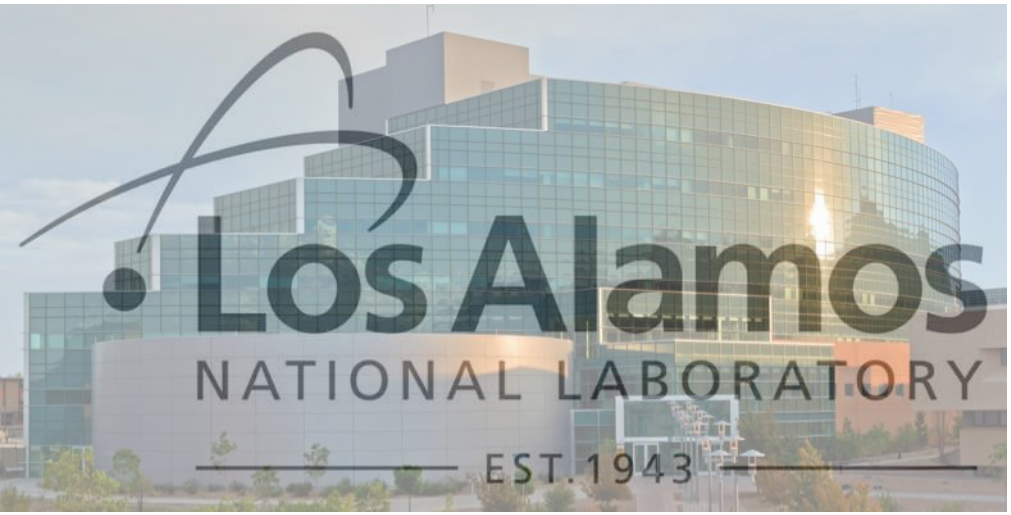
Predicting Local and Regional Phase Amplitudes



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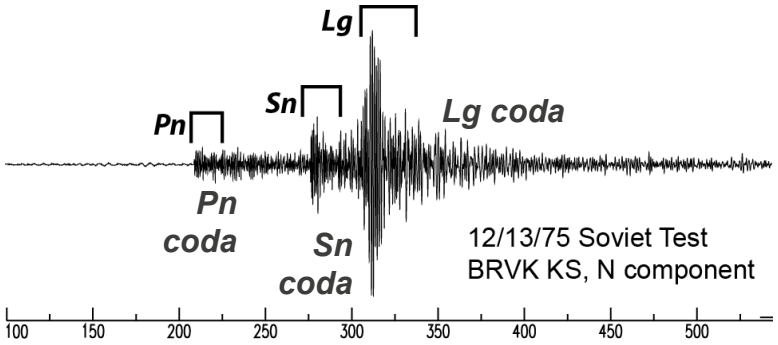
CTBT: Science and Technology 2017 Conference; Vienna, June 29/30
T1.2-O5

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

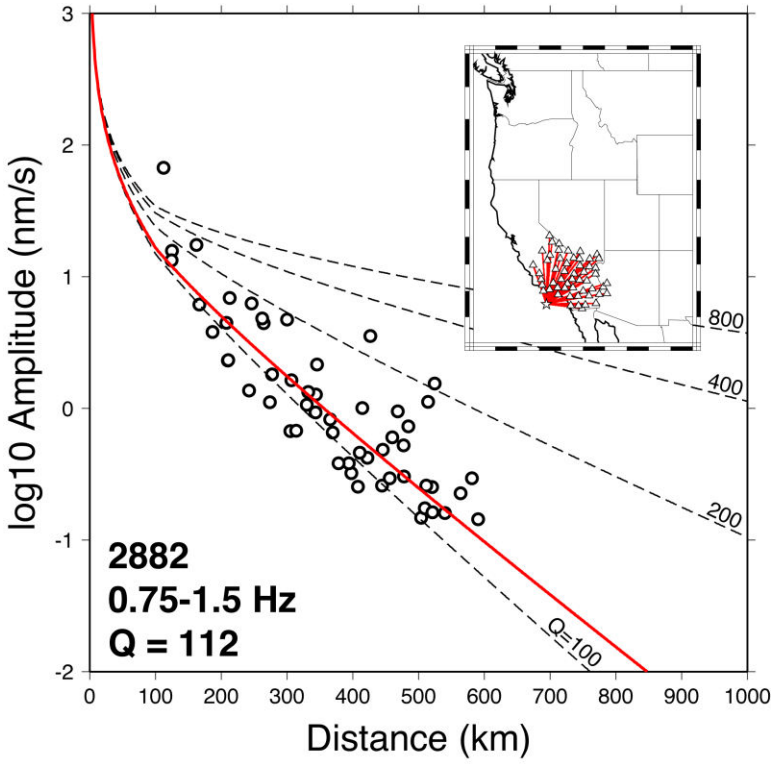
Amplitude Data



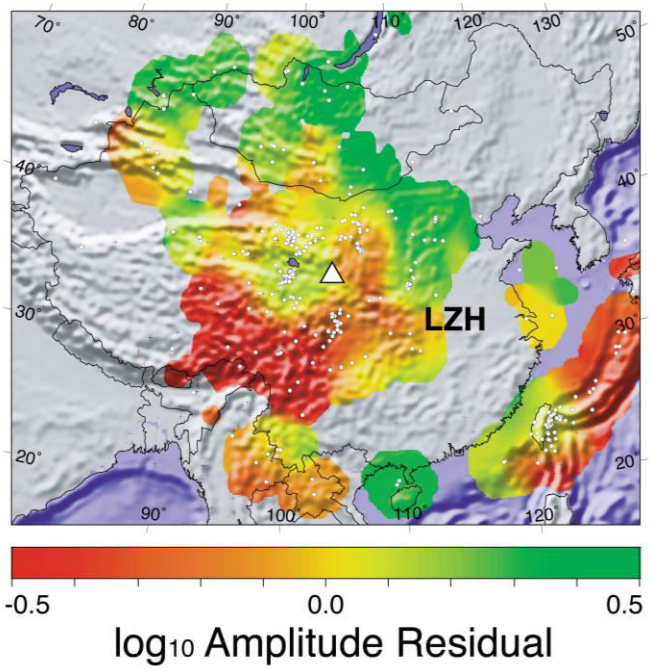
RMS amplitude measurement pictured above.

We also measure background noise and variance, as well as pre-phase noise.

Horizontal motions measured on R and T components, produced using best origins.

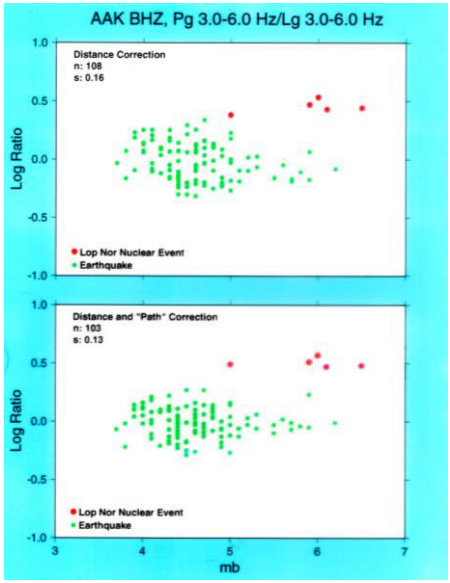


From the 90s: Amplitude Correction Surfaces



- Station LZH, Lg phase, 1 Hz
- Empirical corrections reduce discriminant scatter for earthquakes
- Discrimination range is improved
- Tomography should improve coverage
- Phillips, W.S., G.E. Randall, and S.R. Taylor (1998), Path correction using interpolated amplitude residuals: An example from central China, *Geophys. Res. Lett.*, **25**, 2729-2732.

- Amplitude surfaces improve high-frequency discrimination
- AAK BHZ
- Pg/Lg 3-6 Hz
- Lop Nor tests (red)



1-D

2-D

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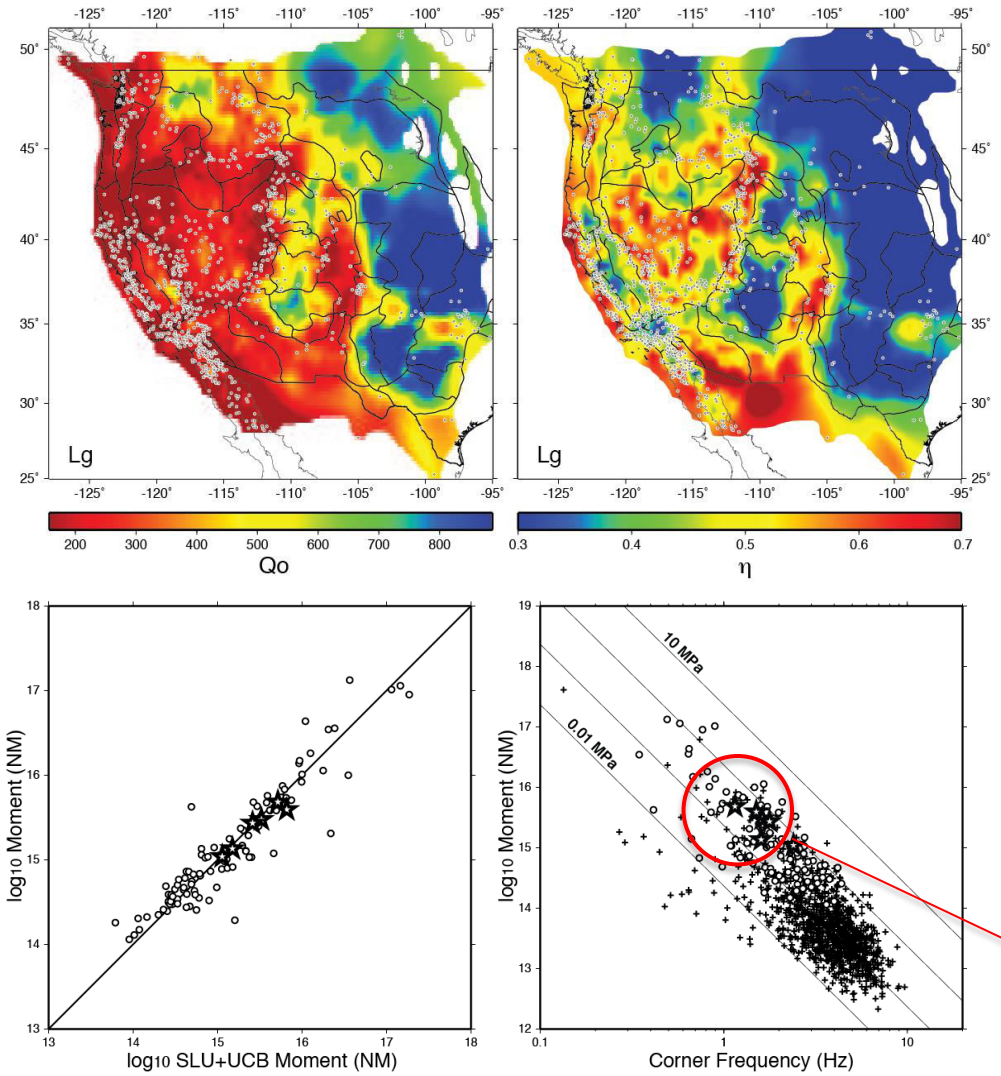
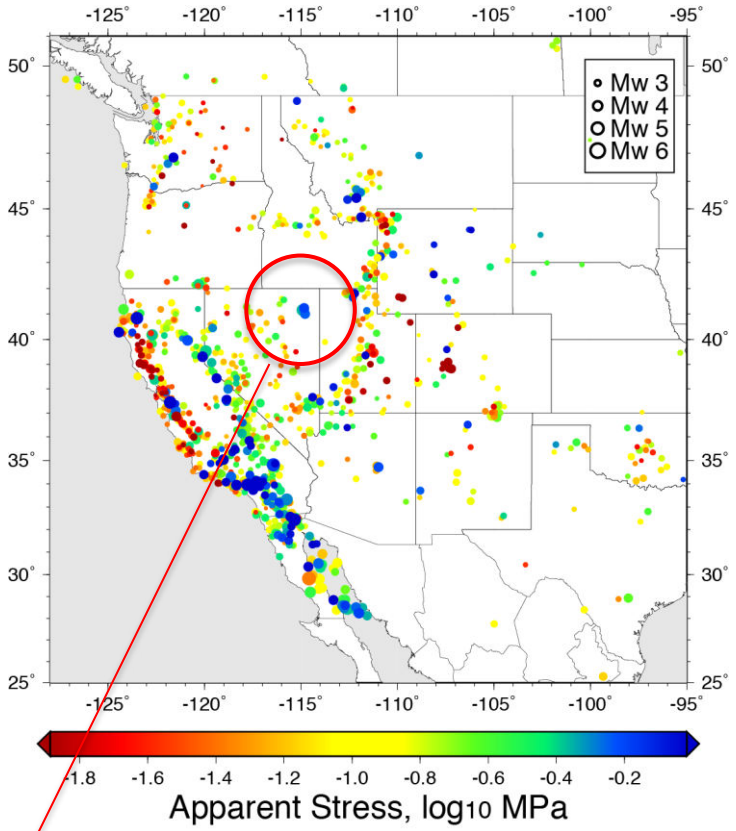
Amplitude (and Coda) Tomography Method

- Invert for Source, 2-D Q, and Site
- Source = ω^2(Mo, fc), isotropic
- Q = Qo f $^{\eta}$ (amplitudes), Q = Q(f) (coda)
- Site = Site(phase, band) + Transfer (absolute site, *Malagnini, et al, 2004*).
- Constrain Q-fc tradeoff using special events with "known" Mo, fc (relative coda, *Mayeda 2007, 2010; Fisk and Phillips 2013ab*).
- R, T, and Z treated as site terms.

Amplitude Tomography with Source Constraints



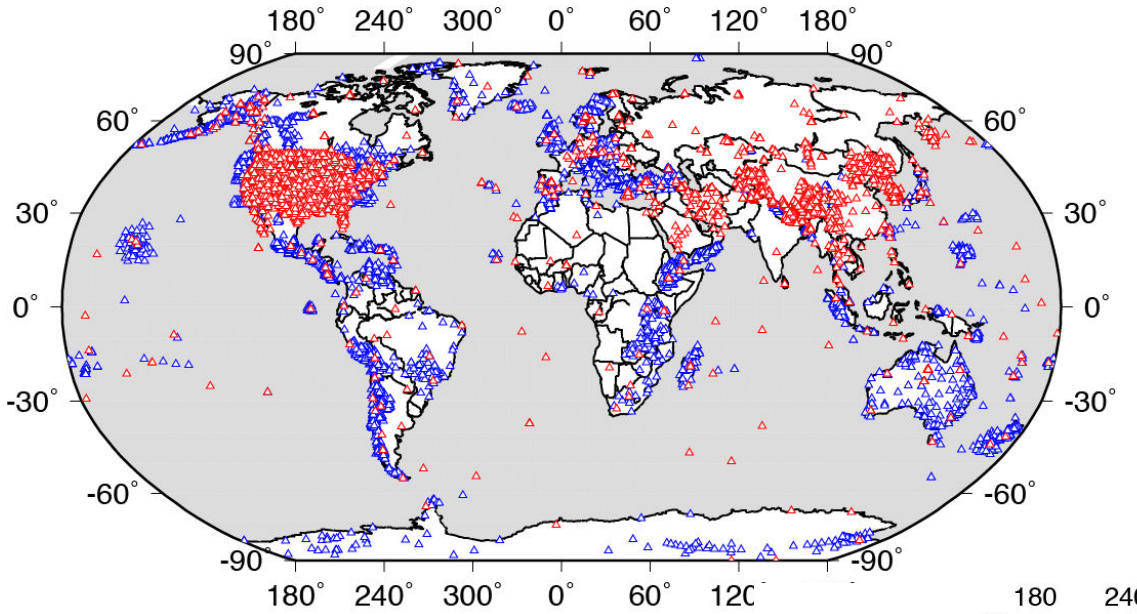


Wells, Nevada

Phillips, Mayeda, Malagnini, 2014

Global Amplitude Models

Current Global Tomography (AMP1.2 adds 3C data)

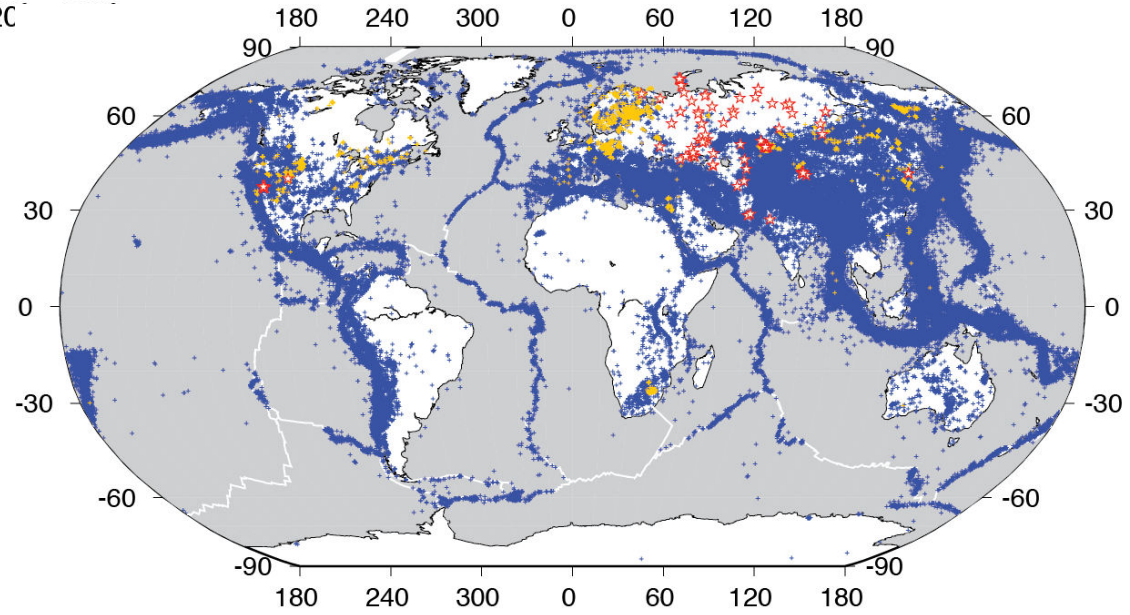


Stations

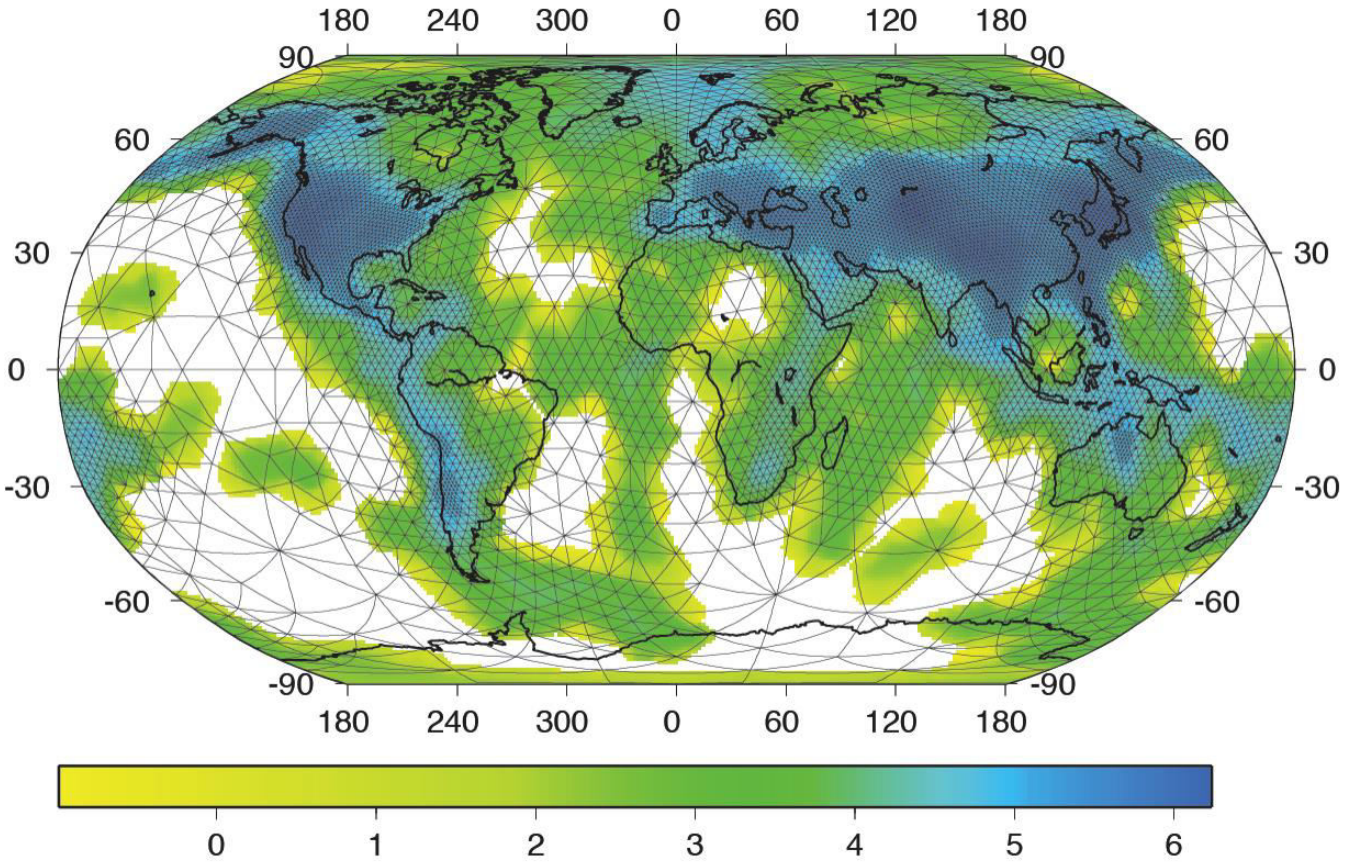
- ***Red**: Current Work*
  - *IRIS Asia, USArray, Global networks*
  - *Regional Networks*
- ***Blue**: New Stations*
  - *IRIS Permanent and PASSCAL networks*

Events:

- **EQ**
- **UNT**
- **Chemical**

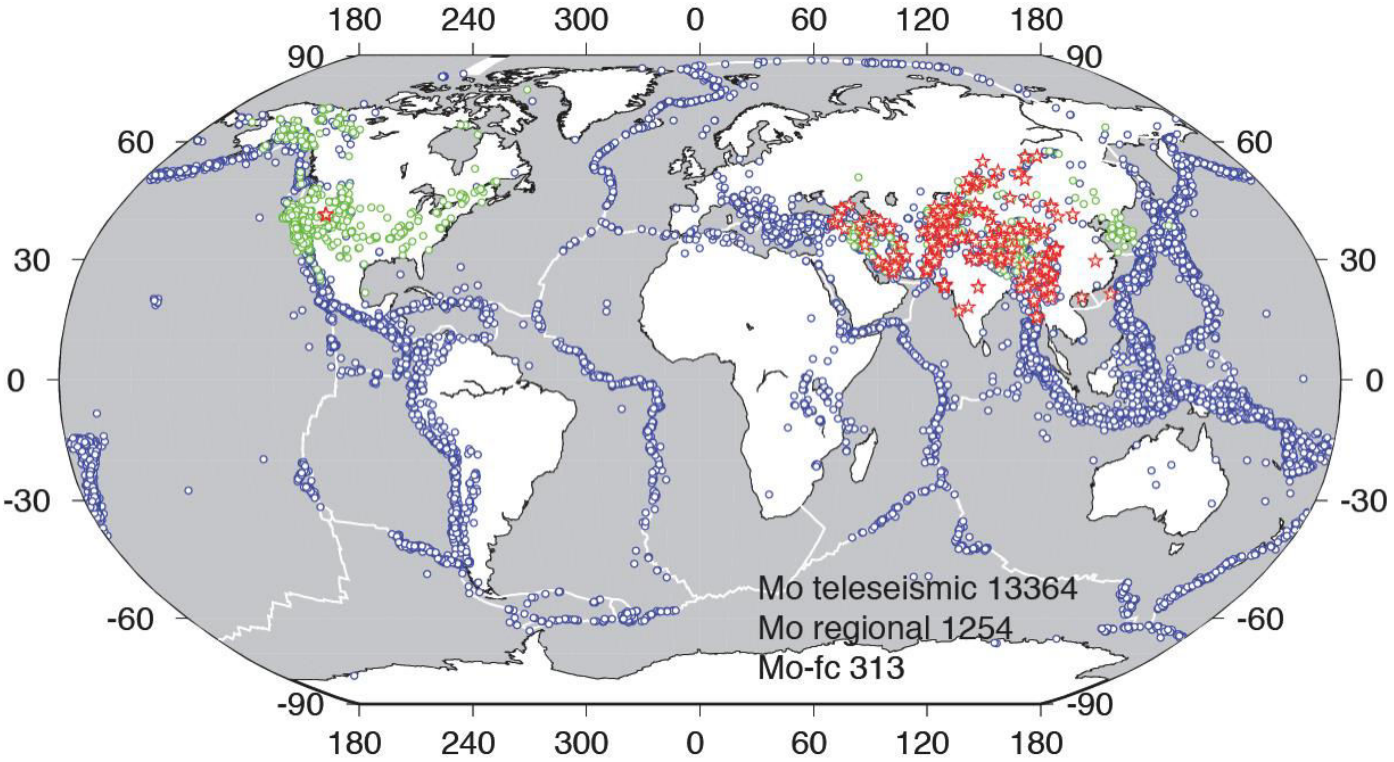


Inversion Grid



Multi-scale grid using GeoTess (SNL)

Source Constraints, AMP 1.2

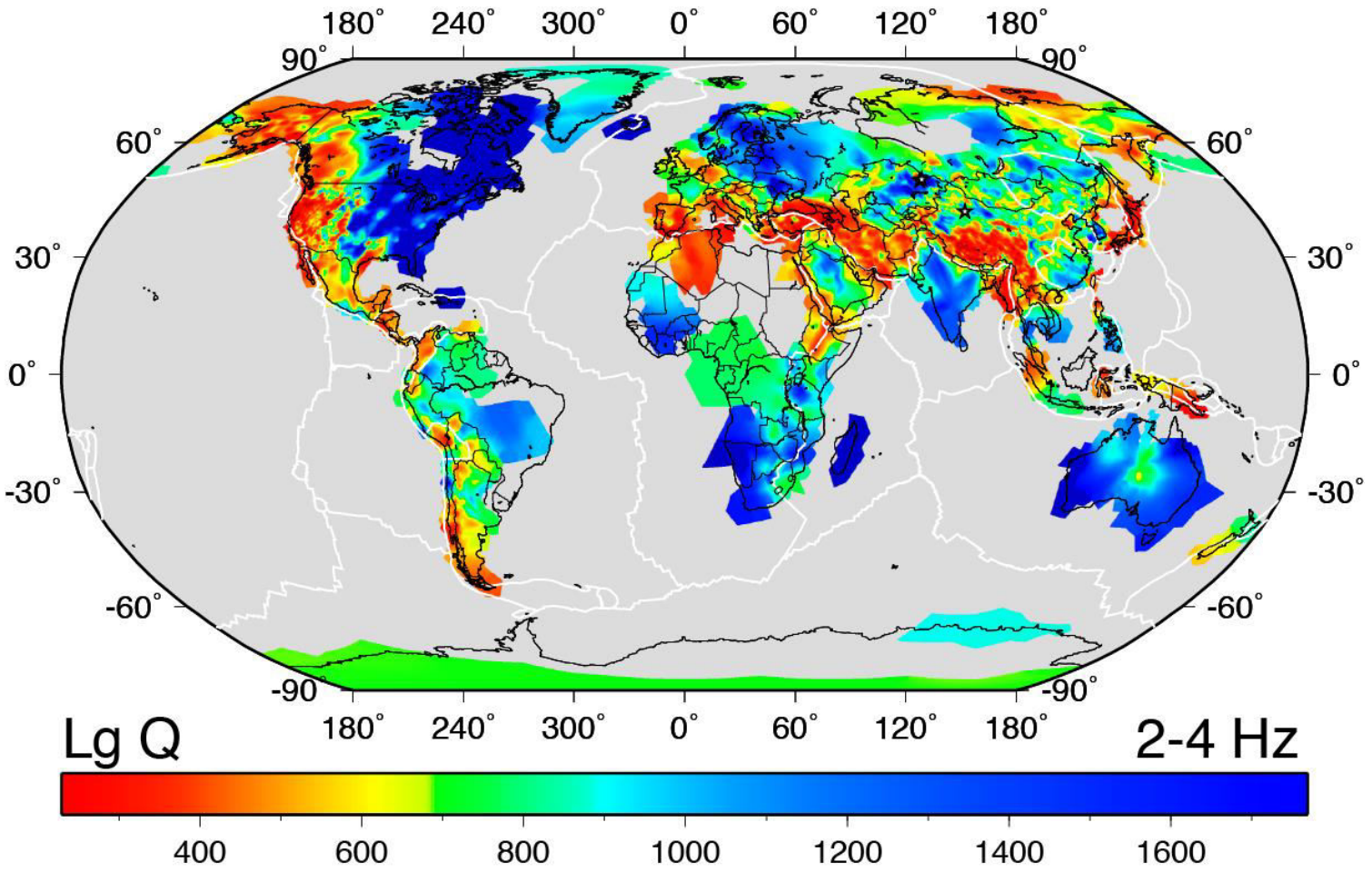


Blue = Teleseismic Mo (CMT, USGS)

Green = Regional Mo (literature, SLU, UCB)

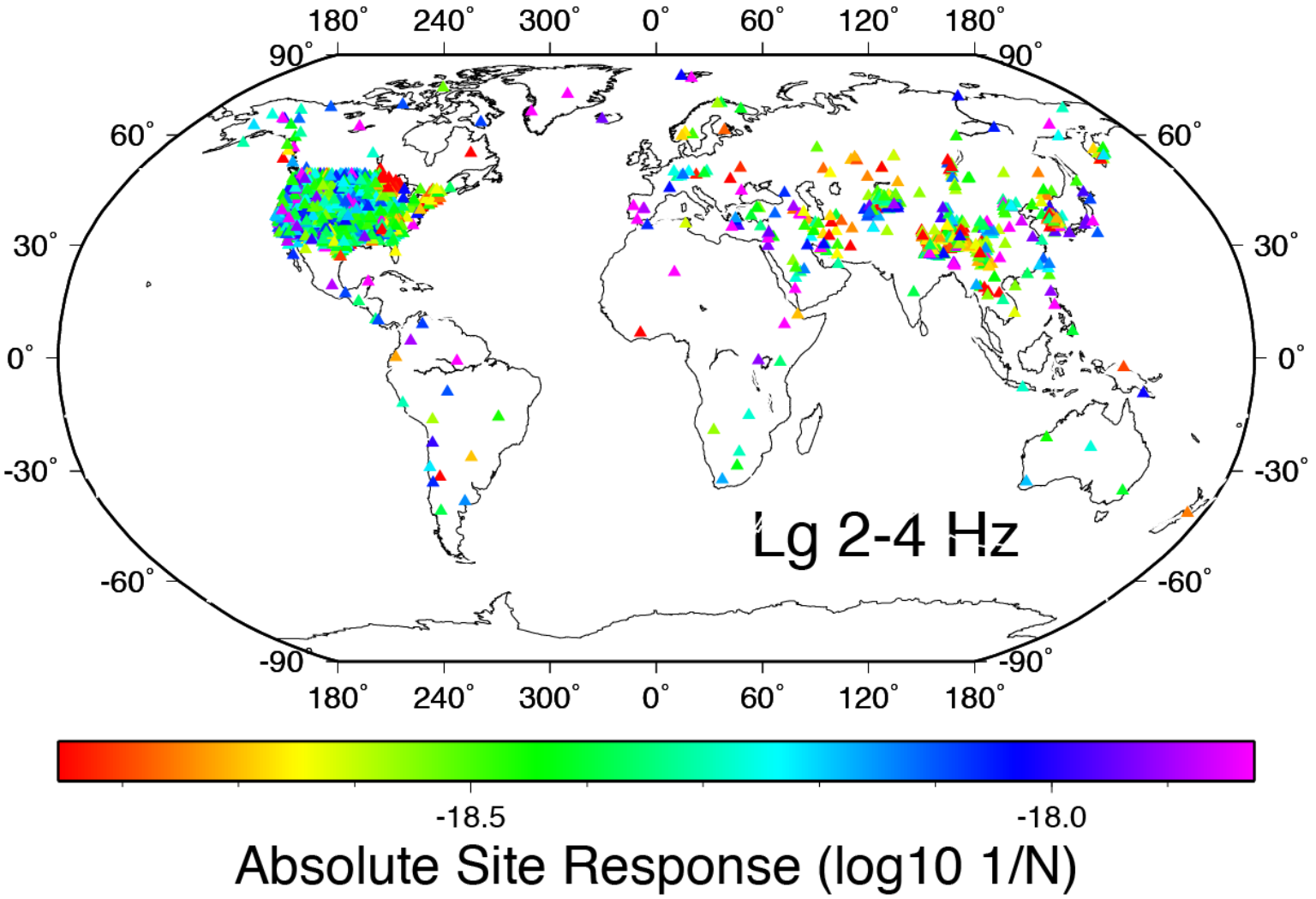
Red = Mo + fc from coda spectral ratio studies

2-4 Hz Lg Q

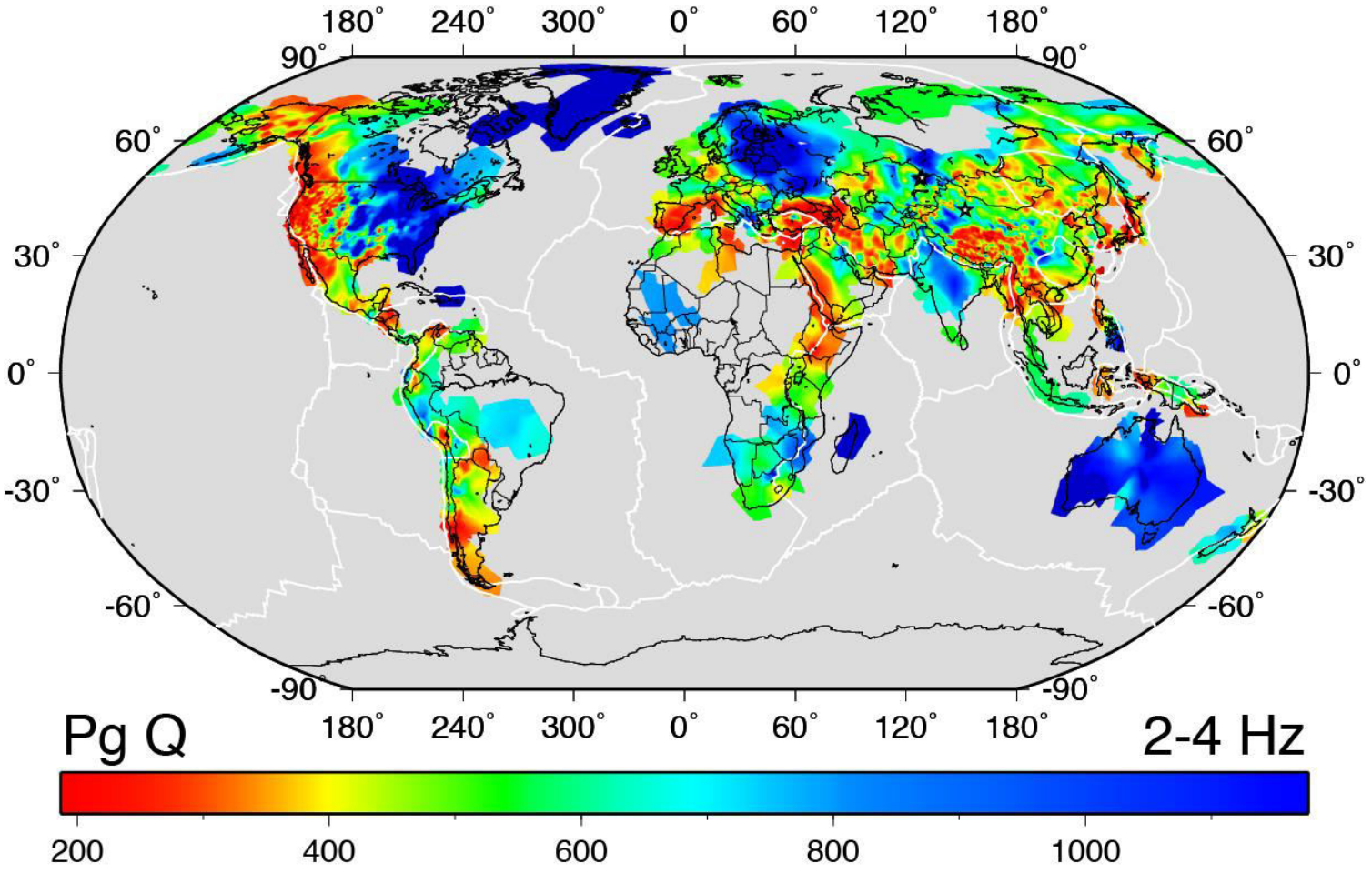


- AMP1.2
- Best in N. America and Asia
- Continents covered, except shield regions, Antarctica

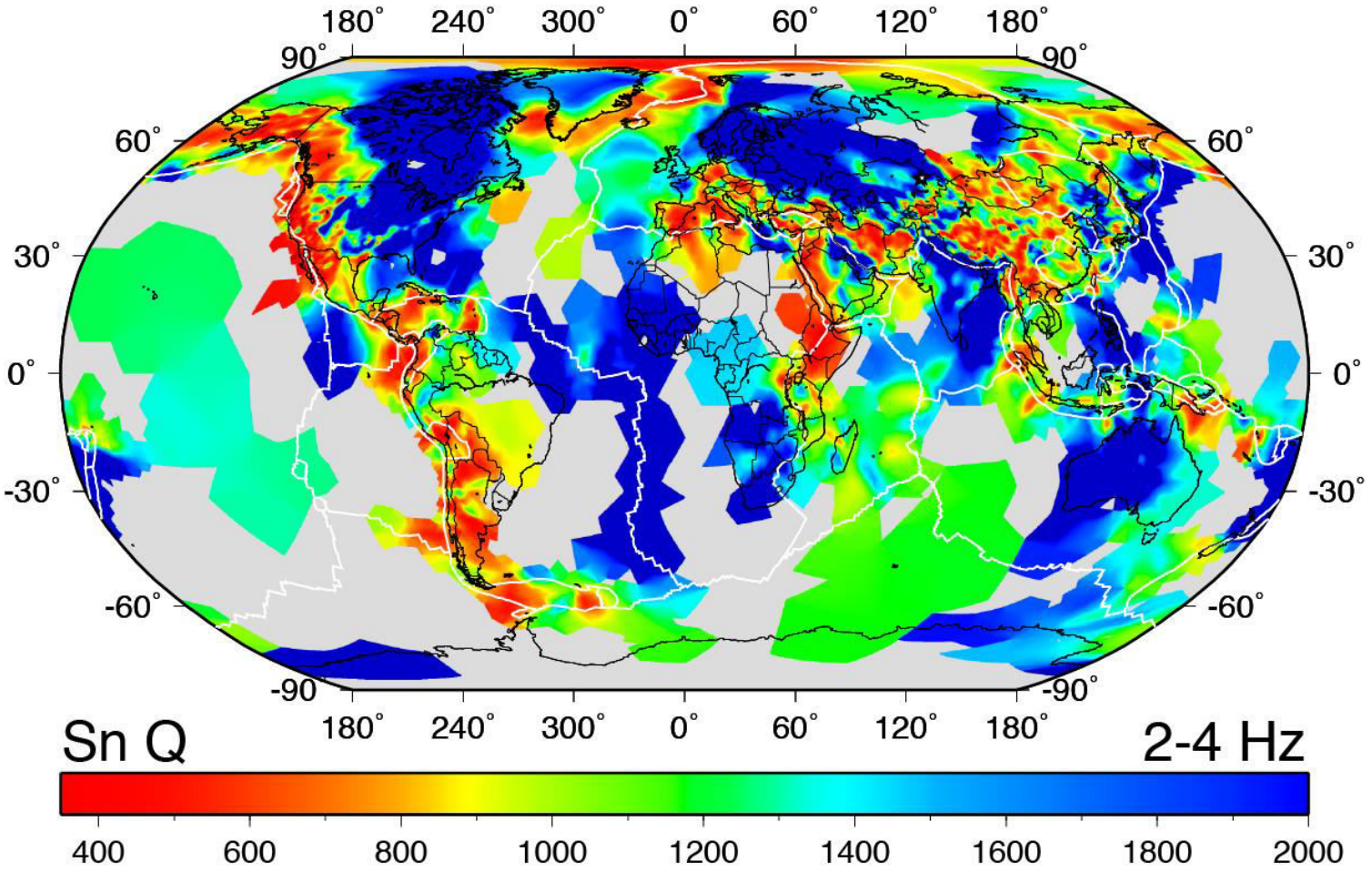
Site Terms


180° 240° 300° 0° 60° 120° 180°
90°
60°
30°
0°
-30°
-60°
-90°
Lg 2-4 Hz
-18.5
-18.0
Absolute Site Response (log10 1/N)

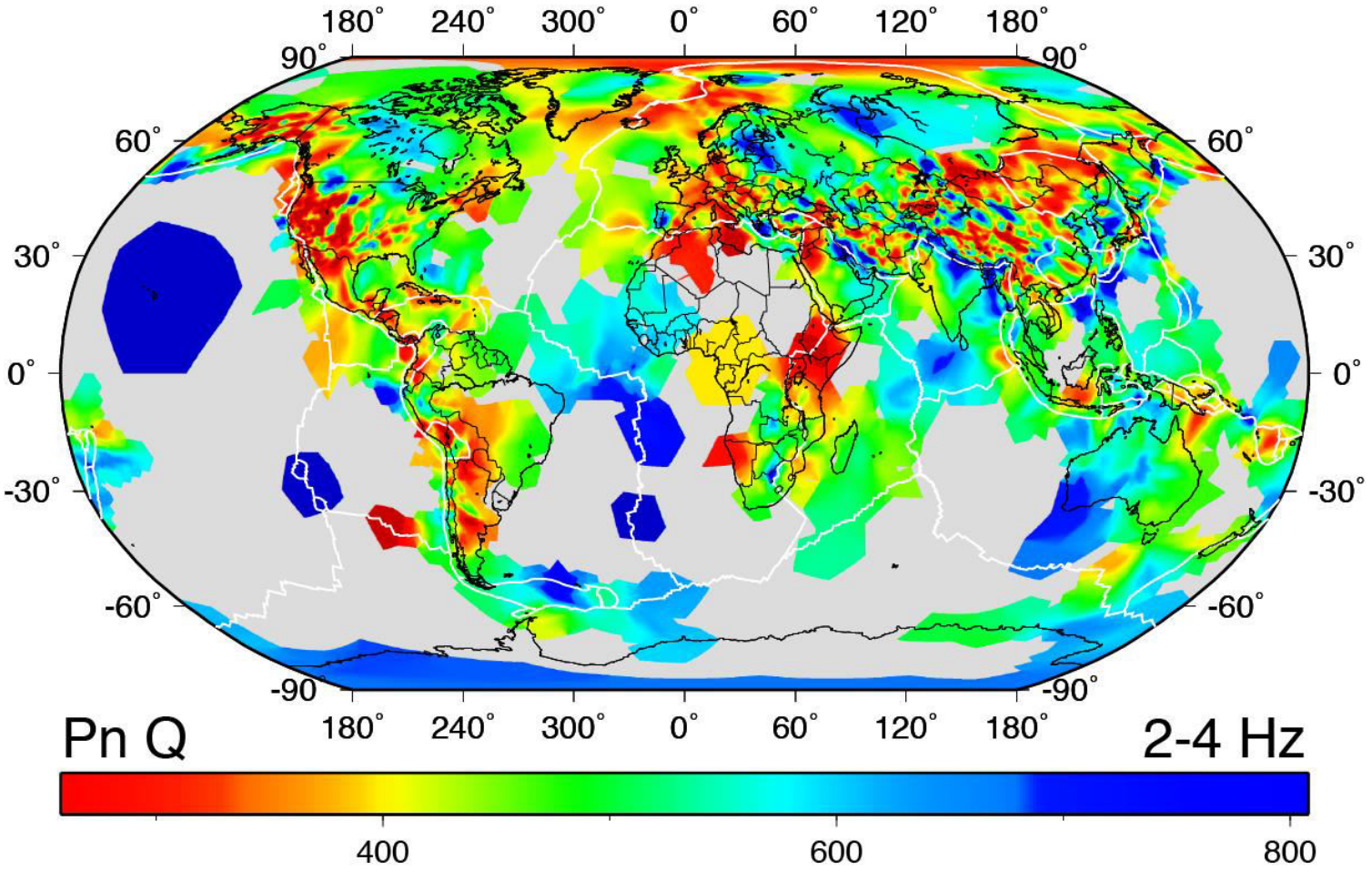
Pg 2-4 Hz


180° 240° 300° 0° 60° 120° 180°
90°
60°
30°
0°
-30°
-60°
-90°
Pg Q
2-4 Hz
200
400
600
800
1000

Sn 2-4 Hz


180° 240° 300° 0° 60° 120° 180°
90°
60°
30°
0°
-30°
-60°
-90°
Sn Q
2-4 Hz
400 600 800 1000 1200 1400 1600 1800 2000

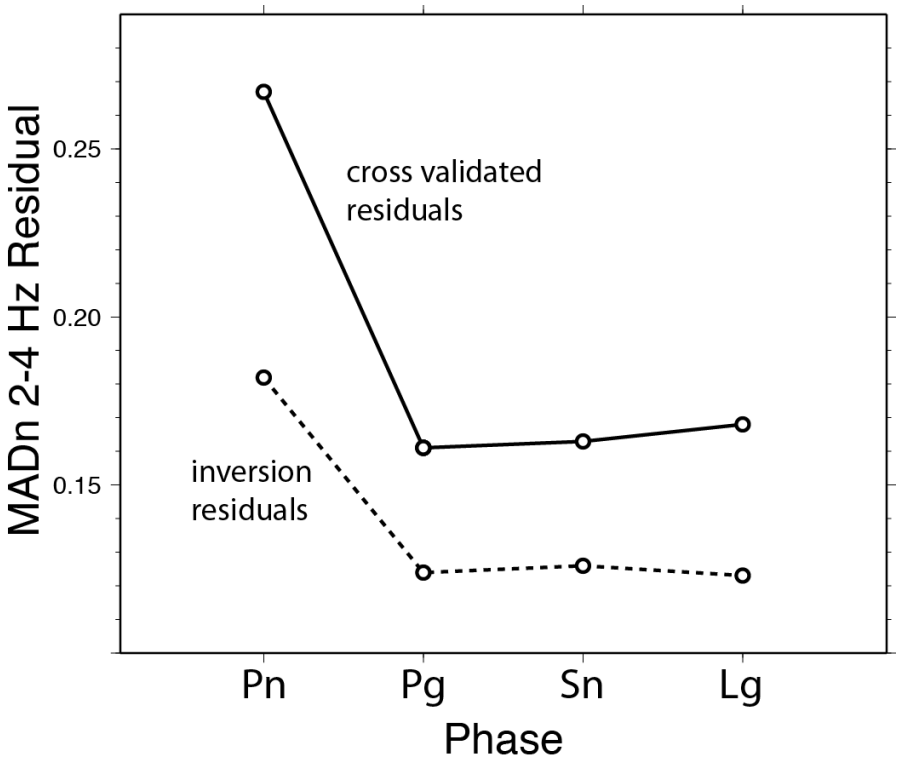
Pn 2-4 Hz



Spreading: Yang 2007, 2011

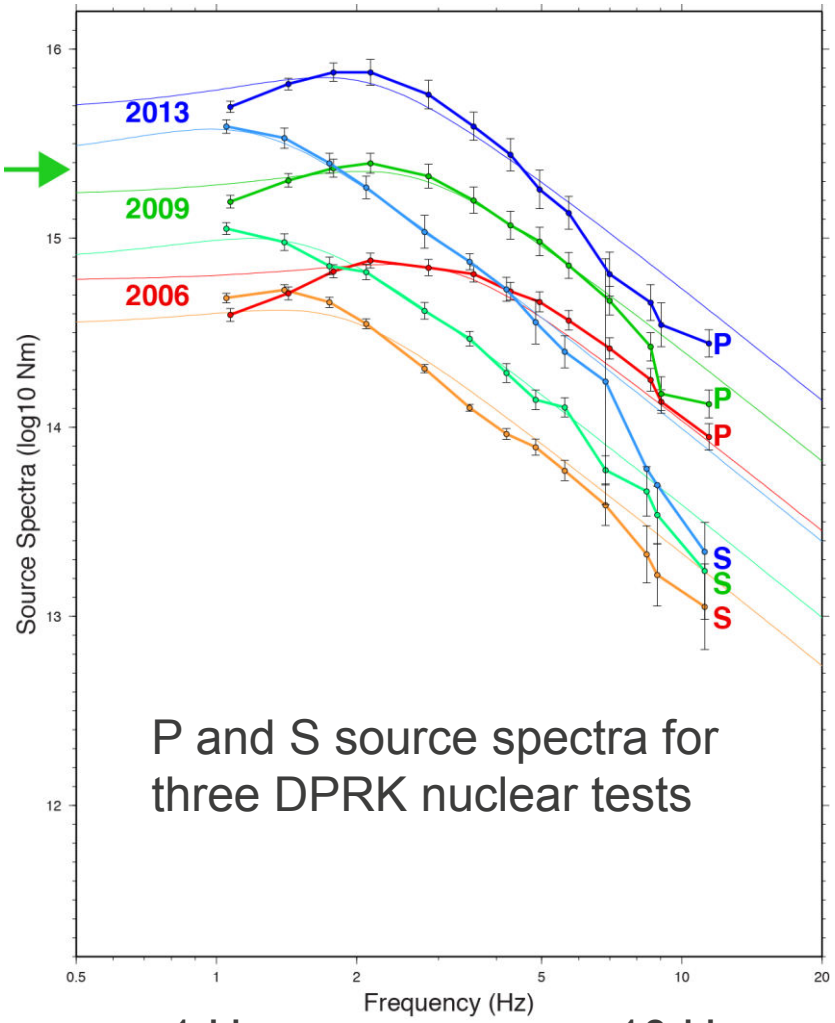
2-4 Hz Residuals by Phase

- Pg, Sn, Lg data fit 2-D Q model well.
- Pn data fit poorly.
- Why is Sn different from Pn?
  - Upper mantle S gradient less than P gradient => Pn dives deeper, 3-D effects more pronounced.
  - Lithosphere S attenuation greater than P attenuation => any diving S dies away.
  - Azimuthal source effects greater for Pn?
  - Also consider Moho curvature effects.



Source Spectra

- We project amplitude data back to the source using Q and site models.
- Network stack with MLE for censored data.
- Separation between P and S => discrimination.
- Fit source models to spectra => yield estimation (Fisk conjecture assumed).

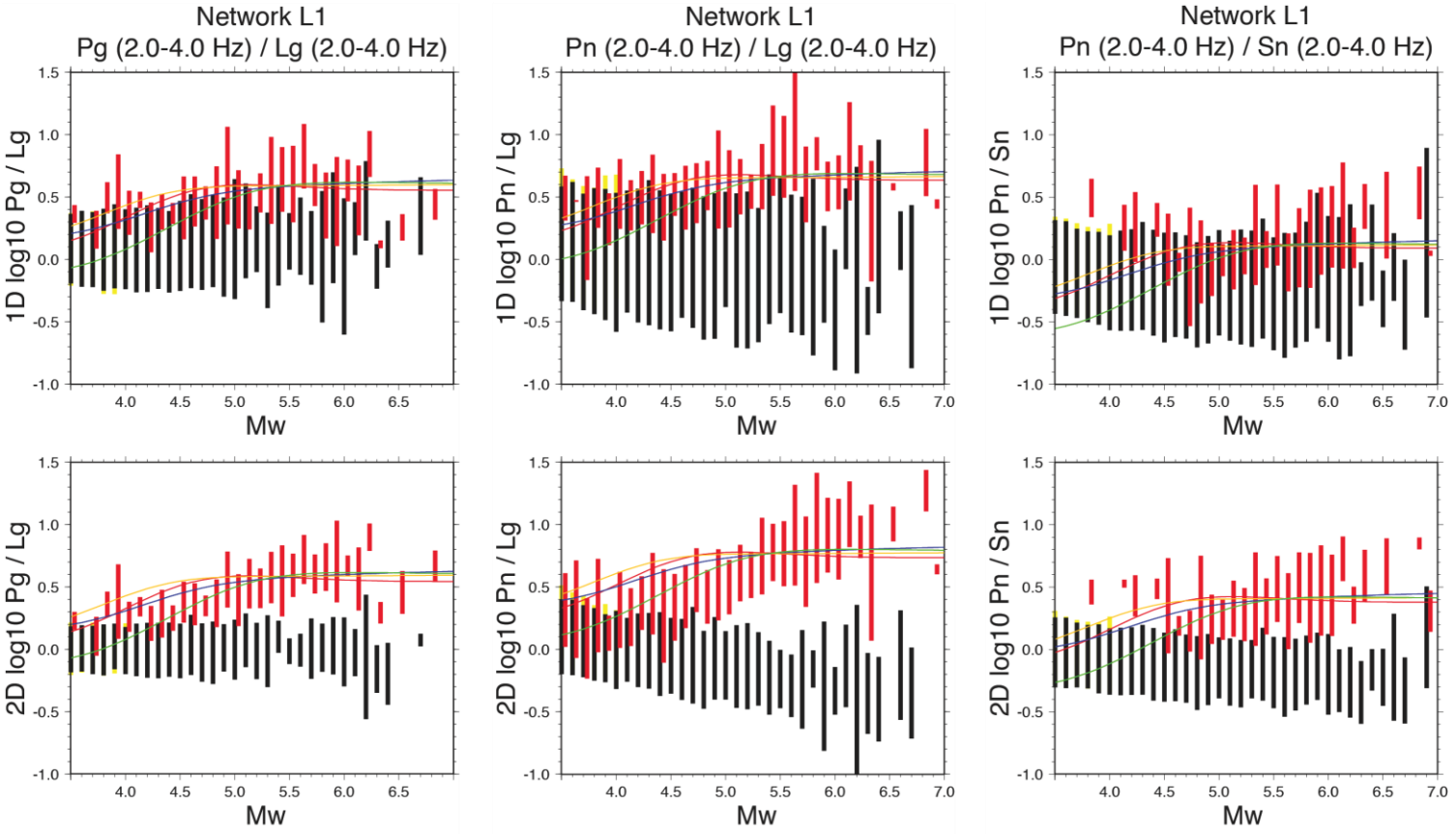


P and S source spectra for three DPRK nuclear tests

High Frequency Discrimination

1-D

2-D

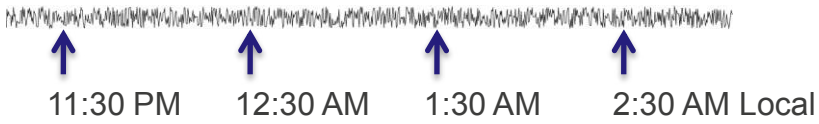


Network Medians
MLE for Censored Data
Mueller-Murphy plus “Fisk Conjecture” curves

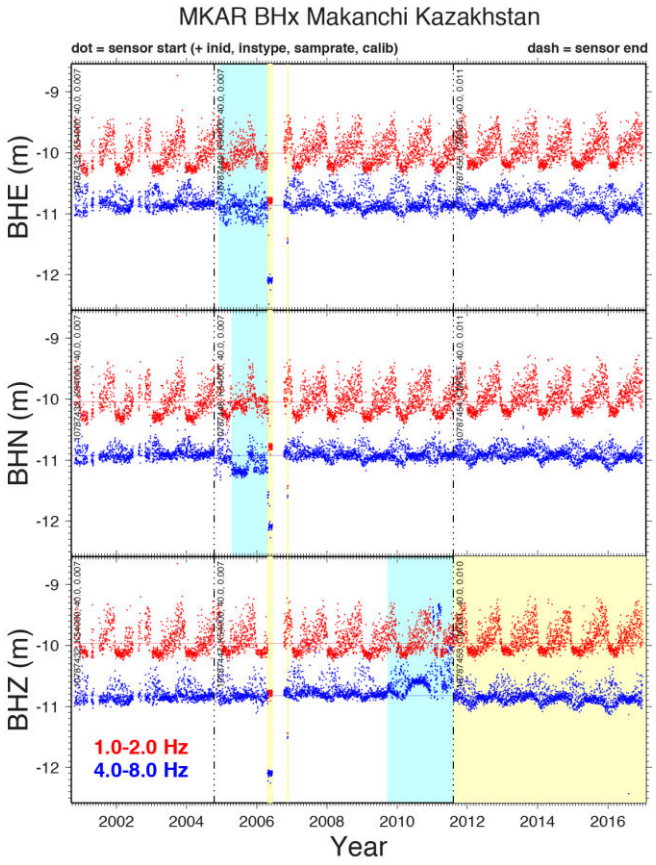
New Work

Midnight Noise for Amplitude Quality Control

- Global coverage, focus on Asia
- Database storage for fast access
- Time domain RMS, bandpassed traces, also check IRIS MUSTANG noise mode
- 0.25×10^9 noise measurements, 5 high-frequency bands, 16,000 stations
- 21,000 manually reviewed channels, 15,000 suspect intervals



- MAK (CTBT primary) example
- Sensor start/end marked
- Suspect intervals chosen manually
  - Level changes (yellow)
  - Drift (cyan)
- Discard from amplitude, coda data
- Fix in future



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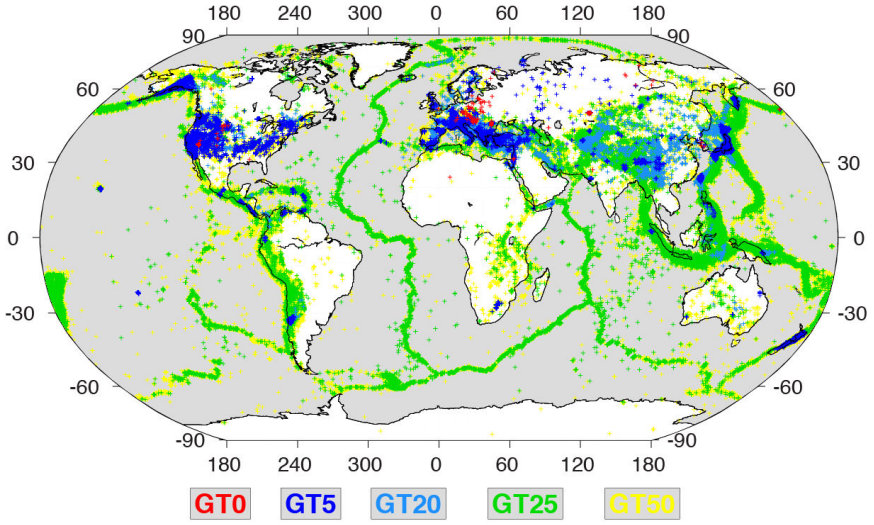
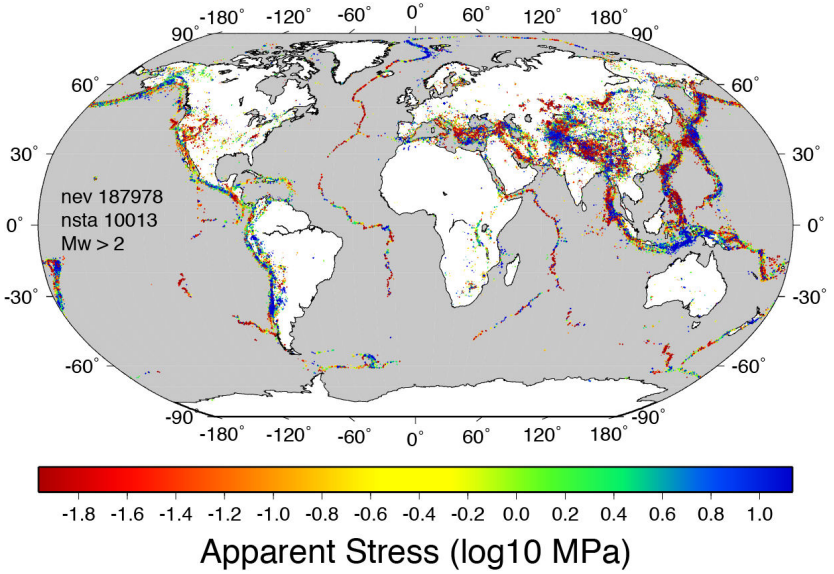
Ground Truth for Model Development

Location Ground Truth:
=>Earth Models (Velocity)
=>Accurate Location

Source Spectra:
=>Earth Models (Q, …)
=>Accurate Discrimination and Yield Estimation

Epicenter Ground Truth



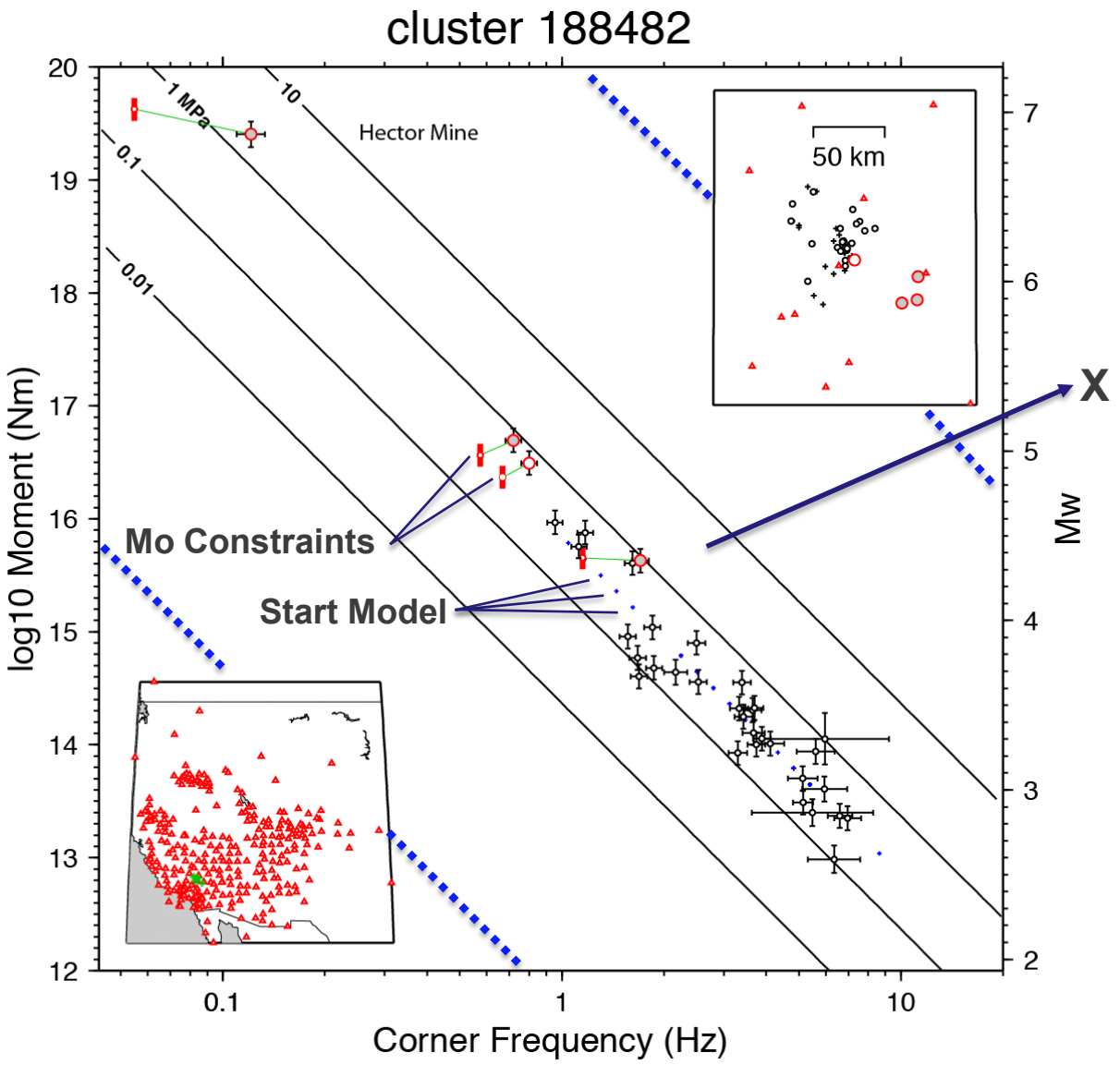


We use GT to develop models, and validate using “leave-N-out” cross-validation schemes.

Models are used to correct observations for path and site effects, providing accurate location, discrimination and yield estimates.

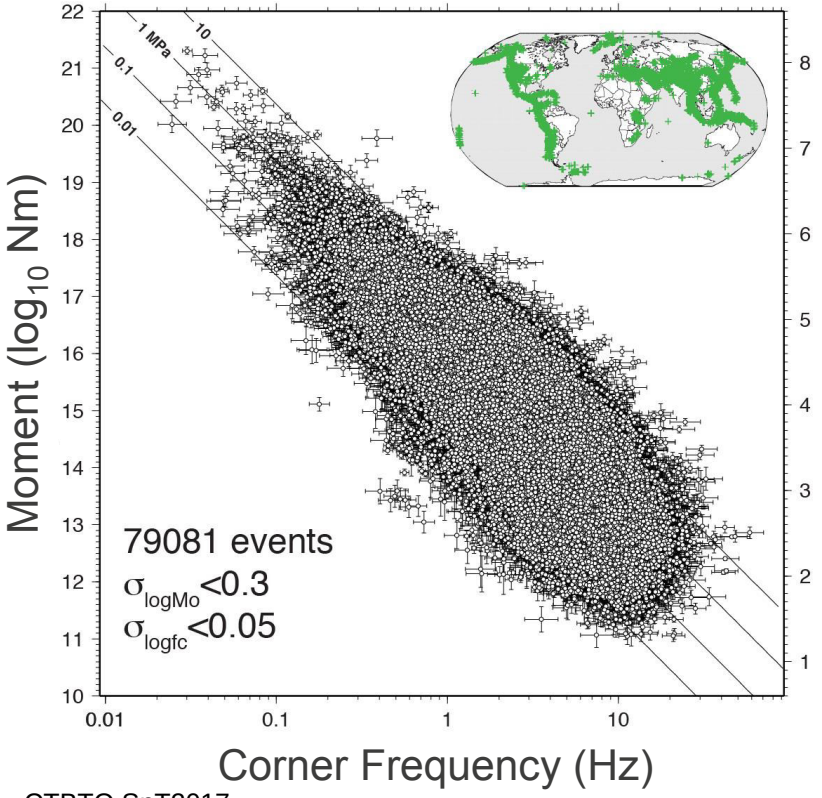
Source Parameter Inversion (Mojave Cluster)

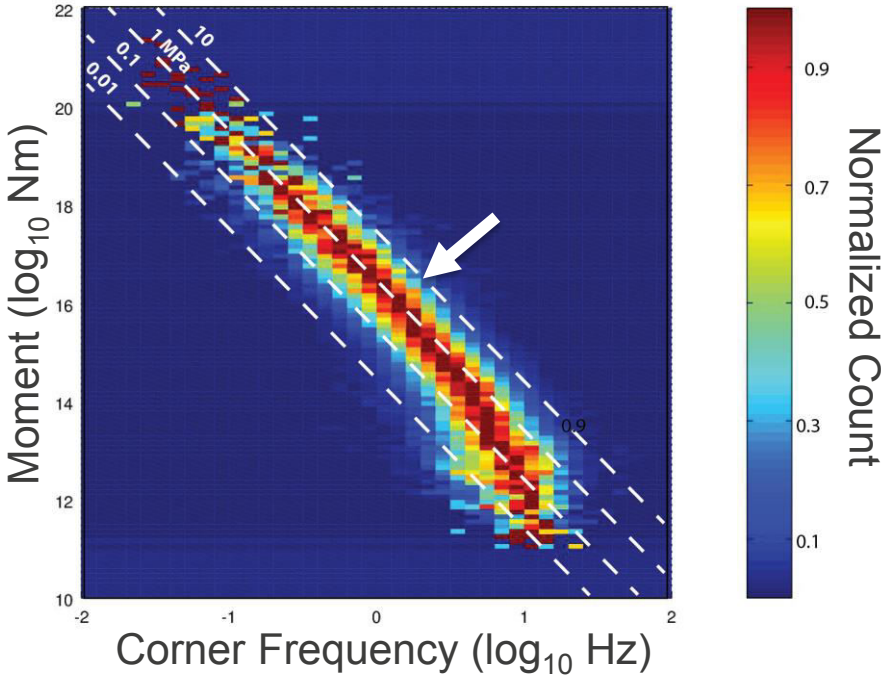
- Omega-2 fit for Mo and corner frequency
- All event pairs in cluster
- 3-bar, self-similar start model
- A-priori σ_{logMo} 0.1
- A-priori σ_{logfc} 0.15
- Levenberg-Marquardt DLS scheme
- Discard event and restart if stress bounds exceeded
- Confirmed (2-station) ratios only
- Allow single station data from confirmed time intervals



Source Parameter Results

- Global Mo vs fc
- Limits on model error
- Large events ~ 1MPa
- Small event scatter is real





- Count density, normalized by events per moment bin
- ~Self similar, Mo > 10^{16} (Mw 4.5, arrow)
- Possible Nyquist effect for small events must be tested

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Summary

- **Pg, Sn, and Lg fit 2-D Q model well, Pn less so.**
- **Models improve discrimination and yield estimation work**
- **Source parameters are fundamental to the development and testing of broad area, local/regional amplitude models.**

- **Relative envelope measurements provide the stability and precision we need to invert for a global set of source parameters.**
- **The source parameter work provides valuable data QC.**
- **Midnight noise also examined for QC.**
- **Future Issues:**
  - Anisotropic source, directivity, inter-station Q constraints.
  - Incorporation of data w/o instrument response.
  - Cross validation using best source parameters as GT.
  - Detection and association applications.

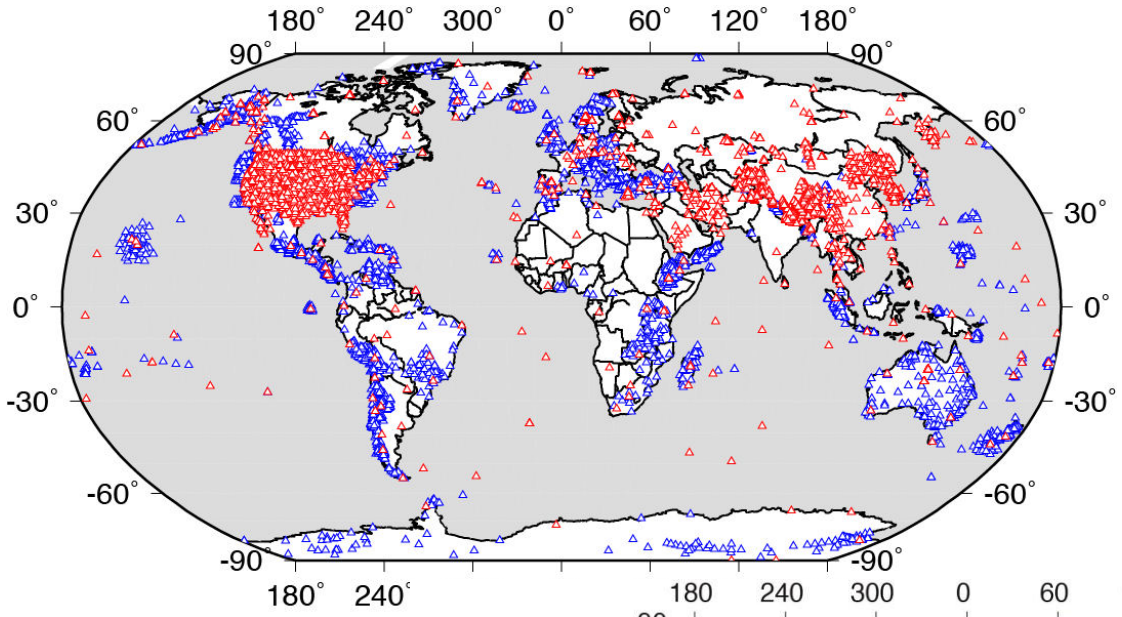
Extra Slides

Amplitude Measurements We Make/Store

- Local/Regional Distances (0-2500 km)
- Global Coverage
- Database storage for fast access

- ***Phase Amplitudes***
  - time domain RMS, bandpassed traces, convert to spectra
  - Pn, Pg, Sn, Lg (Sg)
  - plus pre-event and pre-phase noise
  - 1.3×10^9 phase amplitudes, 21 bands, 980,000 events, 14,000 stations
- ***Envelopes (Coda)***
  - 184×10^6 envelopes, 300,000 events, 14,000 stations
- ***Relative Envelope Amplitude***
  - 300×10^6 relative amplitudes, 7.6×10^6 event pairs, 11,000 stations
- ***Midnight Noise***
  - time domain RMS, bandpassed traces
  - 250×10^6 noise measurements, 9 bands, 16,000 stations
  - 22,000 manually reviewed channels, 17,000 suspect intervals
- ***MUSTANG Daily Noise Mode (IRIS)***
  - 92×10^6 noise measurements, 36,000 channels

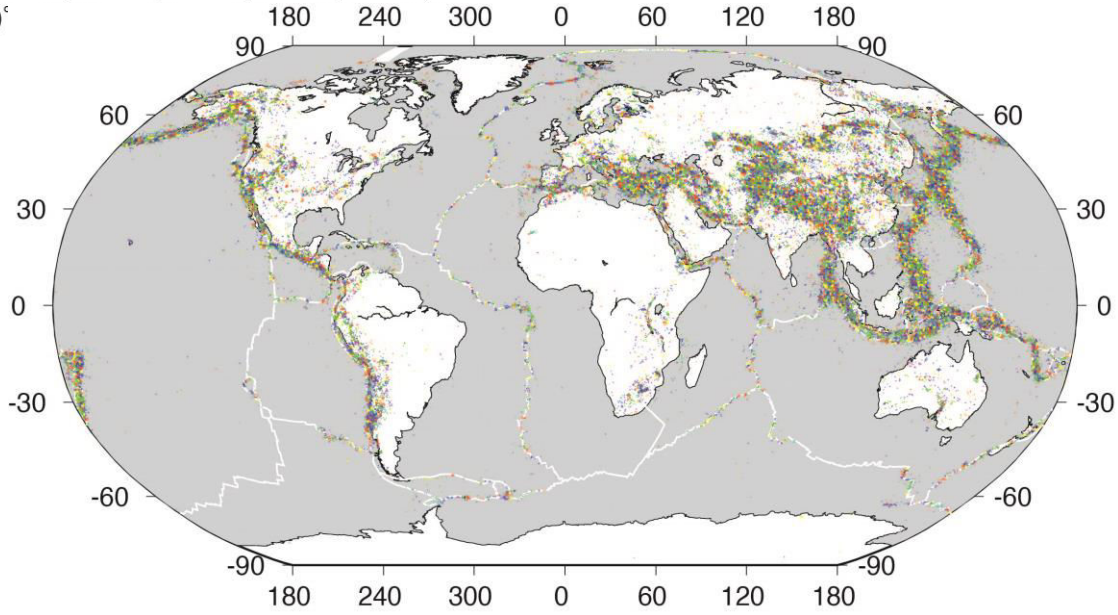
Global Source Parameters from Local/Regional Envelopes

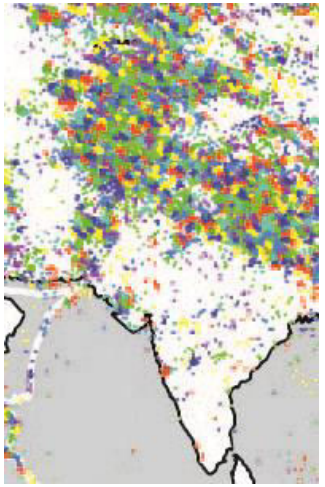


Stations

- ***Red***: *Previous Work*
  - *IRIS Asia, USArray, Global networks*
  - *Regional Networks*
- ***Blue***: *New Stations*
  - *IRIS Permanent and PASSCAL networks*

Event Clusters
Extent < 120 km





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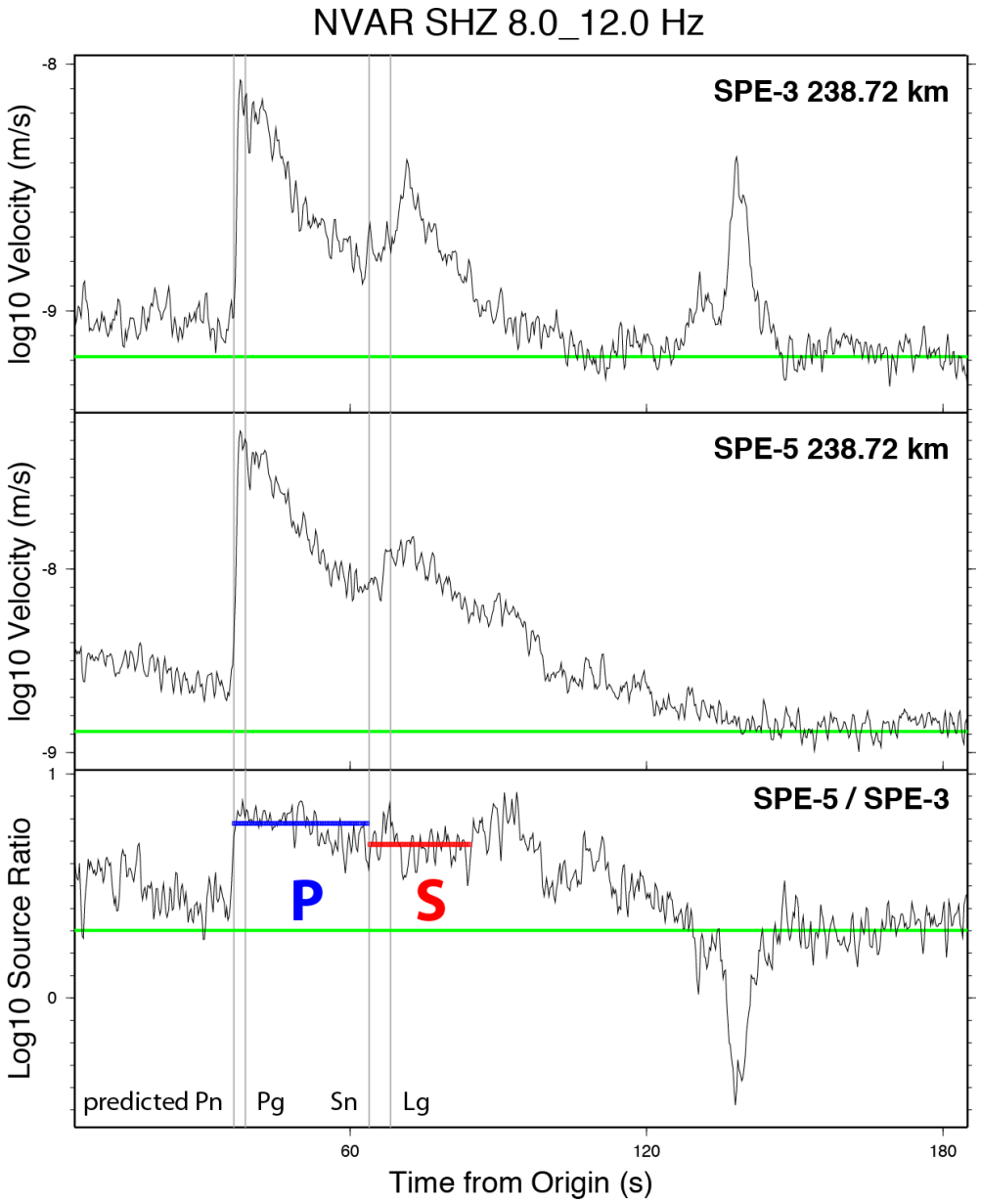
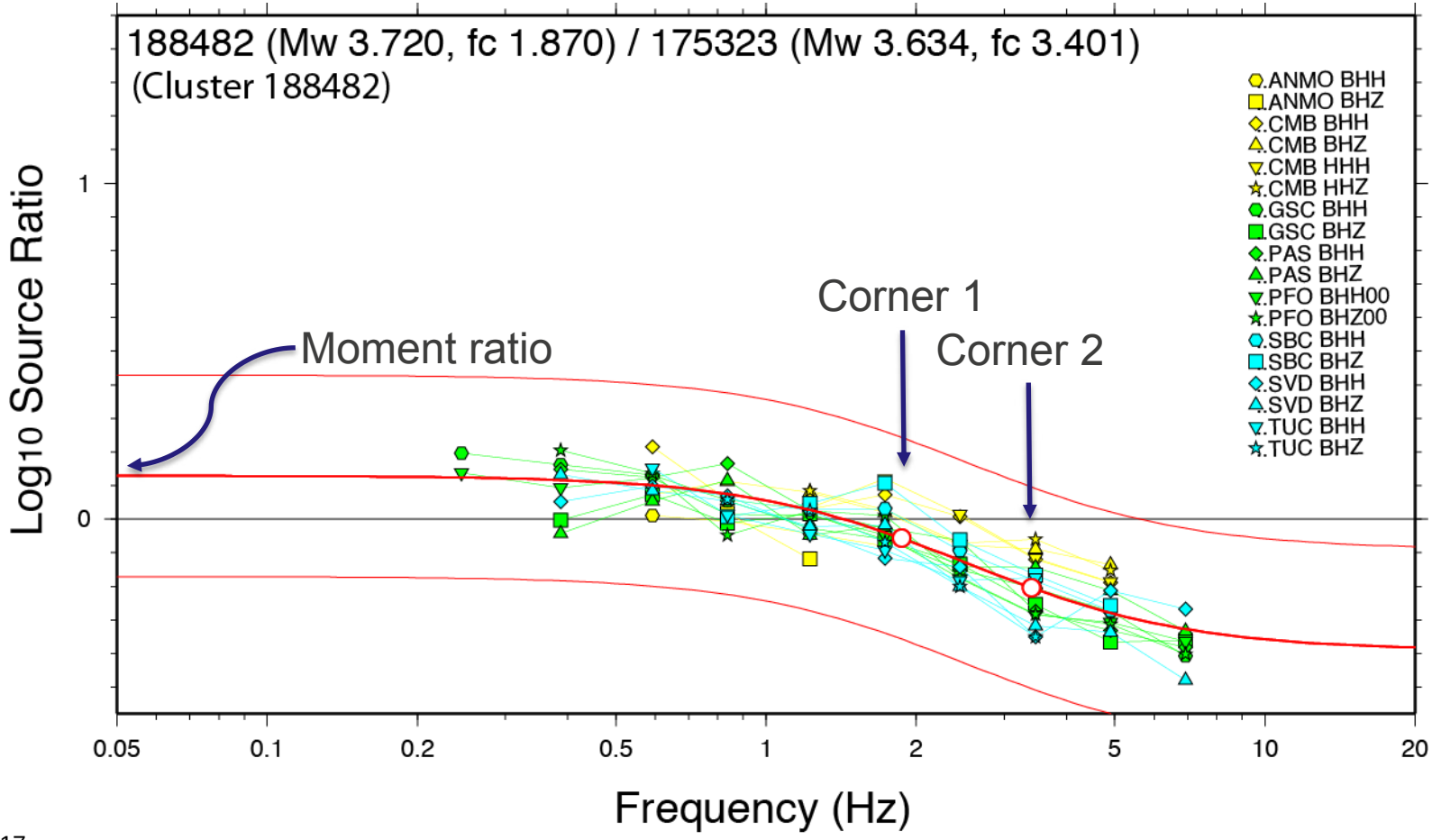
Relative Envelope Measurement

- Narrow band envelopes
- Median time-aligned difference
- SNR > 2
- Must match group velocity-aligned difference
- P+S for EQ

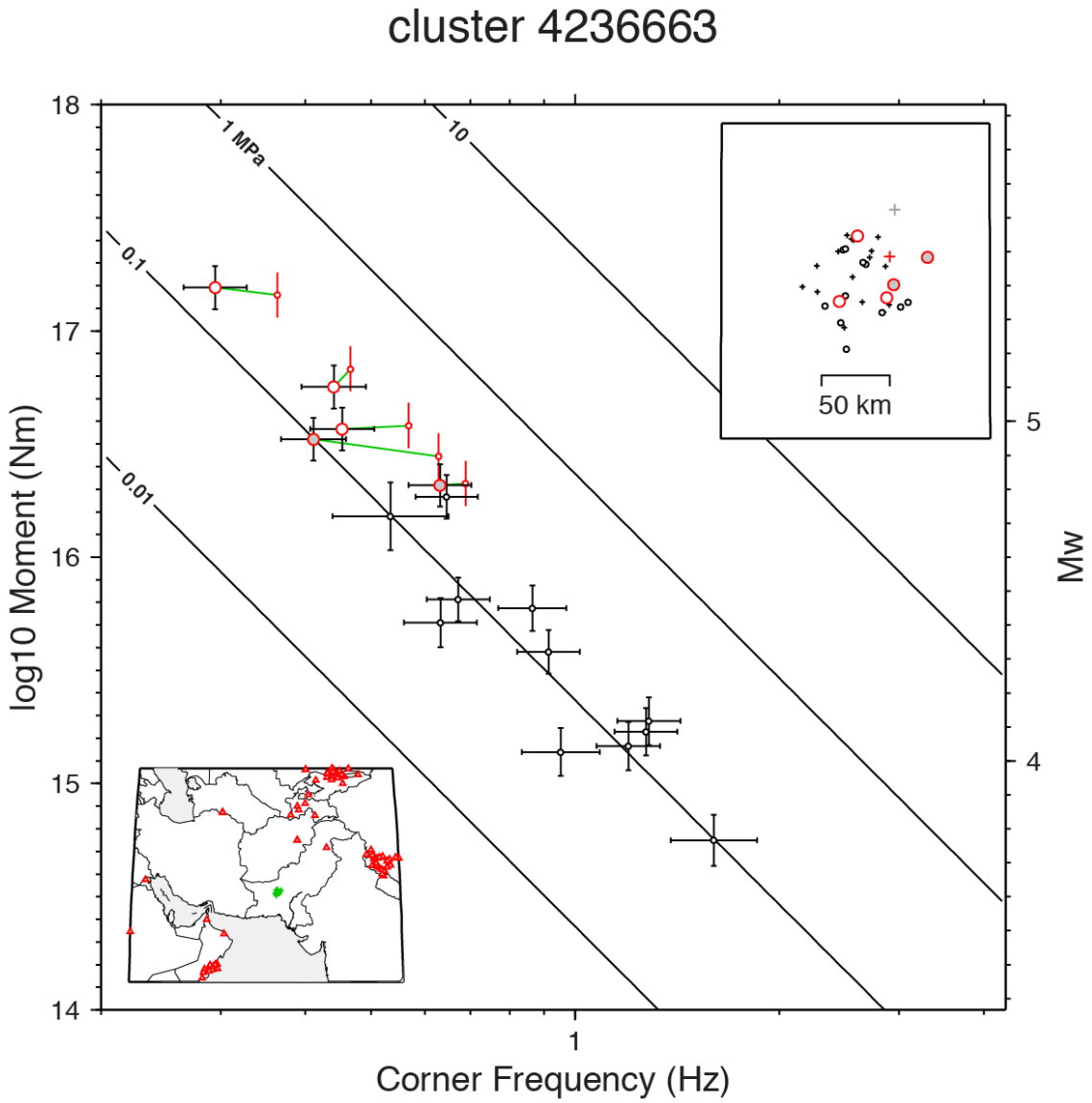


Spectral Ratios

- Mojave Cluster, one event pair
- Median stack over station and channel
- Fit source parameters to all pairs
- Example shows similar sized events with different corners.



Source Parameters, Balochistan, Pakistan



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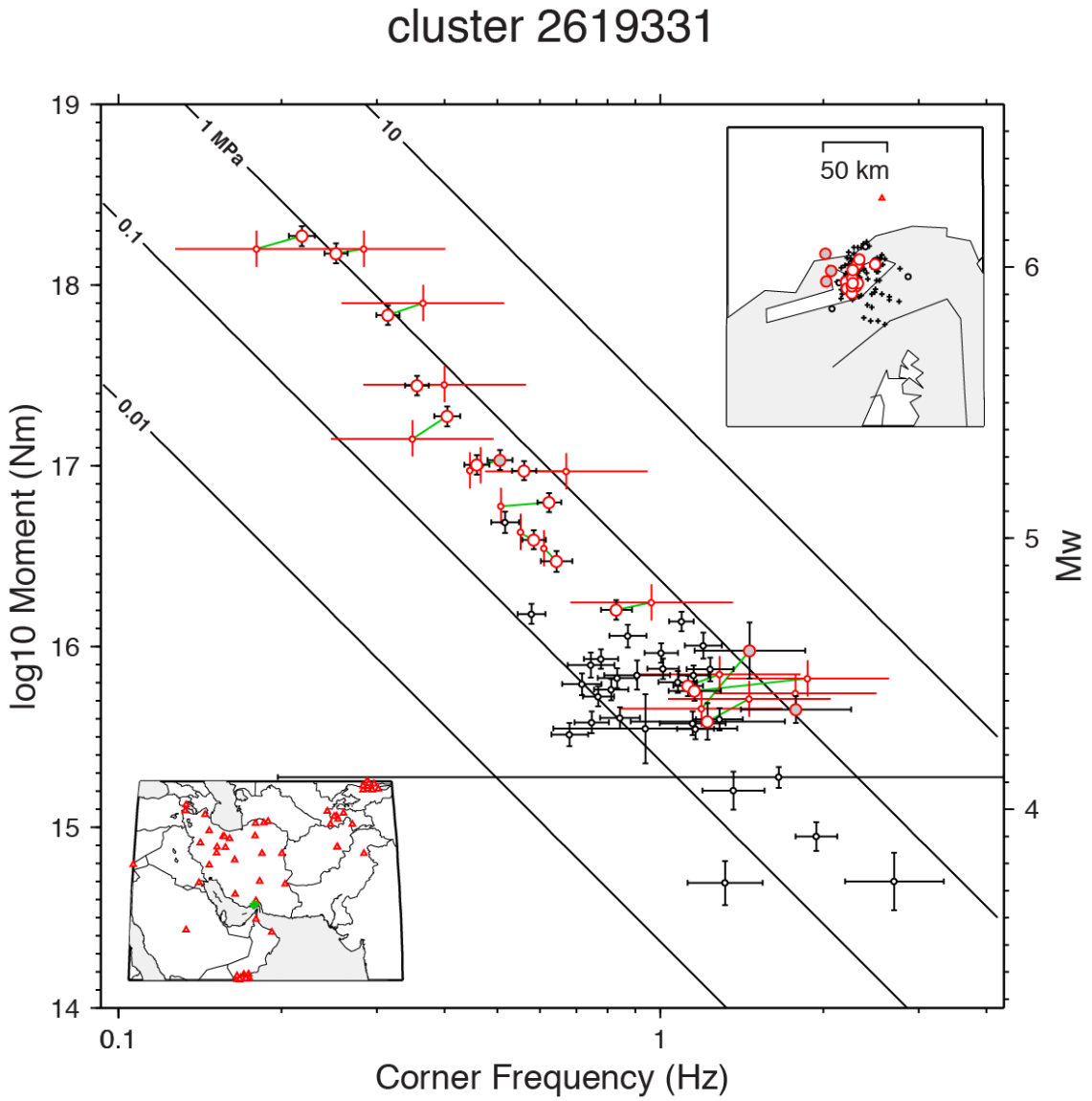
Source Parameters, Qeshm Island, Iran



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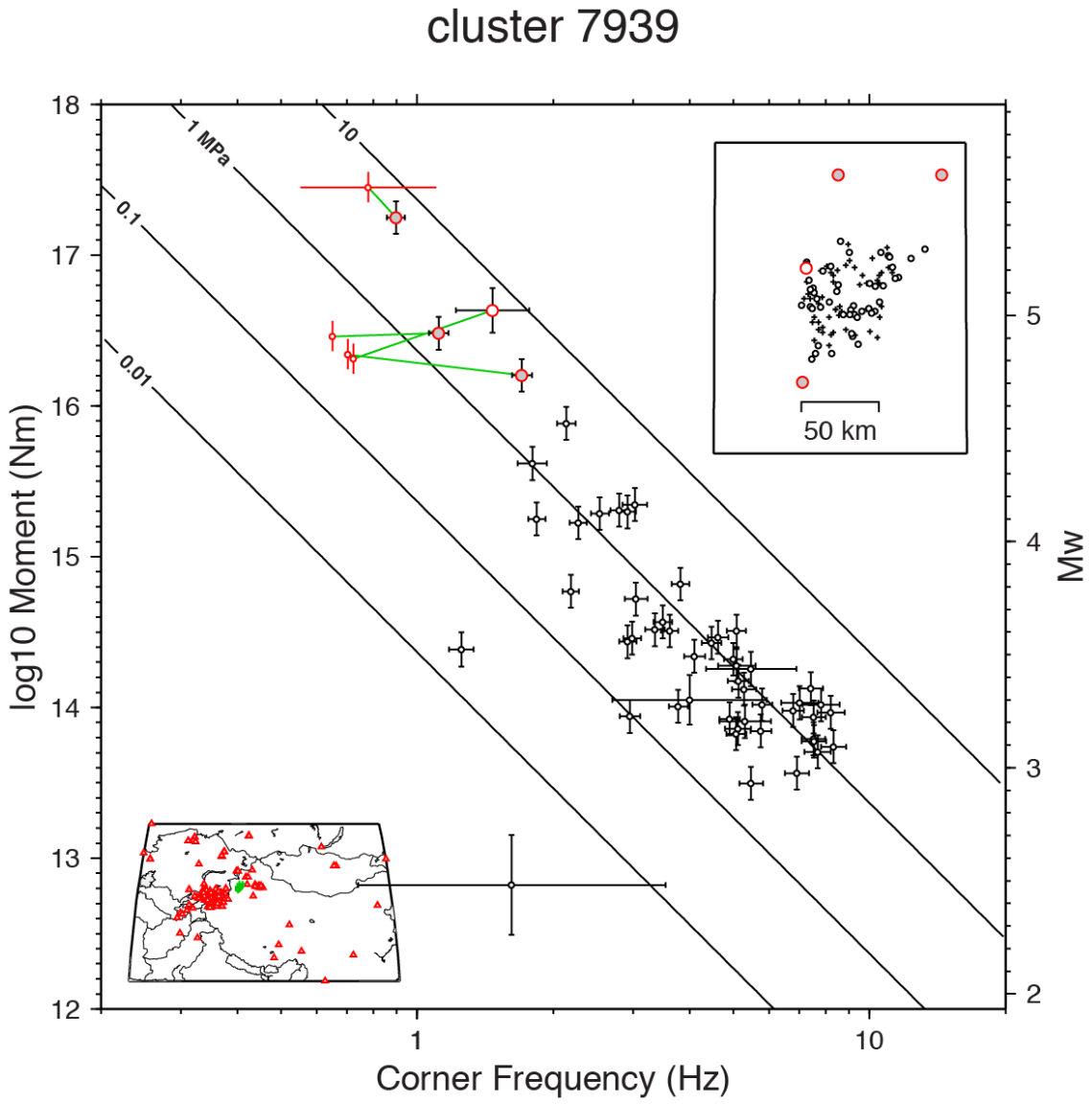
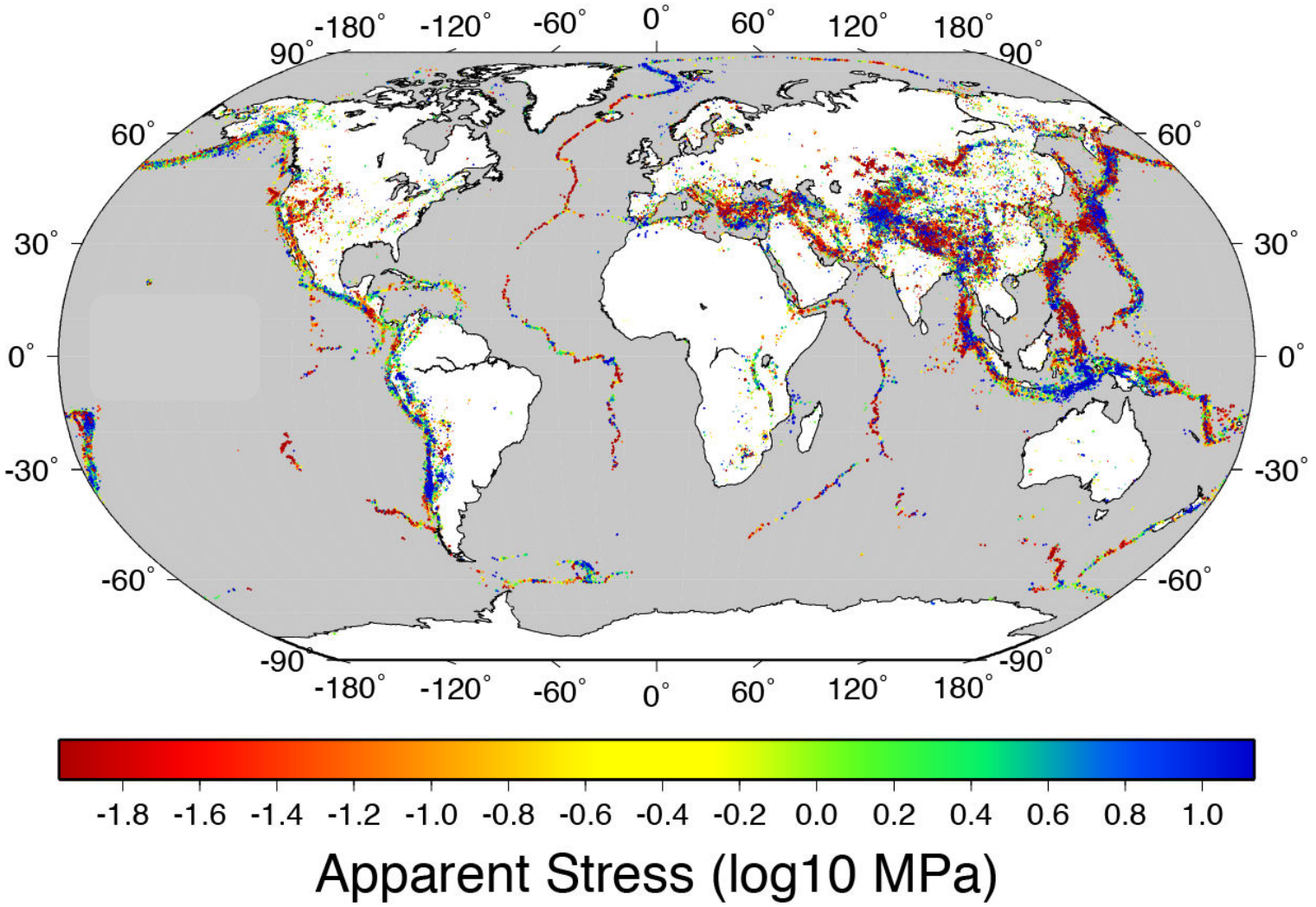
Source Parameters, W. China



Global Source Parameters



Amplitude Tomography with Source Constraints

- Only one Mo-fc event needed to elevate an otherwise well-resolved amplitude tomography model to absolute levels.
- Such constraints help to resolve Q-fc tradeoff in amplitude tomography.
- Additional constraint events help in poorly resolved areas, especially edges (Fisk and Phillips, 2013a, b).
- Additional constraints allow cross validation testing, similar to the use of GT with traveltime models.
- Source parameter studies provide tremendous QC on amplitude data sets (instrument issues, noise measurements, mislocation, secondary events, etc).
- Omega-square source model assumed, but should be explored in future work.