Rapport d'activité

Etude de la génération de séismes et la propagation des ondes sismique
- Study on the earthquake generation and seismic wave propagation processes -

1. General Information

Projet : A00050406700
Responsable : AOCHI Hideo

Allocation
CINES BULL noeuds fins Occigen : 228 000 heures scalaires

Consommation
CINES BULL noeuds fins Occigen : 174 984 heures scalaires, soit 76.7% par rapport à 75.34% de temps passé (02/08/2019)

2. Scientific Results (below is written in English)

As planned in the scientific description of the current project (November 2018 to October 2019), the numerical simulations of dynamic rupture process and seismic wave propagation were carried out mainly for

- the 2016 Amatrice, Italy, earthquake
- the 2015 Illapel, Chile, earthquake

We could finalize our simulations of the 2016 Amatrice, Italy, earthquake (**Aochi & Twardzik, Pageoph, published online, 2019**) using the Boundary Domain Method which we recently developed (**Aochi, Geophys. J. Int., 2018**). Thanks to the allocated resources in 2018 and 2019, we could run more than 250 successful simulations for calibrating the mechanical parameters (location and size of seismogenic asperities, and frictional parameters) of the dynamic rupture process of this earthquake. Note that we needed more preliminary simulations in advance the successful simulations appearing on the paper. **Figure 1** illustrates a part of this analysis. The number of simulations does not allow yet automatic inversion process, and we had to limit the number and range of the model parameters. It took typically about 30 minutes on 20 nodes (560 cores) at CINES/occigen. The obtained dynamic model is very consistent with other kinematically obtained solutions and the obtained frictional parameters supports the scaling relation of fracture energy and earthquake magnitude. Seismologically speaking, it is important to estimate directly the frictional parameters (stress drop, fracture energy of interface) of earthquakes through high performance computation (**Figure 2**), to understand the earthquake physics and quantitatively construct possible earthquake scenarios for earthquake hazard study.

Only limited number of dynamic rupture simulations calibrated with the seismological data are available, and hopefully there will be more examples.

In parallel, we could progress on the modeling of the 2015 Illapel earthquake through the collaboration with University of Chile. We have first constructed the earthquake models by trial-and-error. Different seismogenic patches are spatially distributed under the fracture energy scaling so as to be qualitatively comparable with the ground motion observations (acceleration and continuous GPS networks) in terms of the rupture directivity (**Aochi & Ruiz, AGU, 2018**). Typical dimension of the modeling is a fault of 175 km x 130 km (reduced resolution of a fault element of 1 km; this is a limit for many simulations) and a volume of 300 km x 450 km x 50 km (still reduced resolution of grid of 500 m, but this is enough for discussing very low-frequency behaviors). It is worth remarking that our preferred model is consistent with the geodetic seismic coupling map and may reflect the past large earthquakes (**Figure 3**). However we had to constrain more quantitatively our dynamic model, so that we started kinematic inversion by patch, during which the Green's functions are calculated using Finite Difference Method for all the combination of sub-faults (14 x 22 = 308) and receivers (about 15) for different resolutions. The result of this inversion shows the maximum seismogenic patch located in the north, separated from the epicenter area (**Figure 4**). Furthermore the rupture is launched with a delay of tenth seconds and a rupture directivity different from the hypocenter. This feature is very consistent with the previous dynamic simulations. These results will be presented in AGU (December 2019) and writing a paper is planned in parallel.

Besides the main topics presented above, it is worth mentioning other contributions.

- A version of BIEM has been calibrated for generating many earthquake scenarios in order to study statistically the acceleration phase of source time function (contribution to the PhD thesis of Julien Renou of IPGP in progress).
- Local earthquakes are modelled using FDM such as the 2018/08/29-Mw1.25 earthquake in Fuveau, near Marseille, around the abandoned mining site of Gardanne (unpublished work, **Figure 5**).

For future works, according to the launching of the French national project ANR Modulate (Modeling long-period ground motions, and assessment of their effects on large-scale infrastructures), we started analyzing the observational data and check the existing 3D geological model. The contribution from the numerical simulations is planned in the coming proposal toward 2020.

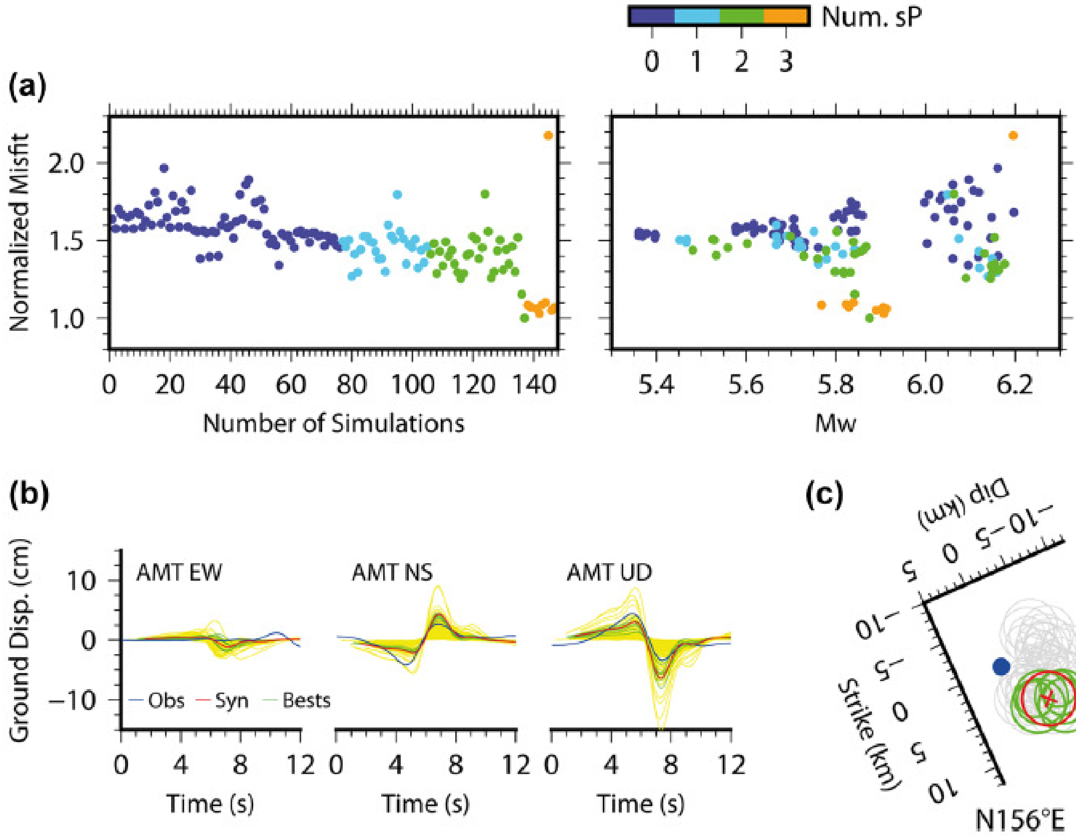

Figure 1 : Convergence process of dynamic rupture simulation (a) comparing to the near-fiield ground motion (b). The best solution of the first seismogenic asperity (red circle) is found with respect to the nucleation point (blue) after about 140 simulations, by changing the position and size of the asperity and frictional parameters . After Aochi and Twardzik (Pagoeph, 2019).

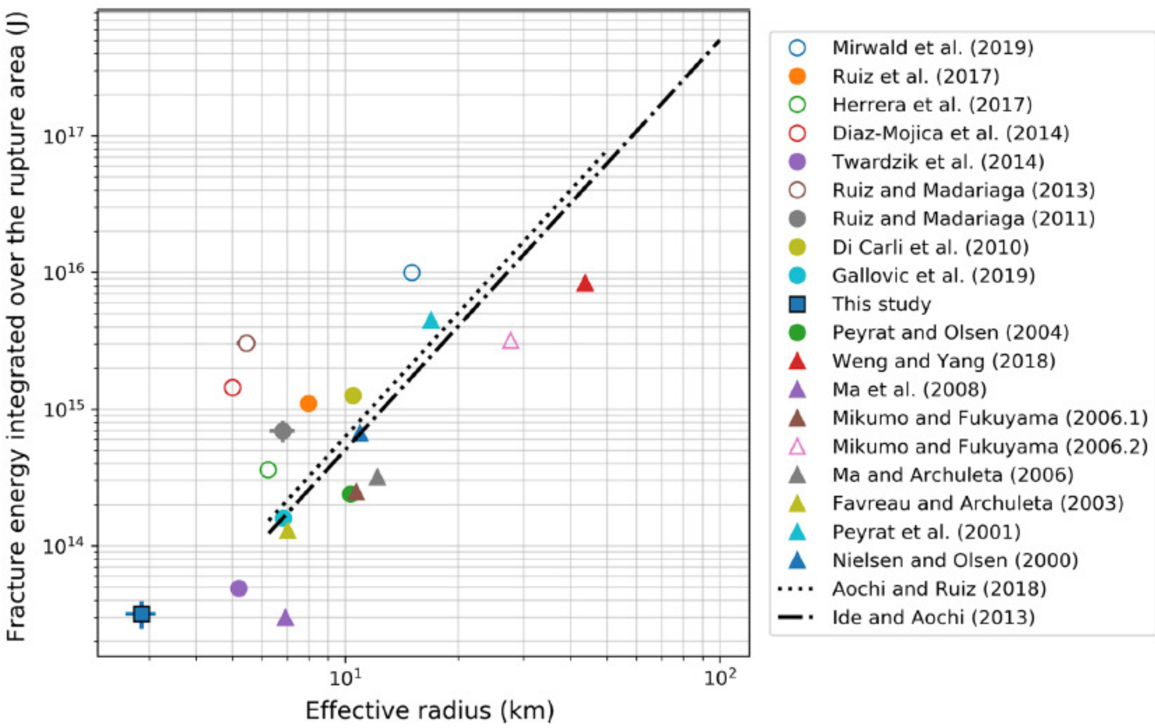

Figure 2: Scaling relation of seismogeic asperity size and fracture energy from dynamic rupture simulations (inversions) for different earthquakes. The 2016 Amatrice earthquake (**Aochi & Twarzik, 2019**) is found in the left-bottom corner, thus, the minimum seismic asperity (Mw~6) among all the studies. The scaling relation assumed for the 2015 Illapel earthquake (**Aochi & Ruiz, 2018**) is also included.

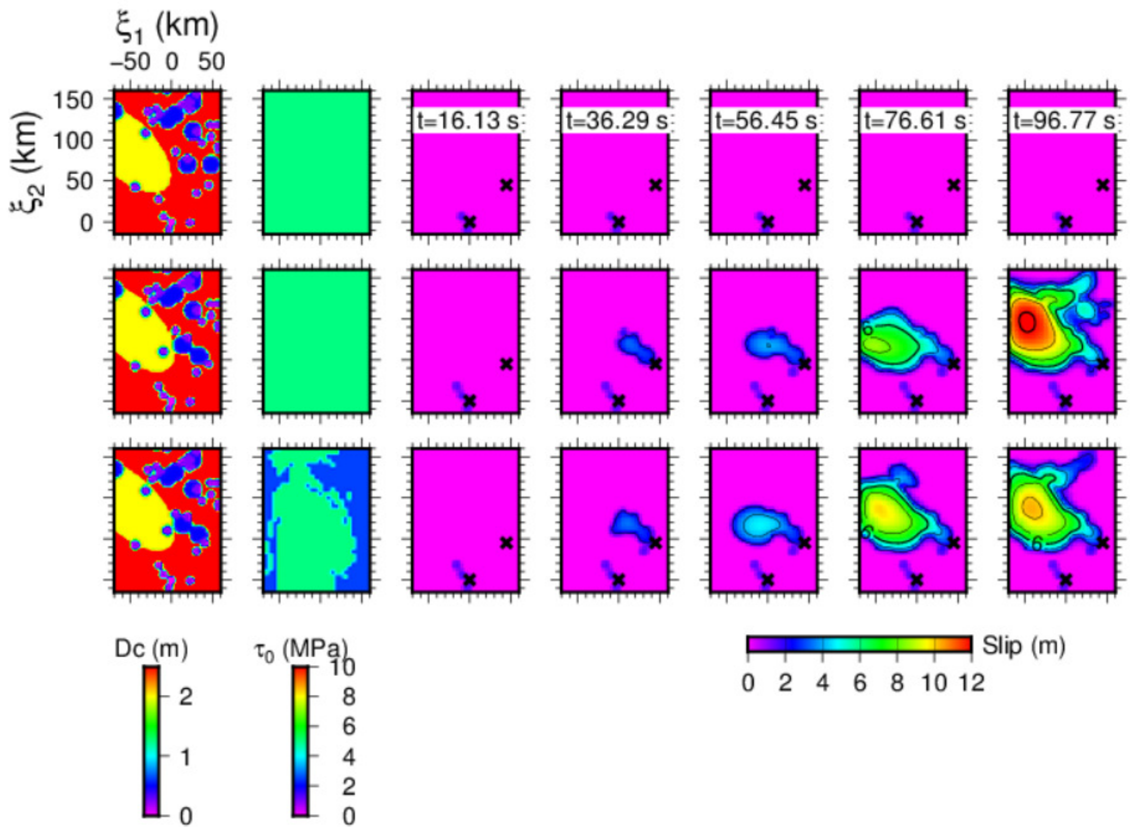

Figure 3 : Calibration of dynamic rupture simulations (**BIEM + FDM**) for the 2015 Illapel earthquake. The seismogenic patch distribution (left column) is assumed after past seismicity of moderate and large earthquakes. The initial stress level is assumed based on the seismic coupling of the interface. The snapshots show the rupture propagation with the first hypocenter (0, 0) and the second one at (40 km, 45 km) with a delay of 17 s.

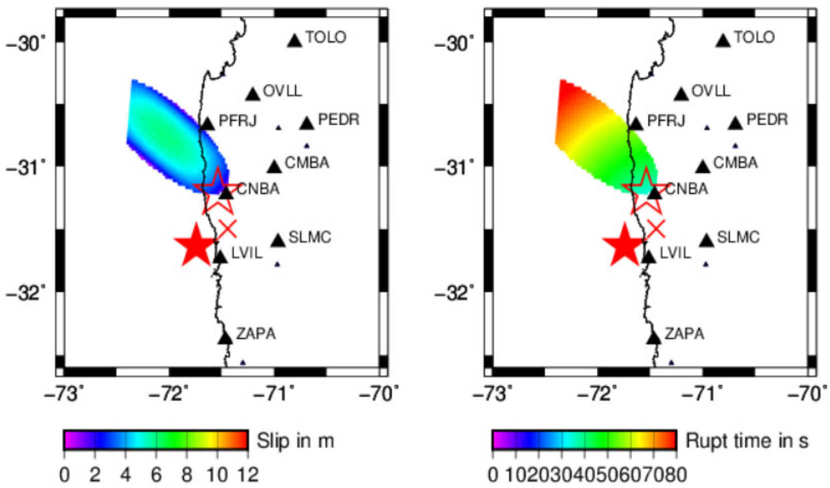

Figure 4: The kinematic inverion of the seismogenic patch. The hypocenter is the solid star. However the origin of the rupture propagation is represented by the cross so that the rupture on the patch starts from the open star.

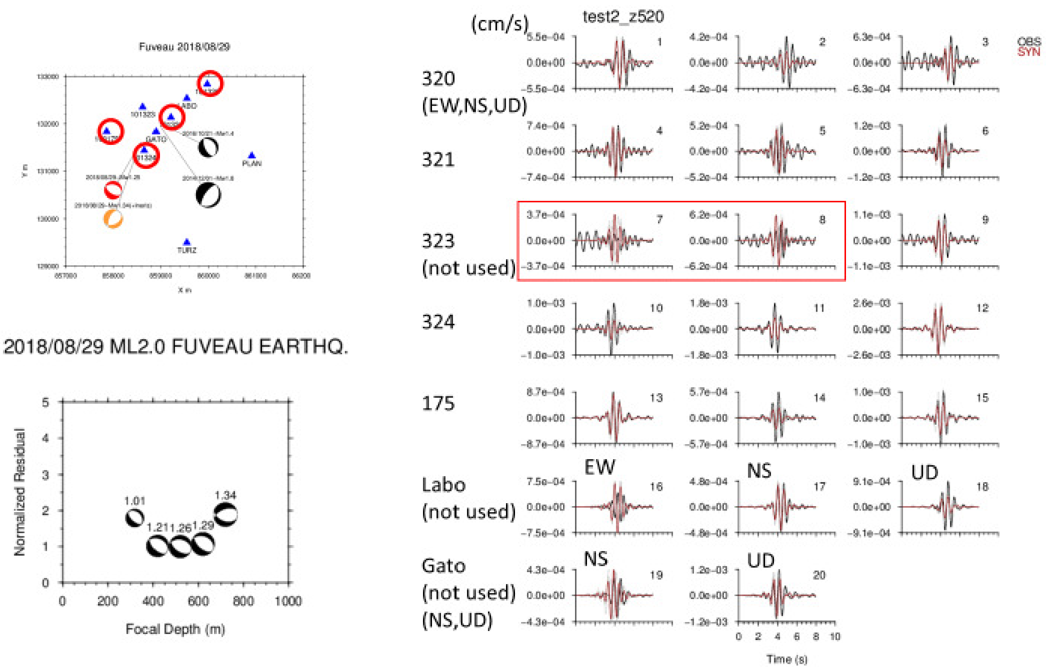

Figure 5: Analysis of the 2018/08/29 ML2.0 Fuveau (Provence) earthquake under the abandonned mining site. The wave propagaiton is calculated through FDM. (Aochi et al., unpublished work, 2019).

3. Publications submitted or in preparation

Aochi, H. and C. Twardzik, Imaging of seismogenic asperities of the 2016 ML6.0 Amatrice, Central Italy, earthquake through dynamic rupture simulations, Pageoph, published on line, doi:10.1007/s00024-019-02199-z, published on line, 2019.

Aochi, H., Dynamic asymmetry of normal and reverse faults due to constrained depth-dependent stress accumulation, Geophys. J. Int., 215, 2134-3243, doi:10.1093/ggy407, December 2018.

In preparation

Aochi, H. and S. Ruiz, Kinematic and dynamic modeling of the 2015 Mw8.3 Illapel, Chile, earthquake, in preparation, according to the presentation planned at AGU Fall Meeting in December 2019.

4. Conferences and posters

Aochi, H. and S. Ruiz, Dynamic rupture simulation of the 2015 Mw 8.3 Illapel (Chile) earthquake, AGU Fall Meeting, San Francisco, USA, December 2018.

Aochi, H., Understanding b-value of Gutenberg-Richter relation from dynamic rupture simulations, EGU General Assembly, Vienna, Austria, April 2019.