Directionality Issues

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Motivation

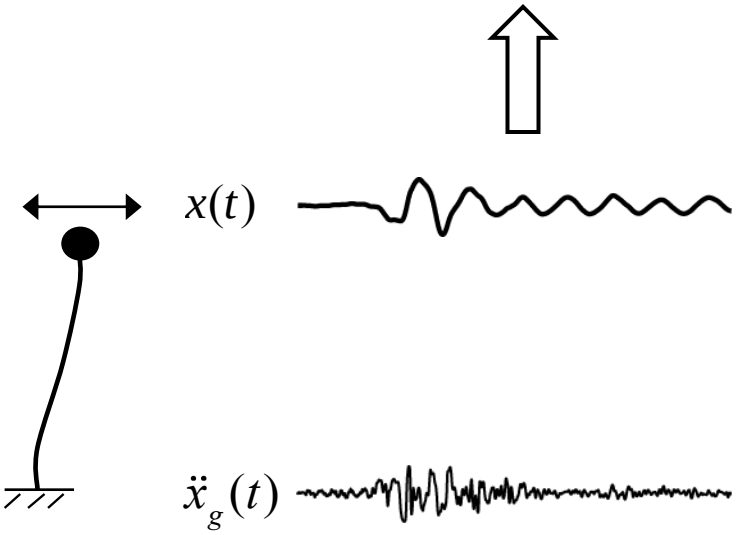
There are a number of ways in which one can define the "response spectrum" of a multicomponent ground motion

Traditionally:	$Sa_{GeoMean}$
NGA-West:	$Sa_{GMRotI50}$
NGA-West2:	Sa_{RotD50}
ASCE 7:	$Sa_{RotD100}$

I will discuss results allowing one can relate these values to each other

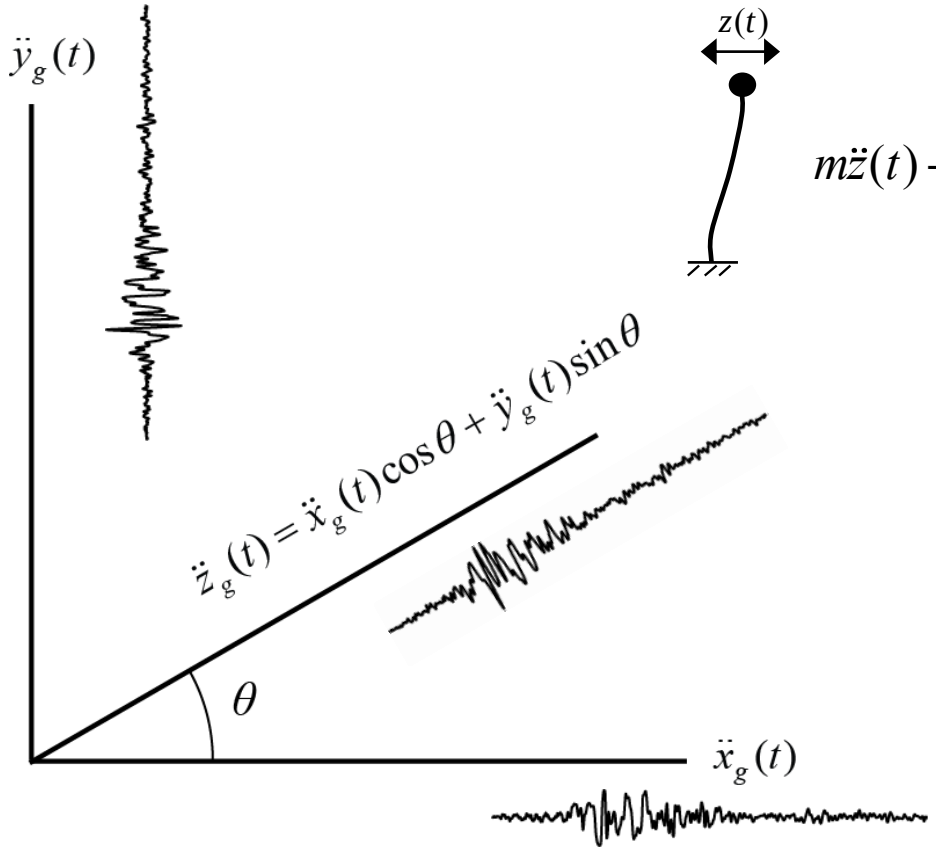
Measuring single-orientation (pseudo) response spectra

$$Sa(T) = \frac{k}{m} \max_t \left[x(t) \right]$$



$$m\ddot{x}(t) + c\dot{x}(t) + kx(t) = -m\ddot{x}_g(t)$$

Measuring direction-dependent response spectra



$$m\ddot{z}(t) + c\dot{z}(t) + kz(t) = -m\left[\ddot{x}_g(t)\cos\theta + \ddot{y}_g(t)\sin\theta\right]$$

$$z(t) = x(t)\cos\theta + y(t)\sin\theta$$

$$Sa(\theta, T) = \frac{k}{m}\max_t\left[x(t)\cos\theta + y(t)\sin\theta\right]$$

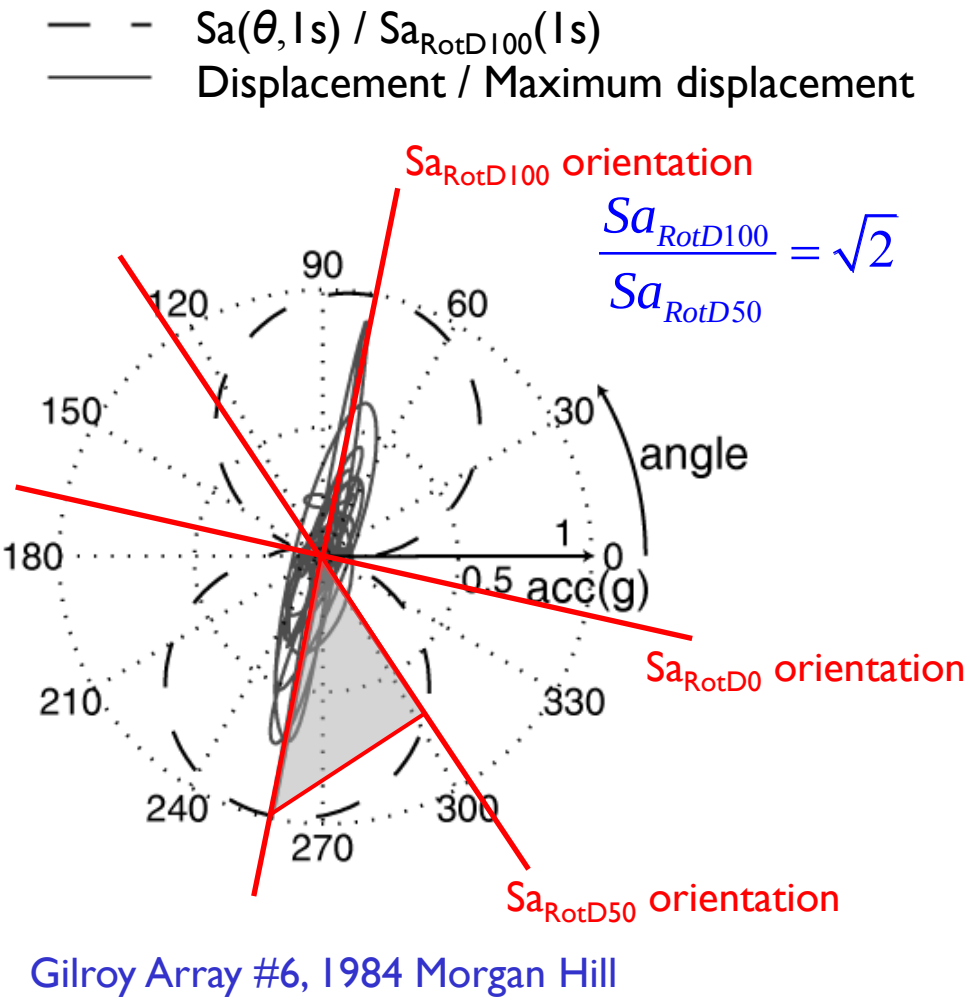
Measuring direction-dependent response spectra

$$Sa_{GeoMean}(T) = \sqrt{Sa_X(T)^2 + Sa_Y(T)^2}$$

$$Sa_{RotD100}(T) = \max_{q}\left[Sa(q,T)\right]$$

$$Sa_{RotD50}(T) = \operatorname{median}_{q}\left[Sa(q,T)\right]$$

$$Sa_{GMRotI50}(T) = \ldots$$



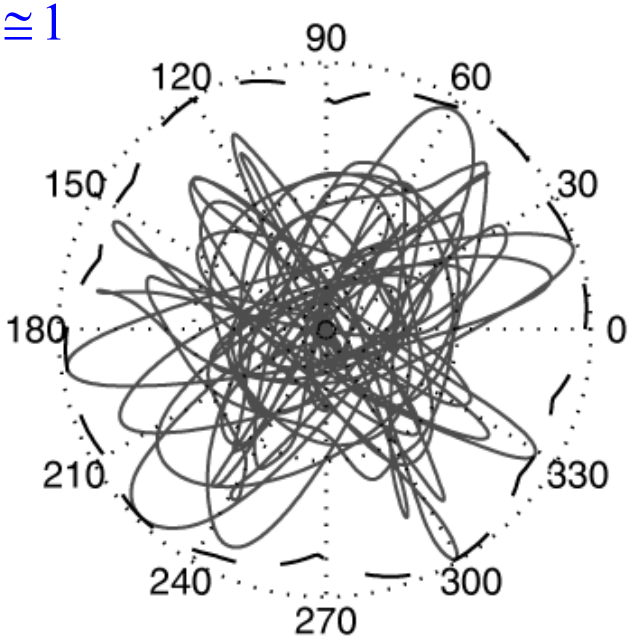
Gilroy Array #6, 1984 Morgan Hill

Example 1-second oscillator responses to multi-component motions

— – Sa(θ,1s) / $Sa_{RotD100}$(1s)

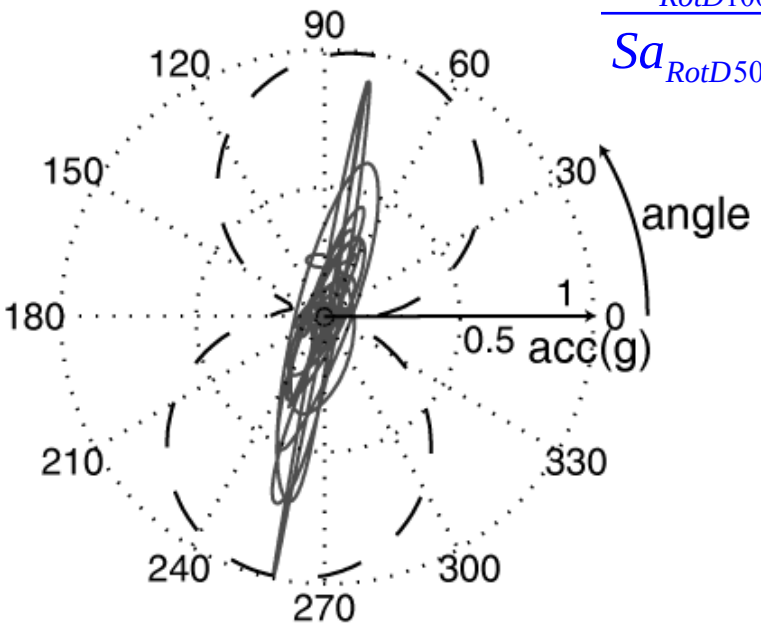
——— Displacement / Maximum displacement

$$\frac{Sa_{RotD100}}{Sa_{RotD50}} \cong 1$$



HWA031, 1999 Chi-Chi-04

$$\frac{Sa_{RotD100}}{Sa_{RotD50}} = \sqrt{2}$$



Gilroy Array #6, 1984 Morgan Hill

Ground motion model for $Sa_{RotD100}$ at a specified period

$$Sa_{RotD100} = \frac{Sa_{RotD100}}{Sa_{RotD50}} \; Sa_{RotD50}$$

$$\ln Sa_{RotD100} = \underbrace{\ln(Sa_{RotD100} / Sa_{RotD50})}_{\text{“Max direction factor”}} + \underbrace{\ln(Sa_{RotD50})}_{\text{Primary GMPE}}$$

$$\ln(Sa_{RotD100} / Sa_{RotD50}) = a + \eta' + \varepsilon'$$

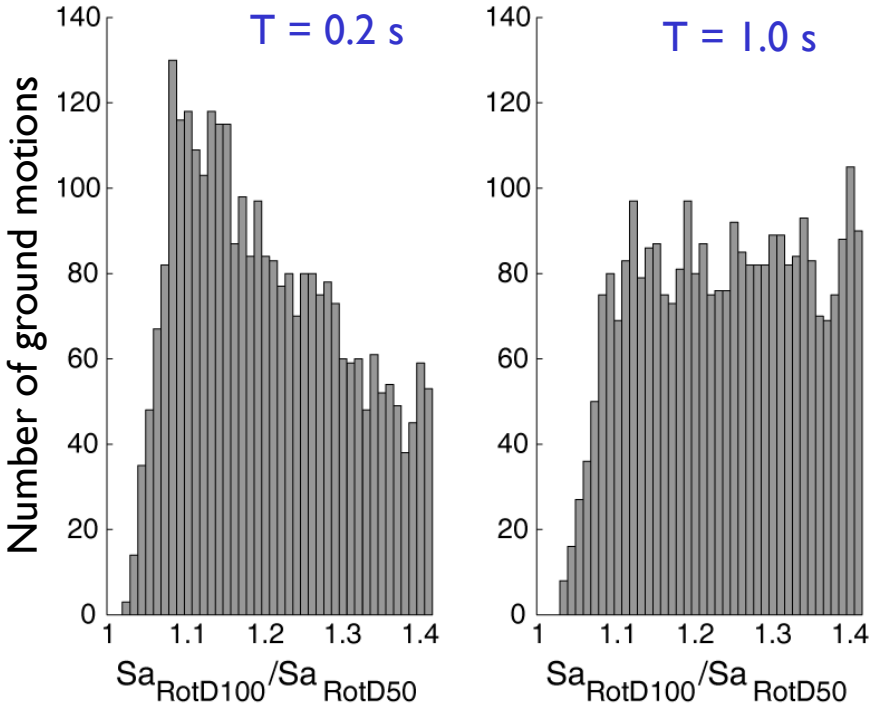
Simple prediction (constant?)

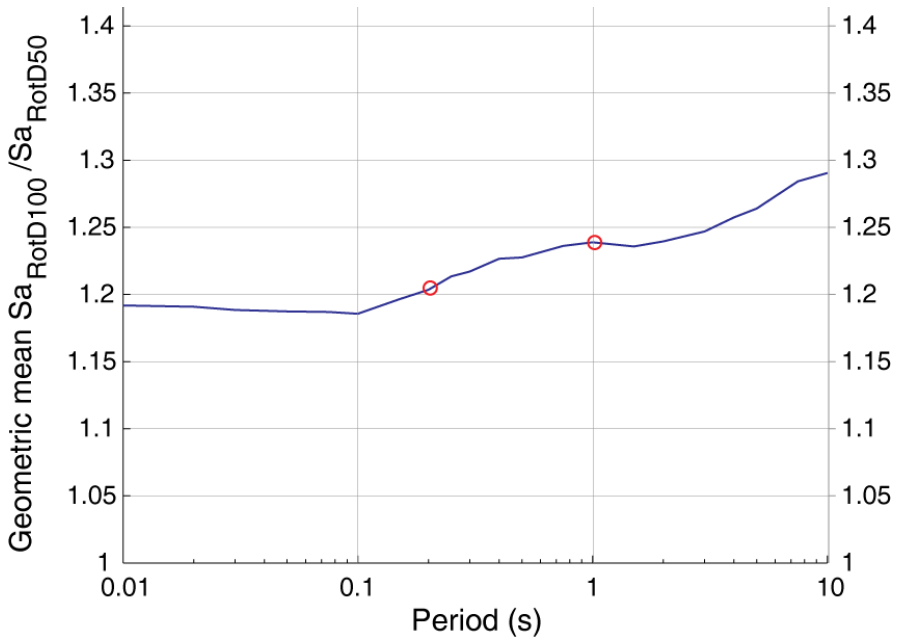
Independent of primary GMPE

$$\ln(Sa_{RotD50}) = f(M, R, V_{S30}, \ldots) + \eta + \varepsilon$$

Complex prediction

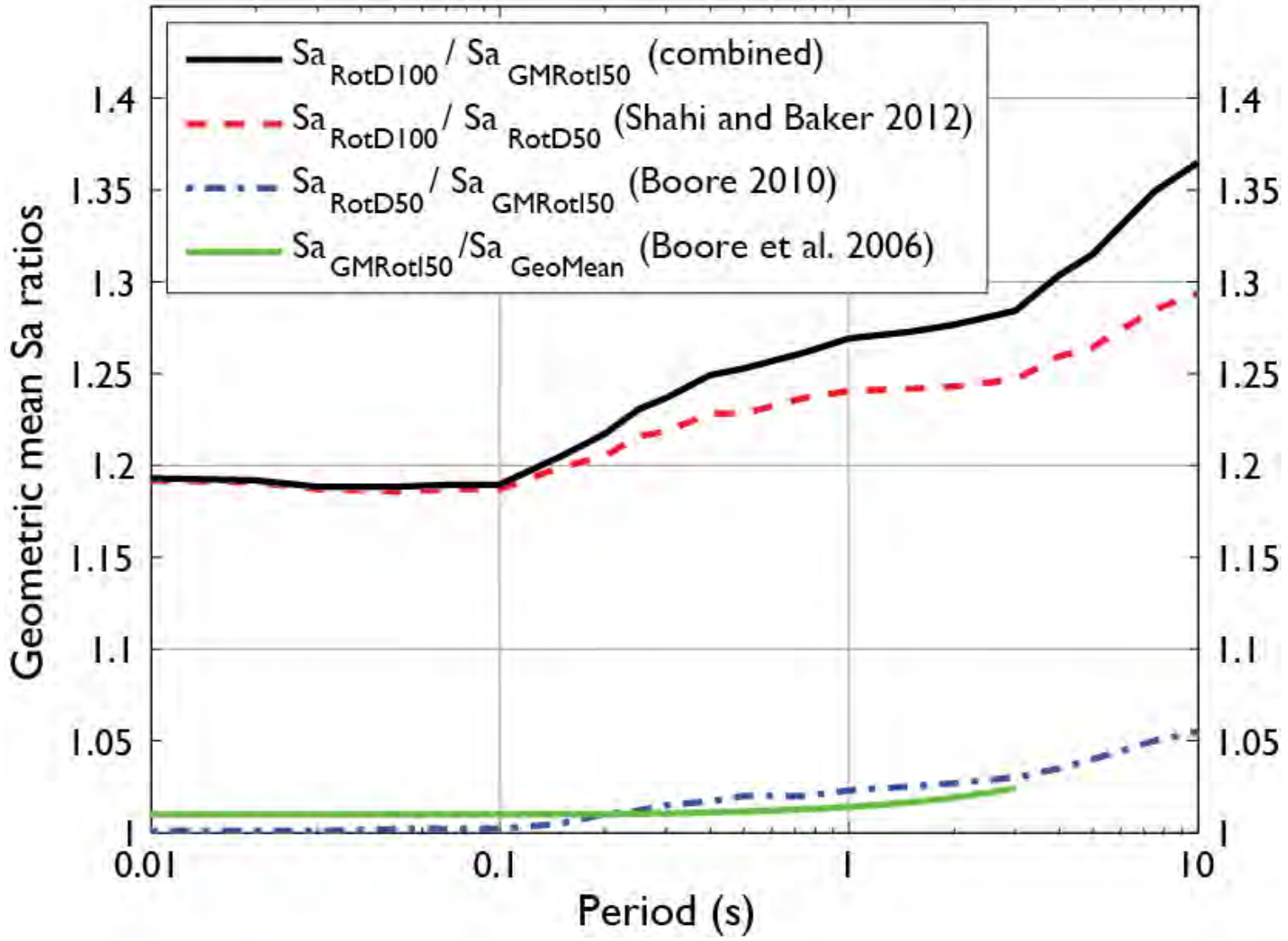
Histograms of $Sa_{RotD100}/Sa_{RotD50}$



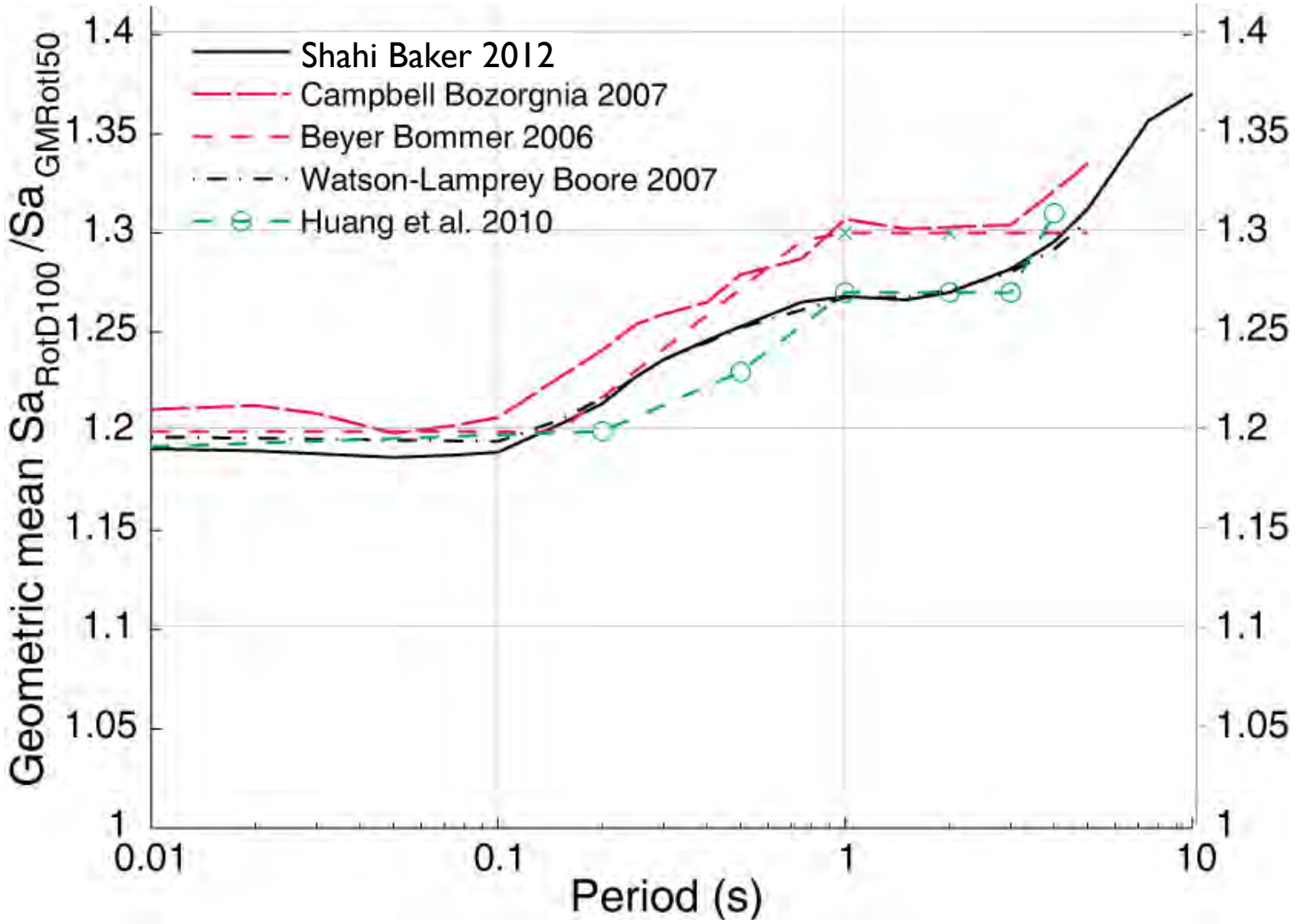


Results from subsets of the NGA -West2 data chosen by the modelers (Abrahamson-Silva data shown here)

Impacts of switching definitions

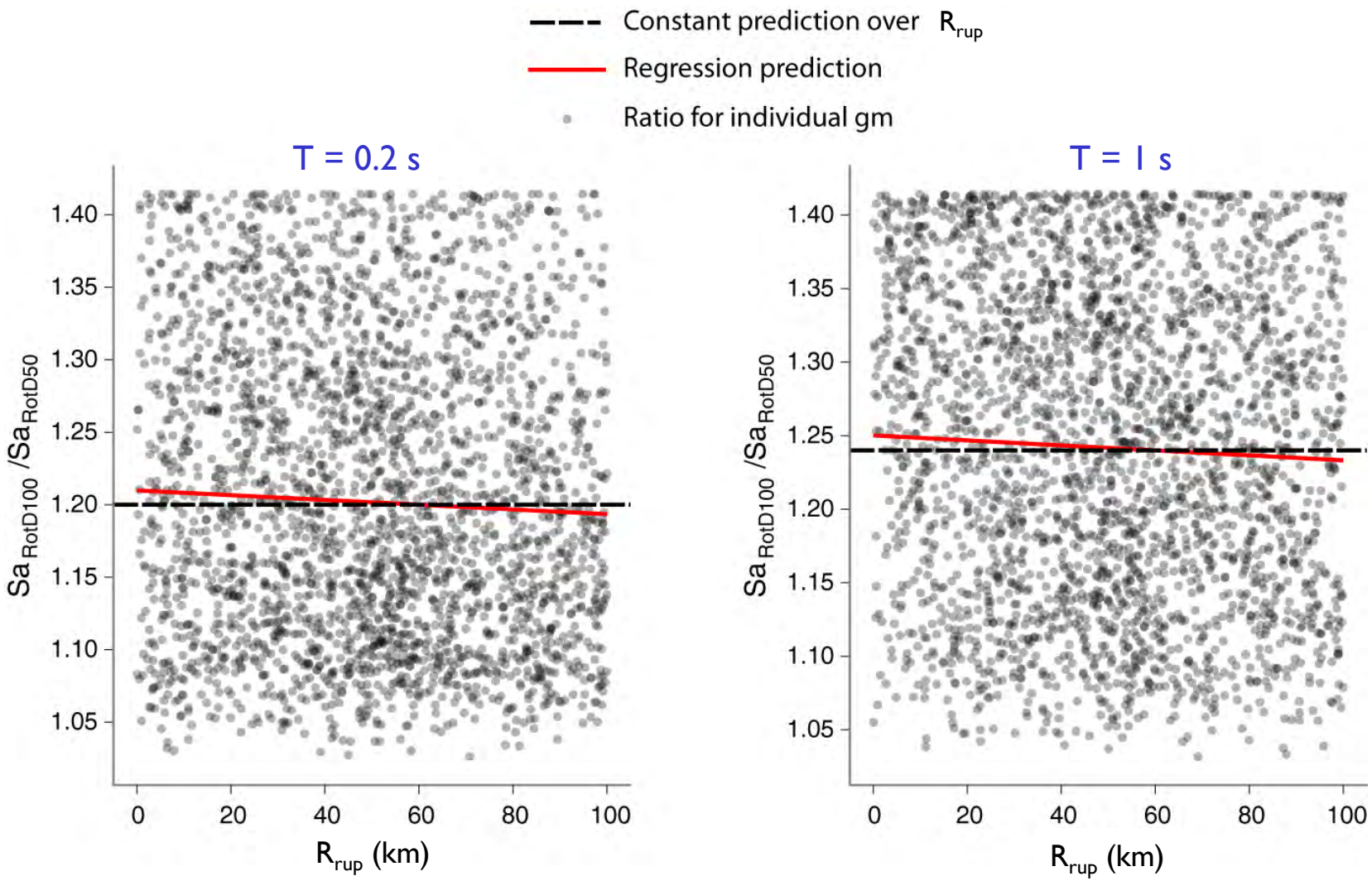


Geomean $Sa_{RotD100}/Sa_{GMRotI50}$ ratios, versus previous models



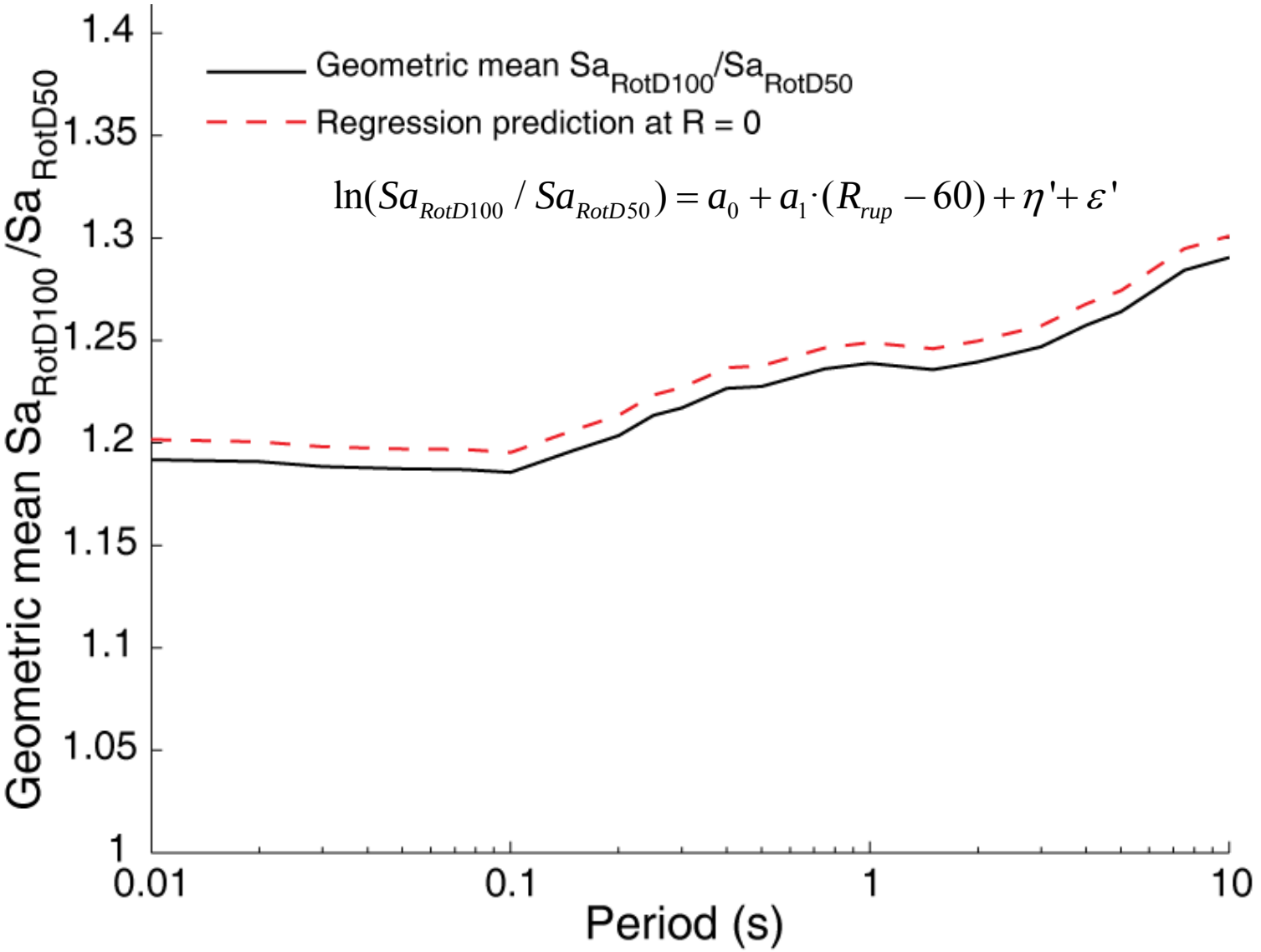
Clear period dependence. All models are consistent.

Variation in $Sa_{RotD100}/Sa_{GMRotI50}$ with closest distance (R_{rup})?



Other variables (M, directivity parameters) had less strong effects

Model with R_{rup} dependence



Standard deviations (example numbers for Sa(1s))

σ' = 0.629 σ = 0.623

$$\ln Sa_{RotD100} = \underbrace{\ln(Sa_{RotD100} / Sa_{RotD50})}_{\text{This study}} + \underbrace{\ln(Sa_{RotD50})}_{\text{Primary GMPE}}$$

$$\ln(Sa_{RotD100} / Sa_{RotD50}) = a + \eta' + \varepsilon' \qquad \ln(Sa_{RotD50}) = f(M, R, V_{S30}, \ldots) + \eta + \varepsilon$$

Shahi and Baker study: $\tau' = 0.010$, $\phi' = 0.083$

Campbell Bozorgnia (2008) NGA: $\tau = 0.255$, $\phi = 0.568$

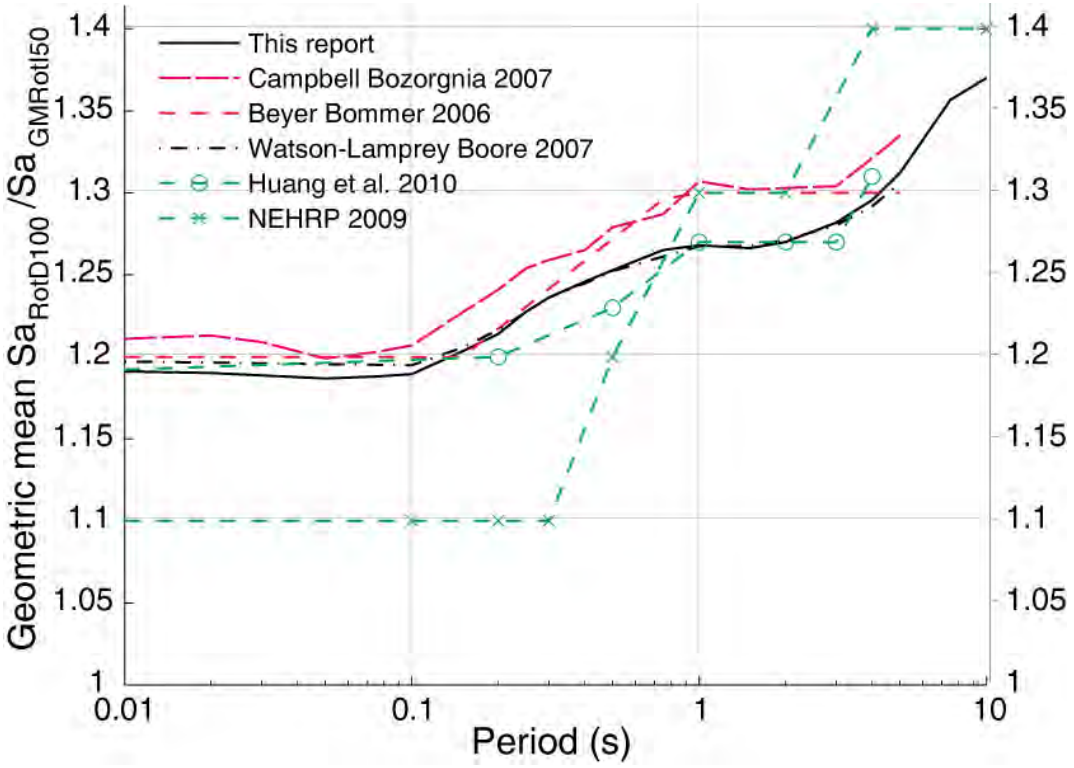
Conclusions

- Models are available for conversion between all popular Sa definitions, including the Sa_{RotD50} adopted by new models

- Ratios of $Sa_{RotD100}$ / Sa_{RotD50} from NGA-West2 data are consistent with previous studies
  - Dependent on period and (weakly) on distance
  - No clear dependence on other properties (magnitude, directivity-related parameters)
  - Standard deviations are small relative to standard deviations of Sa_{RotD50}

- The above properties imply that one can accurately convert from Sa_{RotD50} to $Sa_{RotD100}$ after Sa_{RotD50} hazard analysis has been performed

These ratios differ from the NEHRP Provisions ratios



NEHRP (2009):

- 0.2s → 1.1
- 1.0s → 1.3

Shahi and Baker (2012)

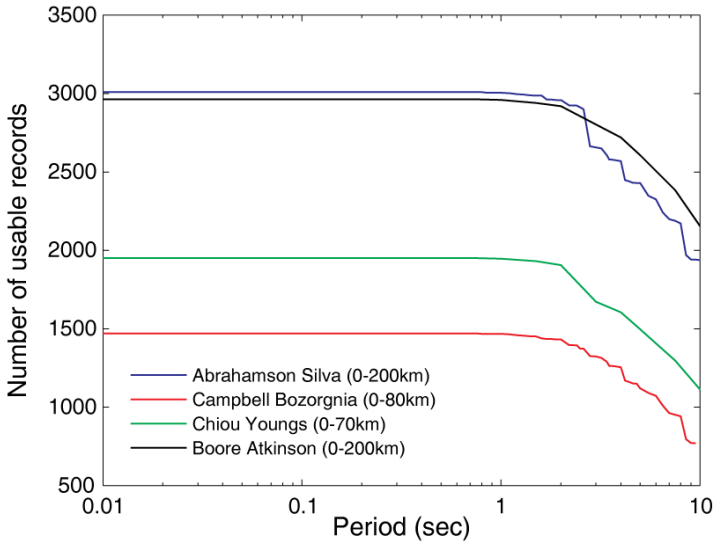
- 0.2s → 1.2
- 1.0s → 1.25

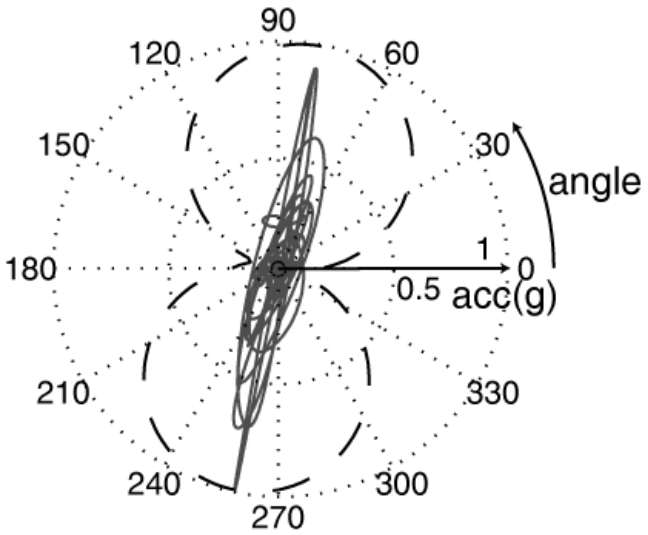
Differences due to

- *change of Sa definition*
- *change of estimation procedure*

Data set

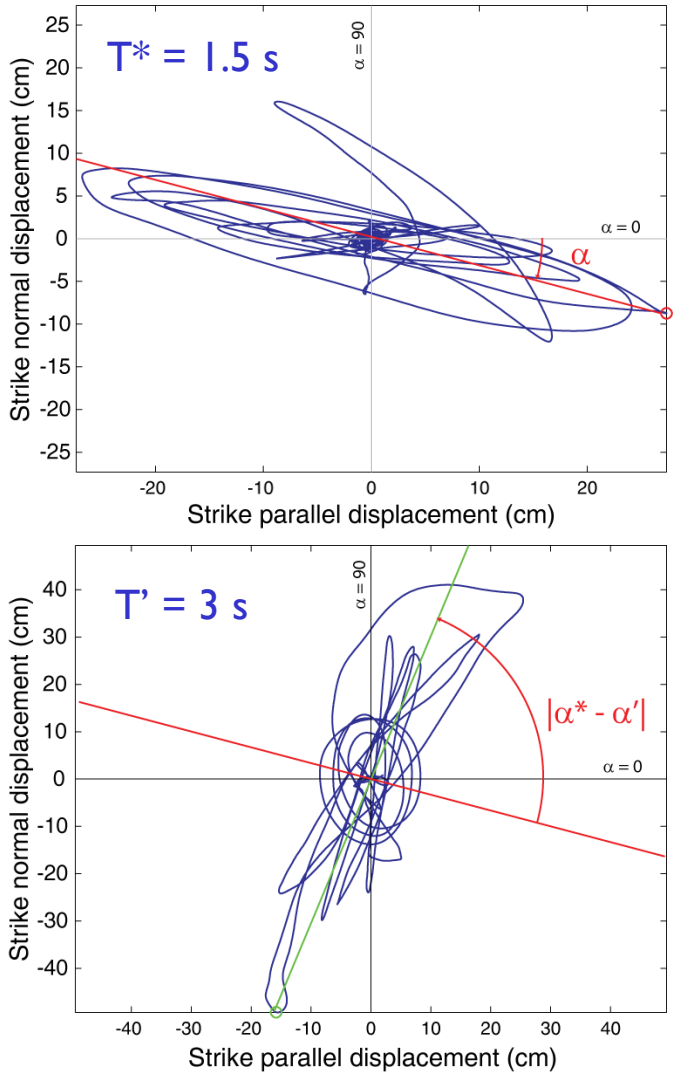
- NGA-West2 database
- We used subsets of the data chosen by the modelers (as of 11/1/2011), to ensure use of appropriate data and to be compatible with NGA West 2 models for Sa_{RotD50}
- Sa values computed for
  - 5% damping only
  - 21 periods
  - All orientations in 1° increments





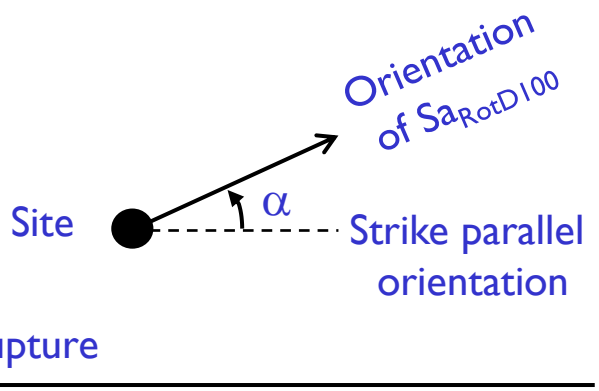
Results to discuss today

- $Sa_{RotD100}$ /Sa_{RotD50} ratios
- Orientation of $Sa_{RotD100}$ relative to strike
- Difference in orientation of $Sa_{RotD100}(T_1)$ and $Sa_{RotD100}(T_2)$
- Change in Sa(T) at angles away from the $Sa_{RotD100}$ orientation
- Amplitude of Sa(T) in a specified direction

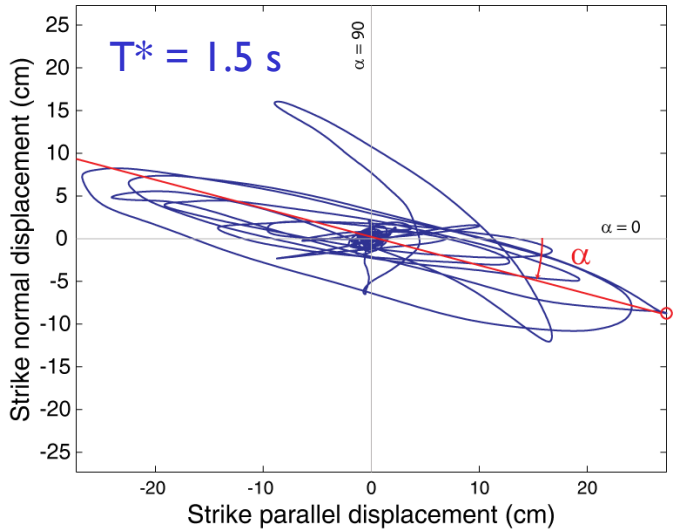


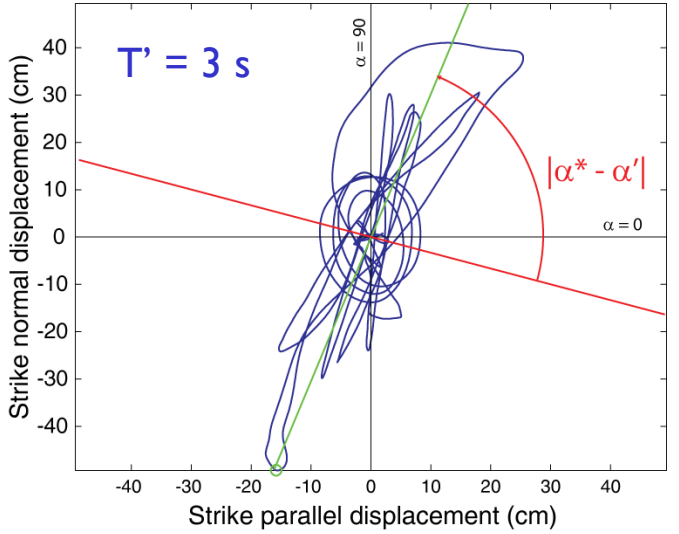
Oscillator responses to 1979 Imperial Valley-06, El Centro Differential Array recording

Orientation of $Sa_{RotD100}$ (using α as angle to strike parallel)



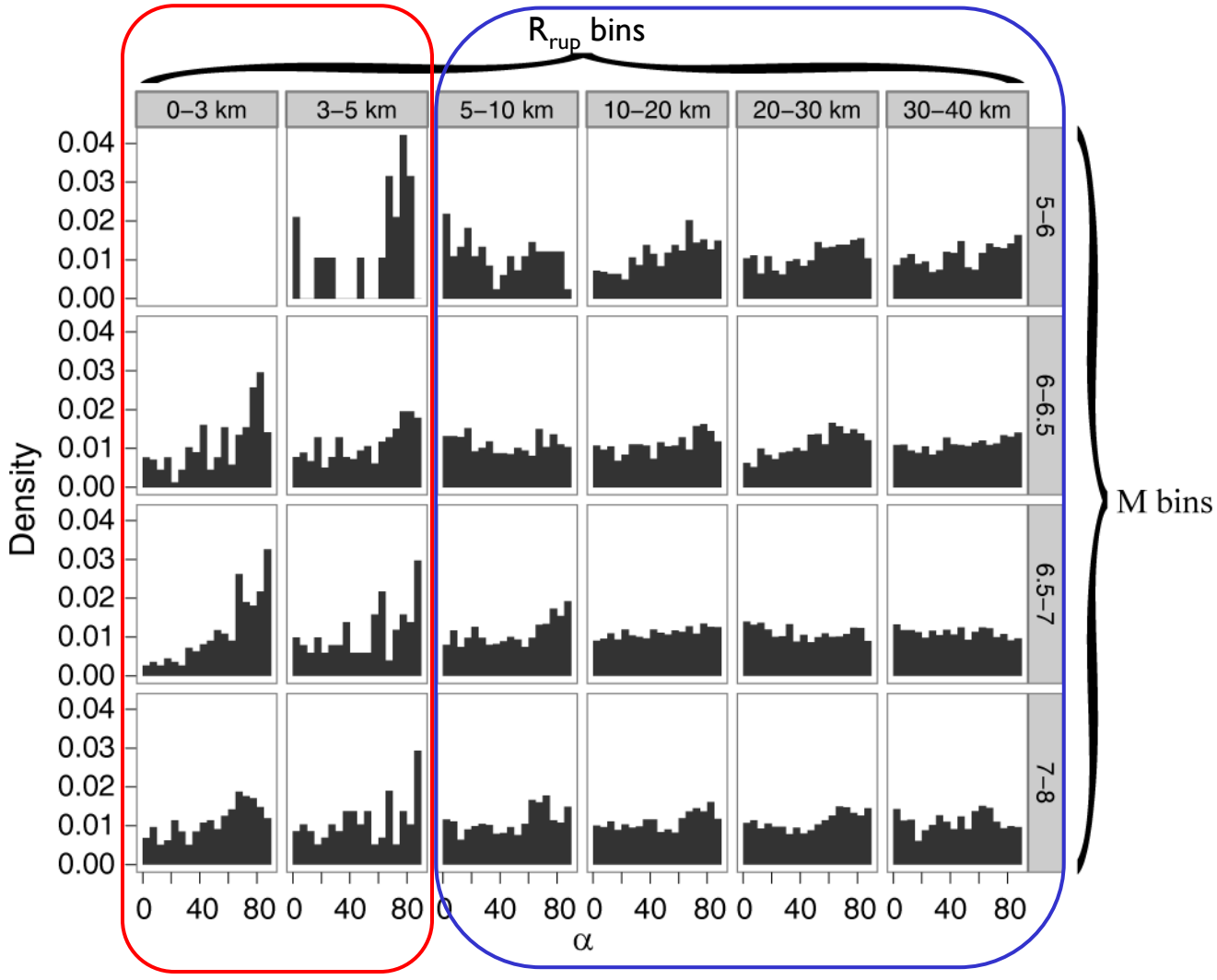
- Dependence of α on various parameters was studied
- A parametric model to predict the distribution of α is proposed



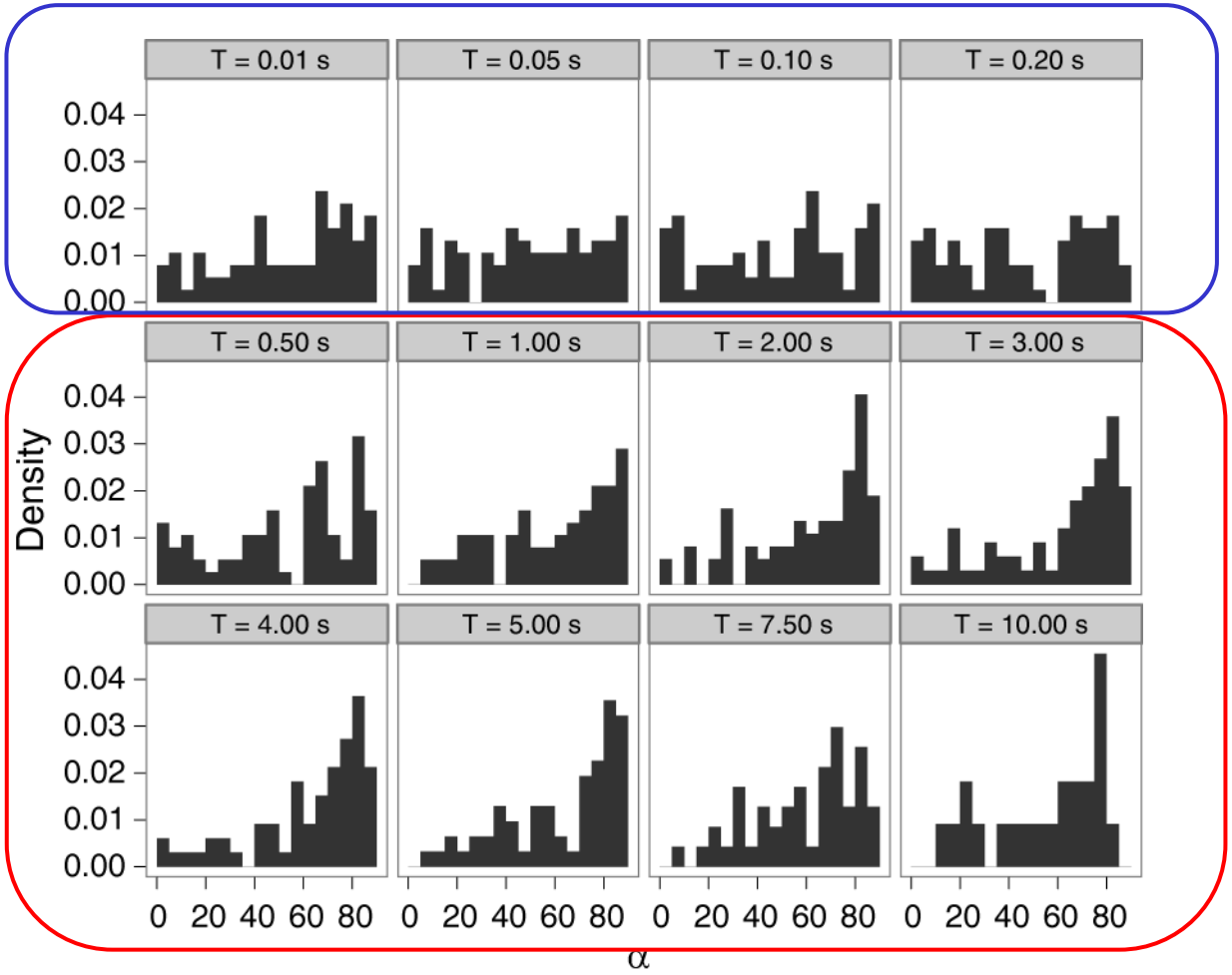


Oscillator responses to 1979 Imperial Valley-06, El Centro Differential Array recording

Dependence of α on M and R_{rup}



Distribution of α for varying T, with R_{rup} between 0 and 5 km



Apparent division at 0.5 or 1 second

Observations regarding distributions of α

Some dependence on distance and period (consistent with previous work)

- The distribution tends towards fault normal for $R < 5$ km and $T \geq 0.5$ s
  (This is not the same as saying α is *always* fault normal)

- The distribution is apparently uniform otherwise

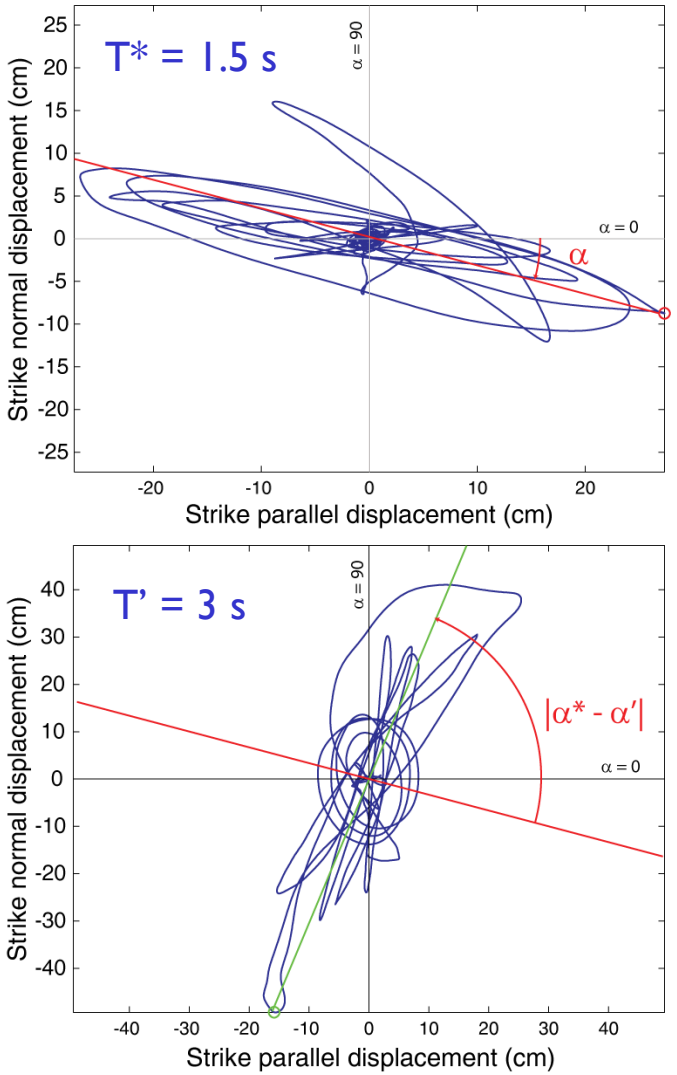
No obvious dependence on magnitude, directivity parameters, etc.

Other models for directionality

The direction of $Sa_{RotD100}(T)$ will vary with period

1. By how much will the azimuths of $Sa_{RotD100}(T^*)$ and $Sa_{RotD100}(T')$ vary?

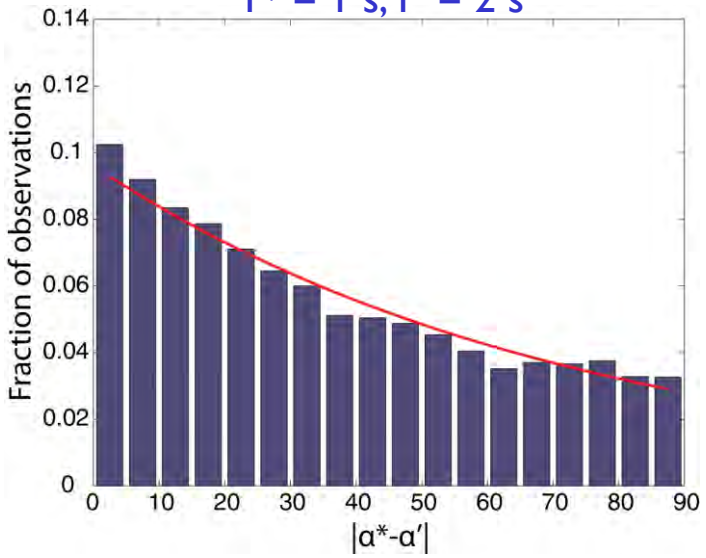
2. If we identify a target $Sa_{RotD100}$ at one period (T^*), what will the spectral value be at some other period (T')?



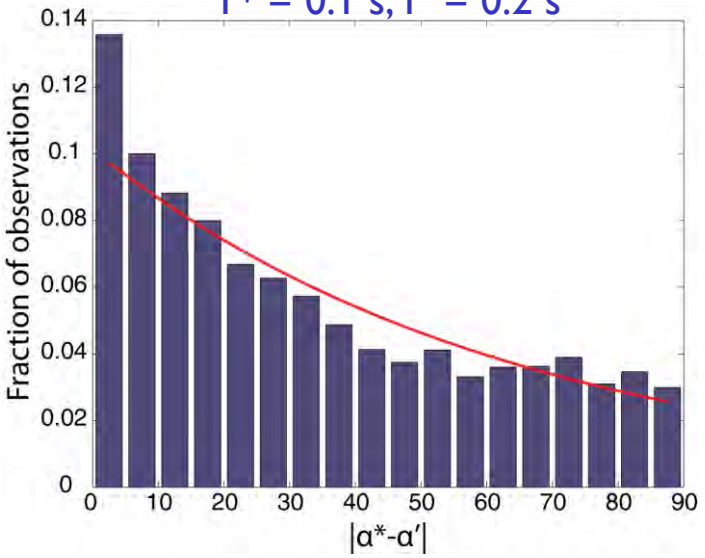
Oscillator responses to 1979 Imperial Valley-06, El Centro Differential Array recording

Distribution of α*-α' for various T* and T'

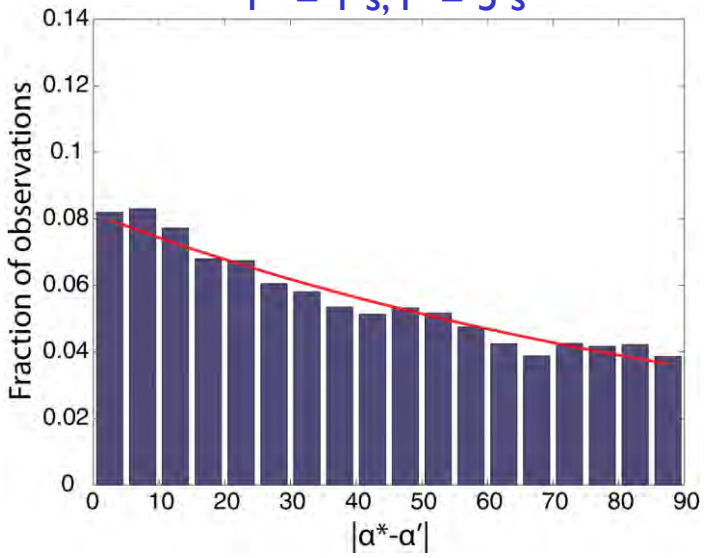
T* = 1 s, T' = 2 s



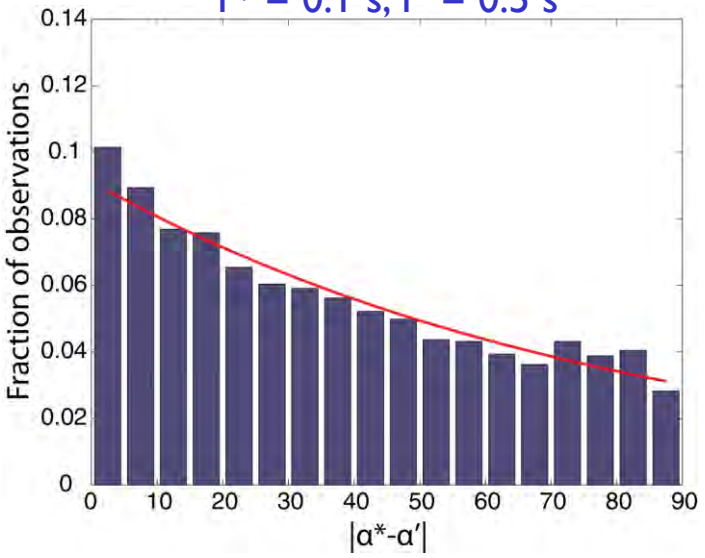
T* = 0.1 s, T' = 0.2 s



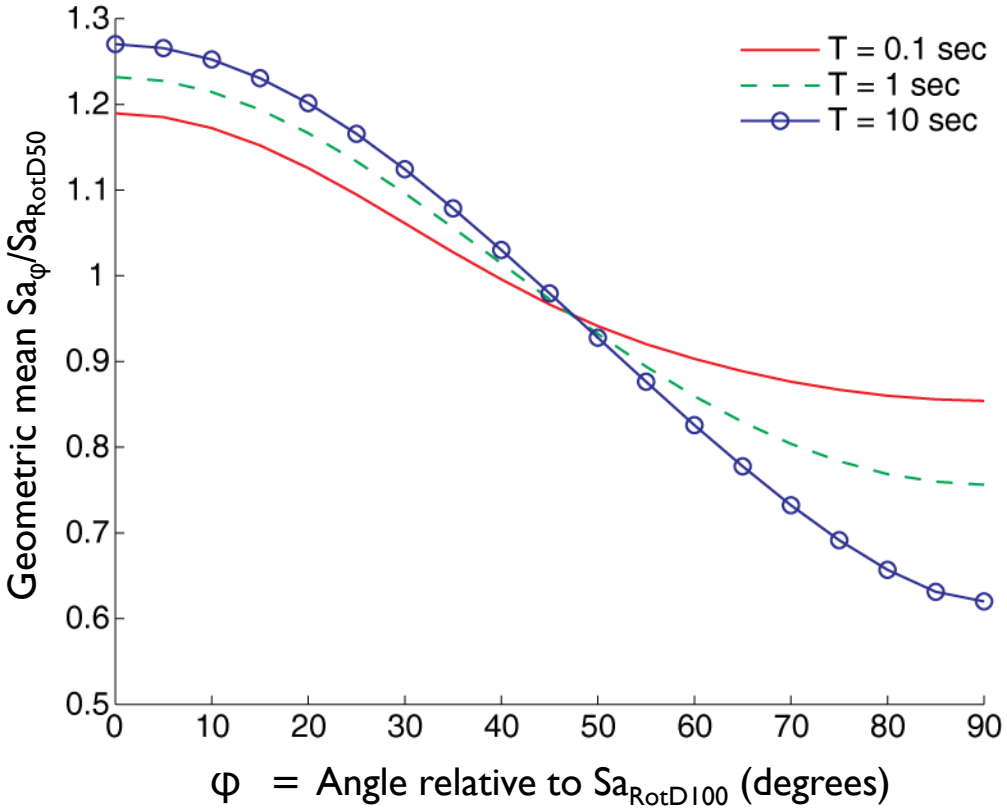
T* = 1 s, T' = 5 s



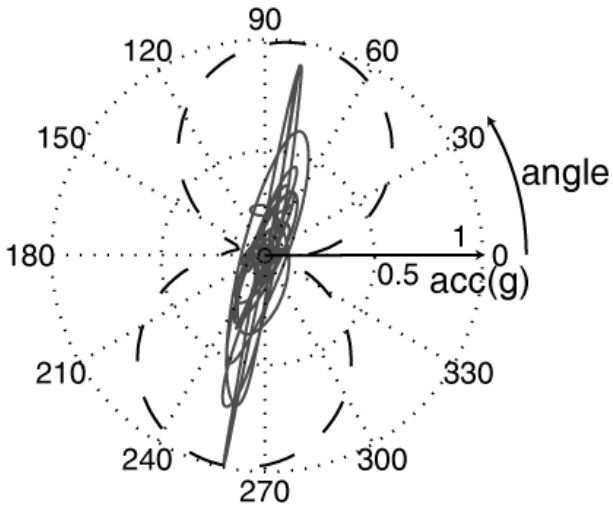
T* = 0.1 s, T' = 0.5 s



Median ratio of Sa_{φ}/Sa_{RotD50}, as a function of distance from $Sa_{RotD100}$ orientation

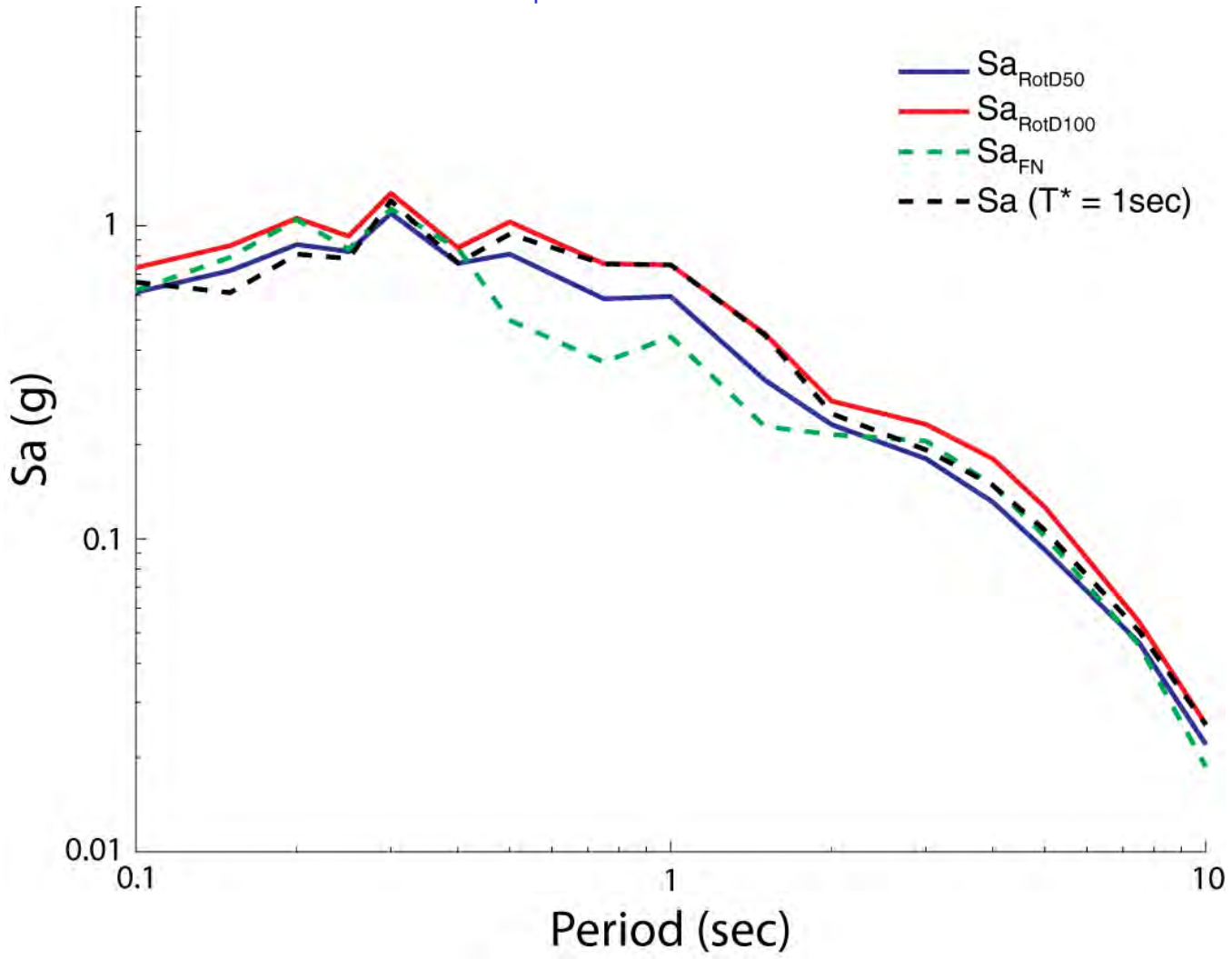


Example 1s response case:



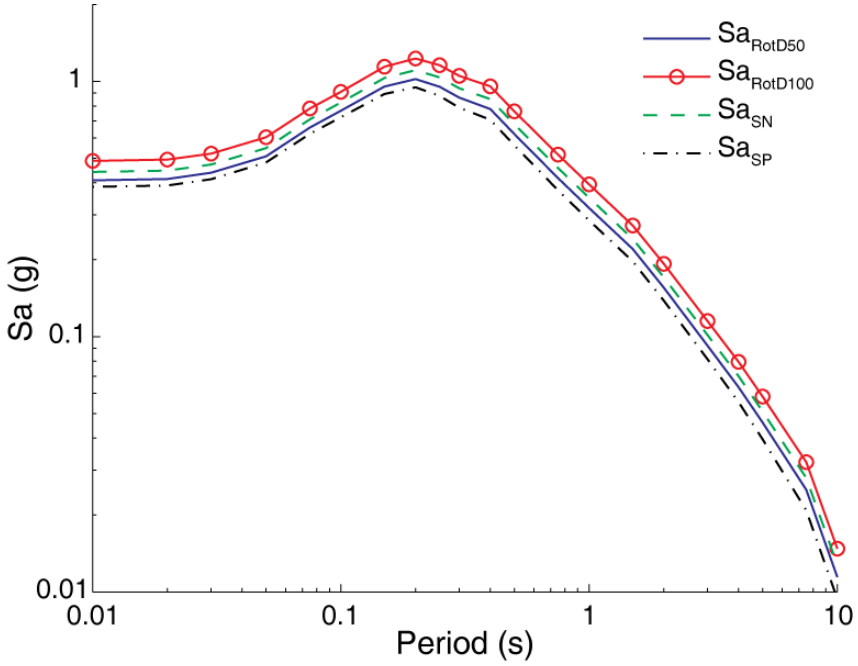
Individual ground motion example

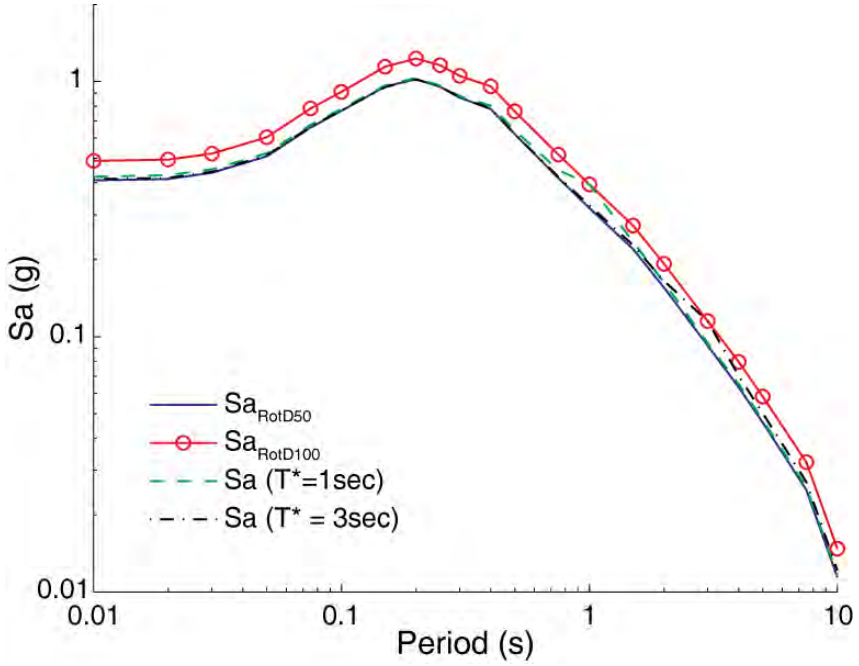
TCU076 station, 1999 Chi-Chi earthquake
R_{rup} = 3 km, M = 7.6



Example predictions using above results

$M = 7$, $R_{clst} = 2.5$ km, $V_{S30} = 760$ m/s

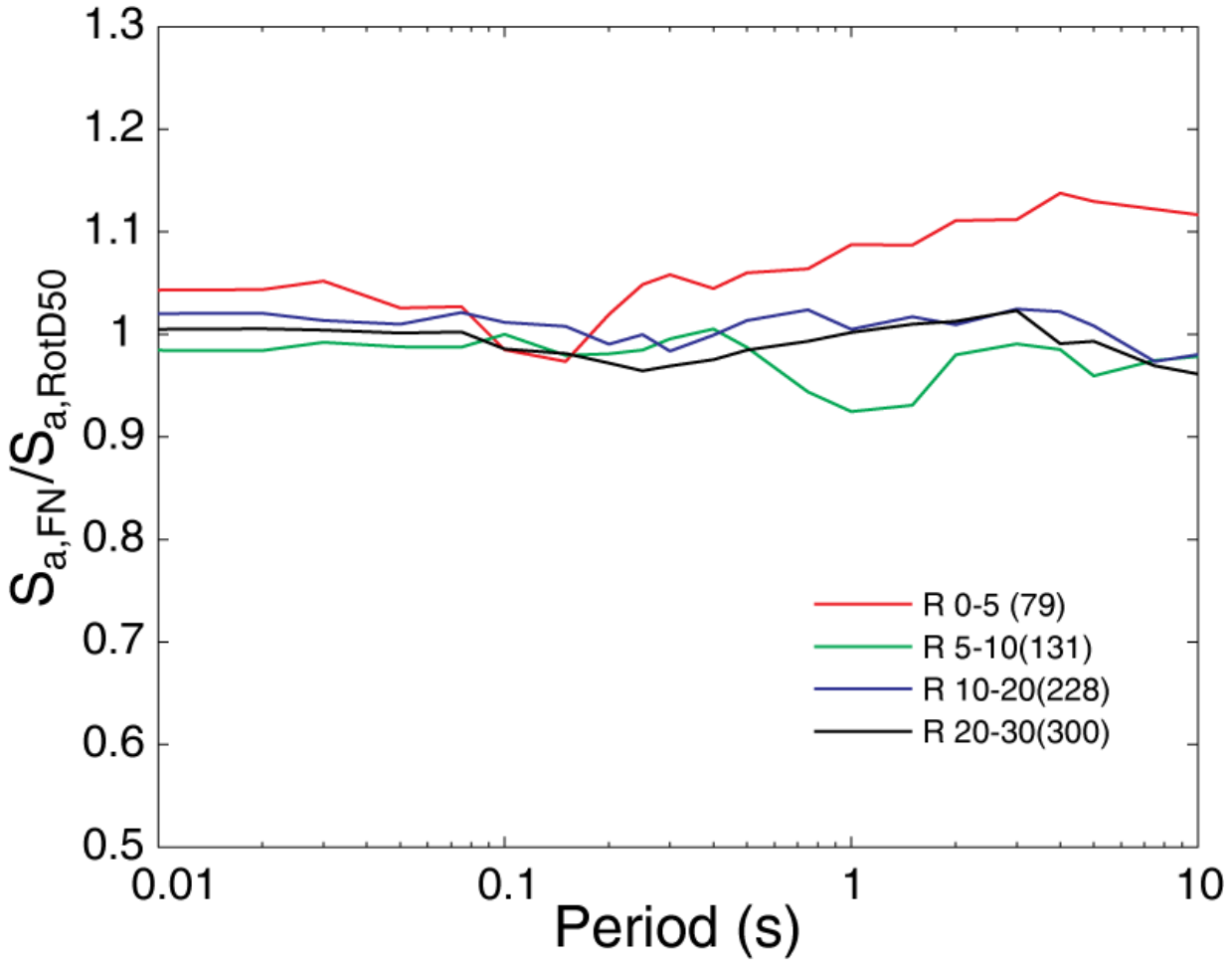




Thanks to the project technical review team:

- Brian Chiou
- Nicolas Luco
- Mahmoud Hachem
- Tom Shantz
- Paul Somerville
- Paul Spudich
- Jon Stewart
- Badie Rowshandel

Fault normal spectra versus Sa_{RotD50}



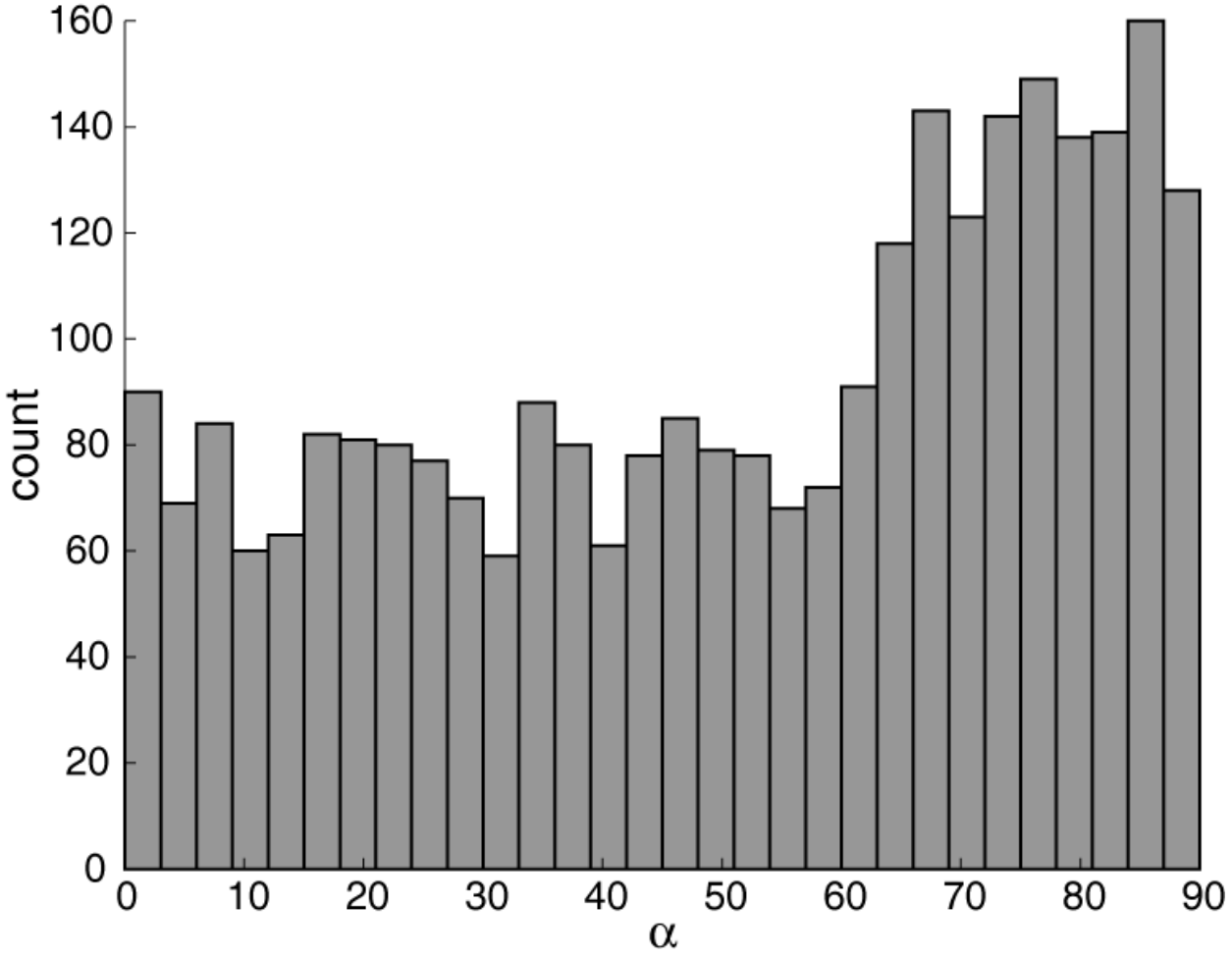
Is $Sa_{RotD100} = Sa_{FN}$ for directivity ground motions?

- Each ground motion in the NGA West 2 database classified as pulse or non-pulse
  - Improved pulse-classification algorithm (Shahi and Baker)
  - Documentation in progress

- Source-site geometry used to manually identify Pulse-like ground motions caused by directivity

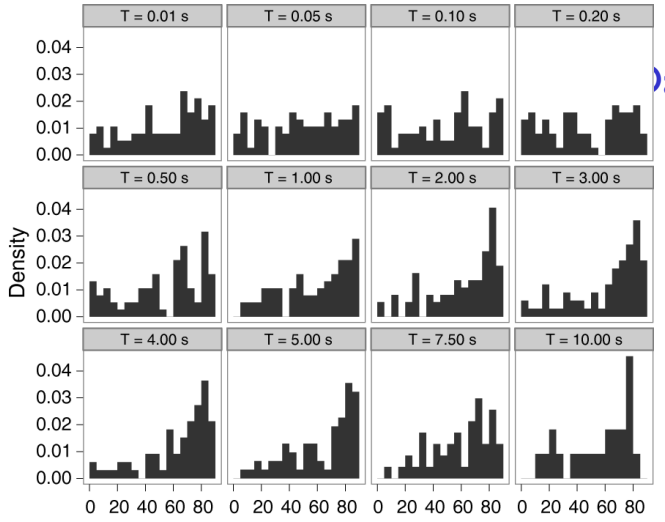
$Sa_{RotD100}$ orientation for directivity ground motions

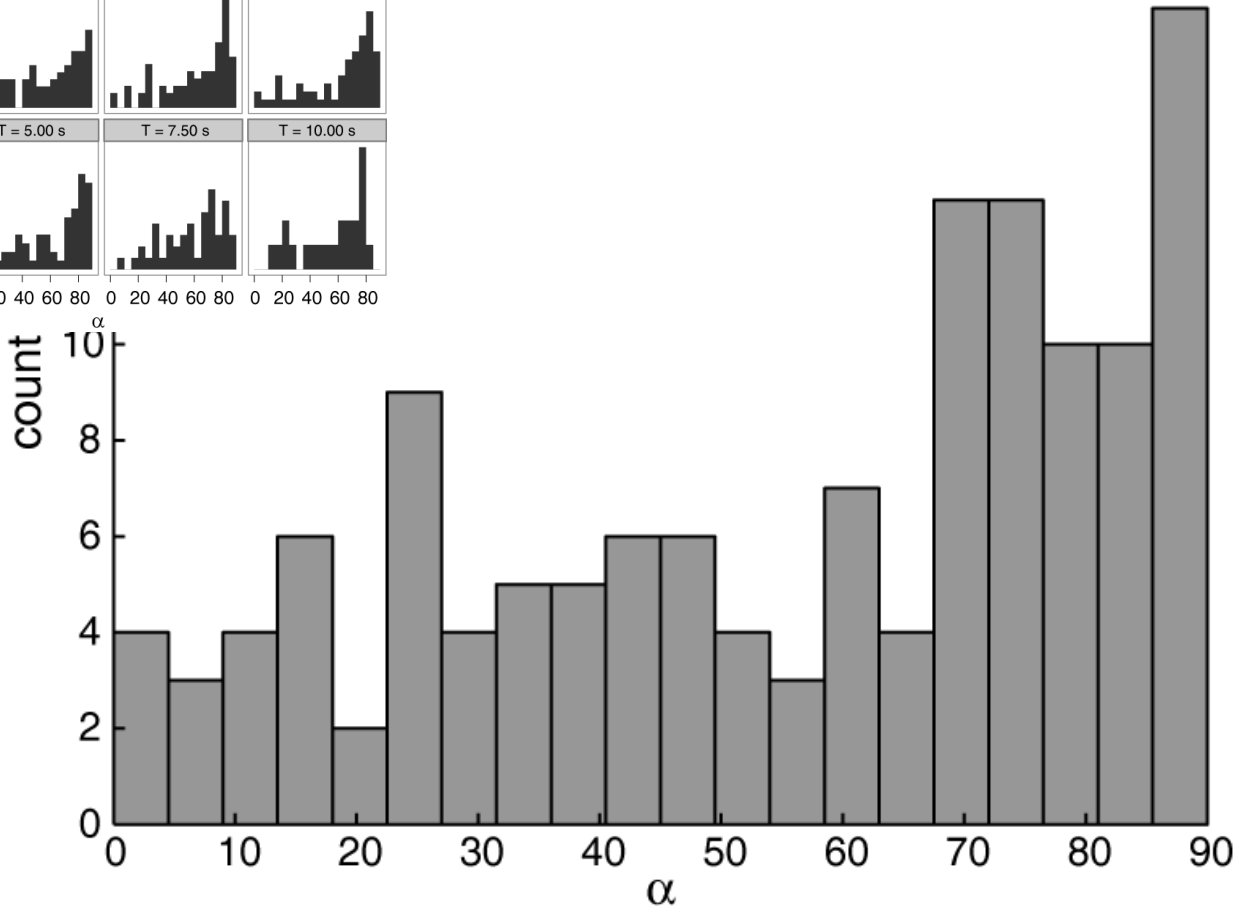
Data pooled from 21 periods



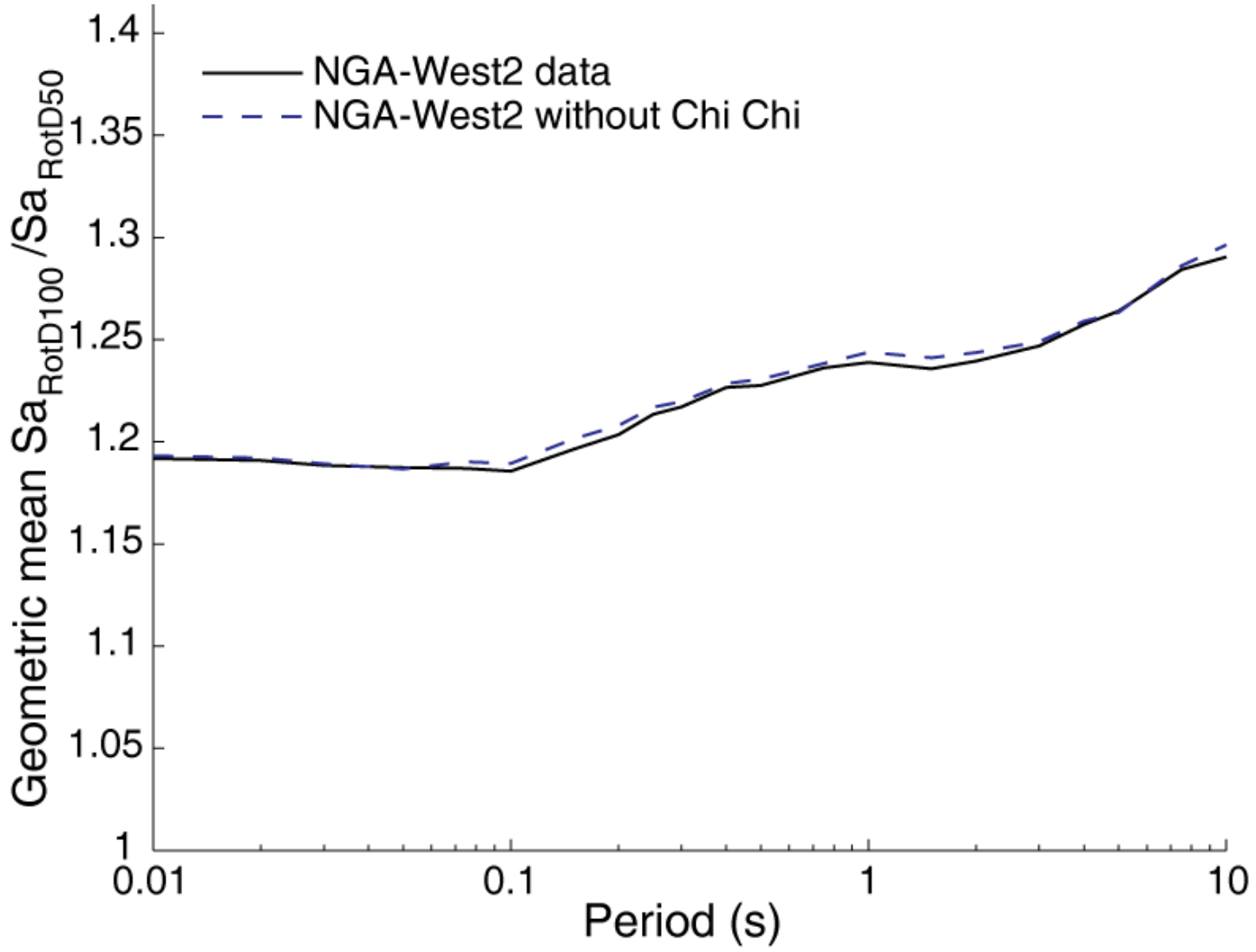
$Sa_{RotD100}$ orientation for directivity ground motions

Data for period closest to Tp

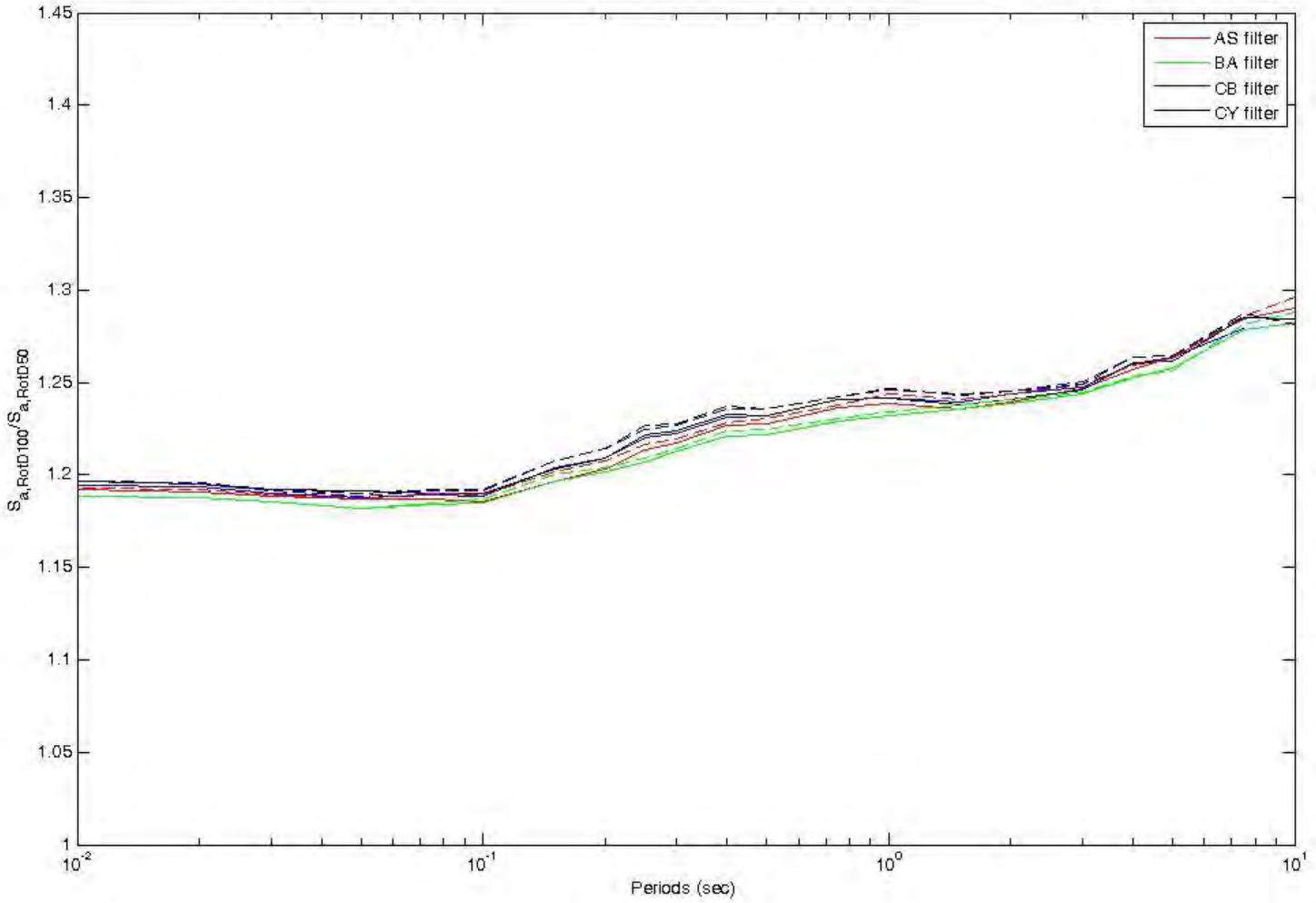




Effect of Chi-Chi

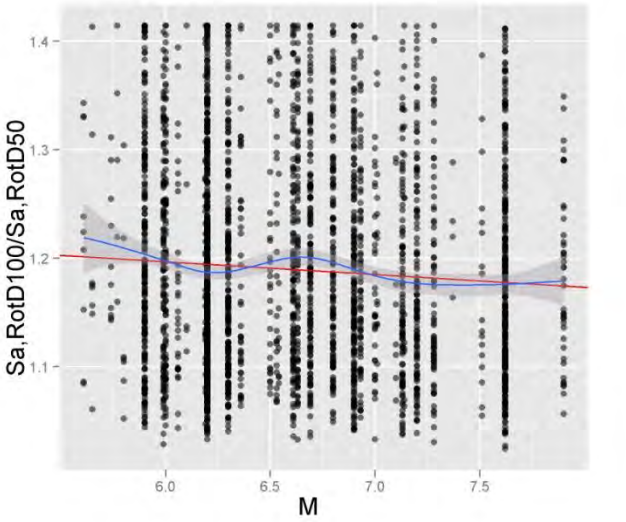


Effect of changing the dataset

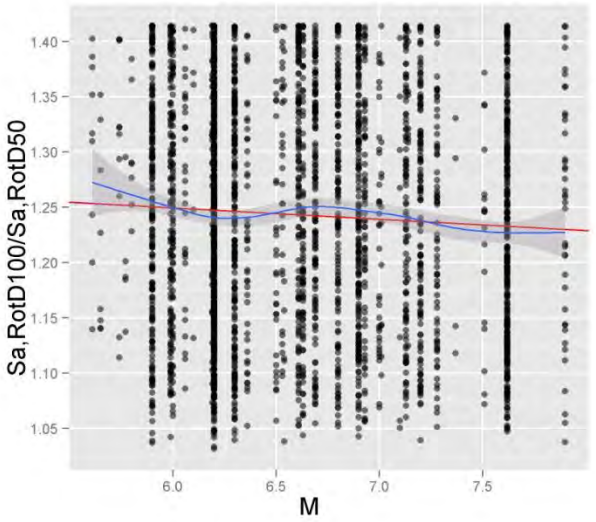


Any variation in this ratio with distance (M)?

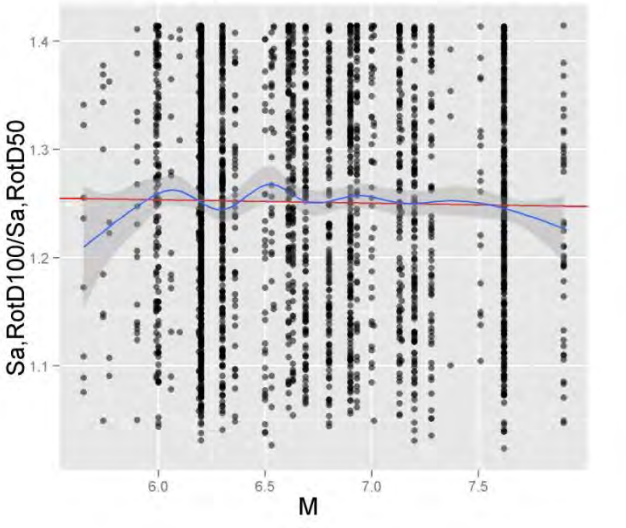
T = 0.1 s



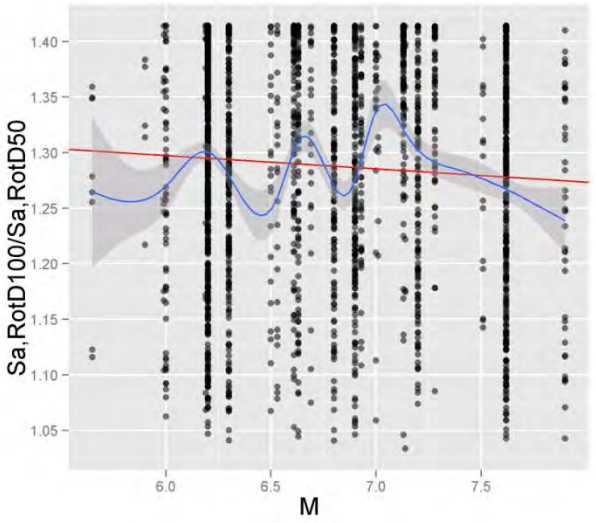
T = 1 s



T = 3 s

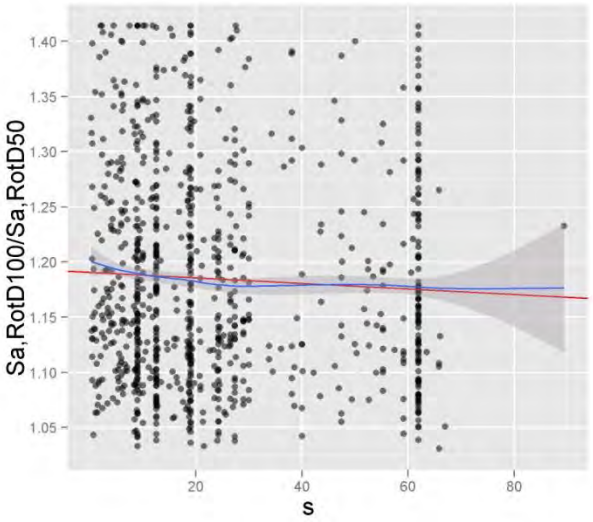


T = 7.5 s

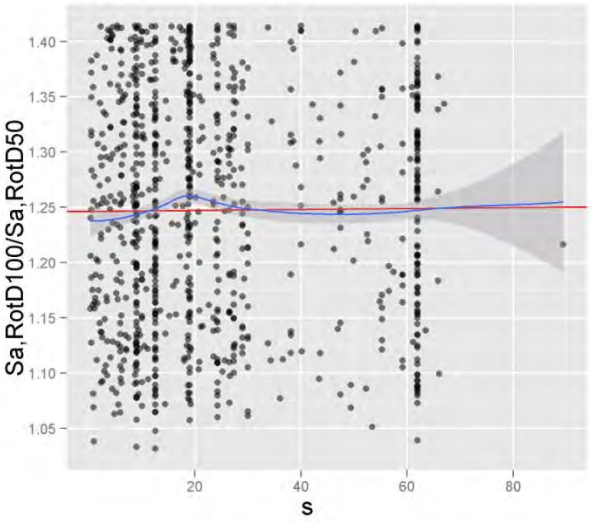


Any variation in this ratio with s? (Strike slip only)

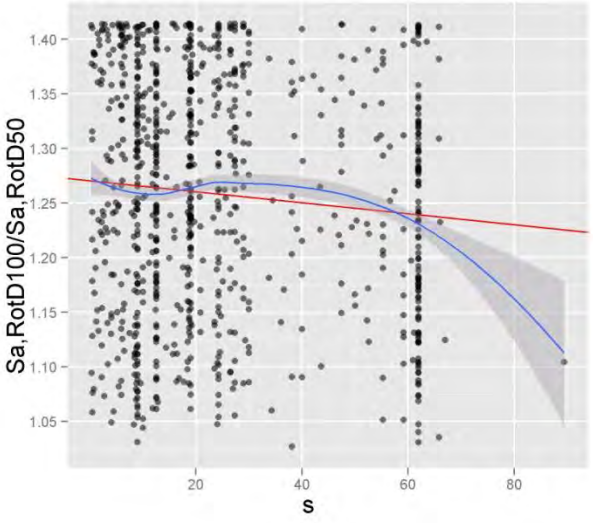
T = 0.1 s



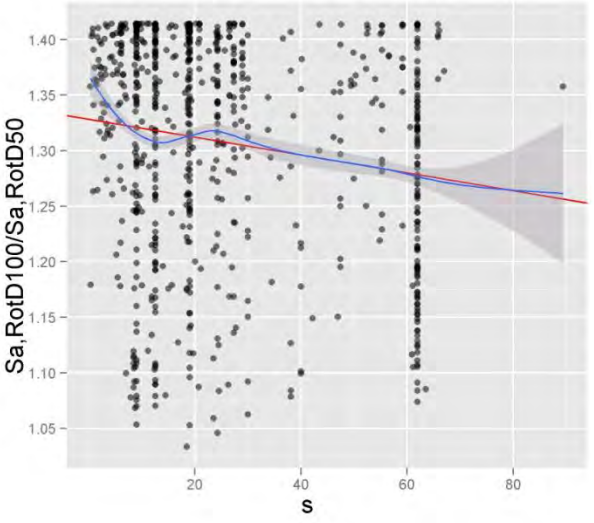
T = 1 s



T = 3 s

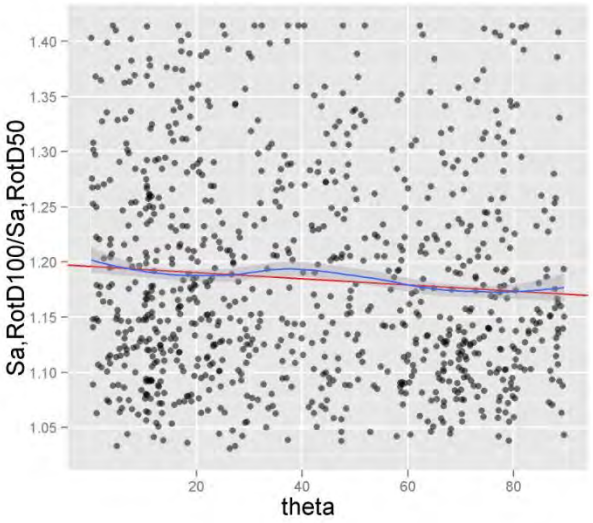


T = 7.5 s

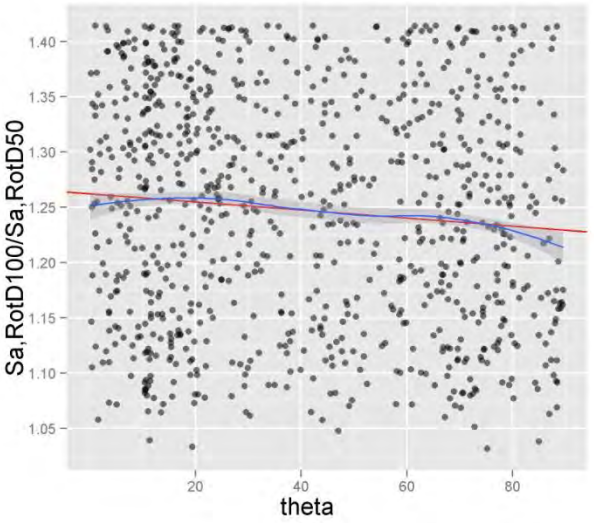


Any variation in this ratio with θ? (Strike slip only)

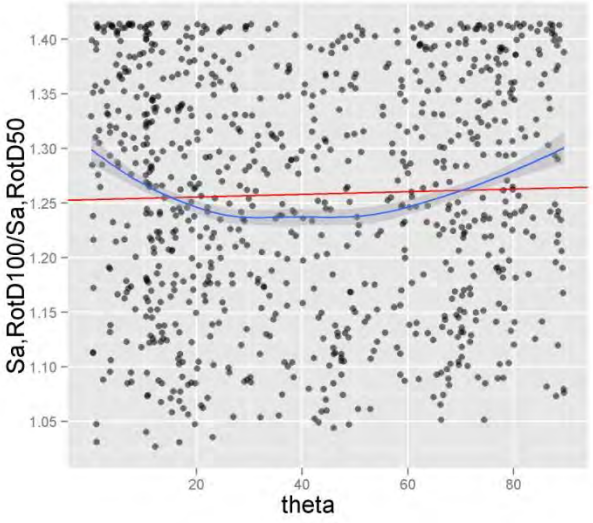
T = 0.1 s



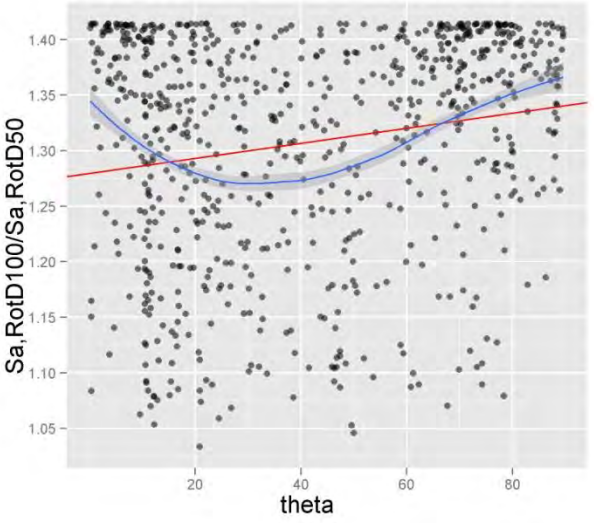
T = 1 s



T = 3 s

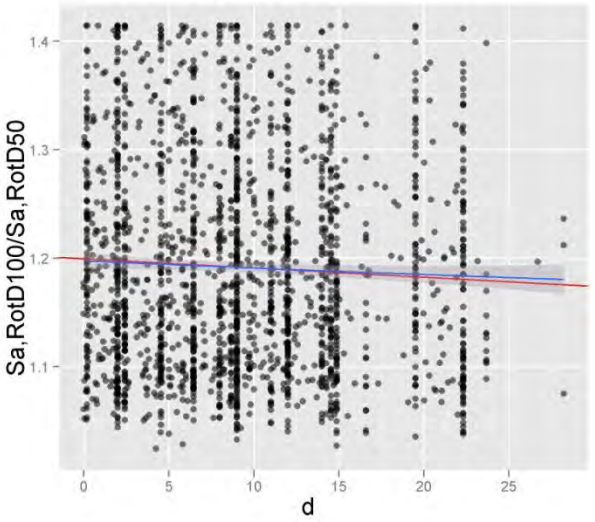


T = 7.5 s

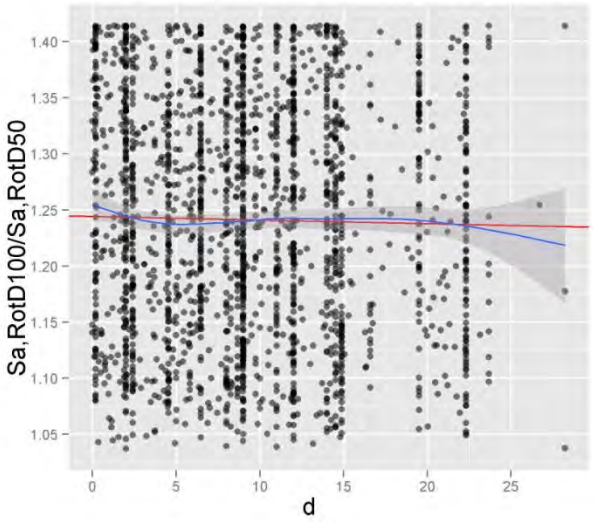


Any variation in this ratio with D? (Non-strike-slip only)

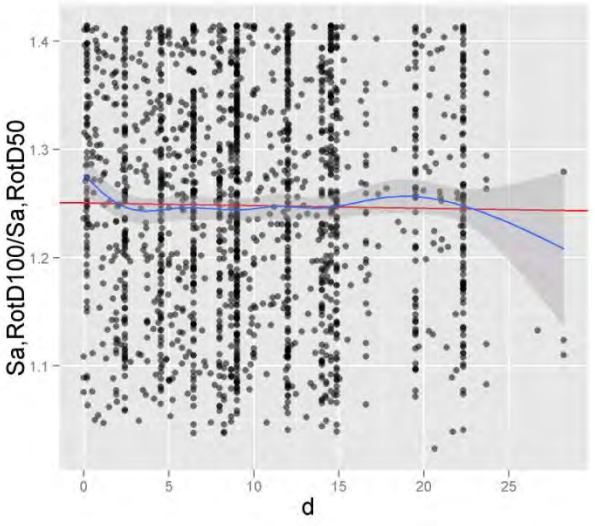
T = 0.1 s



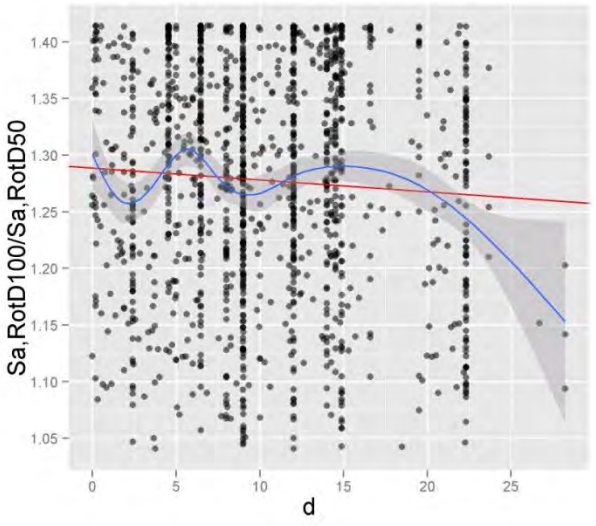
T = 1 s



T = 3 s



T = 7.5 s

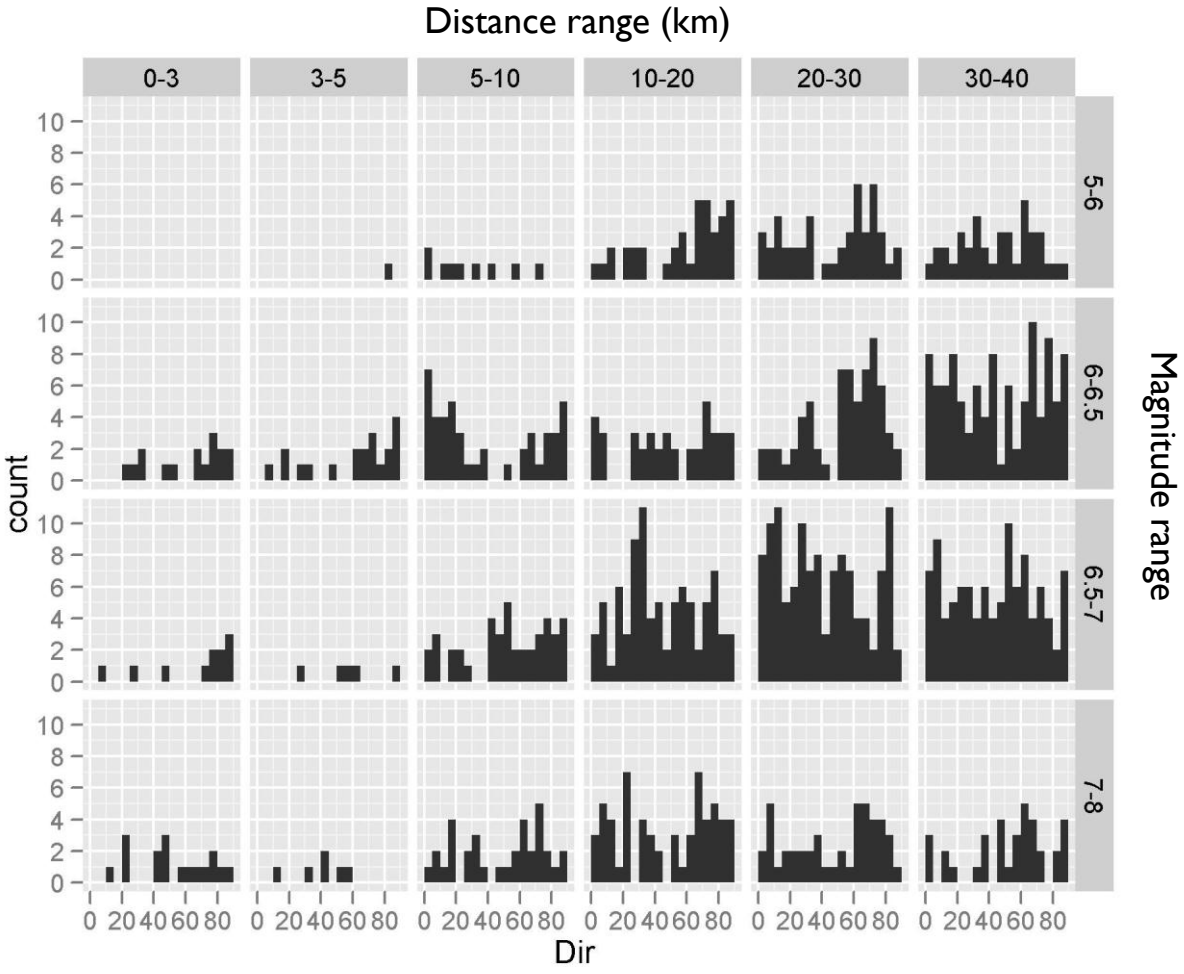


Regression analysis to evaluate significance of above parameters

- Both forward and backward step-wise regression was used to select statistically significant parameters
- Some dependence on M and R (depends upon period)
- Some dependence on directivity parameters at higher periods
- Our recommendation : a simple model dependent on R only

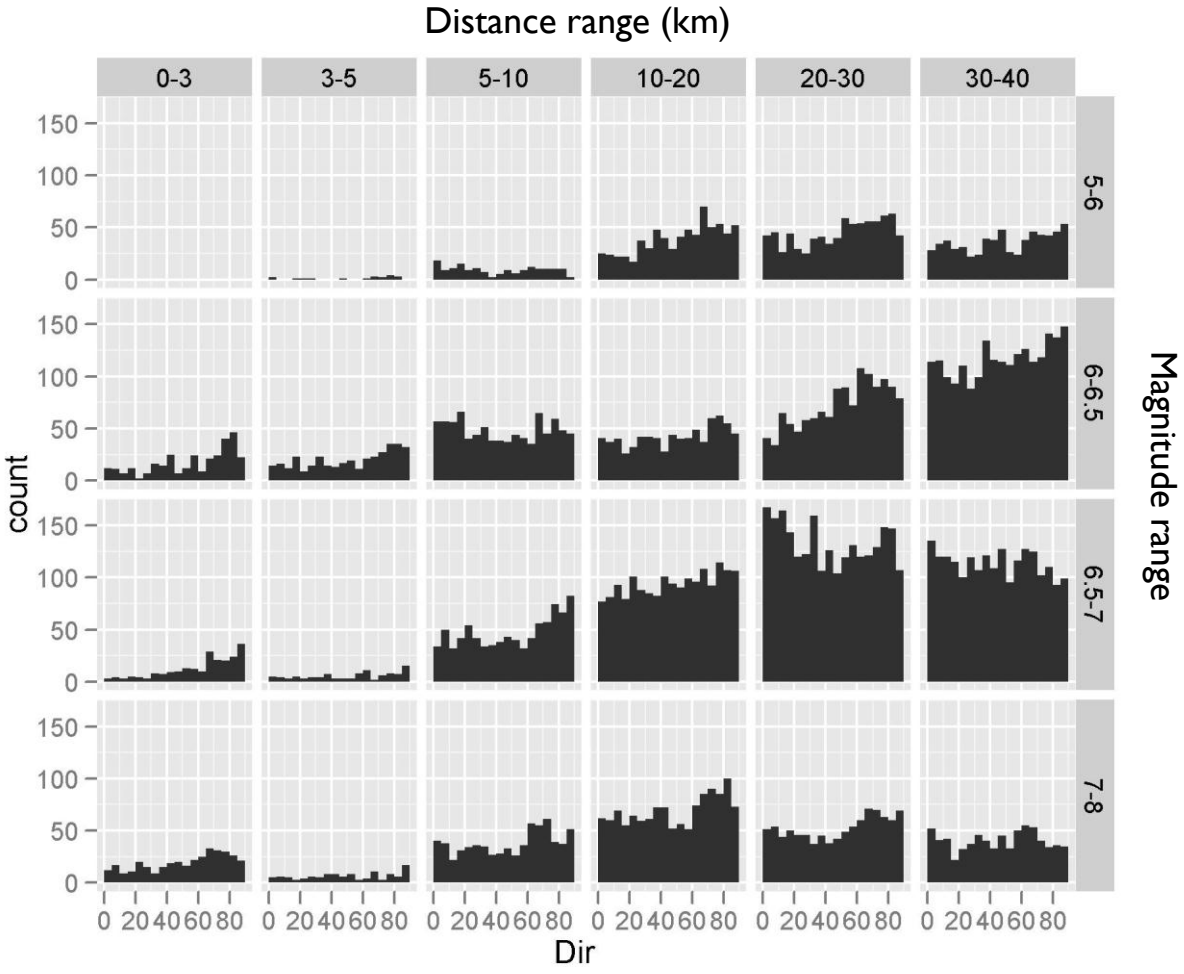
Distribution of α for different M-R bins

T = 1 s



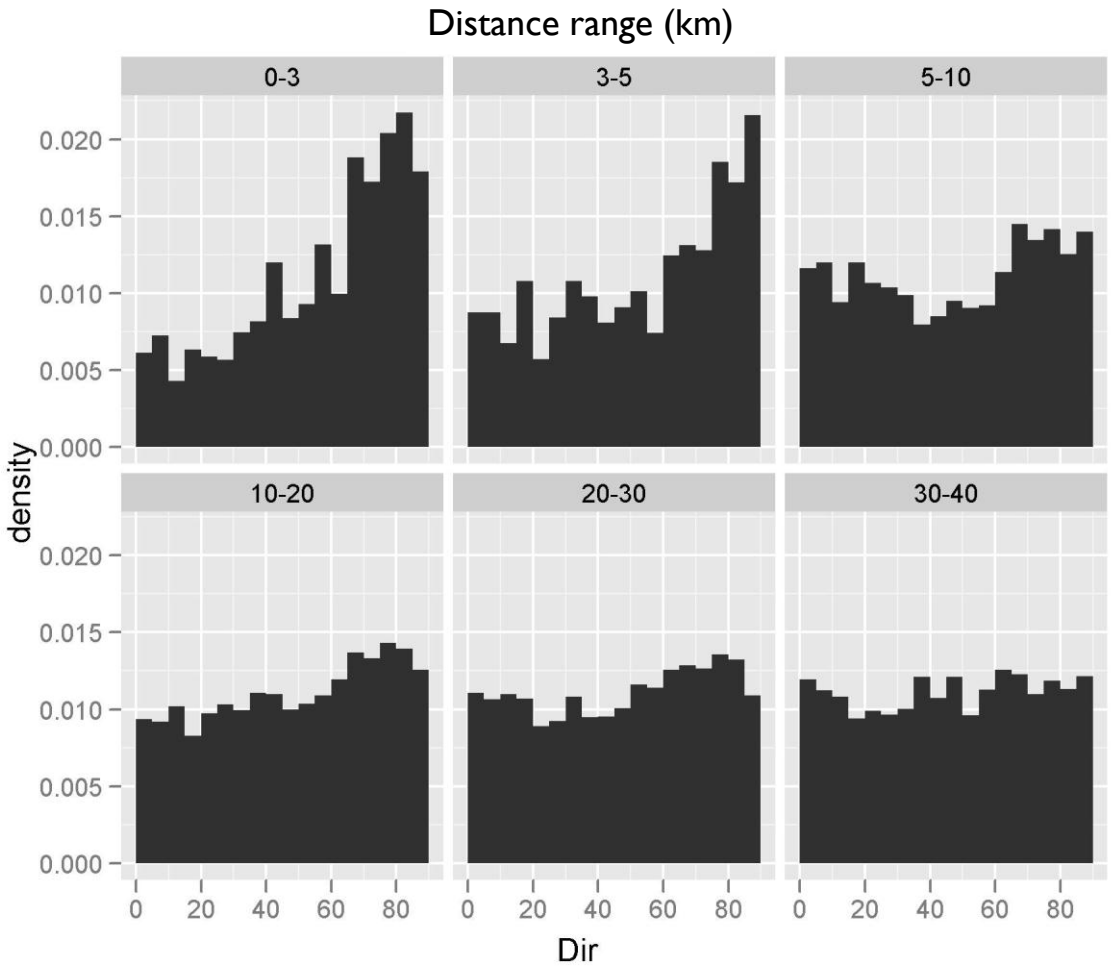
Distribution of α for different M-R bins

Data pooled from all periods



Distribution of α for different R bins

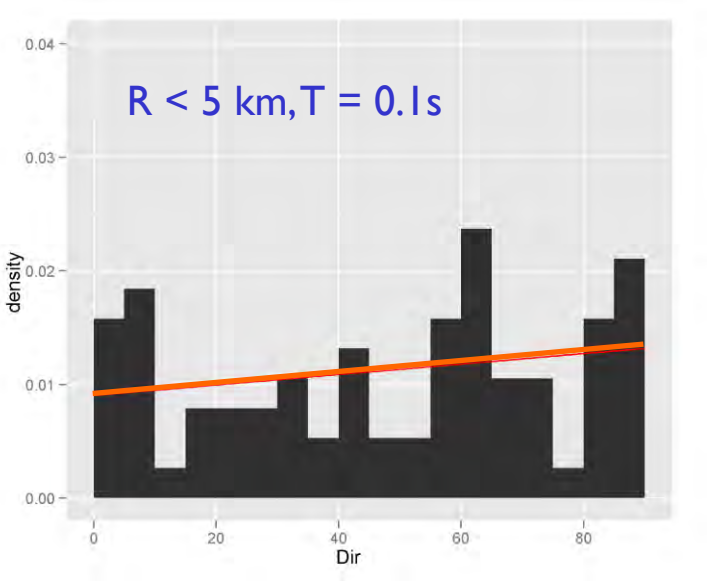
Data pooled from all periods

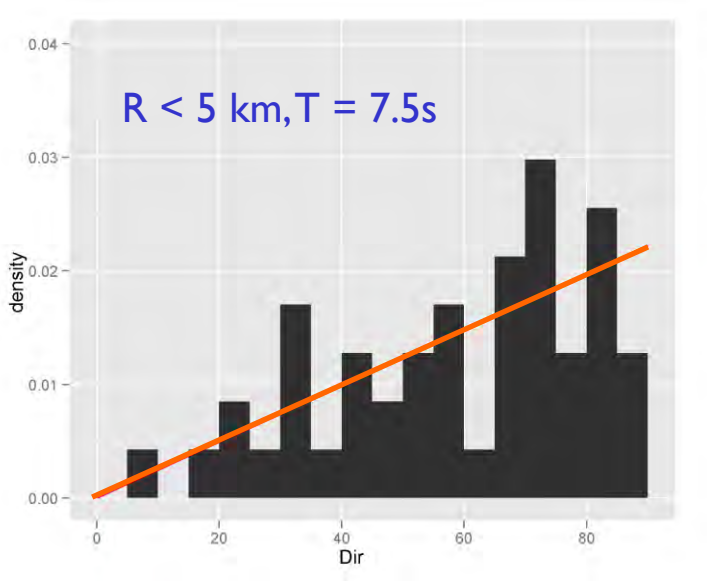


Models for α? Two options:

1. Parametric model for distribution of α (i.e., equation for a probability distribution)
   - Linearly-varying distribution of α for R < 5 km (function of T)
   - Uniform distribution for R > 5 km

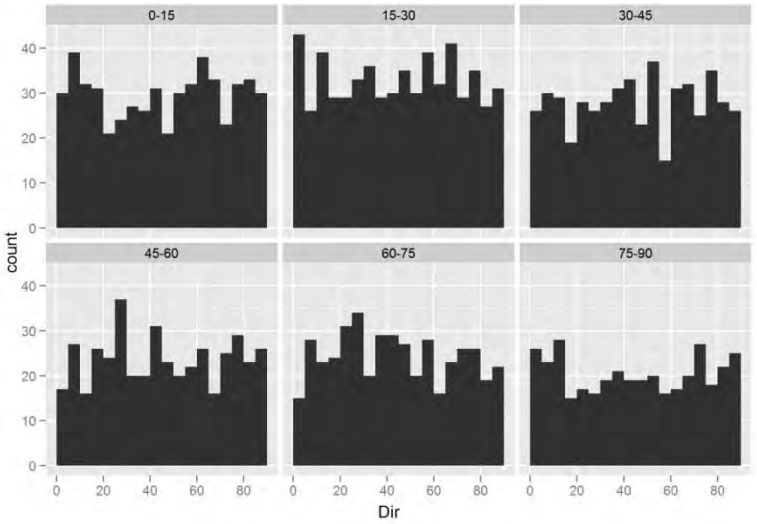
2. Just report histogram values at different T for R < 5 km
   - Simpler, but hard to do calculations with



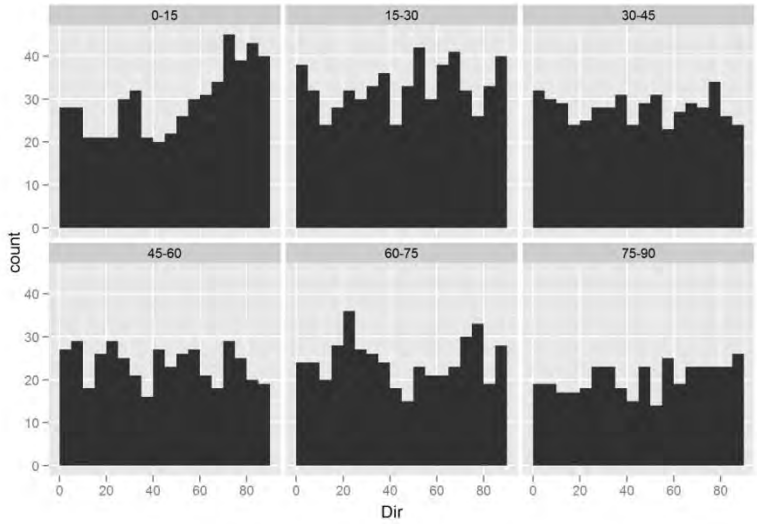


Direction of RotD100 with θ

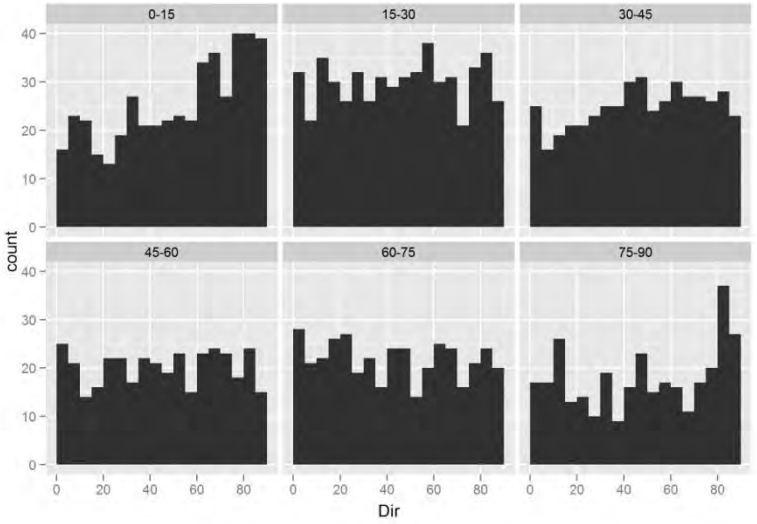
T = 0.1 s



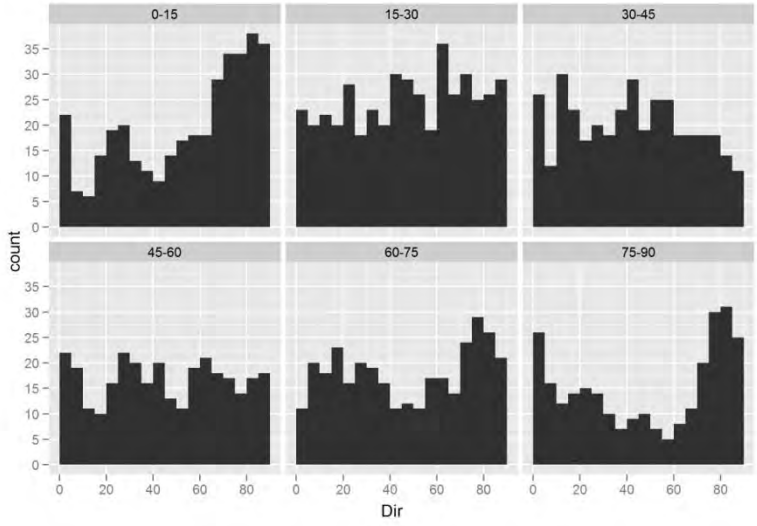
T = 1 s



T = 3 s

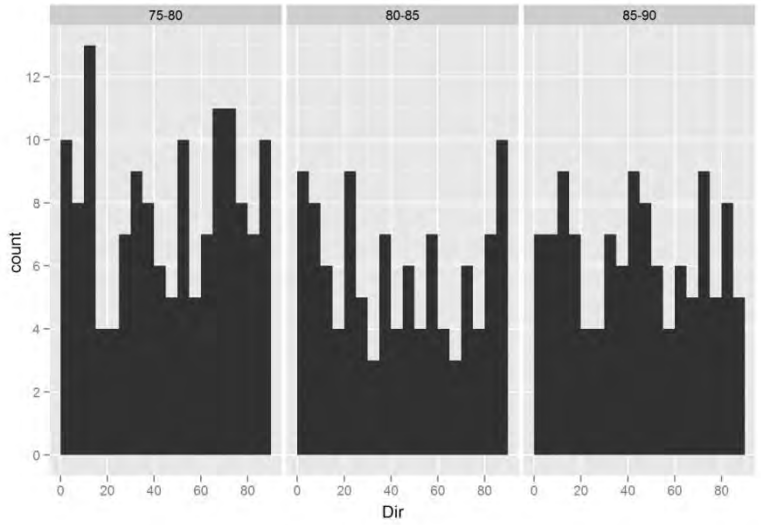


T = 7.5 s

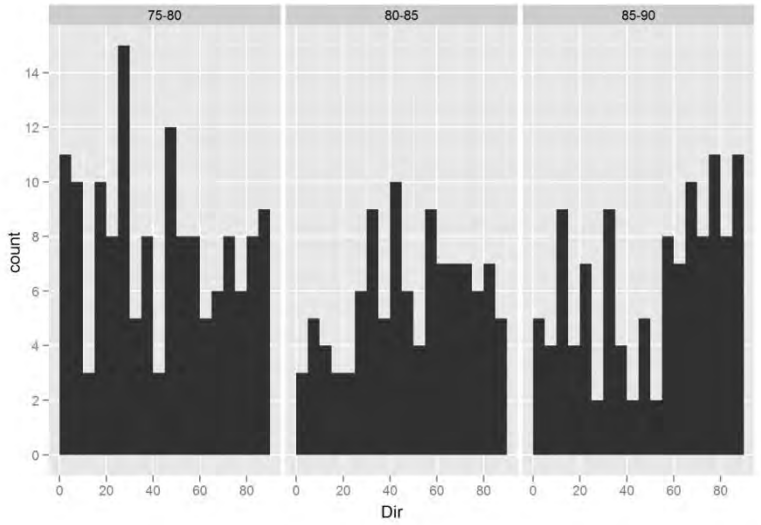


Zooming in towards high θ

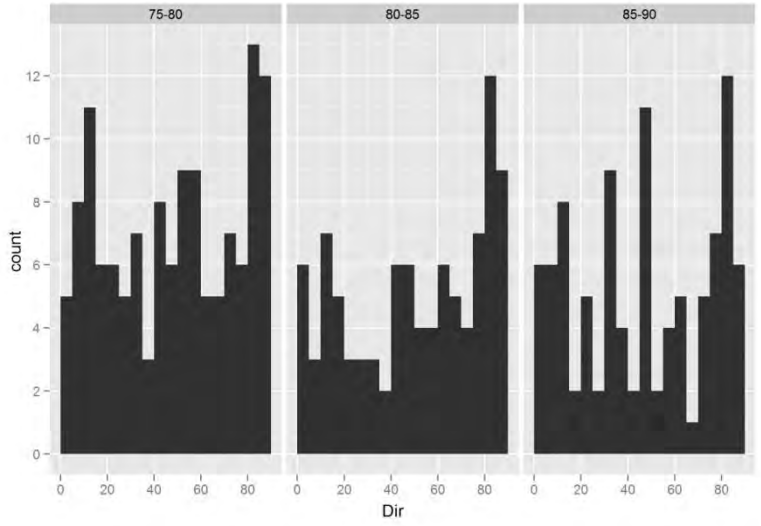
T = 0.1 s



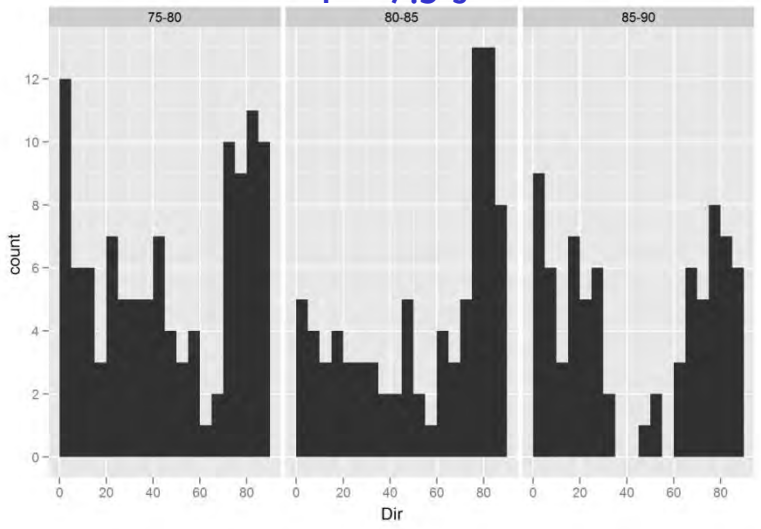
T = 1 s



T = 3 s

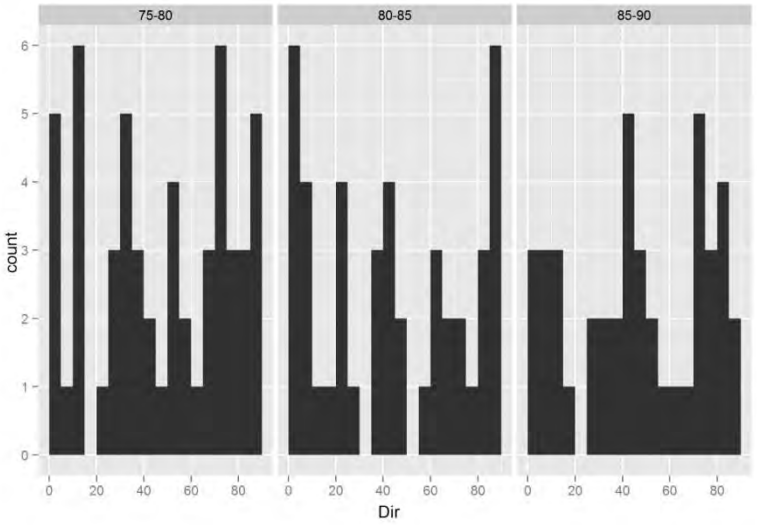


T = 7.5 s

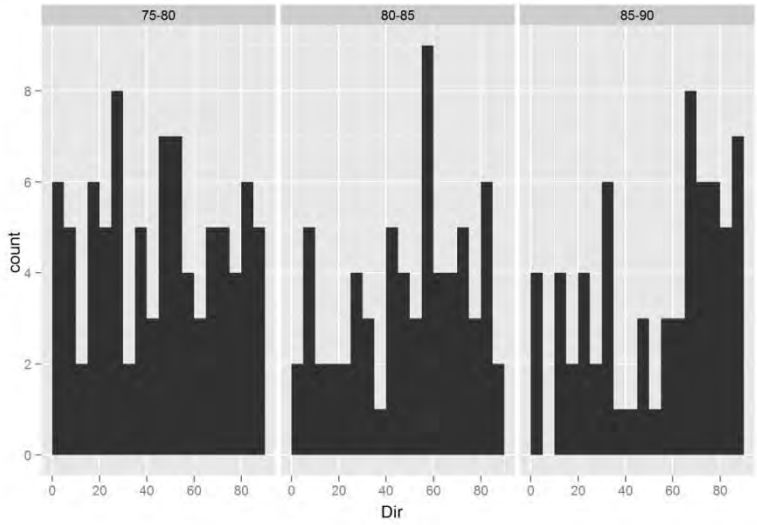


Only records with high amplification

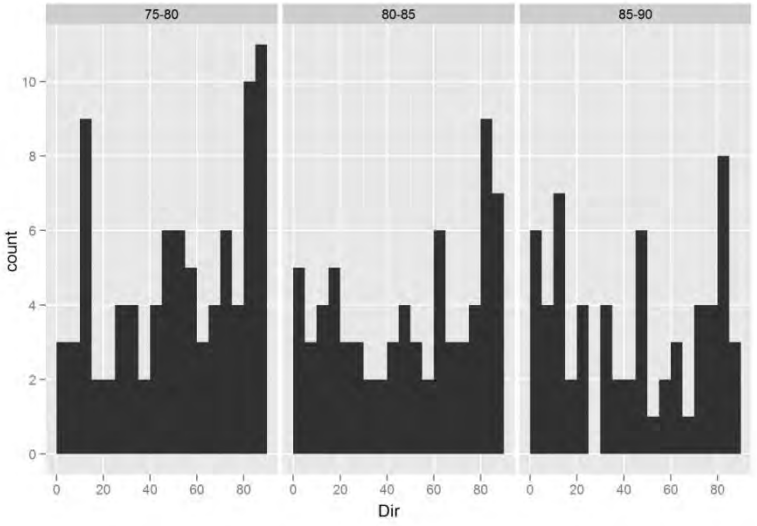
T = 0.1 s



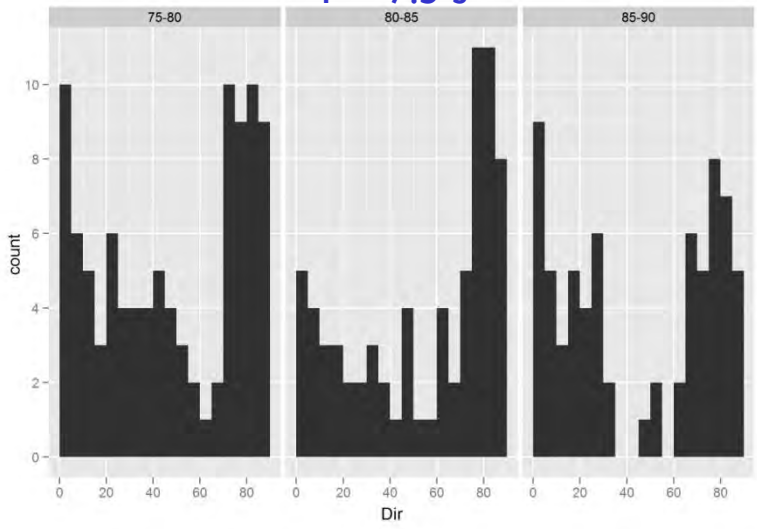
T = 1 s



T = 3 s



T = 7.5 s

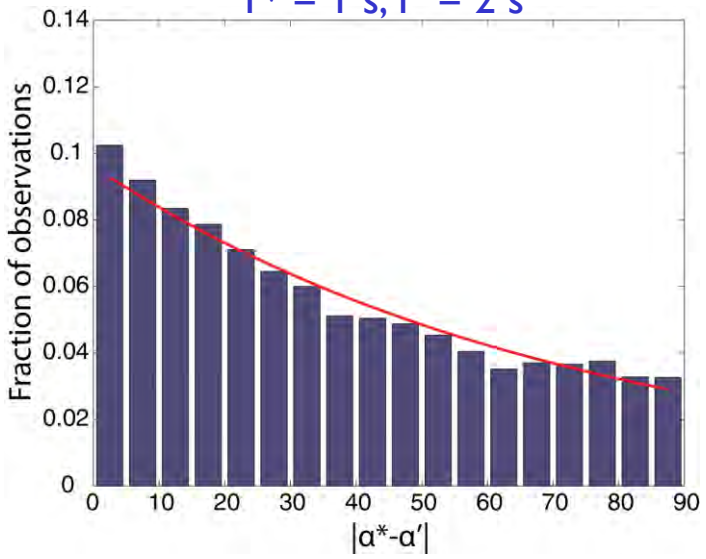


- When θ is high some $S_{a,RotD100}$ values are found in fault parallel orientation. This may be due to the radiation patterns

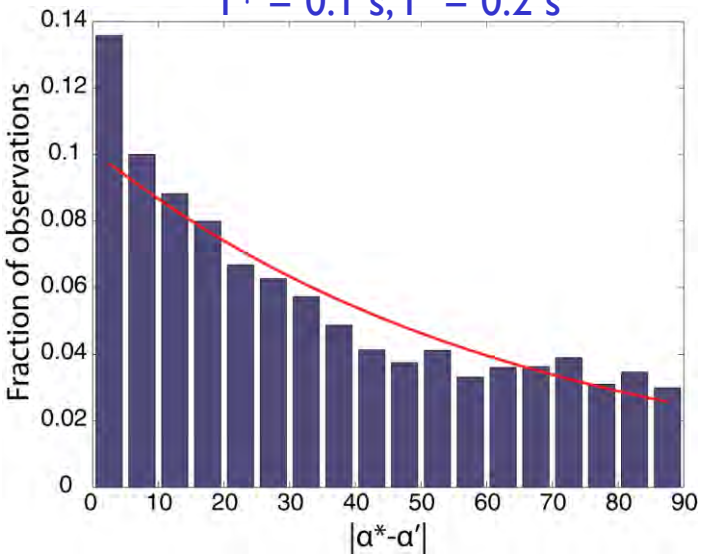
- Due to low sample size and presence of randomness we cant make confident conclusions.

Distribution of α*-α' for different T*,T'

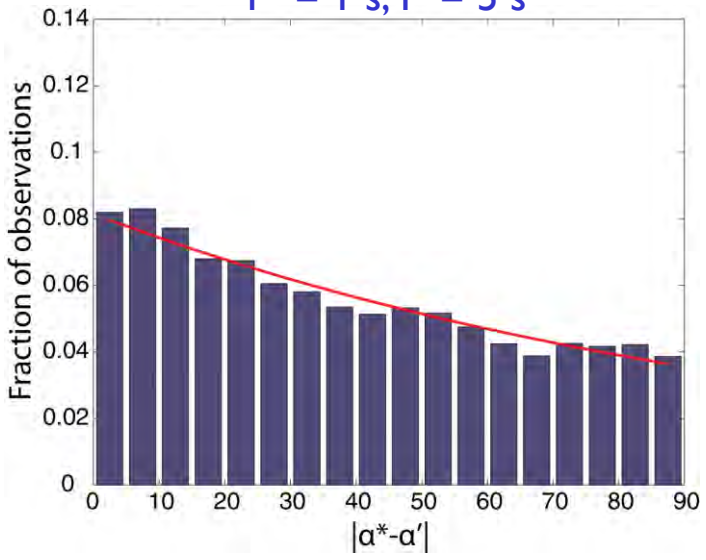
T* = 1 s, T' = 2 s



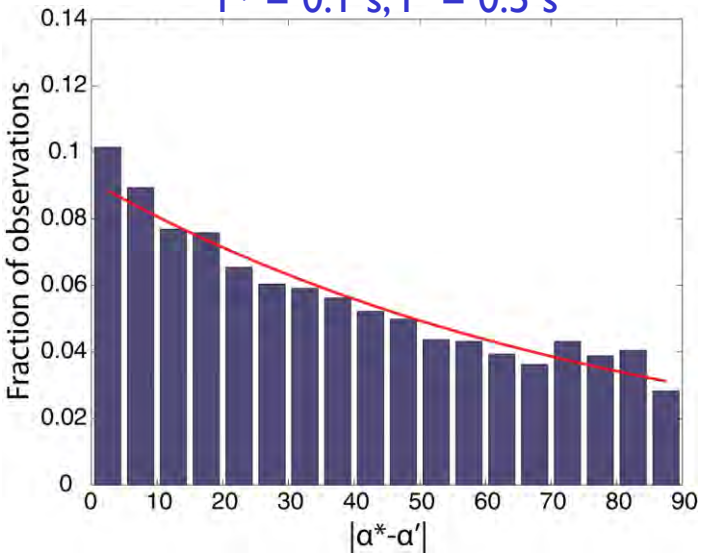
T* = 0.1 s, T' = 0.2 s



T* = 1 s, T' = 5 s



T* = 0.1 s, T' = 0.5 s



Median ratio of $Sa(\Phi)/Sa_{RotD50}$, as a function of distance from $Sa_{RotD100}$ orientation