

La crise sismique induite à Strasbourg

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École et observatoire

des sciences de la Terre

de l'Université de Strasbourg

et du CNRS



La fréquence des séismes s'accroît depuis novembre 2019

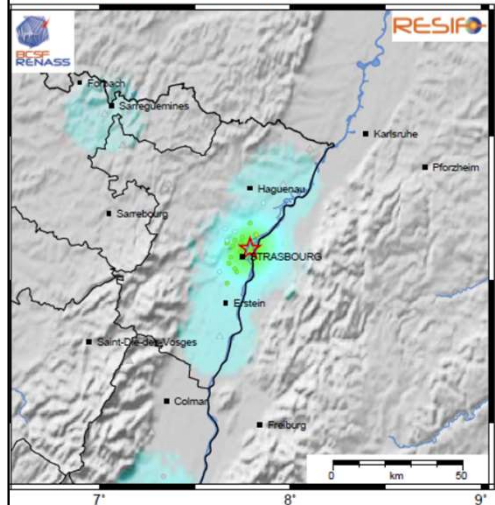


Intensité EMS98	I	II	III	IV	V	VI	VII	VIII	IX	X+
Dégâts potentiels bâtiments vulnérables	aucun	aucun	aucun	aucun	très légers	modérés	quelques effondrements partiels	nombreux effondrements partiels	nombreux effondrements	effondrements généralisés
Dégâts potentiels bâtiments peu vulnérables	aucun	aucun	aucun	aucun	aucun	aucun	très légers	modérés	effondrements partiels	nombreux effondrements
Perception humaine	aucune	très faible	faible	modérée	forte	brutale	très brutale	sévère	violente	extrême

Constaté au casuel	Ne constaté pas au casuel	Type d'observation
○	+	Intensité d'après données macro-sismiques (témoignages internet)
△	△	Intensité issue d'une conversion à partir du PGA / PGV (donnée instrumentale) Conversion PGA, PGV / Intensité basée sur Caprio et al. (2015)

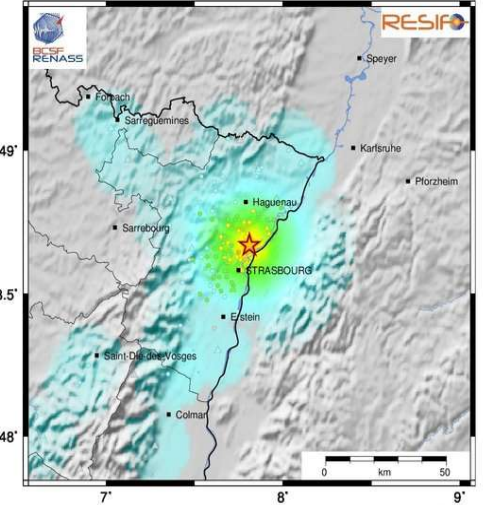
<https://www.franceseisme.fr/>

Estimation régionale de la secousse (à partir des données macro-sismiques et instrumentales)
Séisme du 12/11/2019 14h38 (heure locale)
12/11/2019 13:38:13 GMT M 3.0 48.61°N 7.79°E Prof.: 6.0km [source ReNaSS]



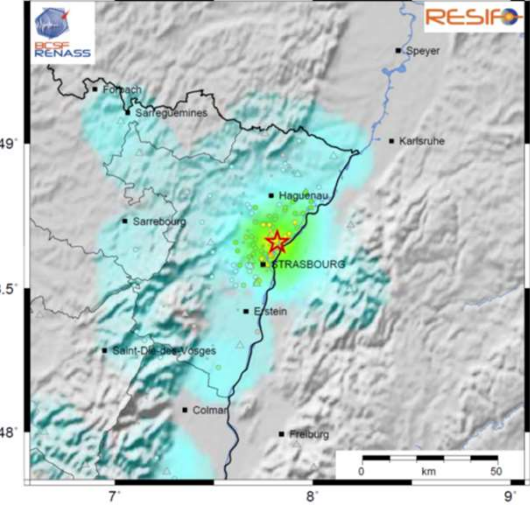
473 testimonies

Estimation régionale de la secousse (à partir des données macro-sismiques et instrumentales)
Séisme du 04/12/2020 06h59 (heure locale)
04/12/2020 05:59:02 GMT M 3.5 48.67°N 7.81°E Prof.: 4.0km [source ReNaSS]



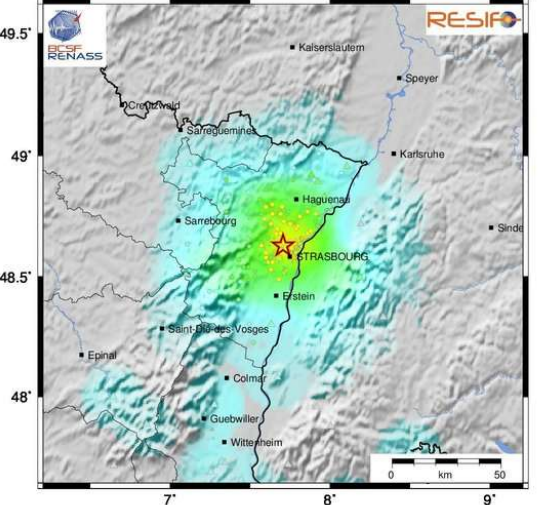
1291 testimonies

Estimation régionale de la secousse (à partir des données macro-sismiques et instrumentales)
Séisme du 22/01/2021 19h33 (heure locale)
22/01/2021 18:33:45 GMT M 3.3 48.66°N 7.82°E Prof.: 5.0km [source ReNaSS]

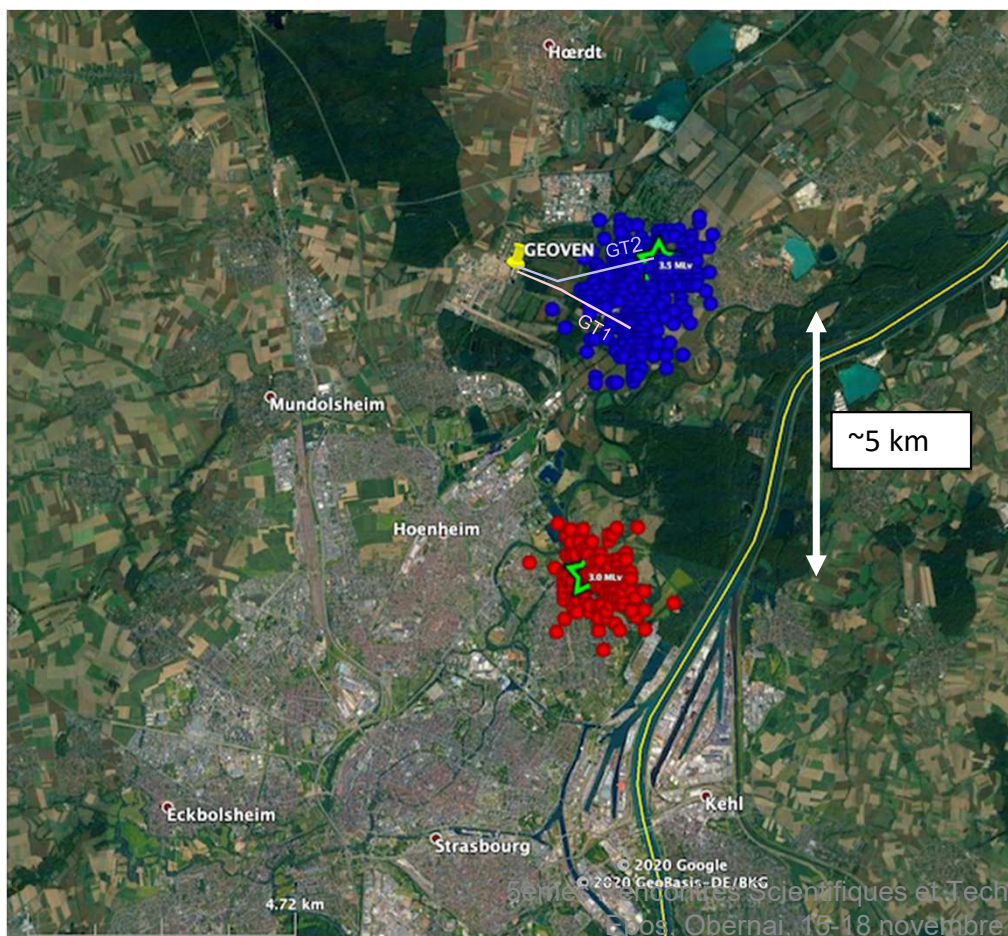


871 testimonies

Estimation régionale de la secousse (à partir des données macro-sismiques et instrumentales)
Séisme du 26/06/2021 05h00 (heure locale)
26/06/2021 03:00:25 GMT M 4.3 48.63°N 7.71°E [source CEA-LDG] / Prof.: 12.0km (fixée)



Strasbourg seismic swarms



Northern swarm Wells GT1 and GT2 – Vendenheim/Wantzenau

Activity : March 2018 – June. 2021

Catalog BCSF-RéNaSS :

- **3** eq $M > 3$ (Mlv 3.9 on 26/6/2021;
Mlv 3.6 on 4/12/2020; Mlv 3.3 on 22/1/2021)



11 eq $2 < M < 3$
23 eq $1.5 < M < 2$
309 eq $M < 1.5$

Southern swarm Strasbourg/Roberstau

Activity : Nov. 2019 – Apr. 2020

Catalog BCSF-RéNaSS :

- **1** eq $M > 3$ (Ml 3.0 on 12/11/2019)
- **3** eq $2 < M < 3$
- **17** eq $1.5 < M < 2$
- **105** eq $M < 1.5$

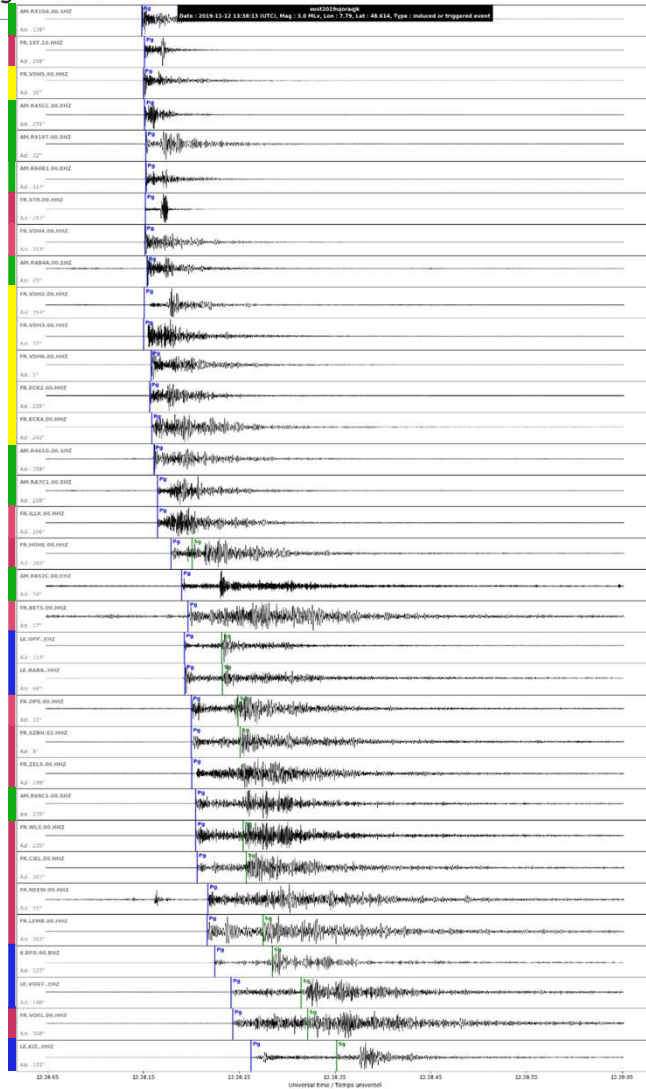




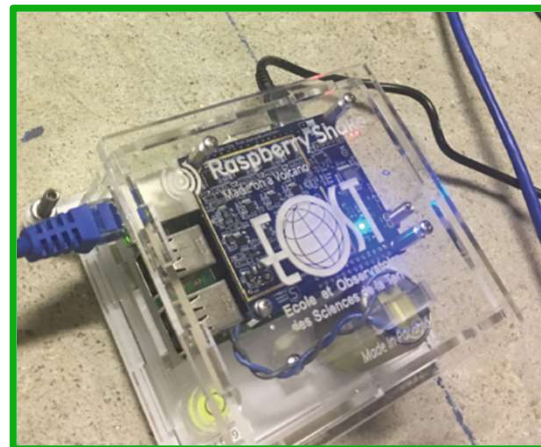
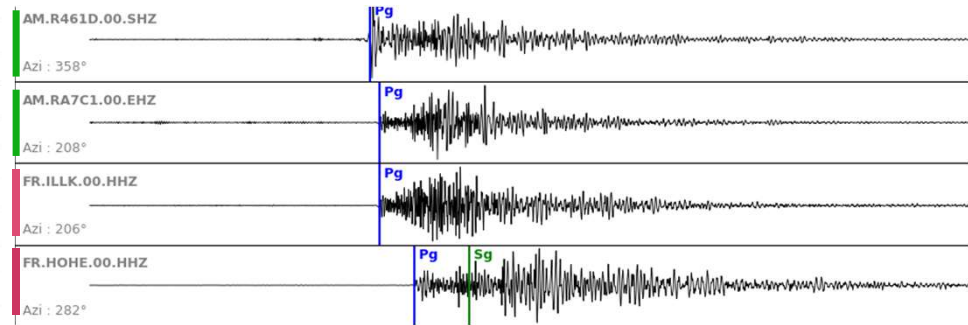
École et observatoire

des sciences de la Terre

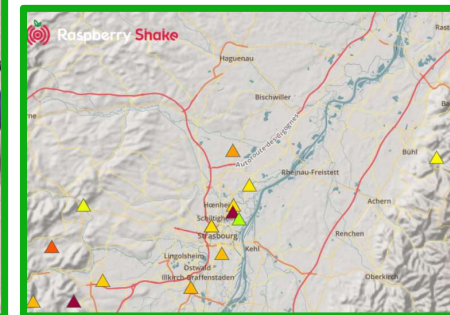
de l'Université de Strasbourg



12/11/2019 earthquake
34 stations / 46 phases



Citizen seismology project



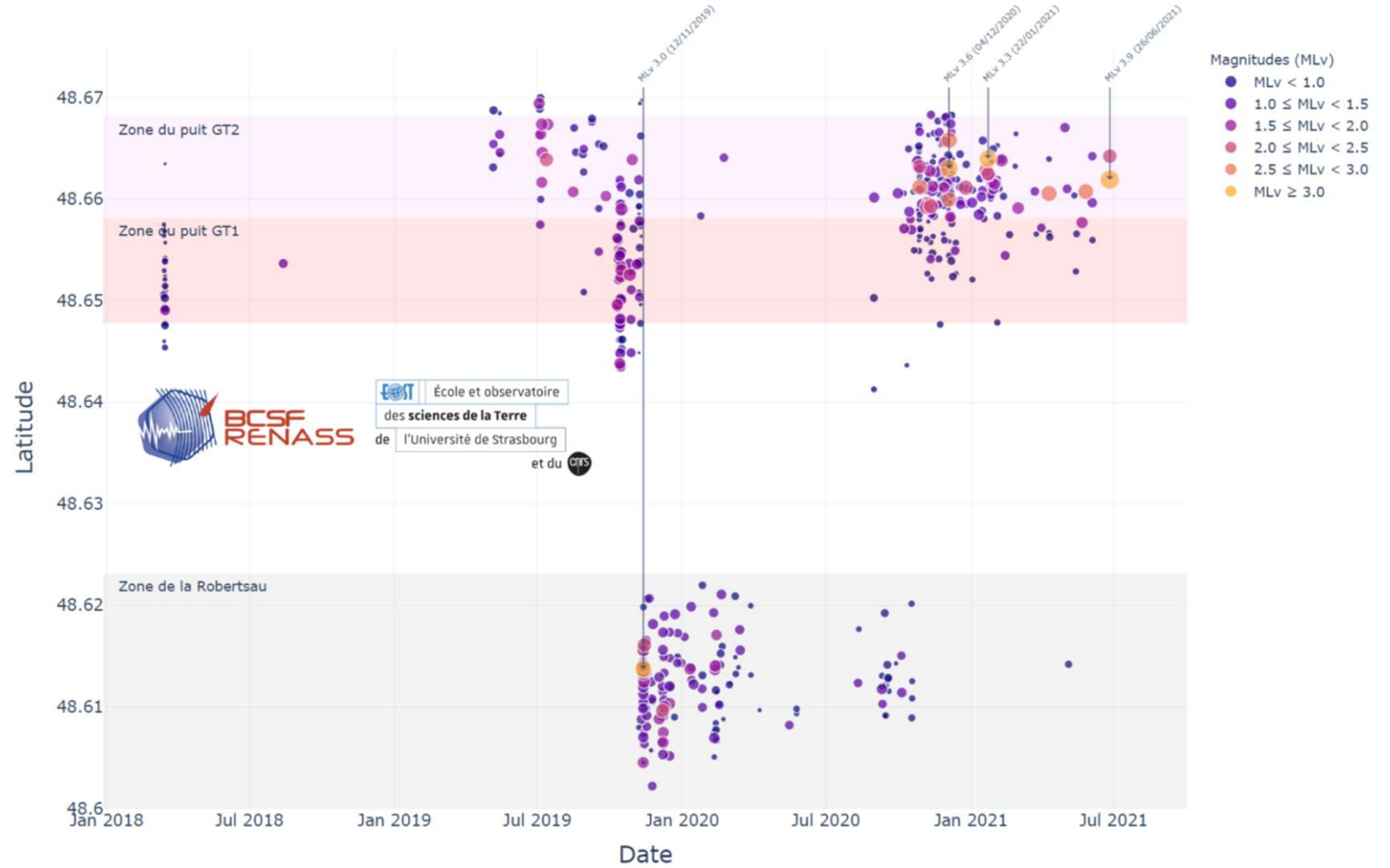
7 RaspberryShake stations

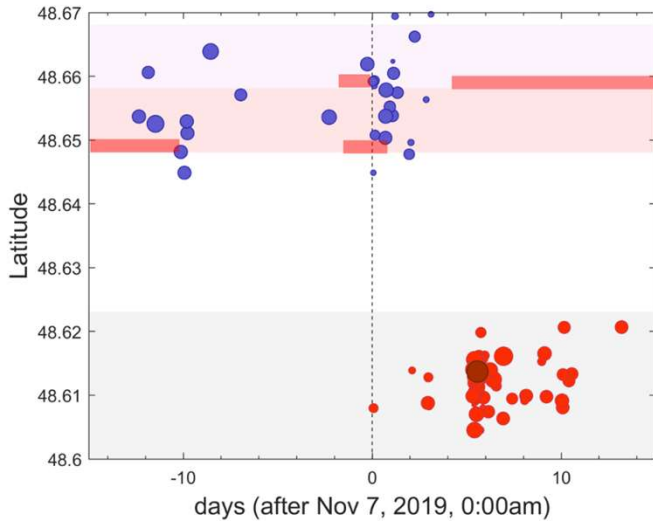
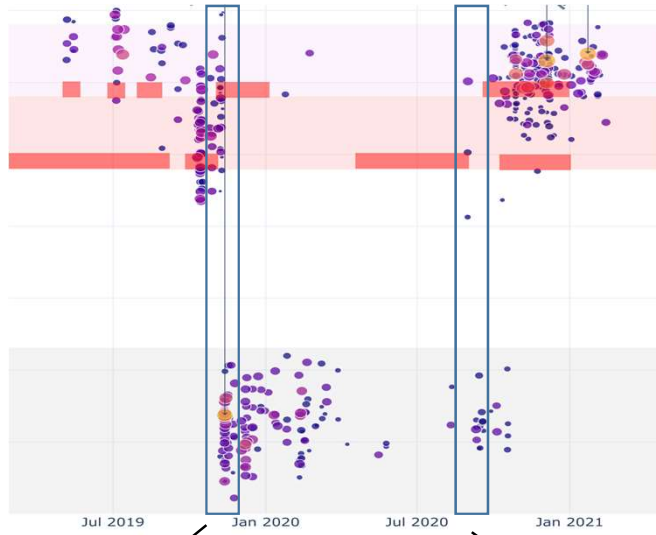
Seismicity From 2018



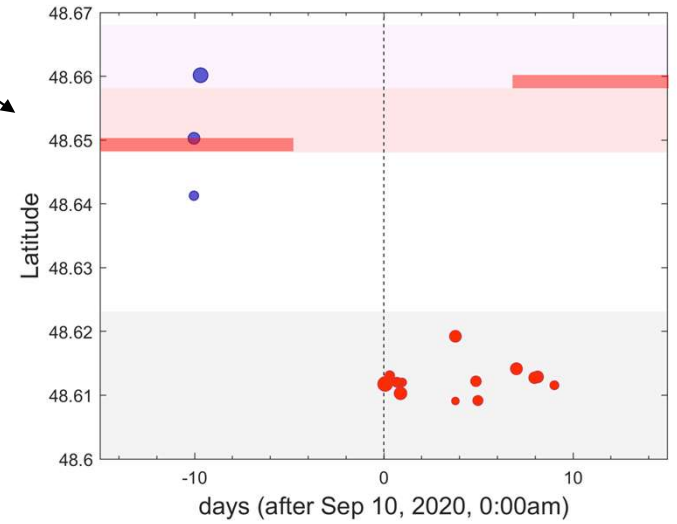
Northern cluster

Southern cluster





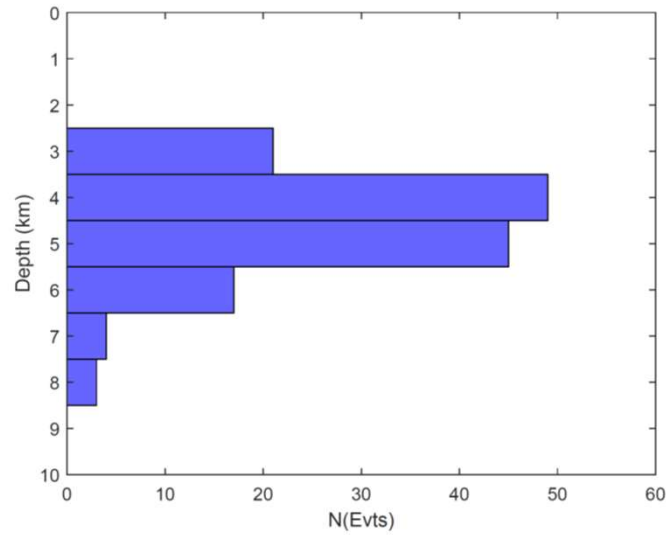
~10 day delay between
GT1 well and the southern
cluster



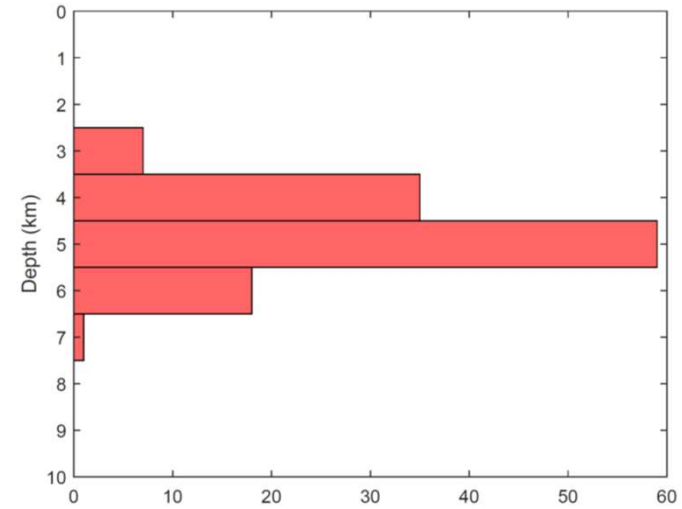
Depth distribution



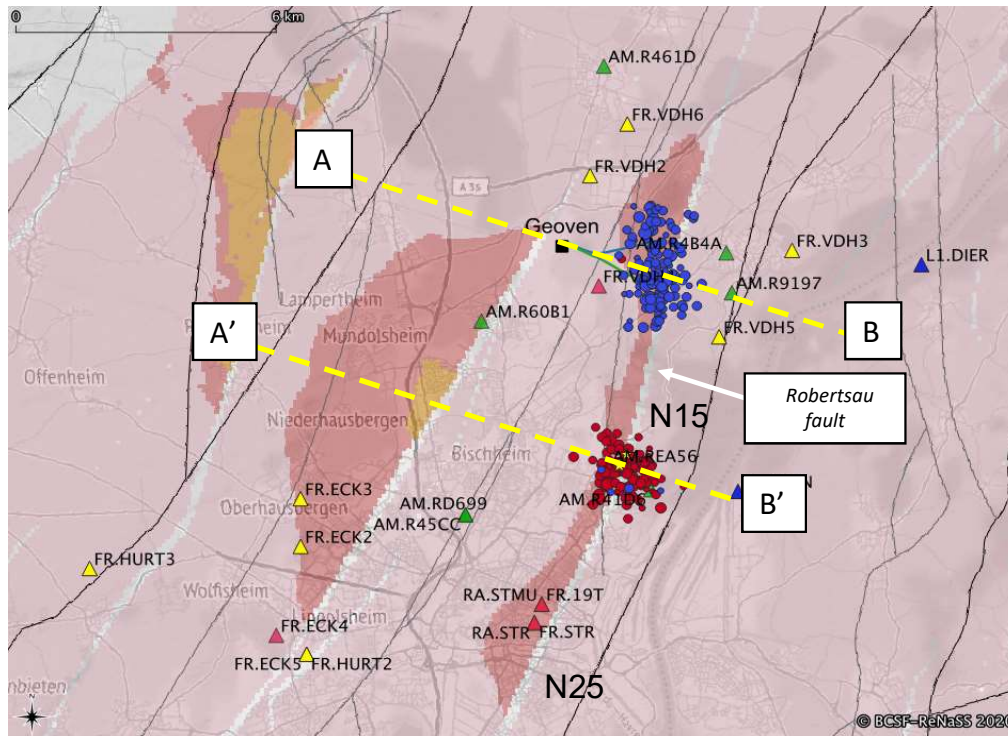
Northern swarm



Southern swarm

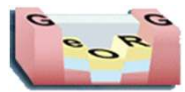
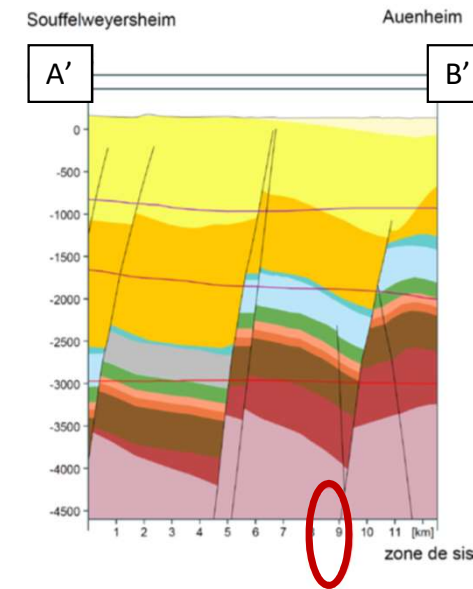
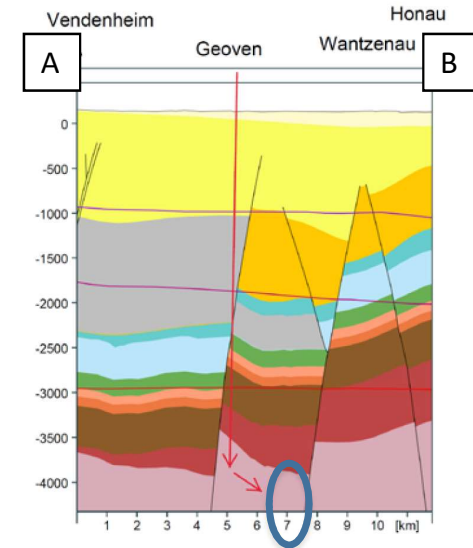


Geological context



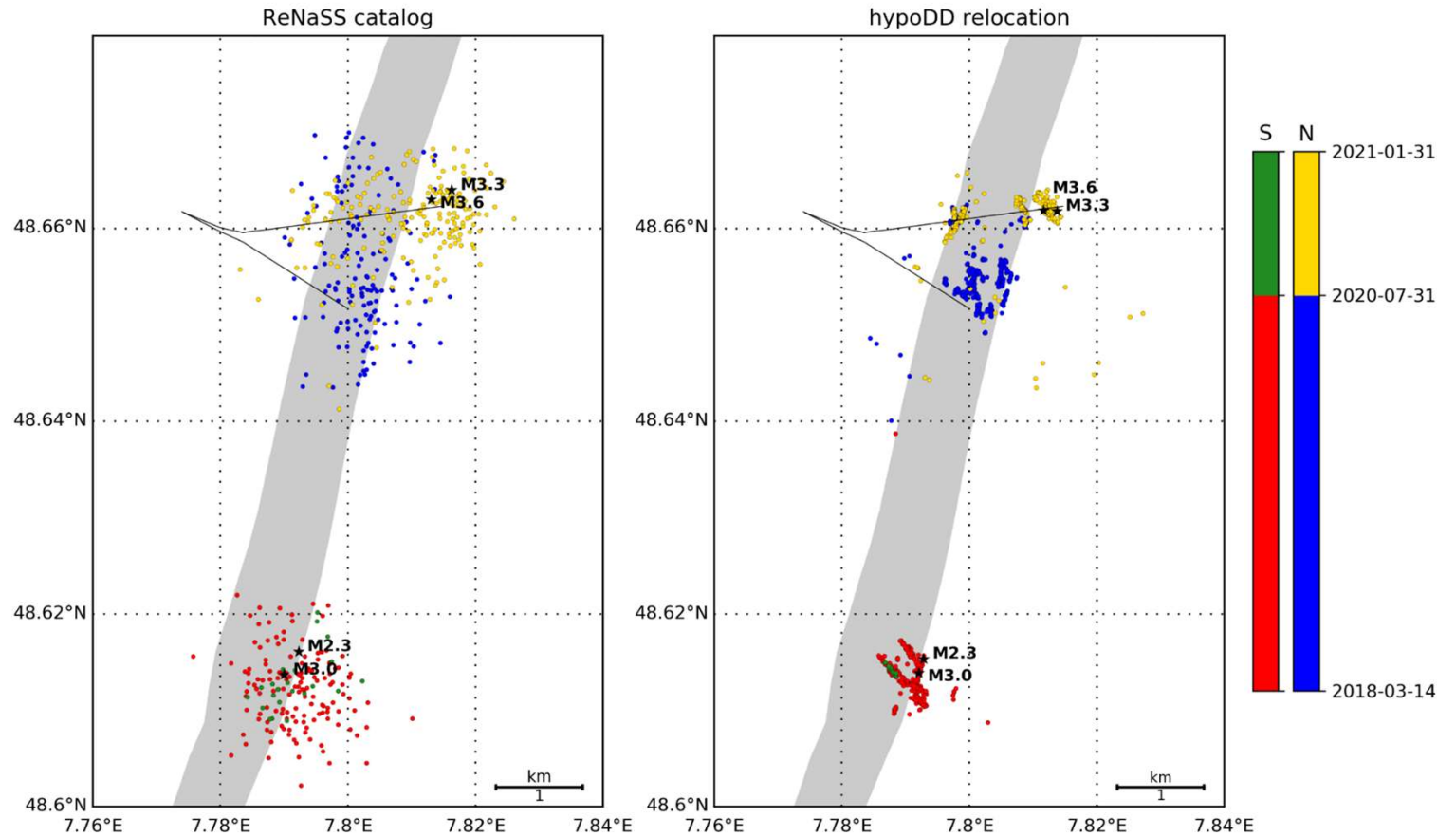
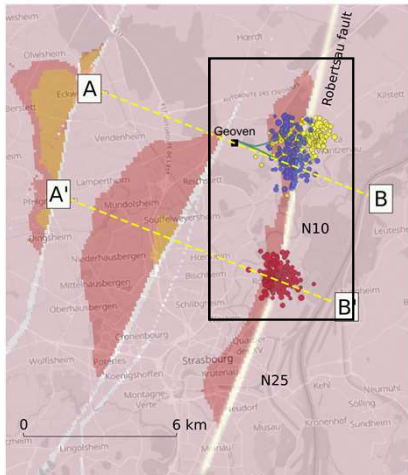
Geological map at a depth of 4000m

5èmes Rencontres Scientifiques et Techniques Résif-Epos, Obernai, 15-18 novembre 2021



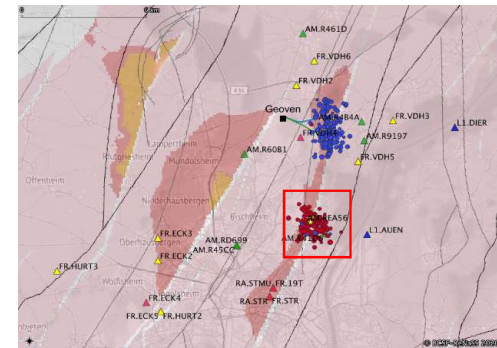
www.geopotentiale.org

Template matching + HypoDD relocations



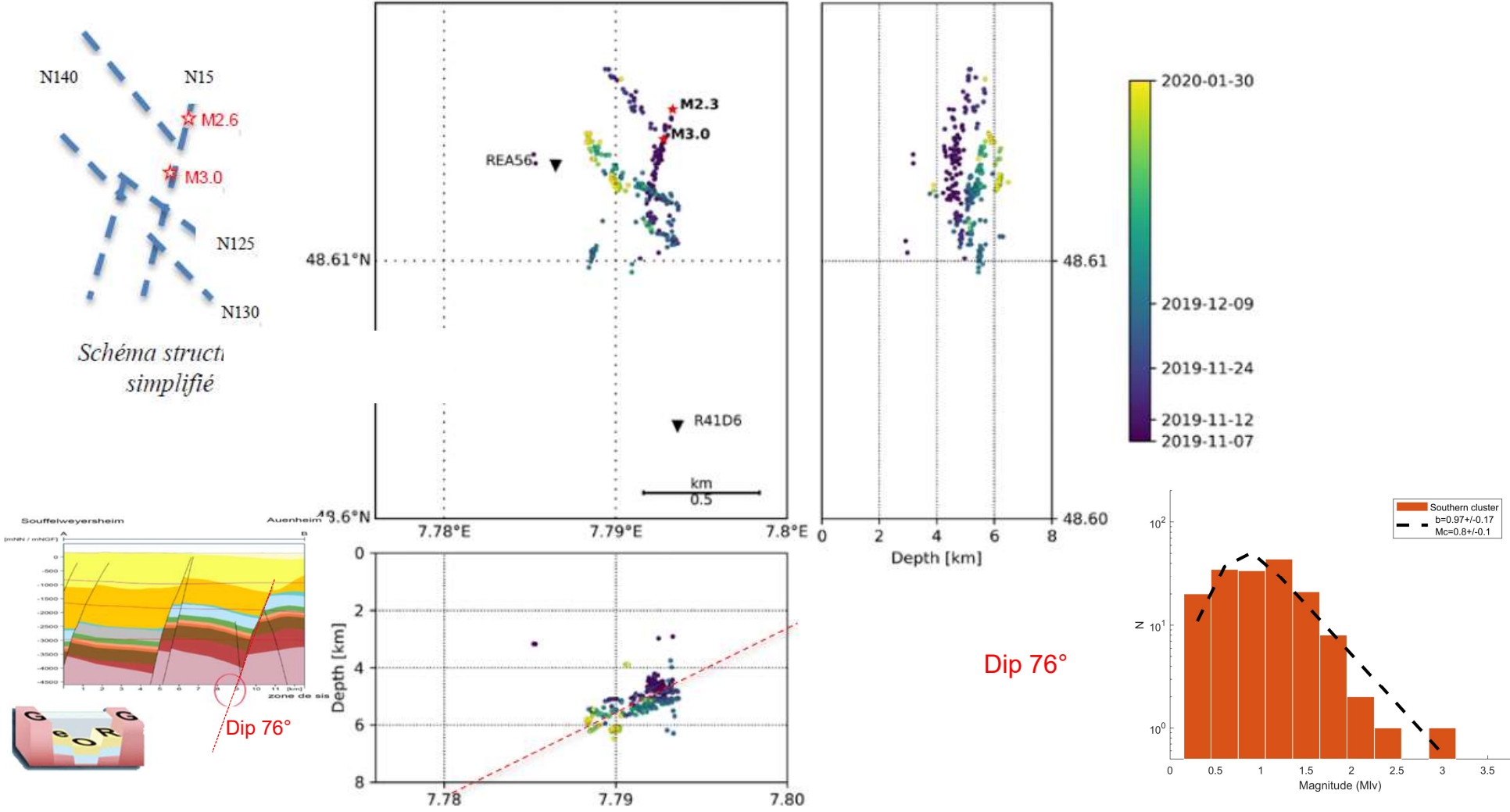
Southern cluster

Robertsau – Nov 2019



HypoDD relocation (zoom)

Southern cluster



Induced/triggered/natural seismicity ?

Davis & Frohlich, SRL, 1993

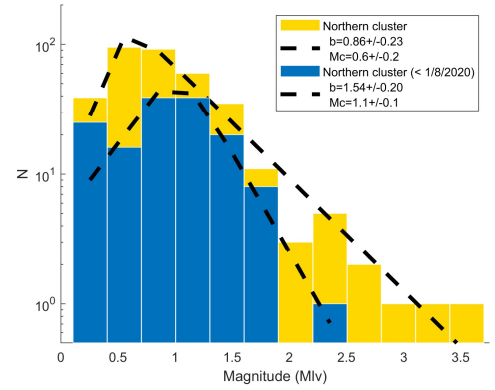
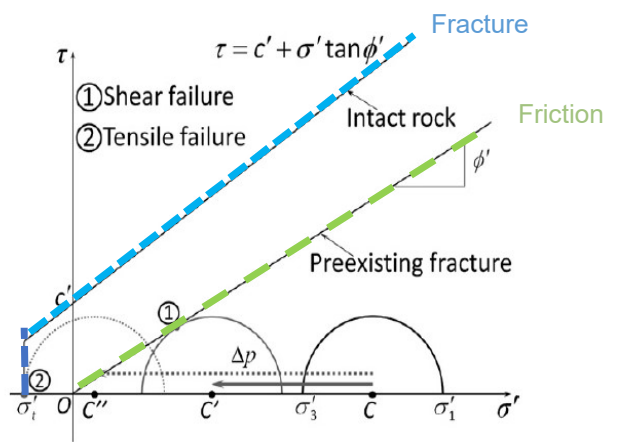
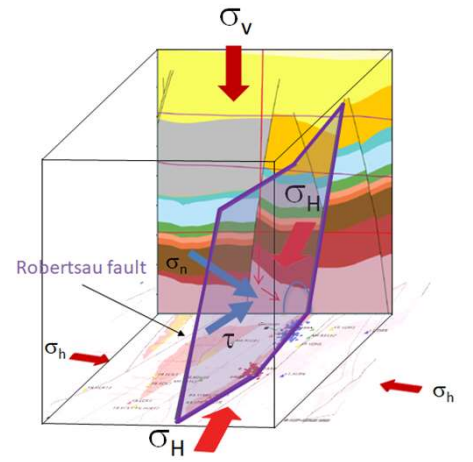
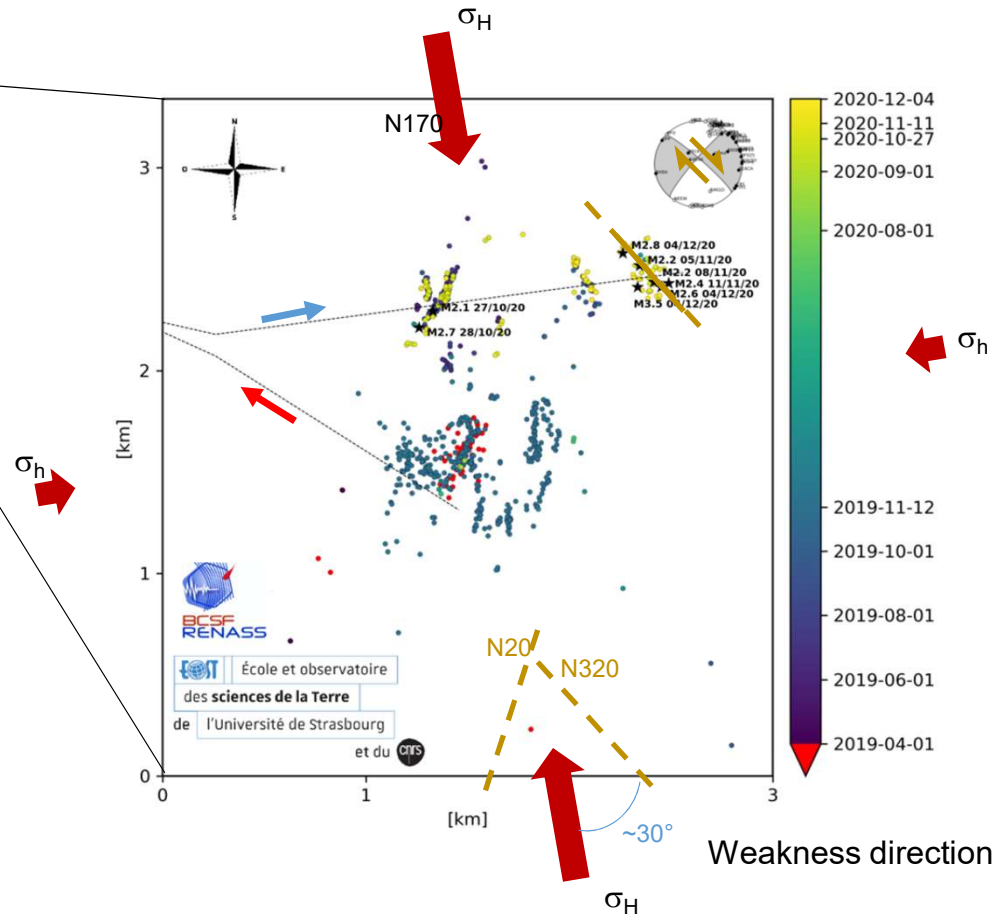
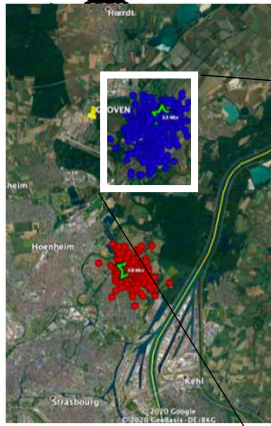
Question	Earthquakes Clearly NOT Induced	Earthquakes Clearly Induced
<i>Background Seismicity</i>		
1 Are these events the first known earthquakes of this character in the region?	NO	YES
<i>Temporal Correlation</i>		
2 Is there a clear correlation between injection and seismicity	NO	YES
<i>Spatial Correlation</i>		
3a Are epicenters near wells (within 5 km)?	NO	YES
3b Do some earthquakes occur at or near injection depths?	NO	YES
3c If not, are there known geologic structures that may channel flow to sites of earthquakes?	NO	?
<i>Injection Practices</i>		
4a Are changes in fluid pressure at well bottoms sufficient to encourage seismicity?	NO	YES
4b Are changes in fluid pressure at hypocentral locations sufficient to encourage seismicity?	NO	?
TOTAL "YES" ANSWERS	0	>5

Informations générales



Date & Heure Locale	12/11/2019 14:38:13
Date & Heure UTC	12/11/2019 13:38:13
Latitude :	48.61°
Longitude :	7.79°
Profondeur :	5 km
Magnitude :	3.0 MLv
Type :	Événement induit

Classified by BCSF-RéNaSS as 'induced event'



Conclusions

- Induced (northern cluster) and triggered (southern cluster) seismicity related to the deep geothermal site (Geoven/Georhin) (12 felt earthquakes $2 < M_{lv} < 4$)

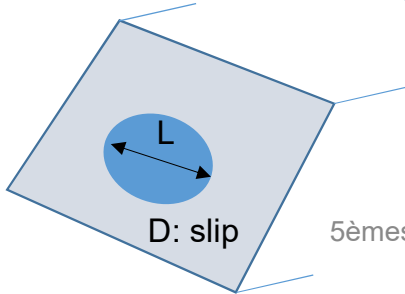
J. Schmittbuhl; S. Lambotte; O. Lengliné; M. Grunberg; H. Jund; J. Vergne; F. Cornet; C. Doubre; F. Masson. Induced and triggered seismicity below the city of Strasbourg, France from November 2019 to January 2021. *Comptes Rendus. Géoscience*, Online first (2021), pp. 1-24. doi : 10.5802/crgeos.71.

- Mechanisms for remote triggering (Southern cluster – 5km) ?
- Mechanisms for delayed triggering (Northern cluster – 6 months) ?
- A moratorium on regional EGS projects since Dec 4, 2020 (M3.6)
- Limited-access to industrial data
- On-going expertise on behalf of the prefecture -> first lessons (relevance of the conceptual model, transfer from previous projects, initial knowledge of the reservoir, effective size of the reservoir, injected volumes, project management, risk management, etc)
- Future projects: ITI GeoT / ANR PrESENCe (2022-2025) / ...

Earthquake characteristics

PGV [cm/s]	0.01-0.02	0.03-0.09	0.07-23	0.2-0.6	0.5-1.6	1.3-4.4	3.5-11.6	9-31	25-82	66-219	176-584	> 412
PGA [cm/s ²]	0.2-1.2	0.6-3.0	1.5-7.3	4-18	9-43	21-105	51-258	126-630	310-1540	750-3540	1830-9170	> 4470
EMS Intensity	I not felt	II scarcely felt	III weakly felt	IV largely observed	V strongly felt, hair cracks	VI slight damages	VII damaging	VIII heavy damages	IX destructive	X very destructive	XI devastating	XII complete devastating
Depth [km]	1 magnitude	2 Landau 2009 Mw 2.6 Soutz-sous-Forêts Mw 2.7	3 Basel 2006 Mw 3.2	4	5 Albstadt, 1911 Mw 5.7	6 L'Aquila 2009 Mw 6.3	7 Izmit 1999 Mw 7.6	8				
D [cm]	0.2 - 0.6	0.6 - 1.9	1.9 - 5.9	5.9 - 18.6	18.6 - 59	59 - 184	184 - 583	> 583				
L [km]	0.01 - 0.04	0.04 - 0.16	0.16 - 0.64	0.64 - 2.6	2.6 - 10	10 - 40	40 - 160	> 160				
Energy	1	× 32	× 1000	× 32,000	× 1,000,000	× 32,000,000	× 1,000,000,000	× 32,000,000,000				

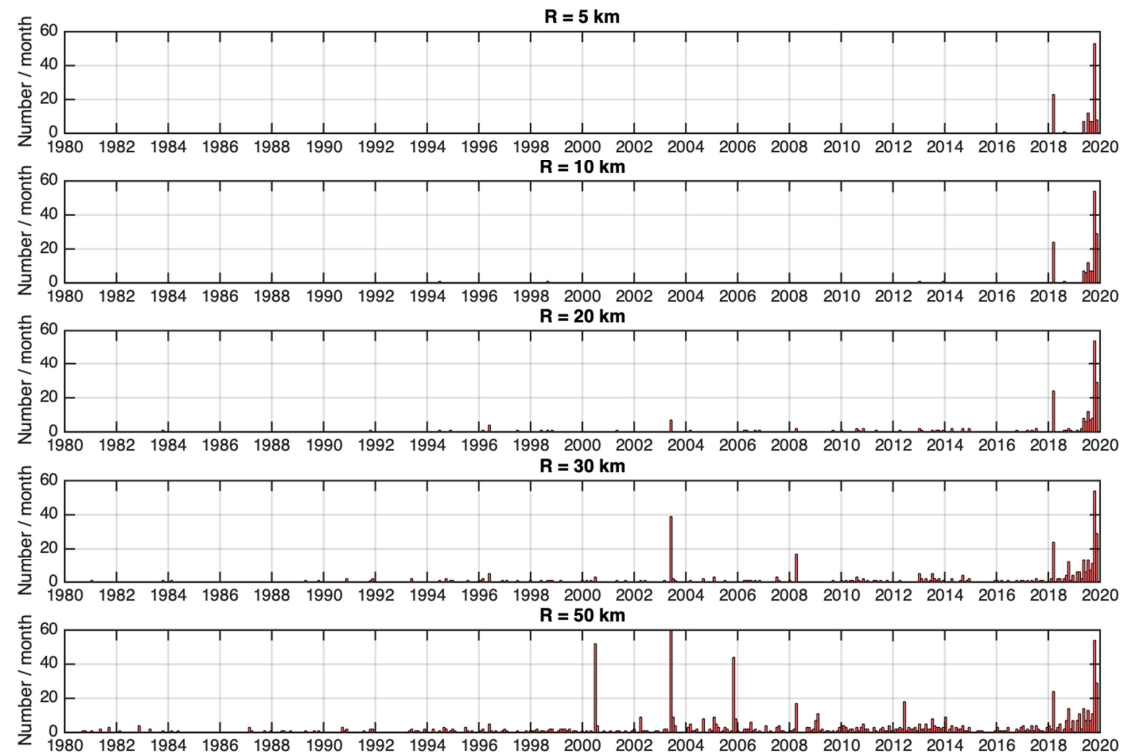
[Zang et al, 2014]



Strasbourg earthquakes: M3.0/M3.9
 L ~ 100-500m
 D ~ 1-5 cm

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 Epos, Obernai, 15-18 novembre 2021

Sismicity history



RéNaSS-BCSF catalog – circles centered on the GEOVEN well