located at 100 km from Grenoble and Nice in the Southwestern Alps.
- High rate of seismicity.
- **Different types of sequence:** Mainshock-aftershocks, swarm sequences, and intermediate behaviour.

What are the processes at play in the Ubaye Region to explain this peculiar seismicity?

II) Historical Seismicity

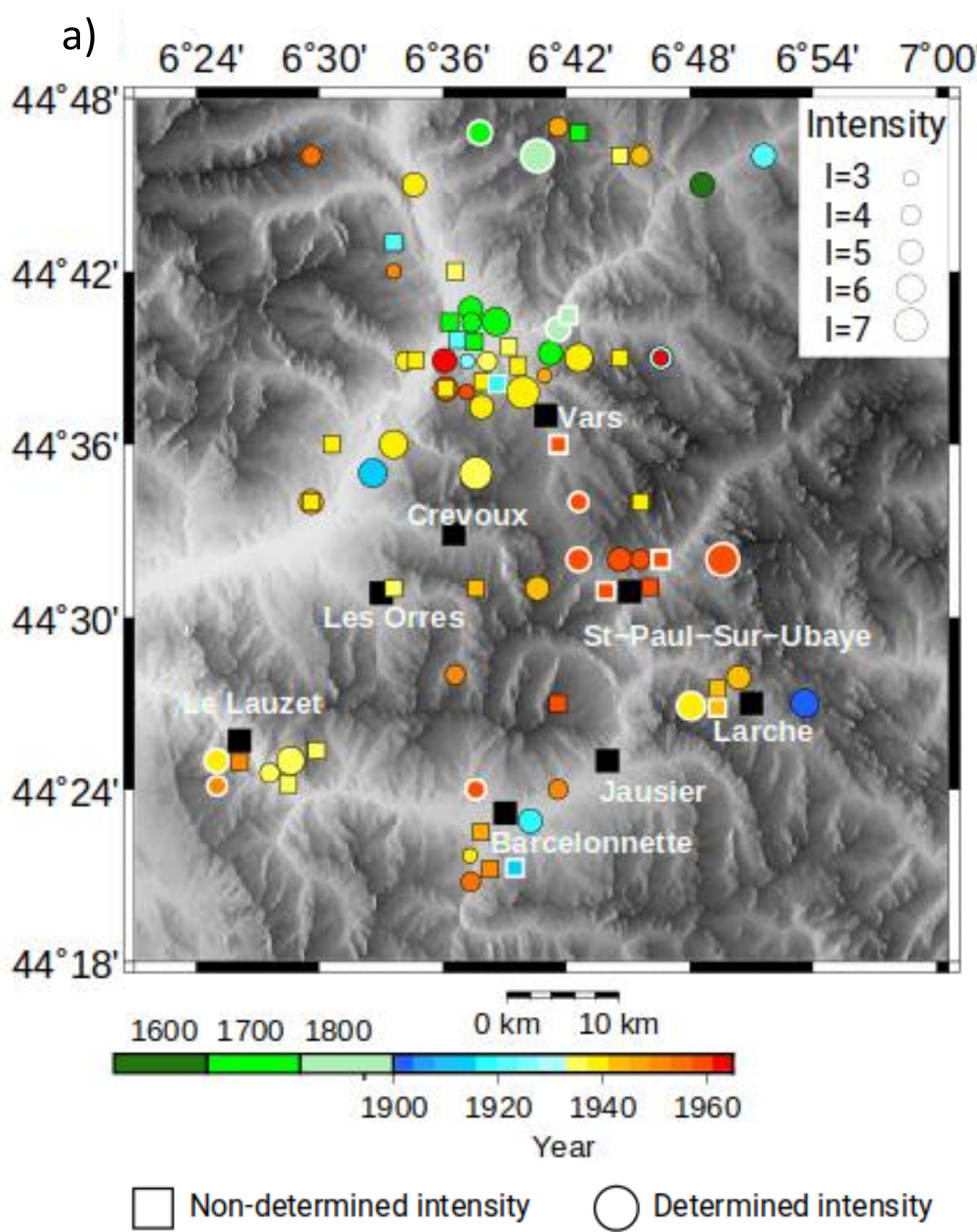


Figure 2: Map (a) and temporal distribution (b) of the historical seismicity (SisFrance catalogue). The white border symbol in a) indicates group of events. Colours in b) indicate the intensity uncertainty where 1 is well determined and 5 is very bad determined intensity. Modified from Baques et al. (2021).

- Seismicity since the 18th century.
- Events with strong intensity (up to VIII).

- Two types of seismicity: Mainshock-aftershocks (e.g. 1959, intensity: VII-VIII), group of events (e.g. 1938, intensity: VII) that might be swarms.

IV) 2003-2004 & 2012-2016 sequences

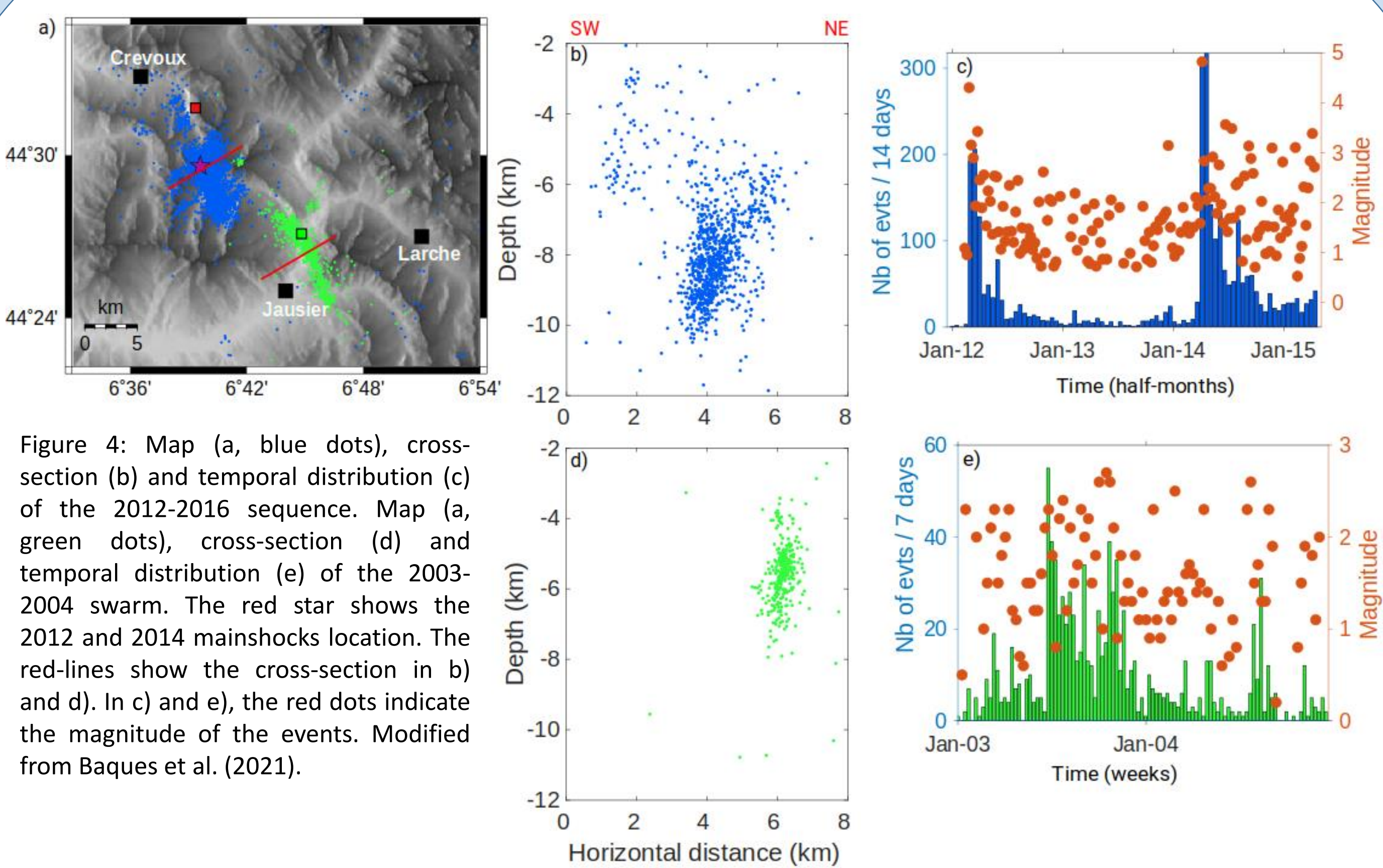


Figure 4: Map (a, blue dots), cross-section (b) and temporal distribution (c) of the 2012-2016 sequence. Map (a, green dots), cross-section (d) and temporal distribution (e) of the 2003-2004 swarm. The red star shows the 2012 and 2014 mainshocks location. The red-lines show the cross-section in b) and d). In c) and e), the red dots indicate the magnitude of the events. Modified from Baques et al. (2021).

Figure 5: Spatio-temporal distribution for 2003-2004 swarm (a), after the 2012 mainshock (c), after the 2014 mainshock (b), and for a cluster (Crevoux) during the 2014 aftershocks sequence (d). Modified from Baques et al. (2021).

Seismic migration in agreement with fluid diffusion for the 2003-2004 swarm, after the 2012 earthquake, and for some clusters during the 2014 aftershocks.

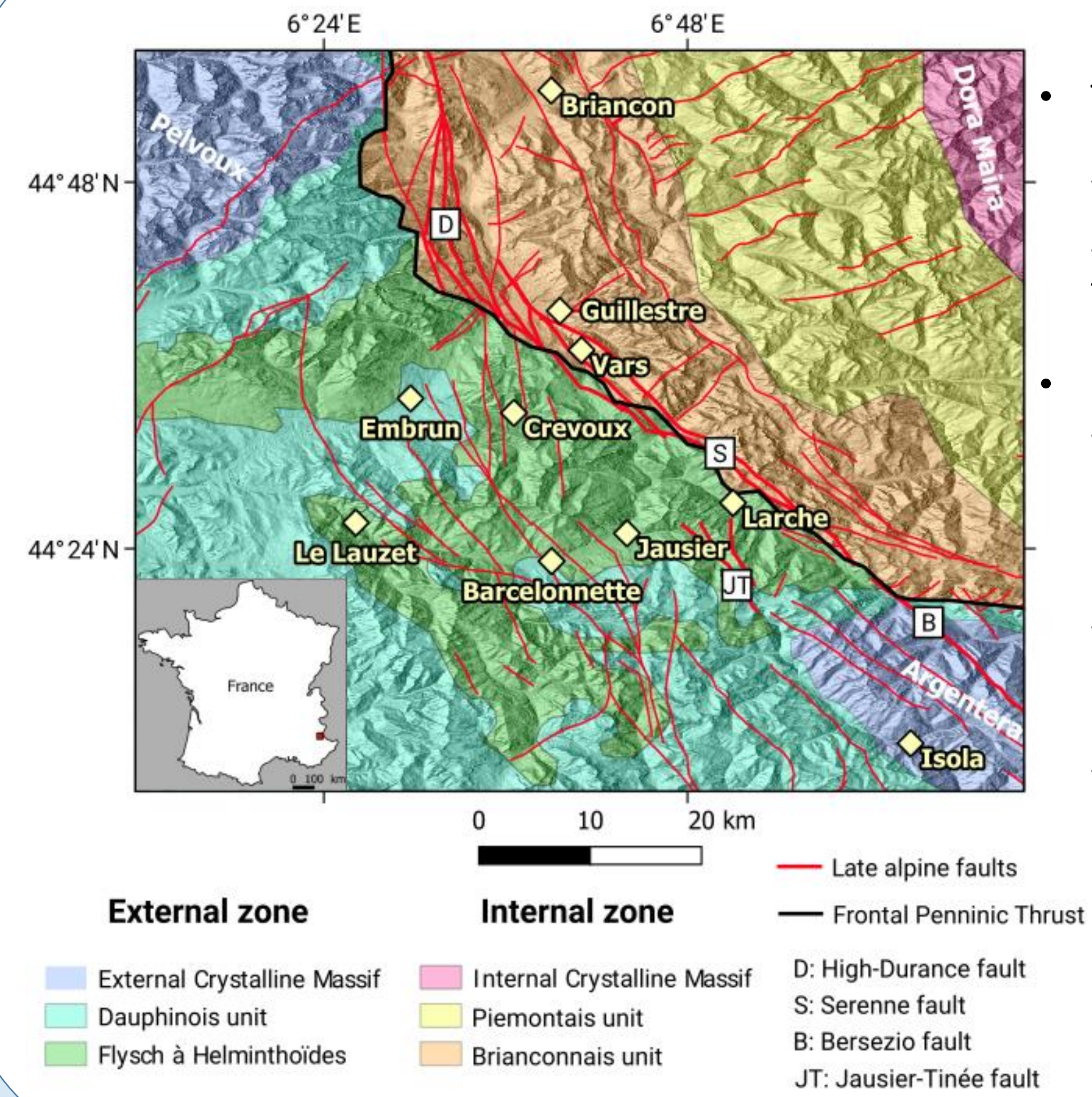
Similarities:

- Same orientation of the seismicity (N140-160°E).
- Fluid-driven process highlighted for the 2003-2004 swarm, and in the 2012 and 2014 aftershocks.

Differences:

- Maximal magnitude: higher than 4. for the 2012-2016 sequence while lower than 3 for the 2003-2004 swarm.
- Temporal distribution completely different: 2003-2004 consistent with a swarm sequence, while 2012-2016 is closer to a succession of mainshock-aftershocks sequence, with a high of aftershocks.

I) Geological Context



- The Frontal Penninic Thrust divides the Ubaye Region: West, Ubaye Valley; East, Serenne and High Durance fault networks.
- External zone composed of:
 - Crystalline basement inherited of the Hercynian chain (highly fractured);
 - Mesozoic-Cenozoic sedimentary cover (1-2 km thick);
 - Flysch à Helminthoïdes (1-2km thick) overlays the sedimentary cover.

Figure 1: Geological map of the Ubaye Region. The Late alpine faults coming from Tricart (2004). Modified from Baques et al. (2021).

III) Instrumental seismicity

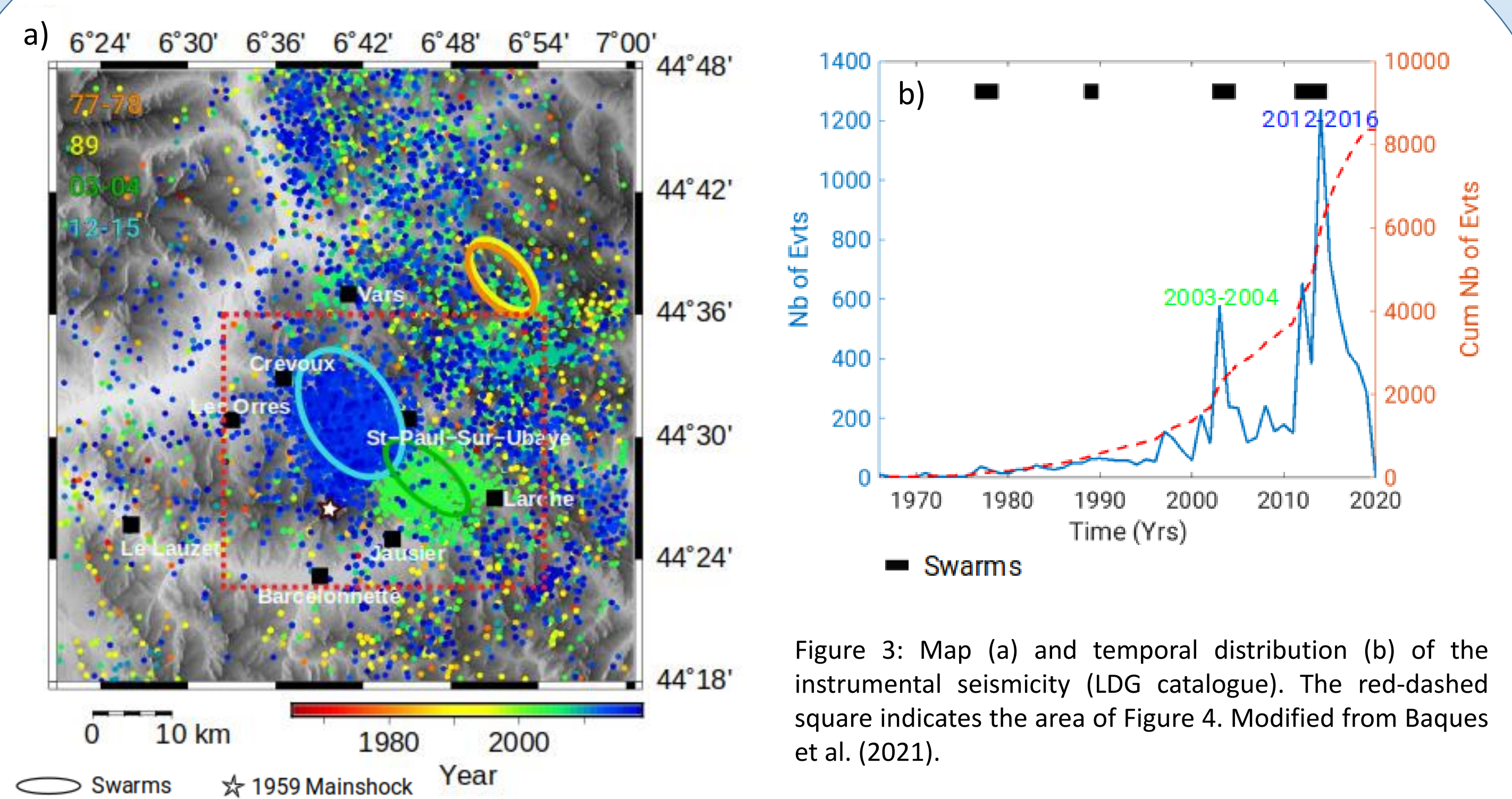


Figure 3: Map (a) and temporal distribution (b) of the instrumental seismicity (LDG catalogue). The red-dashed square indicates the area of Figure 4. Modified from Baques et al. (2021).

Date	Number of earthquakes located/detected	Maximum Magnitude (ML)	Maximum Intensity	Depth (km)	Lieu	References
1977-1978	200 (I)	3.6	-	0-13	Chambeyron	Fr
1989	250 (I)	3.4	-	10	Chambeyron	Gu
2003-2004	1616 (I)	2.7	-	3-8	Jausier	Je
2012-2016	6000 (I)	5.1	V-VI	4-11	Crevoux	Th, Db, Sir

Table 1: Information for the last 4 swarms. Fr: Fréchet and Pavoni (1979); Gu: Guyoton et al. (1990); Je: Jenatton et al. (2007); Th: Thouvenot et al. (2016); Db: De Barros et al. (2019). Sira et al. (2012,2014). Modified from Baques et al. (2021).

Two separated zones:

- Diffuse seismicity associated to the Serenne and High Durance fault system (East of Vars and Larche)
- Cluster of seismicity in the Ubaye Valley (Crevoux to Larche)

3 types of seismic sequences:

- Mainshock-aftershocks sequence (1959)
- Swarms (e.g. 2003-2004)
- Intermediate behaviours (2012-2016)

V) Conclusion

Continuous seismic activity:

Since the 18th century, seismicity is recurrent in the Ubaye Region, occurring between Crevoux and Larche and also East to Vars.

Processes:

- Earthquake-earthquake interaction (stress-transfer) → 59 % of 2003-2004 swarm (Daniel et al., 2011).
- Aseismic slip → No evidence has been found yet.
- Fluid-pressure → Model based on the 'fault valve behaviour' of Sibson (1990). Fluid-process seems mandatory. Presence of cap rock or impervious fault might lead to an increase of pressure at depth.

Complex distribution of seismicity:

The relocated seismicity reveals a complex network of smaller faults while the major faults (D, S, B, JT) are still clearly individualized. The complexity of the fault networks makes difficult to understand how the seismicity is distributed.

Seismic hazards:

- Swarms could lead to large earthquake (e.g. L'Aquila, Papadopoulos et al., 2010).
- Earthquakes occurred on blind, unknown faults that are not considered in seismic hazard assessment.