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Determination of Near Fault Velocity Pulses with Multivariate Naïve Bayes Method

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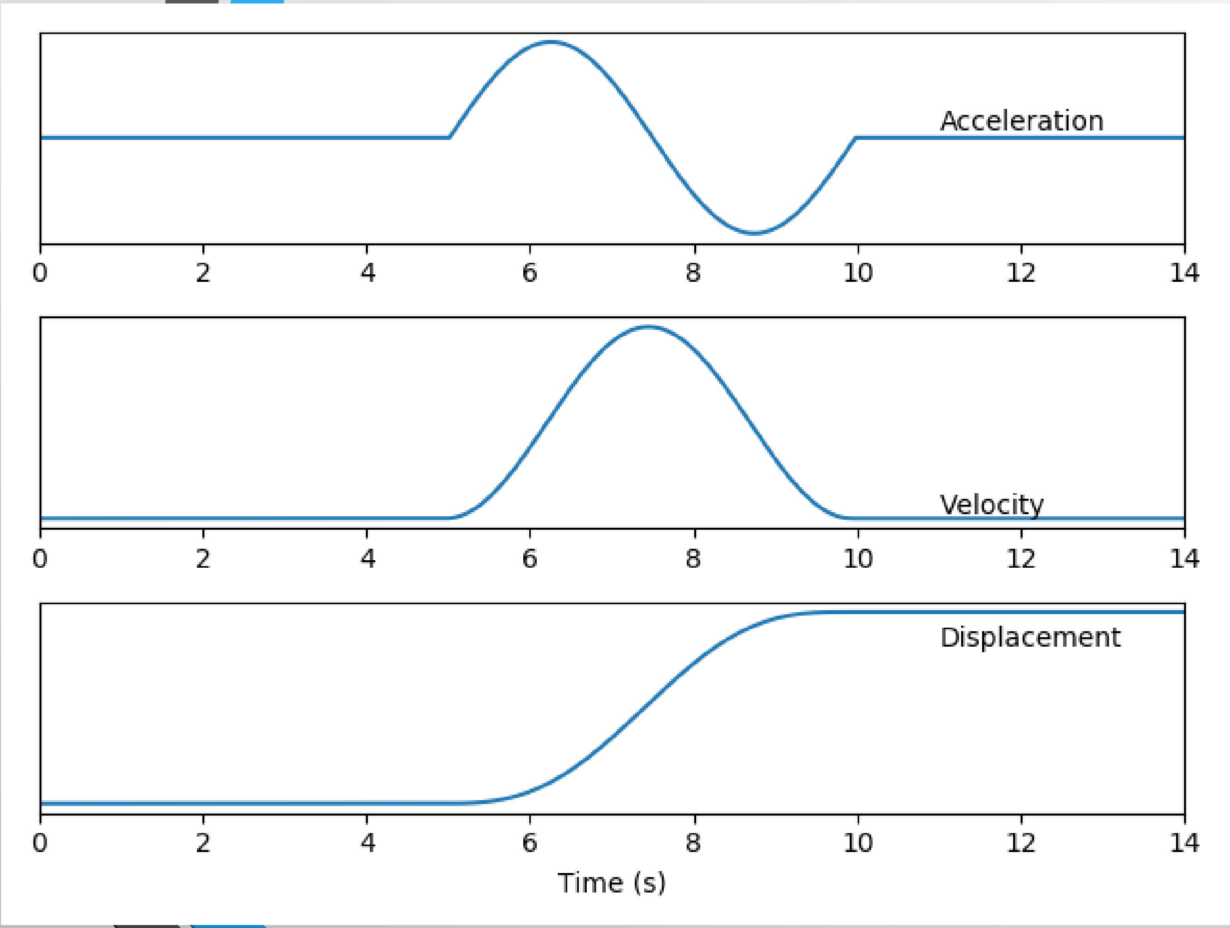
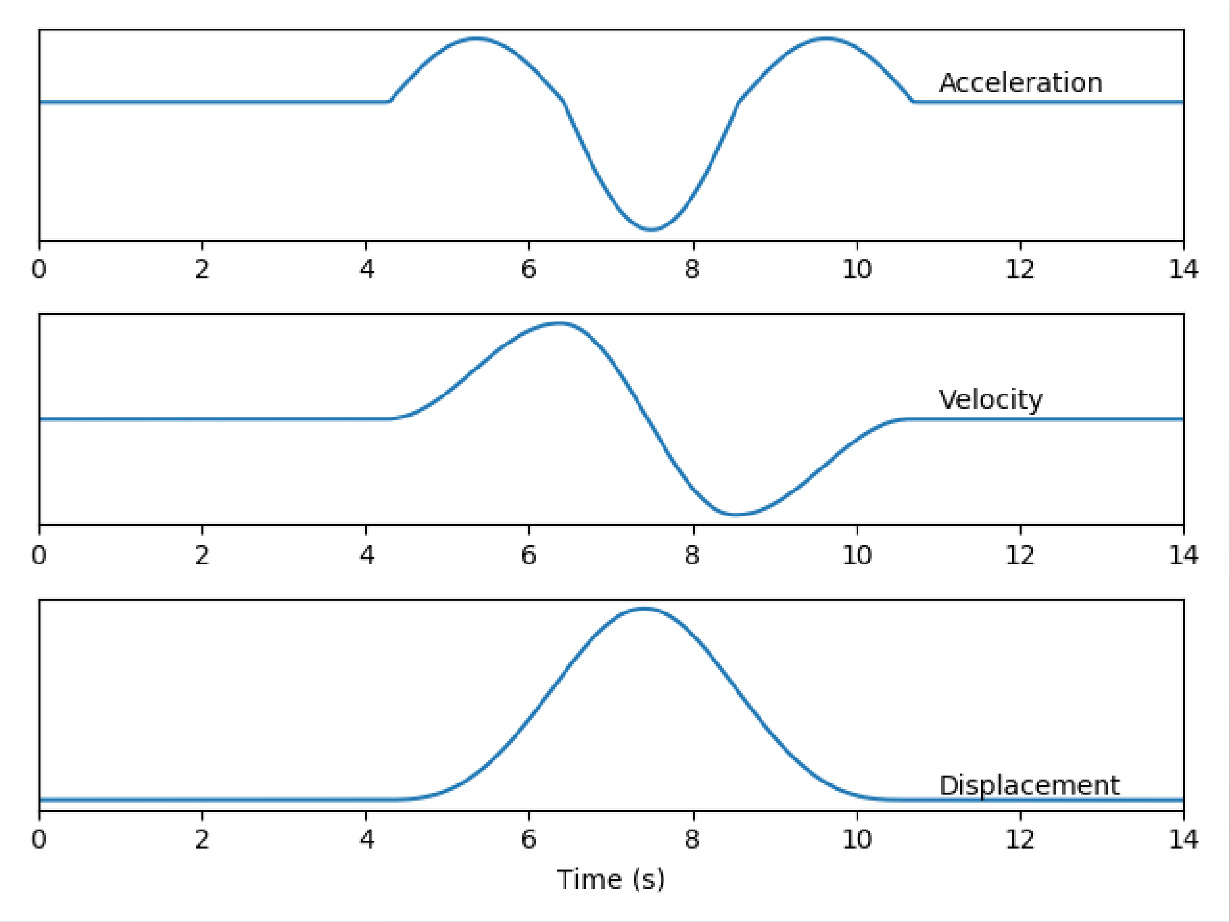
SeisRaM

Source of Velocity Pulses

Fling Step Effect



Directivity Effect



Two main factors for the occurrence of impulsive signals are fling step and directivity effects. The third factor is the local site conditions.

Why it is important?

1. Large velocity pulses can place **severe inelastic demands** on multi story structures (Heaton et al. 1995)
2. Strong response on buildings as they may generate **high seismic loading** demands (Kalkan & Kunnath 2006)
3. For developing appropriate **design strategies for the near-fault** earthquake ground motions it is desirable to have proper understanding of the nature of pulses associated with such motions and to accurately characterize these motions.

Data

$$M_w \geq 5.5$$
$$Depth \leq 55\ km$$
$$Epicentral\ Distance\ \leq 150\ km$$

Data Providers:

1. NGA-West 2 database
2. National Seismological Centre of Chile
3. The Italian Accelerometric Archive (Itaca)
4. Kyoshin Net and Kiban-Kyoshin Net (K-Net & Kik-Net)
5. National Autonomous University of Mexico (SSN)
6. GeoNet
7. Broadband Array in Taiwan for Seismology (BATS)
8. Disaster and Emergency Management Presidency of Turkey (AFAD)
9. IRIS.

We created a database with 25376 stations.

We exclude the signals that are recorded at the earthquakes that do not produce any impulsive signals.

Shahi and Baker (2014) Among the impulsive signal produced earthquakes, 206 stations are identified as impulsive and 5175 stations are identified as non-impulsive.

Method

1 Bayes's Theory

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

A = Impulsive and non-impulsive labels.
B = Parameters

2 Multivariate Bayes's Theory

$$P(A_j|B_{1,\ldots,n}) = \frac{P(B_1|A_j)P(B_2|A_j)\ldots P(A_j)}{P(B_1)P(B_2)\ldots P(B_n)}$$

The probability of the class (A_j), for a given predictor feature combination $(B_{1,\ldots,n})$, is as a function of the probability of the predictor feature combination $(P(B_{1,\ldots,n}|A_j))$ with the given category (A_j).

A **naïve** prior would use 50% to 50% probability of each class. In such a case, conditional probability, $P(B_n|A)$

3

$$P(B_n|A) = \frac{1}{\sqrt{2\pi\sigma_A^2}} e^{-\frac{(B_n - \mu_A)^2}{2\sigma_A^2}}$$

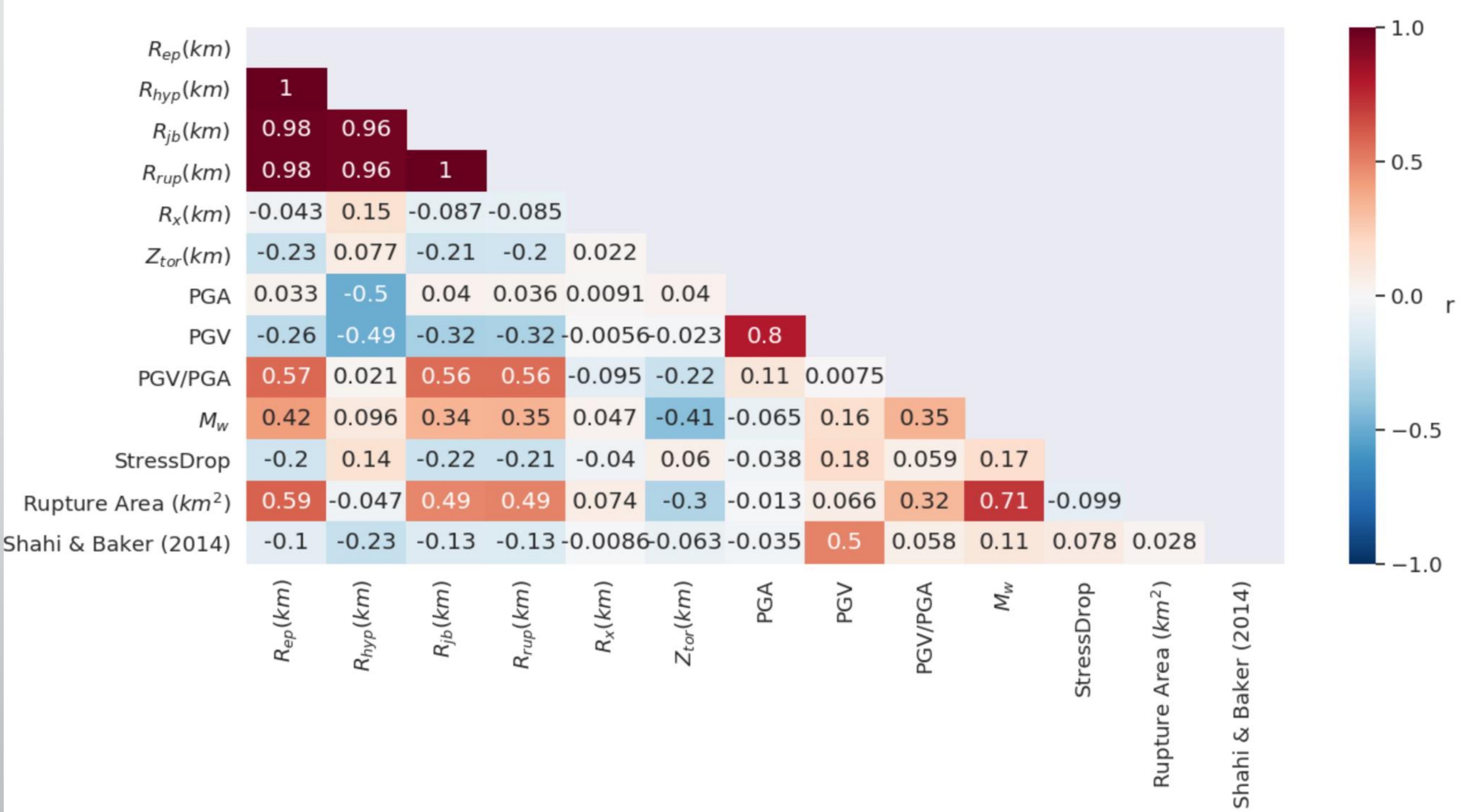
μ = Average of B_n
σ = Std of B_n

4 Multivariate naïve Bayes's Method

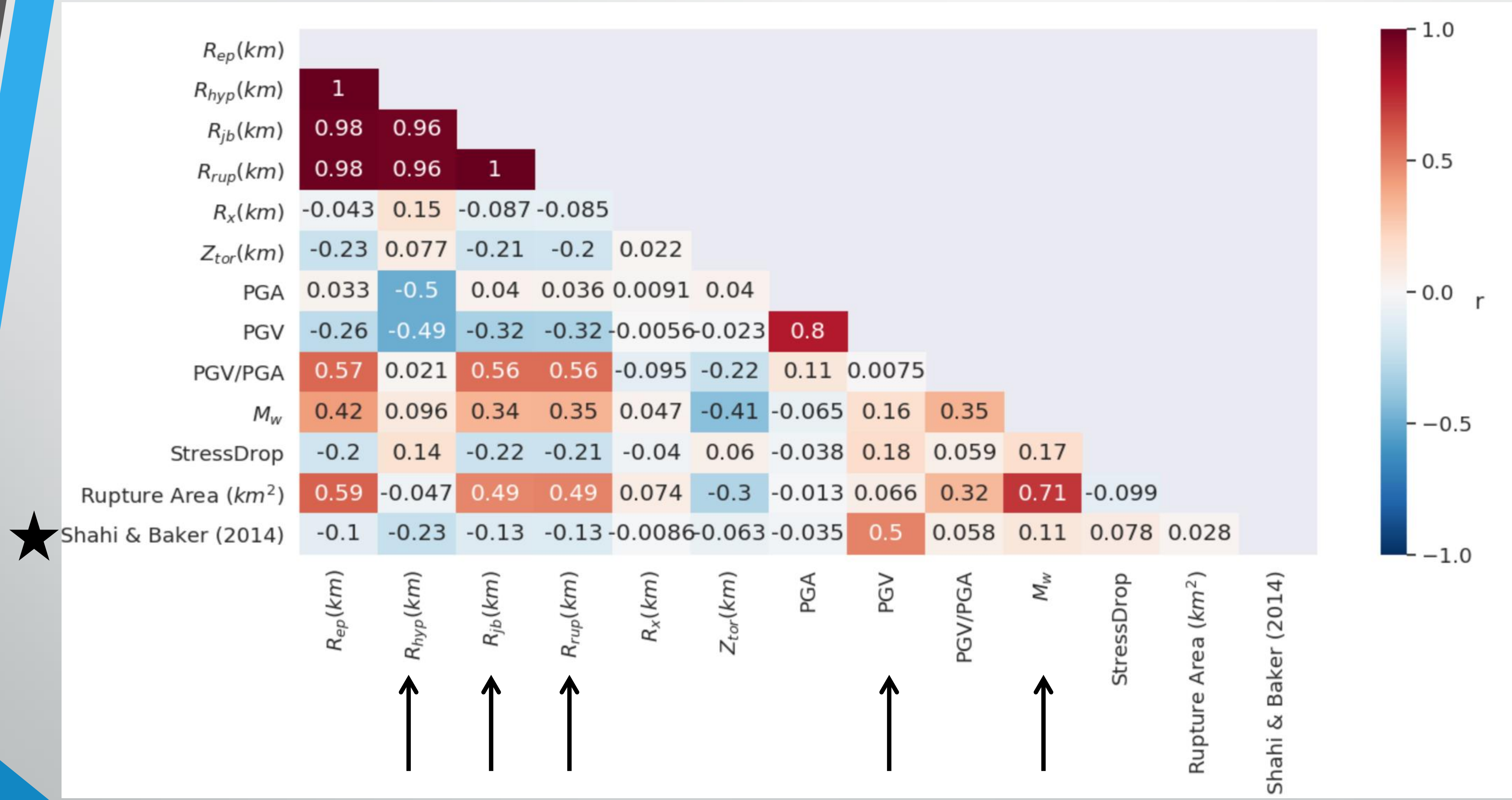
$$P(A|B_{1,\ldots,}B_n) \propto P(A_j)\Pi_{i=1}^{n} P(B_n|A)$$

Denominator of the equation above diminishes since it is constant for all values.

Parameter Selection



Parameter Selection



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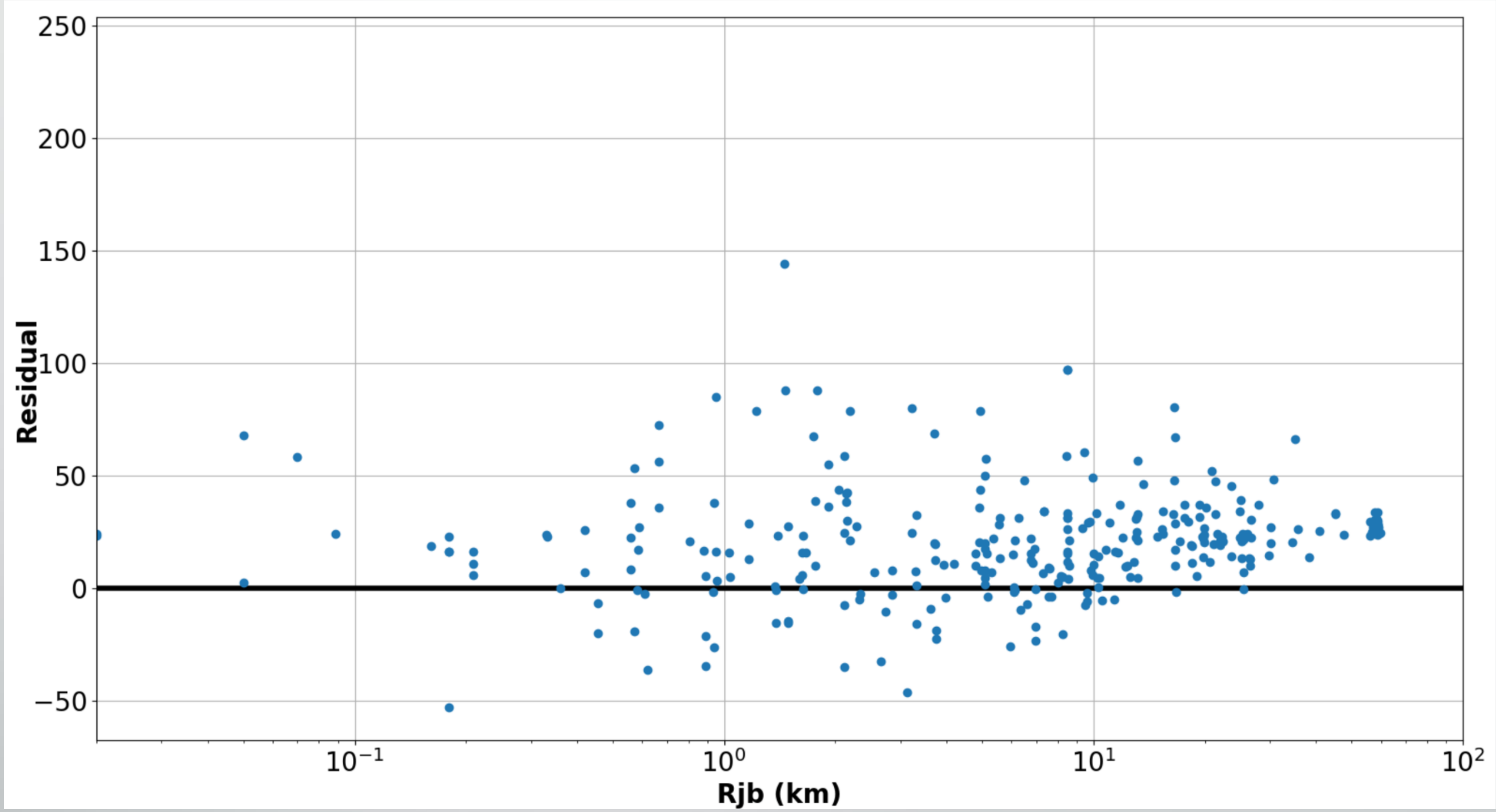
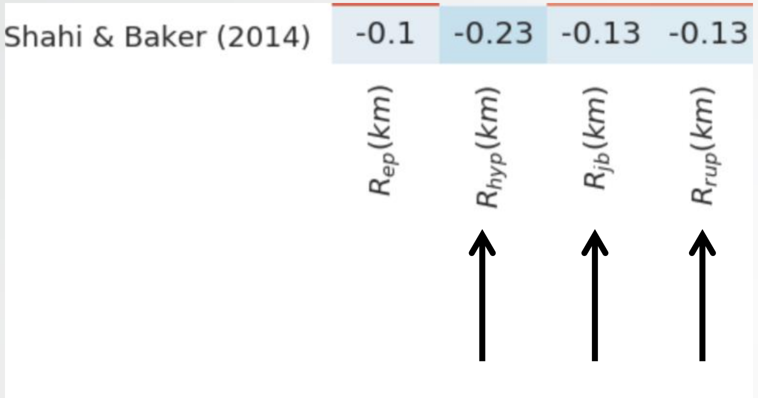
Underestimation of PGV



GMPE: Boore, David M., et al. (2014)

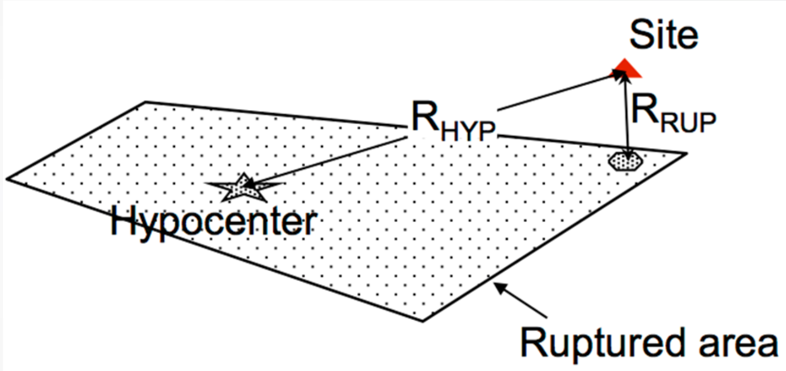
We have found that, PGVs are mostly underestimated by GMPEs. Hence, we excluded PGV for the further analysis.

Distance Parameter Selection



	$R_{ep}(km)$	$R_{hyp}(km)$	$R_{jb}(km)$	$R_{rup}(km)$
Shahi & Baker (2014)	-0.1	-0.23	-0.13	-0.13

2 3 3

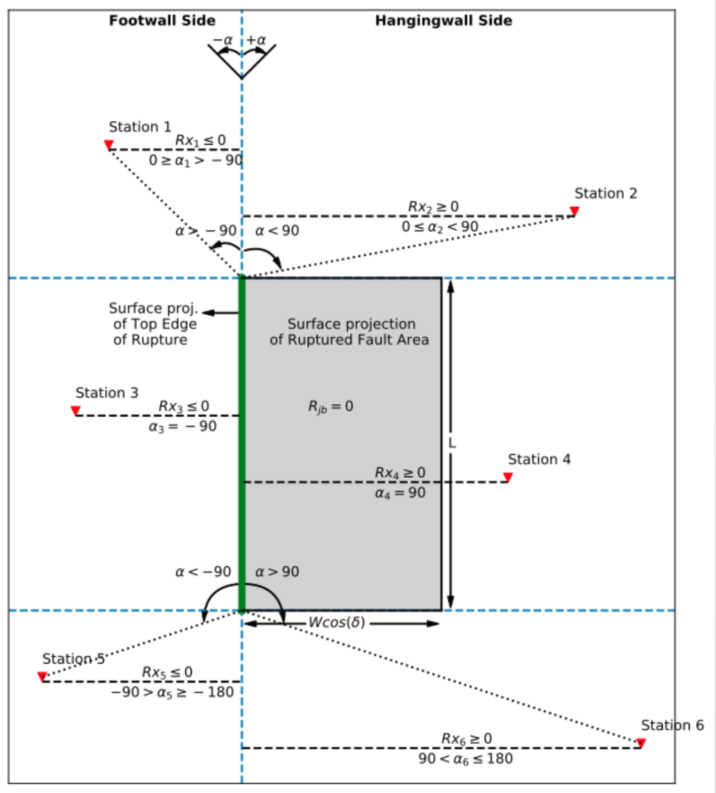


From Ancheta, Timothy D., et al. (2013)

- R_{hyp} - Determination of the hypocenter of an earthquake can change depends of velocity model, station distribution etc. Thus it does not give an idea about the dimensions of the fault. It is an information of a single point.
- R_{jb} - It is the closest distance to the surface projection of the fault rupture plane. It can be used for hanging wall – foot wall determination.
- R_{rup} - Carries more information about the rupture area. However it doesn't give any sense of the exact dimensions of the fault. It is important for hanging wall – foot wall determination.

Selected Parameters

1. M_w
2. R_{jb}
3. Source-to-site azimuth (α) →



Modified from Kaklamanos et al. (2011).

Database

Type of Observation	Strike Slip			Non-strike Slip					
	Source-to-site azimuth								
	[0 90)	90	(90 180]	[-180 -90)	-90	(-90 0)	[0 90)	90	(90 180)
Impulsive	27	50	10	6	36	27	14	29	7
Non-impulsive	751	286	745	676	166	656	811	220	864

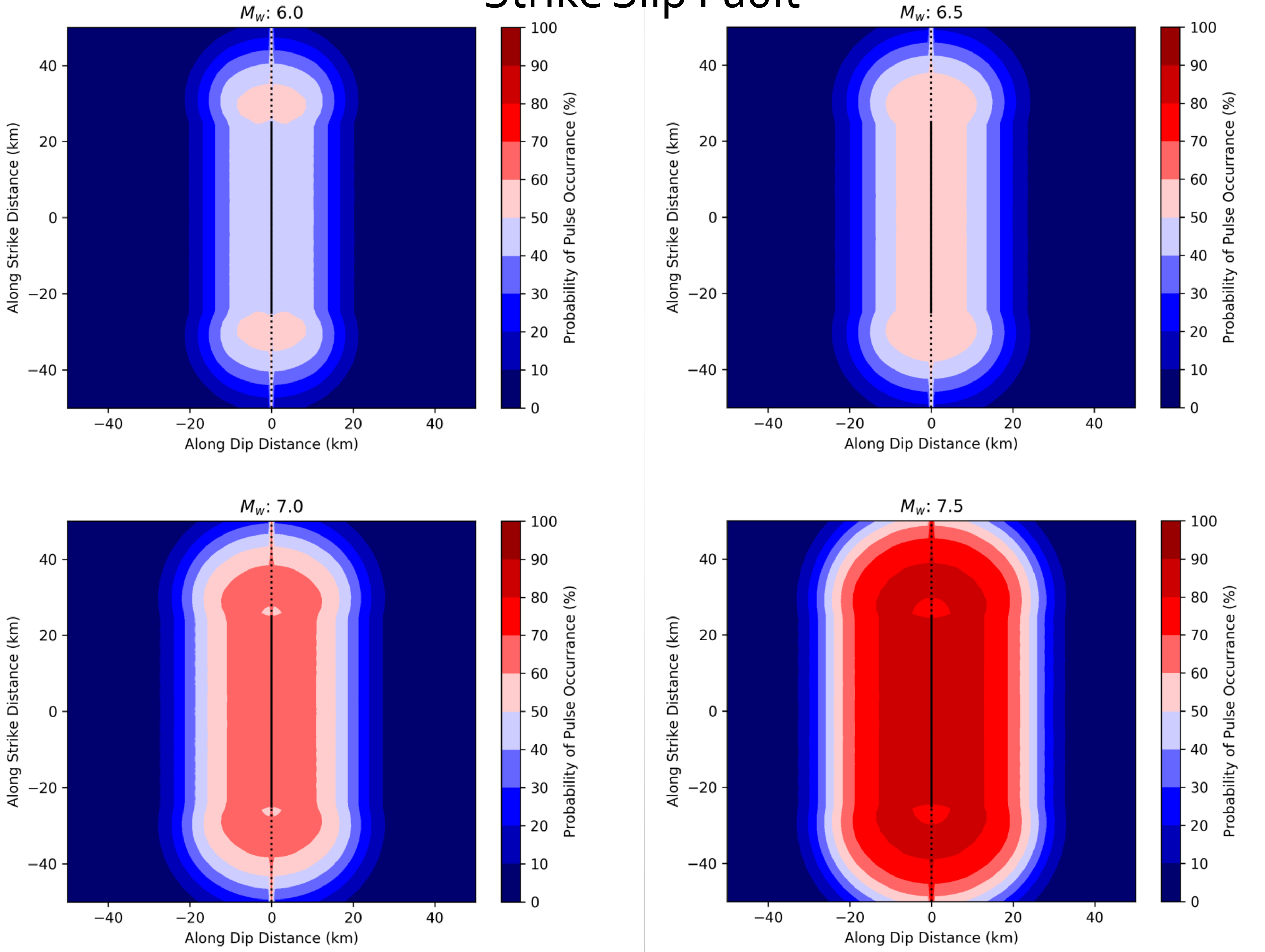
Source-to-site Azimuth Fixation

Type of Observation	Strike Slip			Non-strike Slip					
	Source-to-site azimuth								
	[0 90)	90	(90 180]	[-180 -90)	-90	(-90 0)	[0 90)	90	(90 180)
Impulsive	27	50	10	6	36	27	14	29	7
Non-impulsive	751	286	745	676	166	656	811	220	864

Combined non-90 regions	Strike Slip [0 90) + (90 180]	Non-strike Slip [-180 -90) + (-90 0)	Non-strike Slip [0 90) + (90 180)
Impulsive	37	33	21
Non-impulsive	1496	1332	1675

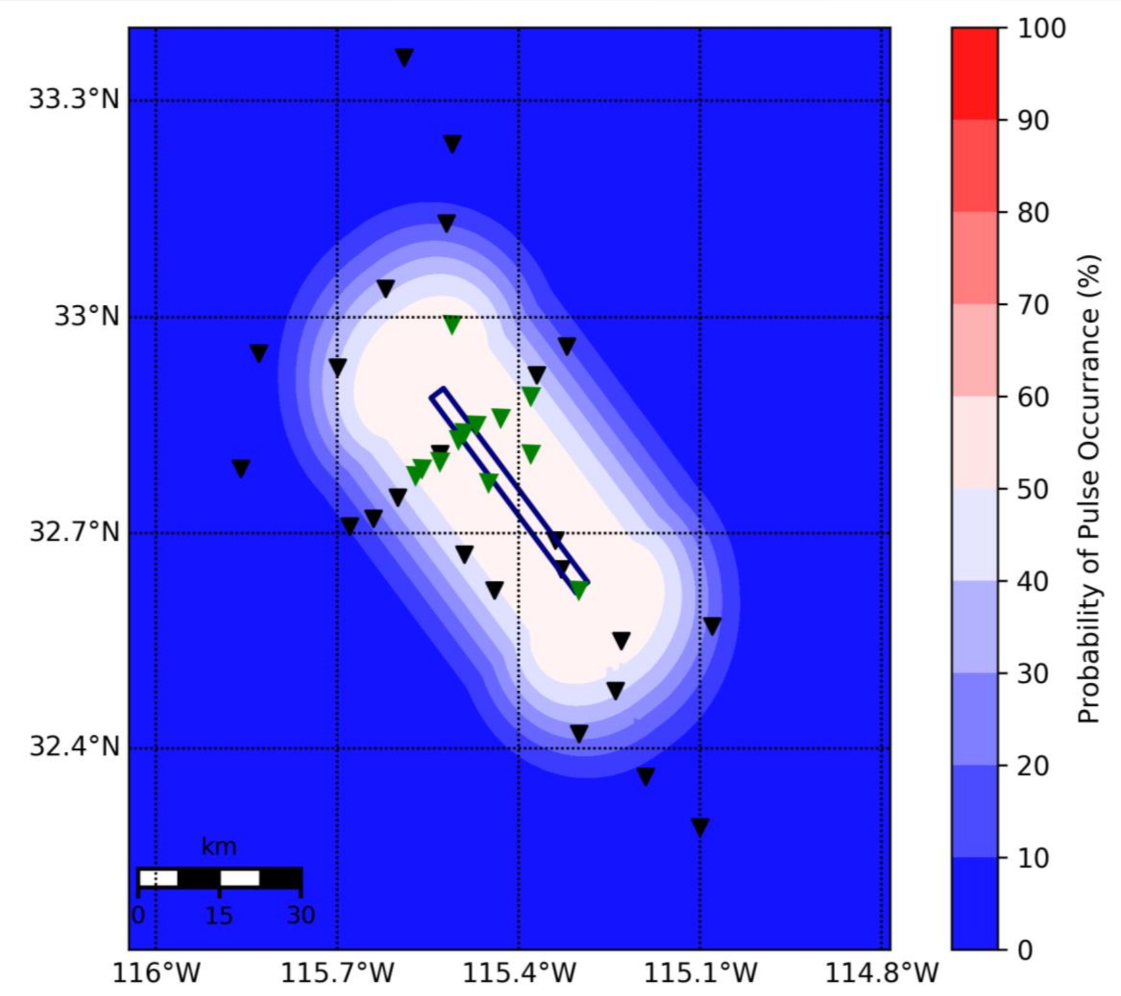
Distribution of impulsive signals in different regions of the fault plane orientation will create unrealistic probability of occurrence models. It is due to fact that directivity effect can only effect one part of the source to site azimuth regions in hanging wall and foot wall, individually. Directivity effect is homogenised by combining non 90 degree regions.

Strike Slip Fault



Imperial Valley Earthquake (15th of October 1979)

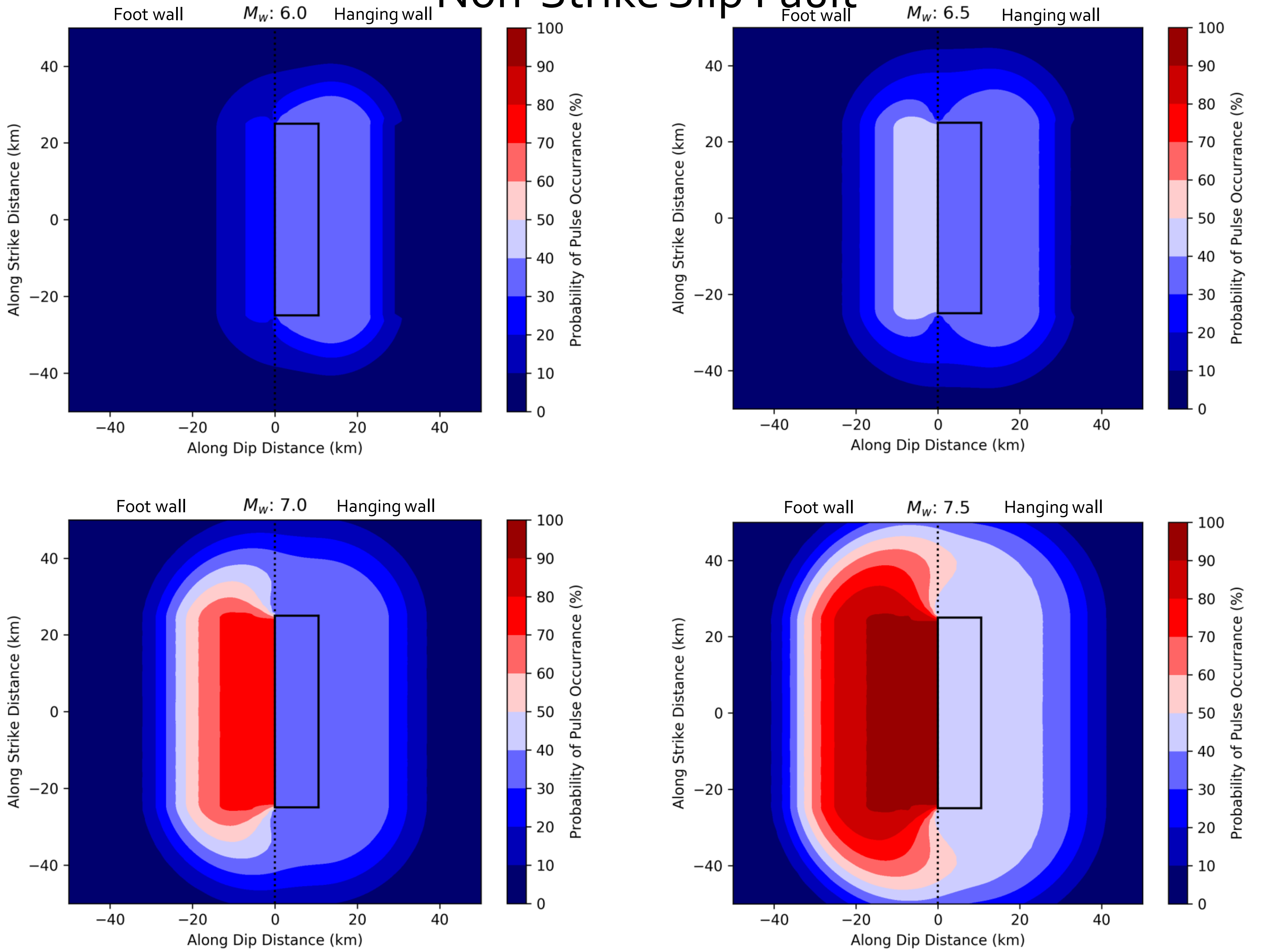
$$M_w = 6.5$$



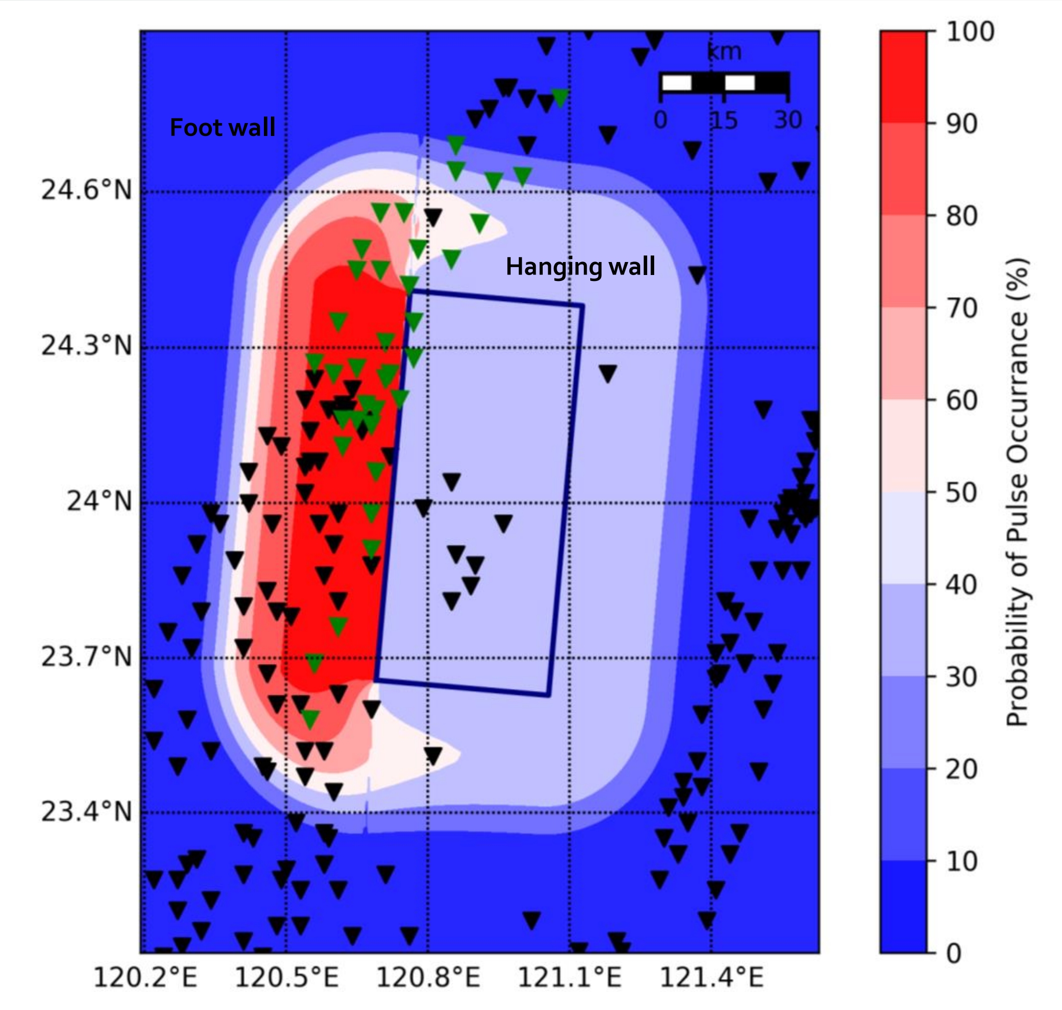
Legend:

- Non-impulsive
- Impulsive

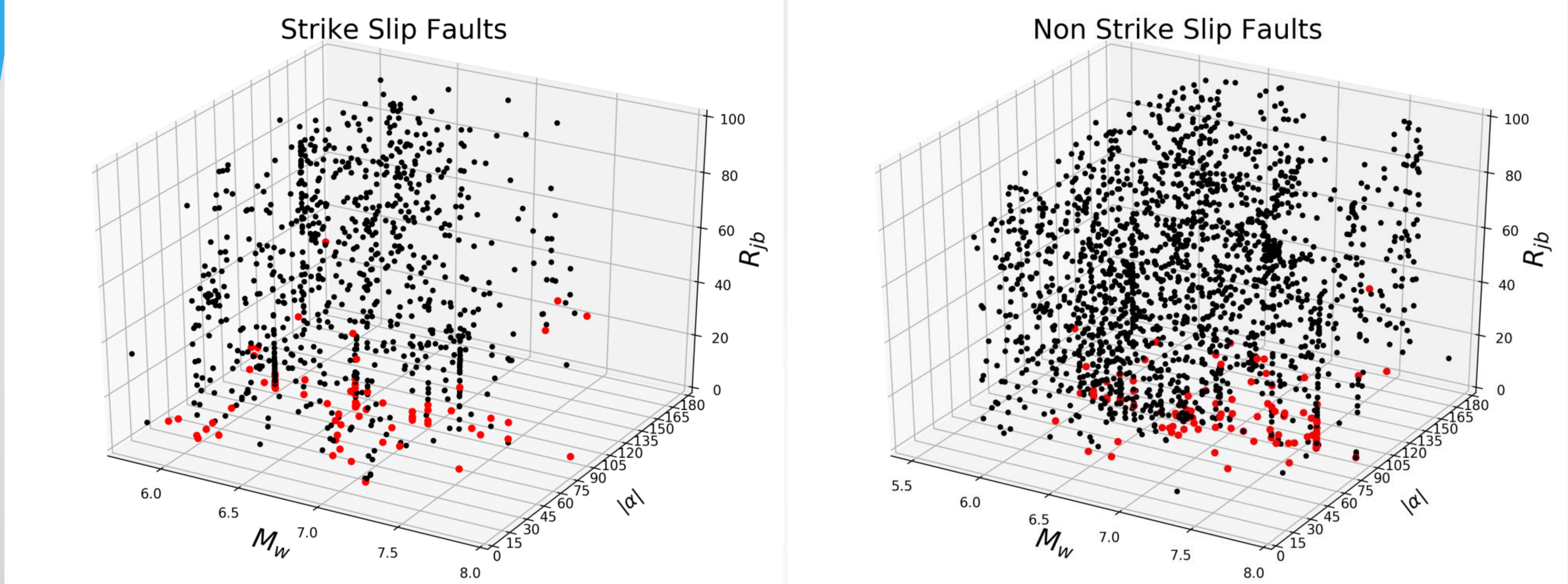
Non-Strike Slip Fault



Chi-Chi Taiwan Earthquake (20th of September 1999)
$M_w = 7.6$



Legend:
Non-impulsive
Impulsive



$$\bar{x} = \begin{cases} 1, & if\ pred(M_w, R_{jb}, \alpha) \geq 50 \\ 0, & otherwise \end{cases}$$

Accuracy Rate	Strike Slip Fault	Non-Strike Slip Fault
Impulsive (%)	45.08	41.35
Non-Impulsive (%)	98.17	97.77
Combined (%)	94.70	96.10

Conclusions:

1. Multivariate naïve Bayes classier approach is applied to a large set of data;
2. M_W,R_{jb} and source-to-site azimuth parameters are chosen for the calculation of probability of observing impulsive signal;
3. Accuracy rates are decreased due to presence of impulsive signals in unexpected locations because of local site conditions, up-dip directivity effect, inhomogeneous distribution of stations and the robust method for calculation of the rates.

References:

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- Kalkan, Erol, and Sashi K. Kunnath. "Effects of fling step and forward directivity on seismic response of buildings." *Earthquake spectra* 22.2 (2006): 367-390.
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- Kaklamanos, James, Laurie G. Baise, and David M. Boore. "Estimating unknown input parameters when implementing the NGA ground-motion prediction equations in engineering practice." *Earthquake Spectra* 27.4 (2011): 1219-1235.