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Supplement of

Nonlinear wavefield characteristics of seismic translation and rotation in small-strain deformation from moment tensor simulations

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Supplement

S1 Numerical code benchmarking with the SPICE validation project

This section presents a benchmarking and validation of the three-dimensional, six-component finite-difference code used in our study. We have executed two distinct validation schemes to assess the accuracy and reliability of our code. The simulation results of our code are compared against the reference solutions provided by the classic SPICE (Seismic wave Propagation and Imaging in Complex media: a European network) code validation project.

S1.1 Parameter setup

The SISMOWINE initiative of the SPICE project offers an open platform for numerical modeling benchmarks (http://www.sismowine.org/), allowing researchers to submit results from their own codes for Comparison against provided reference solutions. We selected both the full-space (WP1_HSP1a) and half-space (WP1_HHS1) models to validate the fundamental performance of our code in simulating seismic wave propagation.

The test model consists of a homogeneous and isotropic elastic medium. The material and source properties are summarized in Table S1. Our simulations used a staggered-grid finite-difference scheme with sixth-order accuracy in space and second-order accuracy in time.

Table S1 Parameters for the benchmark against the SISMOWINE reference solution.

Item	Parameter
Vp	6000 m/s
Vs	3464 m/s
Density	2700 kg/m^3
Source type	Non-zero moment tensor component Mxy ($M_0=10^{18}$ N·m)
Location of source	(0 m, 0 m, 0 m)
Source time function	M_0 ·(1-(1+t/T)exp(-t/T)), where T=0.1 s

S1.2 Full-space model (SISMOWINE case: WP1_HSP1a model)

Figure S1 shows the waveform comparison between our code (labeled mwmc_SGFD) and the SISMOWINE reference solution (labeled Nuquake_PDS) at three receivers with different epicentral distances, where absorbing boundary conditions are applied to all external boundaries. The receiver coordinates are (400m, 400m, 400m), (3200m, 3200m, 3200m), and (6000m, 6000m, 6000m) (with the z-axis pointing downwards), corresponding to rec. 8, rec. 9, and rec. 10 in Table S2 generated in SISMOWINE, respectively.

For kinematic features, the P- and S-wave travel times calculated by our code are consistent with the reference solution. The main phases, amplitude envelopes, and overall waveform shapes of the two results also show consistency for dynamic features. The quantitative waveform misfit analysis (Table S2) indicates that both the envelope misfit and phase misfit are within acceptable ranges.

Table S2 Quantitative misfit analysis (Envelope Misfit EM; Phase Misfit PM) for the full-space model.

Accurracy report

	x		y		z		max			
rec.	EM (%)	PM (%)	EM (%)	PM (%)	EM (%)	PM (%)	EM (%)	PM (%)	EM	PM
8	10.0	2.1	10.0	2.1	8.4	4.6	10	4.6	C	A
9	7.7	2.3	5.5	1.7	6.8	9.1	7.7	9.1	B	B
10	6.1	1.8	5.9	1.8	7.2	9.3	7.2	9.3	B	B

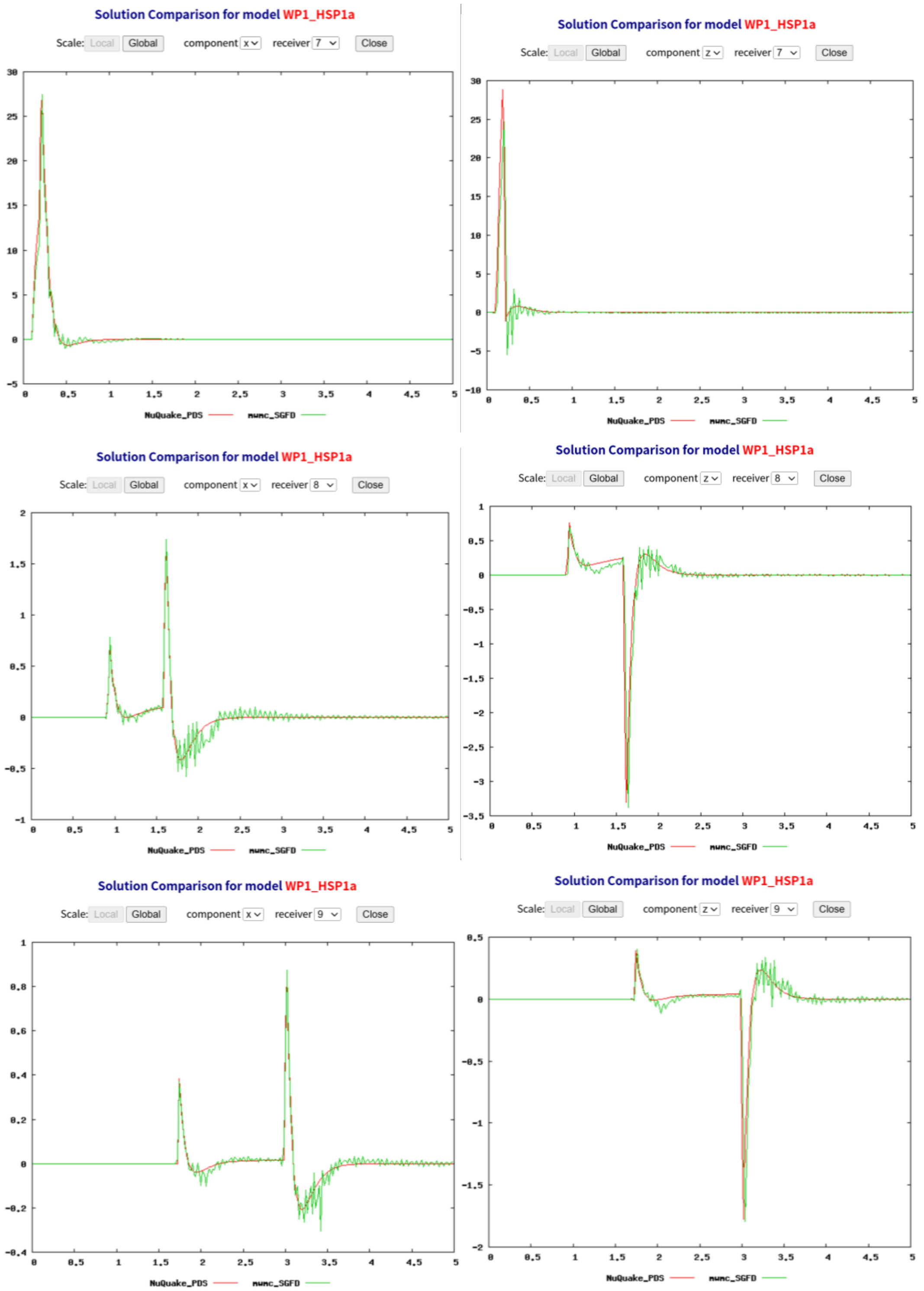

Figure S1. Waveform comparisons between our code (mwmc_SGFD) and the SISMOWINE reference solution (Nuquake_PDS) for the full-space model at receivers 7, 8, 9.

S1.3 Half-space model (SISMOWINE case: WP1_HHS1 model)

We further conducted a benchmark for the half-space model to test the code's ability to handle boundary conditions. This model uses the same medium and source parameters as the full-space test, but the top boundary is set as a free surface, while the other boundaries remain absorbing boundaries to simulate a half-space environment.

The receiver locations are (490m, 490m, 490m), and (577m, 384m, 0m), corresponding to rec. 5, and rec. 8 in Table S3, respectively. Figure S2 displays the waveform comparison for two receivers. The results for the three components show good waveform agreement. The minor discrepancies observed in the later arrivals, especially the surface waves, reflect the inherent characteristics of different numerical methods in handling the free surface. Despite these methodological differences, the two results are entirely consistent in terms of the physical processes involved. The misfit analysis (Table S3) also shows the agreement between the two results.

Table S3 Quantitative misfit analysis for the half-space model.
(Envelope Misfit EM; Phase Misfit PM)

Accurracy report

	x		y		z		max			
rec.	EM (%)	PM (%)	EM (%)	PM (%)	EM (%)	PM (%)	EM (%)	PM (%)	EM	PM
5	8.1	2.7	8.6	3.0	8.7	3.2	8.7	3.2	B	A
8	7.8	4.3	8.5	2.7	9.3	2.5	9.3	4.3	B	A

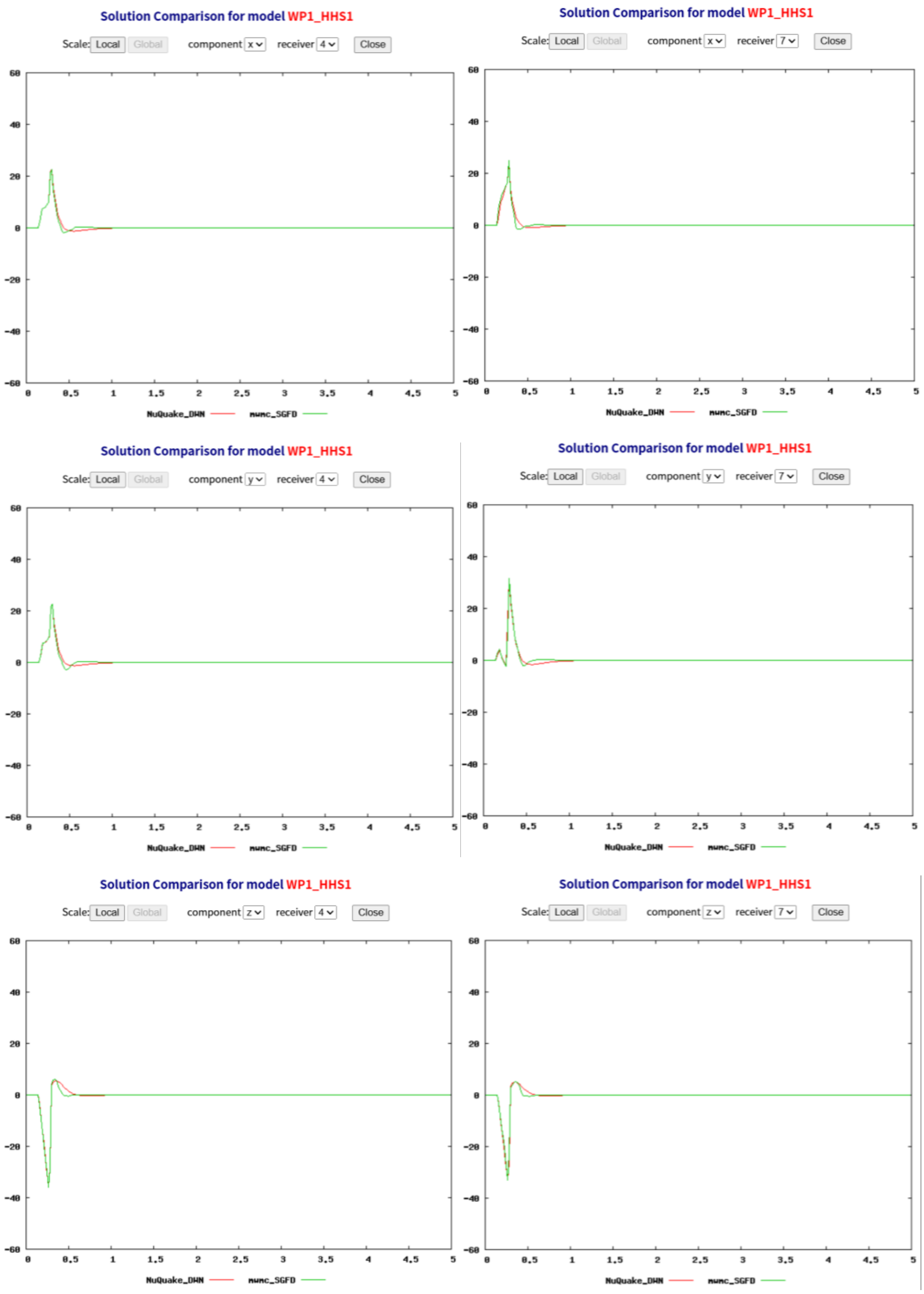

Figure S2. Waveform comparisons between our code (mwmc_SGFD) and the SISMOWINE reference solution (Nuquake_PDS) for the half-space model at receivers 4, 7.

We have validated the effectiveness of our in-house finite-difference codes from different perspectives through comparisons with the SISMOWINE reference solution in both full-space and half-space models. The test results demonstrate that the codes can accurately simulate the kinematic and dynamic features of body waves, correctly implement the free-surface boundary condition, and confirm a certain degree of reliability of our code.

S2 Simulation setup for referenced earthquake events

The epicentral locations of the two events and the positions of their corresponding single receiver stations are shown in Figure S3. The moment tensor solutions for both events are provided in Eq. (13) in the main text. The detailed physical properties of each layer are listed in Table S4. Other key simulation parameters are summarized in Table S5.

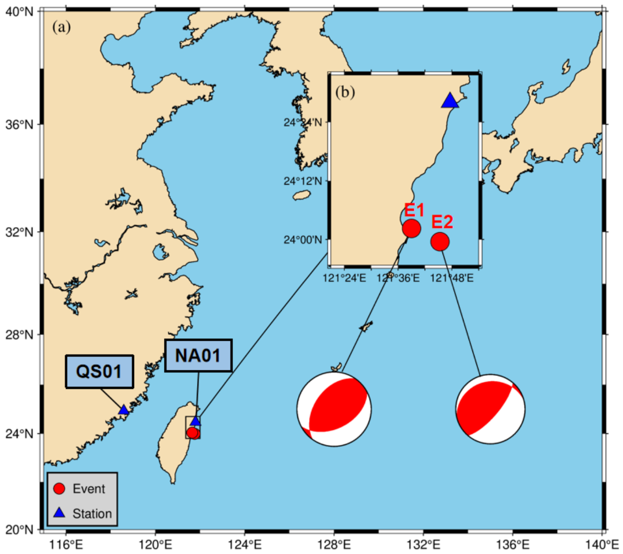

Figure S3. Epicentral locations and observation sites of referenced E1 and E2.

Table S4 Physical properties of the layered media used for simulations.

Layer	Thickness (km)	vp (km/s)	vs (km/s)	ρ (kg/m^3)
1	0.50	2.50	1.07	2.11
2	10.12	5.80	3.40	2.63
3	9.81	6.30	3.62	2.74
4	9.82	6.90	3.94	2.92
5	-	7.70	4.29	3.17

Table S5 Detailed simulation parameters for referenced E1 and E2.

Iterm	Paremeter (E1, E2)
Dominant frequency	1 Hz, 0.5 Hz
Moment magnitude	Mw5.4, Mw6.1
Depth	15 km, 30 km
Grid spacing	1 km, 2 km
Time step	5 ms, 2 ms
Source mechanisms	Eqs. (13)
Spatial differential accuracy	10th order