New Near-Fault Adjustment Factors for Caltrans Seismic Design Criteria Considering Elastic and Inelastic Response Spectra

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Garrick Institute for the Risk Sciences
UCLA

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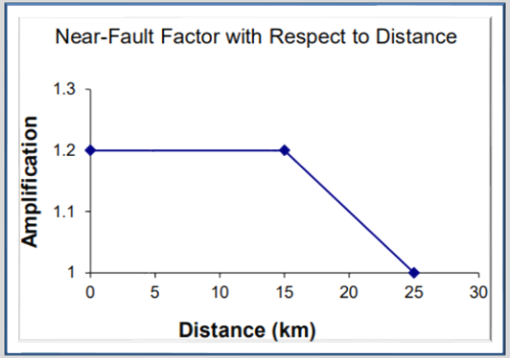
Acknowledgments

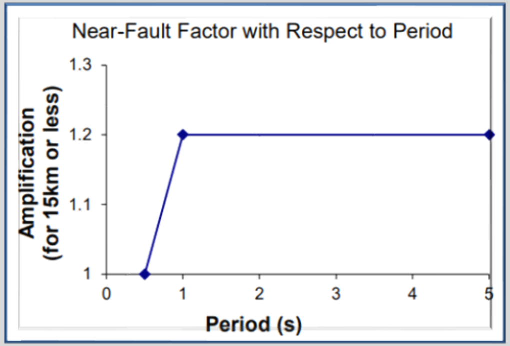
- Caltrans for supporting the research project
- Caltrans engineers for their ultimate cooperations
  - KT
  - Tom Shantz
  - Sharon Yen

Project Scope & Presentation Outline

State of the practice

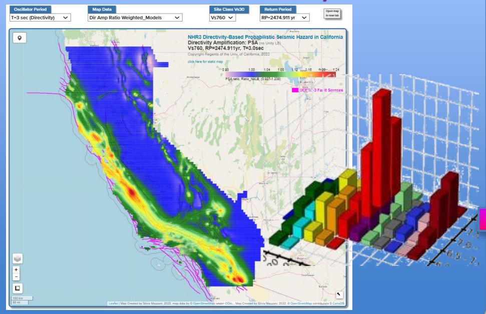
Caltrans Near-Fault Factor



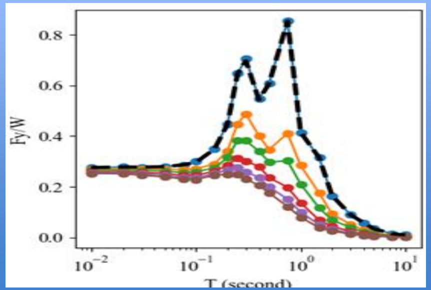


Past-Project Data

NHR3 California Statewide PSHA with Directivity

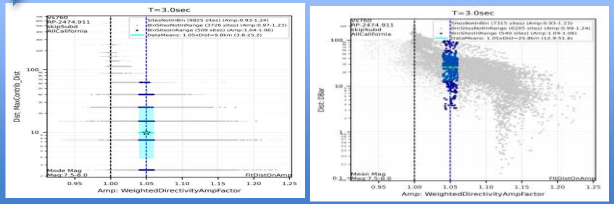


NHR3 Inelastic Response Spectra Database & Models

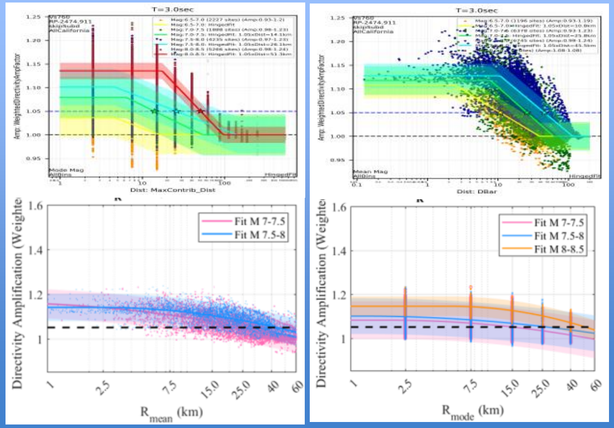


Findings

Threshold Distance



Directivity-Amplification Models



...more...

0. Current Caltrans Near-Fault Factor -- 2019

APPENDIX B
DESIGN SPECTRUM DEVELOPMENT

Near-Fault Factor

Sites located near a rupturing fault may experience elevated levels of shaking at periods longer than 0.5 second due to phenomena such as constructive wave interference, radiation pattern effects, and static fault offset (fling). As a practical matter, these phenomena are commonly combined into a single "near-fault" adjustment factor. This adjustment factor, shown in Figure B.1, is fully applied at locations with a site to rupture plane distance (R_{Rup}) of 15 km (9.4 miles) or less and linearly tapered to zero adjustment at 25 km (15.6 miles). The adjustment consists of a 20% increase in spectral values with corresponding period longer than one second. This increase is linearly tapered to zero at a period of 0.5 second.

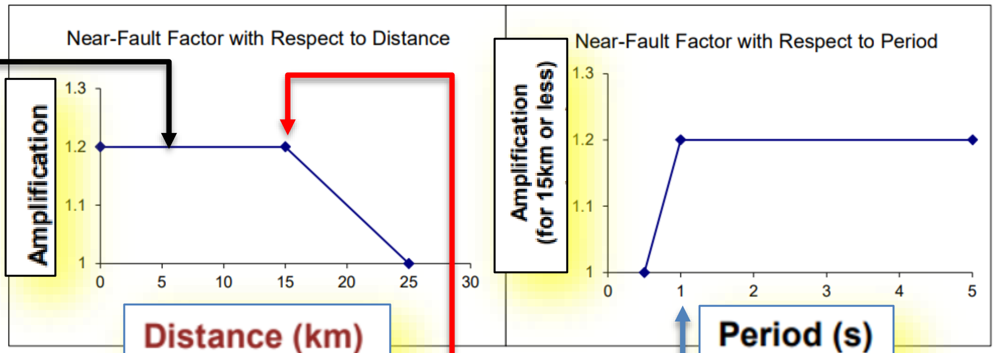


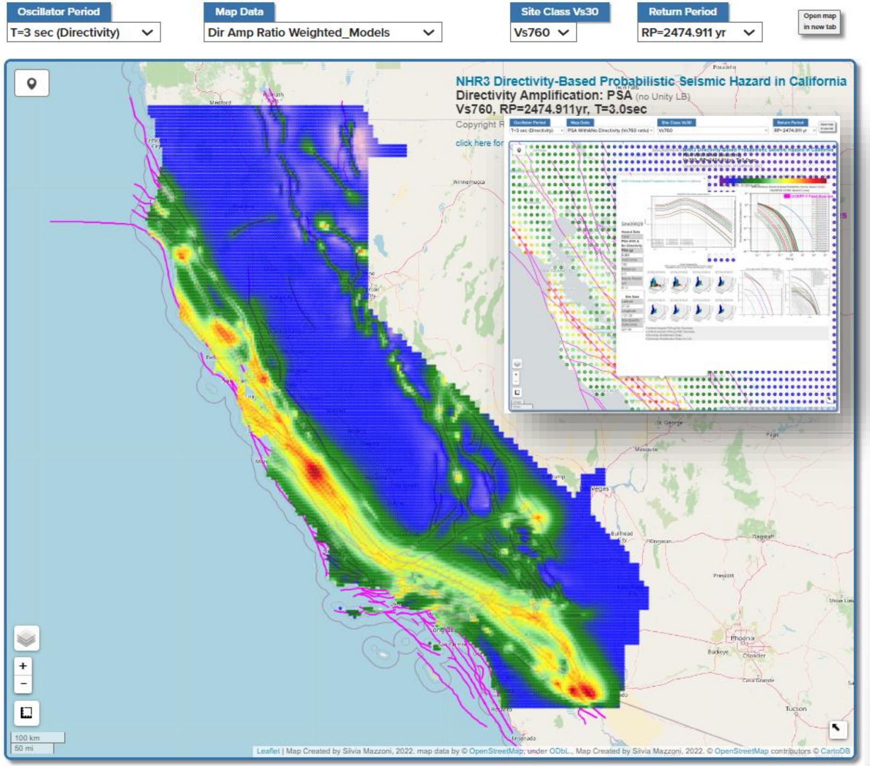
Figure B.1 Near-Fault adjustment factor as a function of distance and spectral period. The distance measure is based on the closest distance to any point on the fault plane

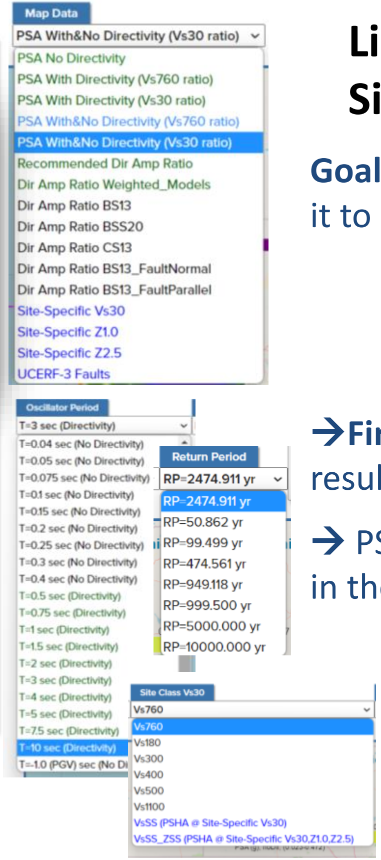
1. Maximum Distance
2. Maximum Amplification Factor
3. Minimum Elastic Period

PAST RESEARCH PROJECTS

1. NHR3 PSHA with Directivity Project & Products: 2023

www.risksciences.ucla.edu/nhr3/california-directivity





Linda Al Atik, Nick Gregor, Silvia Mazzoni, Yousef Bozorgnia

Goal: merge three pieces together and take it to PHSA for the State of CA:

- Directivity models
- NGA models
- UCERF3

→**First** to develop directivity-based PSHA results and maps for the State of CA

→ PSHA was carried out at over 19,000 sites in the State

1. PSA without directivity
2. PSA with Directivity
3. Directivity Amplification Factor

CS13: Chiou and Spudich (2013) (2022)
BS13: Bayless and Somerville (2013)
BSS20: Bayless et al. (2020)

2. NHR3 Inelastic-Response Spectra Project: Database & Models

Silvia Mazzoni, Mahdi Bahrampouri, Yousef Bozorgnia

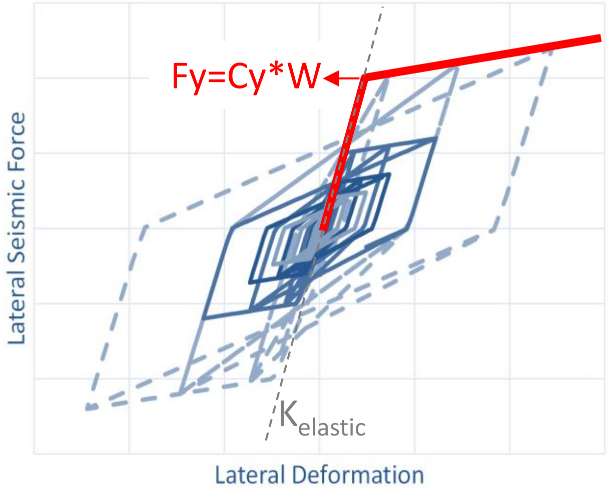
1. Compute **Inelastic** Response Spectra for NGA-West2 database (Bozorgnia, et al, 2014) for strength reduction factors R_mu= 1, 1.5, 2, 2.5, 3, 3.5, 4.
   Silvia Mazzoni

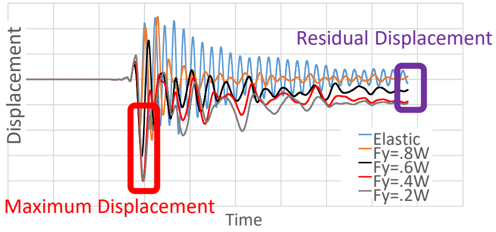
   NSF NHERI DESIGNSAFE

   1,225,230,300 OpenSees 2D-Model Analyses

2. Develop a **ground motion models** for median and uncertainty for **inelastic spectra**:
   Mahdi Bahrampouri
   - Displacement ratio (max inelastic displ / Sd_elastic)
   - Constant-Ductility Inelastic Response Spectrum
   - Adjustment of NGA-West2 elastic PSA model to get inelastic response model

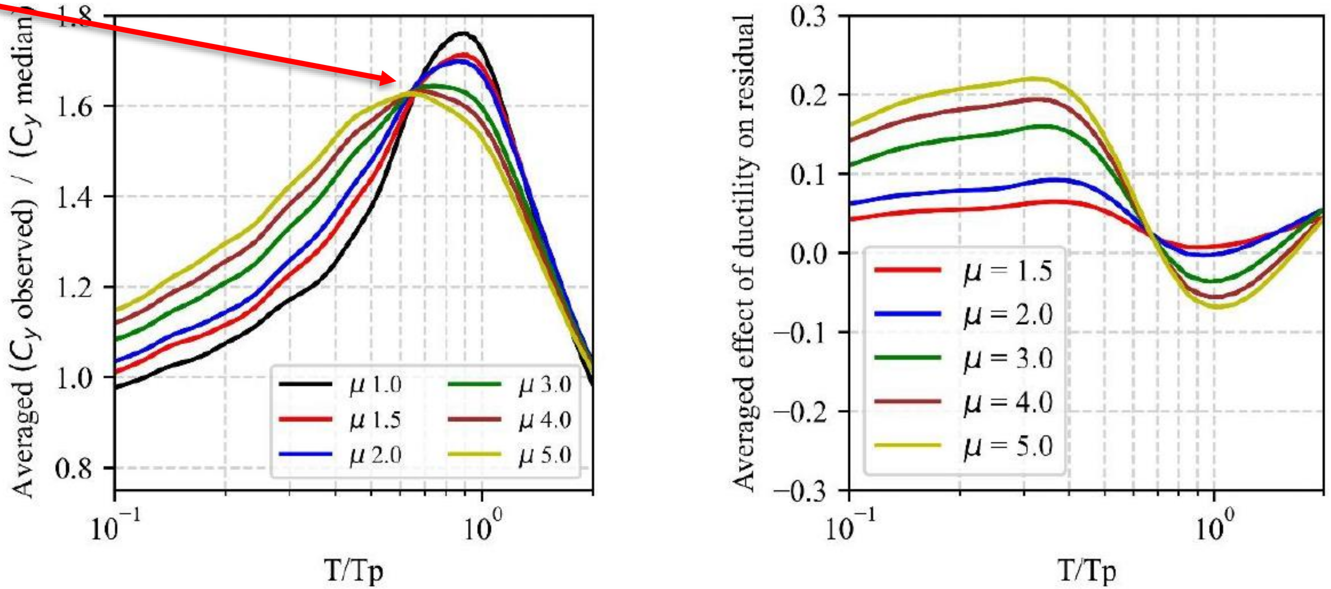
Idealized BILINEAR Model:





Effect of directivity pulses on inelastic and elastic spectra

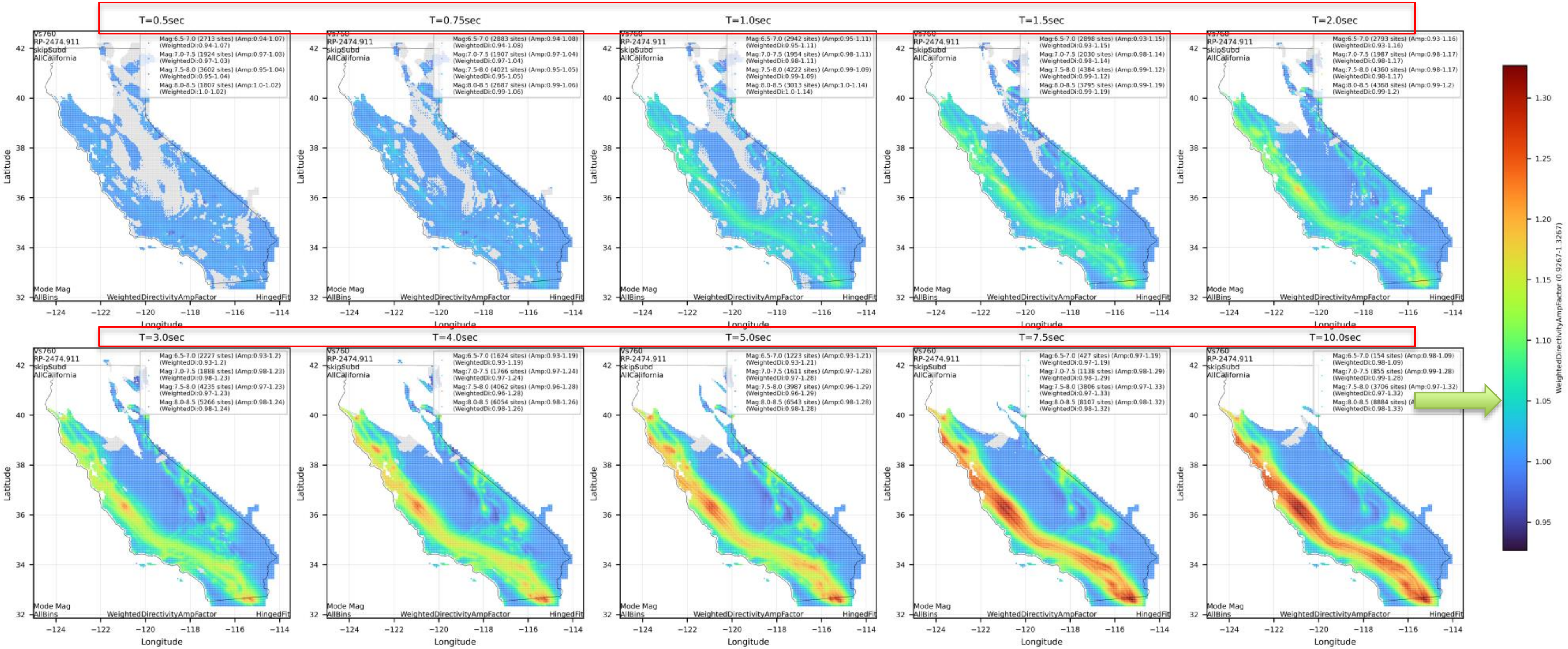
T/Tp = 0.6 to 0.7



The average effect of inelasticity on predicted and observed inelastic C_y for those 137 ground motions identified as pulse-like: (a) the ratios of observed over median predicted C_y and (b) the average of the total residual of inelastic C_y minus the total residual of elastic C_y (i.e., PSA)

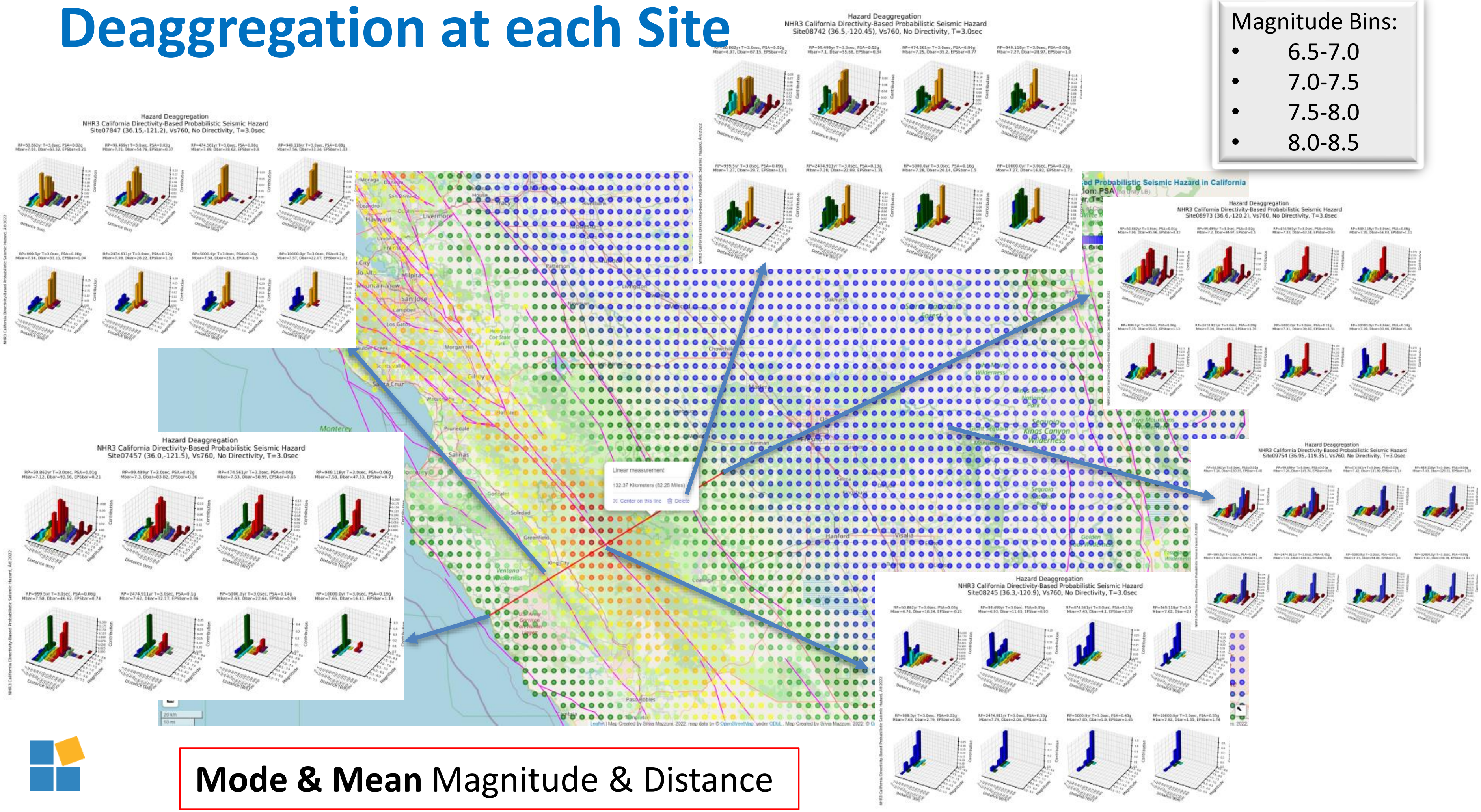
QUANTIFICATION AND SIMPLIFICATION OF DIRECTIVITY EFFECTS AT THE HAZARD LEVEL

Directivity-Amplification Factor (Weighted-Avg Model)



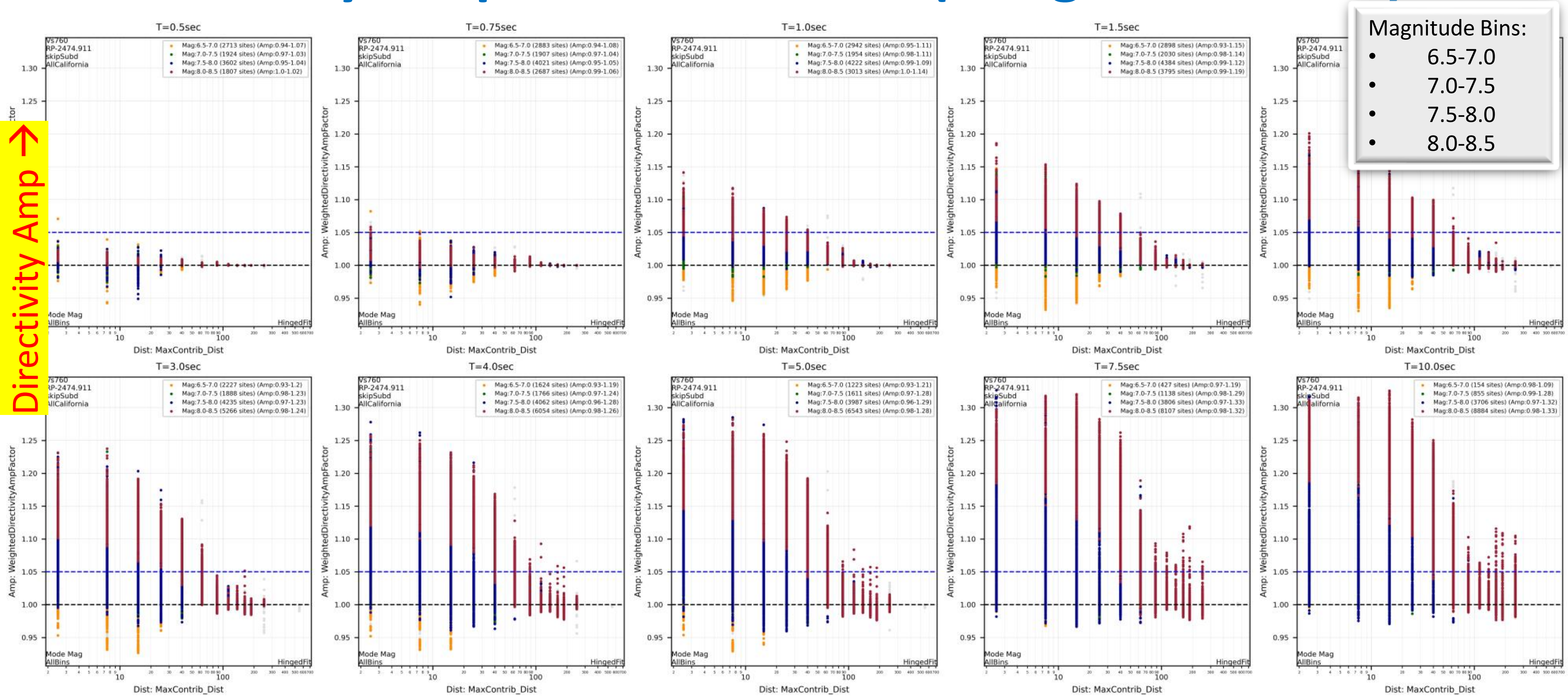
Deaggregation at each Site

Magnitude Bins:
- 6.5-7.0
- 7.0-7.5
- 7.5-8.0
- 8.0-8.5



Mode & Mean Magnitude & Distance

Directivity-Amplification Factor (Weighted Model)

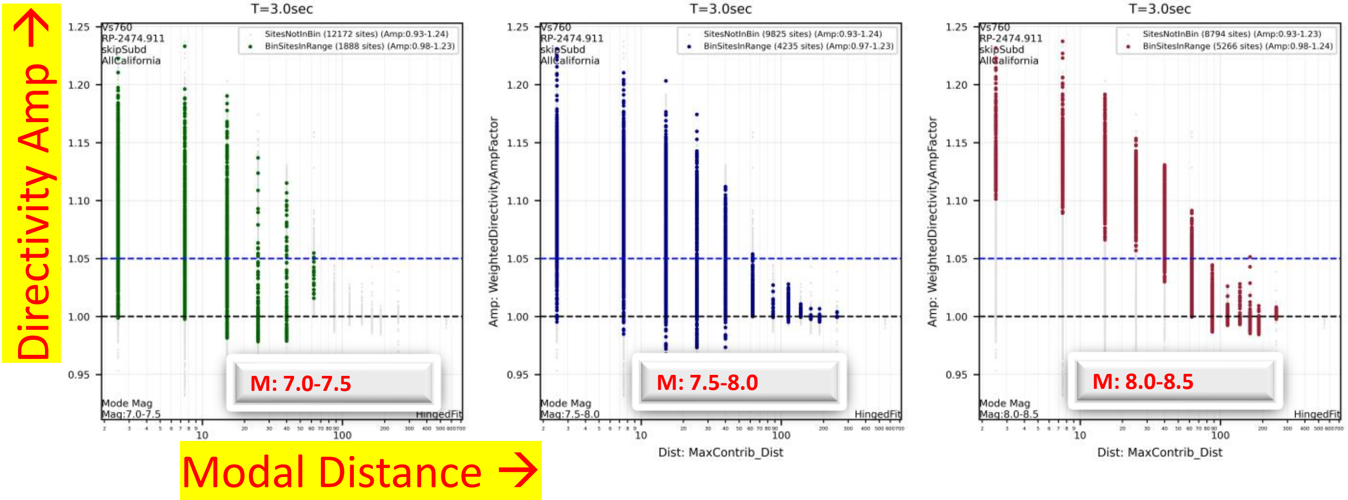


Modal Distance →

Step 1

DATA MODELING

Objectives



1.05x Amplification

1. Determine **Threshold Distance** for Directivity (Modal or Mean)
2. Directivity Amplification Factor vs Distance (& Magnitude?) (& Period)

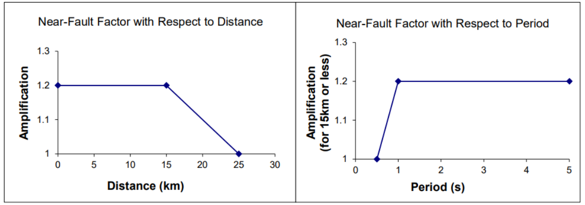
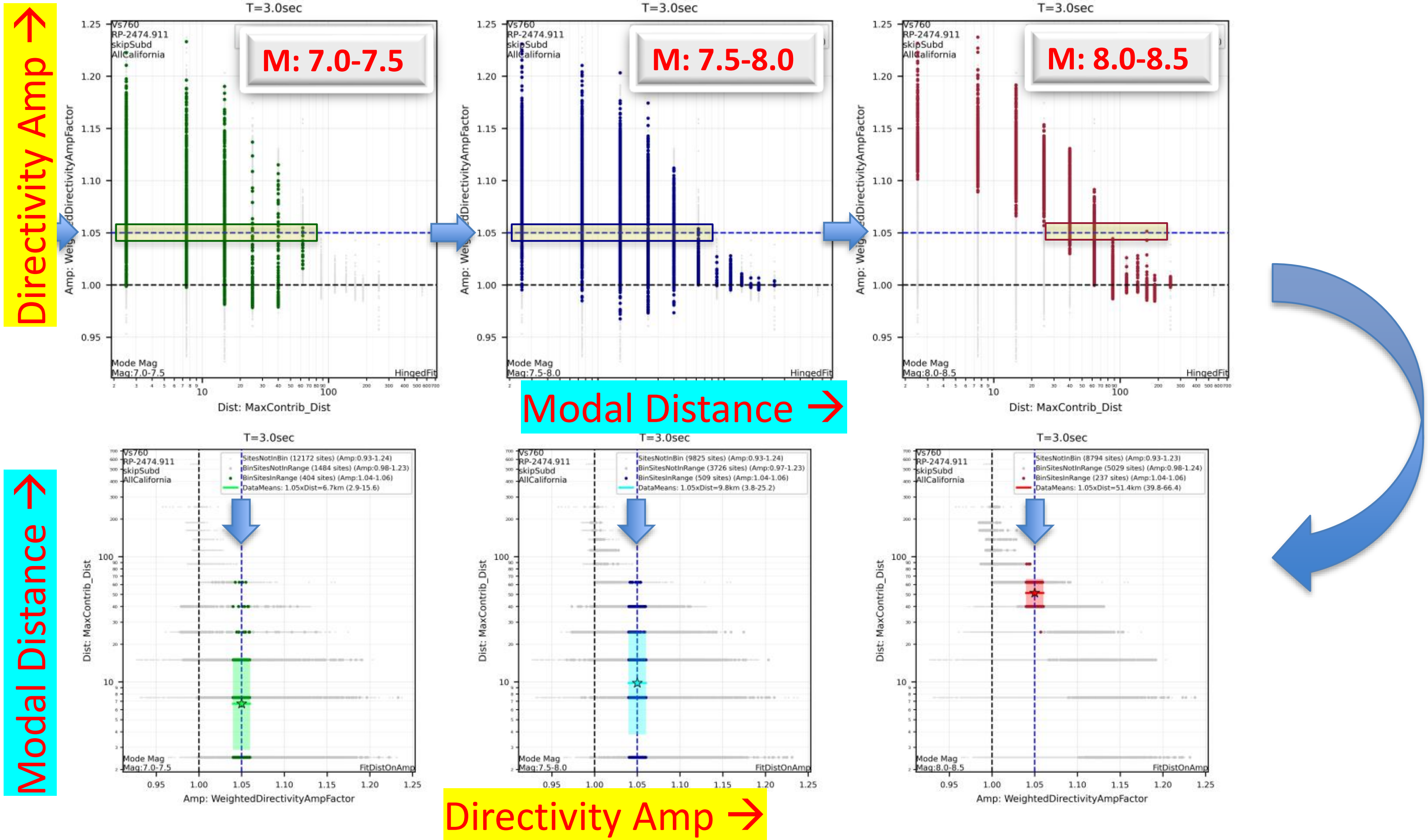


Figure B.1 Near-Fault adjustment factor as a function of distance and spectral period. The distance measure is based on the closest distance to any point on the fault plane

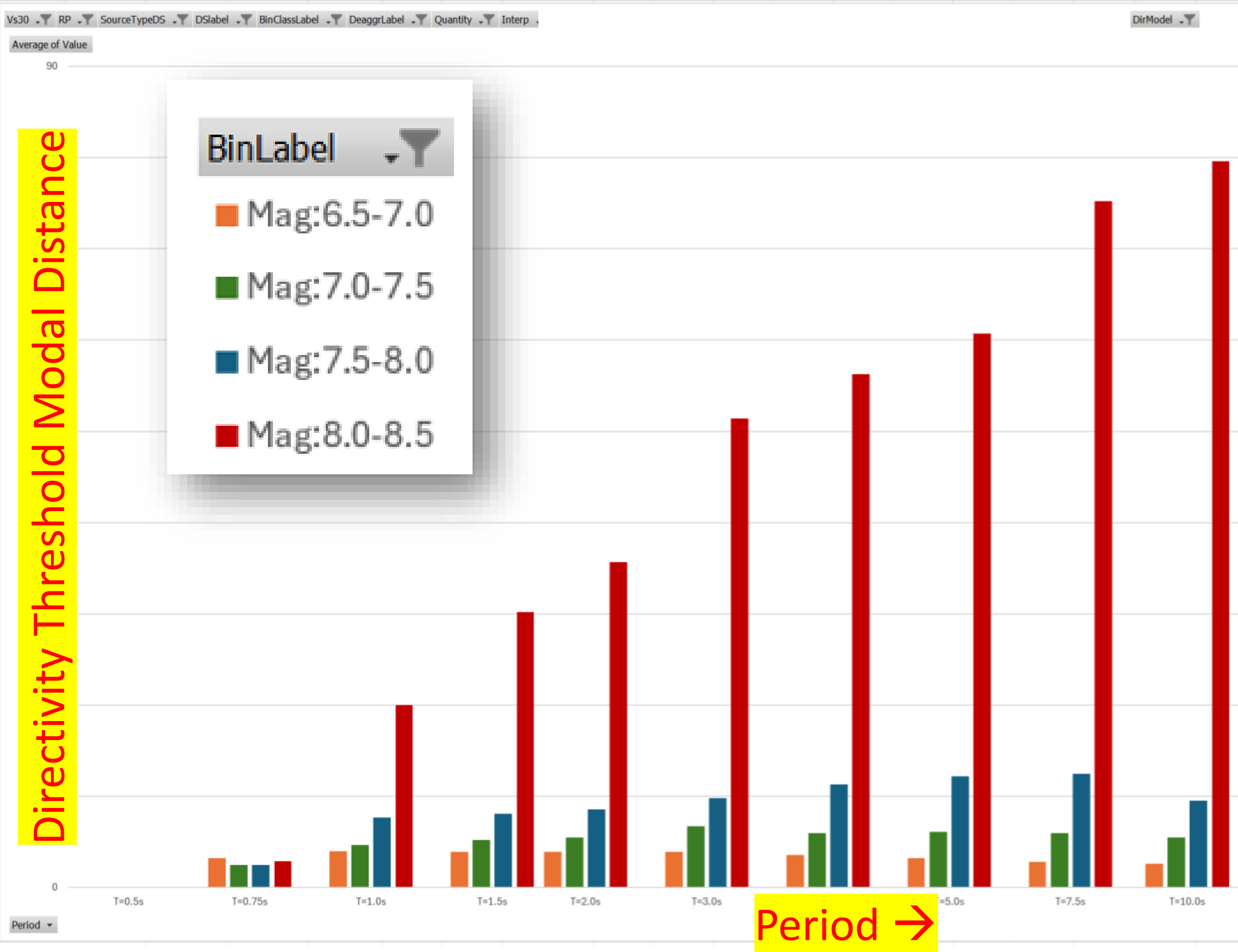
1. Determine Threshold Distance for Directivity



1. Median Value of Directivity-Threshold Distance

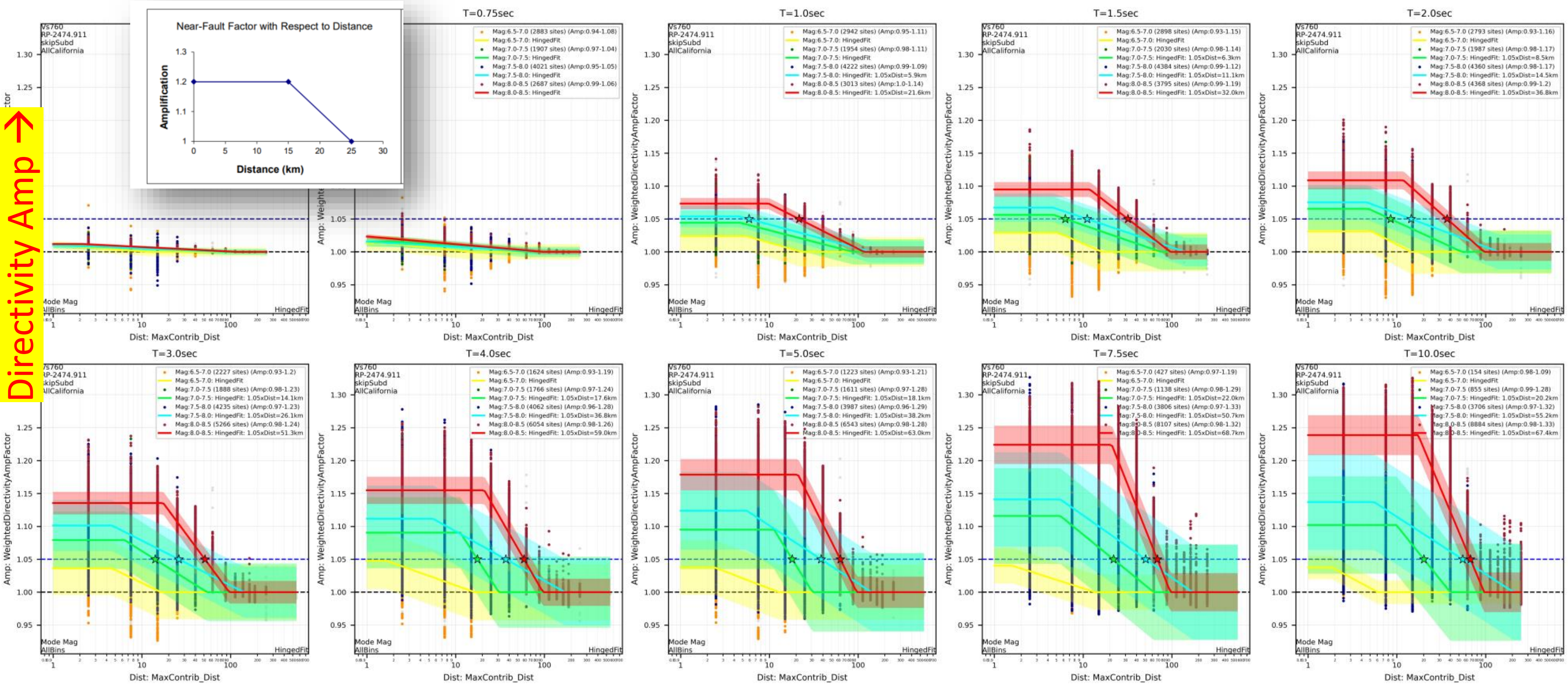
Vs30	Vs760
RP	2474.911
SourceTypeDS	skipSubd
DSlabel	AllCalifornia
BinClassLabel	MagBin
DeaggrLabel	Mode
Quantity	1.05-amp-Dist Median (km)
Interp	FitDistOnAmp
DirModel	WeightedDirectivityAmpFactor

Average of Value	Column Labels
Row Labels	**Mag:6.5-7.0**
T=0.5s	#DIV/0!
T=0.75s	3.2
T=1.0s	4
T=1.5s	3.9
T=10.0s	2.6
T=2.0s	3.9
T=3.0s	3.9
T=4.0s	3.6
T=5.0s	3.2
T=7.5s	2.8
Grand Total	**3.455555556**



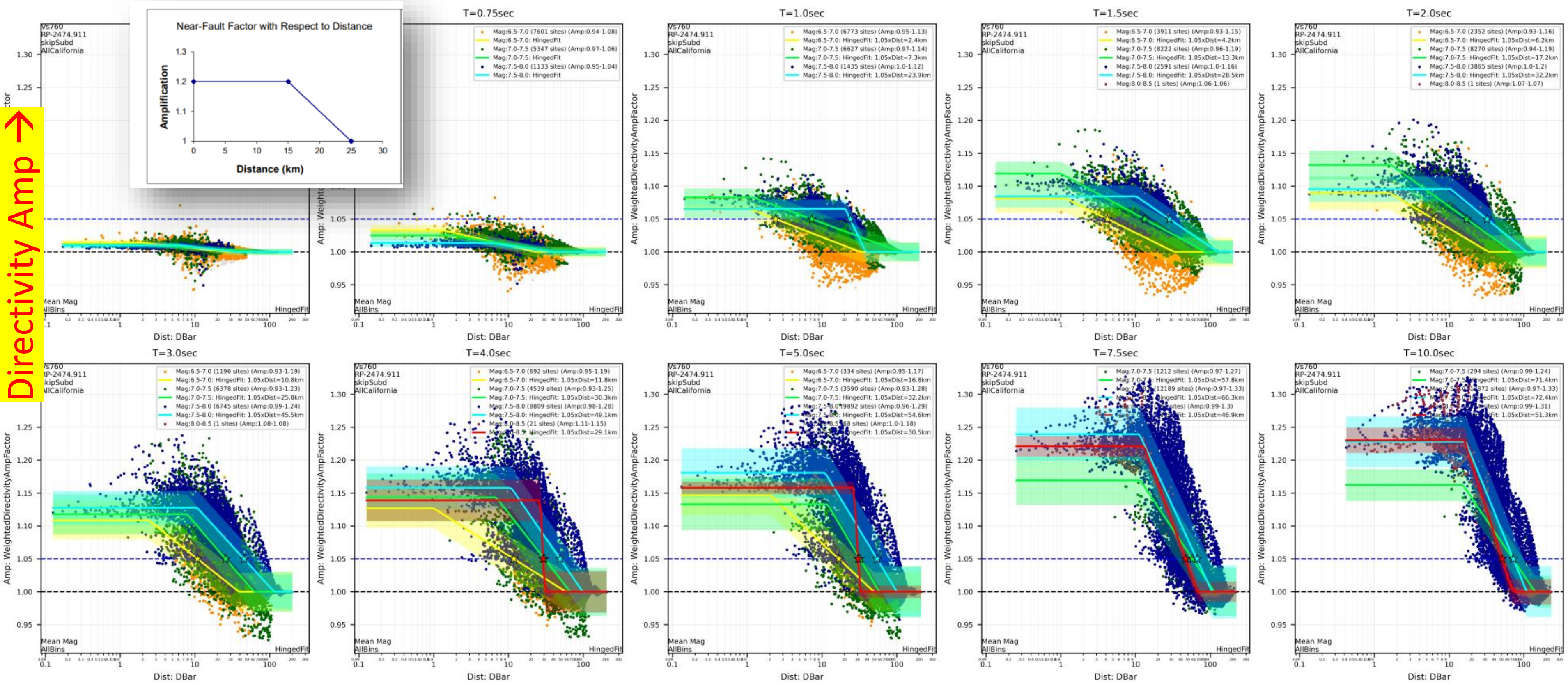
2. Directivity Amplification vs Distance – Hinged Fit

Directivity Amp →



Modal Distance (log) →

2. Directivity Amplification vs Distance – Hinged Fit

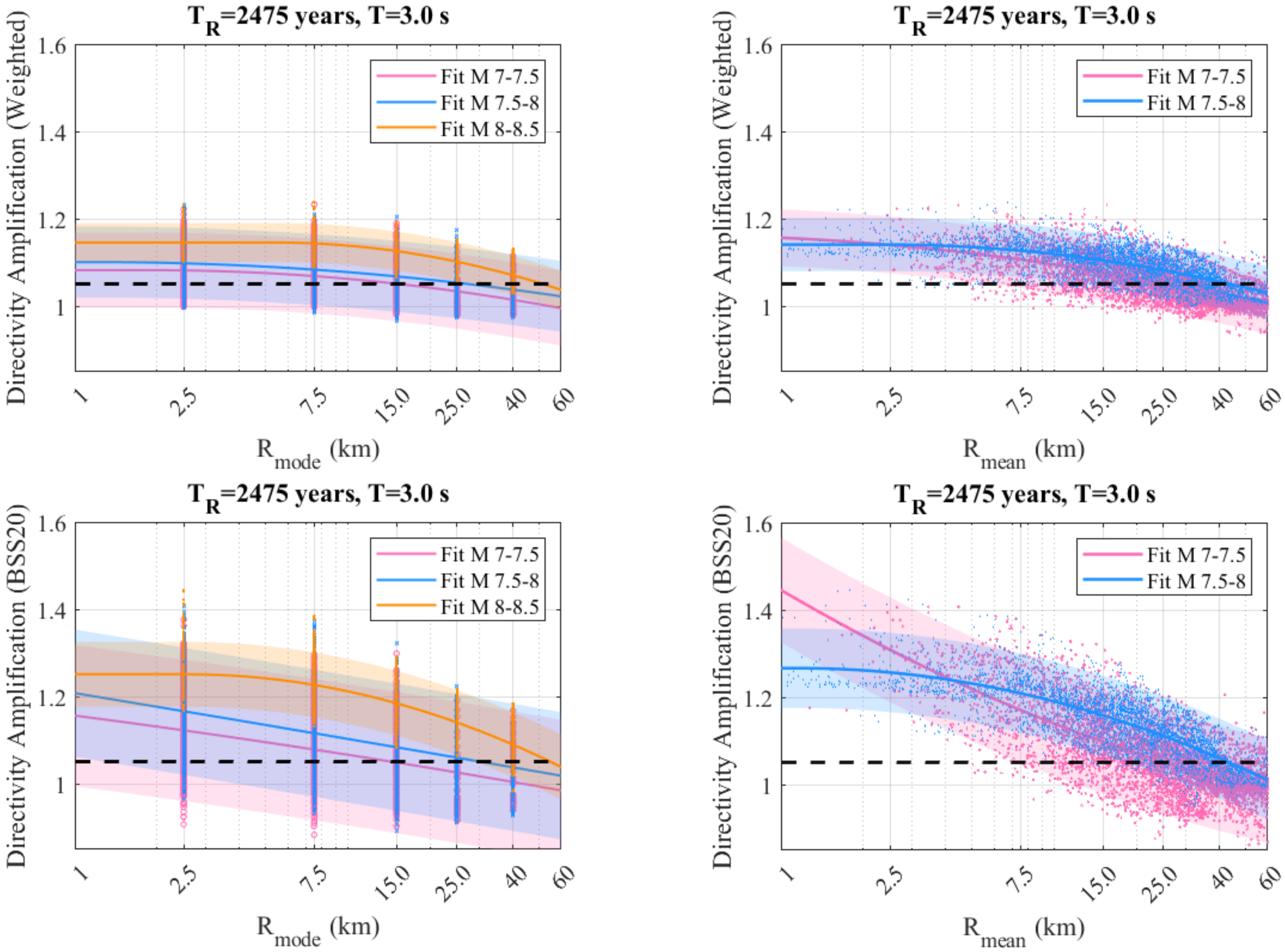


Directivity Amp →

Mean Distance (log) →

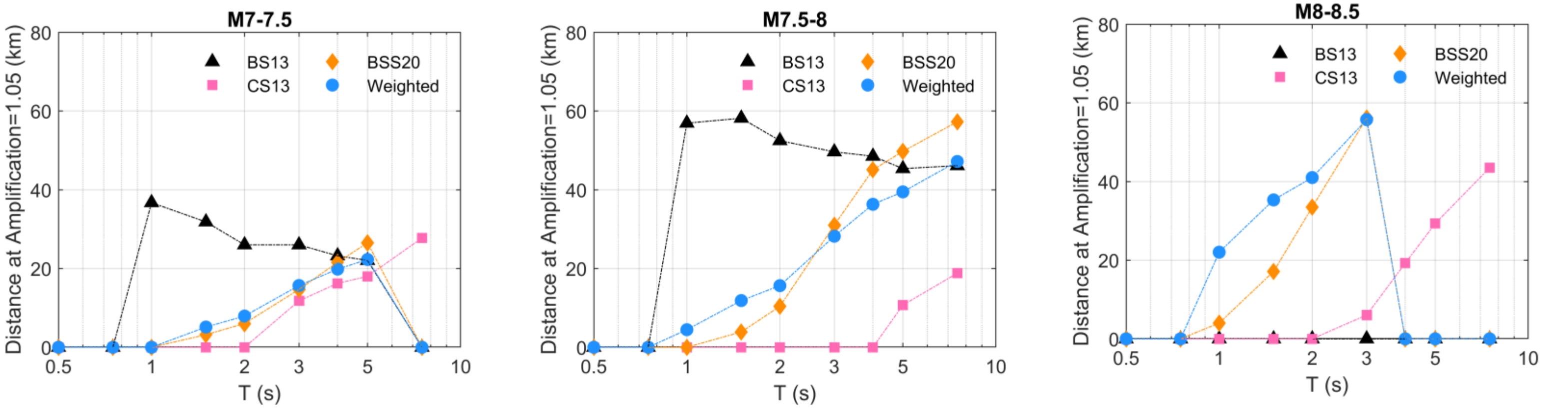
ALT DIRECTIVITY-AMP MODELS

Quadratic fits for different directivity models

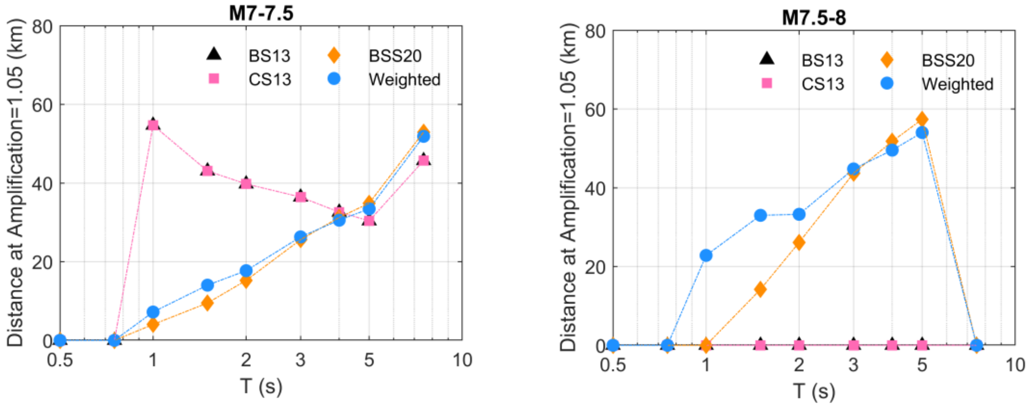


Distance at Directivity Amplification=1.05 vs. Period

Mode Data

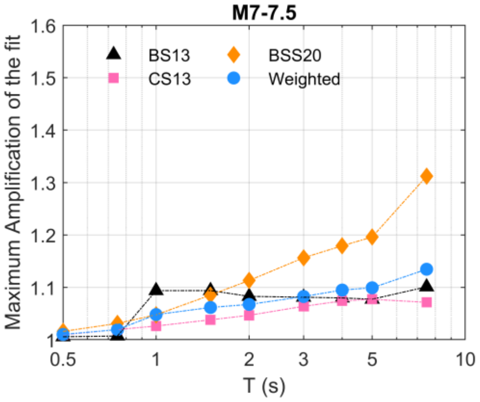


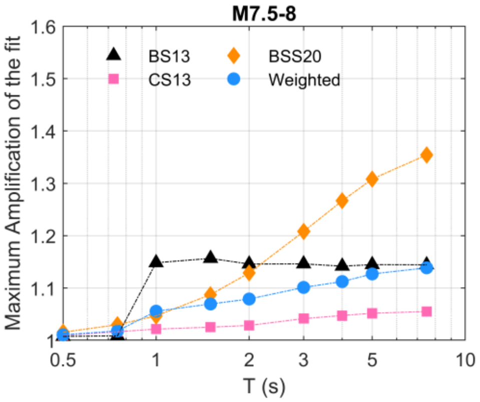
Mean Data

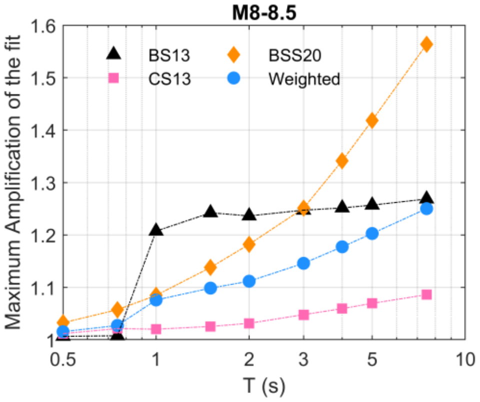


Maximum Amplification vs. Period

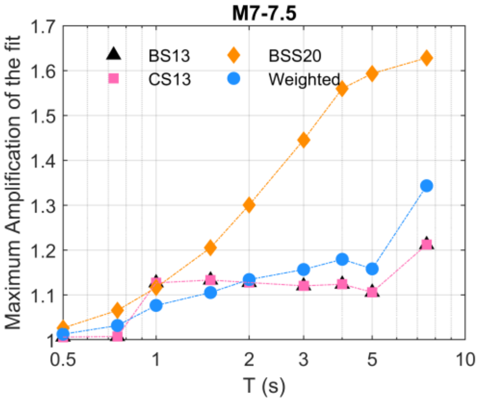
Mode Data

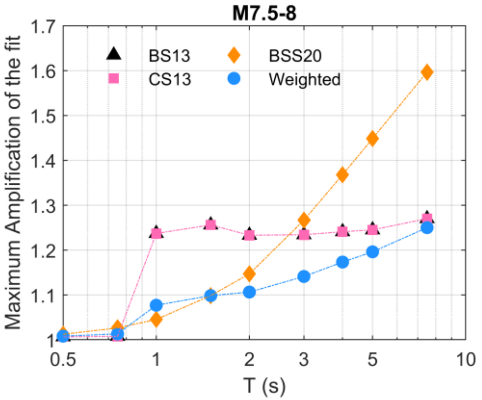






Mean Data





Summary

- Project started April 2024
- Statewide PSHA directivity results have been reduced and simplified
- Distance and directivity amplification ranges for ***elastic*** response spectra have been quantified via different models
- Next: Work with Caltrans to develop the recommendations on model and metrics

  - Disaggregation Magnitude & Distance
    - Modal
    - Mean
  - Threshold Distance
    - Median
    - 84%ile
  - Directivity Amplification Model
    - Hinged
    - Quadratic
  - Directivity-Model Combination
    - Weighted average
    - Envelope the 3 directivity models

Next Steps

- Inelastic-Response Spectra
  - Modification of directivity amplification and oscillator period range for ductility > 1
- Ground-Motion Selection
  - Use the modified near-fault factors, select and scale input motions at various sites in CA for two return periods (e.g., 975 years and 5000 years).
- Numerical Simulation of Bridge
  - Simulate the responses of bridges (e.g., ductility demand) and compare them using the current Caltrans near-fault factors