GMPEs and Dynamic Rupture Models: Which direction to go for validation

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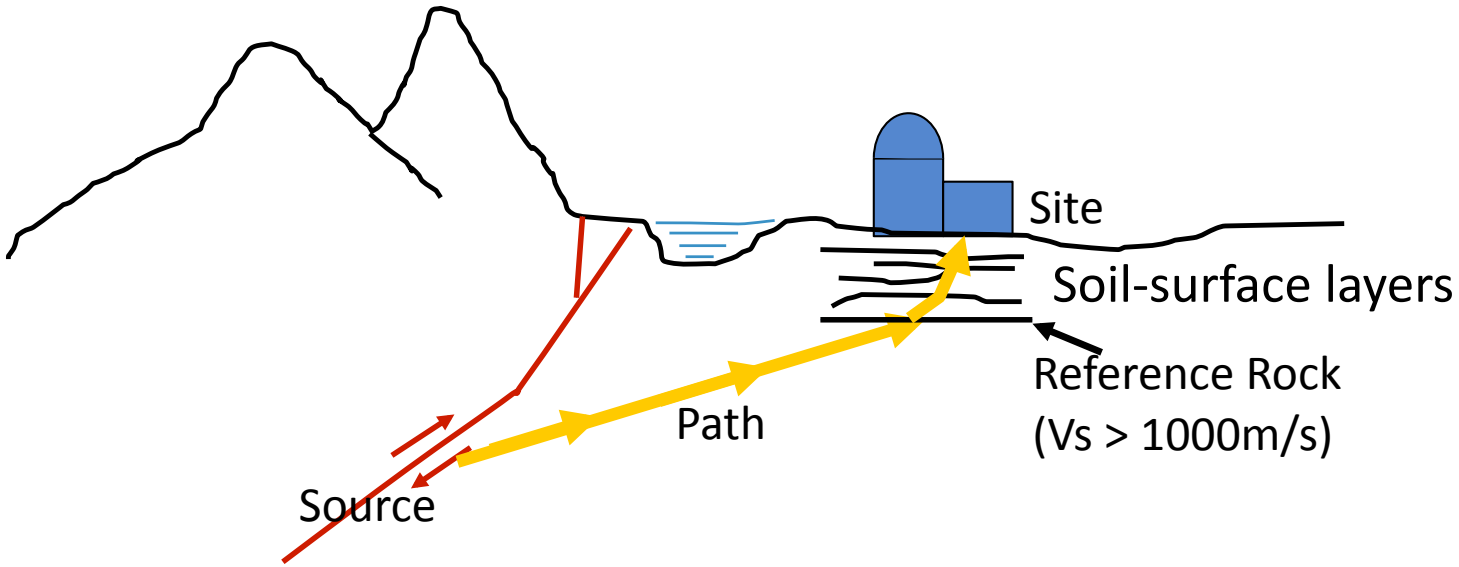
GMPEs and Dynamic Rupture Model



GMPEs for PSHA:

- Usually is ajusted to predict GM for reference rock (Vs > 1000m/s).
- Post processing calculations are done to account for local soil response
- Do not capture complexities of source, path and site

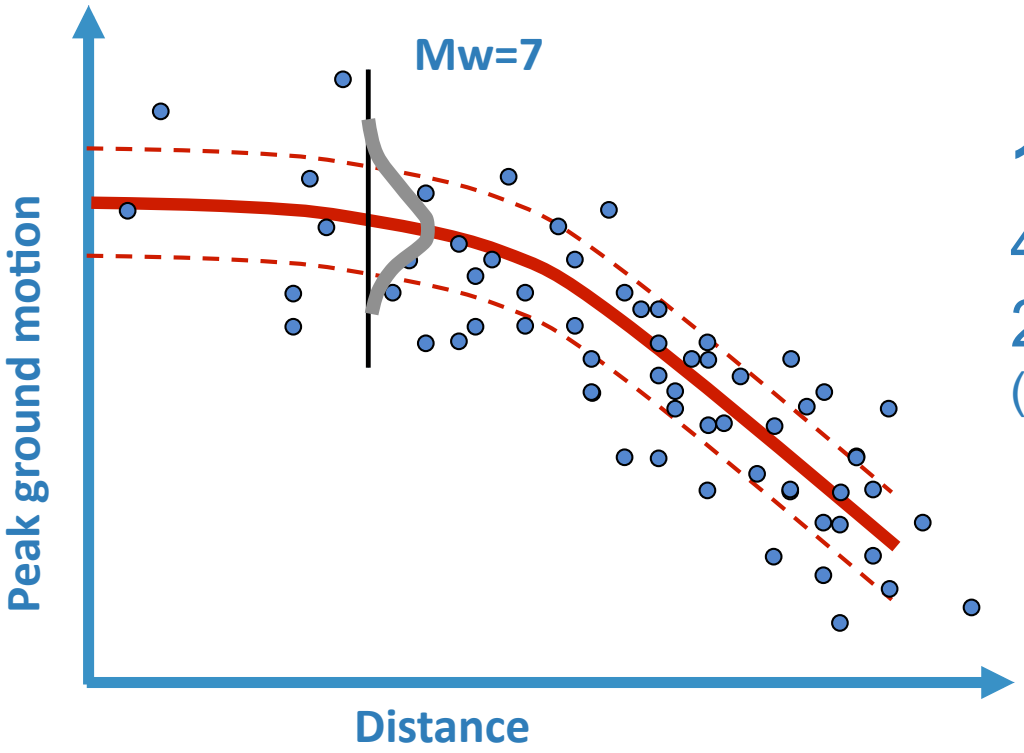
Physics-based models:

- Can include the whole system in a single model (source, path and site)
- Capture complexities of source, path and site

GMPEs

- Use worldwide database (ergodic GM model)
- Usually used in PSHA within the ergodic assumption **(Nature is non-ergodic)**
- Current practice is usually dominated by empirical GMPEs that have been developed most of the time using dataset from other places except from the site of interest.
- Predict only one component of ground motion (e.g. Geo Mean)

$$\ln(Y) = f_{src}(M, \dots) + f_{path}(R, M, \dots) + f_{site}(Vs_{30} \dots) + \Delta$$



1964-2017:

432 empirical GMPEs -> PGA

277 empirical GMPEs ->PSA

(Douglas, 2017, http://www.gmpe.org.uk)

Evolution of empirical GMPEs

Abrahamson and Young (1992): $\ln y = a + bM + d\ln(r + c) + eF$

Abrahamson et al (2014)

$$
\begin{aligned}
\ln \mathrm{Sa} &= f_1 + F_{RV} f_7 + F_N f_8 + F_{AS} f_{11} + f_5 + F_{HW} f_4 + f_6 + f_{10} + \text{Regional} \\
f_1 &= \begin{cases} a_1 + a_5(M - M_1) + a_8(8.5 - M)^2 + [a_2 + a_3(M - M_1)]\ln R + a_{17} r_{rup} & M > M_1 \\ a_1 + a_4(M - M_1) + a_8(8.5 - M)^2 + [a_2 + a_3(M - M_1)]\ln R + a_{17} r_{rup} & M_2 \le M < \\ a_1 + a_4(M_2 - M_1) + a_8(8.5 - M)^2 + a_6(M - M_2) + a_7(M - M_2)^2 & \\ \quad + [a_2 + a_3(M_2 - M_1)]\ln R + a_{17} r_{rup} & M < M_2 \end{cases} \\
R &= \sqrt{r_{rup}^2 + c_{4M}^2} \\
c_{4M} &= \begin{cases} c_4 & M > 5 \\ c_4 - (c_4 - 1)(5 - M) & 4 < M \le 5 \\ 1 & M \le 4 \end{cases} \\
f_7 &= \begin{cases} a_{11} & M > 5 \\ a_{11}(M - 4) & 4 \le M \le 5 \\ 0 & M < 4 \end{cases} \\
f_8 &= \begin{cases} a_{12} & M > 5 \\ a_{12}(M - 4) & 4 \le M \le 5 \\ 0 & M < 4 \end{cases}
\end{aligned}
$$

If R_{y0} not available:

$$
\begin{aligned}
T_5 &= \begin{cases} 1 & r_{jb} = 0 \\ 1 - \frac{r_{jb}}{30} & r_{jb} < 30 \\ 0 & r_{jb} \ge 30 \end{cases} \\
f_6 &= \begin{cases} a_{15}\frac{Z_{TOR}}{20} & Z_{TOR} < 20\,\mathrm{km} \\ a_{15} & Z_{TOR} \ge 20\,\mathrm{km} \end{cases} \\
f_{10} &= \begin{cases} a_{43}\ln\left(\frac{Z_1 + 0.01}{Z_{1,ref} + 0.01}\right) & V_{s,30} \le 200\,\mathrm{m/s} \\ a_{44}\ln\left(\frac{Z_1 + 0.01}{Z_{1,ref} + 0.01}\right) & 200 < V_{s,30} \le 300\,\mathrm{m/s} \\ & \le 500\,\mathrm{m/s} \\ & \text{ı/s} \end{cases}
\end{aligned}
$$

GMPEs are becoming very complex to use!!

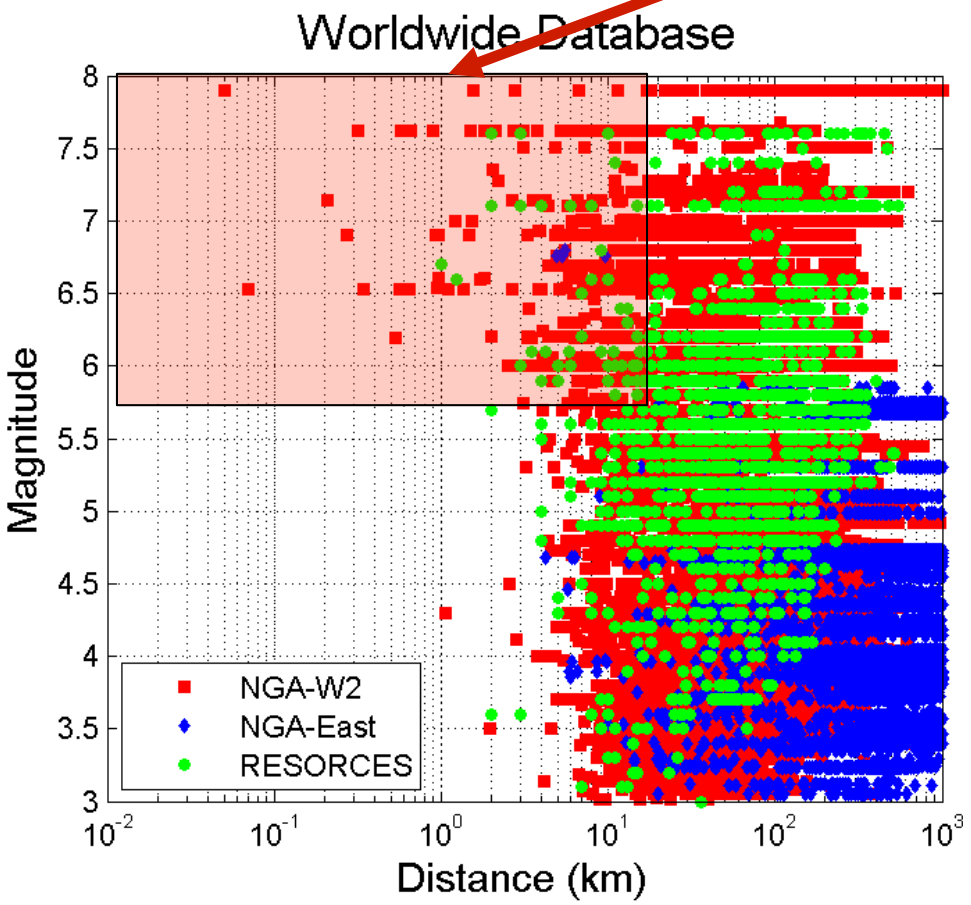
My guess is that they try to mimic what 3D model can do!!

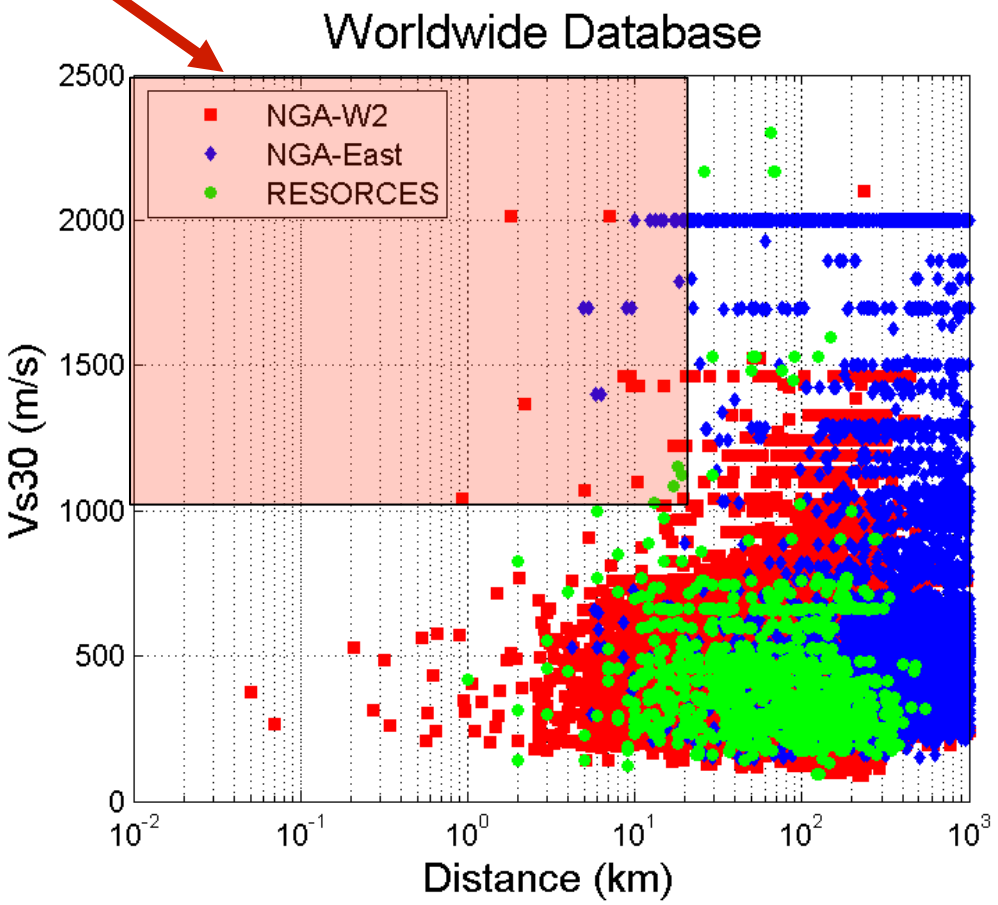
$$
\begin{aligned}
f_4 &= a_{13} T_1 T_2 T_3 T_4 T_5 \\
T_1 &= \begin{cases} (90 - \mathrm{dip})/45 & \mathrm{dip} > 30^\circ \\ 60/45 & \mathrm{dip} < 30^\circ \end{cases} \\
T_2 &= \begin{cases} 1 + a_{2HW}(M - 6.5) & M \ge 6.5 \\ 1 + a_{2HW}(M - 6.5) - (1 - a_{2HW})(M - 6.5)^2 & 5.5 < M < 6.5 \\ 0 & M \le 5.5 \end{cases} \\
T_3 &= \begin{cases} h_1 + h_2(R_x/R_1) + h_3(R_x/R_1)^2 & R_x < R_1 \\ 1 - \left(\frac{R_x - R_1}{R_2 - R_1}\right) & R_1 \le R_x \le R_2 \\ 0 & R_x > R_1 \end{cases} \\
T_4 &= \begin{cases} 1 - \frac{Z_{TOR}^2}{100} & Z_{TOR} \le 10\,\mathrm{km} \\ 0 & Z_{TOR} > 10\,\mathrm{km} \end{cases} \\
T_5 &= \begin{cases} 1 & R_{y0} - R_{y1} \le 0 \\ 1 - \frac{R_{y0} - R_{y1}}{5} & 0 < R_{y0} - R_{y1} < 5 \\ 0 & R_{y0} - R_{y1} \ge 5 \end{cases} \\
R_1 &= W\cos(\mathrm{dip}) \\
R_2 &= 3R_1 \\
R_{y1} &= R_x \tan(20) \\
h_1 &= 0.25 \\
h_2 &= 1.5 \\
h_3 &= -0.75
\end{aligned}
$$

$$
\begin{aligned}
f_{11} &= \begin{cases} a_{14} & CR_{jb} \le 5\,\mathrm{km} \\ a_{14}\left[1 - \frac{CR_{jb} - 5}{10}\right] & 5 < CR_{jb} < 15\,\mathrm{km} \\ 0 & CR_{jb} \ge 15\,\mathrm{km} \end{cases} \\
\text{Regional} &= F_{TW}(f_{12} + a_{25} r_{rup}) + F_{CN} a_{28} r_r up + F_{JP}(f_{13} + a_{29} r_{rup}) \\
f_{12} &= a_{31}\ln\left(\frac{V_{s,30}^*}{V_{Lin}}\right) \\
f_{13} &= \begin{cases} a_{36} & V_{s,30} < 200\,\mathrm{m/s} \\ a_{37} & 200 \le V_{s,30} < 300\,\mathrm{m/s} \\ a_{38} & 300 \le V_{s,30} < 400\,\mathrm{m/s} \\ a_{39} & 400 \le V_{s,30} < 500\,\mathrm{m/s} \\ a_{40} & 500 \le V_{s,30} < 700\,\mathrm{m/s} \\ a_{41} & 700 \le V_{s,30} < 1000\,\mathrm{m/s} \\ a_{42} & V_{s,30} \ge 1000\,\mathrm{m/s} \end{cases}
\end{aligned}
$$

Limitations of empirical GMPEs

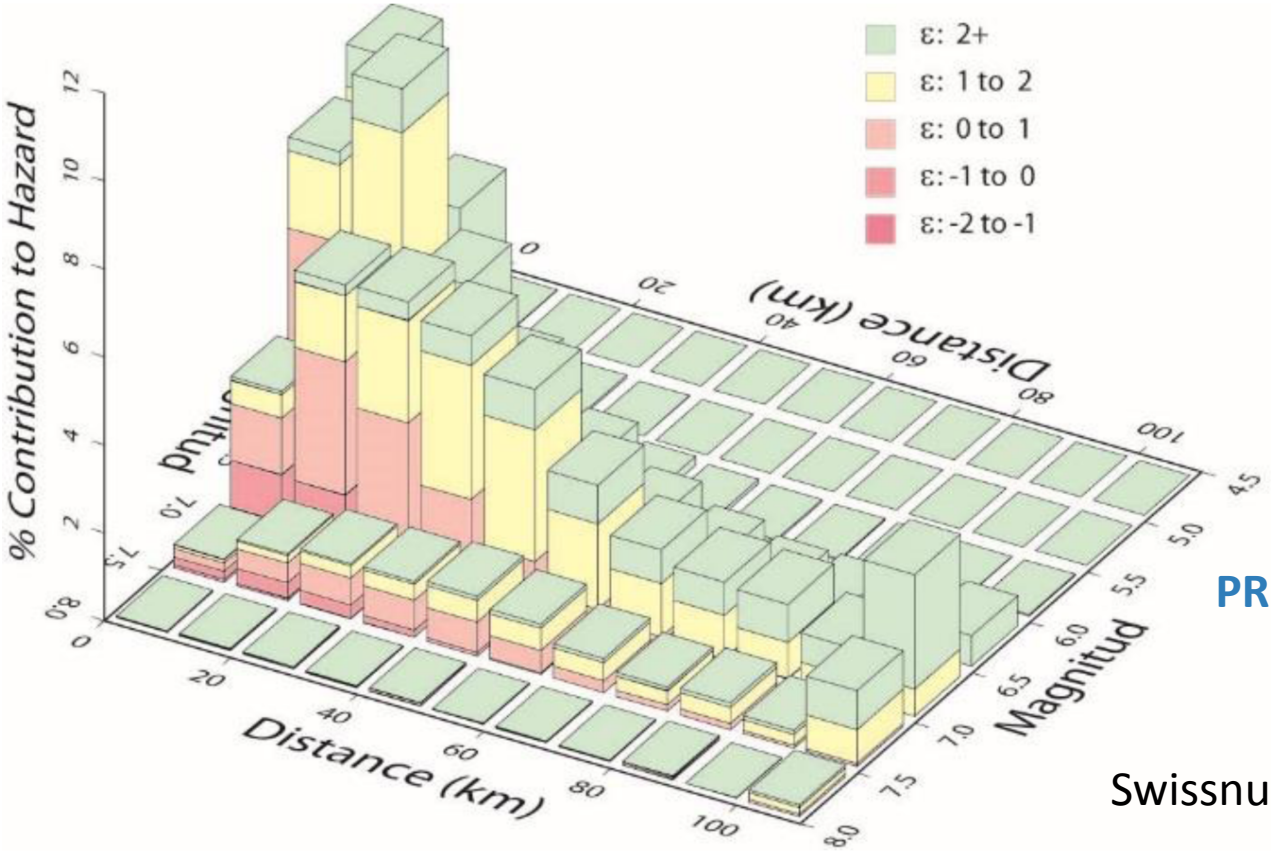
Zone of major interest used for PSHA





Example of Site-specific PSHA for NPPs

PRP project in Switzerland

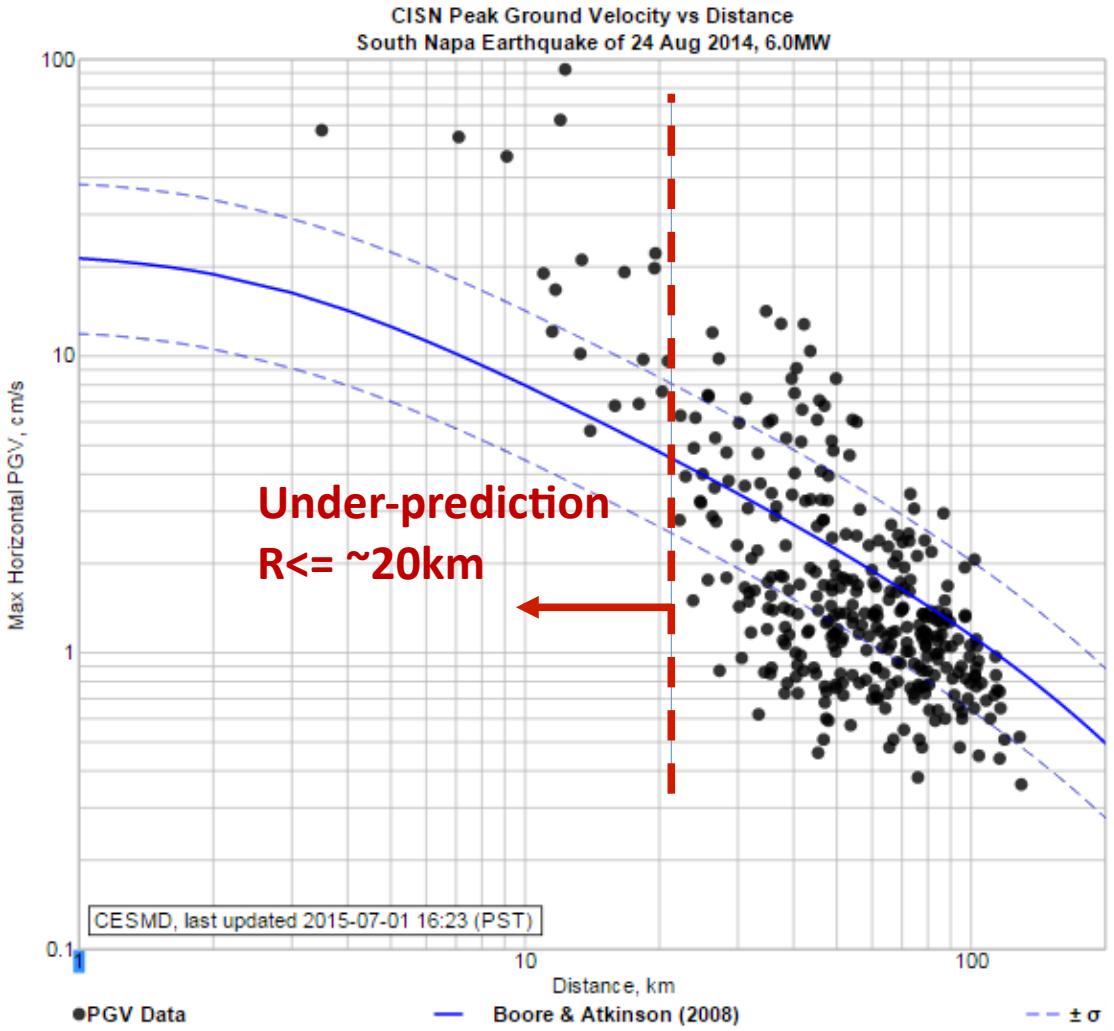


PRP deaggregation

Swissnuclear (2013)

Hazard is controled by Mw ~ 6 and R <= 20km (near fault)

Limitations of empirical GMPEs



(Courtesy of Roberto Paolucci)

GMPEs predict earthquakes similar to events from their database only

Physics-based Dynamic Rupture Models

- physics of wave propagation
- physics of stress and friction at fault interface
- Asumptions: physical foundations
- For best performance:
  - Need best information of source (faults)
  - Need best information available of the geological structure and site

- Ideal for site-specific seismic hazard assessment
- Intrinsically, they are featured to be used as non-ergodic ground motion models
- They can be constrained with all the available information of the area of interest.

Dynamic rupture models in practice?

- For region (site) – specific studies (as a non-ergodic model) calibrated with the data from he site of interest.
- For near-source ground motion prediction
- For displacement, velocity and acceleration ground motions (3 components) at reliable frequency range
- For surface rupture offset (named by other communities as “fault displacement“)
- Need Validation!, how?

Validation of dynamic rupture models

Using models that predict GM for future earthquakes

- Do we want to validate with GMPEs that use data from everywhere, it is an ergodic model, predict only one component and lack of observed data?
- GMPEs are also just models that also need to be validated for future earthquakes
- We can use GMPEs as a reference, but not as a source for validation.
- There are no models to be used for validation
- One model can not validate another model.
- Only nature can validate

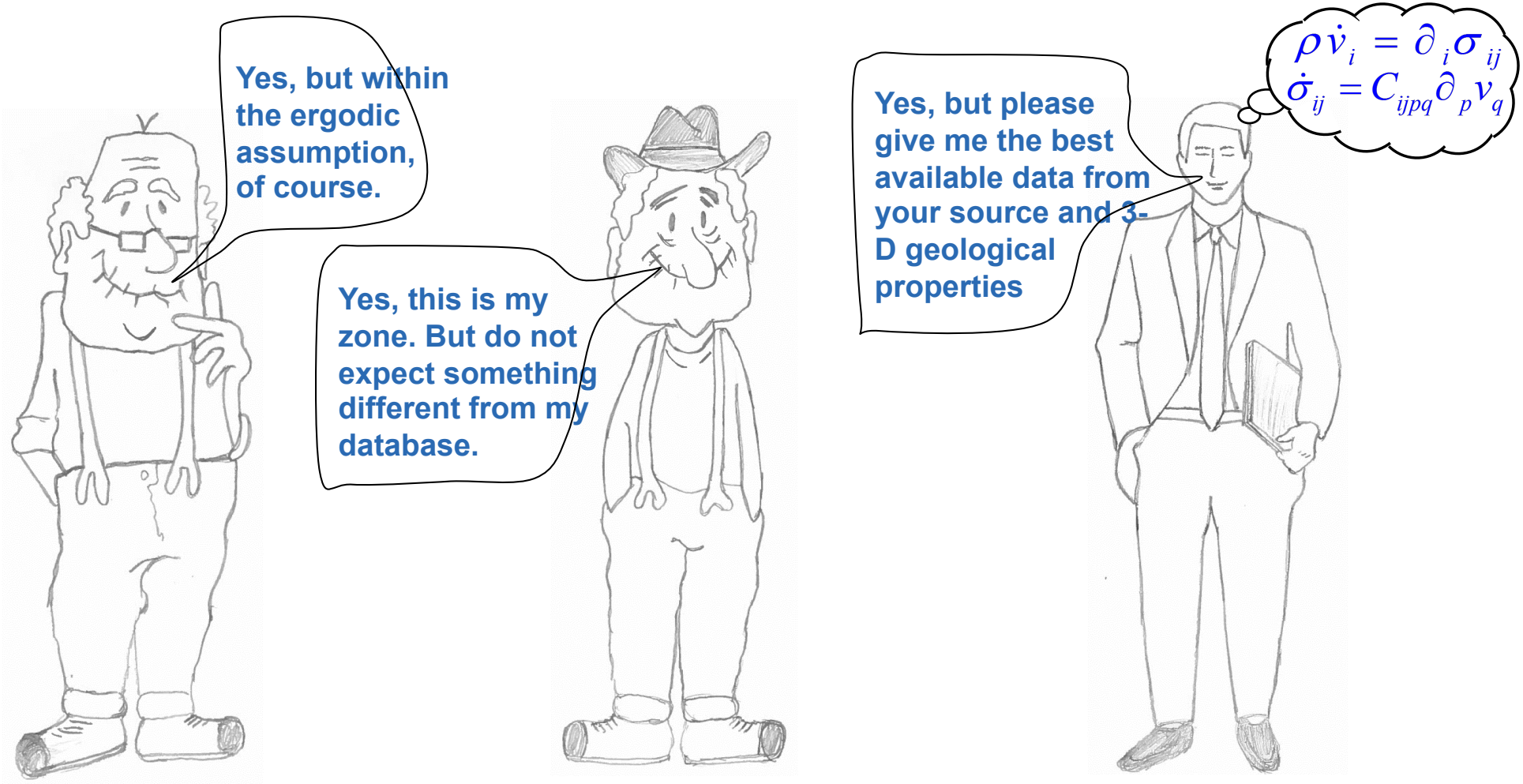
Validation of dynamic rupture models

Using data of past earthquakes

- Yes, here is the domain where a model can be validated
- Validation process needs two steps:
  - **1.** Source characterization (e.g. kinematic source inversion) and 3D geological structure
  - **2.** Forward dynamic rupture and ground motion simulation (10-20 models for statistical comparison with observed data)
- Once validation is successful, the dynamic model can be used to predict future earthquakes that not necessarity have to be similar to past earthquakes.

GMPEs vs Physics-based GM simulation

Request 1: Could you make a prediction in zone A for Mw 7 and distance 20km?



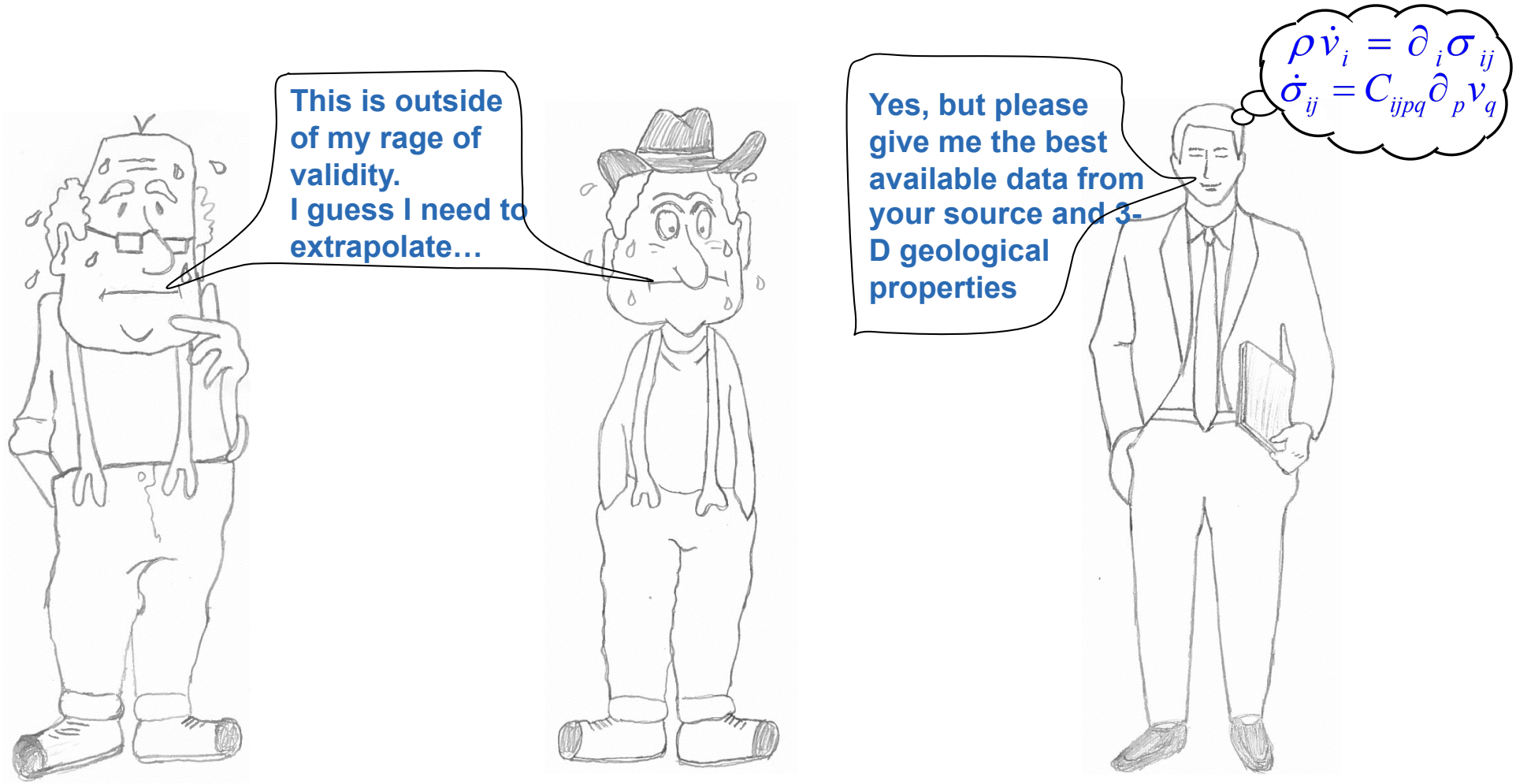
GMPEs
(Global and ergodic)

GMPEs
(For Zone A
maybe partially non-ergodic)

Physics-based GM model
(fully non-ergodic)

GMPEs vs Physics-based GM simulation

Request 2: Now a prediction in zone A for Mw 7 very near the fault?



GMPEs
(Global and ergodic)

GMPEs
(For Zone A
maybe partially non-ergodic)

Physics-based GM model
(fully non-ergodic)

GMPEs vs Physics-based GM simulation

Request 3: Now please a prediction in zone B?

GMPEs
(Global and ergodic)

GMPEs
(For Zone A
maybe partially non-ergodic)

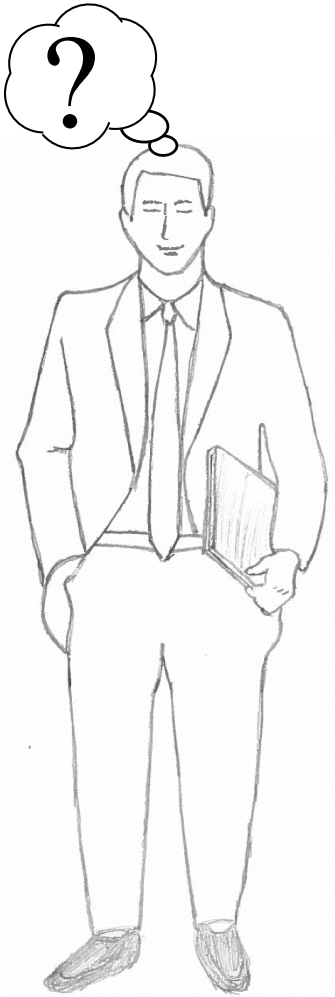
Physics-based GM model
(fully non-ergodic)

GMPEs vs Physics-based GM simulation

Request 3: Please a prediction in zone B?

GMPEs
(Global and ergodic)

GMPEs
(Now almost for Zone B
maybe partially non-ergodic)



Physics-based GM model
(fully non-ergodic)

GMPEs vs Physics-based GM simulation

Request 3: Please a prediction in zone B?

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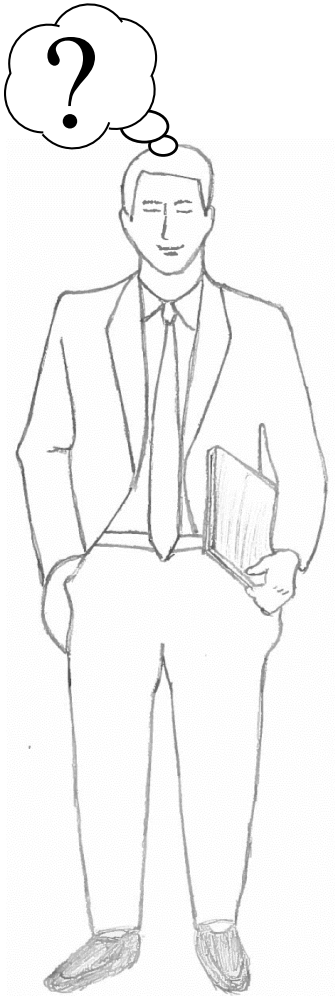

Physics-based GM model
(fully non-ergodic)