SEMINAR · DEPARTMENT OF EARTH SCIENCES · NATIONAL CENTRAL UNIVERSITY · 20 NOVEMBER 2026

How Would Eastern Taiwan Shake in an M 8 Ryukyu Earthquake?

Exploring Ground-Motion Variability and Path Effects with 3-D Scenario Simulations

Ming-Che Hsieh (謝銘哲)

Earthquake Disaster & Risk Evaluation and Management Center (E-DREaM), National Central University

with Chih-Hsuan Sung (宋芝萱, National Chung Hsing University; UC Berkeley) and Yung-Ching Yang (楊詠晴, National Central University)

Hsieh, Sung & Yang (2026). Nonergodic path effects from 3D ground-motion simulations of an M 8 Ryukyu earthquake in eastern Taiwan. Seismol. Res. Lett., doi 10.1785/0220260149

Outline

1. **Ground motion without records**
   A megathrust next door with no near-field record; how shaking is estimated today, and why the scatter of a ground-motion model matters

2. **How the simulations are set up**
   Fault geometry from the national model, slip from the Recipe, waves through two Earth models

3. **No observations: how do we know the synthetics are reasonable?**
   What is measured, and how the source duration is calibrated against the ergodic CH20 model

4. **What the 1,728 scenarios say**
   Which rupture parameters matter, and which map features belong to the Earth rather than to the rupture

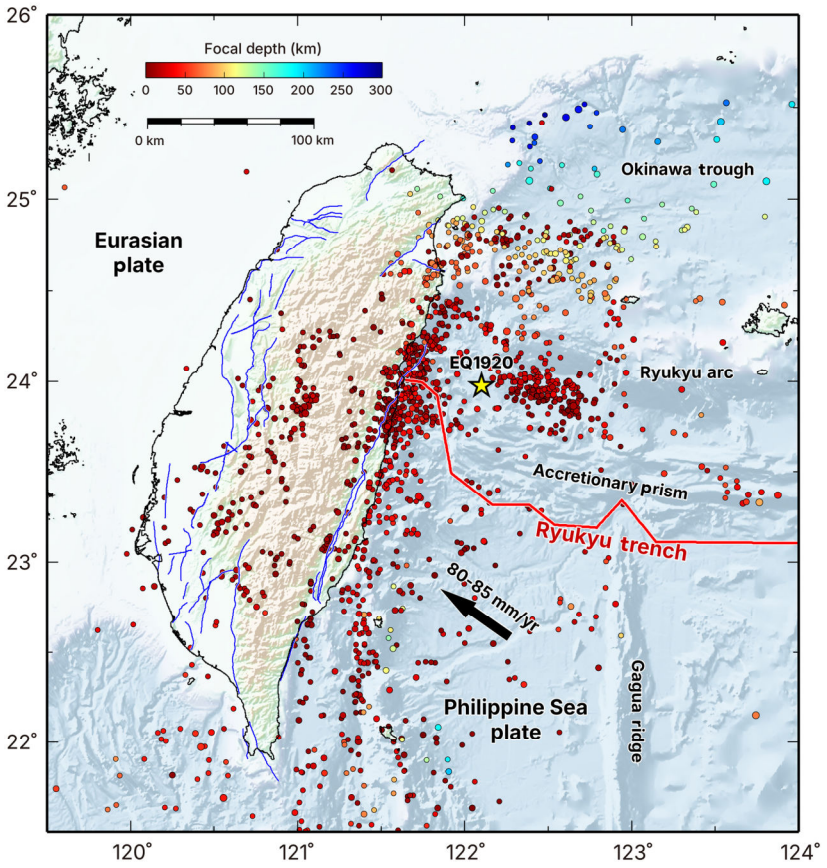
5. **What this is for, and what we are working on next**
   Into hazard analysis, into structural analysis, into a daily forecast; three open questions

1

Ground motion without records

How shaking is estimated today, and what is missing for a Ryukyu M 8

The southern Ryukyu subduction zone can host a megathrust



Red: Ryukyu trench; blue: TEM active faults; dots: ML ≥ 5, 1973–2025 (CWA); star: 1920 event.

80–85 mm/yr — **Plate convergence:** fast convergence on a coupled interface builds up the potential for a great earthquake.

Mw 7.5–8.7 — **Seismogenic potential:** what the coupled plate interface could release, from geodetic data (Hsu et al., 2012).

Mw 7.7 ± 0.2 — **It has happened:** the 1920 earthquake, the largest instrumentally recorded in Taiwan (Theunissen et al., 2010).

0 records — **No record:** no near-field strong-motion record of 1920 or of any comparable event here.

- Scenario: M 8 on the westernmost segment (R1), between the collision zone and the Gagua ridge.

How ground motion is estimated today: a ground-motion model (GMM)

Inputs
source (magnitude, fault type, depth), path (distance), site (Vs30)

→

Ground-motion model
an empirical equation, fitted by regression to past records

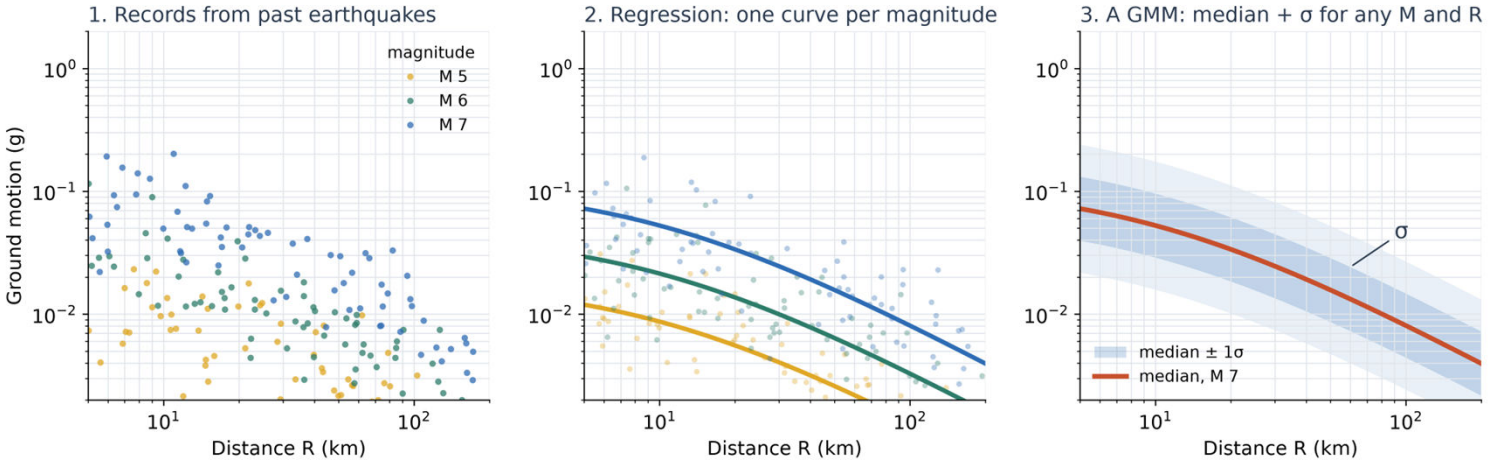
→

Median GM and its σ
at each site, for each period

→

Used for
scenario maps of one earthquake; PSHA hazard curves for design

WHERE THE MODEL COMES FROM: RECORDS → REGRESSION → MODEL



ln (ground motion) = f (magnitude, distance) ± σ
σ: standard deviation of the scatter

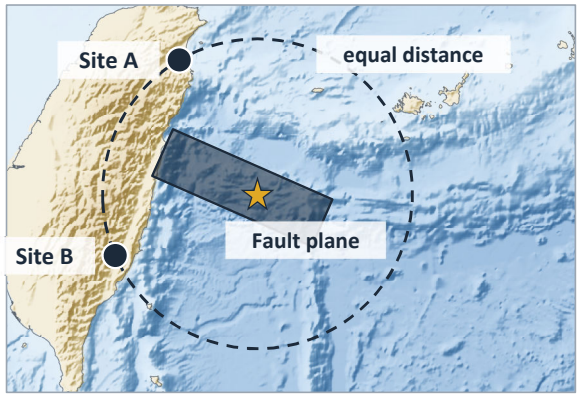
Schematic with synthetic data: each dot is one recording, the curves are the regression, the band is its scatter.

What this procedure relies on

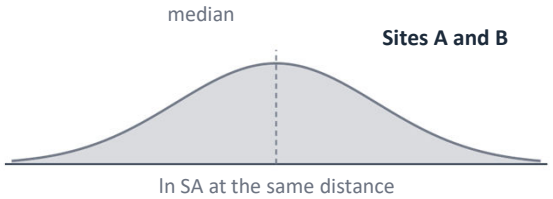
- **Records:** no near-field record of an M 8 on the Ryukyu interface exists.
- **One equation for every place (ergodic):** the 3-D structure along each path is not in it.

Ergodic or non-ergodic: where does the spread go?

Ergodic: distance only

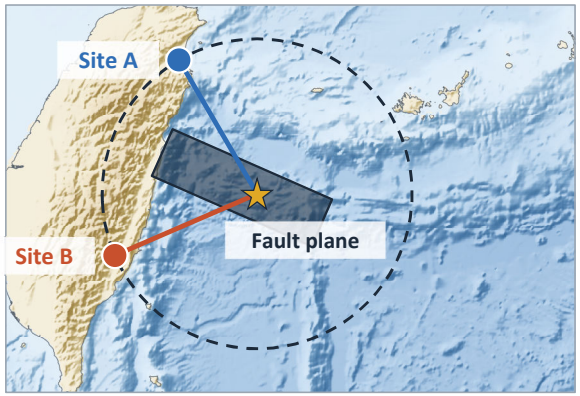


- Sites A and B: same magnitude, same distance.
- The model predicts the same median for both.
- Whatever differs between the two paths is treated as random.

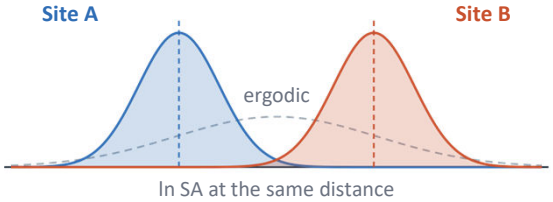


One median, large σ

Non-ergodic: same distance, different paths



- Site A: the 3-D structure along this path weakens the waves: lower than predicted.
- Site B: the structure along this path strengthens them: higher than predicted.
- These effects repeat for every rupture on this fault.



Site-specific medians, smaller σ

Schematic: sites, paths and curves are illustrative.

Site-specific correction terms

$$\ln SA_{\text{non-ergodic}} = \ln SA_{\text{ergodic}} + \delta S2S\ (\text{site}) + \delta L2L\ (\text{source}) + \delta P2P\ (\text{path})$$ ← this study

Taiwan already has several 3-D velocity models. What does each of them contribute to the shaking?
That question is where this study starts.

Simulate many M 8 ruptures, then read the path term



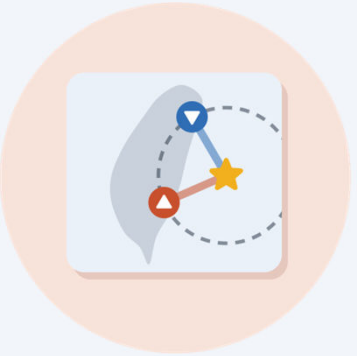
1 Characterized source models

Taiwan SSHAC Level 3 fault geometry, filled in with the Recipe: asperities, hypocenter, rupture velocity.



2 3-D finite-difference simulations

Two tomographic velocity models (KC3D, HH3D) with topography; every source runs in both.



3 Calibrate, then extract δP2P

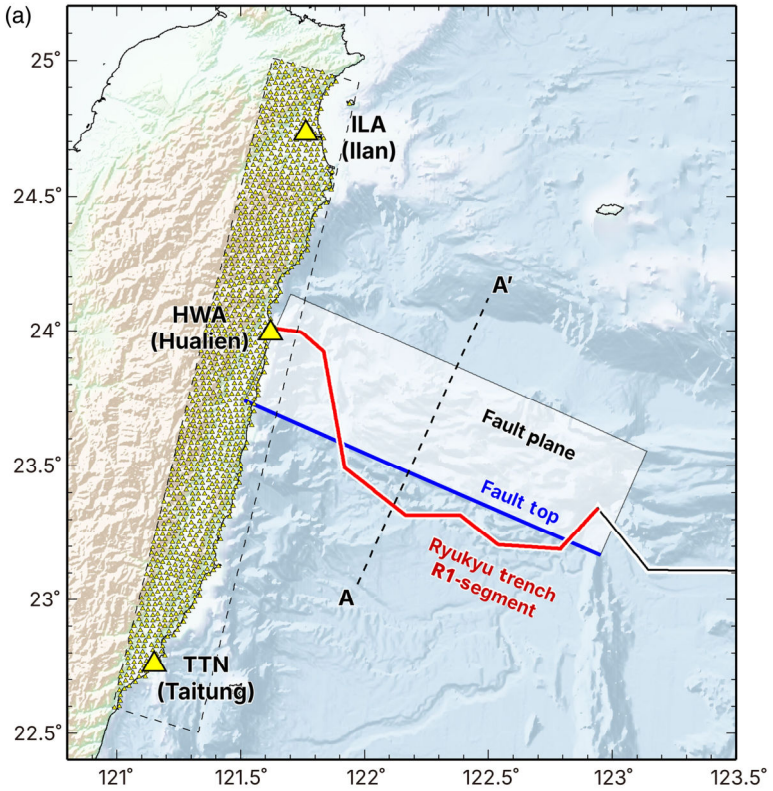
Set the mean level against an ergodic GMM, average over all sources, map what remains.

2

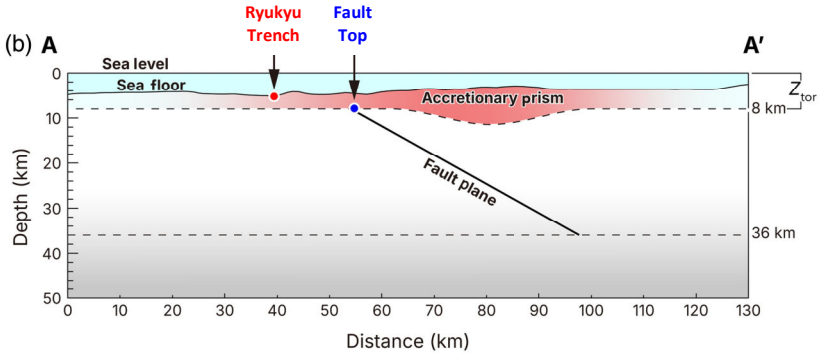
How the simulations are set up

Fault geometry from the national model, slip from the Recipe, waves through two Earth models

Source geometry: the R1 segment of the Taiwan SSHAC model



Triangles: virtual stations; ILA, HWA, TTN: reference sites. A–A′: the section on the right.



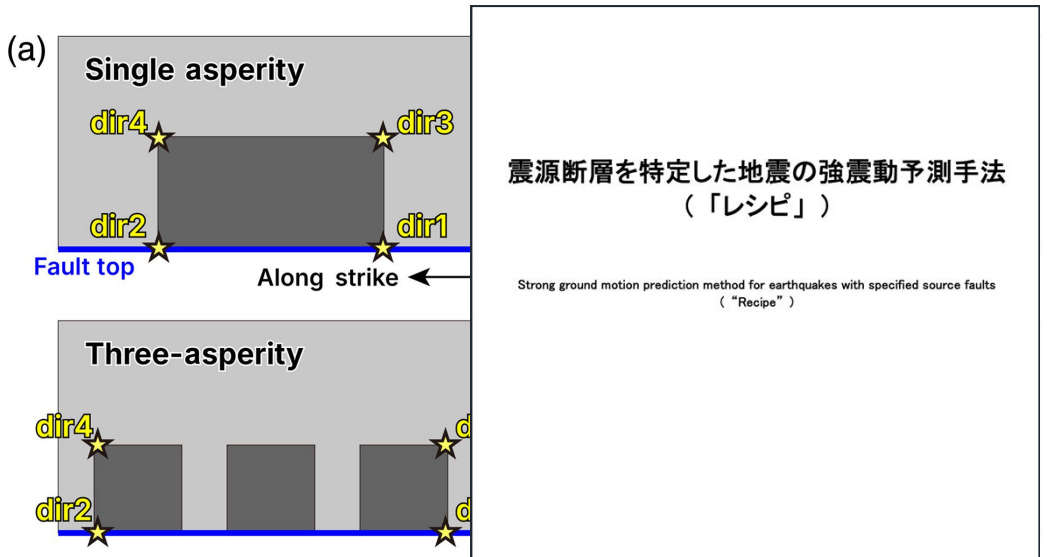
Parameter	Value
Moment magnitude Mw	8.0 (M_0 = 1.26 × 10^{21} N·m)
Fault length × width	161 km × 56 km
Subfault size	1 km × 1 km
Strike / dip / rake	294° / 30° / 90°
Rupture top (Ztor) / bottom	8 km / 36 km
Mean slip / asperity slip	3.49 m / 5.24 m (1.5 × mean)
Rigidity	4.0 × 10^{10} N/m²

4,950

virtual stations across eastern Taiwan, about 1.5 km apart

- **Taiwan SSHAC Level 3:** a Taipower (台電) project to evaluate the seismic safety of nuclear power plants. This fault geometry comes from it.
- Only R1: the velocity models are constrained west of ~123° E (the Gagua ridge).
- Ztor = 8 km keeps the rupture below the accretionary prism, consistent with no major tsunami reported in 1920.

The Recipe: three steps from a magnitude to a slip model



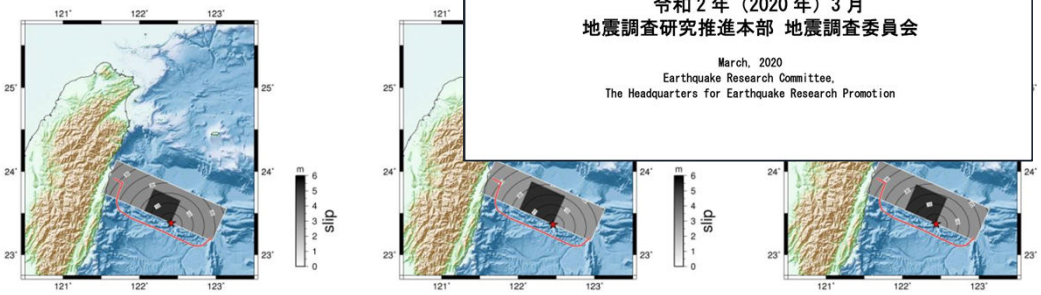
震源断層を特定した地震の強震動予測手法
（「レシピ」）

Strong ground motion prediction method for earthquakes with specified source faults
（"Recipe"）

令和２年（2020年）３月
地震調査研究推進本部 地震調査委員会

March, 2020
Earthquake Research Committee,
The Headquarters for Earthquake Research Promotion

Dark: asperities (1.5 × mean slip); light: backgrou



Three of the 96 source models on the map.

Irikura and Miyake (2011) and
Headquarters for Earthquake Research Promotion (HERP), Japan

1 Scaling first

The magnitude sets the fault area, the seismic moment and the mean slip (3.5 m here).

2 Then the asperities

One to three patches with 1.5 × the mean slip, covering 17–40 % of the fault, on a low-slip background.

3 Then the hypocenter

At a corner of an asperity, so that the rupture can start in four different directions (dir1–dir4).

A total of 96 source models are generated.

What is varied: 96 sources × 2 Earth models × 9 durations

12 × **2** × **4** × **2** × **9**

12 asperity configurations

One to three asperities
17–40% area ratio
swapped locations of major and secondary asperities

2 rupture velocities

2.4 and 3.0 km/s, about 0.65 and 0.8 of the shear-wave speed on the fault

4 hypocenters

dir1–dir4: up-dip or down-dip, and both along-strike directions

2 velocity models

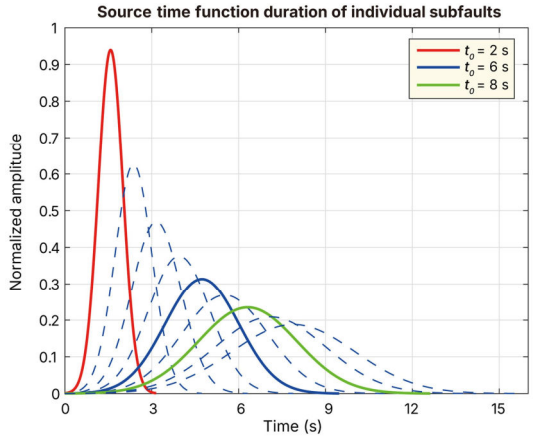
KC3D and HH3D: the only epistemic branch in the design

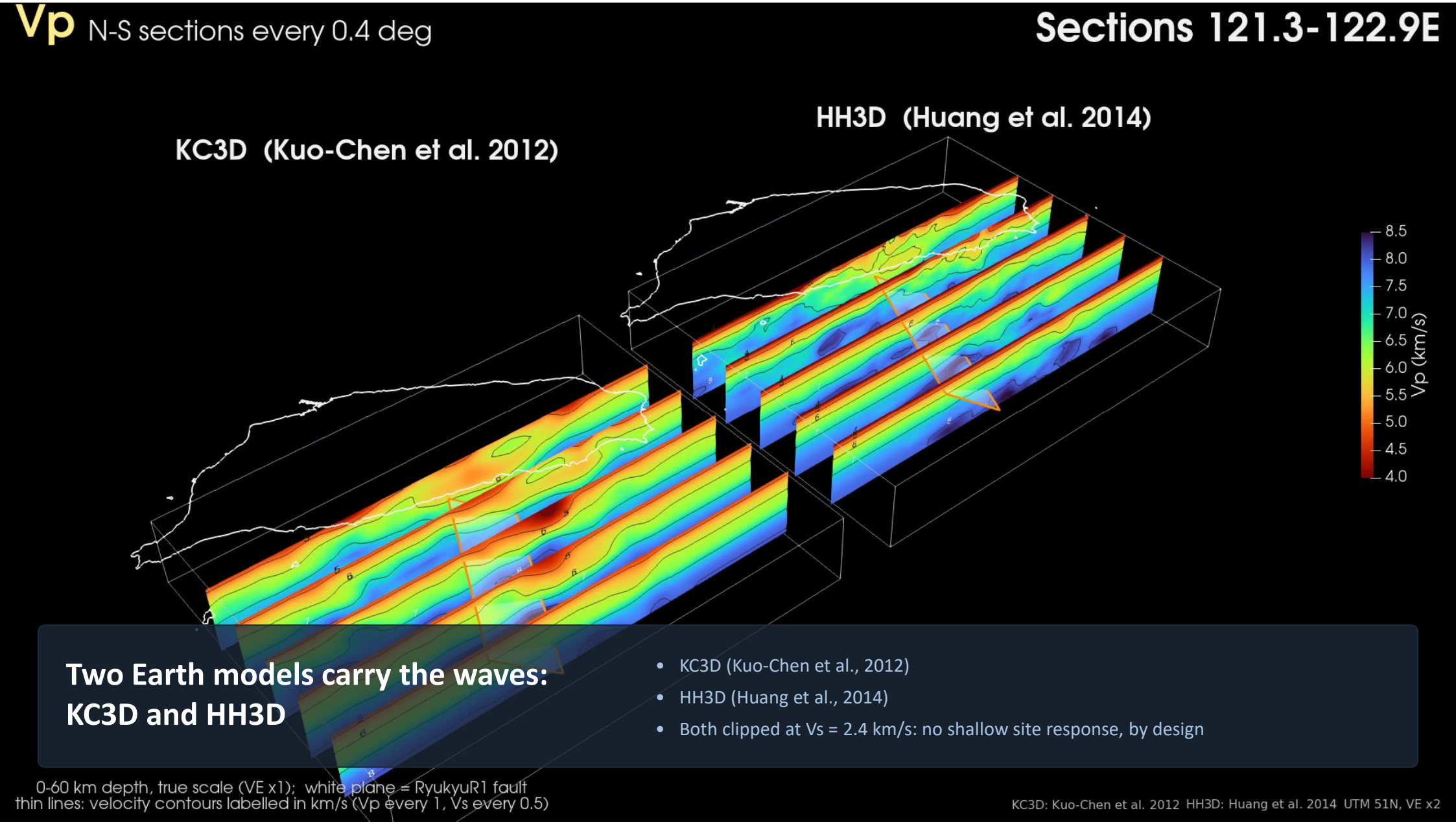
9 source time functions

Gaussian, 2–10 s, swapped in by **convolution**; no rerun of the 3-D simulation

96 source models × **2** velocity models = **192** 3-D simulations → × **9** durations = **1,728** scenarios → × **4,950** stations = **> 8.5 million** records

- All alternatives carry equal weight: a sensitivity scan, not a statement of likelihood.
- Source duration is a calibration parameter: no Taiwan rise-time relation exists for Mw 8, so 2–10 s brackets the published ones.




Vp N-S sections every 0.4 deg
Sections 121.3-122.9E
KC3D (Kuo-Chen et al. 2012)
HH3D (Huang et al. 2014)
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
Vp (km/s)
Two Earth models carry the waves:
KC3D and HH3D
KC3D (Kuo-Chen et al., 2012)
HH3D (Huang et al., 2014)
Both clipped at Vs = 2.4 km/s: no shallow site response, by design
0-60 km depth, true scale (VE x1); white plane = RyukyuR1 fault
thin lines: velocity contours labelled in km/s (Vp every 1, Vs every 0.5)
KC3D: Kuo-Chen et al. 2012 HH3D: Huang et al. 2014 UTM 51N, VE x2

Where the waves are computed



Frontera at TACC. Photo: Texas Advanced Computing Center (tacc.utexas.edu).



Taiwania 3. Photo: National Center for High-performance Computing, NARLabs (Wikimedia Commons, OGDL-Taiwan 1.0).

Frontera, TACC (UT Austin, USA), 2019–2026

NSF-funded; full production September 2019. 8,368 nodes, Intel Xeon Platinum 8280 (Cascade Lake), 56 cores per node, HDR InfiniBand. Over 8 million jobs before its queues closed in October 2026. The Hualien broadband simulations (Zhang, Hsieh & Chen, 2026) ran here with TACC.

Taiwania 3 (台灣杉三號), NCHC, since 2020

NSTC-funded. Taiwan's national CPU system: 900 nodes, Intel Xeon Platinum 8280, 50,400 cores, 2.7 PFLOPS peak, HDR100 InfiniBand. Some of our simulations were run on this system.

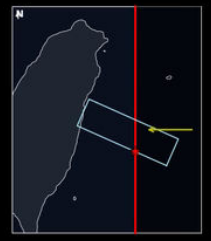
One 3-D run is cheap; the scan over sources, Earth models and durations is what needs a supercomputer, and that scan is what makes a path term readable.

Wavefield on cuts through the 3-D models: KC3D vs HH3D

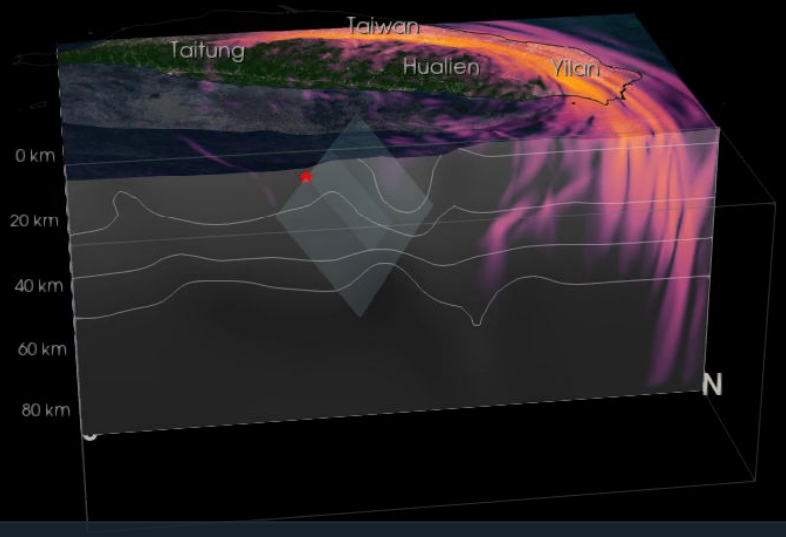
N-S section through the hypocentre (x = 443.2 km)

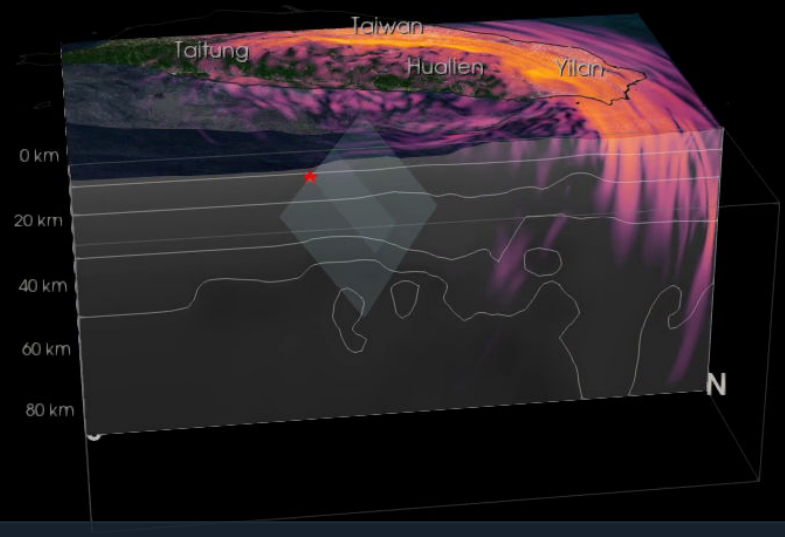
t = 70.8 s

KC3D (Kuo-Chen et al. 2012)



HH3D (Huang et al. 2014)





3-D finite-difference simulation: the same rupture in both models

- Curvilinear-grid finite differences with topography (Zhang et al., 2012)
- 300 m grid, Δt = 0.015 s, Vs,min = 2.4 km/s; three-component waveforms at 4,950 stations
- 192 runs of ~13.5 h on 96 cores

Mw 8.0 SingleAS 0.22, vr 3.0 km/s, mod00001; same source in both models; particle velocity every 0.15 s, 300 m
face: grey = Vs of each model (light = slow), white lines = Vs 3.0 / 3.5 / 4.0 / 4.5 km/s; top: Sentinel-2 image with gentle hillshade
cyan = RyukyuR1 fault plane seen through the block (brighter once ruptured, white = rupture front); red star = hypocentre; VE x2



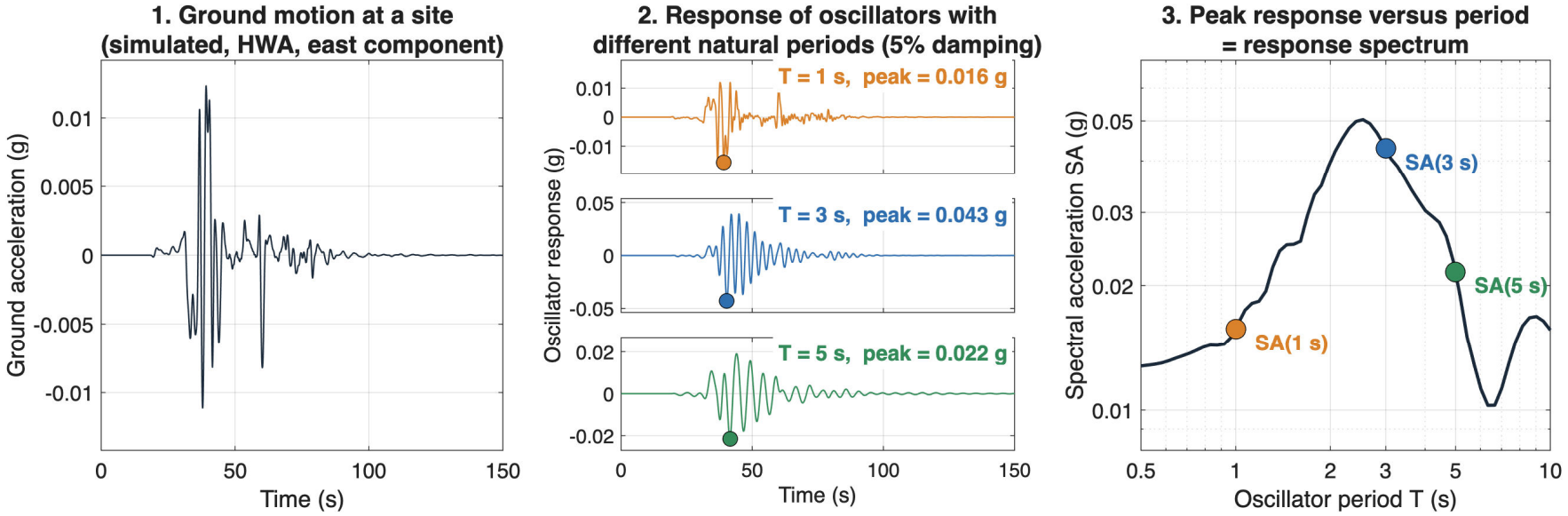
Sentinel-2 cloudless 2025 by EOX IT Services GmbH (contains modified Copernicus Sentinel data)

3

No observations: how do we know the synthetics are reasonable?

What is measured, what the empirical model fixes, and what it deliberately does not

What is measured: spectral acceleration (SA) at 1, 3 and 5 s



Simulated east component at HWA (HH3D, single asperity 22 %, Vr = 2.4 km/s, dir1, 2 s source time function).

Why not the waveform itself

Every synthetic is a long, complex time series. Engineering and hazard analysis need one number per site and period, so the waveform is reduced to a ground-motion parameter.

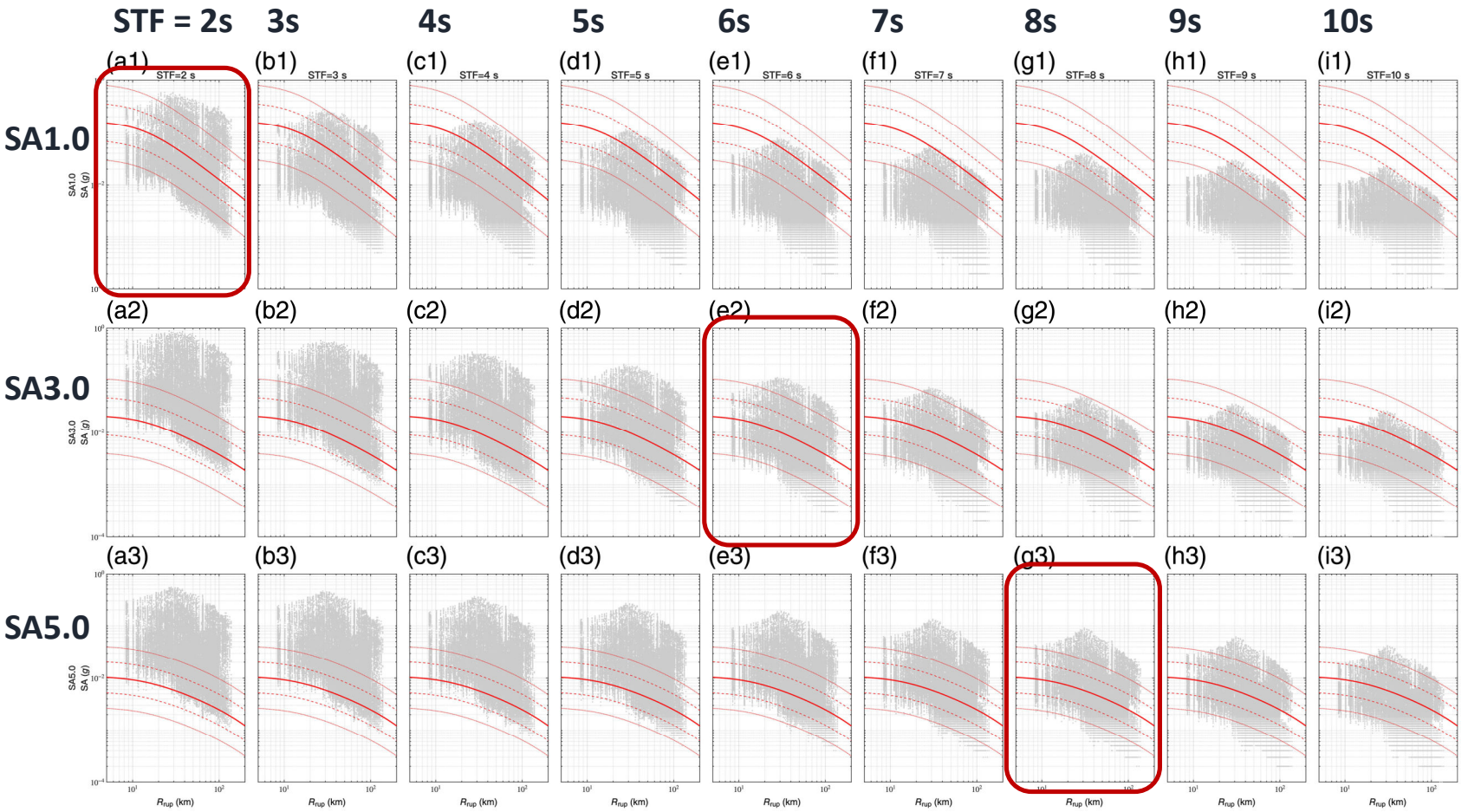
SA(T): what a structure feels

Peak response of a simple oscillator with period T (5 % damping). About 1 s for a 10-storey building; 3–5 s for tall buildings and long bridges.

Why only T ≥ 1 s

Vs,min = 2.4 km/s and a 300 m grid make the synthetics reliable at long periods, which is where the Mw 8 record is empty.

Source duration sets the spectral level: synthetics against CH20



Columns: STF duration 2–10 s; rows: SA at 1.0, 3.0, 5.0 s. Grey: all 192 source–velocity-model combinations at the 4,950 stations; red: CH20 median, ± 1σ (dashed), ± 2σ (dotted). Log–log, Rrup in km.

Read across a row

Short pulses push the cloud above CH20, long pulses pull it below: the duration sets the level.

Read down a column

The same STF sits too high at 1 s and too low at 5 s, so one duration cannot serve all periods.

Chosen: 2, 6 and 8 s

for SA at 1.0, 3.0 and 5.0 s, about 1.5–2 × the period. The fit sets only the mean level; the spatial pattern is left to 3-D wave propagation.

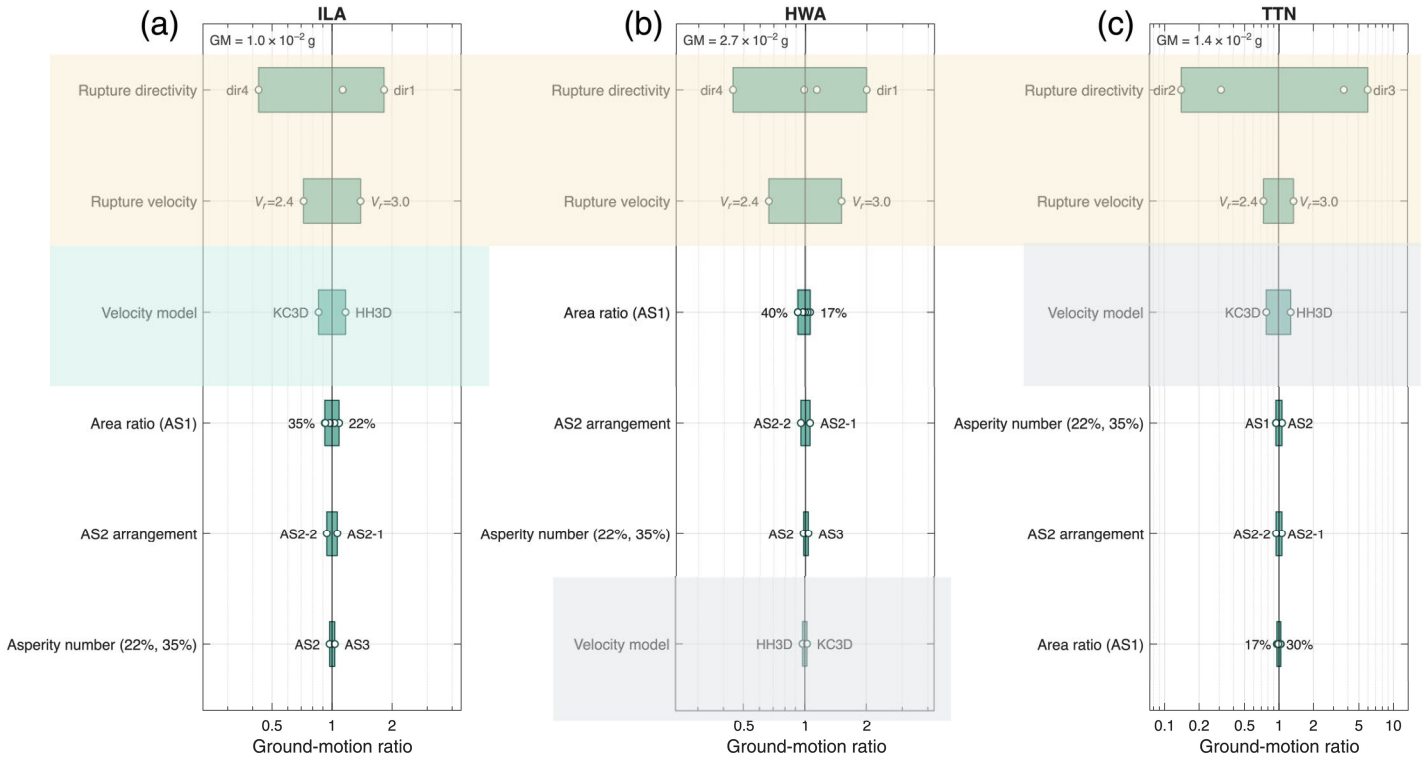
4

What the 1,728 scenarios say

Which rupture parameters matter, and which map features belong to the Earth rather than to the rupture

Sensitivity: directivity first, rupture velocity second

Tornado plot Center (=1): geometric mean of all cases
Vertical axis: one row per tested parameter
Bar length: lowest to highest mean GM



Tornado plots of SA at 1.0 s at ILA, HWA and TTN: range of the mean motion over cases sharing a parameter value. Note the different horizontal scales.

1 Rupture direction

× 4–5 at ILA and HWA
× 40 at TTN

2 Rupture velocity

about × 2
3.0 km/s against 2.4 km/s

3 Velocity model, asperity layout

Both small
Velocity model: differs from site to site

Reading the tornado: the rupture and the Earth model

Simulated ln SA at a site, 192 cases

隨機變異

Aleatory variability

Which rupture will nature produce? (randomness, irreducible)

five source parameters, all cases equally weighted



rupture directivity | **asperities: number, area, arrangement** | **rupture velocity**

spread within one model = σ

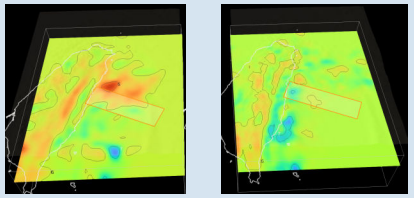
This is what the σ of a GMM represents.



認知不確定性

Epistemic uncertainty

How far is each model from the real Earth?
(lack of knowledge, reducible)



Handled as alternative models (logic-tree branches).

Removed before σ is compared with the GMM.

difference between medians



Non-ergodic path terms δP2P are taken from the medians (per model); the standard deviation at a site is computed after removing the model difference.

The rupture: aleatory

Rupture direction, rupture velocity, asperity layout. They differ from one earthquake to the next, so they are averaged over.

The Earth model: epistemic

KC3D or HH3D. There is one real Earth, so the two are kept as separate branches and compared.

THE NEXT FOUR SLIDES

Average over the ruptures
a path term δP2P at every station

→ **Split by rupture direction**
what the average hides

→ **Split by rupture velocity**
2.4 against 3.0 km/s

→ **Compare the two Earth models**
KC3D against HH3D

From 1,728 scenarios to a path term at every station

1 Residual against the ergodic model

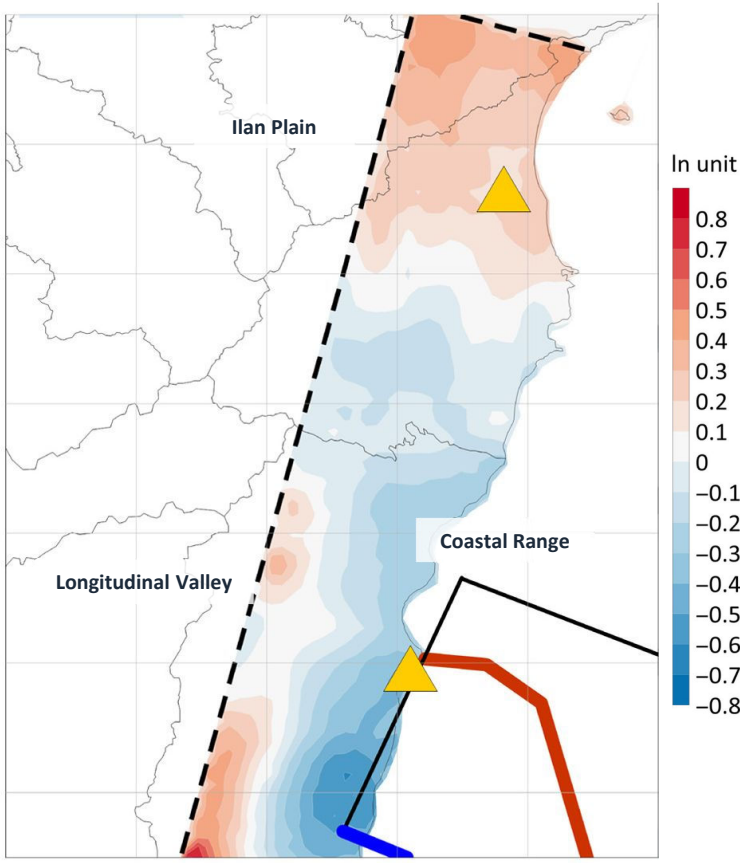
At each station and scenario: ln SA(synthetic) − ln SA(CH20), with CH20 evaluated for the same magnitude, distance, depth and Vs30 = 2.4 km/s.

2 Average over the source models

What is left at each station no longer depends on one rupture: it is the path term δP2P relative to CH20. Red: above the ergodic model; blue: below.

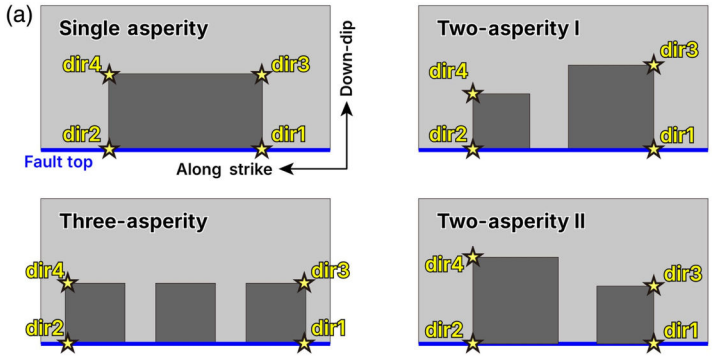
Both velocity models give such a map. A feature is read as a property of the path only when it survives the averaging and appears in both.

HH3D, SA1.0, averaged over the 96 cases



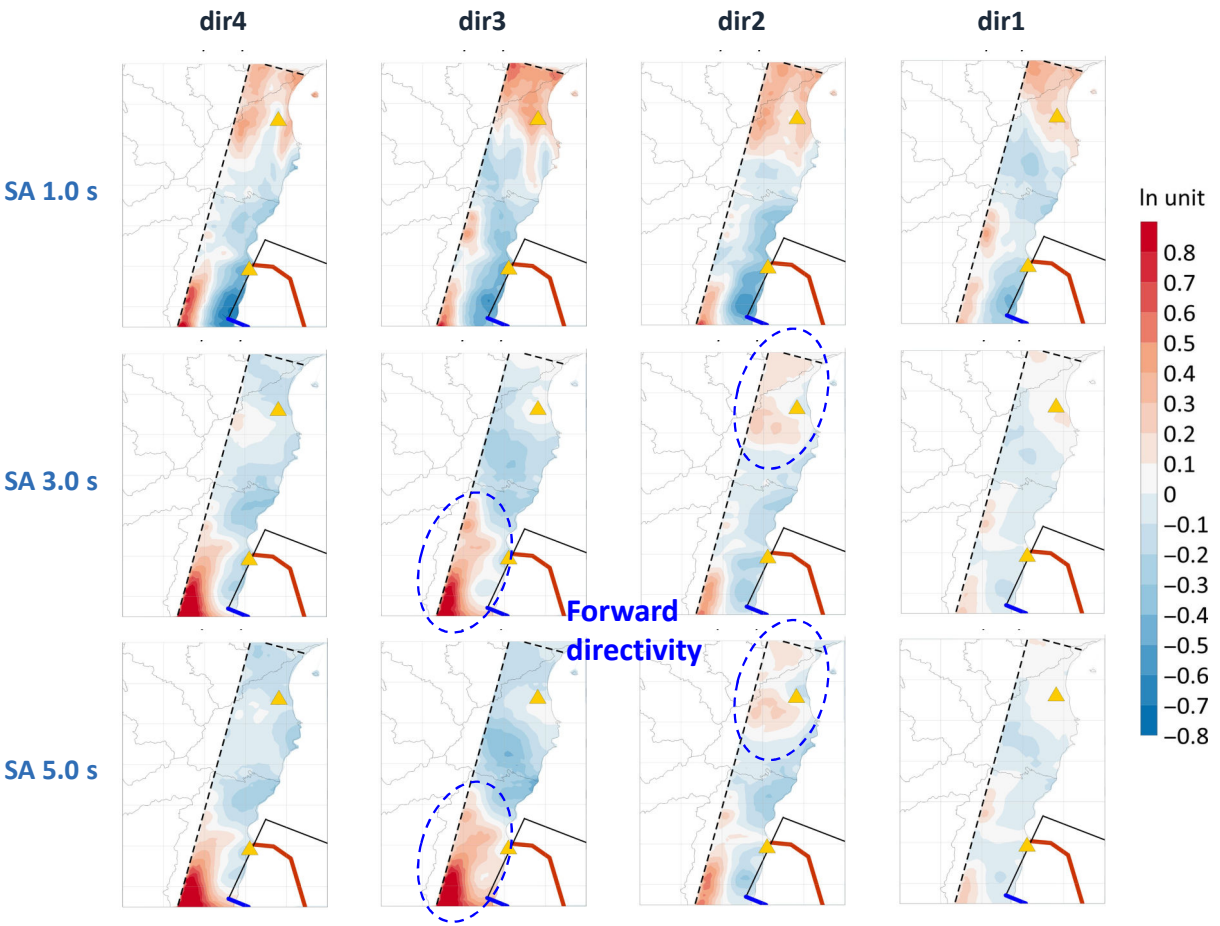
Triangles: ILA, HWA; dashed line: analysis boundary.

Aleatory variability: path terms by rupture direction (HH3D)



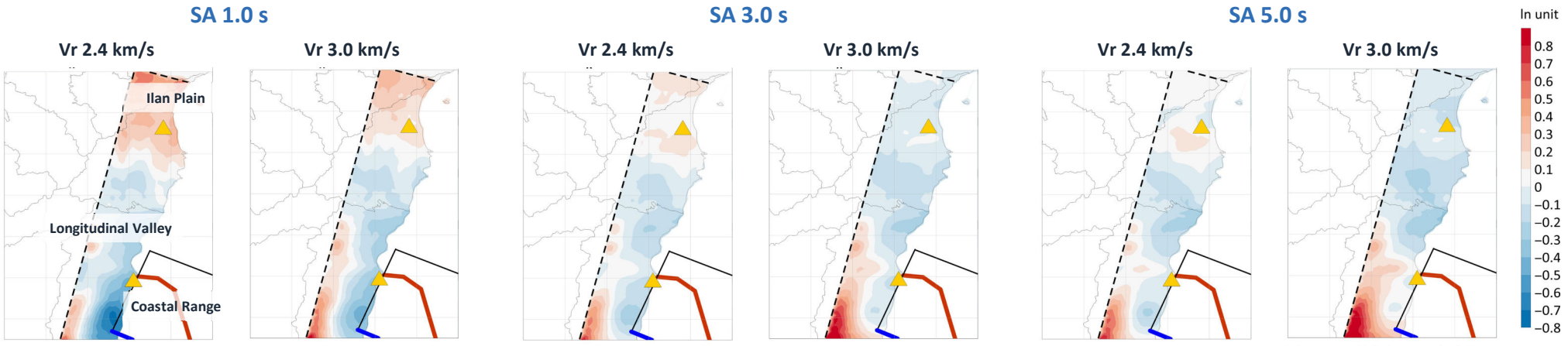
Same panels as on the Recipe slide. Stars dir1–dir4: where the rupture starts.

- Rupture direction changes the amplitude, most clearly at 3 and 5 s: forward directivity red (above CH20), backward blue.
- dir2 gives the largest positive term near ILA.
- dir3 give the strongest in the northern Longitudinal Valley.
- The Hualien amplification stays in the same place for all four directions: a property of the path, not of the rupture.



HH3D, each map averaged over the source models that start at that hypocenter. Triangles: ILA, HWA.

Aleatory variability: path terms by rupture velocity (HH3D)



HH3D, averaged over the source models with the given rupture velocity. Red: synthetics above CH20; blue: below (ln units); triangles: ILA, HWA; dashed line: analysis boundary.

Above the ergodic model in two places

In the Ilan Plain and the Longitudinal Valley the synthetics exceed CH20 for both rupture velocities; the Coastal Range stays below.

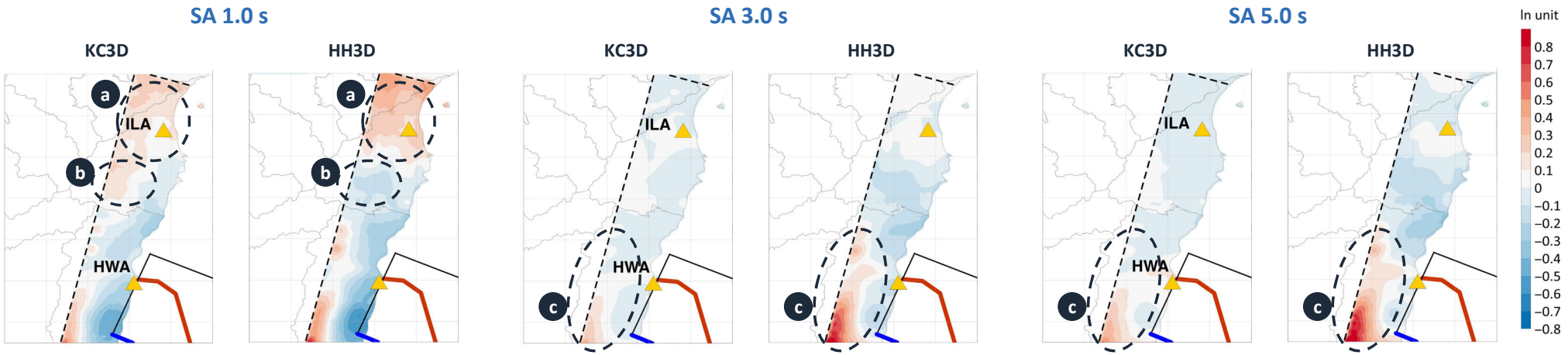
Ilan Plain: kept by the slower rupture

At 3 and 5 s the positive correction survives only under Vr = 2.4 km/s; with 3.0 km/s it fades.

Longitudinal Valley: strengthened by the faster rupture

At longer periods Vr = 3.0 km/s gives the larger positive correction, and the feature stays in place.

Epistemic uncertainty: does the path term depend on the Earth model?



Each velocity model averaged over all 96 source models. Red: synthetics above CH20; blue: below (ln units); triangles: ILA, HWA.

At 1 s the models differ

- **a** Ilan Plain: stronger in HH3D
- **b** 24.4–24.6°N: stronger in KC3D

Why: a ~3 km wavelength sees the upper-crustal differences between the models.

At 3 and 5 s the models agree in pattern

Amplification near Hualien, deamplification along the ranges; the 1 s differences fade.

- **c** Longitudinal Valley: stronger in HH3D, as in the Ilan Plain at 1 s

Why: 10–17 km wavelengths average small structure out. The large-scale low-velocity belt along the east coast remains, and HH3D has the stronger one.

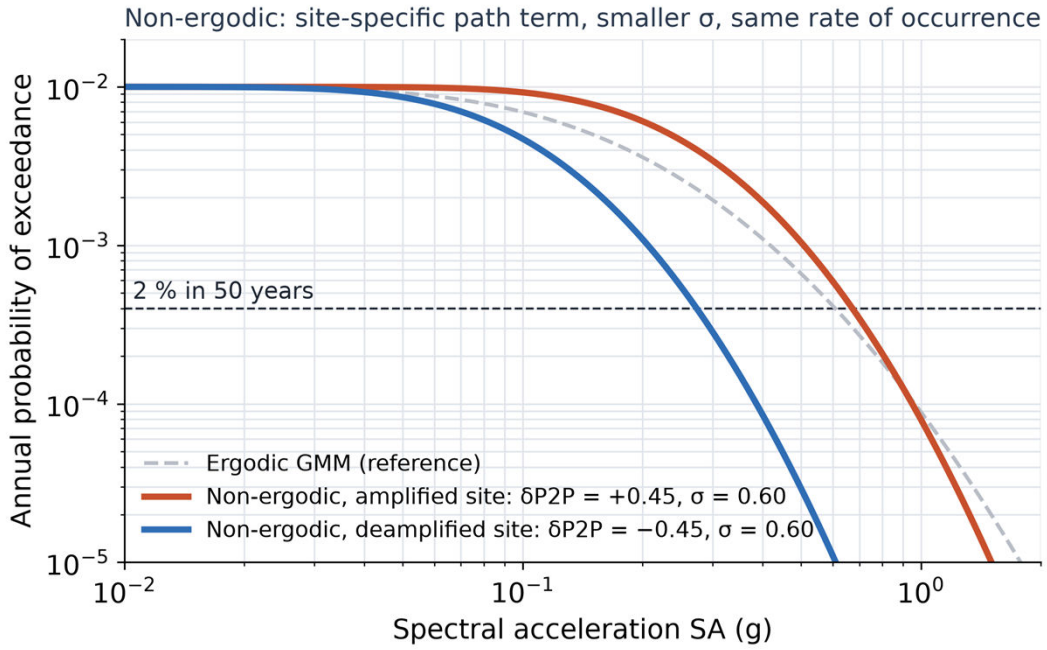
Same pattern in two independent tomographies: the path effect. **But two Earth models give only a limited estimate of the epistemic uncertainty.**

5

What this is for, and what we are working on next

Into PSHA, into structural analysis, into a daily forecast, and three open questions

Putting a non-ergodic GMM into PSHA



Schematic hazard curves for one source and one site. Moving a repeatable path effect into the median and shrinking σ changes the design motion at 2 % in 50 years in both directions.

ERGODIC PSHA TODAY

Sources: TEM, SSHAC → GMM: median + σ → One hazard curve per distance

WITH SIMULATION-DERIVED TERMS

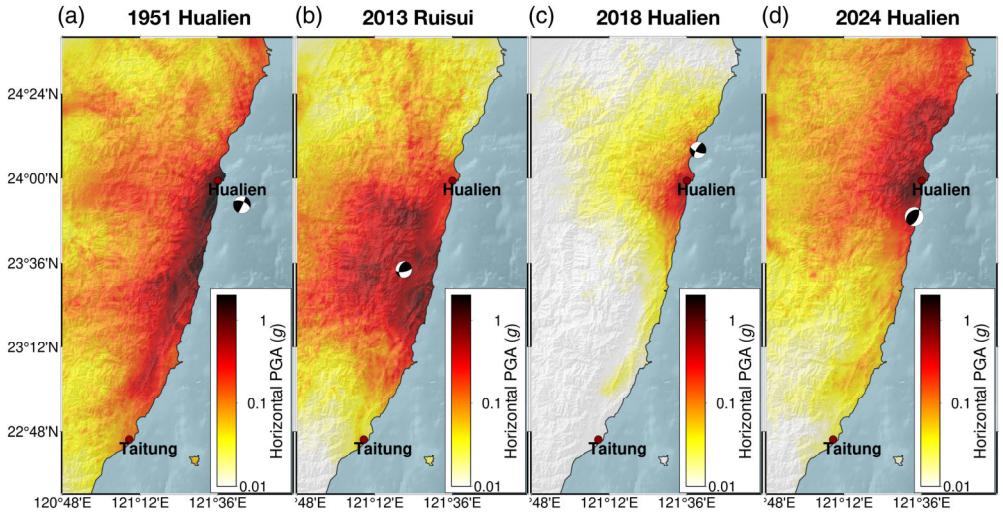
Same sources → Median + δP2P, smaller σ → Location-specific hazard

- The dataset gives relative path effects for an Mw 8 interface source with its variability and an epistemic branch (two Earth models), as in Sung et al. (2023, 2025).
- Still needed before PSHA: weights for the discrete alternatives, soft-rock to hard-rock scaling so that the mean offset from CH20 becomes physical, δS2S and δL2L.

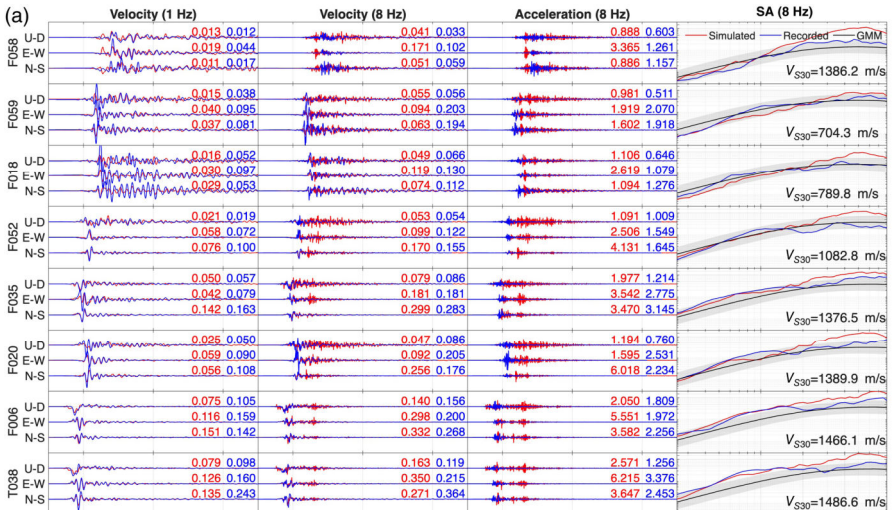
Toward structural analysis: simulated motions as input to buildings

Zhang, Hsieh, and Chen (2026), SRL

1951 Hualien · Mw 7.3 **2013** Ruisui · Mw 6.4 **2018** Hualien · Mw 6.4 **2024** Hualien · Mw 7.4



Simulated horizontal PGA for four damaging earthquakes: 3-D velocity, topography, bathymetry, calibrated slip models; 3 hypocenters × 4 slip models per event quantify directivity and source uncertainty.



Simulated (red) vs recorded (blue) velocity and acceleration, and SA to 8 Hz. 2013 Ruisui: recorded and simulated waveforms agree up to 8 Hz.

THE SAME ENGINE, ONE STEP FURTHER

3-D broadband simulation
validated against records to 8 Hz

Three-component time histories
at any site, with or without a station

Structural response analysis
with Prof. Peng-Yu Chen (Civil Engineering, NCU)

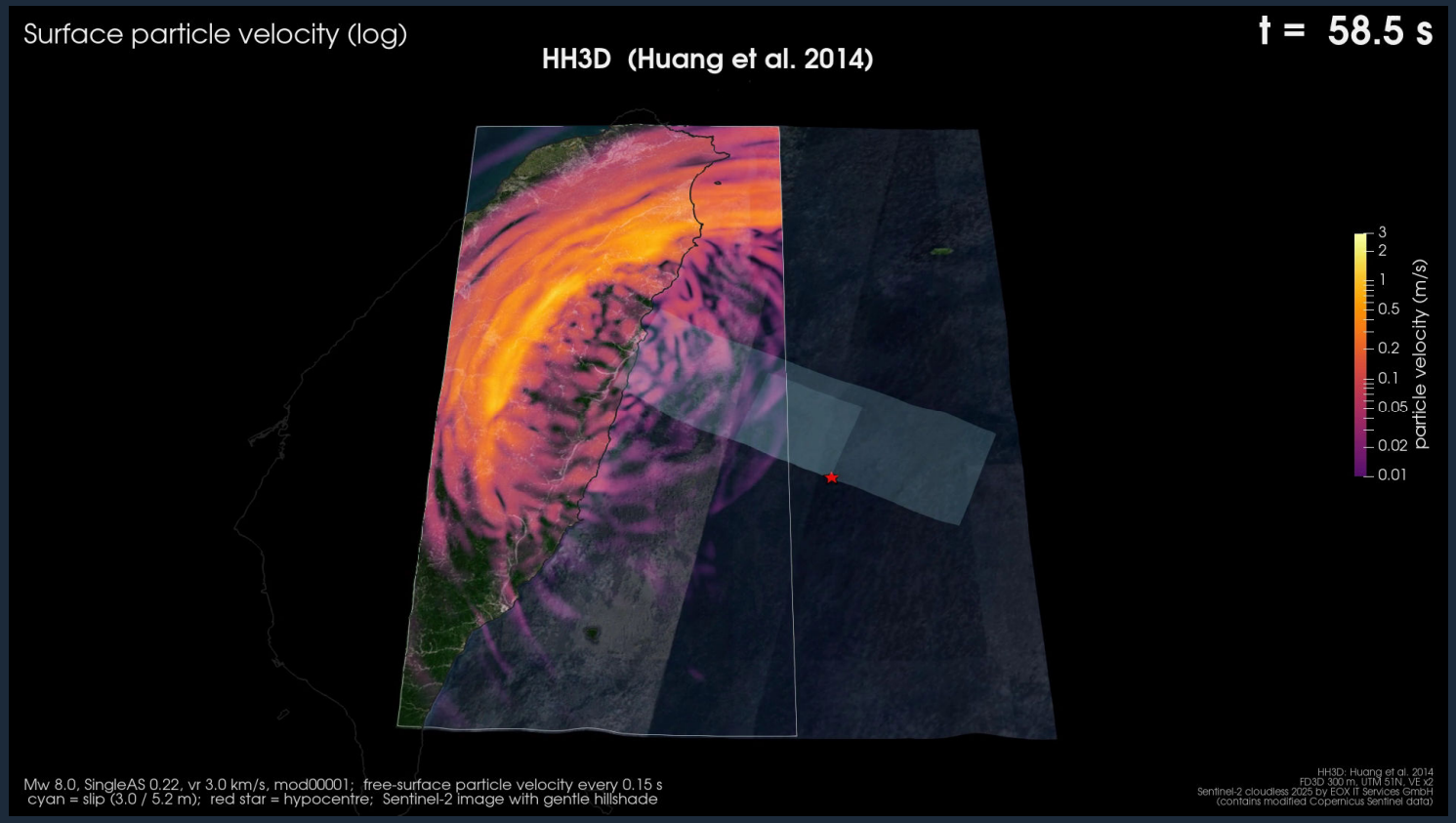
M 8 Scenario Earthquake in the Ryukyu Subduction Zone: Simulated Shaking for the Nationwide Earthquake Drill







2022 nationwide earthquake drill



From simulation to preparedness. The simulated wavefield tells where, how soon, and how strongly the ground will shake, so the drill scenario, rescue deployment, and response planning start from physics rather than from a guess.

3-D FD simulation: finite-fault source + HH3D velocity model + topography, 96 MPI cores (Hsieh, Sung & Yang, 2026). Free-surface particle velocity, then peak ground velocity.

An ergodic GMM in daily use: the ETAS-GMprob shaking forecast

Real-time catalog
CWA earthquake locations and origin times

→

ETAS forecast
seismicity rates and synthetic catalogs for the next day

→

Ergodic GMM
PGA at each site for every synthetic event

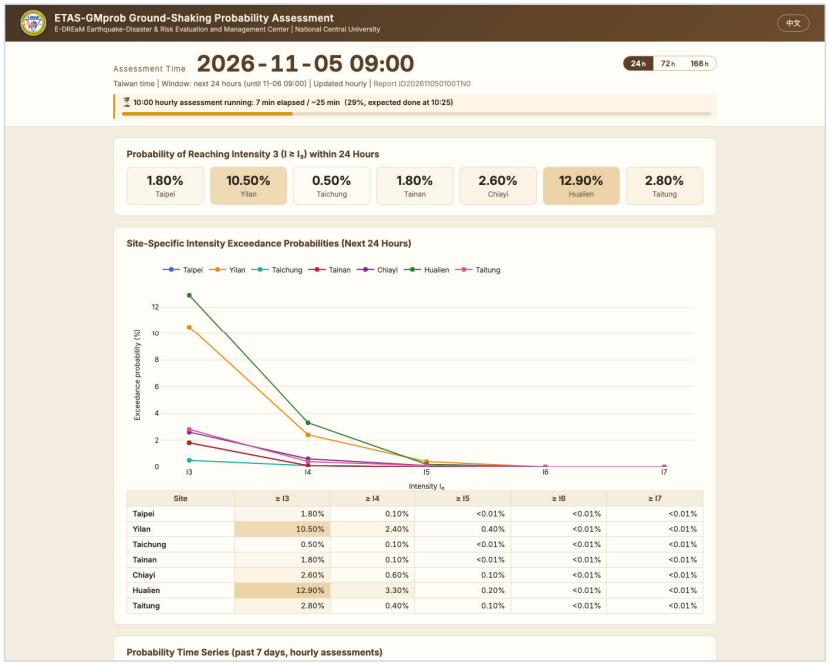
→

Exceedance probability
chance of reaching intensity 3 to 7 at each site

→

Public dashboard
assessed every hour, seven cities at a glance

Flow after Hsieh et al. (2024, SRL, doi 10.1785/0220240180), applied to the 2022 Taitung sequence.



Its weak link is the ground-motion step

With an ergodic GMM, a Longitudinal Valley site and a Coastal Range site at the same distance get the same median. This study says they should not.

A natural upgrade

Keep ETAS, replace the ergodic median with ergodic + δP2P for the sources that matter, including a large Ryukyu event.

ETAS-GMprob dashboard
mchsieh.github.io/etas-gmprob-dashboard
Screenshot: 5 November 2026, 09:00 assessment.

TAKE-HOME

What to remember

1. **The source duration has to follow the period.** Against CH20, Gaussian source time functions of 2, 6 and 8 s fit SA at 1.0, 3.0 and 5.0 s. Only the mean level is calibrated.

2. **Rupture directivity and rupture velocity dominate, and unevenly.** Directivity: × 4–5 near the fault, × 40 at Taitung; rupture velocity: × 1.7–2.3. Sensitivity, and so σ, varies in space.

3. **Three path effects belong to eastern Taiwan, not to any rupture.** Hualien amplification, a Coastal–Central Range deamplification belt, and a frequency-dependent Ilan Plain amplification. Both Earth models agree.

4. **A transferable workflow.** 1,728 Mw 8 scenarios from Recipe-based sources, 3-D wave propagation and an empirical GMM: usable in other subduction zones where records are sparse.

Thank you.

Ming-Che Hsieh (mchsieh@ncu.edu.tw) · Paper: doi 10.1785/0220260149

Backup

One set of simulations, nine source durations

Simulated once, with a 2 s Gaussian

$$U_2(f) = G(f) \cdot S_2(f)$$

G: response of the Earth model; S: source time function

Swap the source time function

$$U_T(f) = U_2(f) \cdot S_T(f) / S_2(f)$$

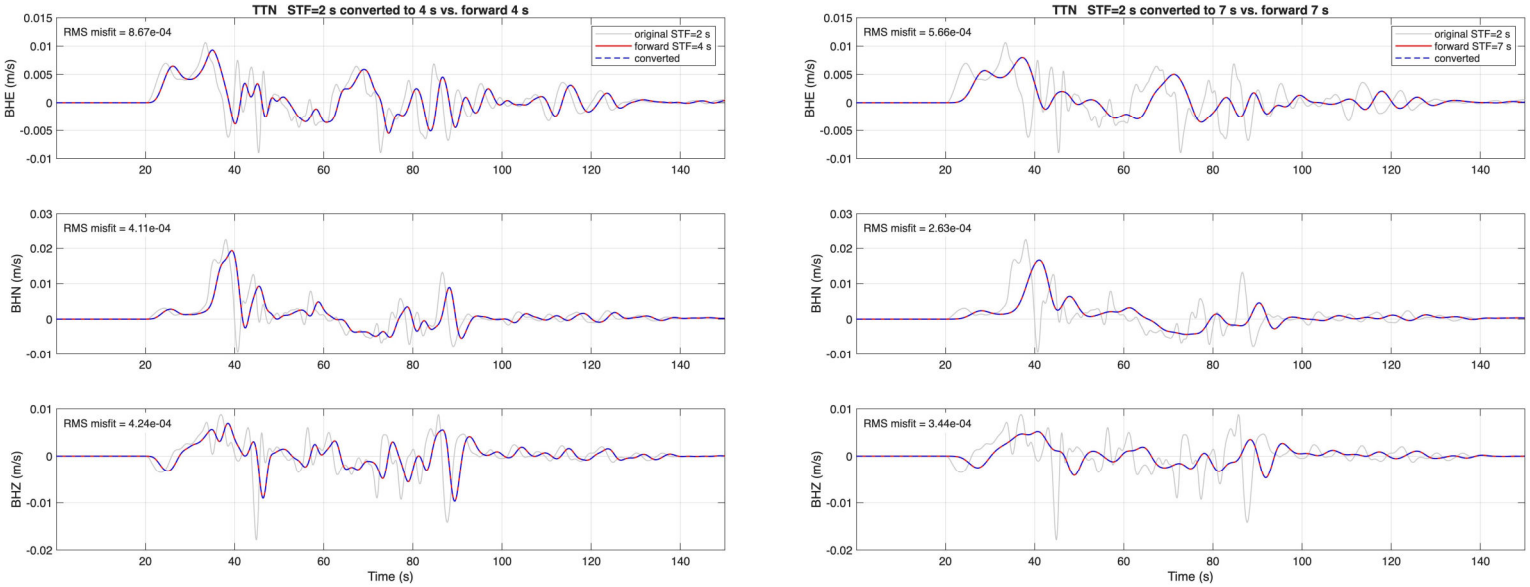
divide out the 2 s Gaussian, multiply in the target one

Result: a single Gaussian of duration T

$$U_T(f) = G(f) \cdot S_T(f)$$

T = 3 to 10 s; the source time function is applied once, not twice

CHECKED AGAINST DIRECT FORWARD SIMULATIONS AT TTN, THE MOST DISTANT SITE



Three components at TTN. Grey: original 2 s simulation; red: forward simulation with the target duration; blue dashed: converted from the 2 s run. Left: 4 s; right: 7 s. Reply to reviewers, Figures R5 and R6.

They overlap

Relative RMS difference below 0.1% on all three components.

Why it is stable

For T ≥ 2 s the ratio of the two spectra only decreases with frequency: nothing is amplified.

What it buys

192 simulations serve all nine durations: 1,728 scenarios.

Calibrating the source time function against the ergodic CH20 model

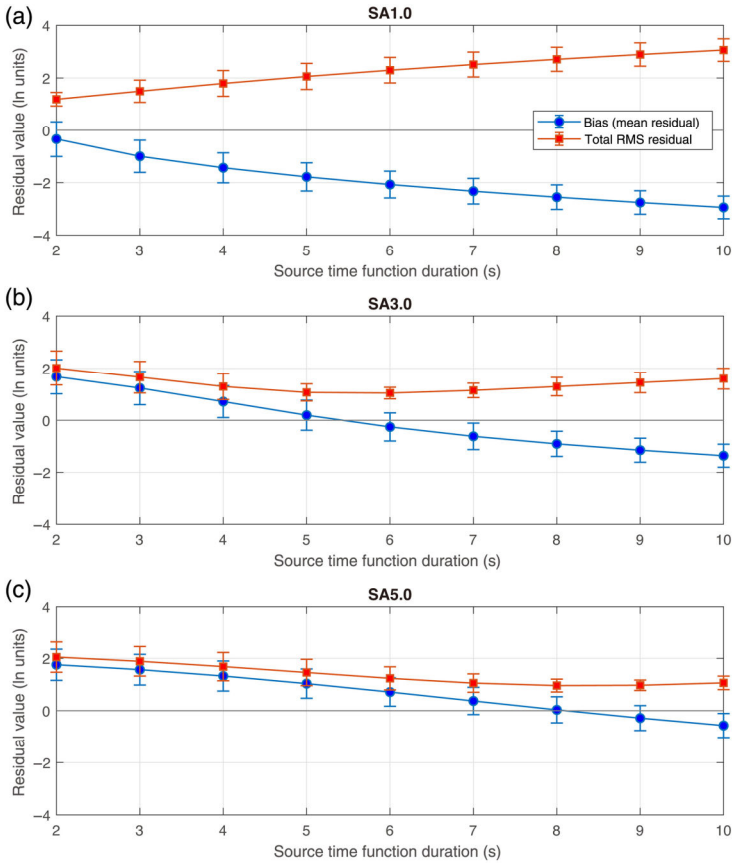


Figure 5. Bias B (blue) and total RMS residual (red) of ln(SA_sim / SA_CH20) vs source duration; bars: ± 1 s.d. over 192 combinations.

- Short pulses over-produce short-period energy, long pulses suppress it: the optimum is period dependent.
- Chosen: 2, 6 and 8 s for SA at 1.0, 3.0 and 5.0 s, about 1.5–2 × the period.
- At 3 s, 6 s beats the lower-bias 5 s because the spread across source models drops from 0.33 to 0.22 ln units.

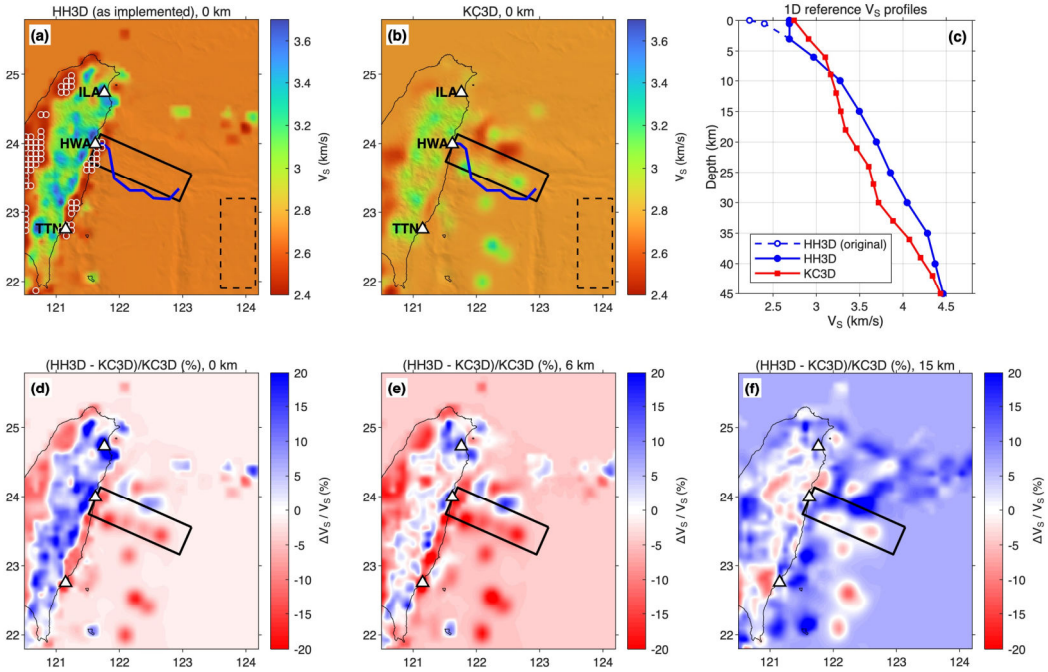
What calibration fixes

Only the global mean level (C_SIM = −0.34, −0.26, +0.03 ln units at 1, 3, 5 s), which also absorbs the uncertain CH20 hard-rock site scaling.

What it does not touch

Where motions are stronger or weaker across eastern Taiwan. That is set by 3-D wave propagation, and it is the part read as δP2P.

Many velocity models exist; their effect on shaking is unexplored



Supplement Figure S6: Vs at the surface in HH3D (as implemented) and KC3D, their 1-D reference profiles, and the difference between them at 0, 6 and 15 km depth.

1 What exists

Several 3-D velocity models of Taiwan, mostly from travel-time tomography, built to image structure rather than to predict shaking.

2 What has not been studied

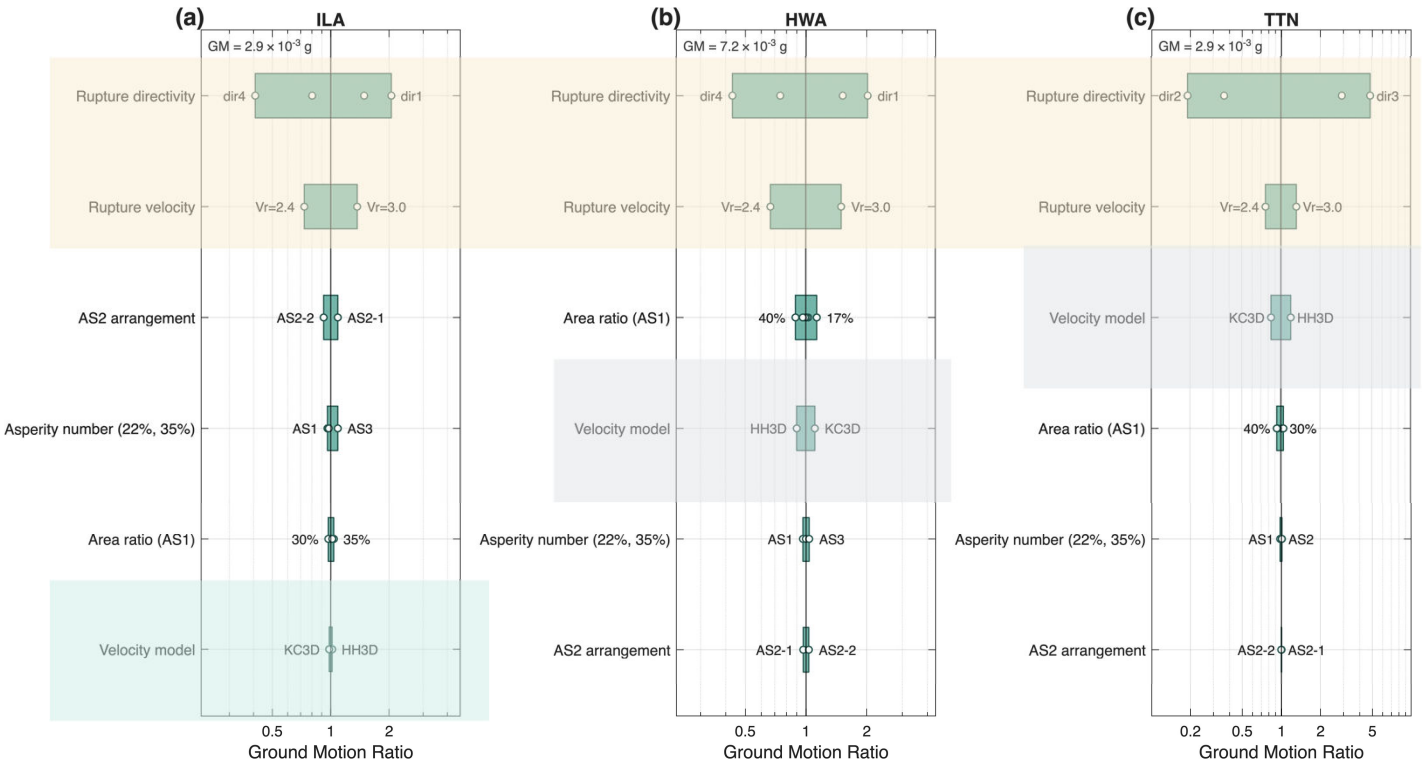
How the choice of model changes the simulated ground motion at each period across eastern Taiwan, and which differences are path effects rather than artifacts of one model.

3 What this study does

Runs every rupture in two independent models, compares the results period by period, and keeps as path effects only what both models share.

Sensitivity at SA 3.0 s: the same ranking

Tornado plot Center (=1): geometric mean of all cases
Vertical axis: one row per tested parameter
Bar length: lowest to highest mean GM



Supplement Figure S1. Tornado plots of SA at 3.0 s (6 s source time function) at ILA, HWA and TTN: range of the mean motion over cases sharing a parameter value. Note the different horizontal scales.

1 Rupture direction

× 5 at ILA and HWA
× 25 at TTN

2 Rupture velocity

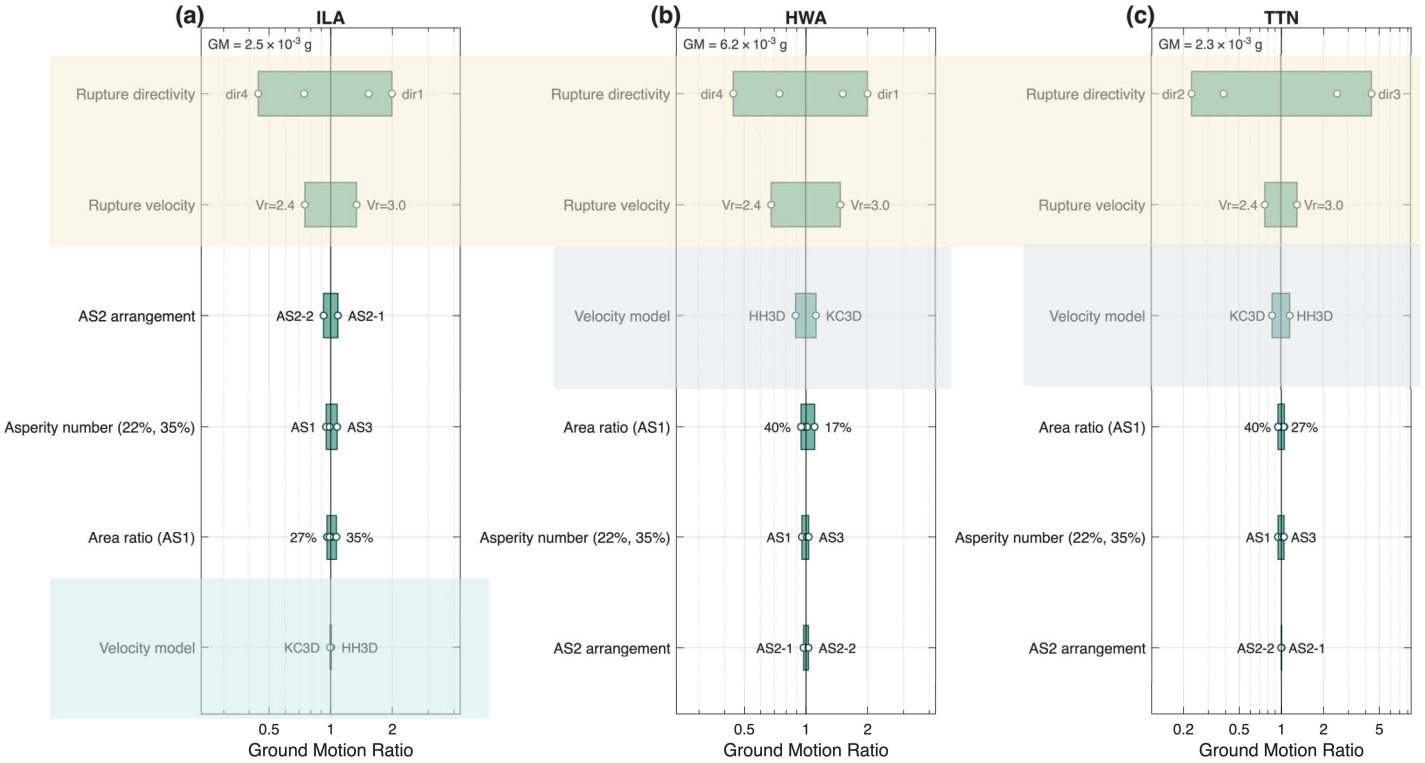
about × 2
3.0 km/s against 2.4 km/s

3 Velocity model, asperity layout

Both small
Velocity model: differs from site to site

Sensitivity at SA 5.0 s: the same ranking

Tornado plot Center (=1): geometric mean of all cases
Vertical axis: one row per tested parameter
Bar length: lowest to highest mean GM



Supplement Figure S2. Tornado plots of SA at 5.0 s (8 s source time function) at ILA, HWA and TTN: range of the mean motion over cases sharing a parameter value. Note the different horizontal scales.

1 Rupture direction

× 4.5 at ILA and HWA
× 20 at TTN

2 Rupture velocity

about × 2
3.0 km/s against 2.4 km/s

3 Velocity model, asperity layout

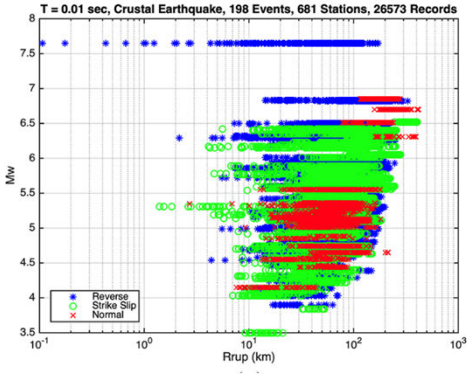
Both small
Velocity model: differs from site to site

Synthetic Ground Motion Dataset: The CH20 GMM

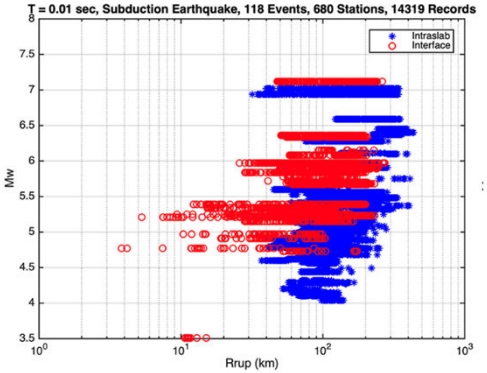
[Chao et al., 2020]

Distance-Magnitude Distribution

Crustal



Subduction Zone



Regression

GMM Functional Form

Median model

$$
\begin{aligned}
\ln Y = {} & c_1 F_{\mathrm{RO}} + c_2 F_{\mathrm{SS}} + c_3 F_{\mathrm{NO}} + c_4 F_{\mathrm{IF}} + c_5 F_{\mathrm{IS}} + c_6 F_{\mathrm{AS}} + c_7 F_{\mathrm{MA}} \\
& + c_8 F_{\mathrm{cr}} (M - M_{\mathrm{ref}}) + c_9 F_{\mathrm{sb}} (M - M_{\mathrm{ref}}) \\
& + c_{10} F_{\mathrm{cr}} \left[(M - M_{\mathrm{ref}})^2 - (M - 7.6)^2 \, H(M - 7.6) \right] \\
& + c_{11} F_{\mathrm{cr}} (5 - M) \, H(5 - M) + c_{12} F_{\mathrm{sb}} (5 - M) \, H(5 - M) + c_{13} F_{\mathrm{sb}} (6 - M) \, H(6 - M) \\
& + c_{14} F_{\mathrm{cr}} Z_{\mathrm{tor}} + c_{15} F_{\mathrm{IF}} Z_{\mathrm{tor}} + c_{16} F_{\mathrm{IS}} (Z_{\mathrm{tor}} - 35) \\
& + \left[c_{17} F_{\mathrm{cr}} + c_{18} F_{\mathrm{sb}} + c_{19} F_{\mathrm{cr}} (M - M_{\mathrm{ref}}) + c_{20} F_{\mathrm{sb}} \big(\min(M, M_c) - M_{\mathrm{ref}} \big) \right] \ln \frac{\sqrt{R_{\mathrm{rup}}^2 + h^2}}{h} \\
& + c_{21} F_{\mathrm{cr}} R_{\mathrm{rup}} + c_{22} F_{\mathrm{sb}} R_{\mathrm{rup}} \\
& + c_{23} \, f_{\mathrm{NL}} + c_{24} \ln \frac{V_{S30}}{V_{\mathrm{ref}}} + c_{25} \ln \frac{Z_{1.0}}{Z_{1.0,\mathrm{ref}}} \\
& + c_{26} F_{\mathrm{Kuo17}} + c_{27} F_{\mathrm{KS17}} + c_{28} F_{\mathrm{RF}} \\
& + c_{29} F_{\mathrm{IF}} (M - M_c) \, H(M - M_c) + c_{30} F_{\mathrm{IS}} (M - M_c) \, H(M - M_c)
\end{aligned}
$$

We compare our synthetic ground motions with the ergodic ground motion model of **Chao et al. (2020)**:

M, **R_{RUP}**, **Z_{TOR}**, **Cr/SubZ**, **fault type**, $Z_{1.0}$, V_S30

Three questions we are currently working on

1 Other sources, same generator

Run the Recipe generator at other source locations (other Ryukyu segments, a multi-segment rupture) in the same Earth models.

This gives **δL2L**, and a test of whether the Hualien amplification is independent of where the rupture is.

Data: public on Zenodo (doi 10.5281/zenodo.19364626).

2 Shorter periods, shallow crust

Add layers slower than 2.4 km/s (Taiwan generic rock profile, Kuo & Abrahamson, 2023) and push toward 1 Hz, as the Hualien work did to 8 Hz.

This gives **δS2S**, the soft-rock scaling that the mean offset now hides, and a test of the Ilan Plain signal under a real basin.

3 A rupture that serves all periods

Replace the Gaussian pulse with a rupture-dynamics-based source (Graves & Pitarka, 2016) or dynamic rupture on the R1 geometry.

This gives one source description for 1, 3 and 5 s, physical rise times for Mw 8, and a path to a spatially varying σ.