Quarterly Report
Massachusetts Institute of Technology
GAGE Facility GPS Data Analysis Center Coordinator

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Period: 2020/07/01-2020/09/30

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Summary

Under the GAGE2 Facility Data Analysis subaward, MIT has been processing SINEX files Central Washington University (CWU) and aligning them to the GAGE NAM08 reference frame. In this report, we show analyses of the data processing for the period 2020/06/15 to 2020/09/30, time series velocity field analyses for the GAGE reprocessing analyses (1996-2020). Several earthquakes were investigated this quarter and two generated coseismic displacements > 1mm. Event files were prepared for event 56 but not event 57 which displaced only 1 station. Estimates of the offsets are available in the Kalman filter offset files generated monthly.

Analysis files (pbo format velocity files and offset files) are generated monthly and sent via LDM in the middle of each month.

We continue to process ANET data. Starting GPS Week 2021 (2018/09/30) only CWU solutions are included. These solutions are in then ANT14 frame as defined in the ITRF2014 plate motion model [*Altamimi et al.,* 2017].

GPS Analysis of Level 2a and 2b products

Level 2a products: Rapid products

Final and rapid level 2a products have been in general generated routinely during this quarter for the CWU solutions. The description of these products, the delivery schedule and the delivery list remain unchanged from the previous quarter and will not be reported here.

Level 2a products: Final products

The final products are generated weekly and are based on the final JPL orbits and clocks. Finals and rapid solutions are now being generated in the IGS14 system. In this quarter 2990 stations were processed which is 16 less than last quarter. We are losing sites each quarter most likely due to failed sites. The loss this quarter is half that of last quarter. In addition up to 54 sites were processed in the ANET solutions, 2 less than last quarter.

Level 2a products: 12-week, 26-week supplement products

Each week we also process the Supplemental (12-week latency) and six months supplemental (26-week latency) analyses from CWU for the main GAGE2 Networks of the Americas stations (NOTA). The delivery schedule for these products is also unchanged.

Analysis of Final products: June 15, 2020– September 26, 2020

For this report, we generated the statistics using the ~3 months of CWU results between June 15, 2020 and September 26, 2020. These results are summarized in Table 1 and figures 1.

For the three months of the final position time series generated by, we fit linear trends and annual signals and compute the RMS scatters of the position residuals in north, east and up for each station in the analysis. Table 1 shows the median (50%), 70% and 95% limits for the RMS scatters CWU. The detailed histograms of the RMS scatters are shown in Figure 1 CWU.

Table 1: Statistics of the fits of 1990 stations for CWU analyzed in the finals analysis between June 15, 2020 and September 26, 2020. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.98	0.90	4.80
70%			
CWU	1.22	1.12	5.54
95%			
CWU	2.18	2.13	9.18

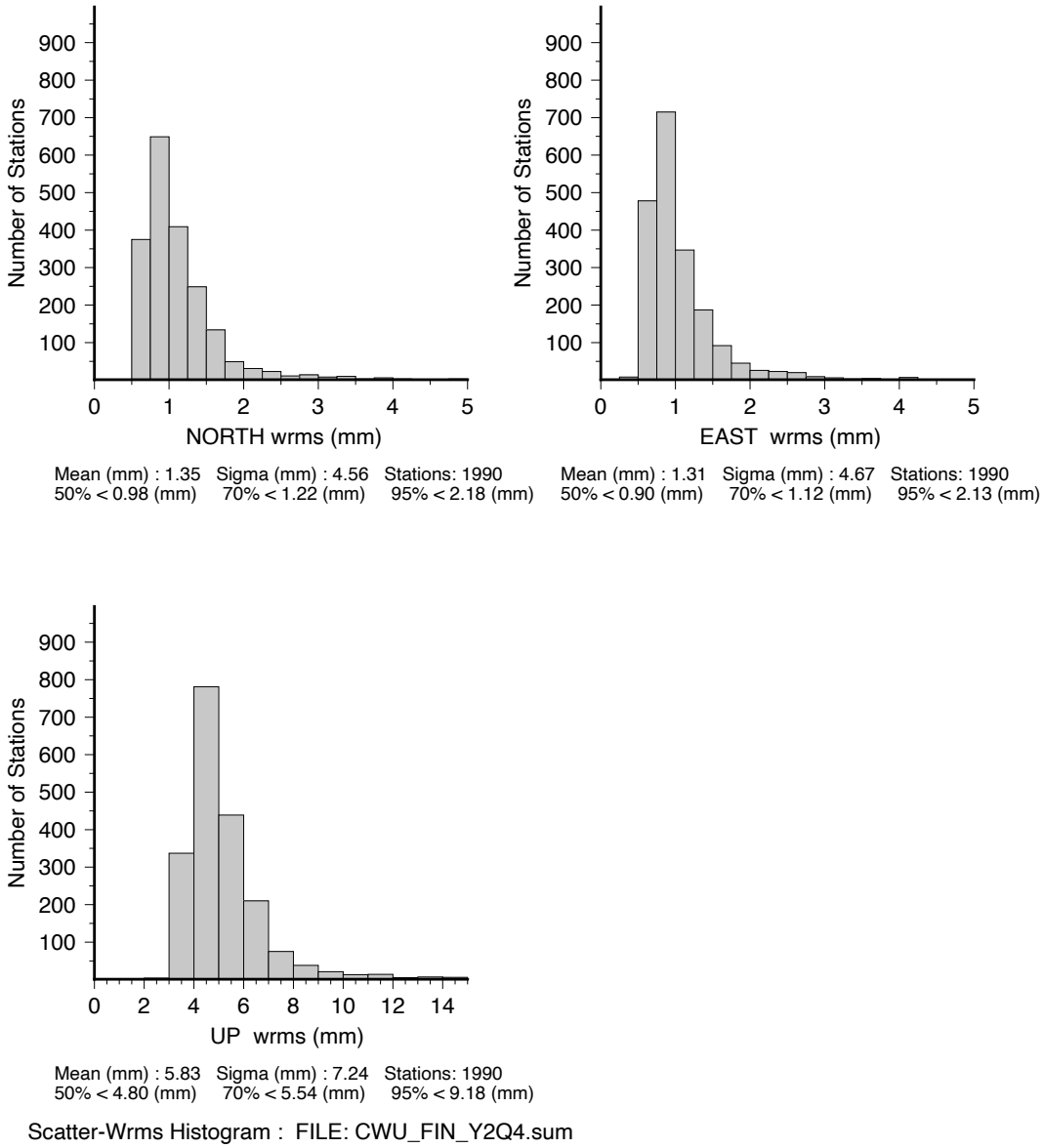

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 1990 stations analyzed between June 15, 2020 and September 26, 2020. Linear trends and annual signals were estimated from the time series.

For the CWU analysis, we also evaluate the RMS scatters of the position estimates by network type. The figures below are based on our monthly submissions but here we use nominally 3 months of data to evaluate the RMS scatters. In Table 2, we give the median, 70 and 95 percentile limits on the RMS scatters. The geographical distributions of the RMS scatters by network type are shown in Figures 2-7. The values plotted are given in CWU_FIN_Y2Q4.tab. There are 1991 stations in the file for sites that have at least 2 measurements

during the month. The Chi values have increased because of re-scaling of the variances in the GipsyX files due to the introduction of an elevation angle dependent phase noise model. The variance re-scaling factor has been reduced from 4.8 to 1.66. The contents of the files are of this form:

```
Tabular Position RMS scatters created from CWU_FIN_Y2Q4.sum
ChiN/E/U are square root of chisquared degree of freedom of the fits.
Values of ChiN/E/U near unity indicate that the estimated error
bars are consistent the scatter of the position estimates

.Site     #    N (mm)  ChiN     E (mm) ChiE   U (mm)  ChiU     Years
 1LSU   104      1.6   0.79      1.8   0.88     5.8   0.60     17.43
 1NSU   103      1.2   0.68      1.4   0.84     5.5   0.71     16.68
 1ULM   104      1.2   0.66      1.2   0.77     5.0   0.64     17.29
 7ODM   104      0.9   0.47      0.9   0.57     4.4   0.59     19.43
…
 ZDV1   103      1.0   0.48      0.9   0.56     4.9   0.64     17.32
 ZKC1   103      1.2   0.59      1.0   0.61     5.7   0.72     17.32
 ZLA1   102      1.0   0.54      0.9   0.57     5.4   0.71     17.32
 ZLC1   102      1.1   0.52      0.8   0.53     4.8   0.62     17.54
 ZME1   103      1.3   0.72      1.2   0.76     5.6   0.71     17.54
 ZMP1   103      1.2   0.60      0.8   0.54     5.2   0.68     17.79
 ZNY1    82      1.2   0.59      0.9   0.56     6.3   0.80     17.70
 ZOA1    96      0.7   0.38      0.7   0.45     3.9   0.53     18.23
 ZSE1   103      0.9   0.43      0.7   0.45     4.3   0.59     17.70
 ZTL4   103      1.2   0.64      1.1   0.67     6.2   0.78     17.89
```

Table 2: RMS scatter of the position residuals for the CWU solution between June 15, 2020 and September 26, 2020 divided by network type. The division of networks is based on the JAVA script unavcoMetdata.jar with network codes PBO, Nucleus, Mid- SCIGN_USGS, America GAMA, COCONet and Expanded PBO

Network	North (mm)	East (mm)	Up (mm)	#Sites
Median (50%)				
PBO	0.86	0.82	4.50	839
NUCLEUS	0.80	0.76	4.24	203
GAMA	1.19	1.05	5.76	13
COCONet	1.49	1.63	6.89	70
USGS_SCIGN	0.83	0.81	4.43	109
Expanded	1.19	1.07	5.51	756
70%				
PBO	1.01	0.95	4.90	
NUCLEUS	0.90	0.85	4.58	
GAMA	1.24	1.16	6.29	
COCONet	1.61	1.77	7.75	
USGS_SCIGN	0.98	0.97	4.98	

Expanded 95%	1.39	1.27	6.22
PBO	1.80	1.64	6.42
NUCLEUS	1.52	1.30	6.66
GAMA	1.32	1.22	7.29
COCONet	2.48	2.98	11.61
USGS_SCIGN	1.78	1.79	8.06
Expanded	2.66	2.53	12.17

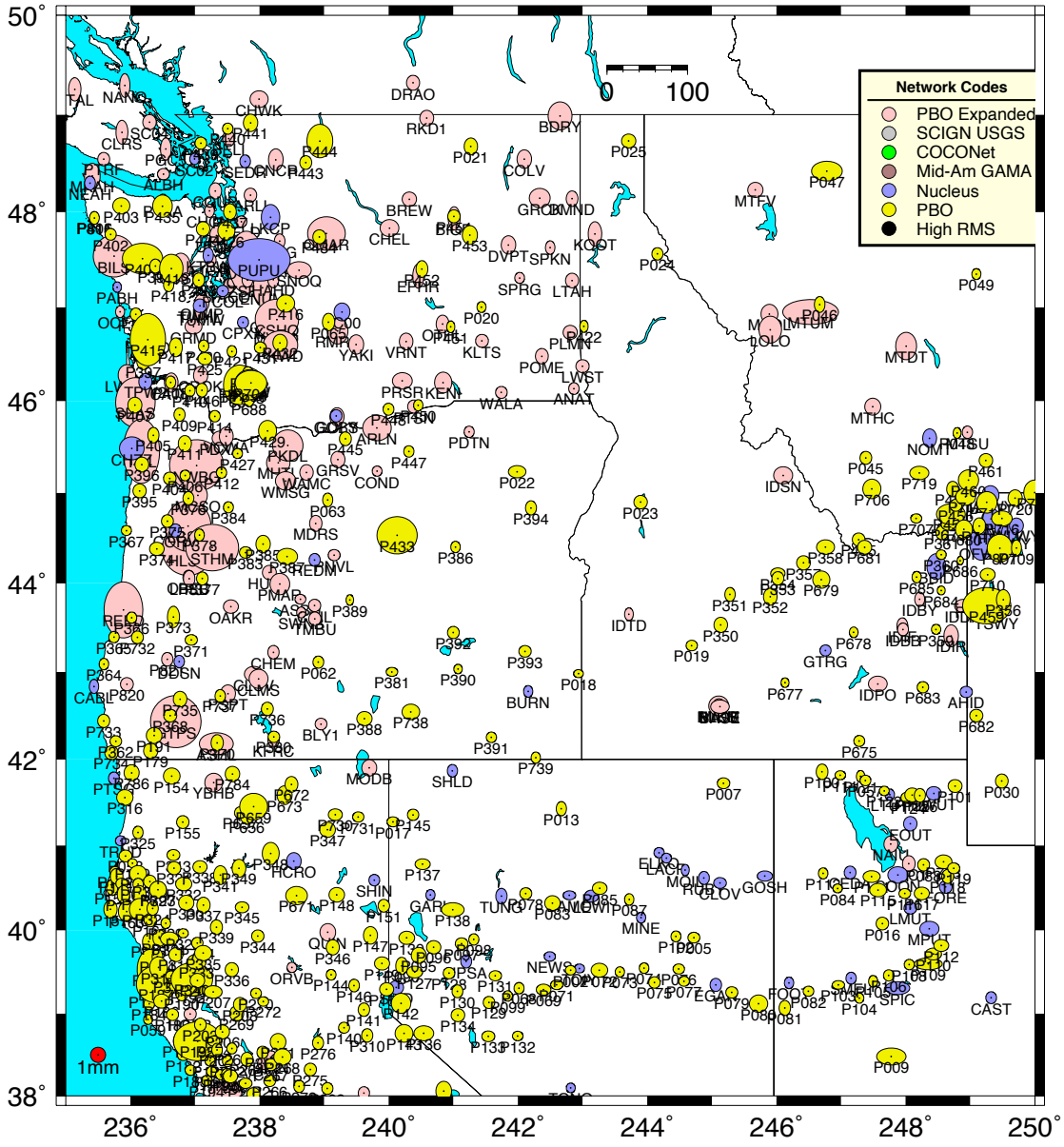

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1 mm scatters. Sites shown with black circles have combined RMS scatters in north and east greater than 5 mm or are sites that have no data during this 3-month interval.

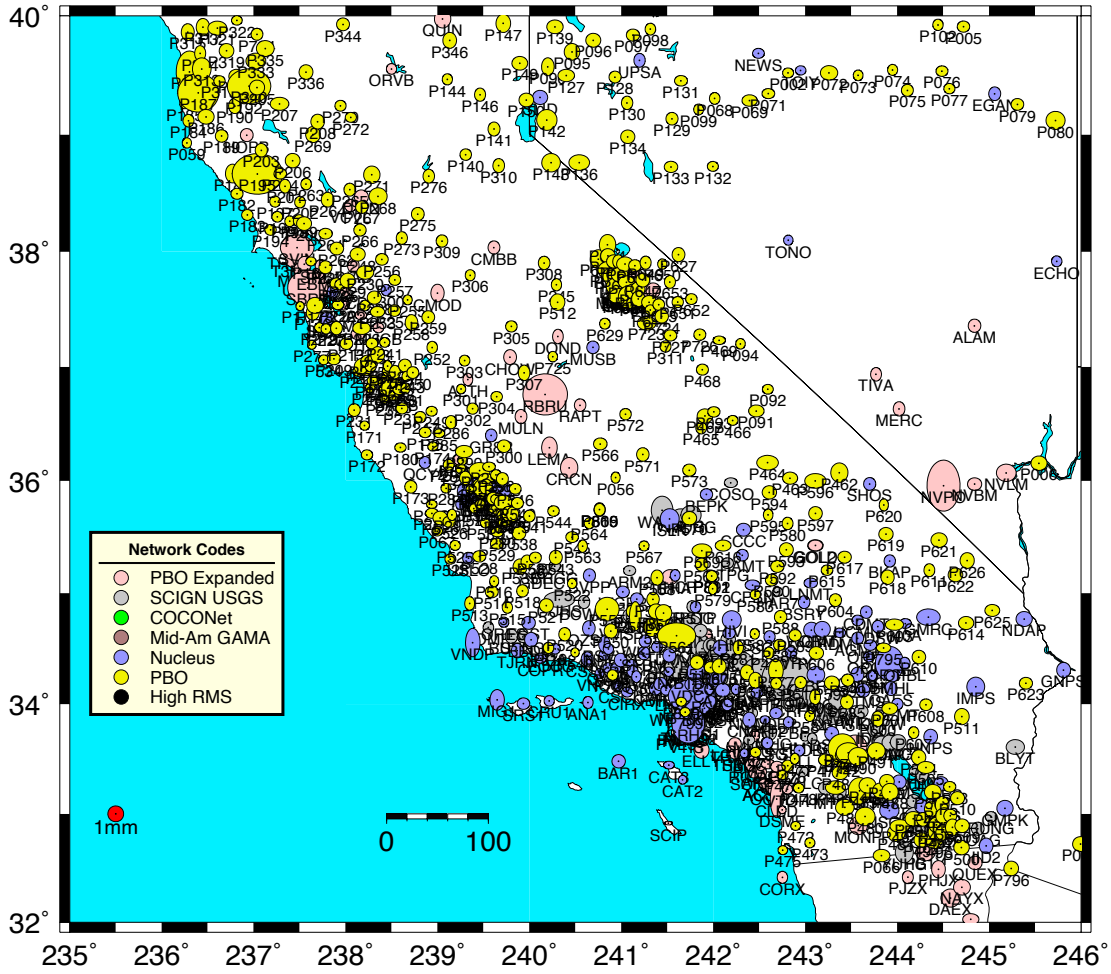

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

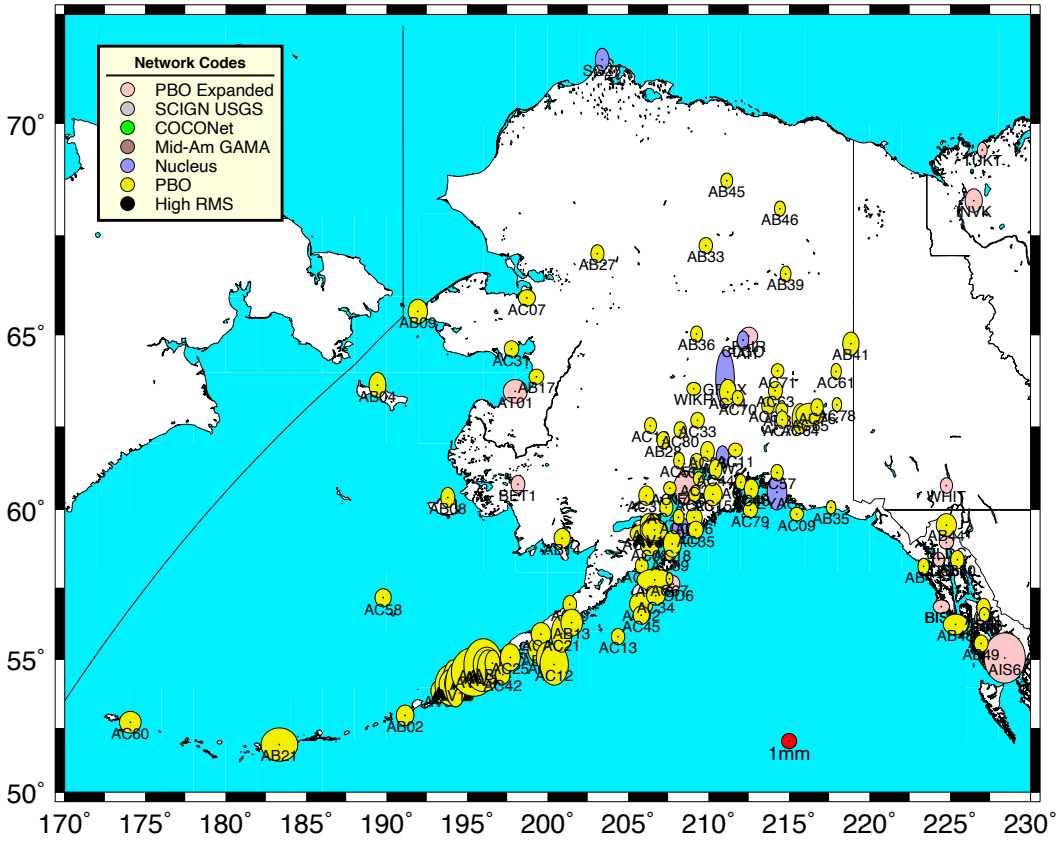

Figure 4: Same as Figure 4 except for the Alaskan region.

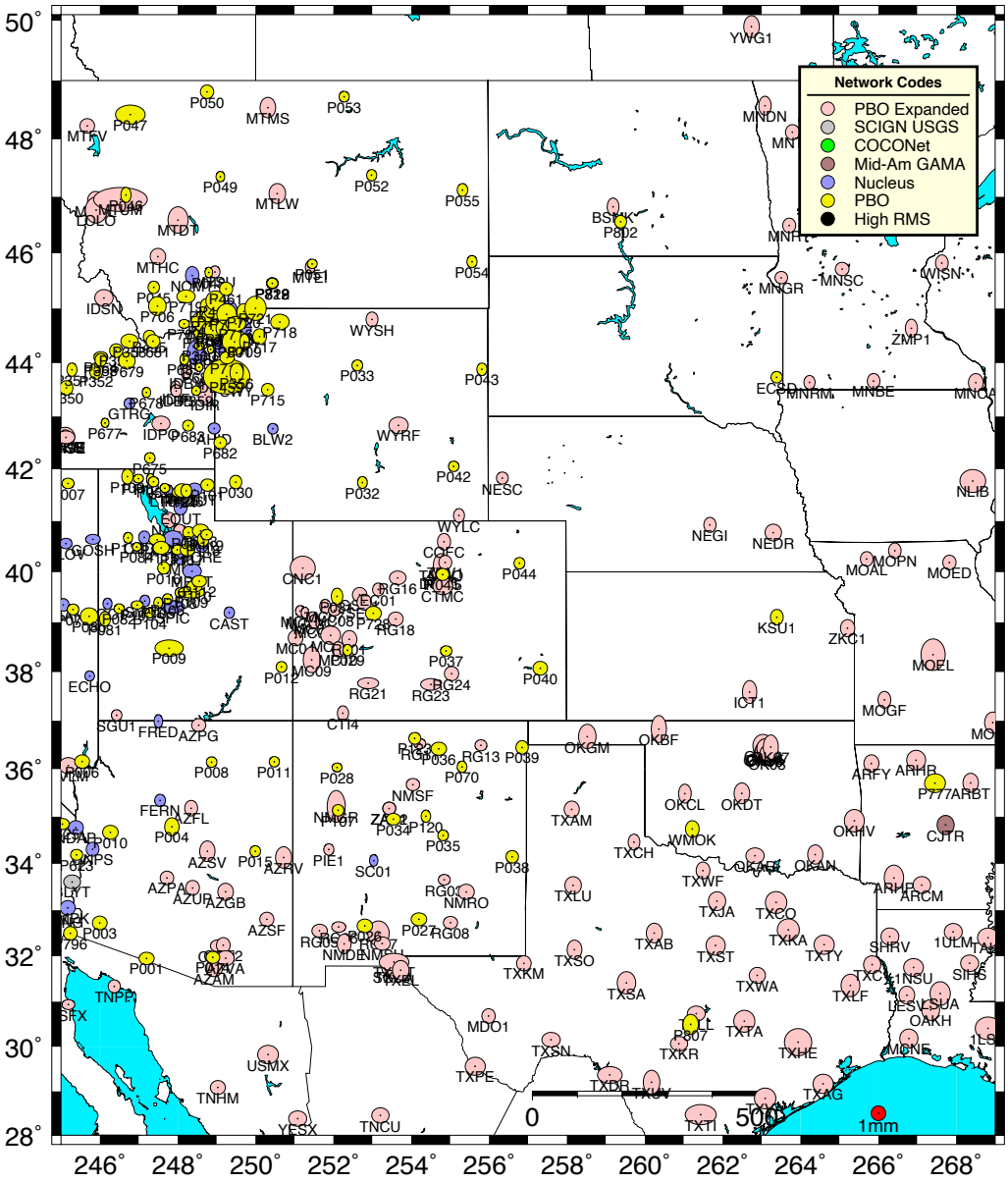

Figure 5: Same as Figure 4 except for the Central United States

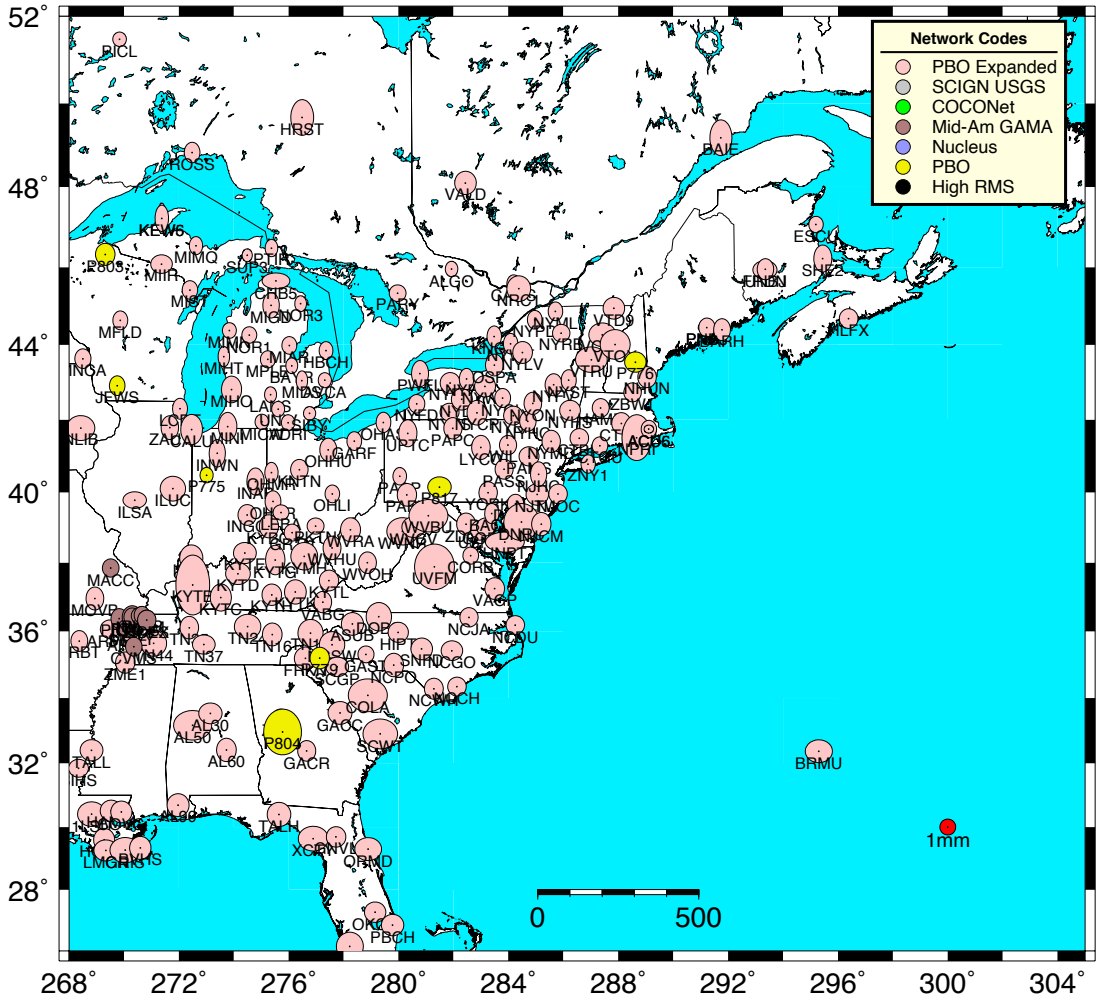

Figure 6: Same as Figure 4 except for the Eastern United States

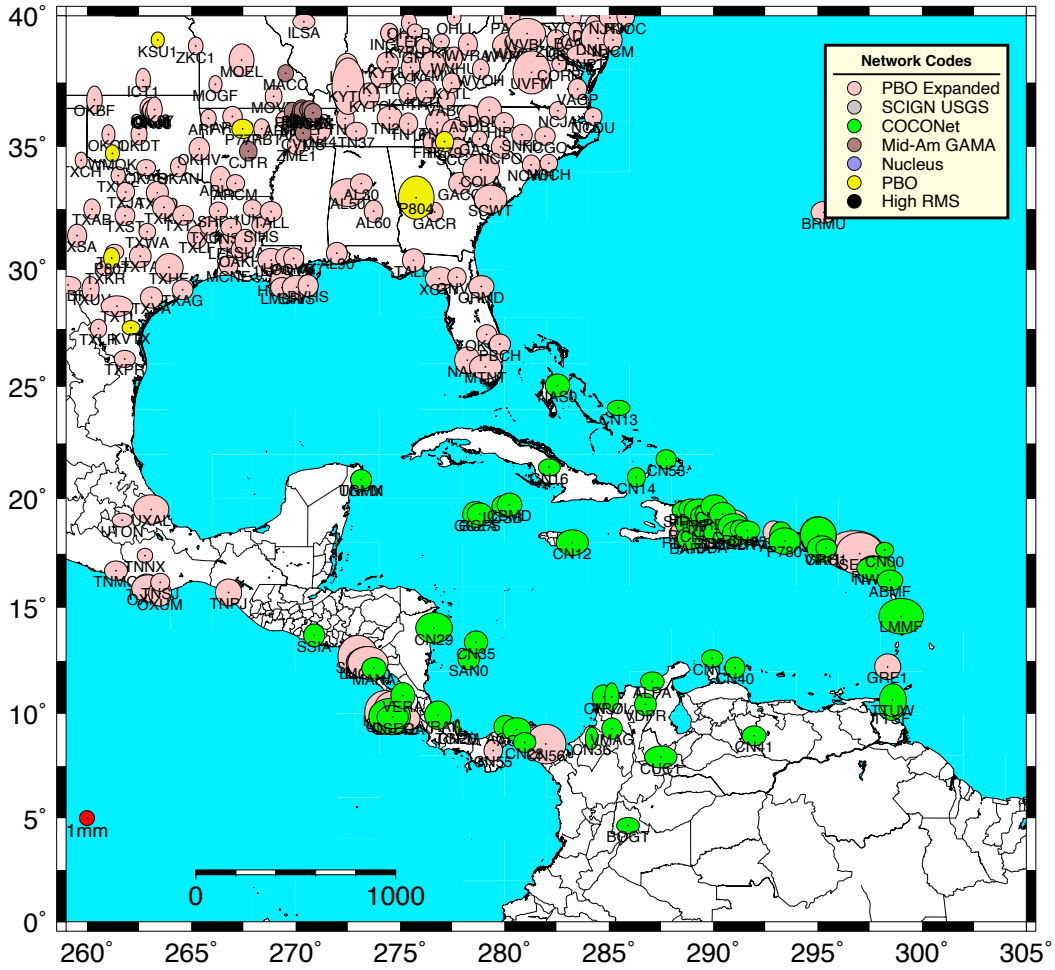

Figure 7: Same as Figure 4 except for the Caribbean region.

GLOBK Apriori coordinate file and earthquake files

As part of the quarterly analysis we run complete analysis of the time series files and generate position, velocity and other parameter estimates from these time series. These files can be directly used in the GLOBK analysis files sent with the GAGE analysis documentation. The current earthquake and discontinuity files used in the GAGE ACC analyses are All_NOTA_eqs.eq All_NOTA_ants.eq All_NOTA_unkn.eq. These names have been changed to reflect that they now refer to the Network of America and no longer just the plate boundary observatory. The GLOBK apriori coordinate file All_CWU_nam14.apr is the current estimates based on data analysis in this quarterly report.

Snapshot velocity field analysis from the reprocessed PBO analysis.

For this quarterly report, we generate velocity estimates for the reprocessed results and the current GAGE analyses that are in the NAM14 reference frame using the CWU analysis. There are 2630 stations in the CWU solution (2 more than last quarter). The statistics of the fits to results are shown in Table 3. Because these are cumulative statistics, they are little changed from last quarter. In this analysis, offsets are estimated for antenna changes and earthquakes. Annual signals are estimated and for some earthquakes, logarithmic post-seismic signals are also estimated. The full tables of RMS fit along with the duration of the data used are given in cwu_nam14_200026.tab. The velocity estimates are shown by region and network type in Figures 8-14. The color scheme used is the same as Figures 2-7. The snapshot velocity field file for CWU is cwu_nam08_200926.snpvel.

Table 3: Statistics of the fits of 2630 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and September 26, 2020.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.41	1.36	6.15
70%			
CWU	1.77	1.69	7.00
95%			
CWU	3.84	3.59	11.68

In Figures 8-14, different tolerances are used for maximum standard deviation in each of the figures so that regions with small velocity vectors can be displayed at large scales without the plots being dominated by large error bar points. The standard deviations of the velocity estimated are computed using the GLOBK First-order-Gauss-Markov Extrapolation (FOGMEX) model that aims to account for temporal correlations in the time series residuals. This algorithm is also called the "Realistic Sigma" model.

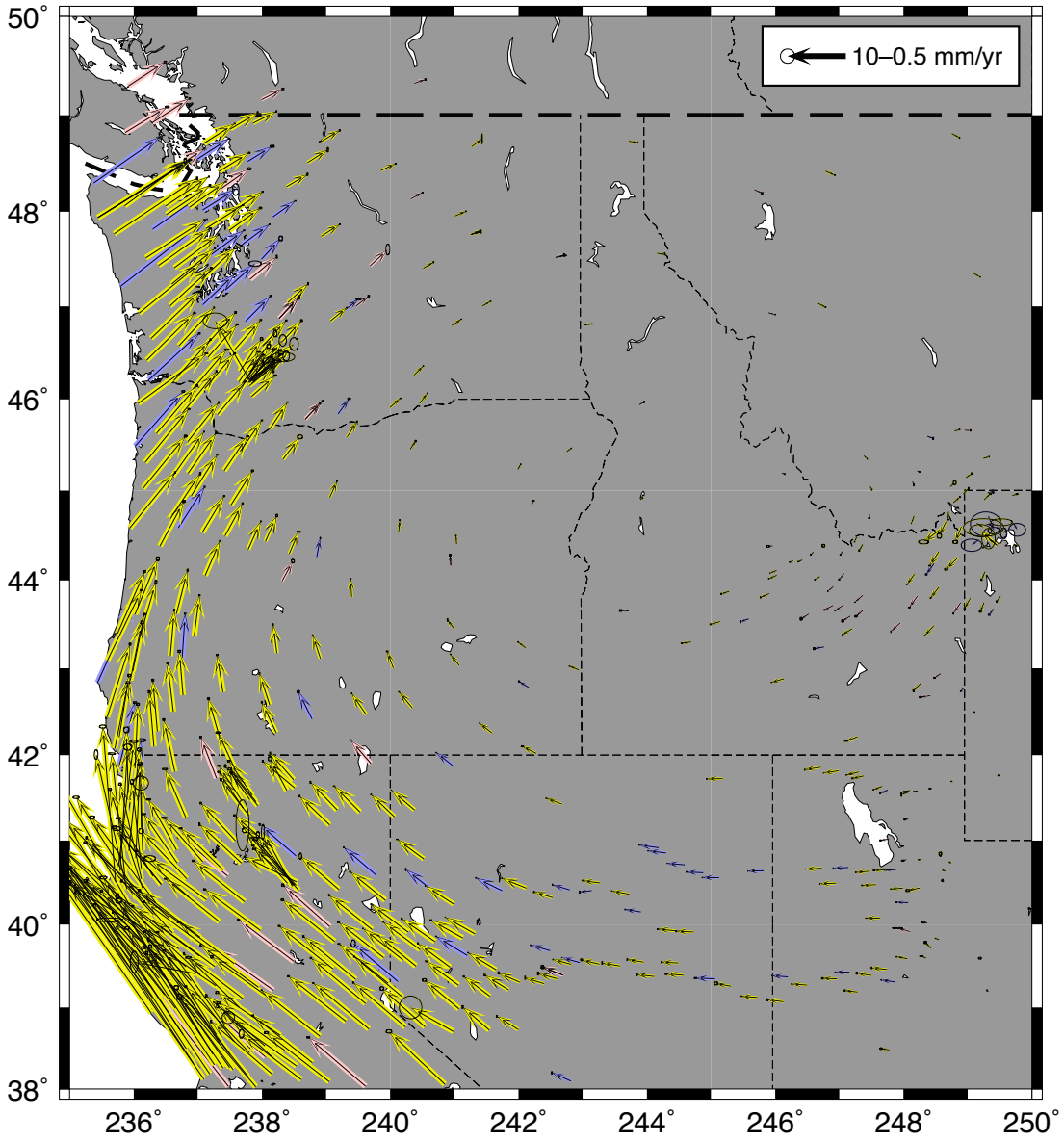

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal standard deviations less than 2 mm/yr are shown (this value is reduced from previous reports due the improved velocity sigmas).

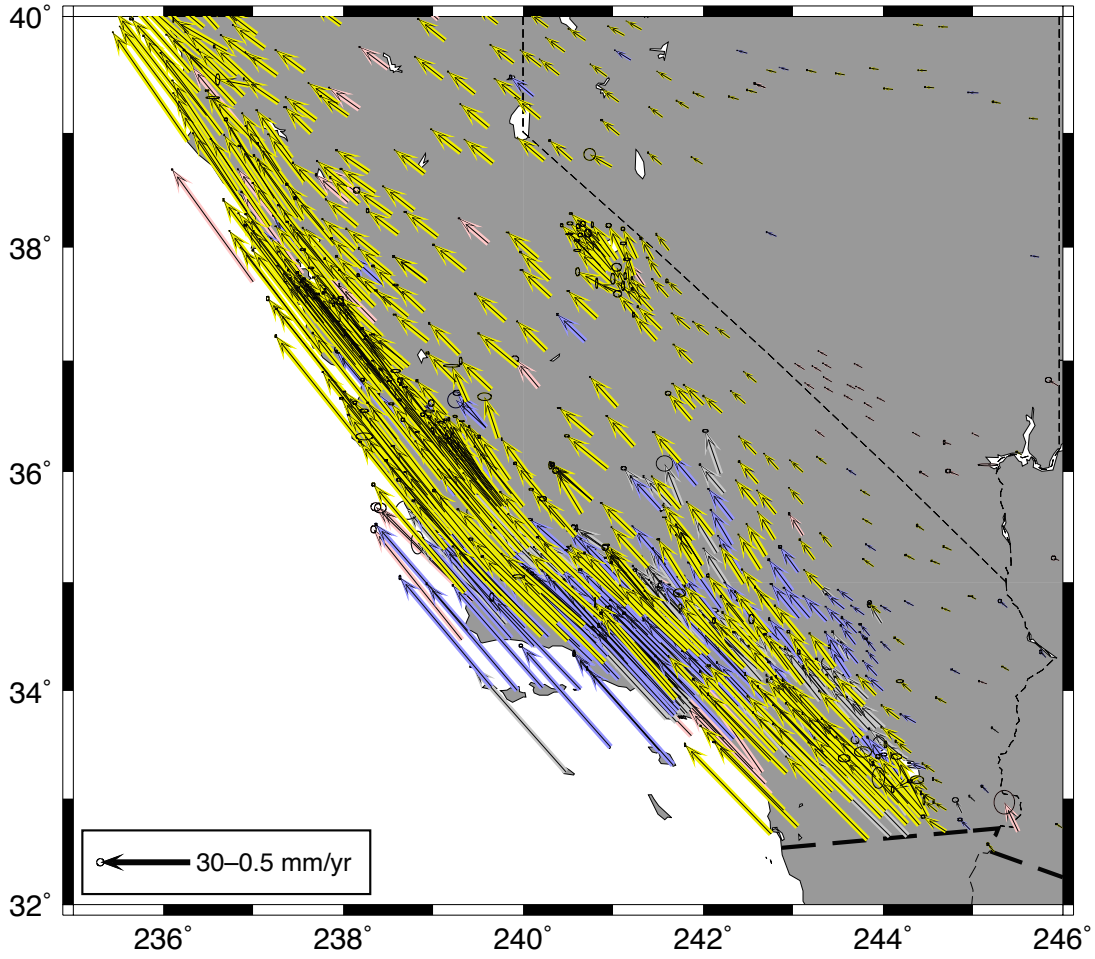

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

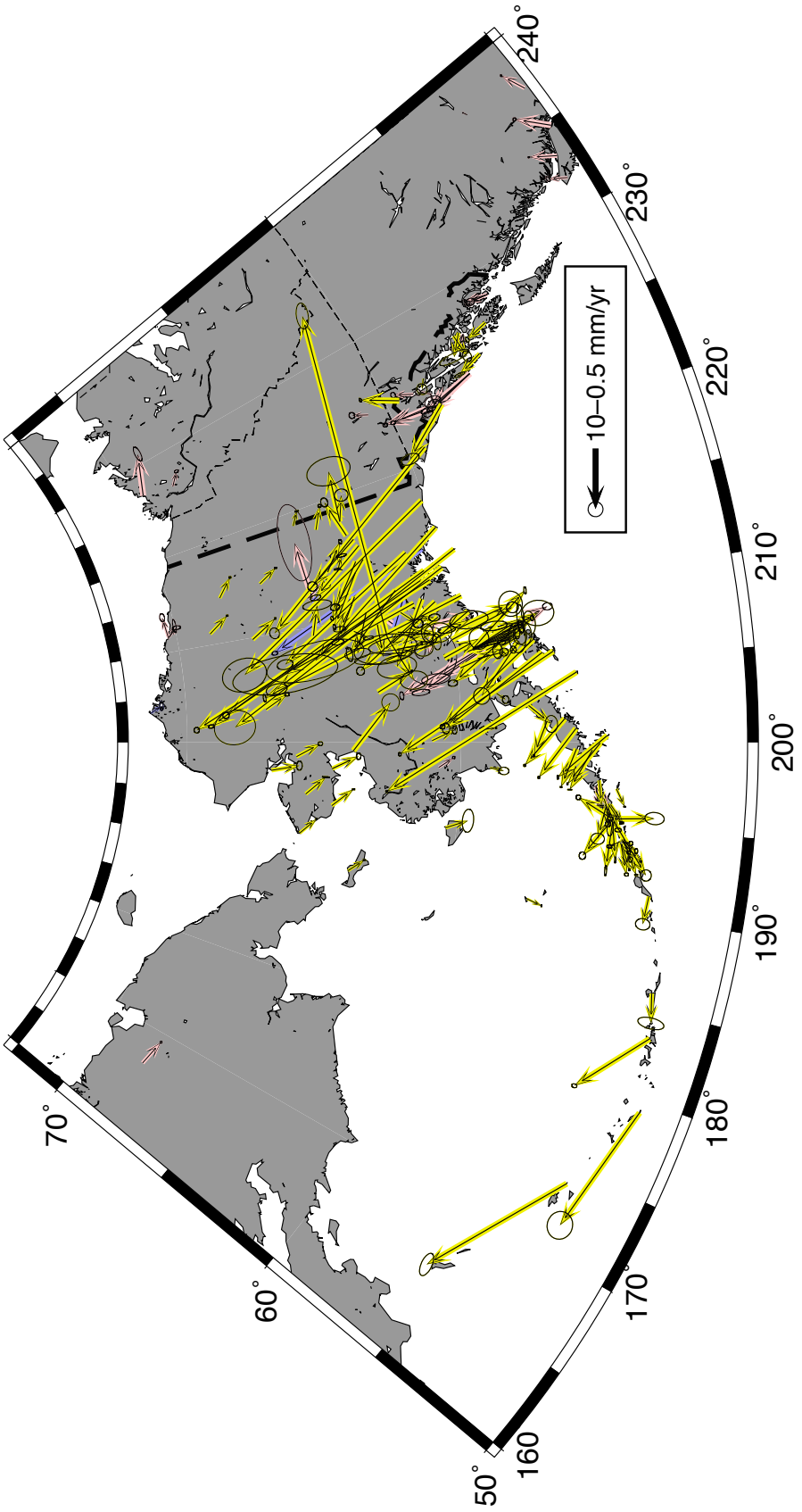
10–0.5 mm/yr
240°
230°
220°
210°
200°
190°
180°
170°
160°
70°
60°
50°

Figure 10: Same as Figure 8 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

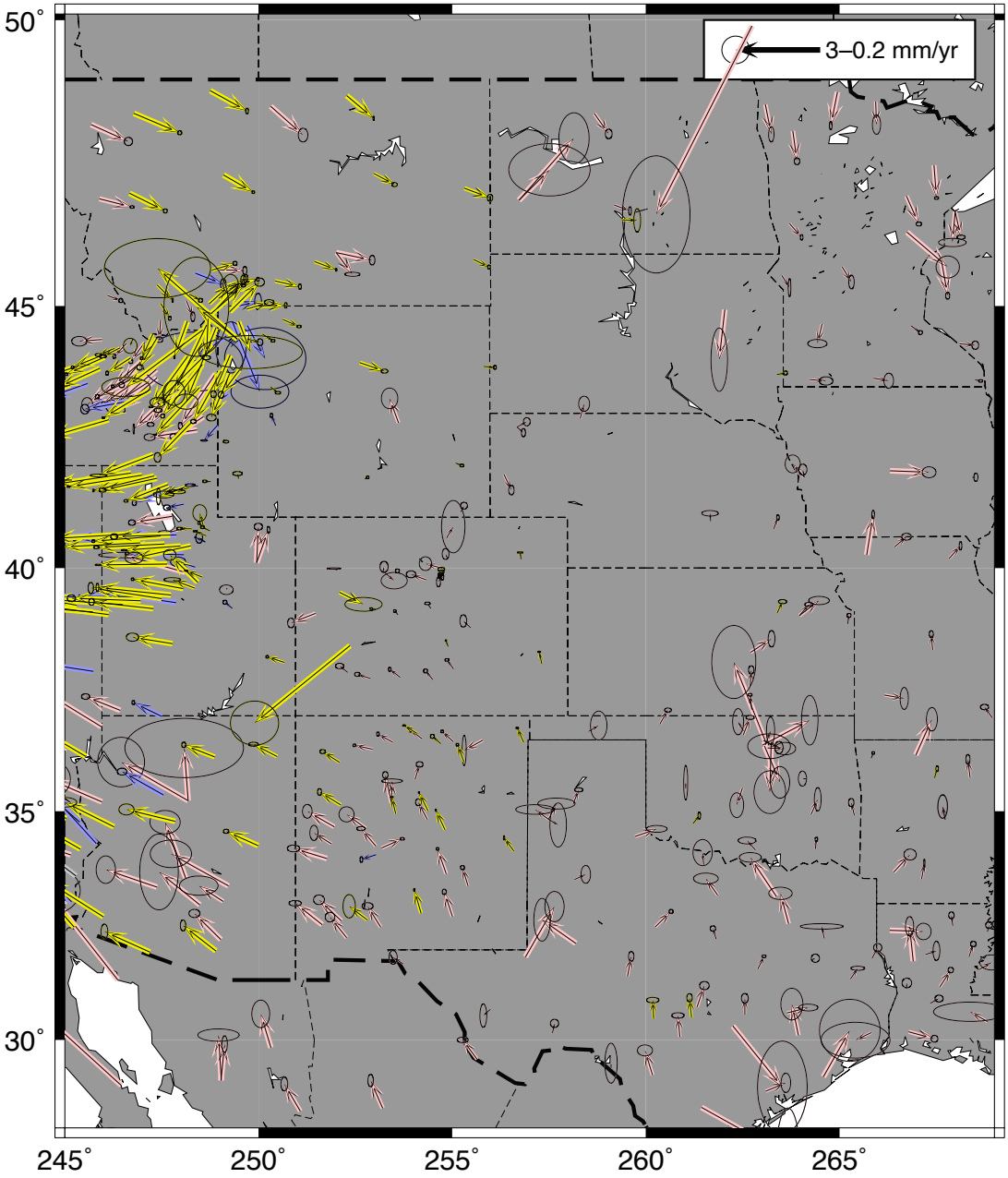

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

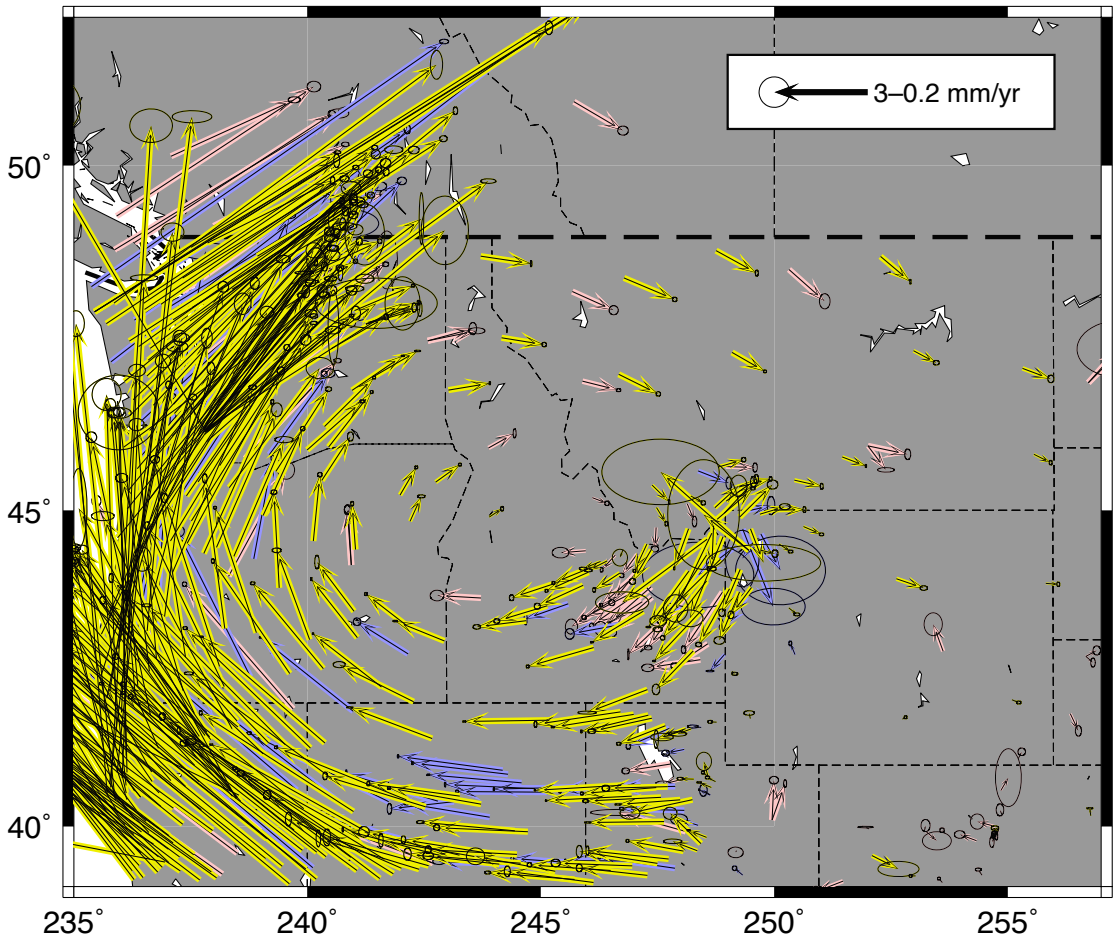

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

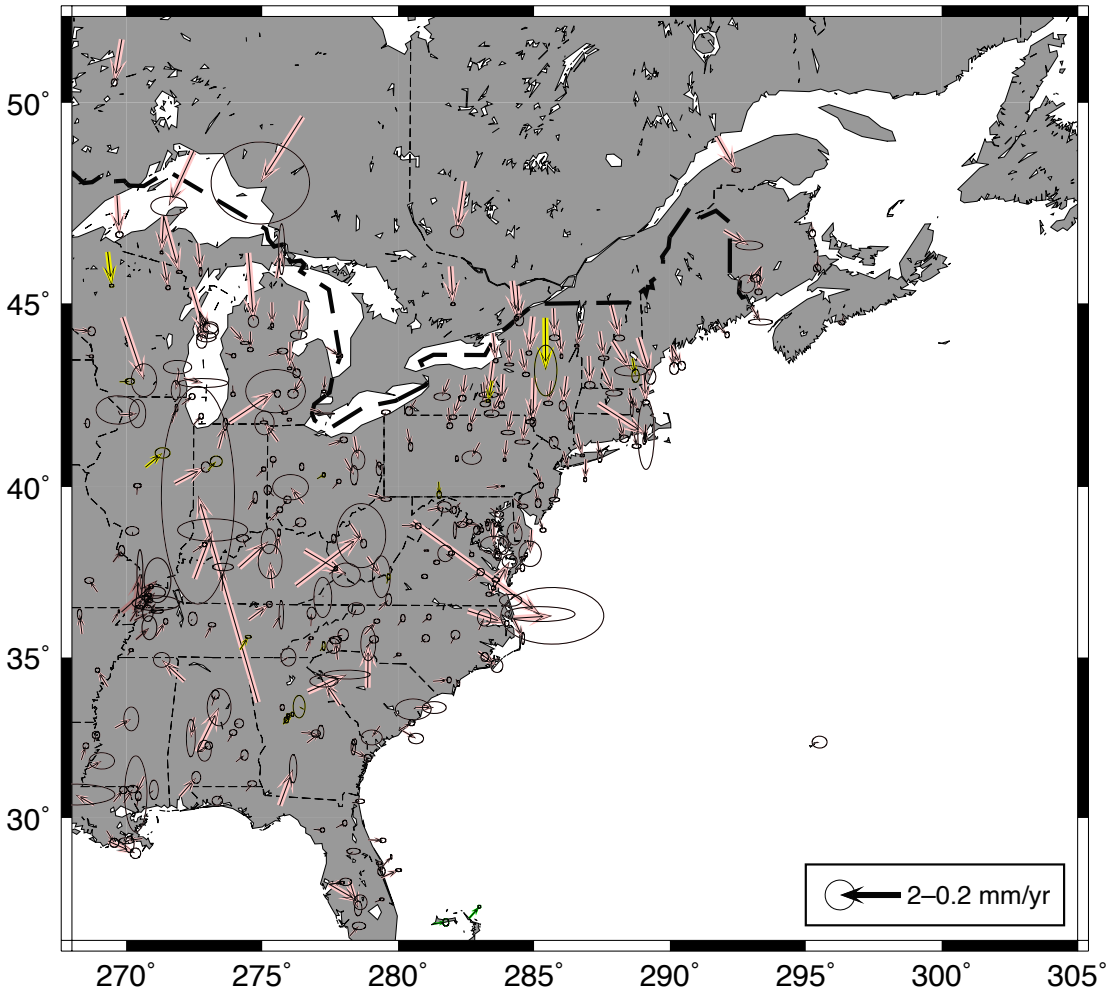

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

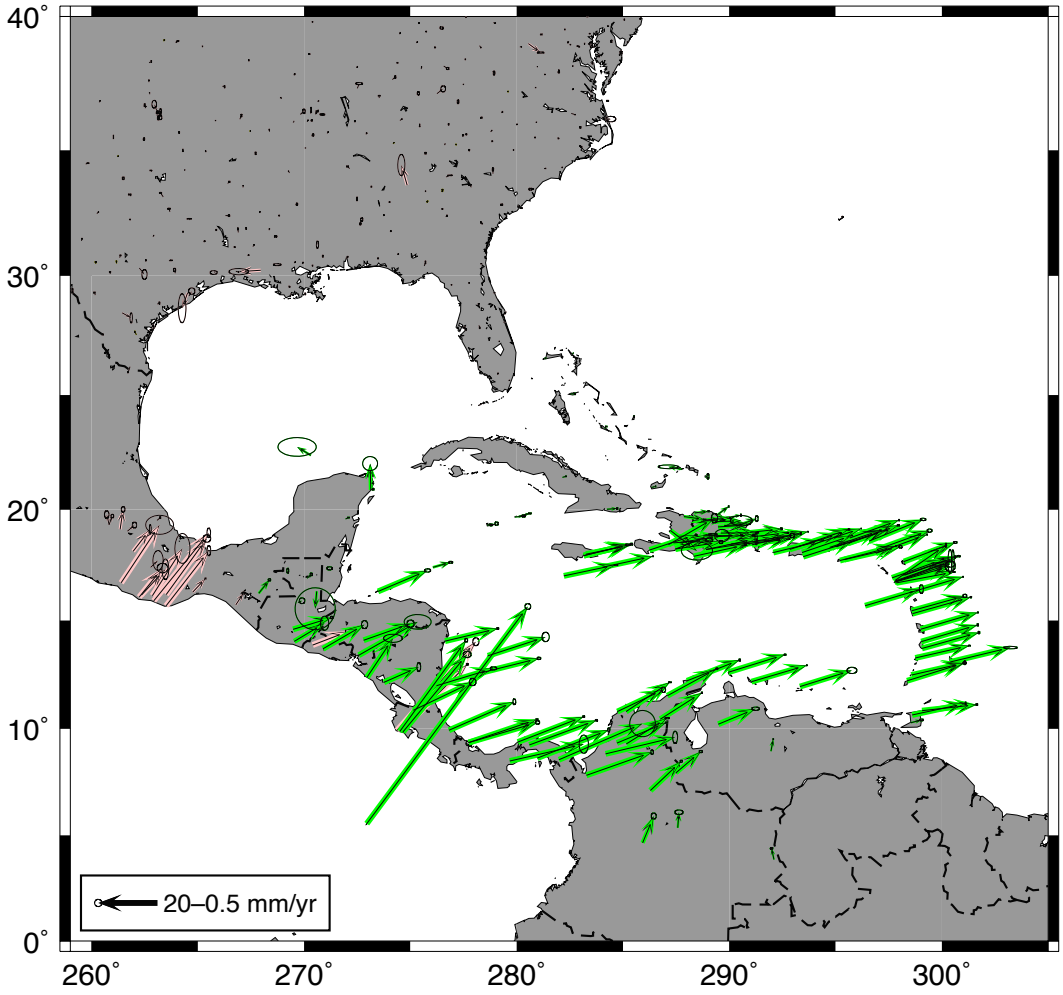

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2020/06/15-2020/09/30

We use the NEIC catalog to search for earthquakes that could cause coseismic offsets at the sites analyzed by the GAGE analysis centers. Of the 23 earthquakes examined during this quarter, 45earthquakes generated displacements more than 1 mm. These have been designated events 54 and 55 (reported last quarter) and 56 and 57. The coseismic offsets from these events are shown in Figures 15 and 16.

The event co-seismic offsets are shown in Figures 15-16.

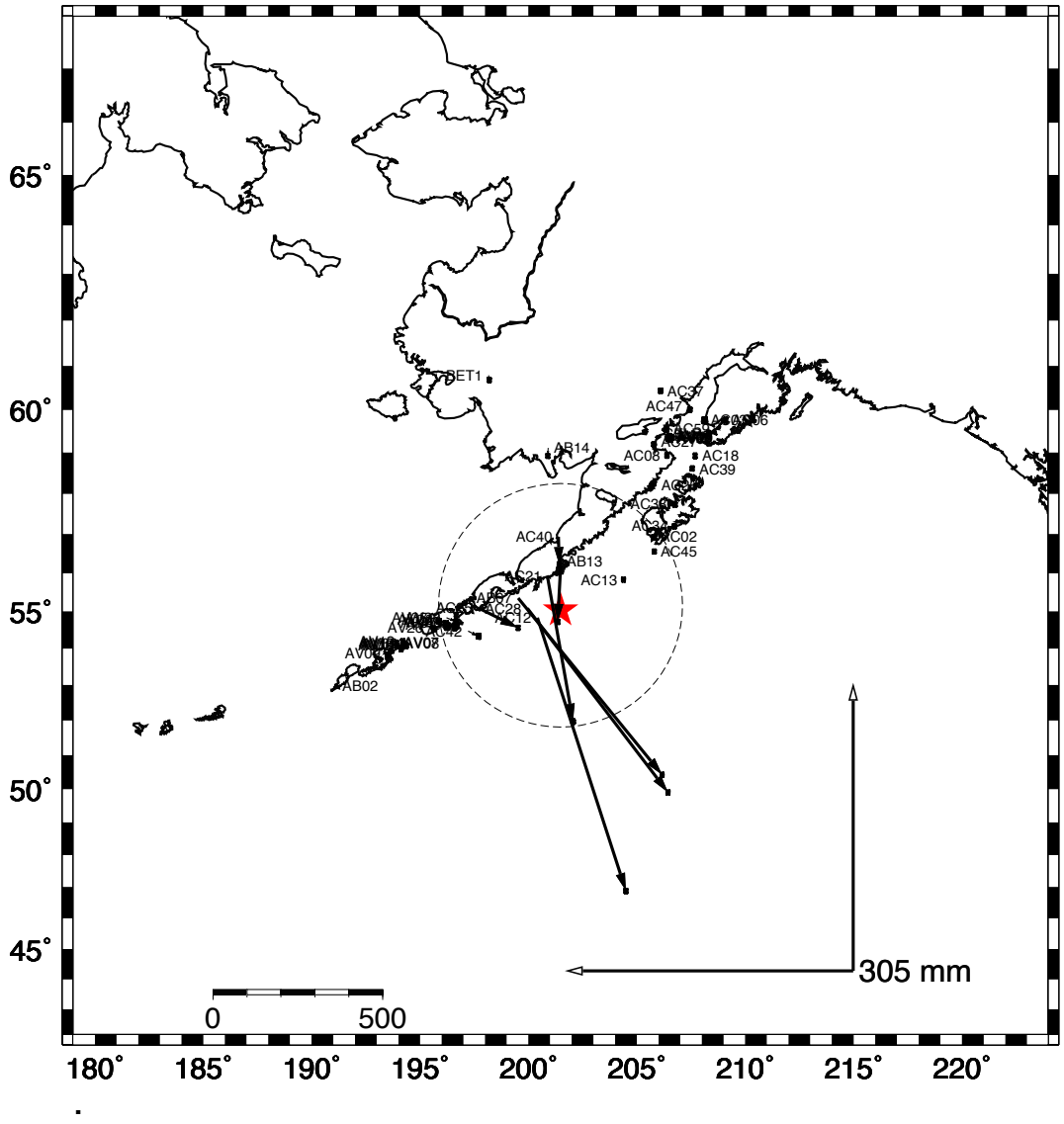

Figure 15: Coseismic offsets from the GAGE event 56 ANSS(ComCat) us7000asvb, mww7.8 105 km SSE of Perryville ϕ 55.0298 λ -158.5217 date 2020 07 22 time 06:13 UTC.

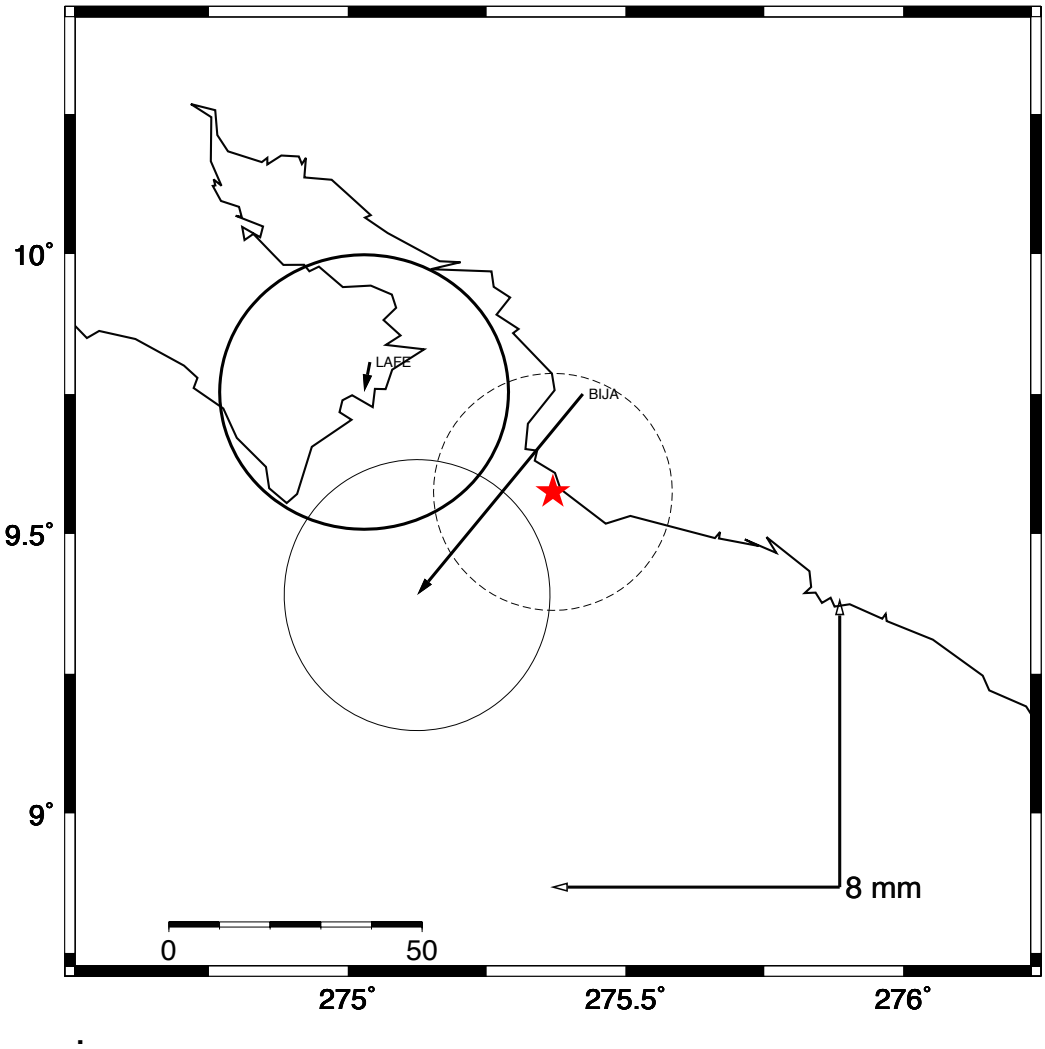

Figure 16: Coseismic offsets from the GAGE event 57. ANSS(ComCat) us7000bcbv, mww6.0 4 km S of JacÌ? ϕ 9.5749 λ -84.date 2020 08 24 time 21:52 UTC. Since only one site was displaced, not event file created. The offset is given in the cwu.kalts_nam14.off file.

Antenna and other discontinuity events.

Antenna swaps at 20 sites have been added to the list of offsets that are estimated when fitting velocities and other parameters to the CWU time series. All of these offsets were in May and July 2020.

ANET Processing

The ANET additional sites are being processed as a separate network and the frame resolved SINEX files will be given in the Antarctica 2014 reference frame (Altamimi *et al.,* 2016, 2017). We label this frame ant14. Time series and SINEX files are generated only for final orbit solutions and are labeled as fanet (instead of final to avoid name conflicts with loose solutions). The IGS14 loose submission files are labeled with "lse14" to differentiate them for the IGS08 loose submissions which were simply label as loose. The statistics of the time series fits from the CWU solution for this quarter are given in Table 4.

Table 4: Statistics of the fits of 54 stations in the ANET region for CWU analyzed in the final orbit analysis between June 15, 2020 and September 26, 2020.

CWU	North (mm)	East (mm)	Up (mm)
ANET	1.27	1.01	6.78
ANET	1.69	1.26	7.35
ANET	2.30	1.87	9.95

The histogram to the RMS scatter of the results for this quarter are shown in Figure A.1

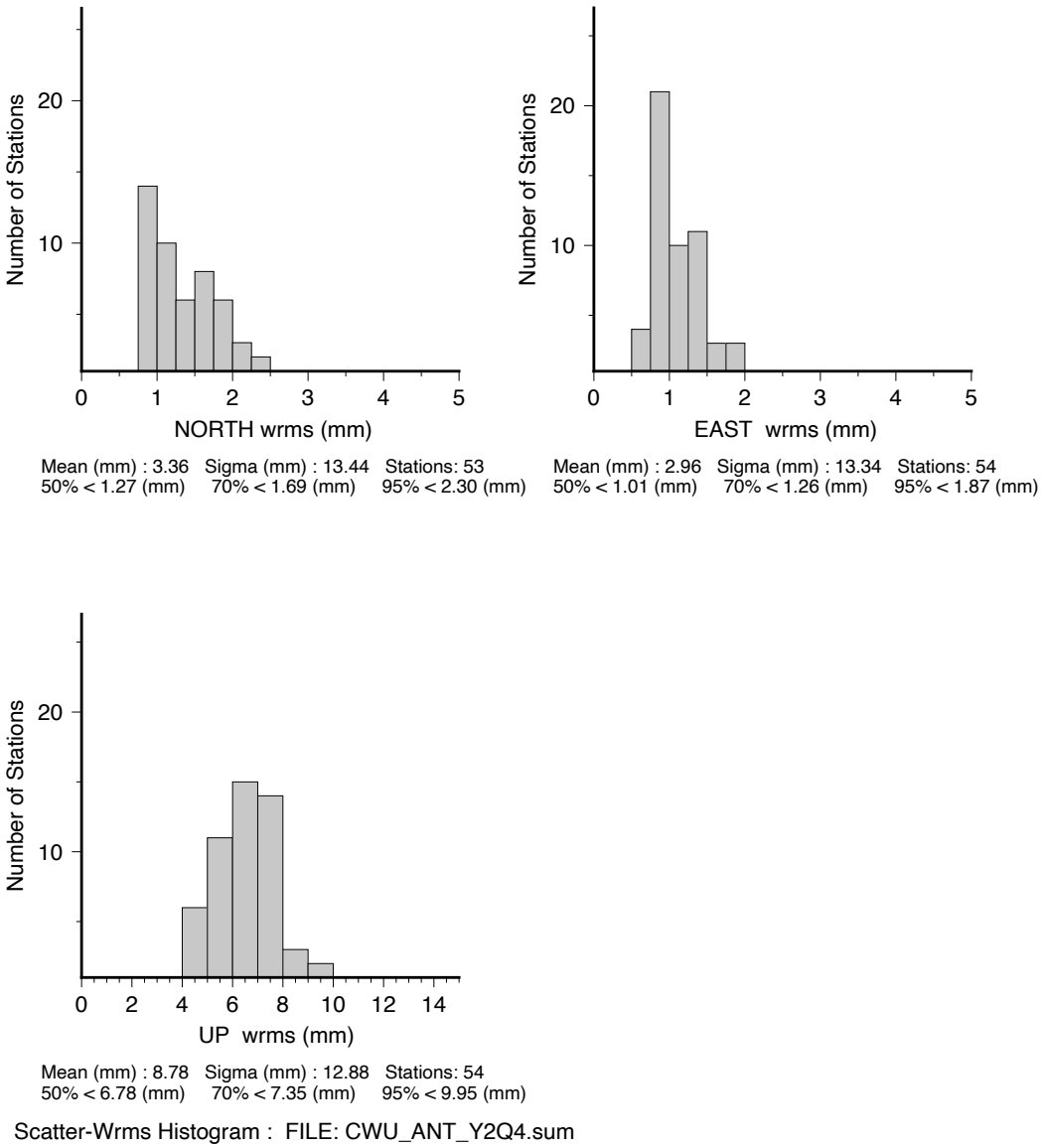

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 60 stations in Antarctica analyzed between June 15, 2020 and September 26, 2020. Linear trends and annual signals were estimated from the time series.

References

Altamimi, Z., P. Rebischung, L. Metivier, and X. Collilieux (2016), ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions, *J. Geophys. Res. Solid Earth*, 121, 6109-6131, doi: 10.1002/2016JB013098.

Altamimi, Z., L. Metivier, P. Rebischung, H. Rouby, X. Collilieux; ITRF2014 plate motion model, *Geophysical Journal International, Volume 209*, Issue 3, 1 June 2017, Pages 1906-1912, https://doi.org/10.1093/gji/ggx136