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

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Acknowledgments

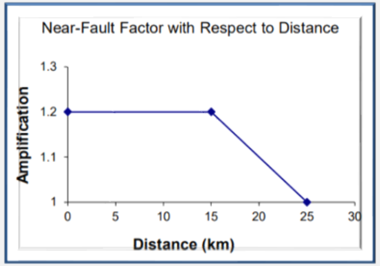
- Caltrans for supporting the research project
- Caltrans engineers for their collaboration and feedback
  - KT
  - Tom Shantz
  - Sharon Yen

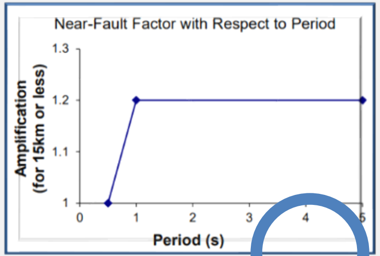
Project Outline

State of the practice

Caltrans

Near-Fault Factor

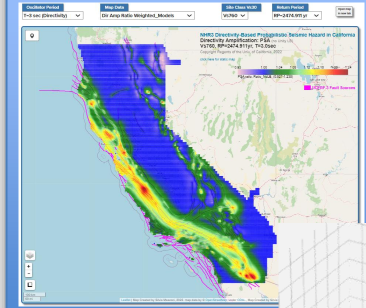


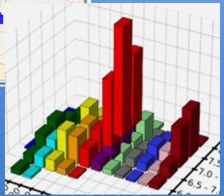


Past-Project Data

NHR3 California Statewide

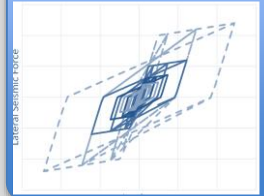
PSHA with Directivity

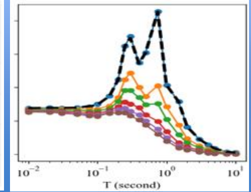




NHR3 **Inelastic Response**

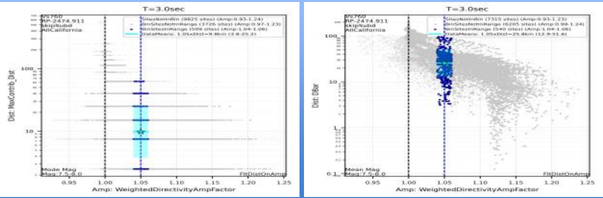
Spectra Database & Models



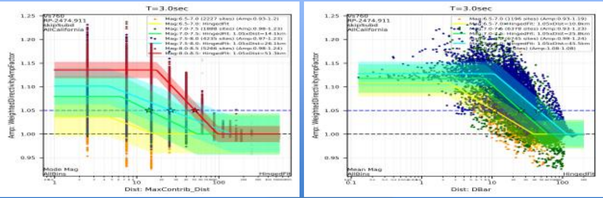


Findings

Threshold Distance

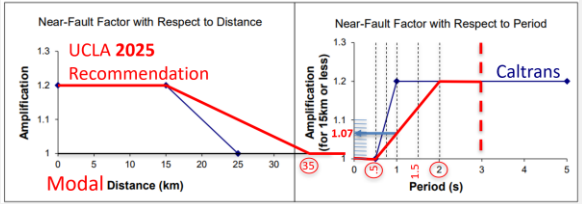


Directivity-Amplification Models



Recommendations

New Near-Fault Factor



0. Current Caltrans Near-Fault Factor -- 2019

APPENDIX B: DESIGN SPECTRUM DEVELOPMENT B-1

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.

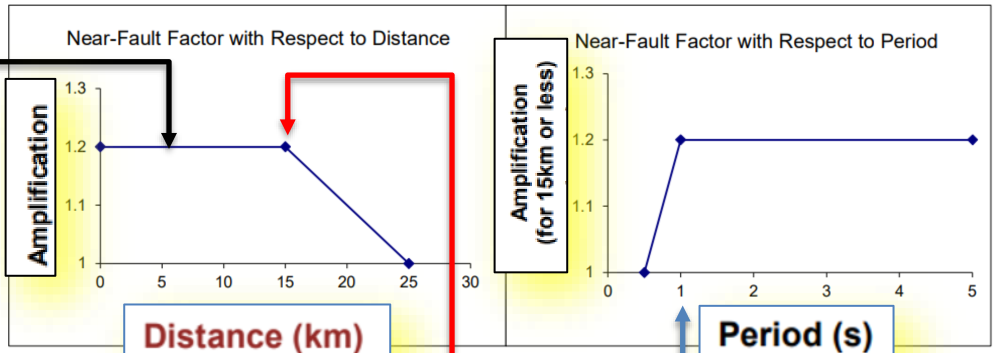
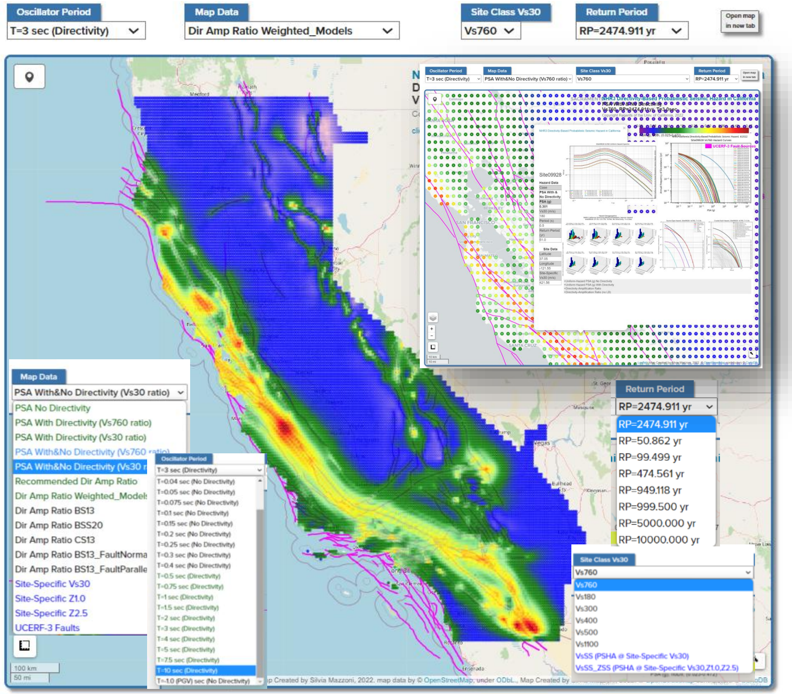


Figure B.1 Near-Fault adjustment factor as a function of distance and spectral period. The distance measure is based on the closest distance to any point on the fault plane

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

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: PSHA for the State of CA:

- Directivity models
- NGA models
- UCERF3

Directivity Models:

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

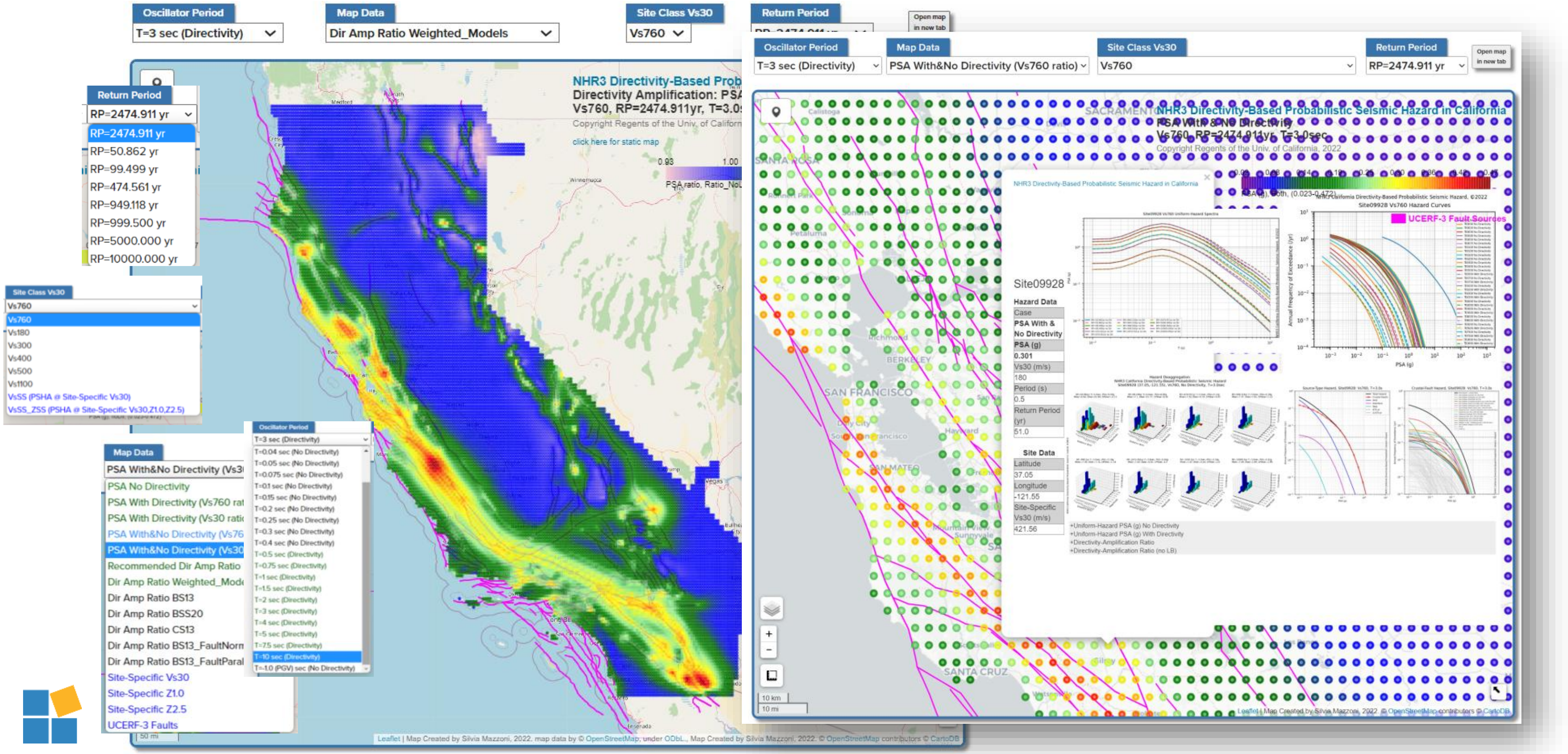
4. Weighted-Average

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

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

→ Deaggregation Data for no-directivity PSHA

California PSHA-Directivity Maps



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

Silvia Mazzoni, Mahdi Bahrampouri, Yousef Bozorgnia

a) 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

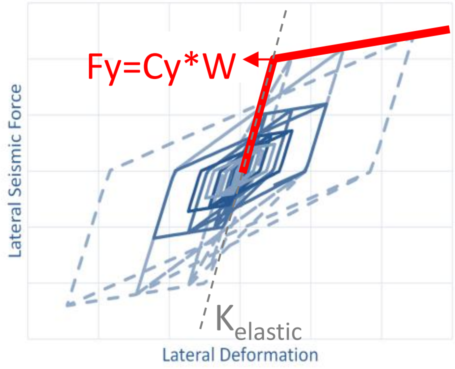
1,225,230,300 OpenSees 2D-Model Analyses

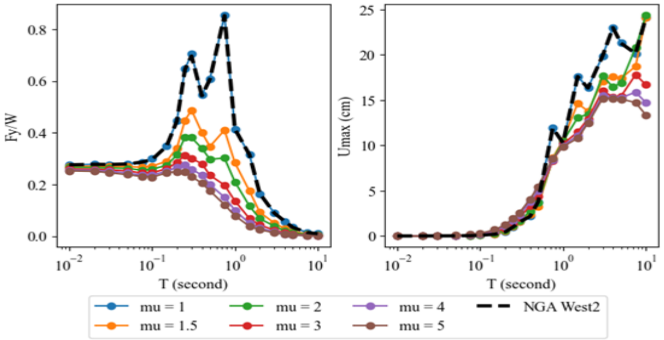
b) Develop a **ground motion model** for median and uncertainty for **inelastic spectra**:

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**
- **Effect of directivity pulses on inelastic & elastic spectra**

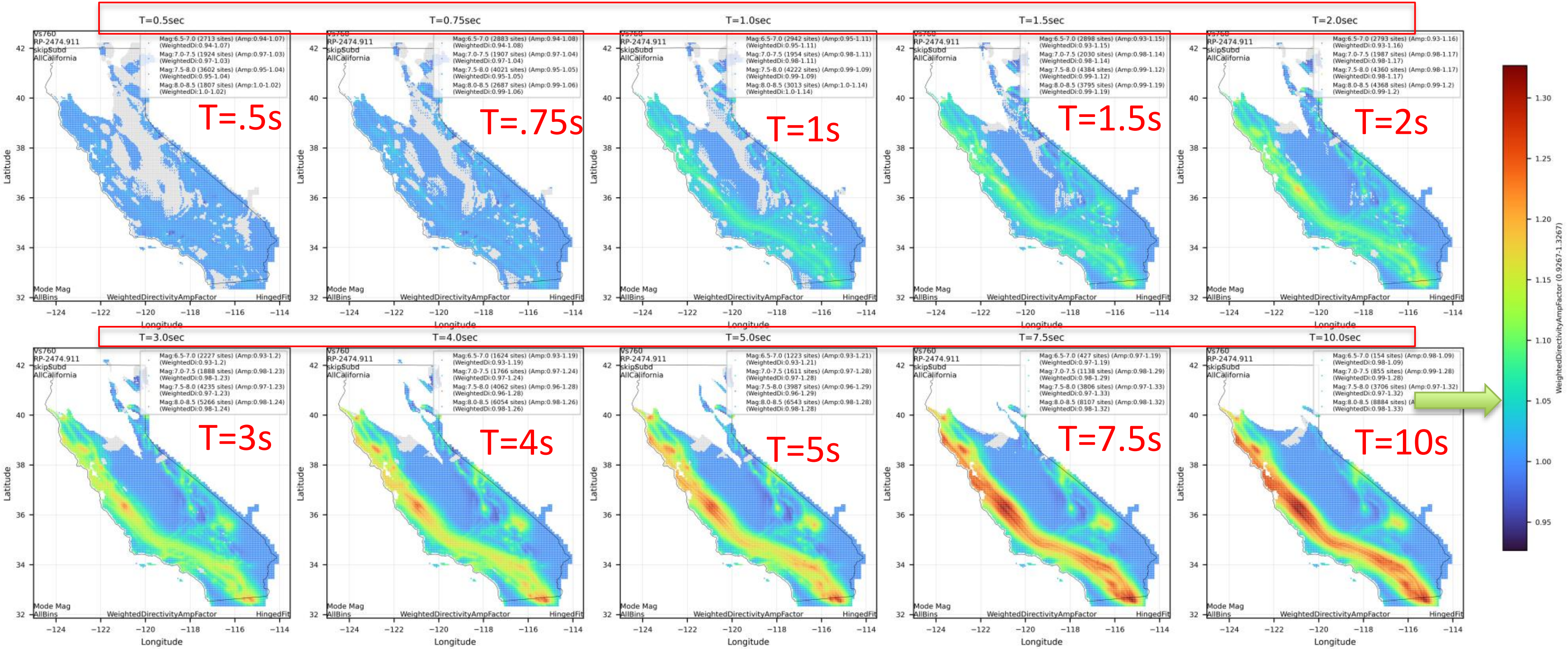
Idealized BILINEAR Model:





QUANTIFICATION & SIMPLIFICATION OF DIRECTIVITY EFFECTS AT THE HAZARD LEVEL

Directivity-Amplification Factor (Weighted-Avg Model)



Directivity Models:

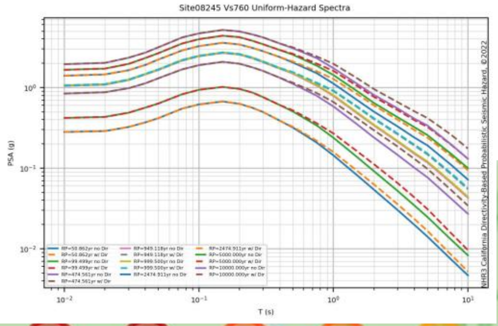
1. CS13: Chiou and Spudich (2013) (2022)
2. BS13: Bayless and Somerville (2013)
3. BSS20: Bayless et al. (2020)

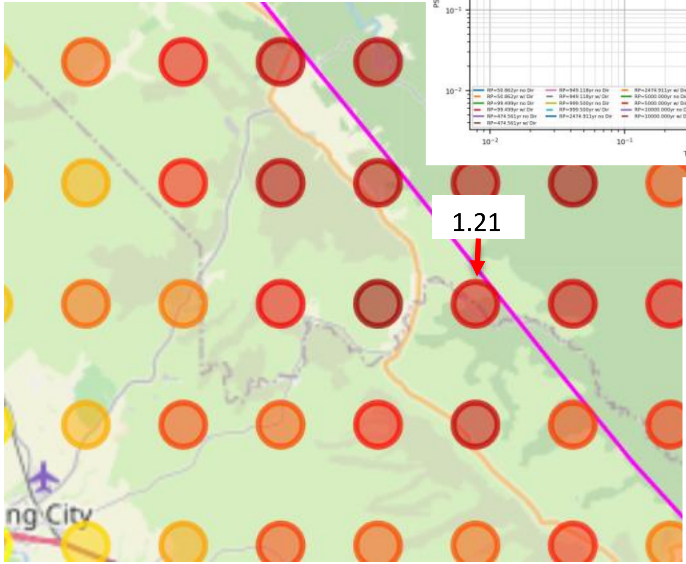
4. Weighted-Average Directivity

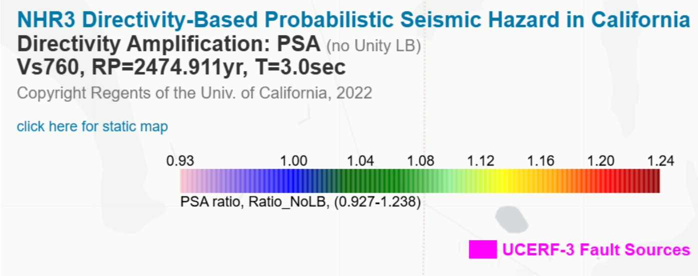
Vs30=760m/s
RP=2475yr
Sites controlled by Crustal Events

T : 0.5-10sec

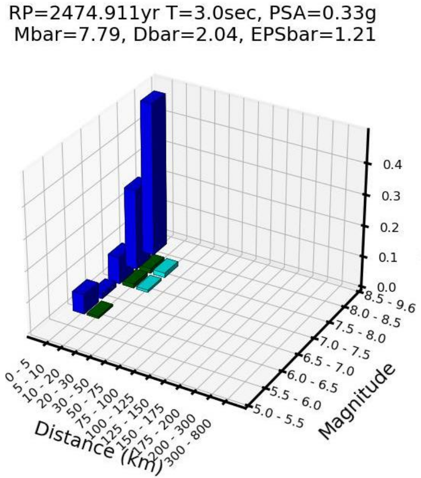
SanAndreas Fault

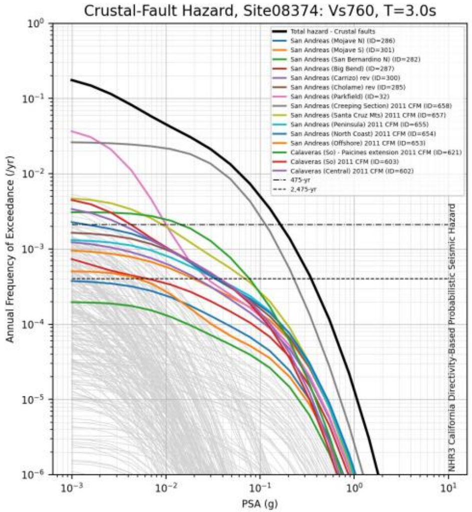






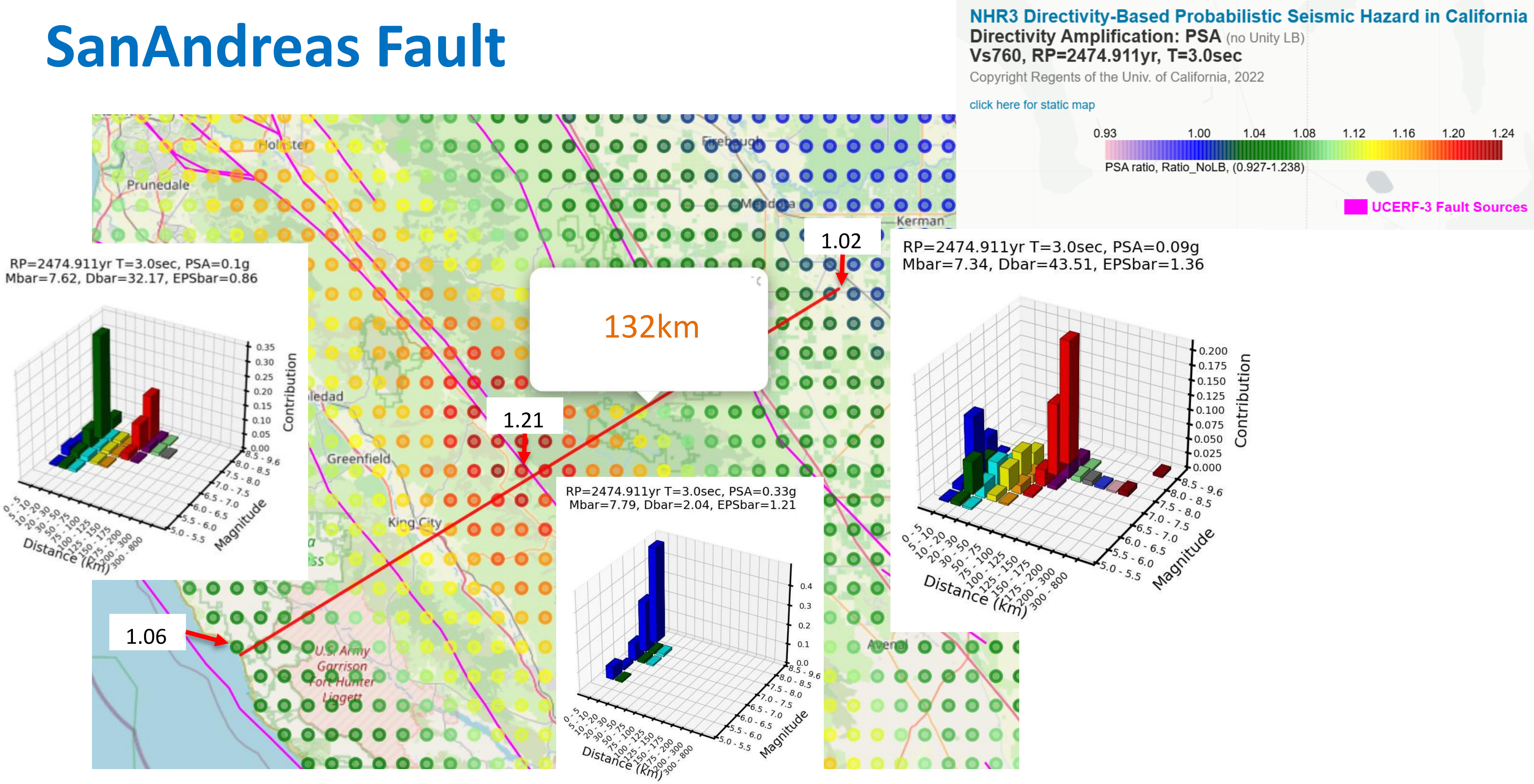
Directivity Amplification Ratio
Vs30=760m/s
RP=2474pt911yr
T=3.0sec





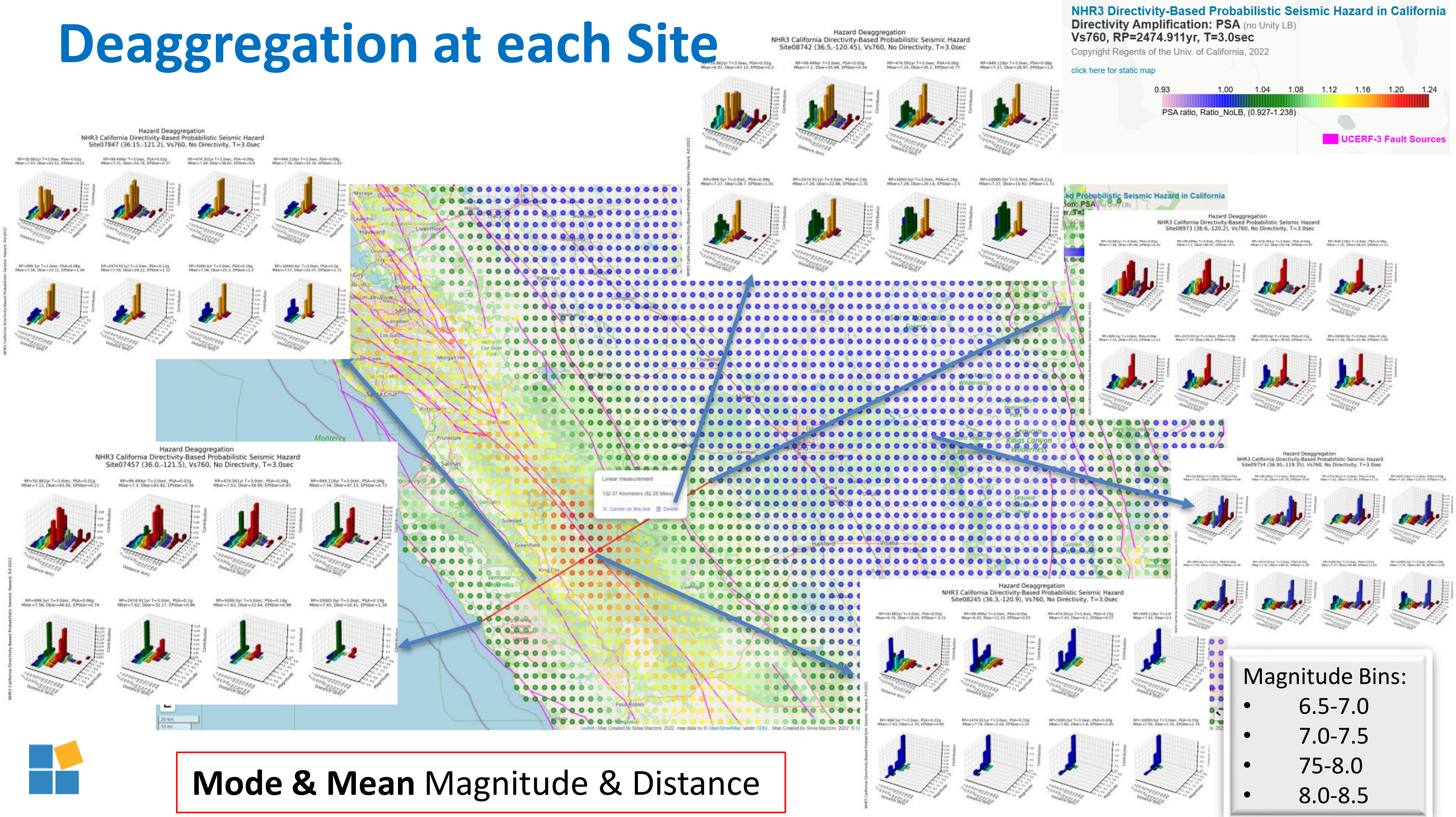
Mode & Mean Magnitude & Distance

SanAndreas Fault



Mode & Mean Magnitude & Distance

Deaggregation at each Site

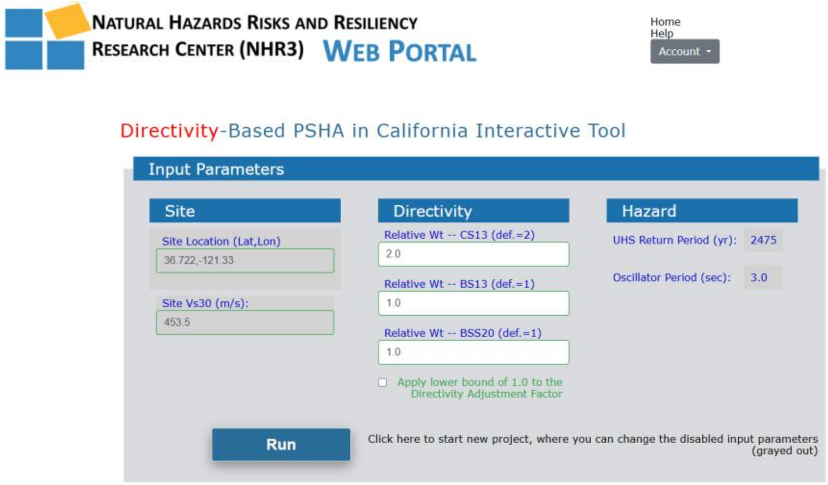


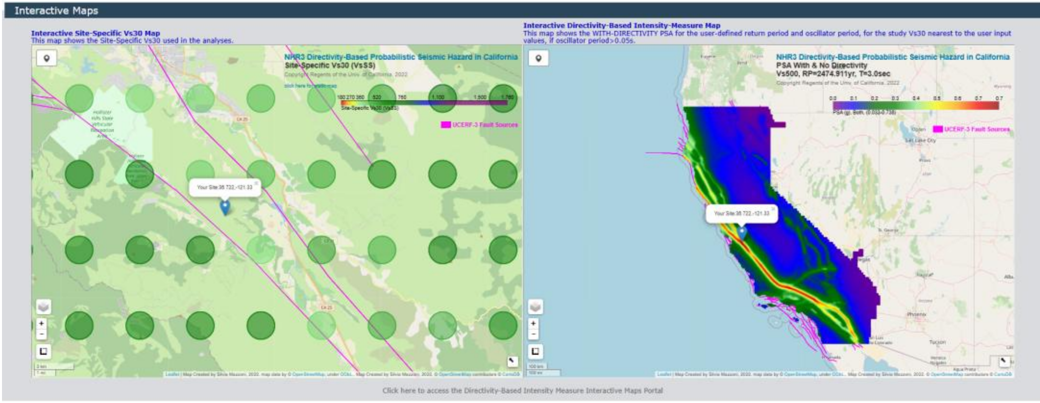
Mode & Mean Magnitude & Distance

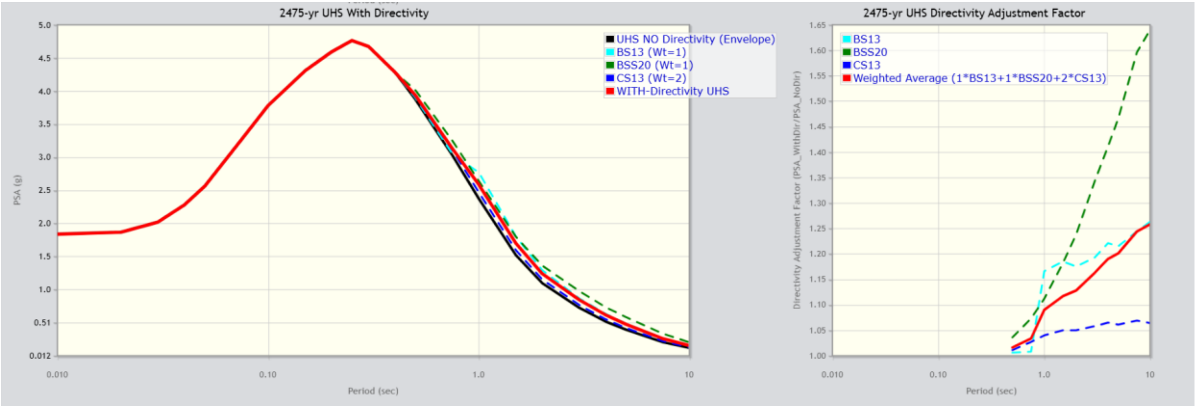
Magnitude Bins:

- 6.5-7.0
- 7.0-7.5
- 75-8.0
- 8.0-8.5

Site-Specific Web Tool, of course…



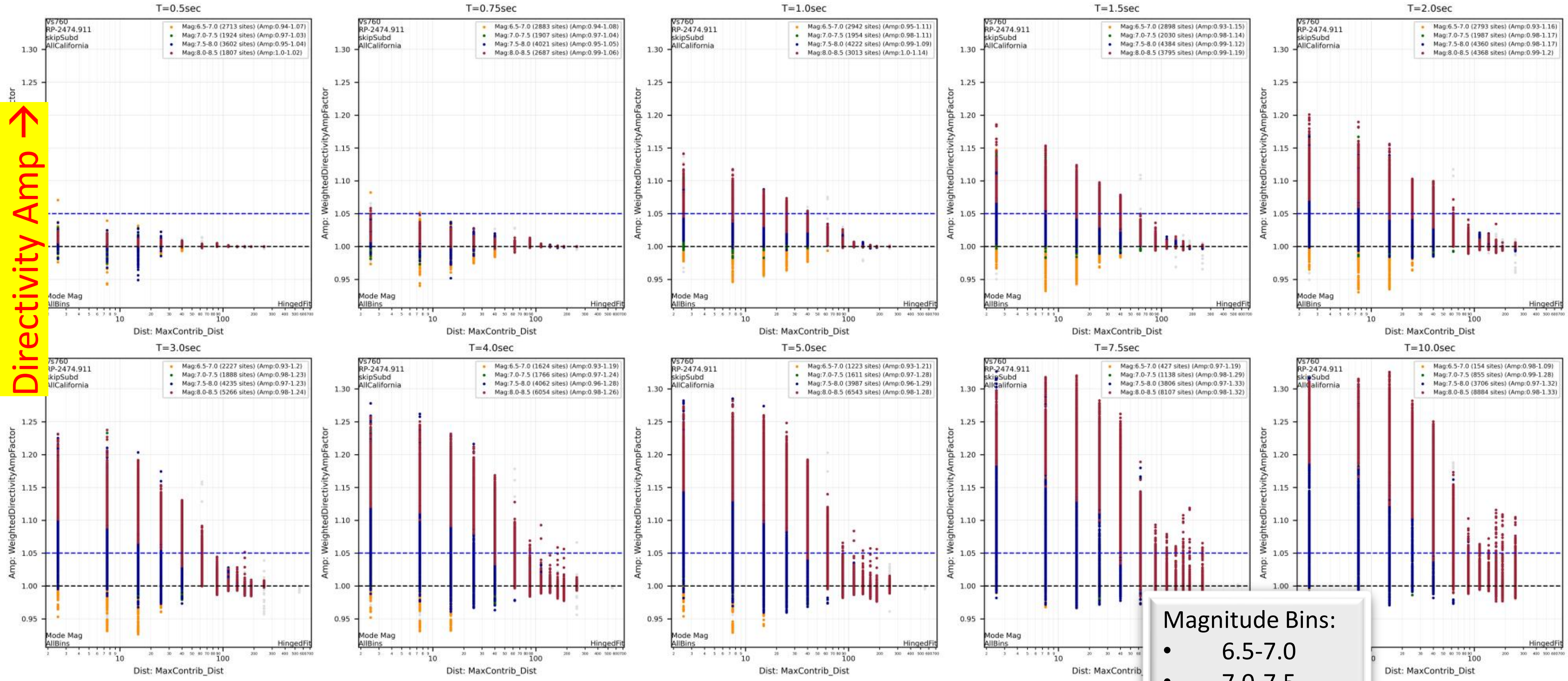




Step 1

DIRECTIVITY-AMPLIFICATION MODELS

Directivity-Amplification Factor (Weighted Model)



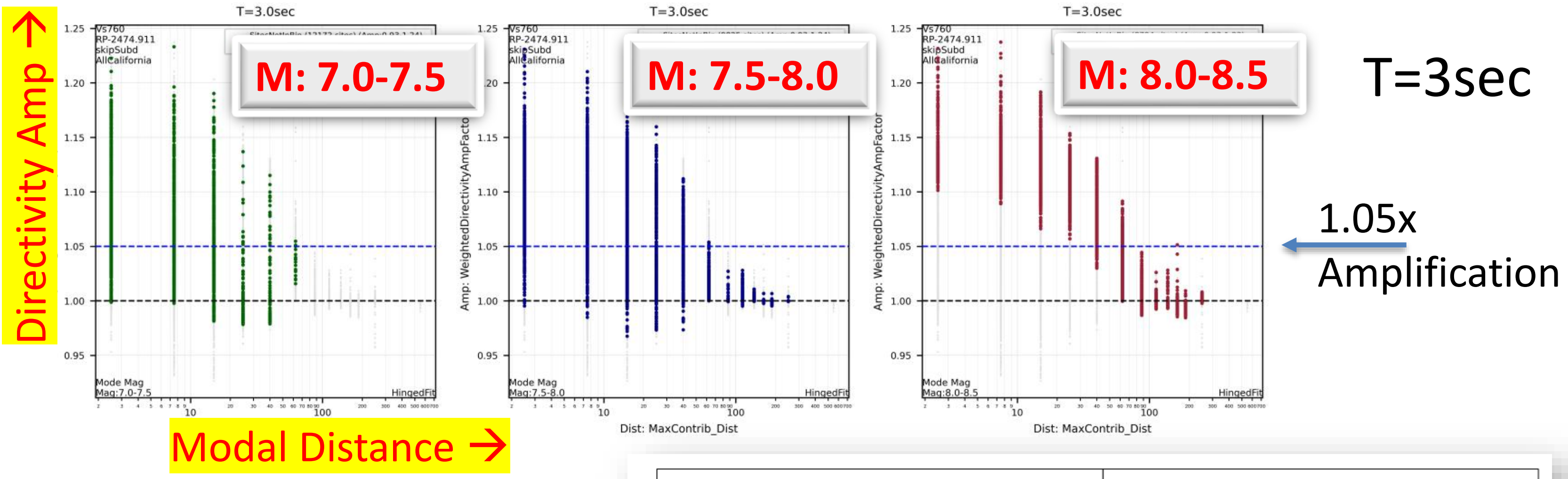
Directivity Amp →

Modal Distance →

Magnitude Bins:

- 6.5-7.0
- 7.0-7.5
- 7.5-8.0
- 8.0-8.5

Objective



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

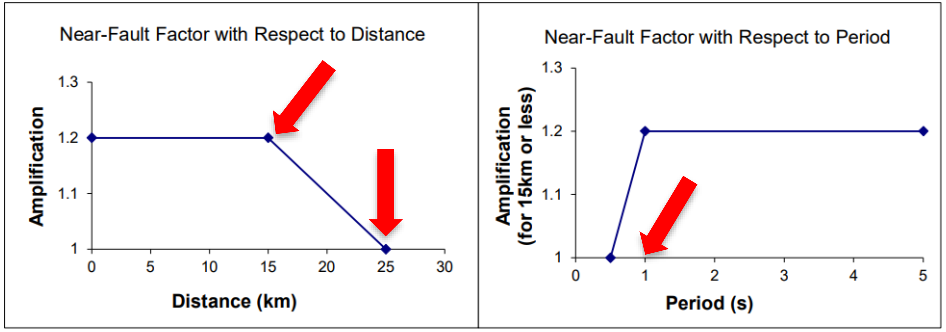
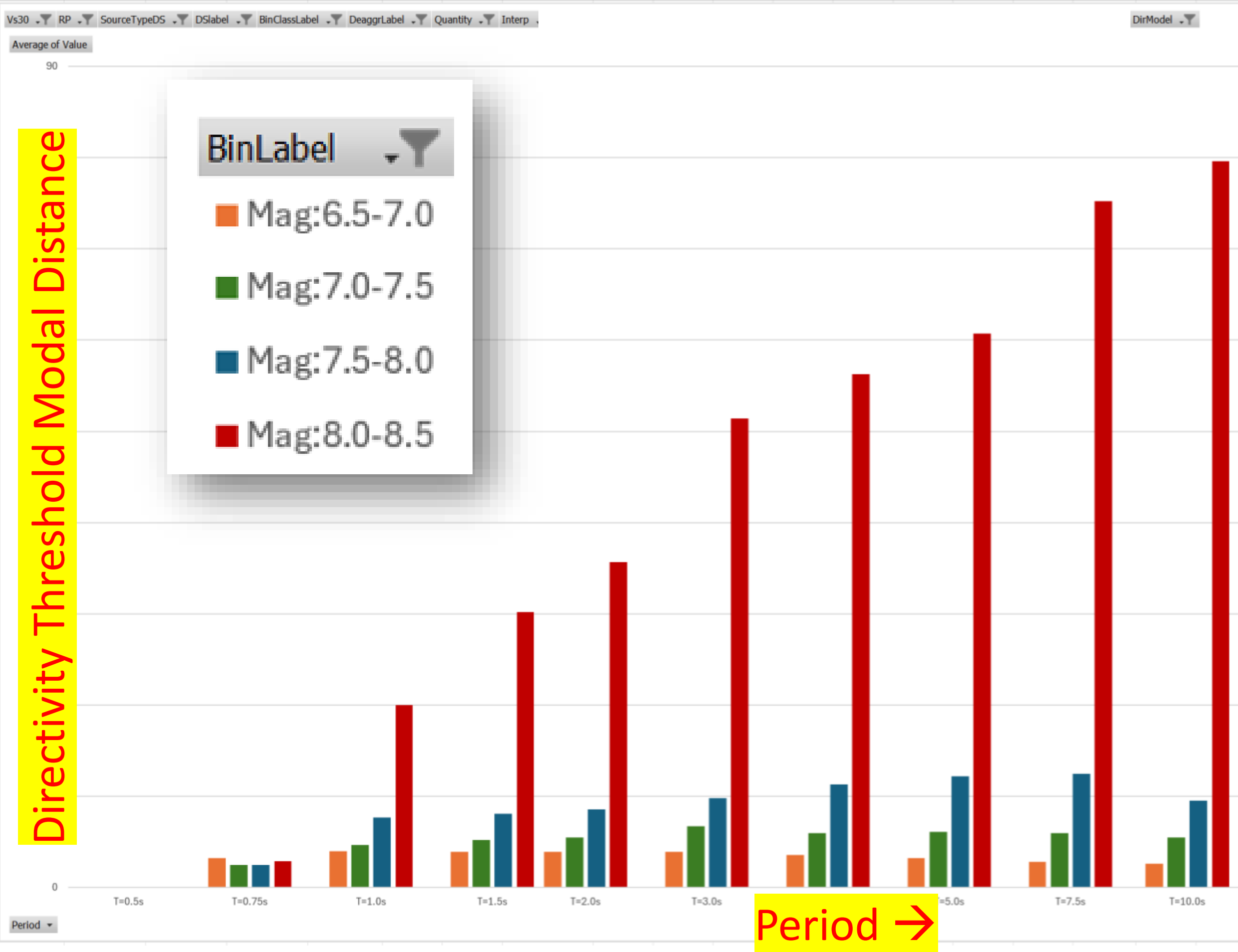


Figure B.1 Near-Fault adjustment factor as a function of distance and spectral period. The distance measure is based on the closest distance to any point on the fault plane

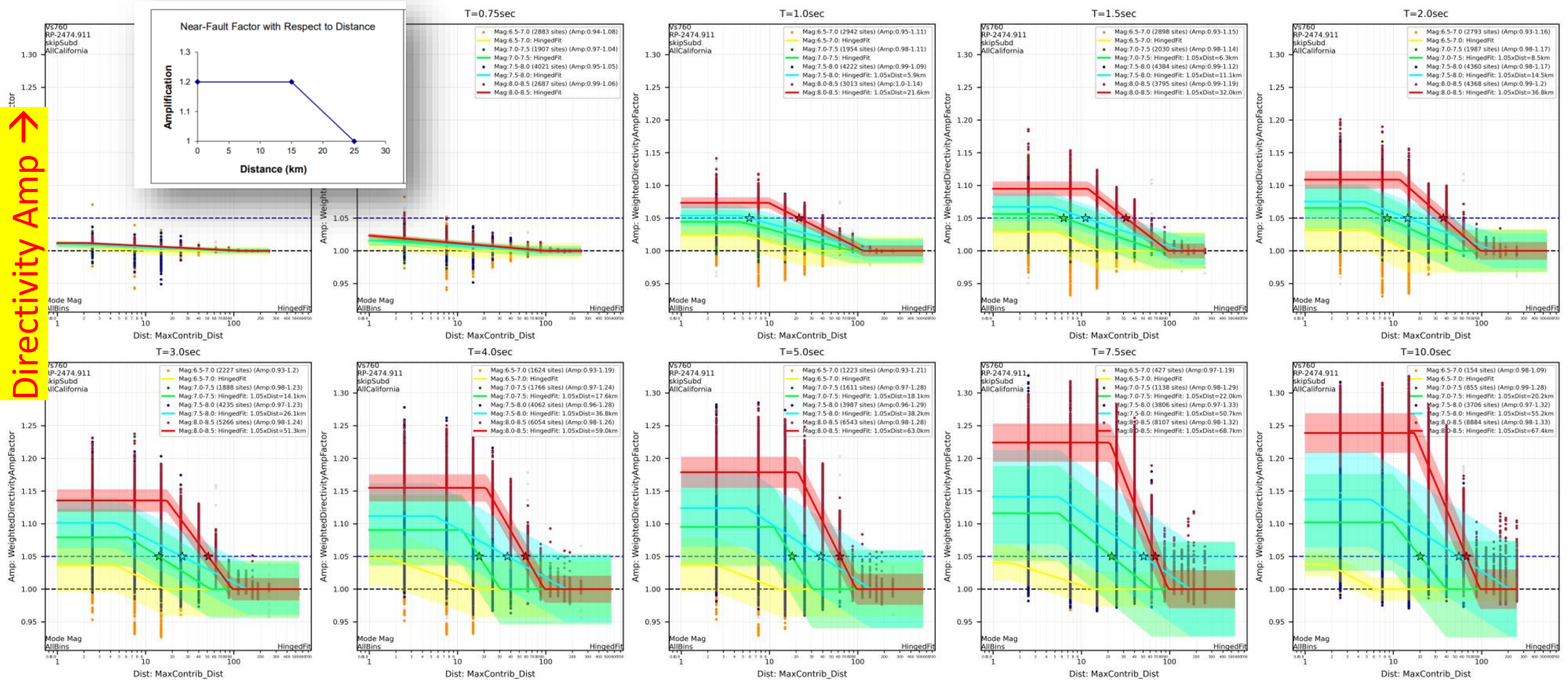
1. Median Value of Directivity-Threshold Distance

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	Ma
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	5.



2. Directivity Amplification vs Modal Distance Model



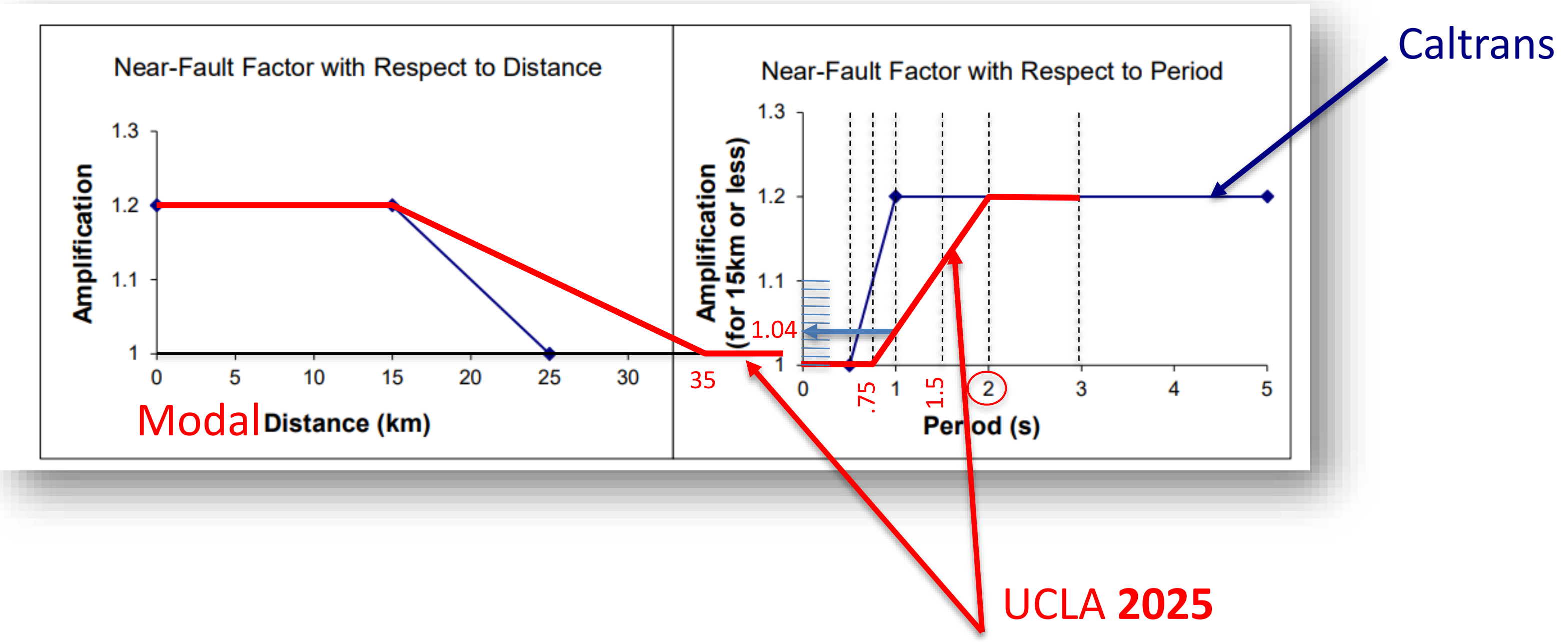
Directivity Amp →

Modal Distance (log) →

RECOMMENDATIONS

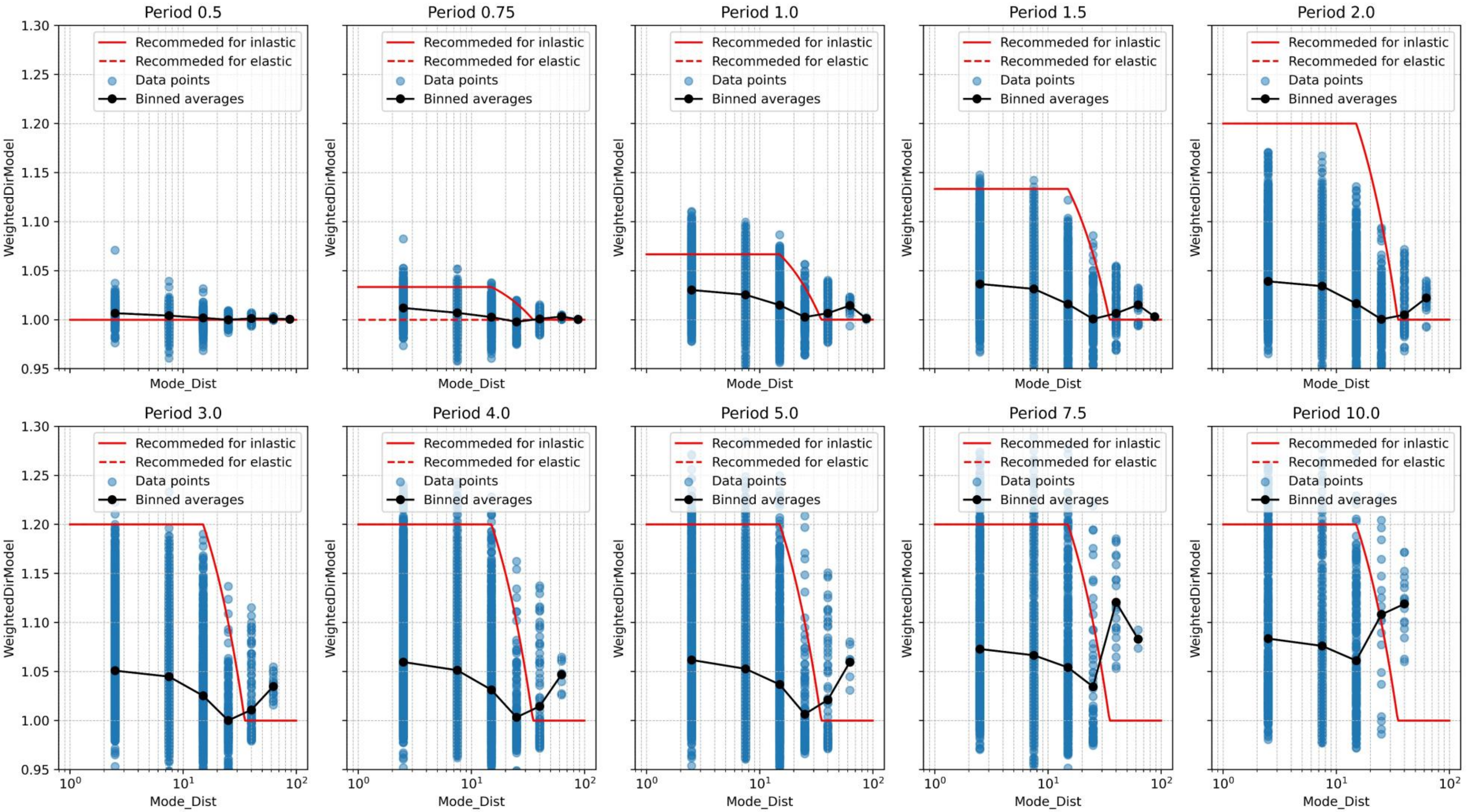
BASED ON LINEAR-ELASTIC RESPONSE

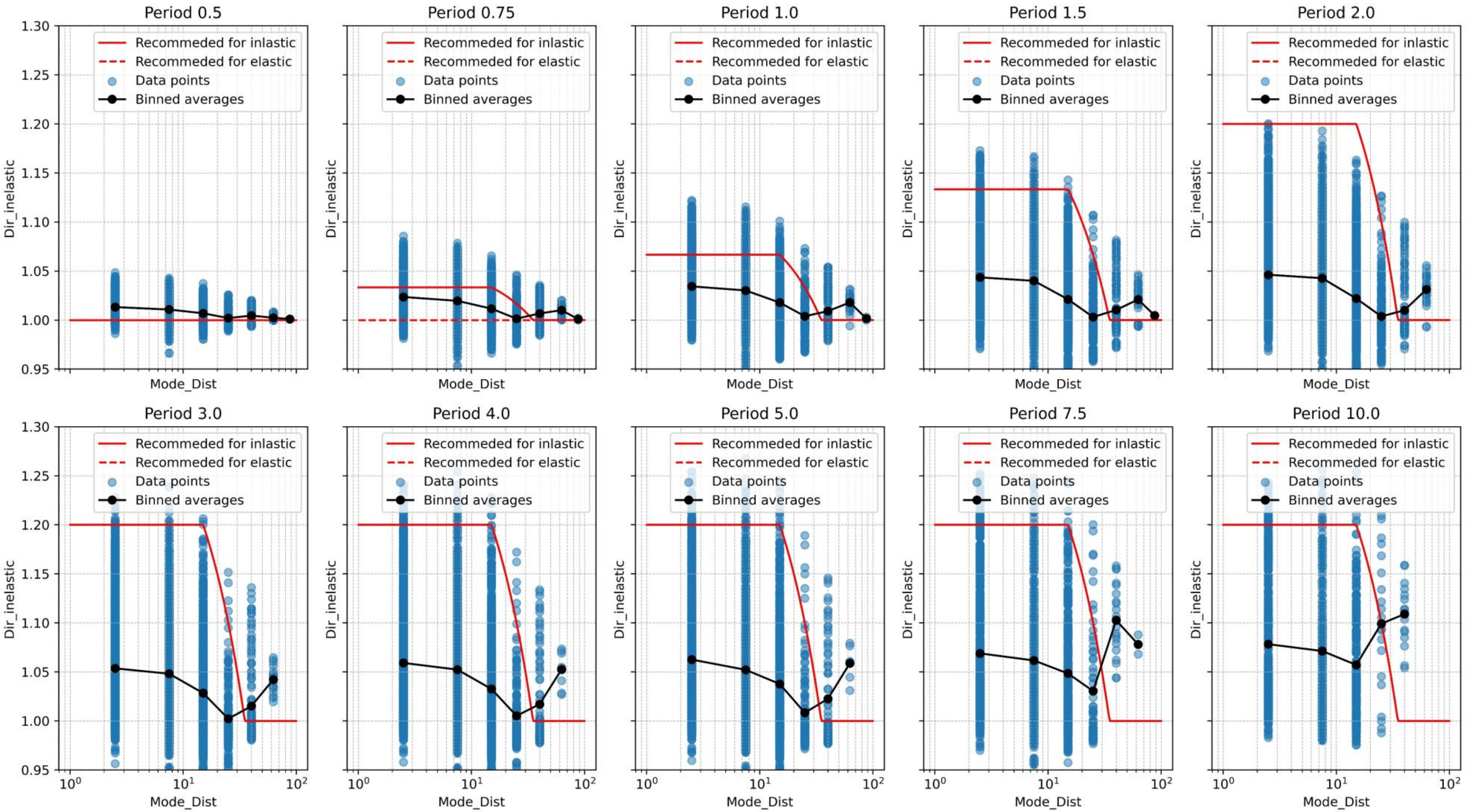
Recommendation – linear-elastic response ONLY



RECOMMENDATIONS

BASED ON INELASTIC RESPONSE

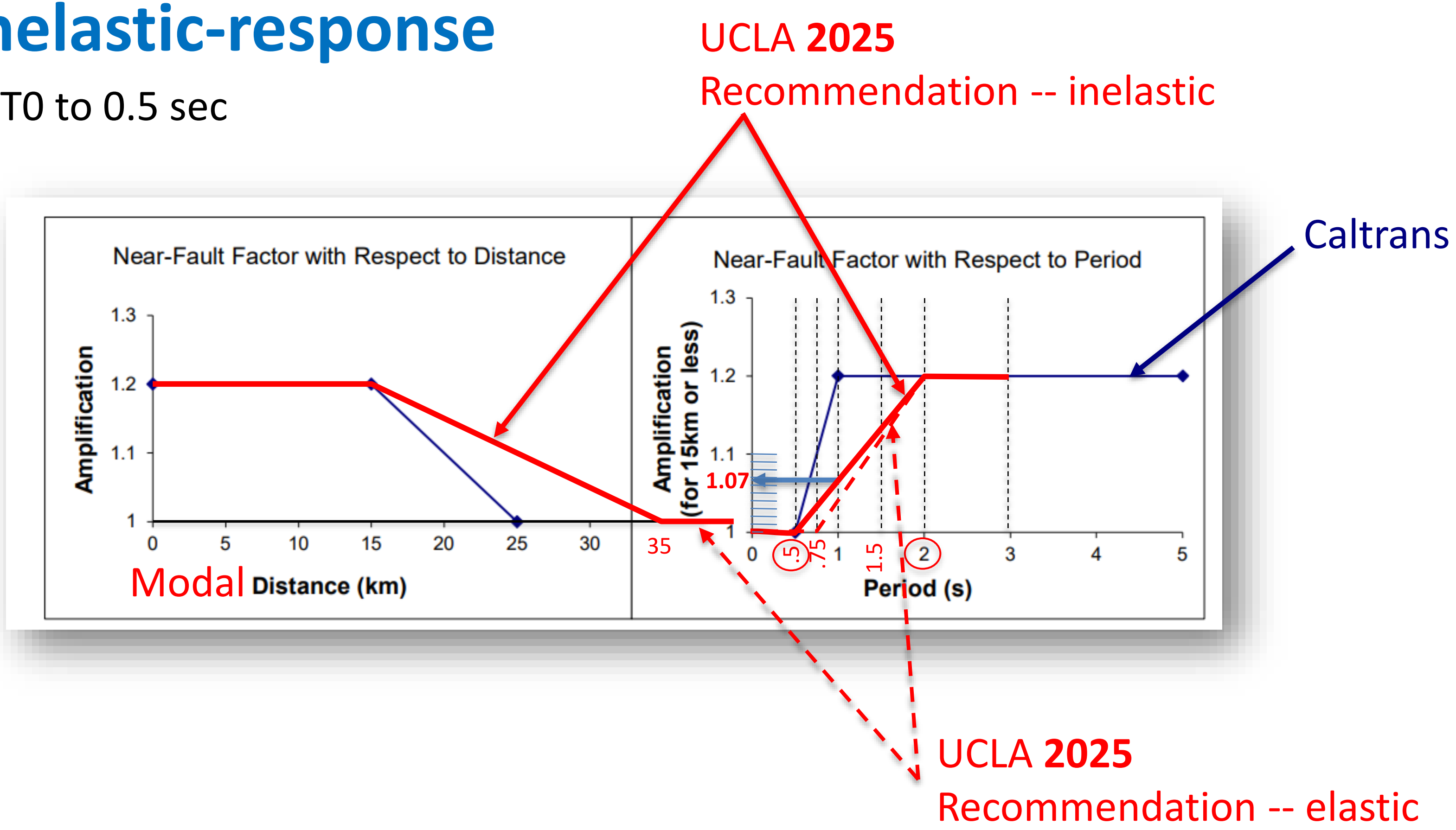

Period 0.5
Period 0.75
Period 1.0
Period 1.5
Period 2.0
Period 3.0
Period 4.0
Period 5.0
Period 7.5
Period 10.0
Recommeded for inlastic
Recommeded for elastic
Data points
Binned averages
WeightedDirModel
Mode_Dist
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
10^0
10^1
10^2



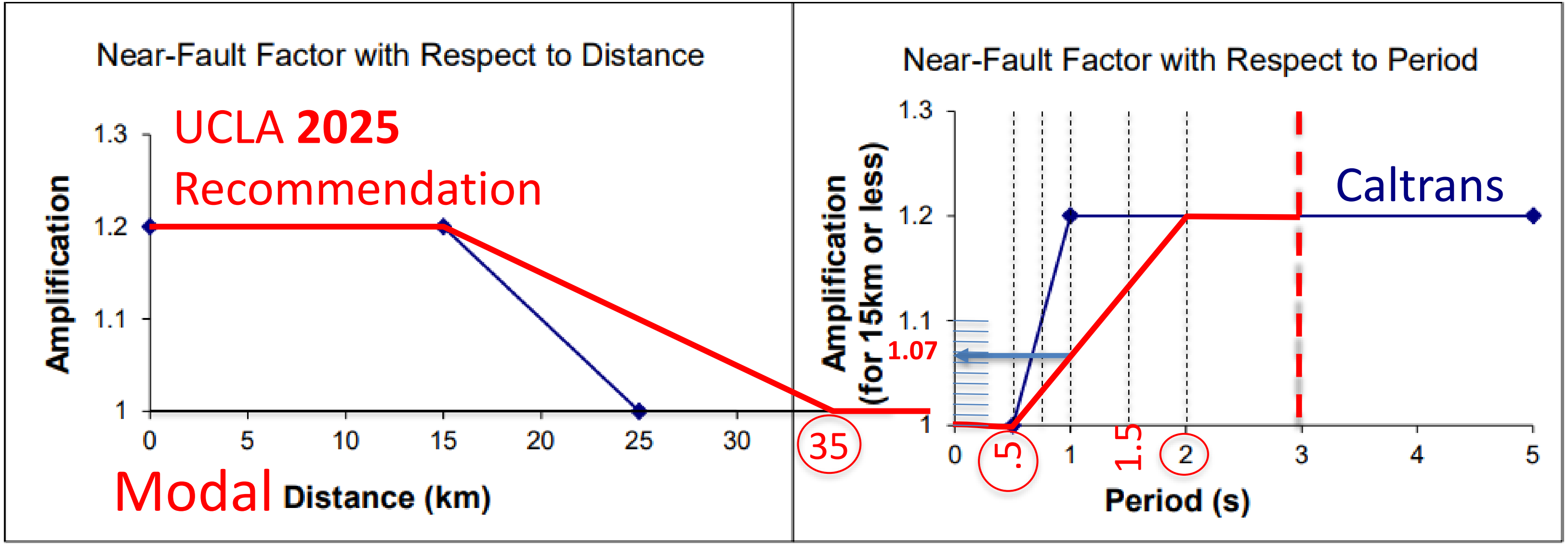
Period 0.5
Period 0.75
Period 1.0
Period 1.5
Period 2.0
Period 3.0
Period 4.0
Period 5.0
Period 7.5
Period 10.0
Recommeded for inlastic
Recommeded for elastic
Data points
Binned averages
Dir_inelastic
Mode_Dist
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
10^0
10^1
10^2

Recommendation considering period shift due to inelastic-response

Shift T0 to 0.5 sec



Recommended Model:



Distance →

Period ↓

UCLA-Directivity Recomm, Inelastic Effects	Distance (km)												
Period (sec)	0.1	1	2.5	5	7.5	10	12.5	15	20	25	30	35	40
0.01	1	1	1	1	1	1	1	1	1	1	1	1	1
0.1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2	1	1	1	1	1	1	1	1	1	1	1	1	1
0.3	1	1	1	1	1	1	1	1	1	1	1	1	1
0.4	1	1	1	1	1	1	1	1	1	1	1	1	1
0.5	1	1	1	1	1	1	1	1	1	1	1	1	1
0.75	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.025	1.017	1.008	1	1
1	1.067	1.067	1.067	1.067	1.067	1.067	1.067	1.067	1.05	1.033	1.017	1	1
1.25	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.075	1.05	1.025	1	1
1.5	1.133	1.133	1.133	1.133	1.133	1.133	1.133	1.133	1.1	1.067	1.033	1	1
1.75	1.167	1.167	1.167	1.167	1.167	1.167	1.167	1.167	1.125	1.083	1.042	1	1
2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.15	1.1	1.05	1	1
2.5	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.15	1.1	1.05	1	1
3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.15	1.1	1.05	1	1
5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Ratio: UCLA-Directivity Recomm, Inelastic Effects/Caltrans SDC	Distance (km)												
Period (sec)	0.1	1	2.5	5	7.5	10	12.5	15	20	25	30	35	40
0.01	1	1	1	1	1	1	1	1	1	1	1	1	1
0.1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2	1	1	1	1	1	1	1	1	1	1	1	1	1
0.3	1	1	1	1	1	1	1	1	1	1	1	1	1
0.4	1	1	1	1	1	1	1	1	1	1	1	1	1
0.5	1	1	1	1	1	1	1	1	1	1	1	1	1
0.75	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.98	1.02	1.01	1	1
1	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.95	1.03	1.02	1	1
1.25	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.98	1.05	1.03	1	1
1.5	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	1	1.07	1.03	1	1
1.75	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	1.02	1.08	1.04	1	1
2	1	1	1	1	1	1	1	1	1.05	1.1	1.05	1	1
2.5	1	1	1	1	1	1	1	1	1.05	1.1	1.05	1	1
3	1	1	1	1	1	1	1	1	1.05	1.1	1.05	1	1
5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Summary

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

- Dr. Bahrampouri, Dr. Zengin, and Prof. Bozorgnia are currently working on:
  - 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