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CONDITIONAL PULSE PROBABILITY FOR NEAR-SOURCE HAZARD ANALYSIS

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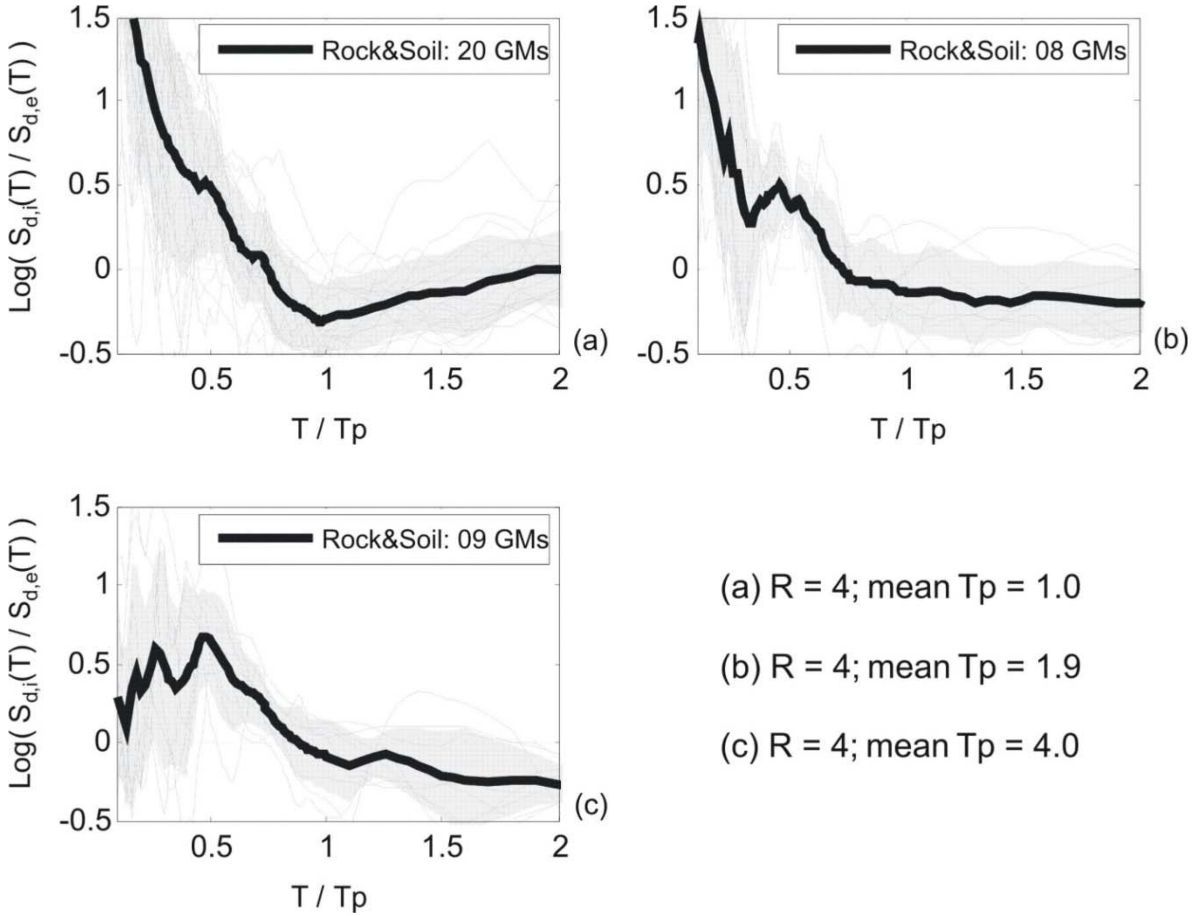
Pulse-like records can induce comparatively large inelastic nonlinear demand in structures having a period which is a fraction of that of the pulse*.



(a) R = 4; mean Tp = 1.0

(b) R = 4; mean Tp = 1.9

(c) R = 4; mean Tp = 4.0

*Tothong, P., and Cornell, C.A. (2006). *Probabilistic seismic demand analysis using advanced ground motion intensity measures, attenuation relationships, and near-fault effects*, PEER Report 2006/11, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA.

To account for the pulse threat appropriate adjustments to PSHA* are required; in fact pulses are not always observed in near-source conditions where directivity effects are expected, therefore:

$$\lambda_{S_a,NS}(x)=\lambda_{S_a,NS\,\&\,pulse}(x)+\lambda_{S_a,NS\,\&\,no\,pulse}(x)$$

MAF Sa>x (hazard)

Attenuation

$$\lambda_{S_a,NS\,\&\,pulse}(x)=\nu\int_m\int_r\int_{\underline{z}}\int_{t_p} P[pulse\,|\,m,r,\underline{z}]\,G_{S_a|pulse,M,R,\underline{Z},T_p}(x\,|\,m,r,\underline{z},t_p)\times$$

$$\times f_{T_p|\underline{Z},M,R}\;f_{\underline{Z}|M,R}\;f_{M,R}\;dt_p\;d\underline{z}\;dm\;dr$$

Distribution of pulse period

Distribution of Magnitude and Distance

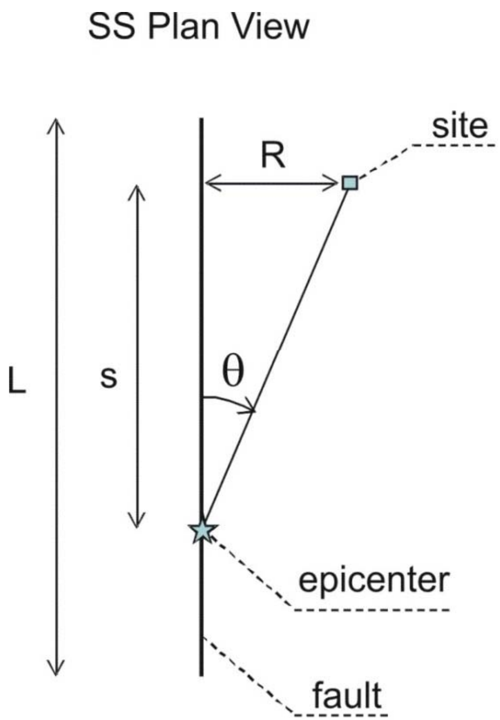
Distribution of pulse predictors

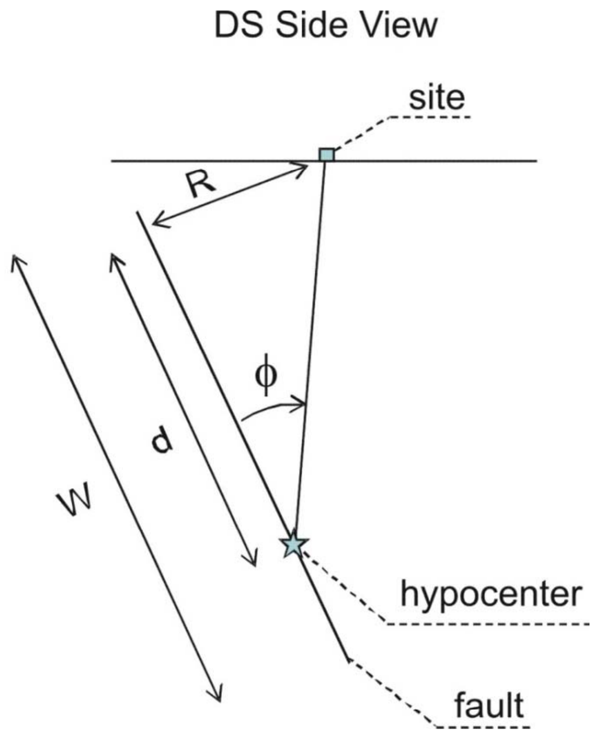
$$\lambda_{S_a,NS\,\&\,no\,pulse}(x)=\nu\int_m\int_r\int_{\underline{z}}(1-P[pulse\,|\,m,r,\underline{z}])\,G_{S_a|no\,pulse,M,R}(x\,|\,m,r)\times$$

$$\times f_{\underline{Z}|M,R}\;f_{M,R}\;d\underline{z}\;dm\;dr$$

*Iervolino, I, and Cornell, CA (2007). Prediction of the Occurrence of Velocity Pulses in Near-Source Ground Motions. *Unpublished manuscript*.
*Tothong, P., Cornell, C.A., and Baker, J.W. (2007). Explicit directivity-pulse inclusion in probabilistic seismic hazard analysis. *Earthquake Spectra*, **23**, 867–891.

Directivity effects' predictors for strike-slip (SS) and dip-slip (DS) events*:





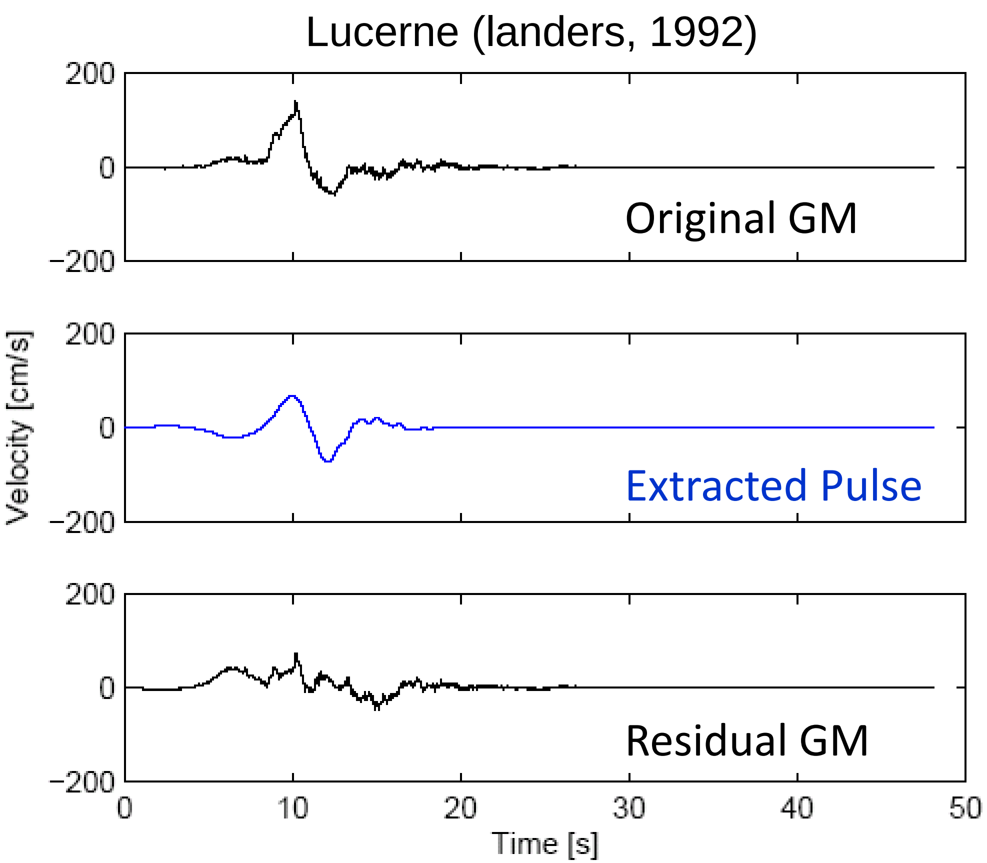
Parameter	
R [km]	Closest distance of the site to fault rupture
s [km]	Distance to the site measured along the rupture
ϑ [deg]	Angle between the rupture and the site
L [km]	Length of the fault
X=s/L	Length ratio
M	Magnitude
Xcos(ϑ)	Somerville's amplification parameter

Parameter	
R [km]	Closest distance of the site to fault rupture
d [km]	Distance to the site measured along the rupture
φ [deg]	Angle between the rupture and the site
W [km]	Width of the fault
Y=d/W	Width ratio
M	Magnitude
Ycos(φ)	Somerville's amplification parameter

*Somerville, P.G., Smith, N.F., Graves, R.W., and Abrahamson, N.A. (1997). Modification of empirical strong ground motion attenuation relations to include the amplitude and duration effects of rupture directivity, *Seism. Res. Lett.* **68** 199–222.

Pulse identification is based on that of Baker 2007*.

- Baker (2007) developed a method based on wavelets to assign a score, a real number between 0 and 1, to each analyzed record and to determine the pulse period. The larger the score determined the more likely the record is to show a pulse.
- Herein only those in the fault-normal component have been considered; in particular those ground motions which have a pulse score larger or equal to 0.85 have been, arbitrarily, counted as pulse-type records.
- Baker analyzed extensively the NGA database and he is the only researcher the authors are aware of who has looked systematically at all records in the database. Therefore, we know which are the pulses, and also which are the non-pulses.



* Baker, J.W. (2007). Quantitative classification of near-fault ground motions using wavelet analysis, *Bull. Seism. Soc. Am.* **97** 1486–1501.

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The information about the dataset have been retreived by the Next Generation Attenuation (NGA) of Ground Motions Project*

Data Within 30km in Terms of Closest Distance to Fault Rupture (Magnitude Range: 5.2÷7.5)				
Type	**Events**	**Records**	**Pulse-Like Records**	**Marginal Pulse Probability**
Strike-Slip (SS)	12	133	34	26%
Non-Strike-Slip (NSS)	11	229	39	17%
Total	***23***	***352***	***73***	***20%***

*http://peer.berkeley.edu/assets/NGA_Flatfile.xls
*http://peer.berkeley.edu/nga/NGA_Documentation.xls

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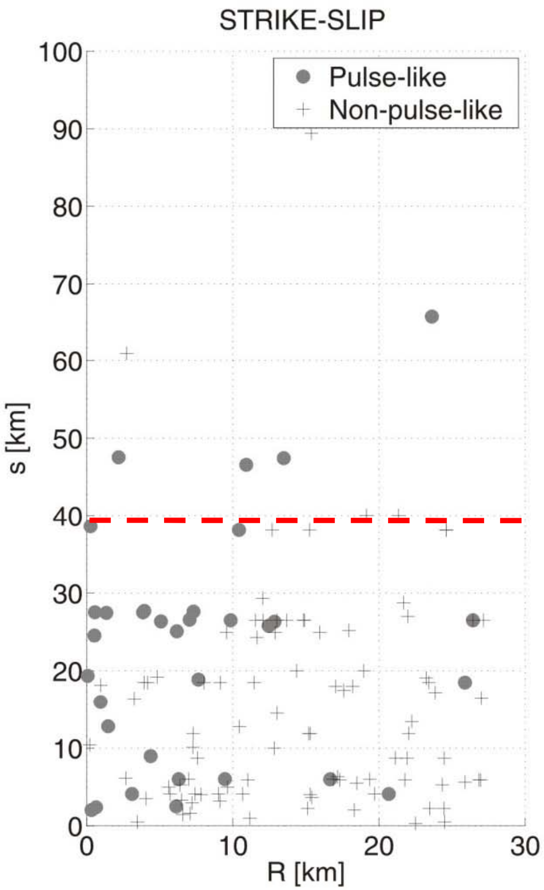
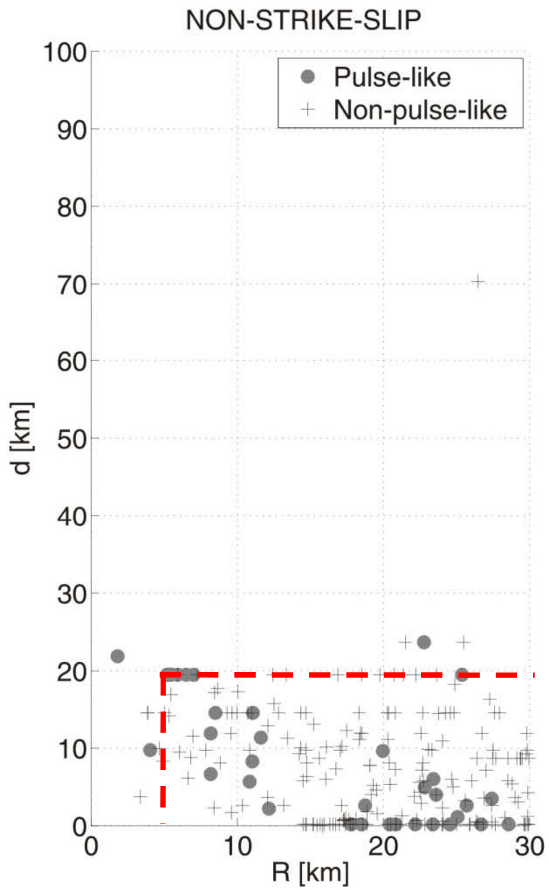
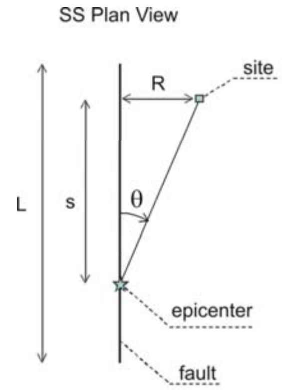
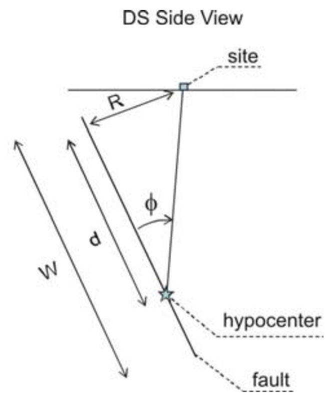
Projected distance (along the rupture plane) from the origin of the rupture toward the site versus the closest distance to fault rupture

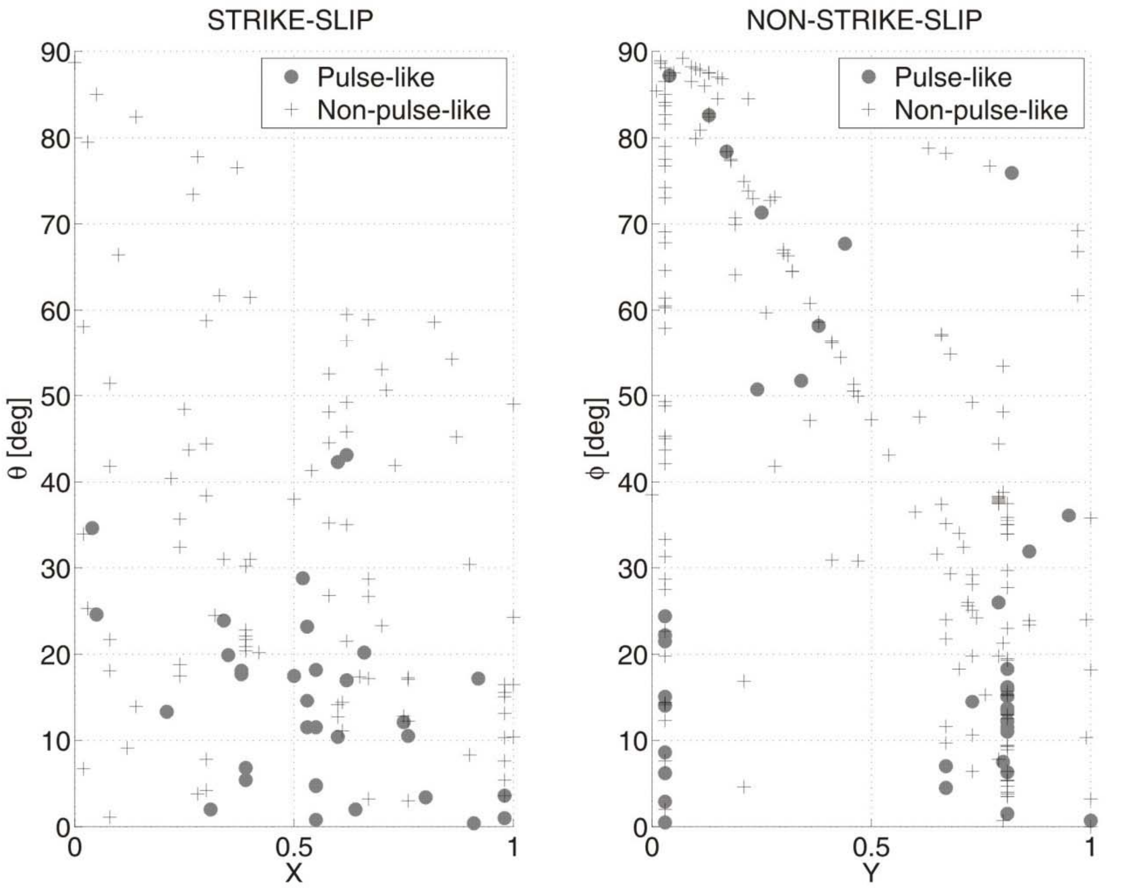


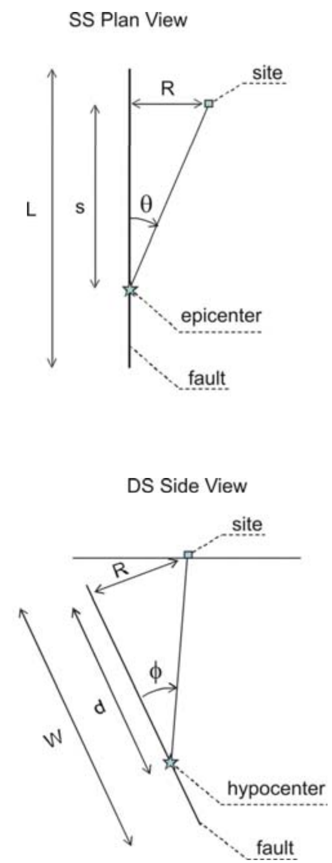




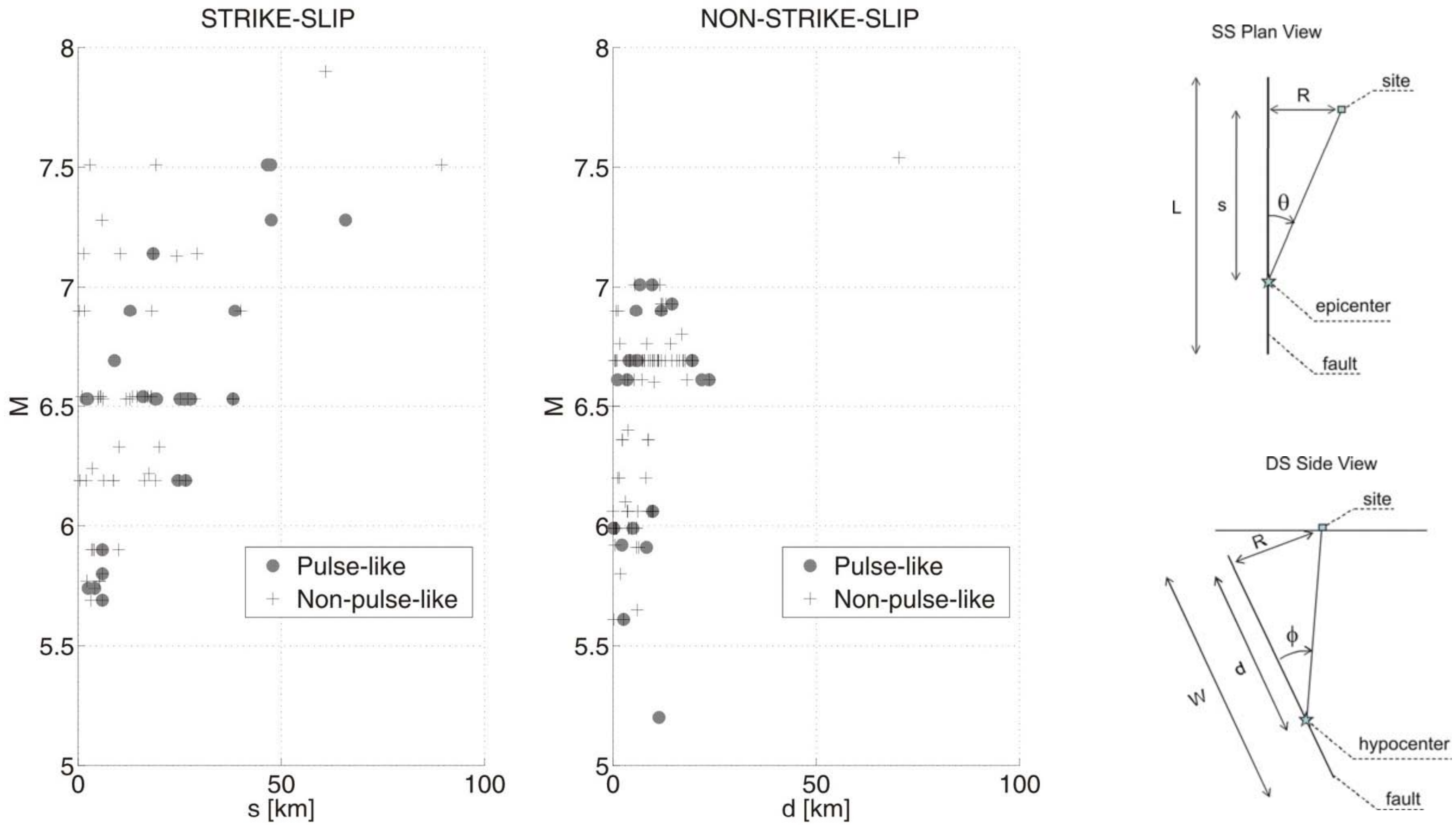


Angle between the site and the fault plane versus the normalized distance





Magnitude versus the projected distance (along the rupture plane) from the origin of the rupture toward the site



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Logistic regression

$$p = P[\textit{pulse in the record}]$$

$$1 - p = P[\textit{no pulse}]$$

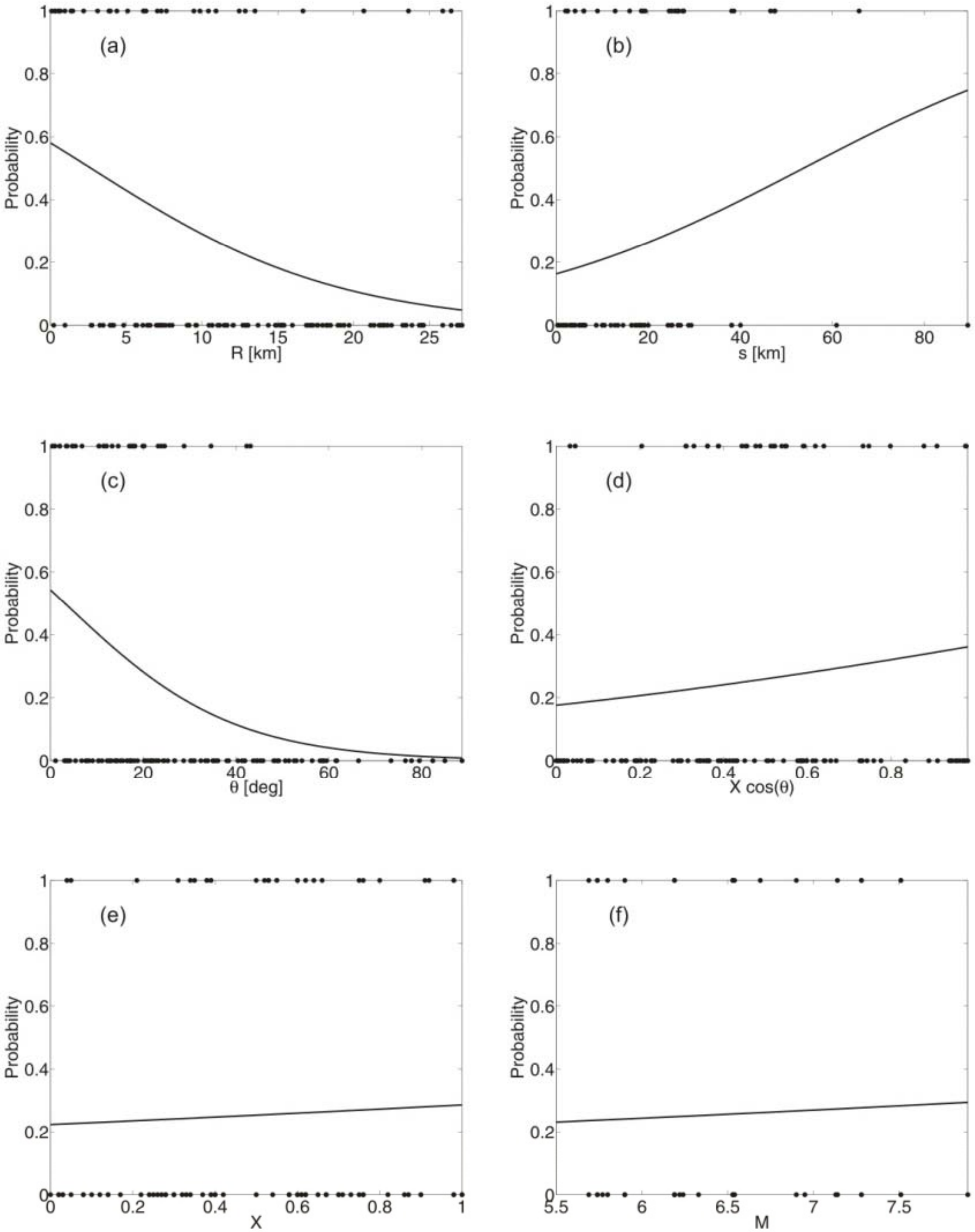
$$\log\left(\frac{p}{1-p}\right) = \alpha + \beta_1 z_1 + \beta_2 z_2 + \ldots + \beta_k z_k$$

- It is not easy to determine the prediction power and to compare logistic models. Furthermore, there is no widely-accepted direct analog to R^2 as defined for ordinary least-square regressions. Nonetheless, several logistic R^2 measures have been proposed, all of which should be reported as approximations of R^2, not as actual percents of variance explained by the model, but rather attempts to measure strength of association.
- To choose the best functional form, the *Akaike Information Criterion* (*AIC*) may be used; it allows one to compare models with a different number of terms counterbalancing the improvement of fit with the manageability of the equation. The lower is *AIC* the better is the model.

$$R^2_{MF} = 1 - \frac{\sum_{i=1}^{n} y_i \log\left(\hat{p}_i\right) + (1-y_i)\log\left(1-\hat{p}_i\right)}{n\left(\bar{p}\log\left(\bar{p}\right) + \left(1-\bar{p}\right)\log\left(1-\bar{p}\right)\right)}$$

$$R^2_E = 1 - \frac{\sum_{i=1}^{n}\left(y_i - \hat{p}_i\right)^2}{\sum_{i=1}^{n}\left(y_i - \bar{p}\right)^2}$$

$$AIC = -2\left[\left(\sum_{i=1}^{n} y_i \log\left(\hat{p}_i\right) + (1-y_i)\log\left(1-\hat{p}_i\right)\right) - q\right]$$



Strike-Slip Model Scores

Covariate	R^2 *(E)*	R^2 *(MF)*	*AIC*
R [km]	0.16051	0.12467	136.3561
s [km]	0.040238	0.034712	149.958
ϑ [deg]	0.12381	0.12873	135.7425
M	0.000848	0.000775	155.0894
X	0.001278	0.001522	154.9764
Xcos(ϑ)	0.011531	0.013597	153.1507

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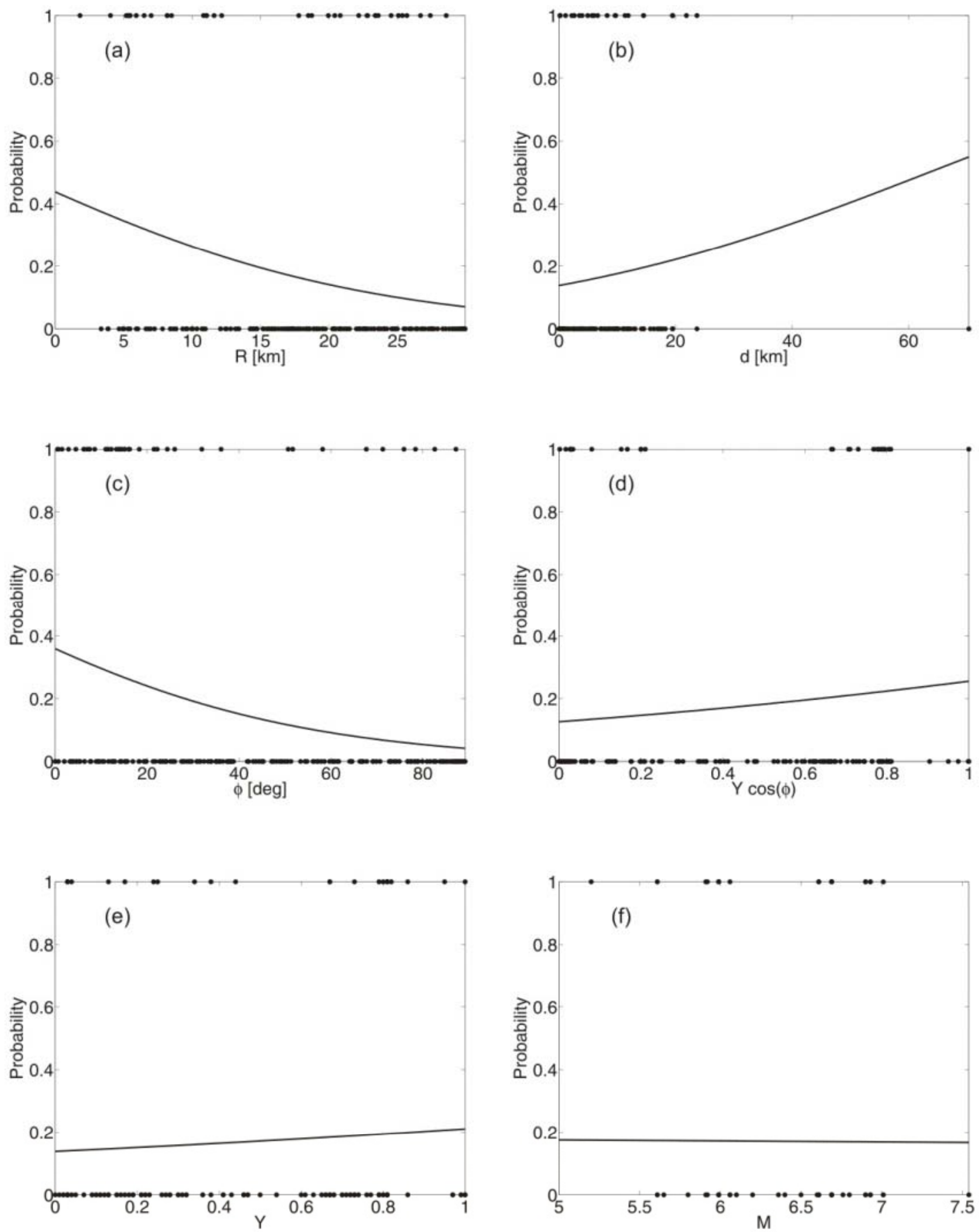


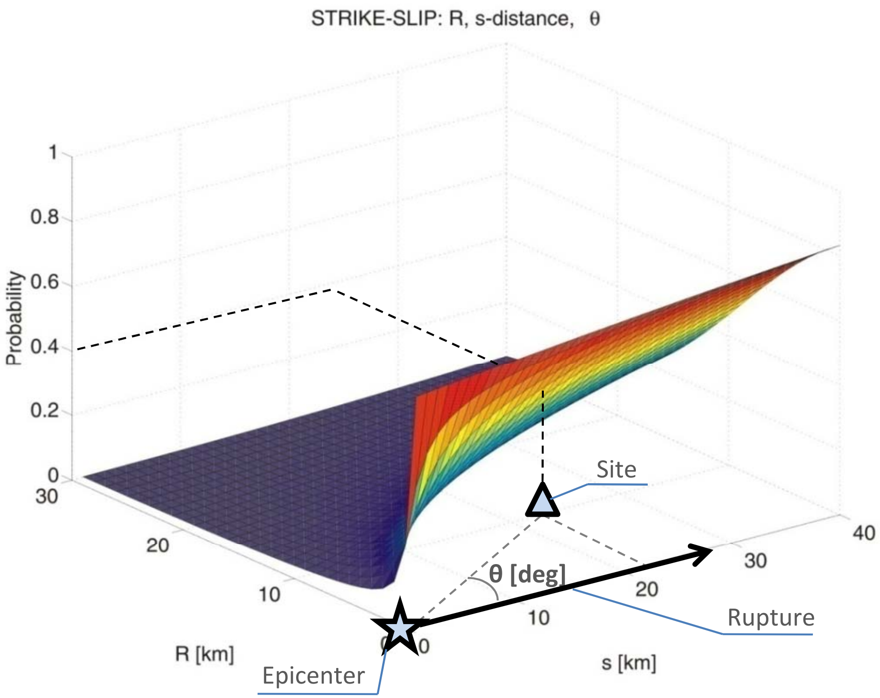
Non-Strike-Slip Model Scores

Covariate	*R^2 (E)*	*R^2 (MF)*	*AIC*
R [km]	0.058661	0.050954	202.3675
d [km]	0.007687	0.009624	211.0061
φ [deg]	0.082195	0.080198	196.255
M	1.42E-05	1.36E-05	213.0149
Y	0.004479	0.004608	212.0546
Ycos(φ)	0.013224	0.012865	210.3287

Strike-Slip Model Scores

Covariates	R^2 *(E)*	R^2 *(MF)*	*AIC*
$\{R,s\}$	0.22514	0.17175	131.2366
$\{R,\theta\}$	0.25698	0.21624	124.5098
$\{s,\theta\}$	0.12816	0.13093	137.4095
$\{R,s,R\cdot s\}$	0.22516	0.17189	133.2153
$\{R,\theta,R\cdot\theta\}$	0.26221	0.22699	124.8835
$\{s,\theta,s\cdot\theta\}$	0.12768	0.13104	139.3921
$\{R,s,\theta\}$	0.2708	0.22511	125.1679
$\{R,s,\theta,R\cdot s\}$	0.27147	0.22521	127.1535
$\{R,s,\theta,R\cdot\theta\}$	0.27482	0.23457	125.7386
$\{R,s,\theta,s\cdot\theta\}$	0.27505	0.22602	127.0316
$\{R,s,\theta,R\cdot\theta,s\cdot\theta\}$	0.27718	0.23504	127.6677
$\{R,s,\theta,R\cdot s,R\cdot\theta\}$	0.27721	0.23649	127.4479
$\{R,s,\theta,s\cdot\theta,R\cdot s\}$	0.27526	0.22603	129.0296
$\{R,s,\theta,R\cdot s,R\cdot\theta,s\cdot\theta\}$	0.27836	0.23658	129.4335
$\{R,s,\theta,R\cdot s,R\cdot\theta,s\cdot\theta,R^2,s^2,\theta^2\}$	0.30062	0.26244	131.5234

$$P[pulse\,|\,R,s,\theta]=\frac{e^{\alpha+\beta_1\cdot R+\beta_2\cdot s+\beta_3\cdot\theta}}{1+e^{\alpha+\beta_1\cdot R+\beta_2\cdot s+\beta_3\cdot\theta}}$$



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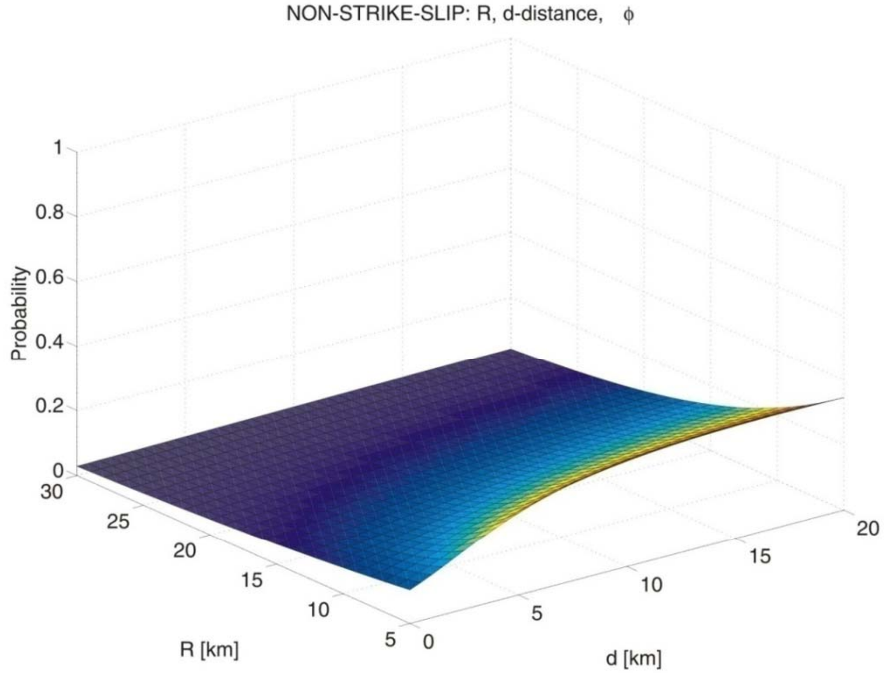
Non-Strike-Slip Model Scores

Covariates	R^2 (E)	R^2 (MF)	AIC
$\{R,d\}$	0.064345	0.052306	204.0847
$\{R,\phi\}$	0.10374	0.099313	194.2595
$\{d,\phi\}$	0.085203	0.08153	197.9765
$\{R,d,R\cdot d\}$	0.15439	0.12236	191.4417
$\{R,\phi,R\cdot\phi\}$	0.10185	0.10033	196.0464
$\{d,\phi,d\cdot\phi\}$	0.085204	0.081532	199.9761
$\{R,d,\phi\}$	0.10726	0.10404	195.2706
$\{R,d,\phi,R\cdot d\}$	0.18724	0.15551	186.5141
$\{R,d,\phi,R\cdot\phi\}$	0.10377	0.10594	196.8751
$\{R,d,\phi,d\cdot\phi\}$	0.10712	0.10456	197.1626
$\{R,d,\phi,R\cdot\phi,d\cdot\phi\}$	0.10247	0.10726	198.599
$\{R,d,\phi,R\cdot d,R\cdot\phi\}$	0.19828	0.1601	187.5541
$\{R,d,\phi,d\cdot\phi,R\cdot d\}$	0.20045	0.16652	186.2113
$\{R,d,\phi,R\cdot d,R\cdot\phi,d\cdot\phi\}$	0.20266	0.16735	188.0384
$\{R,d,\phi,R\cdot d,R\cdot\phi,d\cdot\phi,R^2,d^2,\phi^2\}$	0.23177	0.20505	186.1593

$$P[pulse \mid R,d,\phi]=\frac{e^{\alpha+\beta_1\cdot R+\beta_2\cdot d+\beta_3\cdot\phi}}{1+e^{\alpha+\beta_1\cdot R+\beta_2\cdot d+\beta_3\cdot\phi}}$$



Summary

- Simple and multiple logistic regression models have been investigated to associate pulse occurrence in the dataset to the covariates, for both SS and NSS samples. General findings hold for SS and NSS. Pulse occurrence probability has shown, as expected, significant dependence on distance to the rupture, *R*, along the rupture, *s (d)*, and also on the angle;

- Less explanatory power, if at all, for pulse-like records occurrence, was found for the event's magnitude and other pulse amplitude-related factors. Although these results may sound intuitively unexpected, it has to be recalled here that this study dealt with pulse occurrence probability alone, rather than on the prediction of the amplitude of such pulses, for which the excluded parameters do play a role;

- The strength of the association between the response variables and the covariates, in simple logistic models, has been found to be systematically weaker in the NSS case than in the SS;

- Multivariate logistic regression models were also investigated. For the SS case the proposed model is the linear combination of the geometrical predictors, as there is no empirical support to use models which include interaction or quadratic terms. The proposed NSS multivariate model has been arbitrarily selected by analogy with the SS case*.

*Iervolino, I., and Cornell, C.A. (2008). Probability of Occurrence of Velocity Pulses in Near-Source Ground Motions, *Bull. Seism. Soc. Am.* **98** 2262-2277.

Photos by Philip J. Caldwell, August 27, 2004

Thank you!