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 : A00090406700
Responsable : AOCHI Hideo

Allocation
CINES BULL noeuds fins Occigen : 276 000 heures scalaires

Consommation
CINES BULL noeuds fins Occigen : 202 780 heures scalaires, soit 73.5 % des heures accordées (20/08/2021)

2. Scientific Results (below is written in English)

First of all, we could archive the work on the 2015 Mw8.3 Illapel (Chile) earthquake after several revisions (**Aochi & Ruiz, JGR, April 2021**). We had to carry out numerical verification tests of BIEM (Boundary Integral Equation Method) according to the reviewer's demand. The major results were already reported in the previous report of year 2019-2020.

On the other hand, we began to configure Boundary Domain Method (BDM), a hybrid method combining boundary integral equation and finite difference methods. The targets are both for a strike-slip faulting such as the 2019 Mw7.1 Ridgecrest, California, earthquake and a reverse faulting such as the 2019 Mw4.9 Le Teil, France, earthquake. Physical questions are always raised on the initial and boundary conditions, namely initial stress field and frictional parameters along the causal faults. In parallel, we have developed a theoretical concept of strain-constrained depth-dependent stress accumulation (**Aochi & Tsuda, EGU, 2021**). According to this idea, we realize certain numbers of simulations, particularly in order to reply to the question why the earthquake rupture is limited at certain depths with and without surface rupture.

Figure 1 shows two simulation examples for a strike-slip fault. Initial stress field is given based on the Mohr-Coulomb diagram. Instead of assuming that the stress is accumulated at any depth as much as possible (in most cases), we start with the constraint that the strain is continuous and decreases from depth to the surface in a given 1D layered medium, which is typical in the Earth's crust. Consequently, the rupture favorites are not uniform along the depth. There appears a depth layer which is not likely for the rupture progress (4 km depth in this example), and this controls the earthquake extension. Only the difference in the two simulations is the fault dimension. The rupture starts in the same way (until t = 100 Δt). The less favorable layer of 4 km depth obliges the rupture to propagate laterally or toward the depth. If the rupture becomes sufficiently large at depth, a shallower layer can be ruptured upto the ground surface such as Case (a). However if the horizontal extension of rupture is limited at depth, a shallow part is not ruptured. These numerical examples indicate that the rupture scenario (earthquake dimension and magnitude) is pre-controlled by the 1D structure in the stress accumulation and also restricted by the horizontal extension of fault segment at depth. This insight had been ignored in most cases of dynamic rupture simulations and should be important for seismic hazard applications. The same discussion is possible for normal and reverse faults. Theoretical formulation and some of the synthetic simulations are included in **Aochi & Tsuda (submitted to GRL, August 2021**) and the other simulations are to progress further in the framework of the new ANR project (See the research plan 2021-2022).

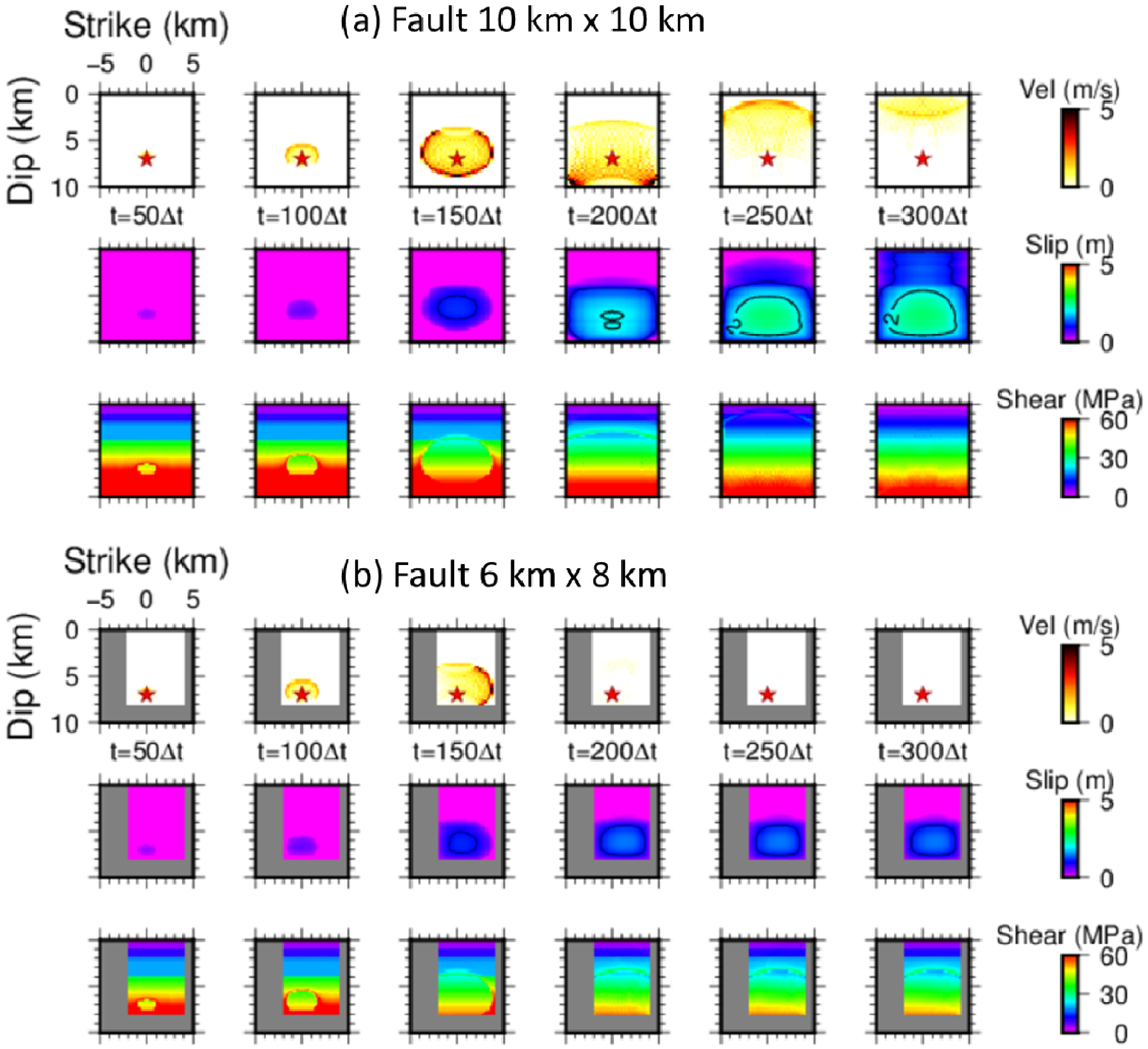

Figure 1: Snapshot of dynamic rupture simulations of a strike-slip fault (partially presented in Aochi & Tsuda, EGU, 2021). The same initial stress field is assumed

according to the strain-constrained condition. The initial nucleation area is supposed at 7 km depth indicated by a star. Slip rate, cumulative slip and absolute shear stress on the fault are shown in each row. (a) Fault dimension of 10 km x 10 km. (b) 6 km (strike) x 8 km (dip). Although the stress condition is the same for both cases, the rupture is limited at depth for case (b). Spatial grid of 200 m and time step of 0.017 s.

Similarly, **Figure 2** shows a simulation of the 2019 Le Teil earthquake (**Aochi & Tsuda, submitted to GRL, 2021**). It is a question why a M5 event ruptured the shallowest part of the crust less than 1 km depth. This is important in the sense if a similar earthquake may happen in the area and if a deeper portion of the fault remains hazardous for a future earthquake. We believe that the 1D layered structure representing the area is a key to answer. By applying the same formulation of strain-constrained depth variation model in constructing the initial stress field, we remark that a hard layer between 600 and 1200 m principally controls the stress accumulation on the fault. Dynamic rupture simulation shows that the rupture initiated at around 1 km depth propagates first laterally and arrives slowly at the ground surface, while the rupture is limited at depth. This explains why this M5 event has a very shallow ruptured area with surface traces. If our hypothesis is correct, the stress is only accumulated around one shallow layer. The deeper part is not charged enough to launch the earthquake rupture.

Numerically speaking, this earthquake (M ~ 5) is small such that the physical domain of calculation is also small (7500 m x 7500 m x 3750 m). However, according to the scale-dependent frictional parameters and fine layers, we need fine numerical grids of 25 m and a time step of 0.0005 s. In the BDM, the fault has 73 x 131 = 9563 elements and the 3D volumes of 320 x 320 x 270 = 27.6 million grids. The presented example takes about 24 hours over 20 nodes (x 28 cores) using OpenMP-MPI parallel techniques.

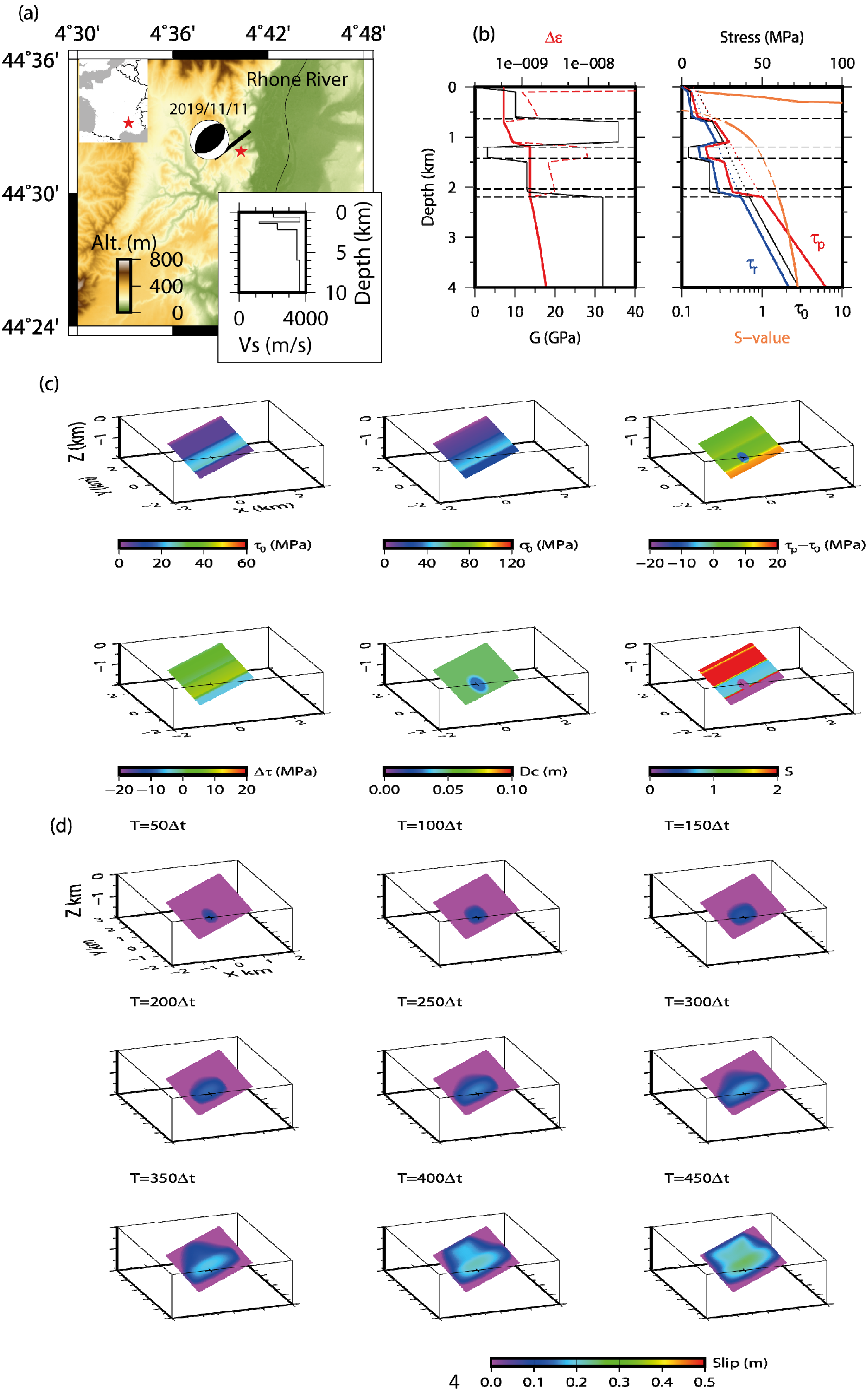
(a)
4°30'
4°36'
4°42'
4°48'
44°36'
44°30'
44°24'
Rhone River
2019/11/11
Alt. (m)
800
400
0
0
5
10
Depth (km)
0
4000
Vs (m/s)
(b)
Δε
1e−009
1e−008
Depth (km)
G (GPa)
Stress (MPa)
0
50
100
0.1
1
10
τ0
τp
τr
S−value
(c)
Z (km)
Y (km)
X (km)
τ0 (MPa)
σ0 (MPa)
τp−τ0 (MPa)
Δτ (MPa)
Dc (m)
S
(d)
T=50Δt
T=100Δt
T=150Δt
T=200Δt
T=250Δt
T=300Δt
T=350Δt
T=400Δt
T=450Δt
Z km
Y km
X km
Slip (m)
0.0
0.1
0.2
0.3
0.4
0.5

Figure 2: Simulation of the 2019 Mw4.9 Le Teil, France, earthquake. (a) Map of the area (approximative fault by solid line, focal mechanism and estimated epicenter location after Delouis et al. (2019, http://www.cnrs.fr/sites/default/files/press_info/2019-12/Rapport_GT_Teil_phase1_final_171219_v3.pdf). 1D layered structure is estimated by Cornou et al. (2021, https://doi.org/10.5802/crgeos.30). (b) Construction of stress field along depth. Depth variation of strain-constrained Δε in bold red line. Broken line indicates a homogeneous medium for reference. The grey line indicates the depth variation of the rigidity G, for which each layer is indicated by horizontal lines. (c) The initial stress field and frictional parameters supposed on the fault. (d) Snapshot of the dynamic rupture simulation.

3. Publications submitted or in preparation

Aochi, H. & K. Tsuda, On the depth-dependent stress accumulation controlling earthquake rupture, submitted to Geophysical Research Letters, August 2021.

Aochi, H. and S. Ruiz, Early Stage and Main Ruptures of the 2015 Mw8.3 Illapel, Chile, Megathrust Earthquake: Kinematic Elliptical Inversions and Dynamic Rupture Simulations, J. Geophys. Res., 126, e2020JB021207, 2021. https://doi.org/10.1029/2020JB021207

4. Conferences and posters

Aochi, H. & K. Tsuda, On the depth-dependent stress accumulation for earthquake generation process, EGU General Assembly conference Abstracts, EGU21-8682, online, April 2021. https://doi.org/10.5194/egusphere-egu21-8682