Focal Mechanisms and Preliminary Attenuation Measurements in Arizona

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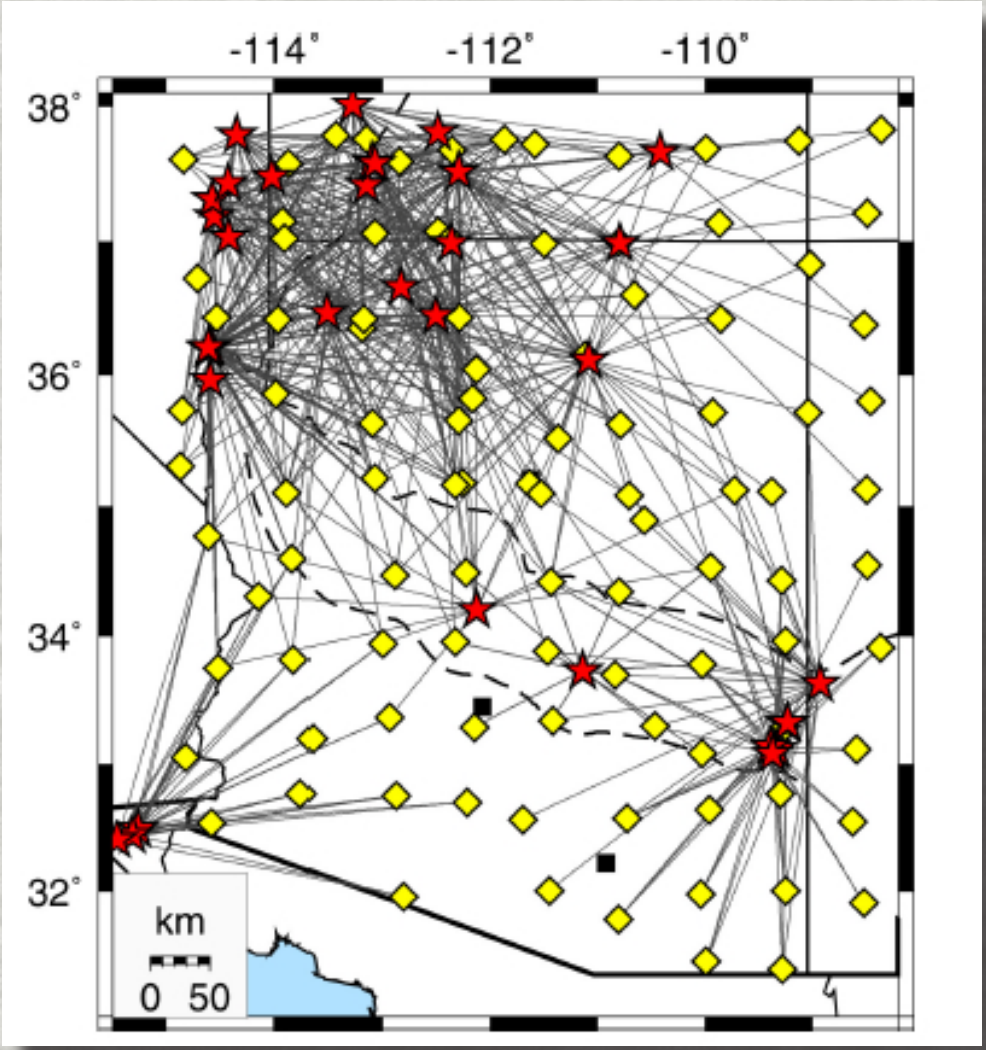

Map of Arizona showing paths connecting earthquakes (red stars) and stations (yellow diamonds)

CONTRIBUTED REPORT CR-13-C

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Focal Mechanisms and Preliminary Attenuation Measurements in Arizona

Susan Beck, Lepolt Linkimer, George Zandt, Austin Holland

Introduction

The tectonics of Arizona is dominated by the extension in the southern Basin and Range province, and the transition to the less deformed Colorado Plateau. However, earthquakes in Arizona tend to be small with most occurring in the northwest part of the state in the western part of the Colorado Plateau and transition zone. Many of these earthquakes (magnitudes usually < 4) occur north or south of Grand Canyon indicating that the western portion of the Colorado Plateau is deforming and not as "stable" as often described (Kreemer et al., 2010; Brambaugh, 2008). The southern Basin and Range in Arizona has had few earthquakes over the last century and appears to be less active than the Nevada or Utah portion of the Basin and Range. However, in 1887 there was a magnitude 7 earthquake, just south of the Arizona border in Mexico that was widely felt in southern Arizona (Bull and Pearthree, 1988). The 1887 Great Sonoran Earthquake produced a sizeable normal fault scarp with up to 4 meters of offset indicating the southern Basin and Range is capable of significant earthquakes despite the relative low number of earthquakes presently occurring (Sumner, 1977; see http://www.geo.arizona.edu/gsat/1887eq/bibliography.html for additional references). The western part of Arizona is close to Baja and southern California with high rates of seismicity associated with the San Andreas transform system, hence cities such as Yuma, could be at risk if a major earthquake occurred on in southern California. Due to the overall low rates of seismicity there have been few permanent broadband seismic stations in Arizona until recently and hence, very few studies of earthquakes or seismic attenuation in Arizona. The NSF funded EarthScope project recently deployed seismic stations in Arizona for 18 months and the 8 stations that were adopted by the Arizona State Geological Survey has provided a wealth of data to better characterize the earthquakes, present day deformation in Arizona, and make preliminary attenuation measurements for the state (Fig. 1). In order to characterize the present-day deformation we have determined 21 first motion focal mechanisms for small earthquakes in Arizona. In addition, we have determined coda Q measurements of attenuation in much of Arizona.

Focal Mechanisms

We determined P-wave first motion focal mechanisms for 21 earthquakes in or near Arizona using a very simple crustal velocity model. We used both Pg and Pn arrivals depending on the distance from the event to the station. We analyzed a total of 45 earthquakes but only 21 earthquakes gave enough P-wave first motions for a well-resolved focal mechanism. The crustal thickness changes across Arizona from 30-34 km in the southern basin and Range to 40-45 km in the Colorado Plateau (Frassetto et al.,

2006). The majority of the earthquakes are near the transition zone between the Colorado Plateau and the Basin and Range, hence, we used a simplified crustal model with a crustal thickness of 40 km (modified from Brumbaugh (2008)). The focal mechanisms are sensitive to the crustal velocity model but the overall style of faulting (normal, thrust or strike-slip) does not change dramatically for the well determined mechanisms. The focal mechanisms were determined using the code FOCMEC (Snoke et al., 1984) that gives a range of possible focal mechanisms consistent with the first motions. Figure 2 shows the focal mechanisms in map view and Appendix 1 shows the polarities of the P-wave first motions and range of possible focal mechanisms. We used USGS locations and magnitudes in our study. Earthquake mislocations could affect the backazimuth and distance between the earthquake and the station (especially for stations located close to the earthquake), and hence, impact the focal mechanisms. Most of the earthquakes in the vicinity of northwest Arizona have normal or strike-slip mechanisms. However, we found several strike slip events with a component of oblique thrusting (for example Oct. 26, 2008 and Jan. 4, 2010).

Table 1 – Velocity model used to determine local focal mechanisms.

Depth (km)	P-Wave Velocity (km/s)	Vp/Vs	Layer Thickness (km)
0	4.7	1.73	1
1	6.2	1.73	26.85
27.85	6.8	1.73	12.15
40	8.04	1.79	

Attenuation

We have done a preliminary analysis of frequency dependent attenuation in Arizona using broadband seismic data recorded at the EarthScope USArray transportable array stations (Figure 1). Our goal is to map out first order seismic attenuation as a function of frequency for Arizona to determine appropriate Q values that can be used for estimating seismic wave propagation and ground motion. Numerous previous studies have looked at attenuation in the northern and central Basin and Range and California as well as many other parts of the U.S. but very few attenuation studies have been done in Arizona or the southern Basin and Range. Detailed attenuation maps of the U.S. can provide valuable information about shaking intensities as a function of frequency for seismic hazards (e.g. Erickson et al., 2004). Variations in the attenuation of seismic waves in different tectonic regions have been extensively studied through the world (e.g. Erickson et al, 2004; Jin and Aki, 2005, Parvez et al., 2008; Gonzales and Persson, 1997; Yun et al, 2007).

Method

The decay of the coda wave amplitude of a local earthquake after the passage of the primary waves provides a quantitative estimate of the attenuation and is referred to as Coda Q (Q_c) (Aki and Chouet, 1995; Parvez et al., 2008). The decay of the coda amplitude is a function of (after correction for geometric spreading) intrinsic attenuation (absorption of seismic energy) and scattering attenuation as the waves propagate through the crust. Hence, Q_c is an important property for studying the physical properties of the crust and useful for assessing the seismic hazard potential of a region (Jin and Aki, 1988).

We have determined Q_c for local earthquake station pairs in Arizona at different frequency bands (Figure 3). The Q_c values are calculated using the CODAQ subroutine of SEISAN (Havskov and Ottemoller, 2003). We filter each earthquake recording in frequency bands of 1-2 Hz, 3-5 Hz, 6-10 Hz, and 12-20 Hz and then identify a coda window starting at twice the S-wave travel time ($2t_s$) to ensure we are sampling well after the primary S arrival (Figure 4). We use a lapse time window of 20 sec to measure the decay of the coda and measure the signal to noise (S/N) for the last 5 seconds of our window of interest and only use traces with S/N >3 in our analysis (Figure 4). We calculate Q_c values by measuring the slope of the linear regression of the logarithm of the product of the RMS amplitude and lapse time, $\ln(A(f,t)t)$ against lapse time t. This method does not require information about the earthquake source; hence, it is ideal for our study in Arizona where we can use small earthquakes.

Data

We use 29 local earthquakes (magnitude > 3.0) in Arizona or near the border recorded at stations in Arizona to determine the Q_c for each earthquake station pair (Figure 3). We use the earthquake locations from the USGS PDE catalogue. Most of these earthquakes are shallow so our Q_c values are representative of the crust. Our earthquake distribution is limited in Arizona so we have an uneven sampling of the state with many more earthquakes in the northwest part of the state near the border of Arizona, California, Utah and Nevada, and very few earthquakes in the southern Basin and Range. Hence, our estimates of Q_c are better determined for the northwest part of Arizona. Figure 5 shows the total number of Q_c calculations with S/N > 3 per station for all frequency bands.

Results

Figure 6 shows examples of the Q_c values as a function frequency for select stations with the largest number of Q_c calculations. As expected we have the most measurements for station in northwest Arizona where we have the most seismicity. Stations U15A, V14A and V15A are on the western edge of the Colorado Plateau near the transition zone where there is active deformation. Station W13A is in the transition zone near the Arizona-California border. The average Q_c values for these stations at 1-2 Hz are between 74 and 112, at 3-5 Hz between 244 and 290, at 6 and10 Hz between 401 and 531, and at 12-20 Hz between 932 and 1050 (Figure 6). There is a large amount of scatter in the highest frequency range. For the southern Basin and Range we have very

few measurements because of the lack of earthquakes. For some stations we have only 2 or 3 measurements per frequency band at each station. We have combined measurements from 4 stations with the most measurements in the southern Basin and Range (stations 319A, 118A, 113A and 114A) (Figure 7). The Q_c values are reasonable but we do observe very large scatter at the 12-20 Hz range. Hence, we do not consider the 12-20 Hz frequency range to have a reliable Q_c value. Figure 8 shows average Q_c in Arizona in map view for the different frequency bands.

In general the Q_c values across the state are similar but with some hint of lower values in the northwestern part of the Colorado Plateau and transition zone and the southern Basin and Range as compared to the central and eastern part of the Colorado Plateau. This fits with the general observations that Q_c is lower in tectonically active regions and higher in more stable regions.

We have compared our average values of Q_c with Lg coda Q measurements made across the U.S. by Erickson et al. (2004) (Figure 9). We find that the values we obtain are similar to the low Q values found for northern California and slightly lower than the central and northern Basin and Range, and southern California Q values. We should note that Erickson et al. (2004) used much longer paths for their determination of coda Q. We also obtain similar Q_c values to the total coda Q values from Mayada et al. (1992) for central California. Our preliminary results indicate that the Q_c values in Arizona are similar to other tectonically active regions of the western U.S. and much lower than the Midwest or Northeast U.S. Our preliminary study indicates that low Q values can be used in estimating seismic propagation effects in Arizona.

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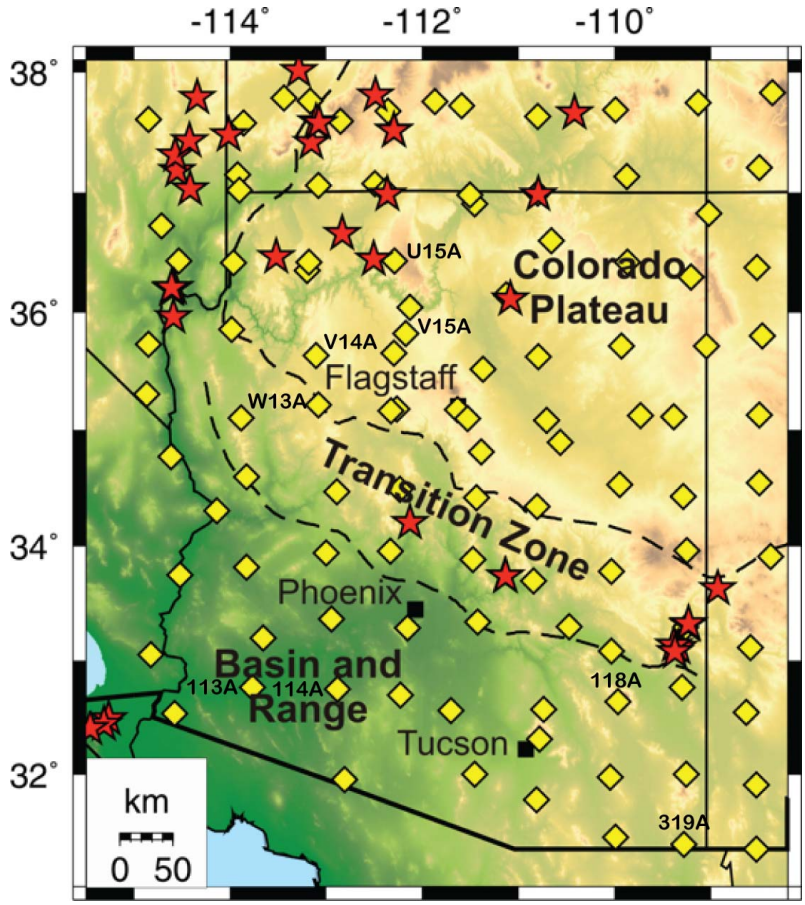


Figure 1. Location map of earthquakes and stations used in this study. Yellow diamonds and red stars denote seismic stations and earthquakes, respectively. Also shown are the approximate boundaries of the Colorado Plateau, transition zone and southern Basin and Range provinces in Arizona. The western edge of the Colorado Plateau is diffuse and much more seismically active than the core or eastern part of the Plateau.

Arizona Focal Mechanisms

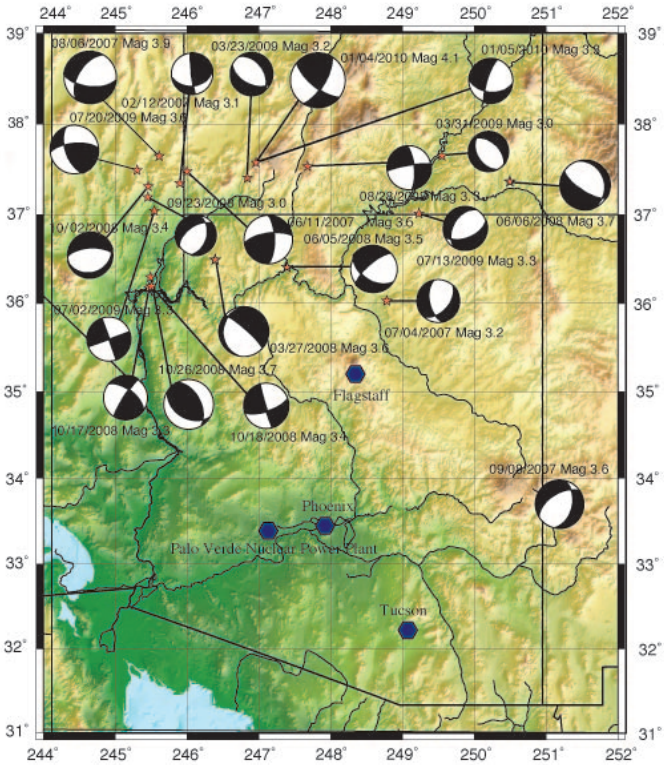


Figure 2. Map of focal mechanisms determined using P-wave first motions recorded on the EarthScope transportable Array. The earthquake locations and magnitudes are from the USGS catalogue. See Appendix 1 for details.

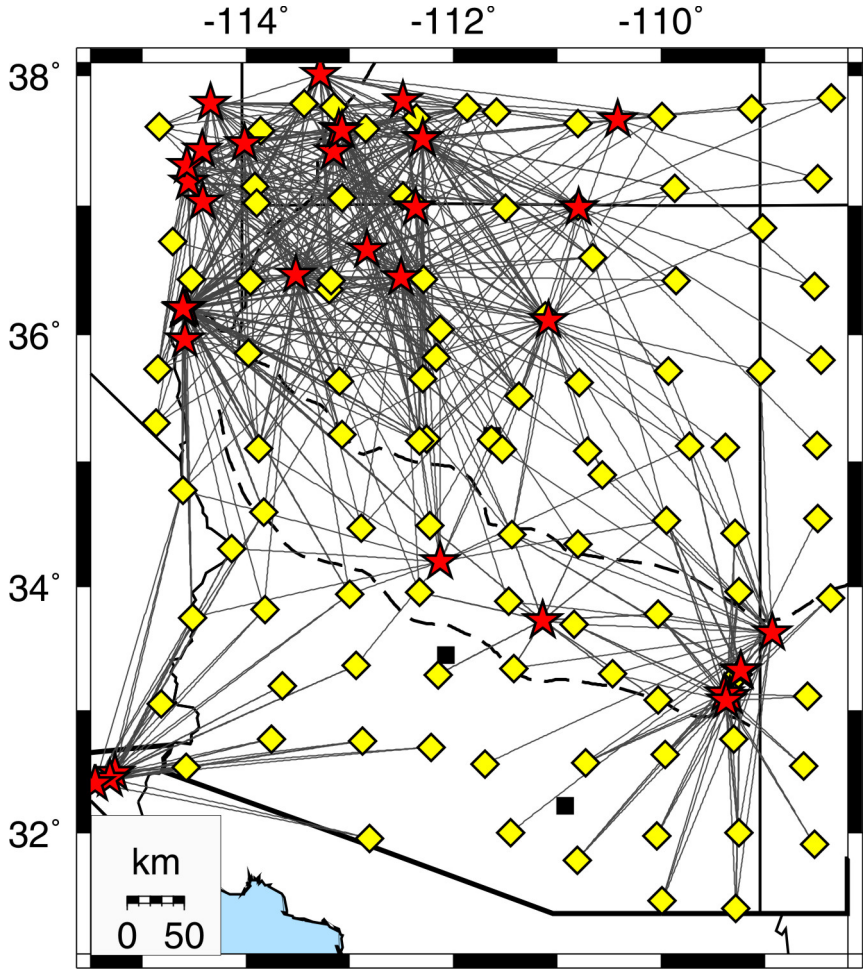


Figure 3. Map of Arizona showing paths connecting earthquakes (red stars) and stations (yellow diamonds) for which Q_c was calculated.

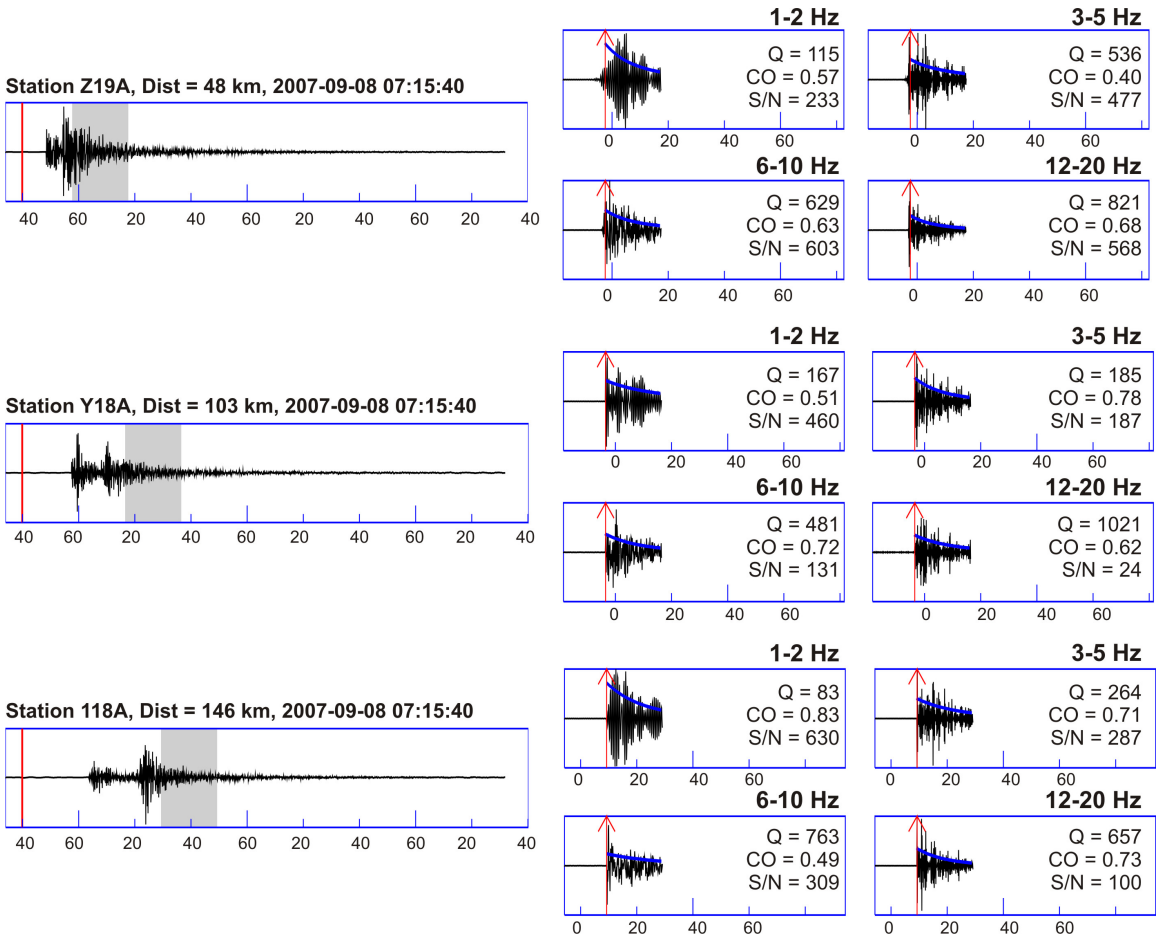


Figure 4. Example of unfiltered and band-passed filtered traces for one event at three different distances. The signal on the left is the unfiltered data trace where the red vertical red line represents the origin time and the gray area denotes the 20 second coda window used for the Q calculation. The traces on the right correspond to the band-passed filtered traces in four different frequency bands: 1-2 Hz, 3-5 Hz, 6-10 Hz, and 12-20 Hz. The fit to each filtered segment is shown as a blue decaying curve. Each graph also displays the calculated coda Q (Q), the correlation coefficient (CO), and the signal to noise ratio (S/N) of the last 5 seconds of the coda signal used. We only analyzed coda Q results with CO > 0.40 and S/N > 3.

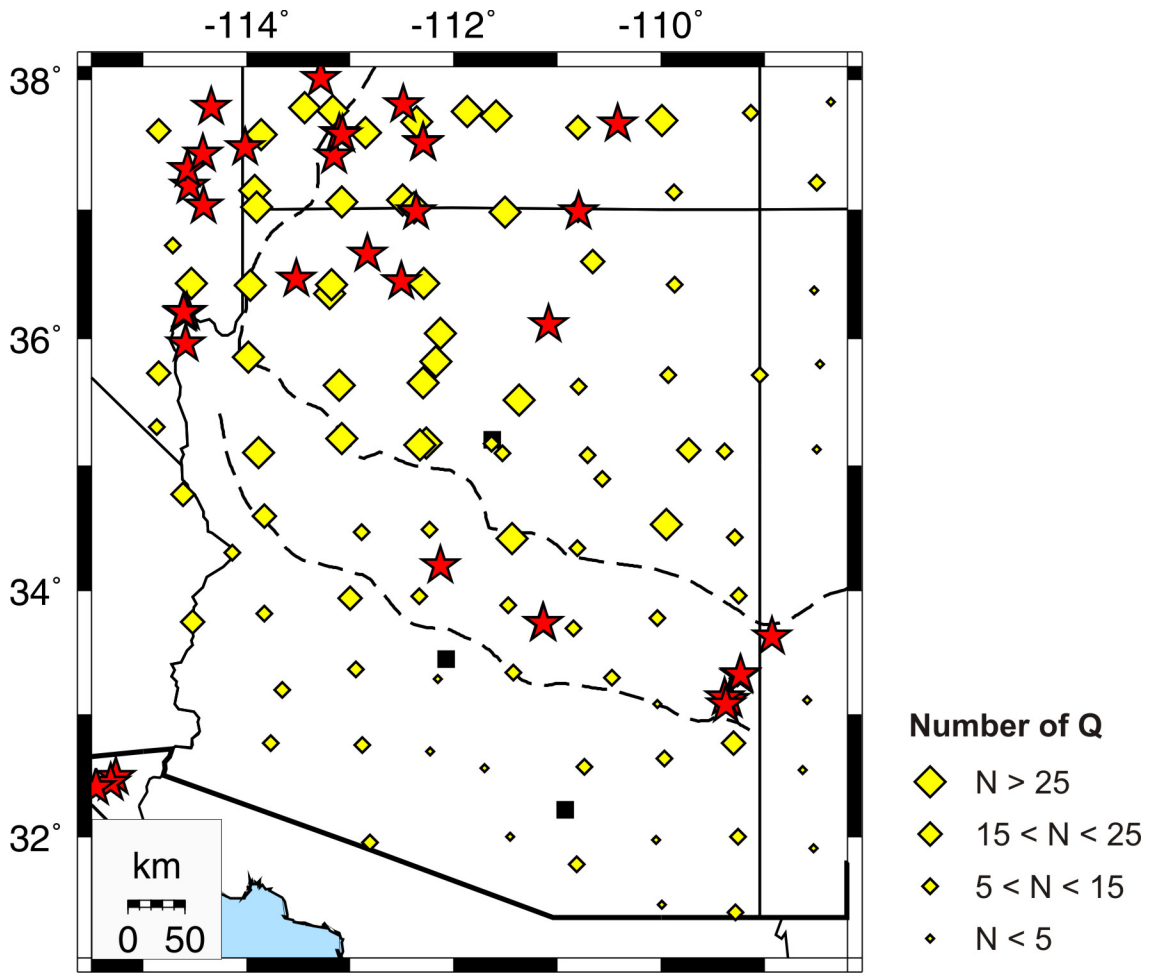


Figure 5. Map showing the total number of Q calculations with CO > 0.40 and S/N > 3 per station for all frequency bands. Note that we have very few measurements in the southern part of Arizona.

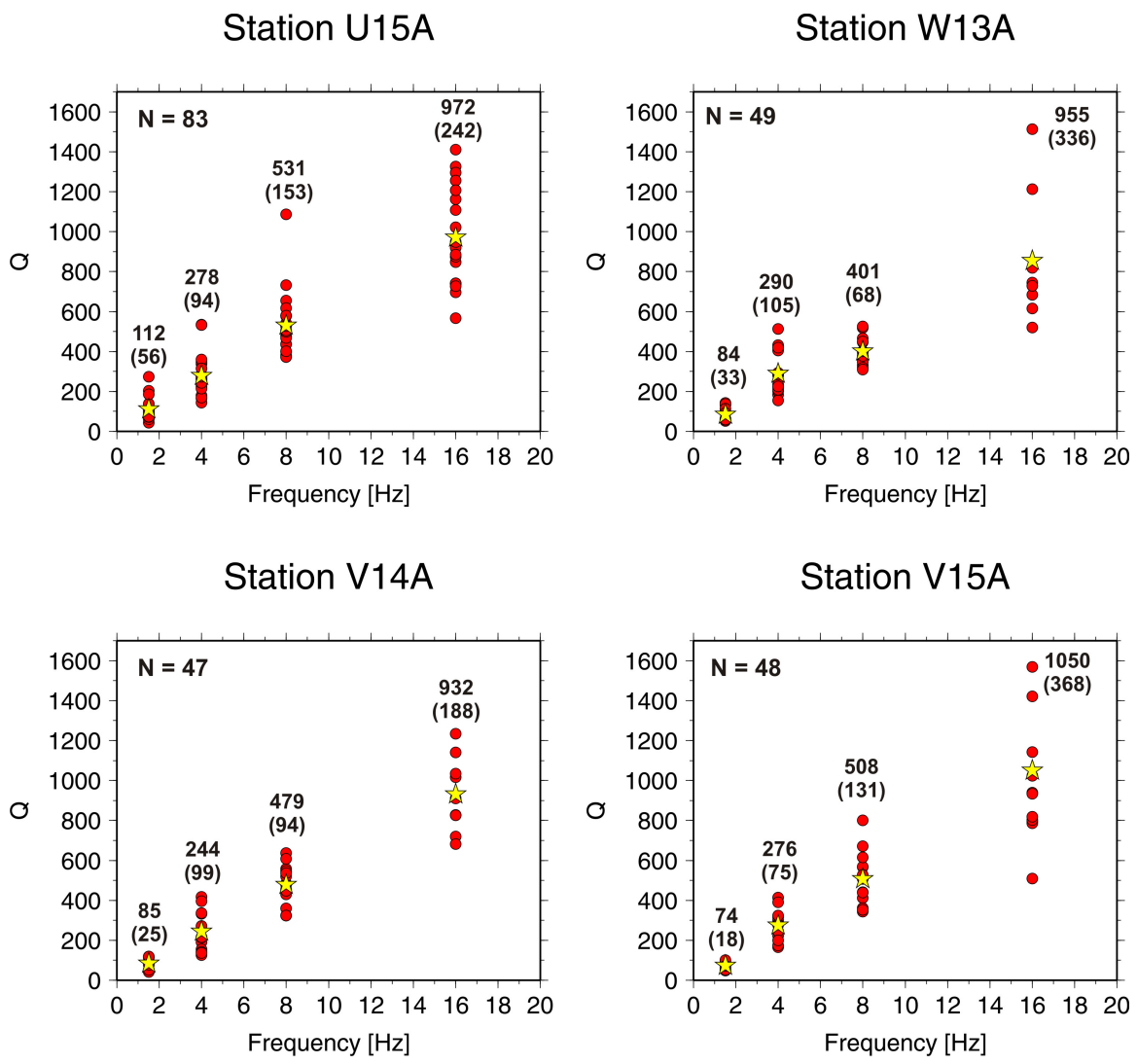


Figure 6. Q_c vs Frequency for the stations with the largest number of Q_c calculations (N). The yellow star denotes the average for each frequency band and the actual value is shown above each frequency. The corresponding standard deviation is shown in parenthesis.

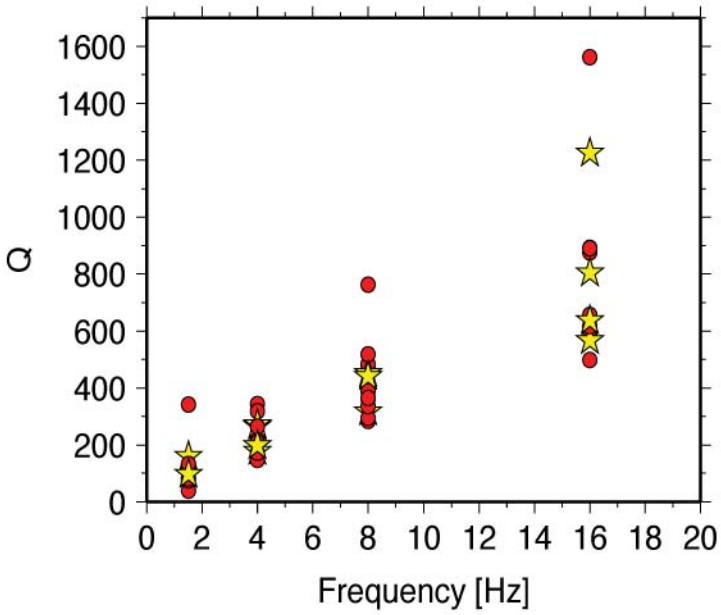


Figure 7. Q_c vs Frequency for four stations (113A, 114A, 319A and 118A) in the southern Basin and Range where we have very few measurements. The yellow star denotes the average for each frequency band at each station while the red circles are individual measurements. The Q_c values are similar at the lower frequencies but the scatter is large at the 12-20 Hz range.

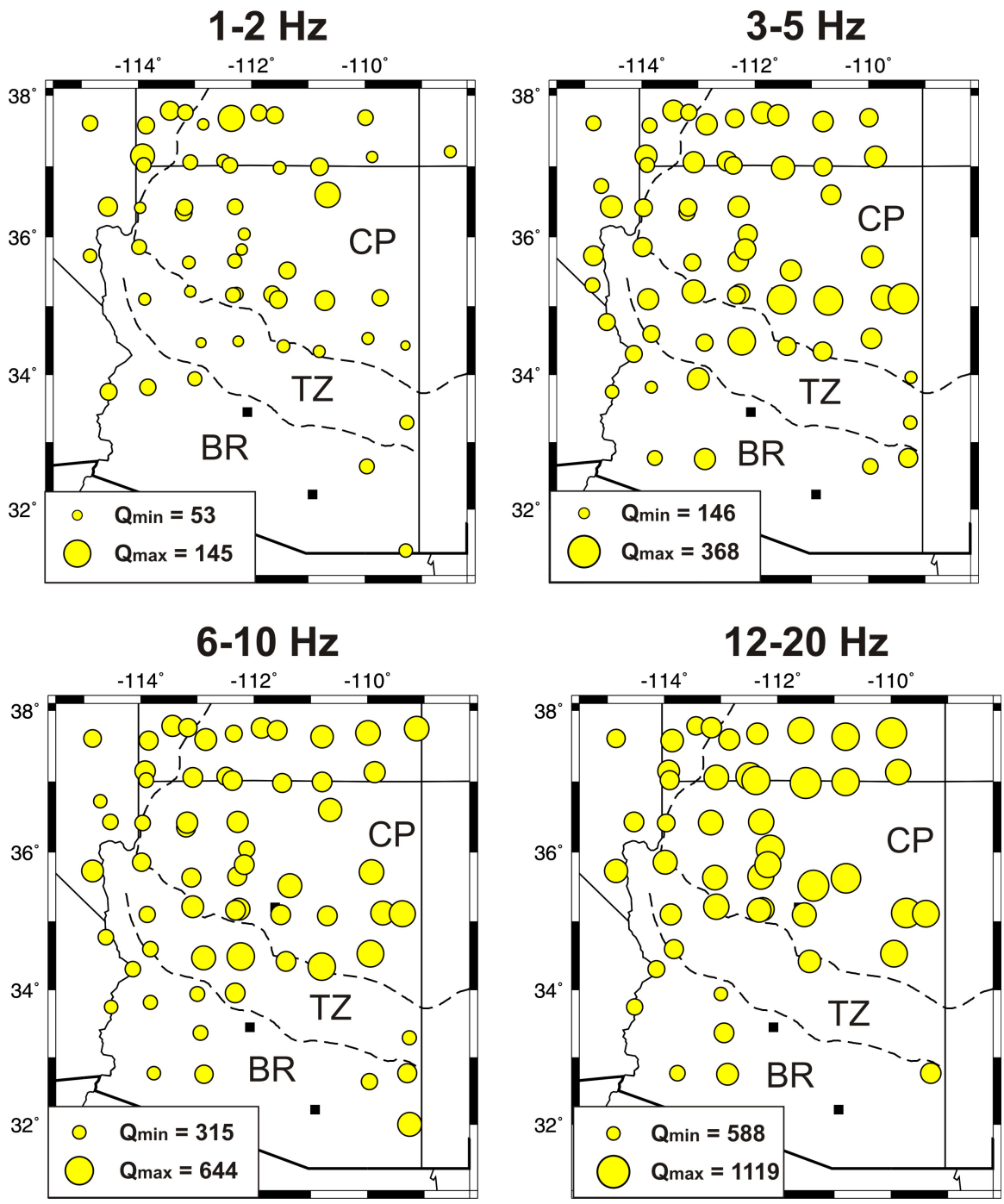


Figure 8. Spatial distribution of coda Q for four different frequency bands: 1-2 Hz, 3-5 Hz, 6-10 Hz, and 12-20 Hz. Each map shows the average Q for stations with more than 2 calculations with CO > 0.40 and S/N > 3 in each frequency band. Circles are scaled by the minimum and maximum Q values observed in the region, shown on the lower left corner of each map.

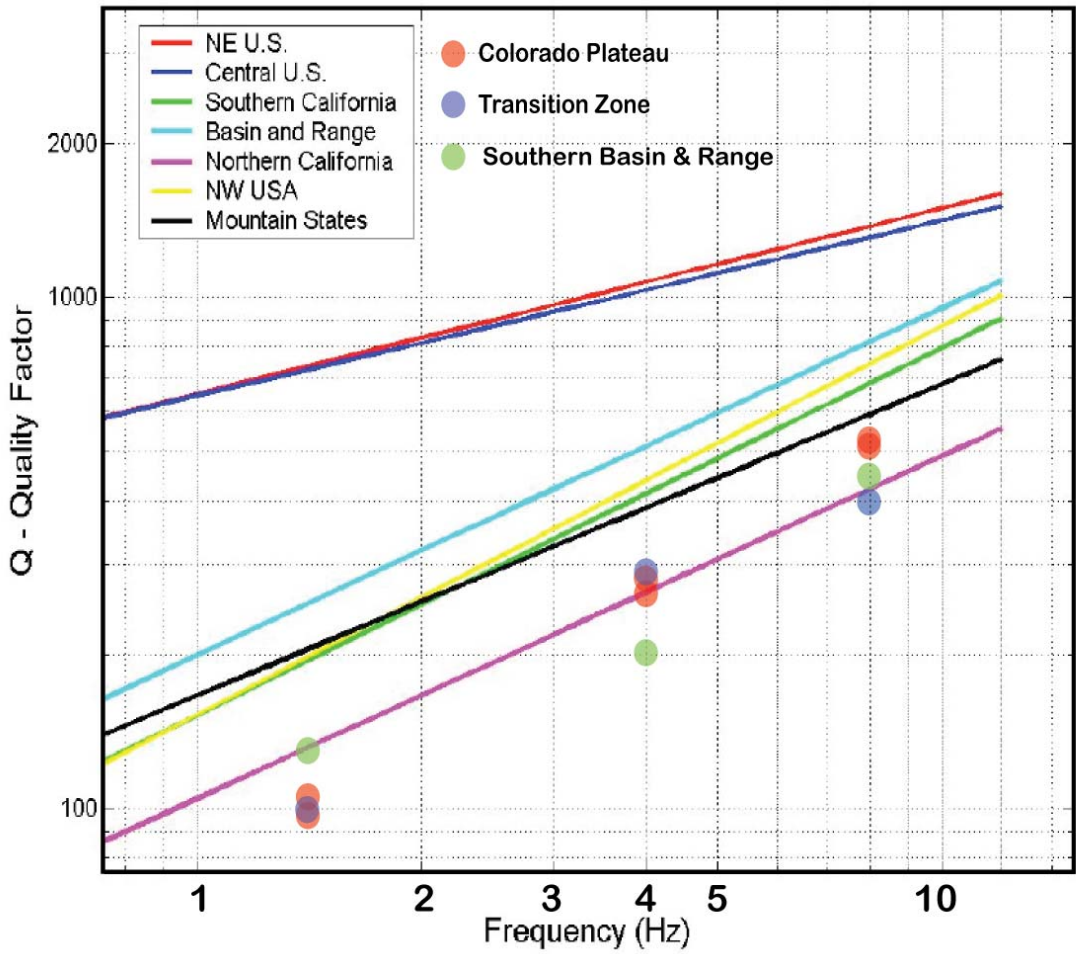
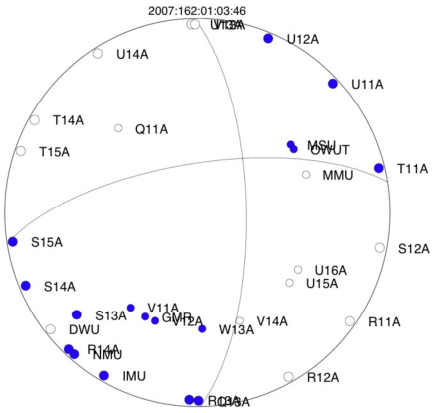


Figure 9. Plot of Q versus frequency modified from Erickson et al., (2004) showing Q values for different regions of the U.S. Circles are Q_c values from this study for 3 frequency ranges, 1-2 Hz, 3-5 Hz, and 6-10 Hz.

Appendix 1. Stereographic plots showing first motions (blue circles compressional and open circles dilatational) and possible nodal planes for our 21 well determine focal mechanisms.



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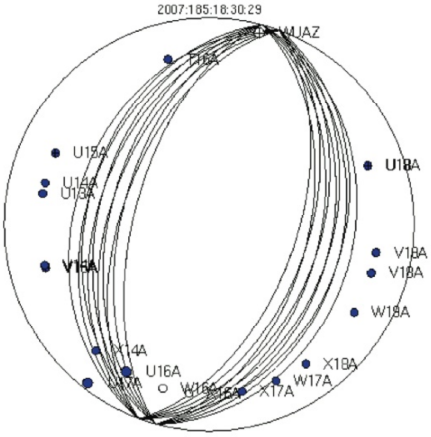

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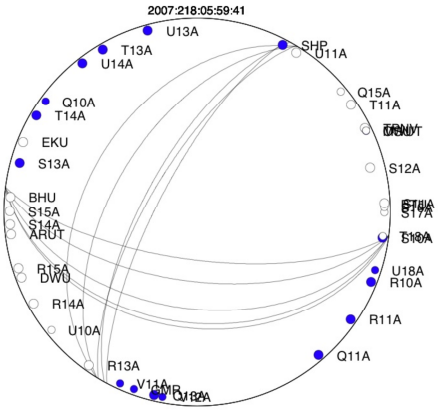

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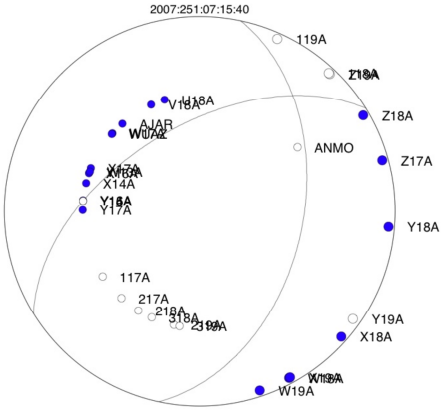

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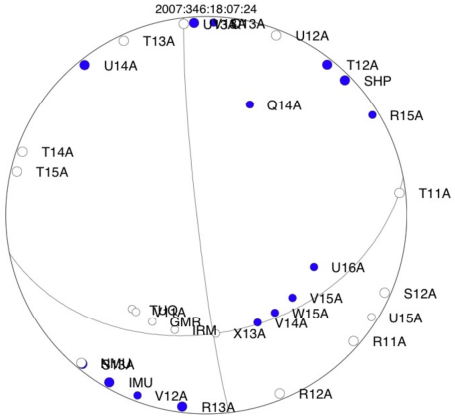

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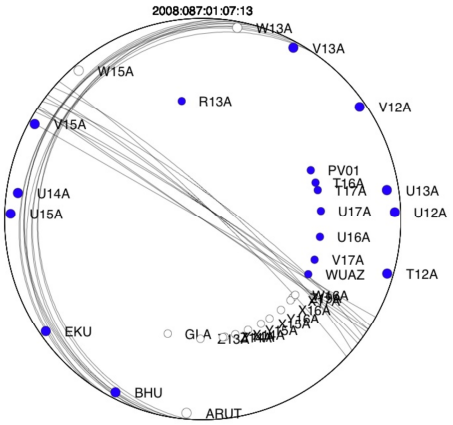

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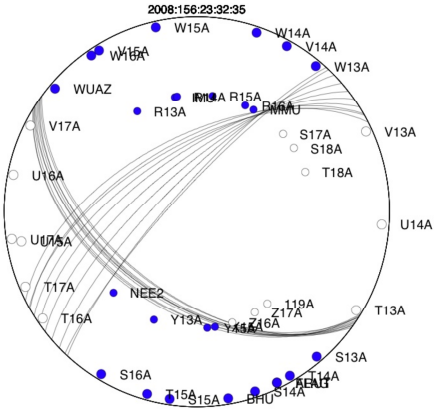

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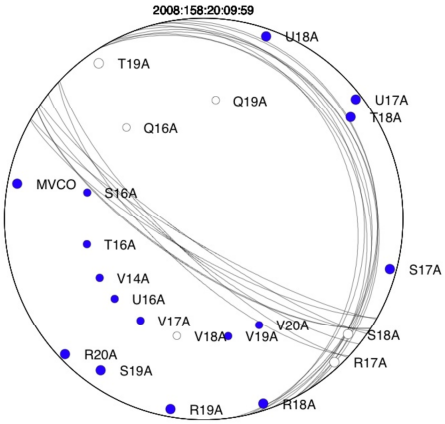

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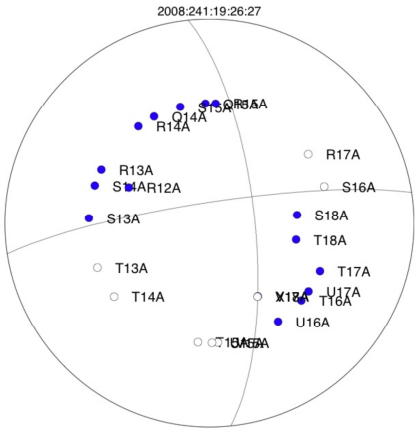

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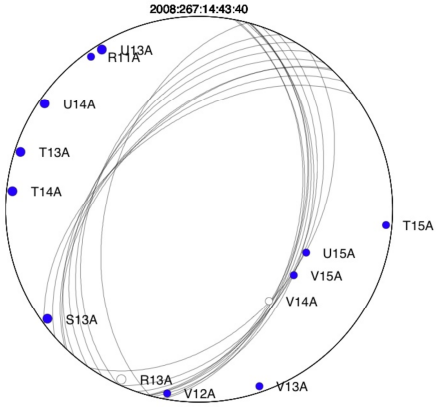

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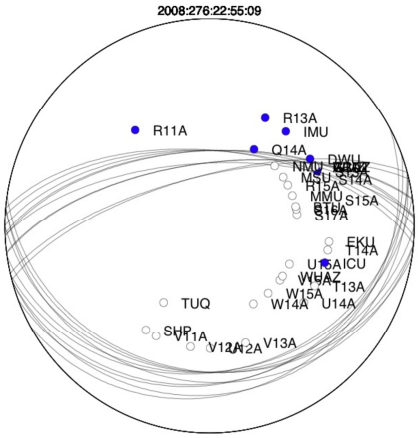

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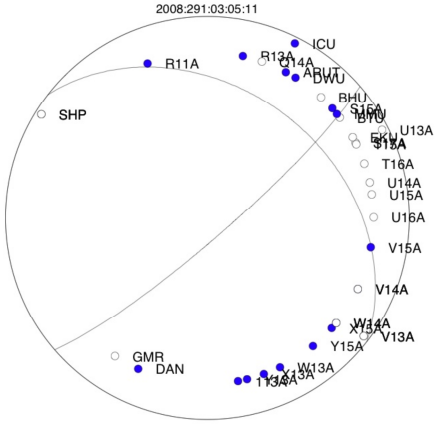

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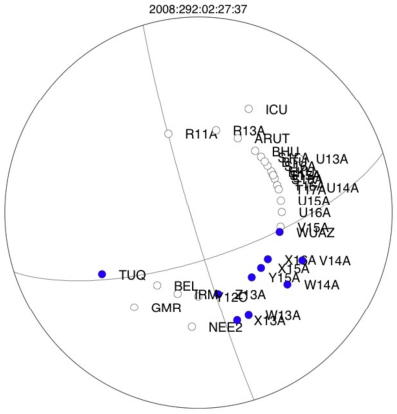

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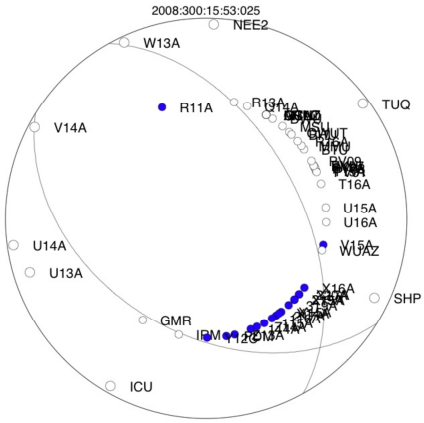

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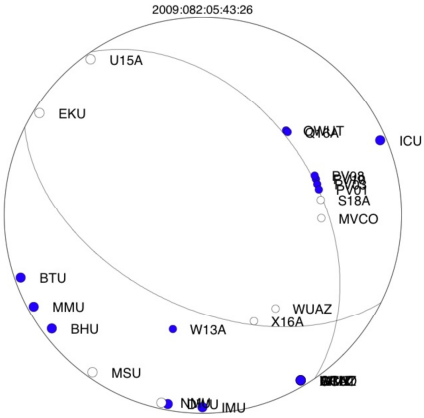

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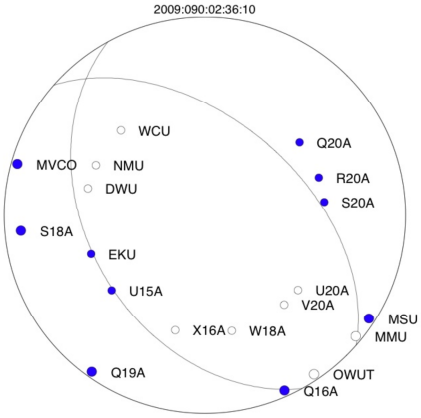
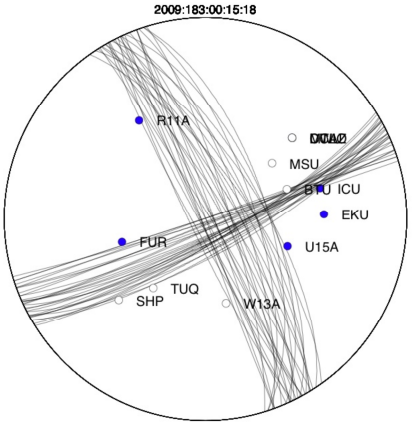
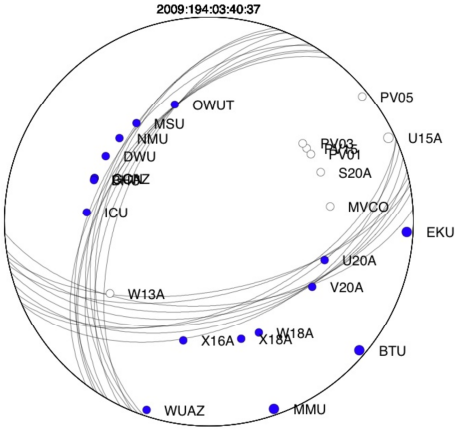
Depth 4, Magnitude: 3.2



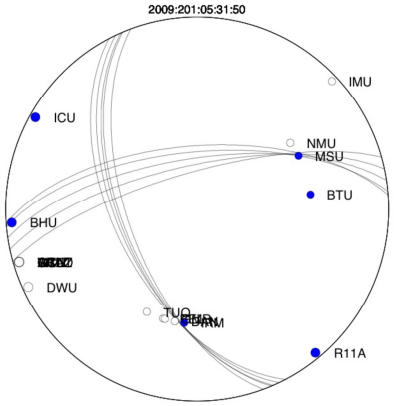
March 31, 2009
Coordinates: 37.66, 249.55
Depth: 7.2, Magnitude: 3.0



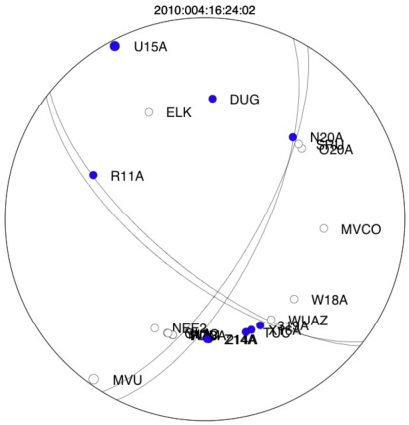
July 2, 2009
Coordinates: 37.04, 245.54
Depth: 0, Magnitude: 3.3



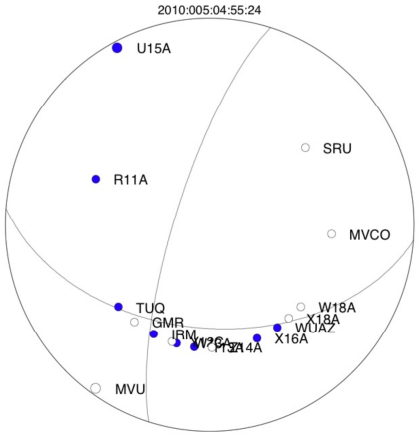
July 13, 2009
Coordinates: 37.01, 249.23
Depth 3.0, Magnitude: 3.3



July 20, 2009
Coordinates: 37.5, 245.31
Depth: 2.9, Magnitude: 3.6



January 4, 2010
Coordinates: 37.59, 246.96
Depth: 4.0, Magnitude: 4.1



January 5, 2010
Coordinates: 37.58, 246.96
Depth: 5, Magnitude: 3.3