Point Source Seismogram using 2D staggered-grid finite difference method

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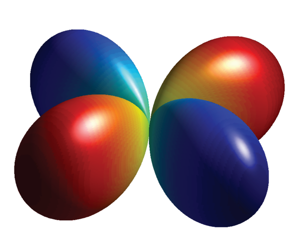
Introduction

Our understanding of earth structure has increased significantly based on our ability to model seismograms. While considerable progress has been made in modeling 3D structure at the longer period (> 3 s), the shorter periods are more challenging due to large computing demanding, and thus 2D synthetics are widely used. However, it proves difficult to treat the 3D nature of earthquake sources with 2D solutions of the wave equation. Here, we use the Cagniard-de Hoop method to separate motions from a shear dislocation into SH and P-SV system, which can then be used in 2D modeling. This interfacing becomes complicated for staggered grid FD code, which is developed here. We first test our method against the existing theoretical and FK synthetics, and then study the effects of water on regional seismograms.

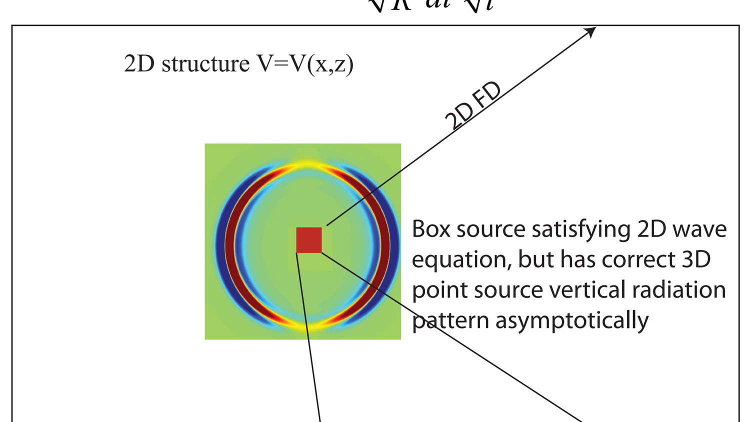
Method

The main difficult with 2D simulation is how to implement the point source with the correct radiation pattern. Helmberger and Vidale (1988) proposed an approach, which can tackle this problem effectively. Following this approach, the complete point source solution is expressed in an asymptotic form, which is further separated into SH and P-SV system. This formalism enables us to model the earthquakes with a line source excitation in 2D by performing FD simulation.



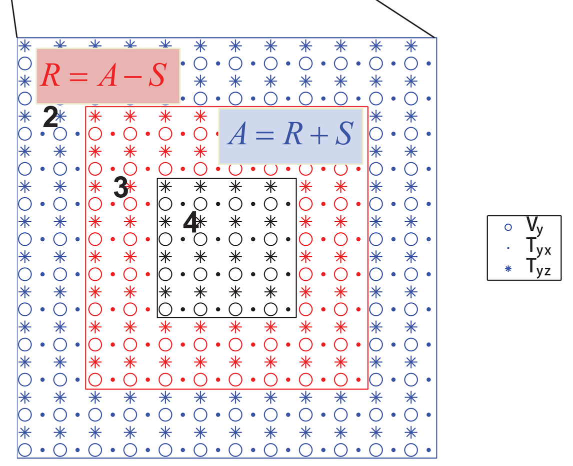
far field P radiation pattern

$$\frac{1}{\sqrt{R}}\frac{d}{dt}\frac{1}{\sqrt{t}}*(\text{2D solution})$$



Because of the singularity of the source, we need to use a source region rather than a source point. The source region behaves like a reflector if implemented as a hard source. This kind of artifacts can be reduced using the transparent box approach.

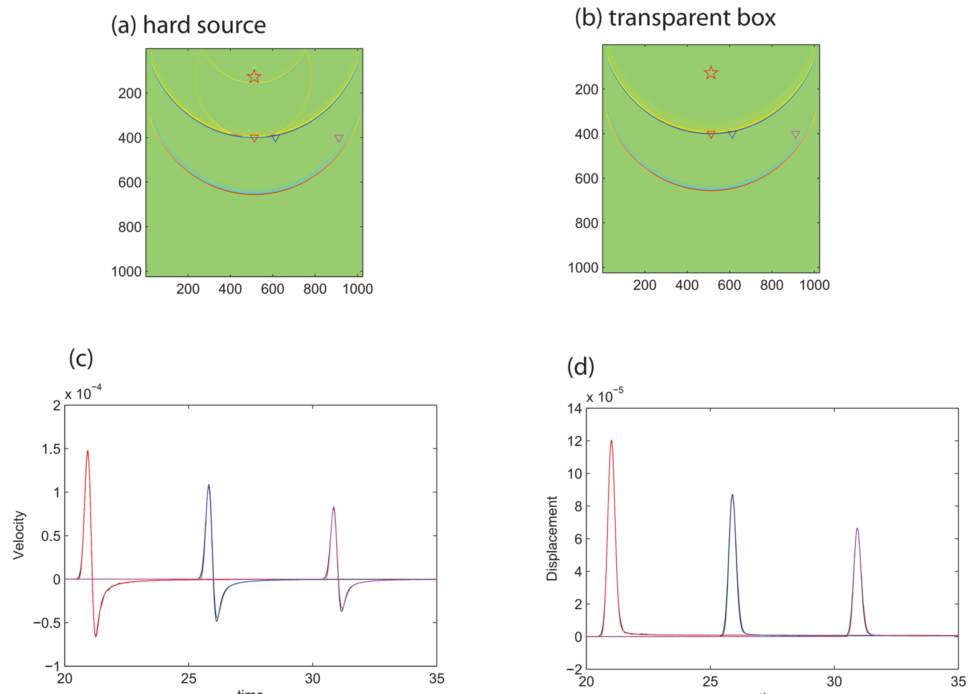
Total wave field A is combination of known source term S and unkown reflection R. The computing domain is divided into four regions. We will update A field in the outer regions (1 and 2), and will update R in inner regions (3, 4). Correct boundary conditions in region 3 and 2 are needed for updating A and R.



Validation

First we test SH wave in a homogeous half space.

Figure 1. (a) and (b) shows wavefield snapshot for hard source and transparent box source approaches. Note the artifact reflection in a) is elliminated in b).
(c) shows 2D velocity seismogram of three receivers in b). This is what FD directly computed. After 2D to 3D correction, the 3D displament is shown in (d). It fits the analytical calculation (black line) quite well.



Application

2011 Tohoku earthquake procuced a remarkable set of observations, which is strongly influced by local structures, such as water, slab and basins. Our method will be an efficient tool to study those features.

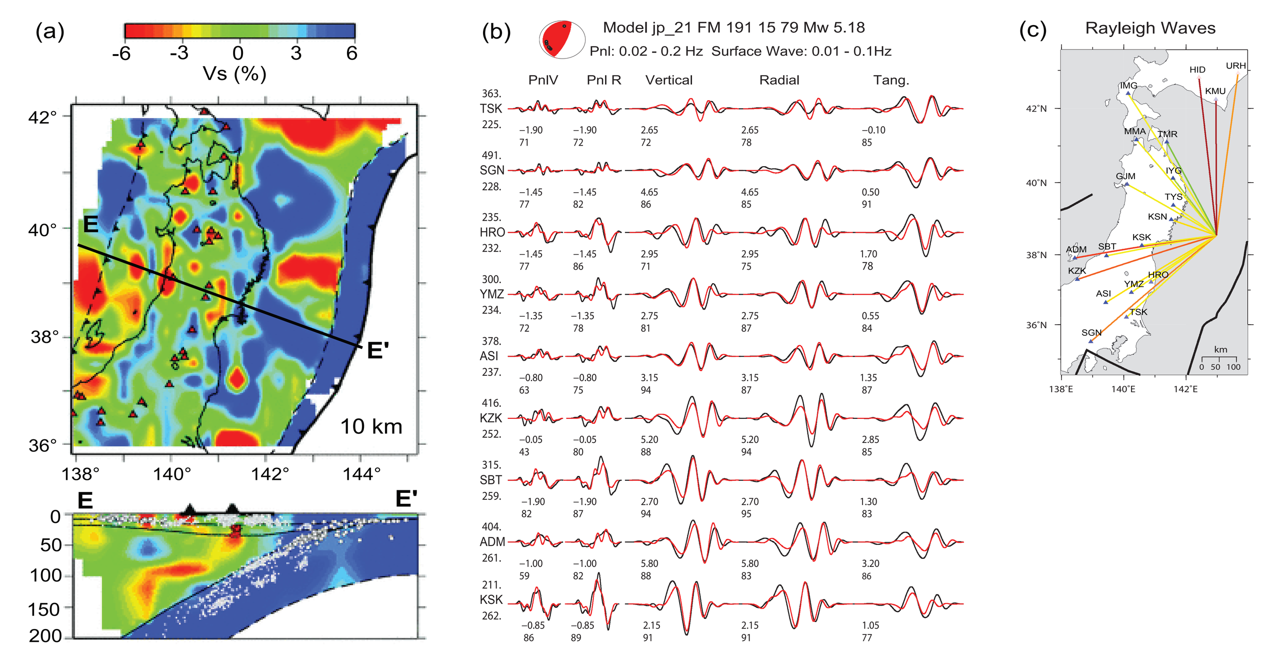


Figure 3. (a) [After Huang et al., 2011] S-wave tomographic image at 10-km depth under the NE Japan arc. (b) Sample waveform fits for regional CAP inversion of the master event with the crust model in Table 1. (c) Spider diagram for the CAP inversion of the master event. The stations (triangles) are colored by cross-correlation coefficients, and lines are colored by time shifts needed to align data and synthetics.

Table 1. Crust model of northeasten Japan

Thickness (km)	Vp (km/s)	Vs(km/s)	Density (g/cm^3)
4	4.4	2.51	2.0
10	6.0	3.46	2.6
16	6.7	3.87	2.9
12.5	7.7	4.50	3.3

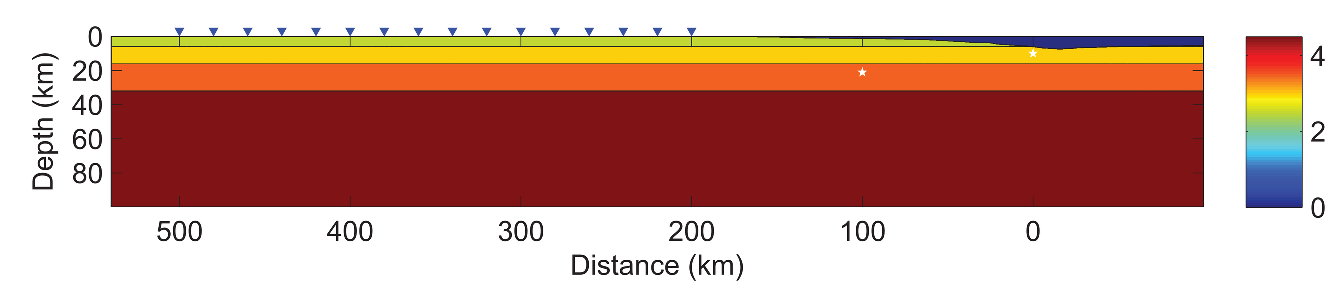
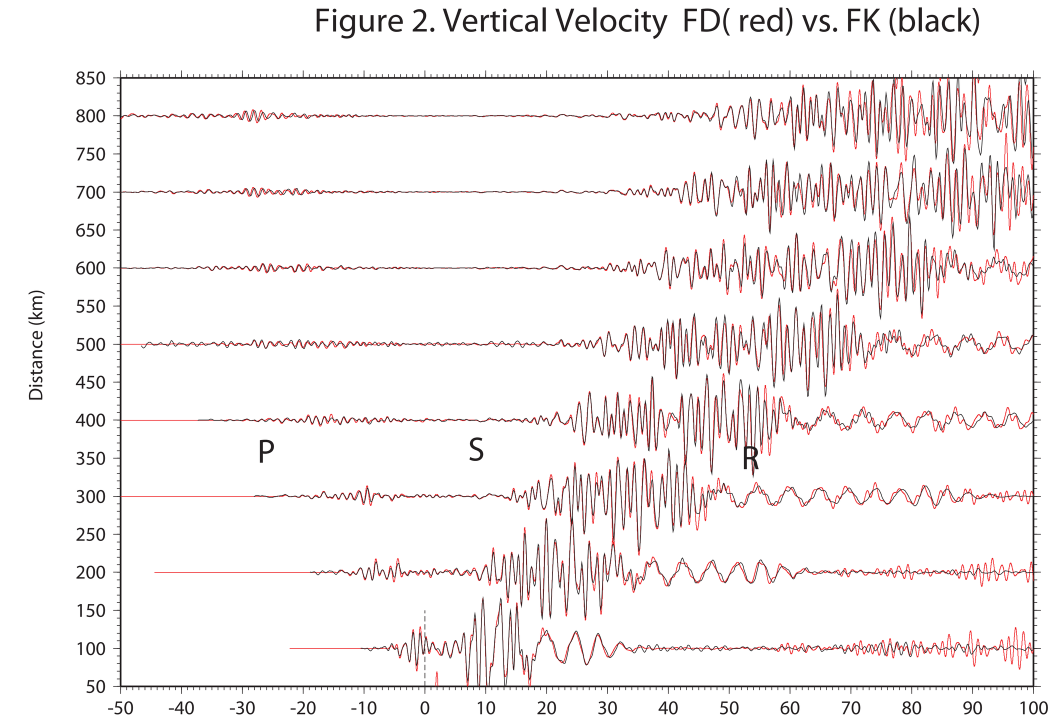


Figure 4. Vs model with water layers. White star shows sources position and blue triangle shows receivers .

Then we test FD results with FK using a 1D layered model shown below. The earthquake happens at 10 km with strike/dip/rake of 201°/10°/90° , and reciver azimuth of 270°. The source time function is trapozoid with 0.3 s half width.

Figure 2. Vertical Velocity FD(red) vs. FK (black)



As a first application of our method, we study the water effects on seismic wave. We compared the case with and without water layers for a 10km deep double couple source and a 21km deep explosion source.

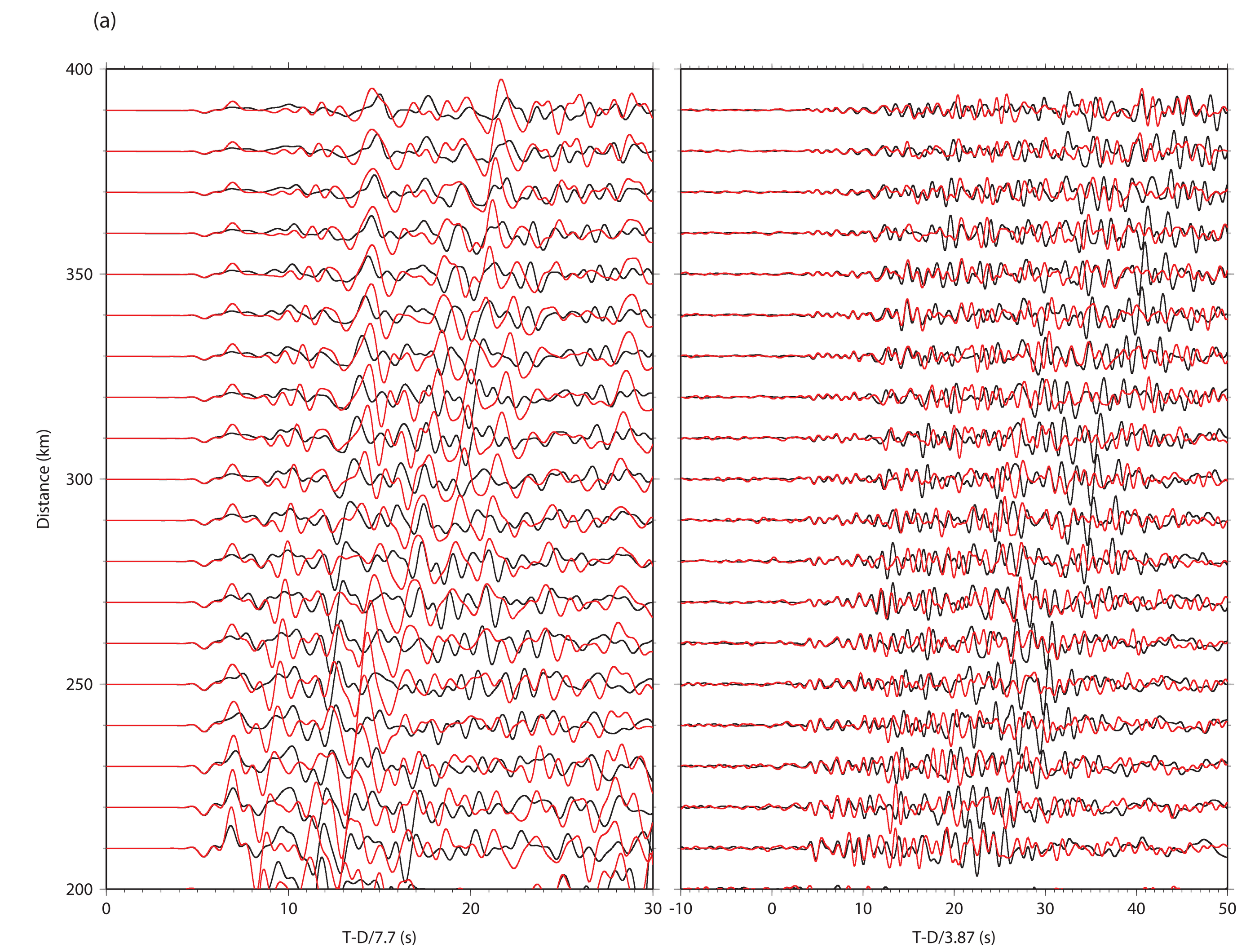
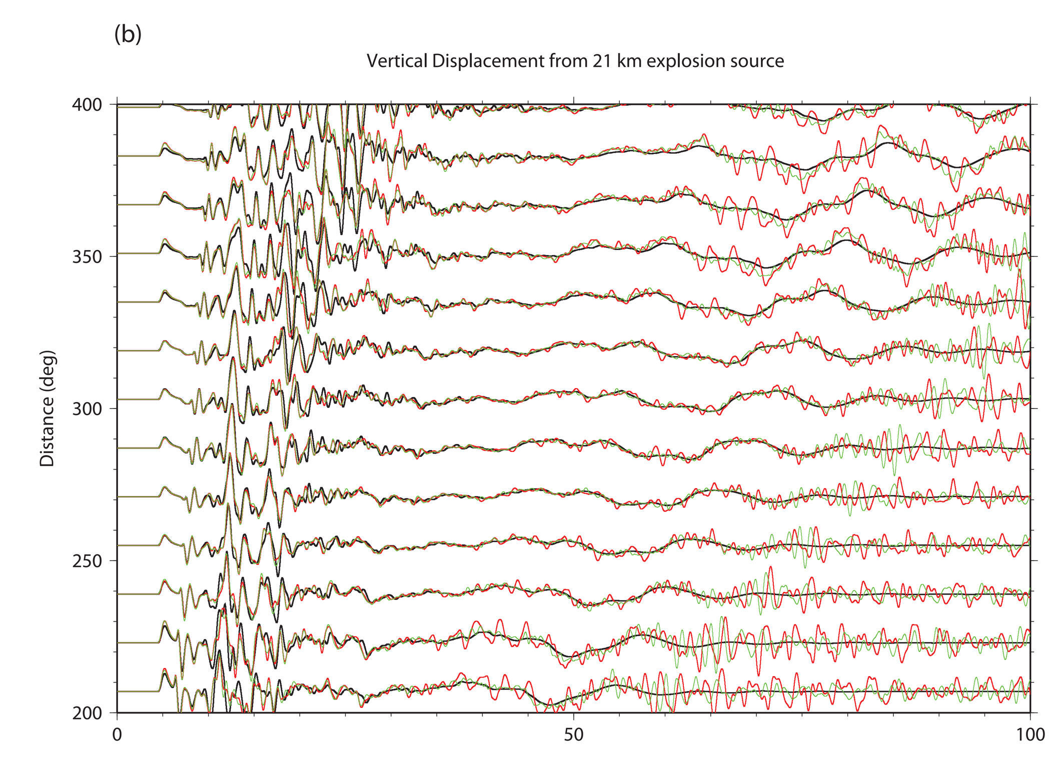
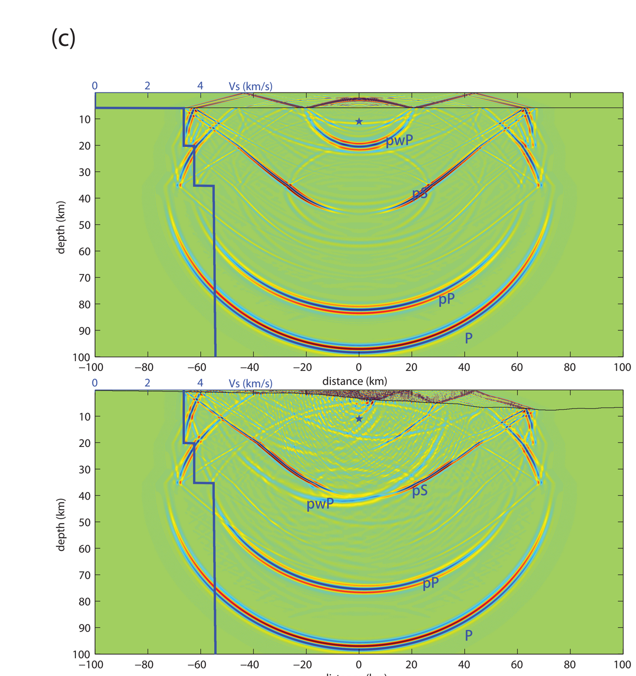


Figure 5. (a) Vertical velocity from the depth 10 km double couple source in Figure 4. Black is 1D layed model without water, red is 1D layed model with water on top. Left panel shows P wave train, and right panel shows S wave train.

(b) Vertical displacement from the 21km explosion source in Figure 4. Black is no water cases, red and green are both water cases. Red has grid size 200m and green has grid size 100m.

(c) Snapshot of vertical velocity from a flat water layered model (top) and a slope water layed model(bottom). Source is an explosion. Note the clear water phase (PwP) and high frequency energy in bottom panel.





Conclusion

Our method provides an efficient tool to study 3D effects of structure. The prelimary result in this study shows: the effect of water layer on regional seismic body wave depends largely on ray path geometry. When the source is shallow, and more energy goes into water, the influence is strong, and when the source is deep, the effects may be negligible. There are some high frequency energy present in the seismogram. It may due to the roughness of seafloor, or trapped energy in the water, which needs further study.