Study on the Near-Field/Far-Field boundary in finite-fault strong motion simulations

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UR 3.13 "Reference ground-shaking map of the Italian territory"

In the framework of the project S1:
"Analysis of the seismic potential in Italy for the evaluation of the seismic hazard" (Co-ordination of S1 project by: Barba S. (INGV, Roma) and Doglioni C. (Roma University of the "La Sapienza")

Agreement INGV-DPC 2007-2009

Objective n°1

Maximum Observable Shaking (MOS) maps of the Italy

ES9/P3/ID224

POSTER

Objective n°2

Definition of near-field areas surrounding major seismogenic sources

ES9/TH/01

this contribute

SUMMARY

- We present some key aspects of seismic-source theory that address near-field and far-field seismic radiation.
- We then describe our simulation strategy for examining the properties of NF- and FF-seismic waves from extended sources.
- The original project description includes a theoretical/analytical study on this issue, however, we decided to focus on the numerical aspects of this work to gain insight into the NF/FF properties from to potentially derive an application-oriented empirical relations.

Near-field/far-field boundaries of the major seismogenic faults

The near-field (NF), Intermediate-Field (IF) and Far-Field (FF) terms represent different properties of the wave-field:

- the near-source motions are more sensitive to the spatio-temporal details of the rupture process,
- while far-field terms carry the overall signature of the rupture encoded into the moment-rate function.

There is no distance at which the NF terms can be completely ignored, but they have different distance decays :

Aki & Richards, 2002, Eq. 4.29

$$M_{pq} * G_{np,q} \propto \frac{1}{r^4}\int_{r/\alpha}^{r/\beta} \tau M_{pq}(t-\tau)\,d\tau + \frac{1}{r^2} M_{pq}\left(t-\frac{r}{\alpha}\right) + \frac{1}{r^2} M_{pq}\left(t-\frac{r}{\beta}\right) + \frac{1}{r}\dot{M}_{pq}\left(t-\frac{r}{\alpha}\right) - \frac{1}{r}\dot{M}_{pq}\left(t-\frac{r}{\beta}\right)$$

NF **IF** **FF**

1. NF-waves depend on the temporal slip-evolution on the fault plane, and decay as $1/r^3$ with distance r;
2. IF-waves have amplitude and properties depending on the slip function, and decays as $1/r^2$
3. FF-waves depend on the slip-rate function and decay as $1/r$.

The equation is valid for point-sources, but it is unclear how NF, IF, FF terms behave for more realistic extended sources.

The FF motions often exhibit peak ground acceleration (PGA) within the resonance frequency of buildings, and hence are important for engineering purposes

In this context it is of interest to be able to define the (approximate) region in which **NF-radiation** needs to be included for accurate shaking-level estimation (and beyond which it is sufficient to only consider the dominating far-field radiation), and where FF-waves dominate

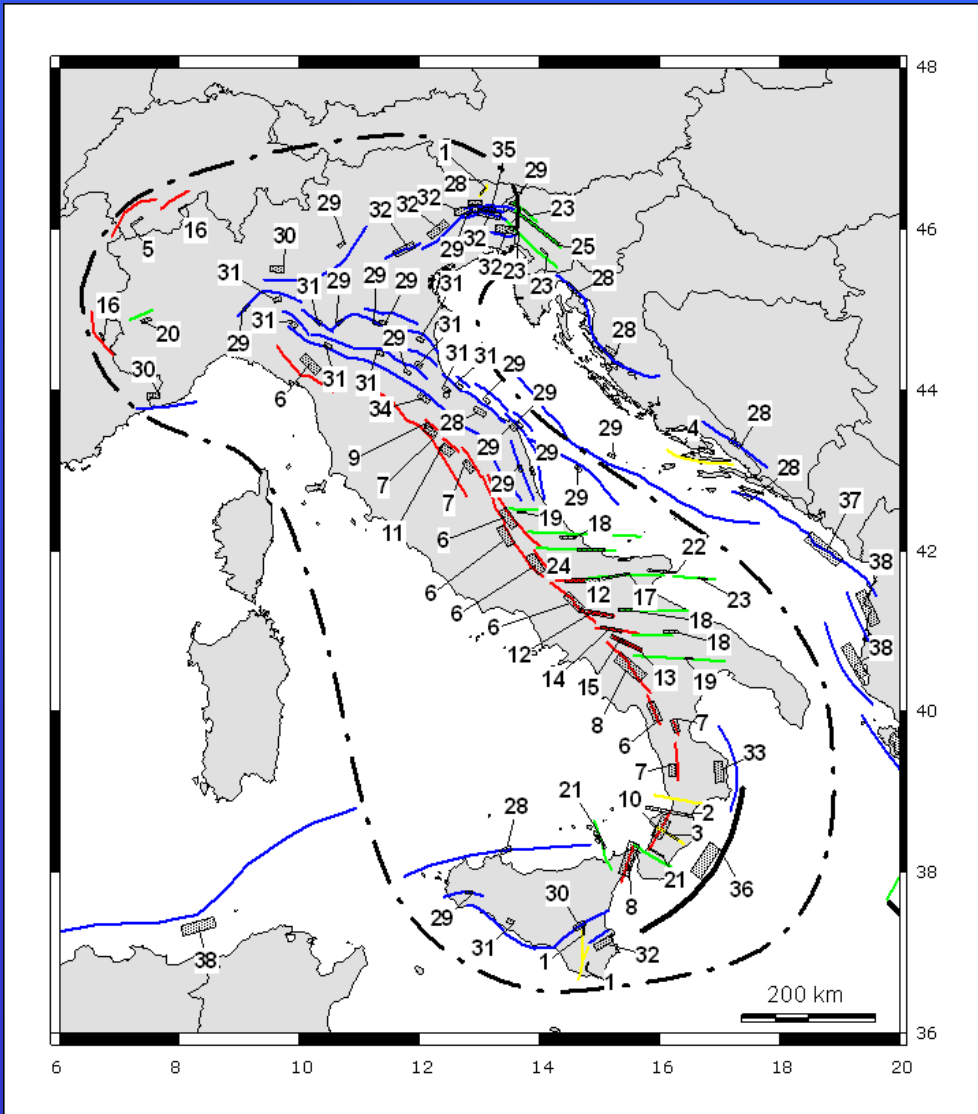
Depending on the particular engineering application and seismic design criteria, it could be sufficient to perform approximate high-frequency far-field ground-motion simulation instead of carrying out expensive full wavefield computations that contain all NF, IF, and FF-terms

Numerical simulations performed in this study are based on two different **finite-fault ground-motion simulation techniques** that account for rupture model complexity. Both numerical codes consider 1D layered velocity structures

Simulation Strategy

To study the importance of near-field and far-field contributions, we perform numerical simulations for a number source-model realizations, using two different finite-fault ground-motion simulation techniques that account for rupture model complexity.

- We compute high-frequency (up to ~10 Hz) far-field (FF) radiation using the **ISOSYN package (Spudich&Xu, 2003)** for arbitrarily complex source-rupture models
- Low frequency ($f \leq 2$ Hz) complete seismograms, containing additionally all NF and IF terms, are computed using the **COMPSYN package (Spudich&Xu, 2003)**, a discrete-wavenumber / finite-element code



Map of the 33 rectangular **Typical Faults** (TF) grouped according to the adopted criteria and associated with each CSS. Bold colored lines mark the top edge of fault sources and the TF floating paths.

We select for the simulations the TFs:

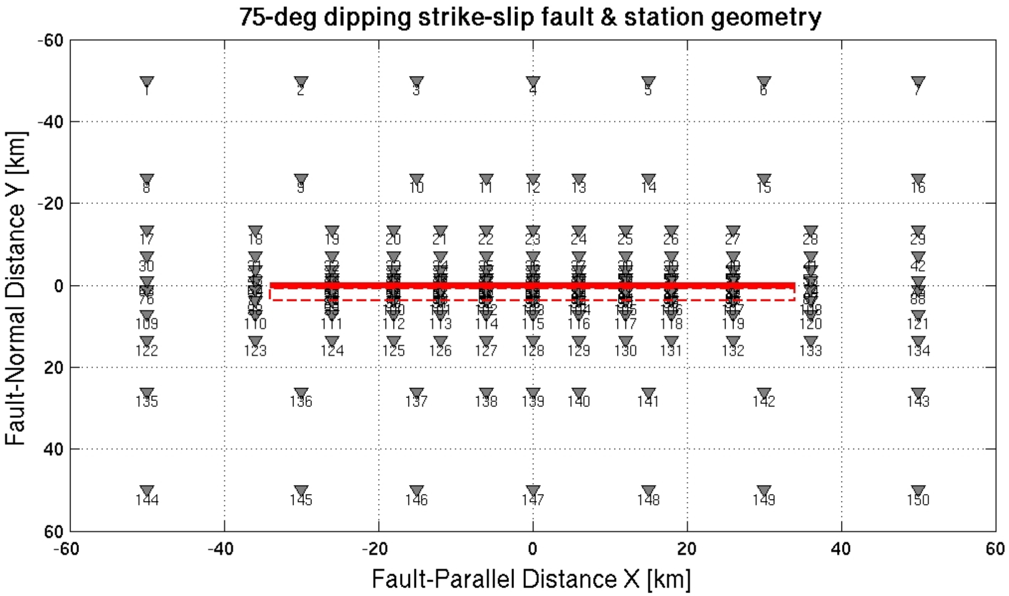
Mw 7.1 scenario events on a:

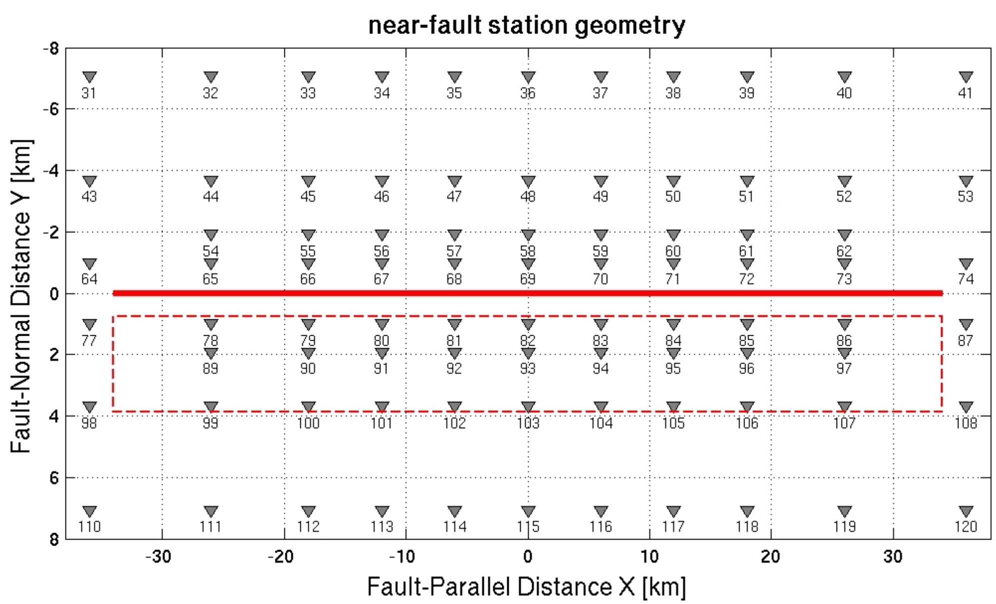
25°-dipping thrust-fault

45°-dipping normal fault

75°-dipping normal fault

75°-dipping strike-slip



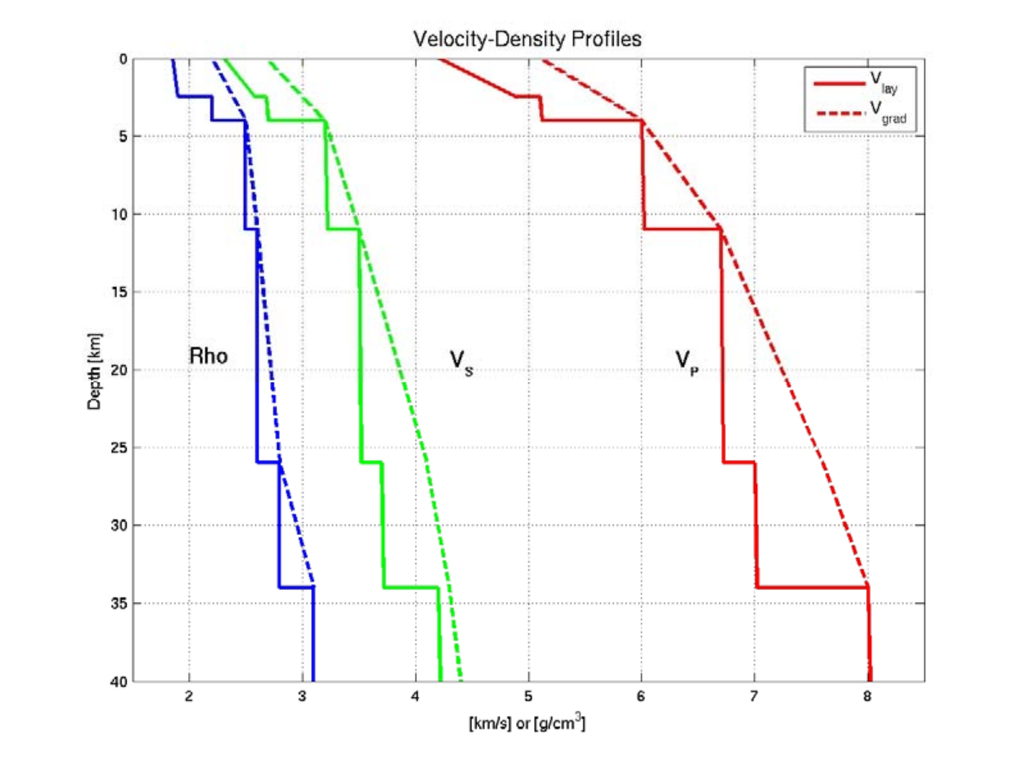


Station geometry used in this study:

150 sites are located at approximately regular inter-station spacing in fault-parallel (X) direction, approximately logarithmically spaced in fault-normal (Y) direction.

The bold red line marks the surface-projection of the upper edge of the fault plane, the dotted line shows the projection of the 75°-dipping fault. **Top**: entire simulation domain; **bottom**: near-fault region only.

Velocity-density model for near-field & far-field ground-motion simulation:

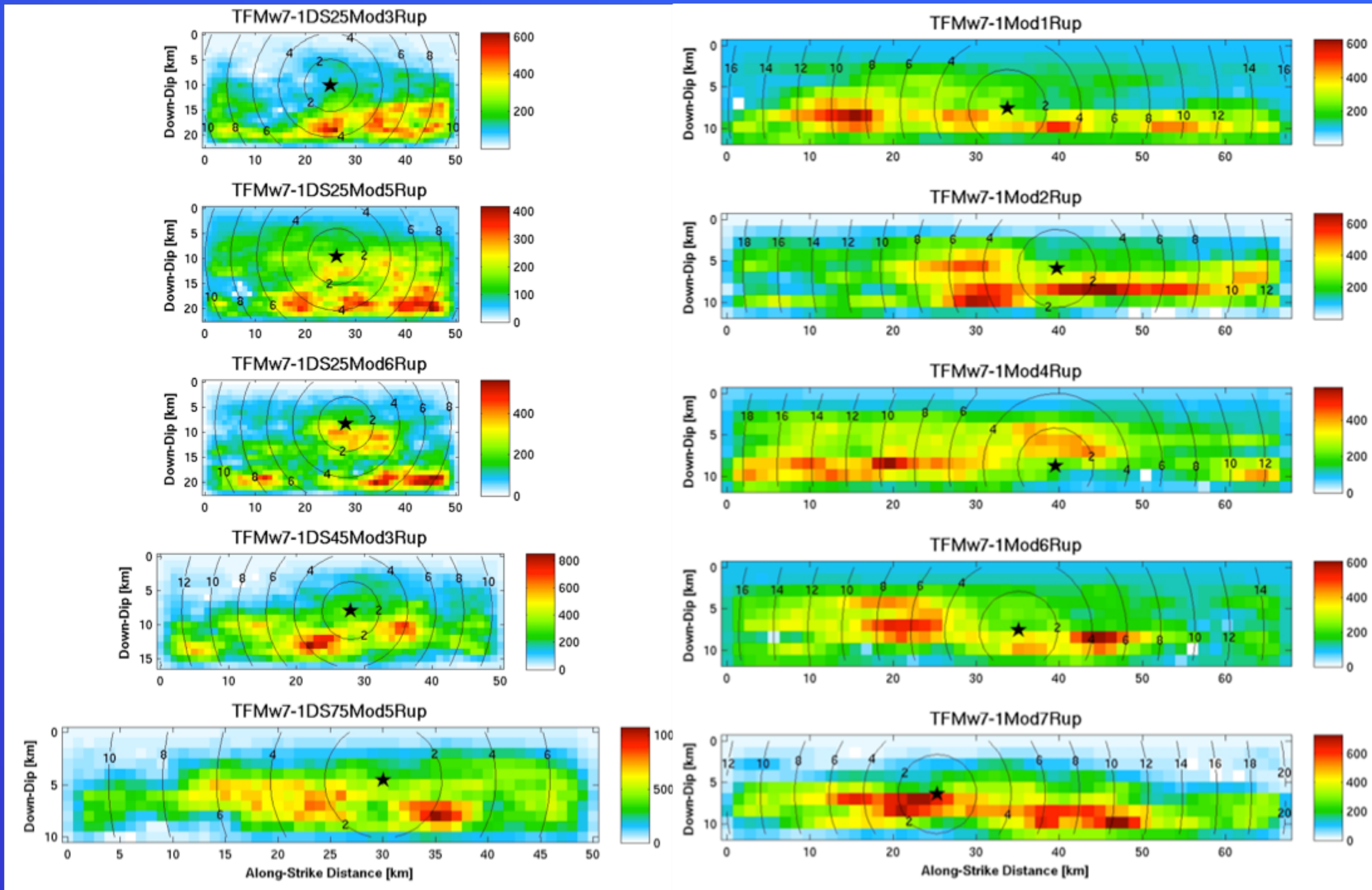


model V_{lay} consists of several layers with strong discontinuities;

model V_{grad} is a piecewise linear-gradient model (dashed line) anchored to **V_{lay}**, and avoids travel-time triplications.

Name	Faulting Style	Dip [deg]	Size [LxW km]	Rise time [s]
DS25Mod3	thrust faulting	25	50 x 23	1.4
DS25Mod5	thrust faulting	25	50 x 23	1.4
DS25Mod6	thrust faulting	25	50 x 23	1.4
DS45Mod3	normal faulting	45	50 x 16	1.4
DS75Mod5	normal faulting	75	50 x 11	1.4
TF71Mod1	RL strike slip	75	69 x 12	1.4
TF71Mod2	RL strike slip	75	69 x 12	1.4
TF71Mod4	RL strike slip	75	69 x 12	1.4
TF71Mod6	RL strike slip	75	69 x 12	1.4
TF71Mod7	RL strike slip	75	69 x 12	1.4

Specification of rupture models used in this study

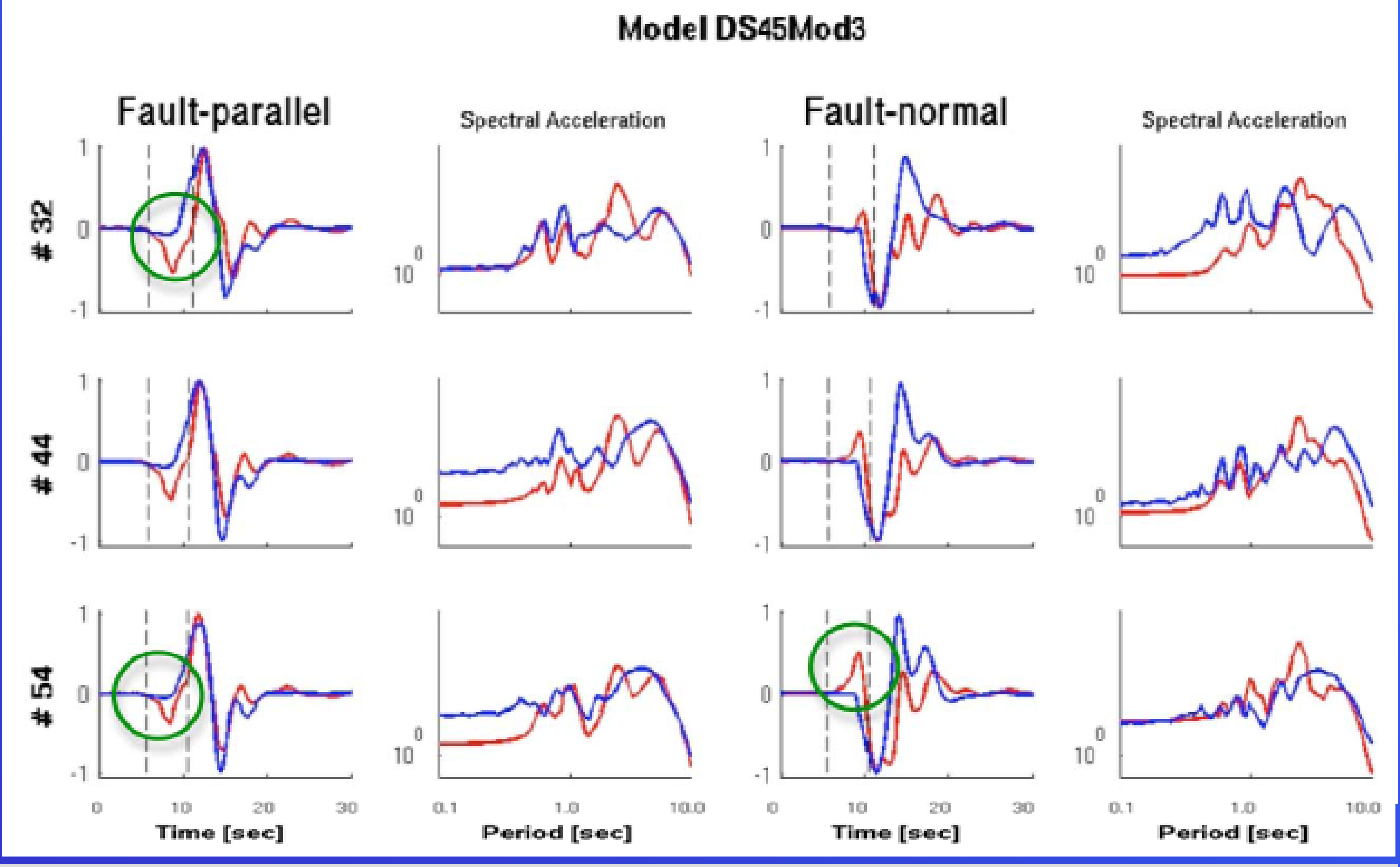


Dip-slip rupture models (left) and **strike-slip rupture models** (right). The color indicate the slip (in cm) on the fault plane, the star marks the hypocenter.

Black contour lines show the rupture propagation over the fault plane at 2-sec intervals.

The rise time for all rupture models was chosen to be a uniform 1.4 sec over the fault plane, consistent with scaling relations of Somerville et al. (1999). We use a simple boxcar slip-velocity function of this width to compute both COMPSYN and ISOCHRONE synthetics. Rupture speed is fixed at 80% of the local shear-wave speed, and thus leads to rupture propagation at 2.2-2.7 km/s, depending on depth-extent of the rupture model. In our simulations, we put the upper-edge of the fault plane at a uniform Z_{top} = 1 km.

SPOT on three waveforms for thrust-faulting scenario event DS45Mod3



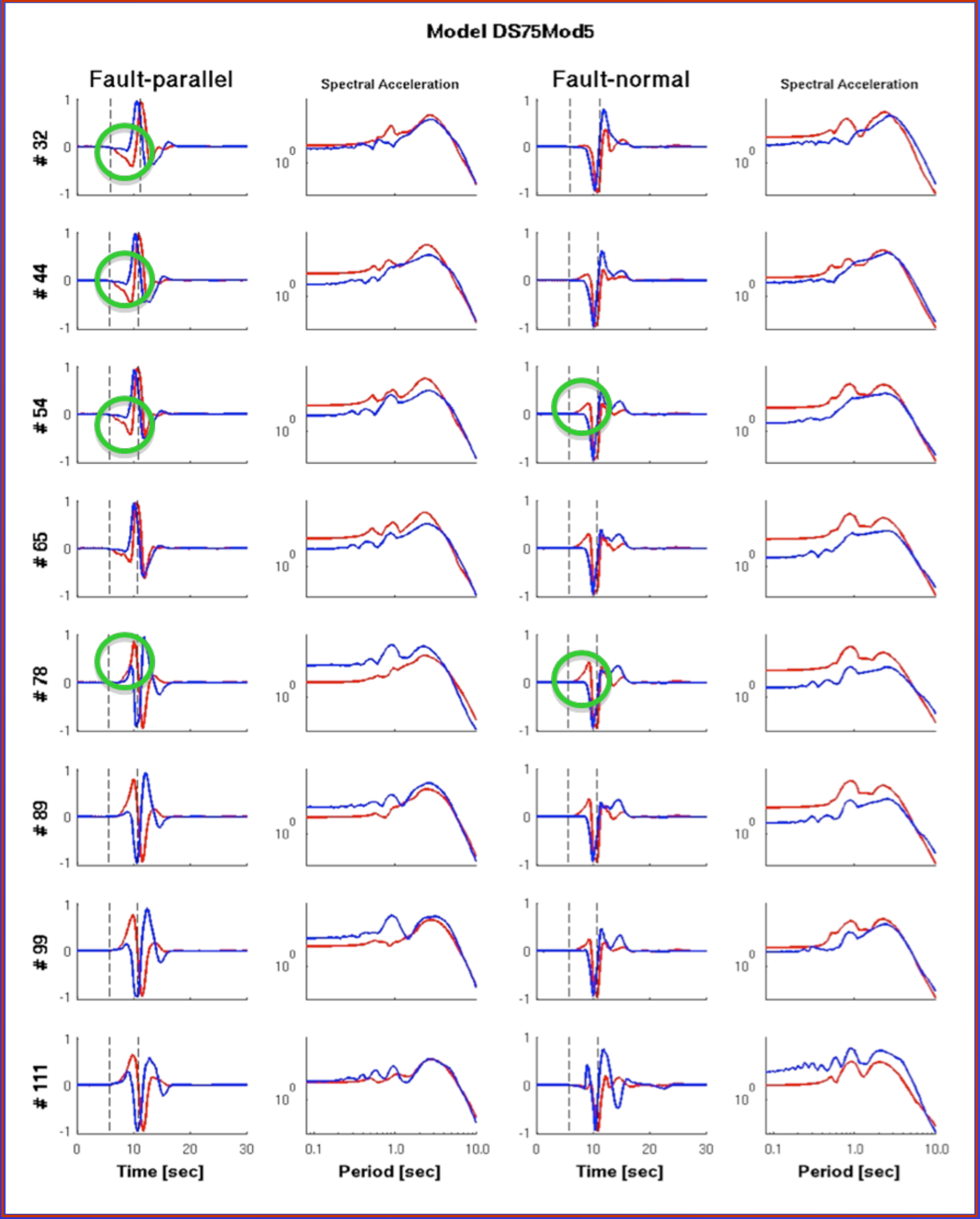
Normalized **fault-parallel** and **fault-normal** velocity time series;

response spectra (5% damping)

red: Full-wavefield synthetics, incl. NF terms

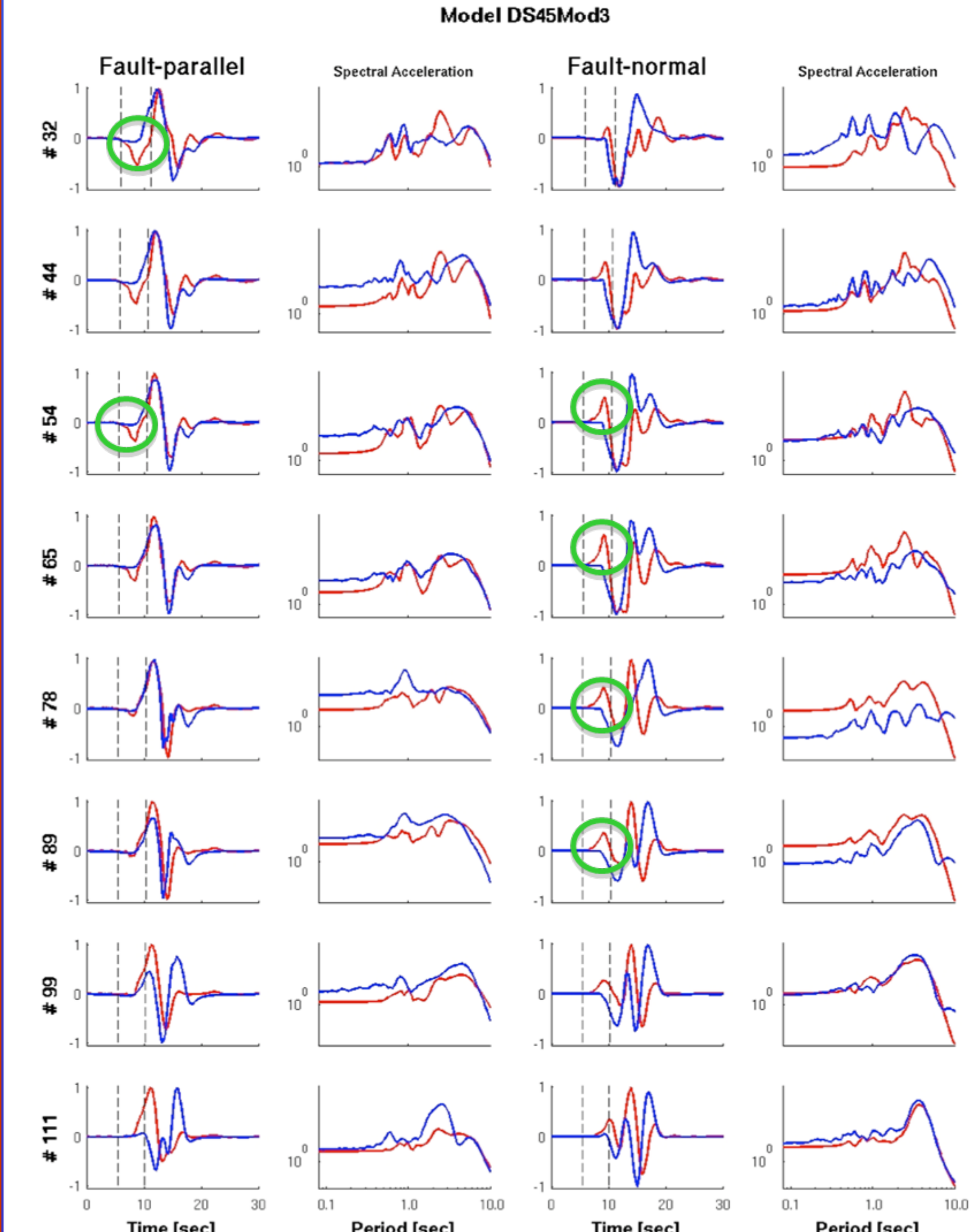
blue: isochrones synthetics, FF only

Note: sismograms are normalized to unit amplitude



Fault-normal and fault-parallel seismogram, and respective response spectra, for rupture models **DS75Mod5** on a *fault-normal array of 8 near-fault stations*.

Red traces mark full-wavefield synthetics that include near-field contributions, **blue traces** denote ray-theory synthetics. (Approximate) P- and S-wave arrival times are marked by vertical dotted lines.

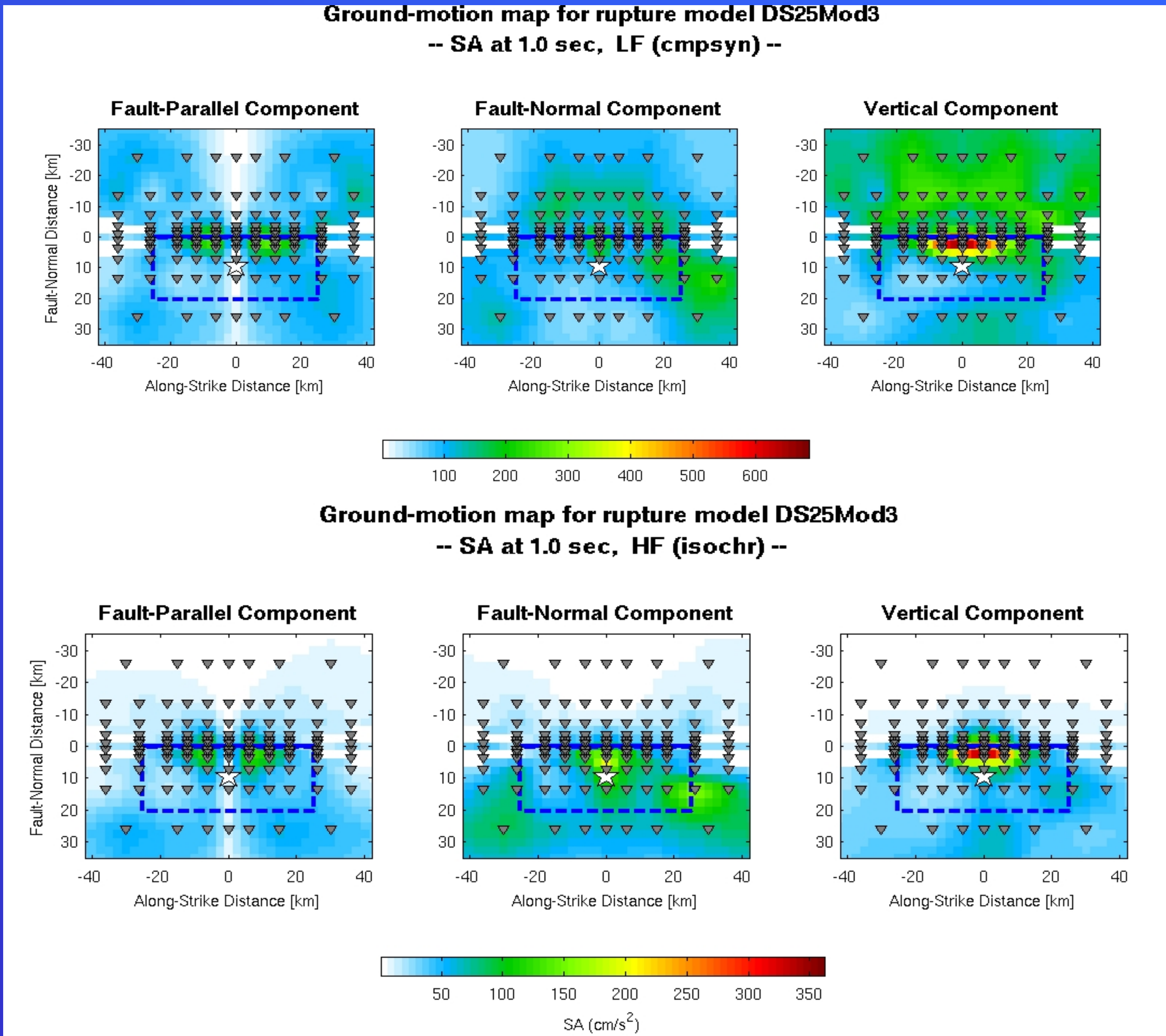


Model DS45Mod3

Aside from their expression in the seismic waveforms, the near-field terms also leave a signature on the response spectra. Note that the COMPSYN synthetics (red) are valid only in a frequency range of 0 – 2 Hz.

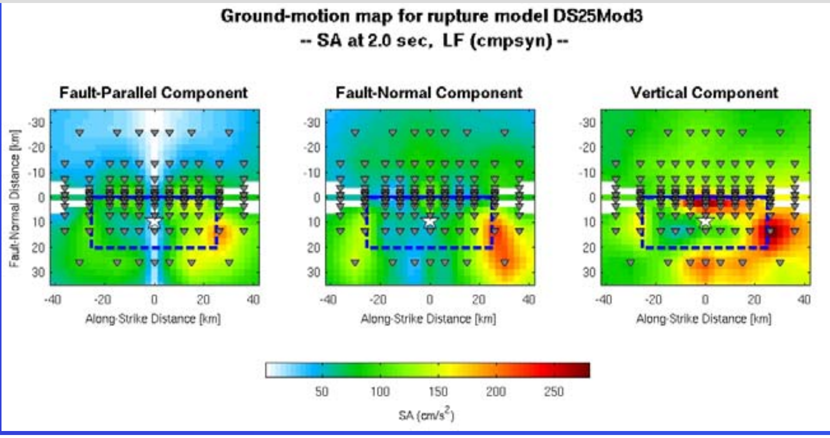
we see distinctly different spectral values SA_T between the two sets of synthetics, over a period range from roughly 1 – 10 secs, suggesting that the **near-field terms** are important of a **wide range of distances** and a **wide range of frequencies** relevant for earthquake engineering applications.

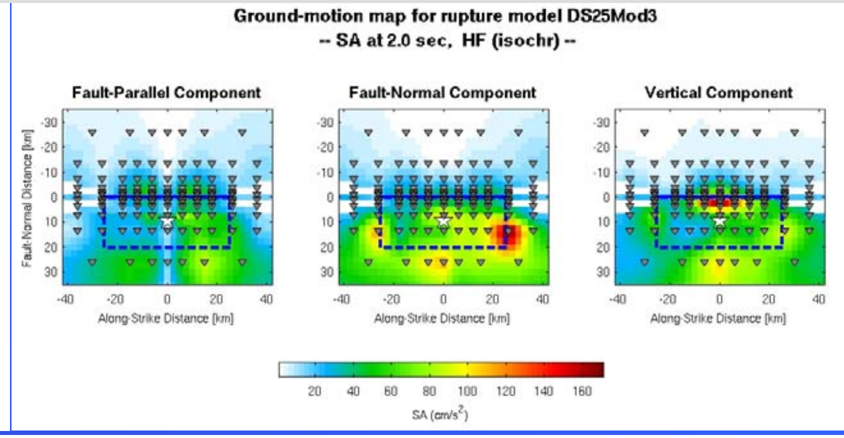
SHAKE MAPS TO IDENTIFY NEAR-FIELD EFFECTS



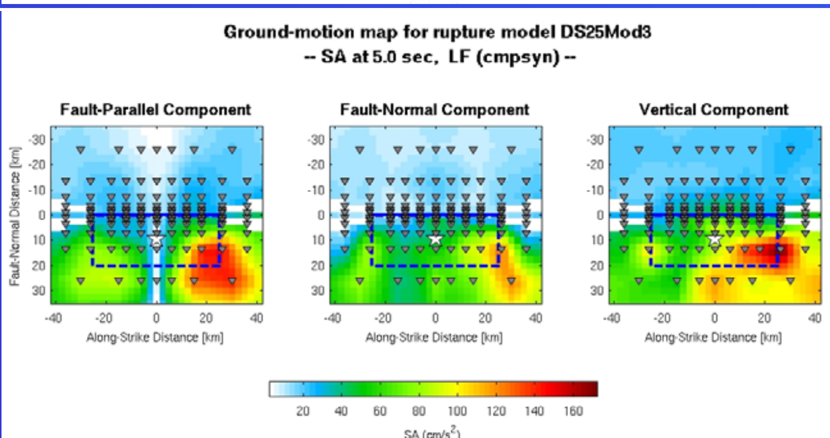
Shake maps for **thrust-faulting scenario event DS25Mod3**, showing spectral acceleration SA_T at T = 1s for full-wavefield (COMPSYN, top) and ray-theory far-field (ISOCHRONE, bottom), for the fault-parallel (left column), fault-normal (center column) and vertical component of motion (right column)

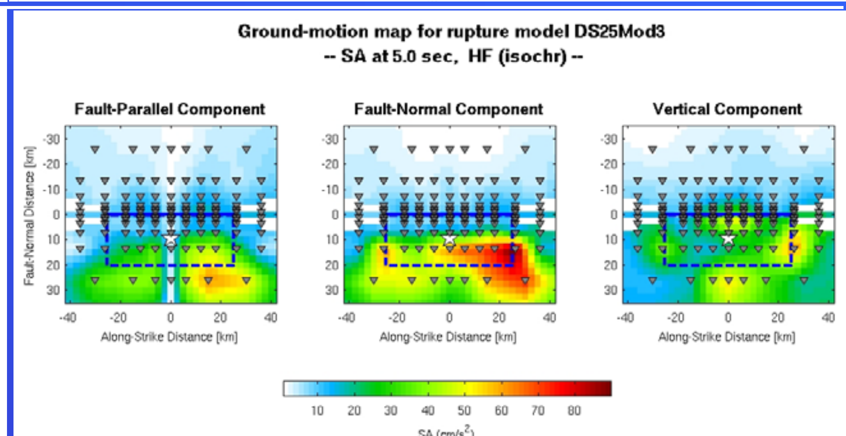
Shake maps for **SA(2 sec), SA (5 sec) and PGV** for **25°** dipping thrust-faulting scenario event **DS25Mod3**



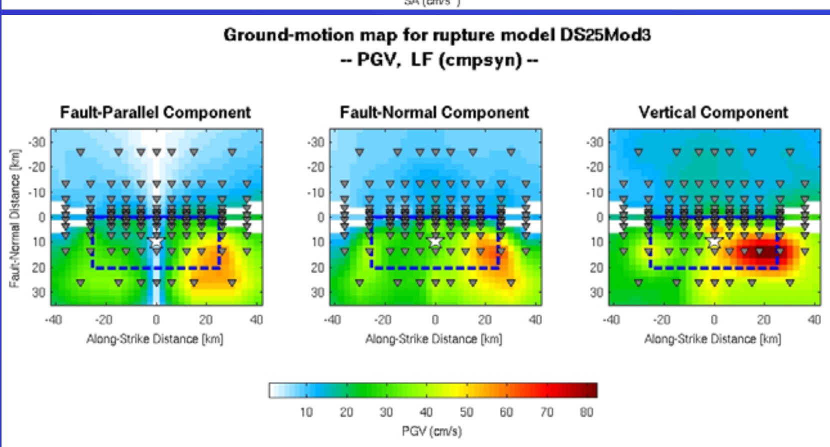


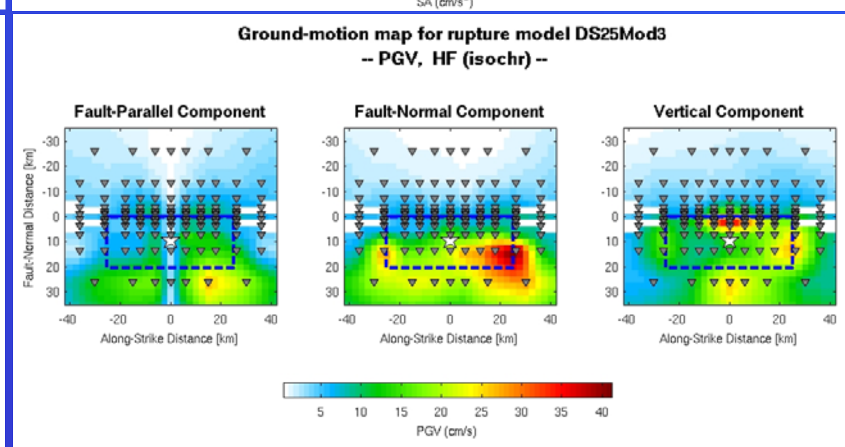
SA at 2 sec





SA at 5 sec





PGV

Summary on near-field / far-field seismic radiation effects

Analyzing our suite of ground-motion simulations for 150 sites in the distance range of ±50 km from a **Mw 7.1 scenario event**, occurring on a **25°-dipping thrust-fault**, a **45°-dipping** or **75°-dipping normal fault**, or a **75°-dipping strike-slip fault**, we come to the following preliminary conclusion which await further detailed quantification

- The influence of the near-field term on ground-motion intensities is **very strong for dip-slip ruptures** (normal fault and thrust-faulting), but less so for ruptures on near-vertical strike slip faults;

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- The near-field terms **are not equipartioned** on the two horizontal component of motion, and hence need to be examined independently; they are also strongly developed on the vertical component, in particular for the dip-slip events on dipping fault;
- For thrust and normal-faulting events, the ground-motion intensities on the vertical component **are particularly high**; hence, any seismic hazard study concerned about the load on the building/structure due to vertically acting forces has to consider vertical motions for the radiated seismic wavefield;
- As the fault-dip becomes shallower, **the symmetry** of seismic radiation **is broken more strongly**, and near-field effects are more clearly distinguishable on the footwall and hanging wall sides of the fault;

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- We do not find **a significant effect of the velocity-density structure** chosen in this study on the near-field terms and/or ground-motion intensities, most likely because none of the selected models is prone to surface-wave generation;

- The distance range in fault-normal direction over which the **near-field effects are significant** appears to depend on fault dip, in that for steeper dipping faults the range is smaller while the near-field effects are important over a wide region for shallowly dipping faults;

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- Examining spectral acceleration **SA** at T = [1 2 3 5] sec and **PGV**, we do not find significant differences in the extent of the near-field region depending on period (or frequency of seismic waves);

- Based on our current analysis, we conjecture that the spatial extent in fault-normal direction of the near-field affected area is related to **fault width (W)** and **fault dip (δ)**; a first-order estimate would be that this length scale is twice the surface-projection of the down-dip extent of the rupture, i.e.

$$\mathbf{Y_{NF} = 2W \cdot \cos \delta}$$

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- **No conclusive statements** are possible for the along-strike extent of the near-field affected area due to the limited domain size in our simulations;

- **Realistic ground-motion simulations** have to include near-field effects for any seismic hazard study that is concerned with ground-motion intensity measures (SA, PGV) that are sensitive to seismic waves at frequencies of 2 Hz and below.

CONCLUSIONS

- Our simulations for examining near-field and far-field effects **establish the base reference cases** against which refined numerical work could be carried out that includes more complex source models and a wider magnitude range

- It is important to **avoid a "contamination"** of the spectral-response analysis of near-field terms by later arriving surface waves. This was partially achieved in this study, by avoiding near-surface shallow S-wave velocity layers. However, such layers are important contributors to ground motion complexity and site amplification, and hence should be included in a more comprehensive study on near-field effects

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- Moreover, refinement of this work requires a thorough analysis of **the relative importance of near-field effect**, depending on magnitude and source parameters (rupture speed, rise time, slip complexity).

- Finally, with a database of simulation results for many source models, faulting styles, and velocity models, **one should attempt to develop an empirical relation that allows to estimate the "importance range" of near-field effects**, based on source parameters (magnitude, distance, faulting style) and the frequency range of interest.

Thank you
for
your attention