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

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Period: 2020/04/01-2020/06/30

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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 2020/03/15 to 2020/06/30, time series velocity field analyses for the GAGE reprocessing analyses (1996-2020). Several earthquakes were investigated this quarter but none generated coseismic displacements > 1mm.

Analysis files (pbovel 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 2006 stations were processed which is 32 less than last quarter. We are losing sites each quarter most likely due to failed sites. The loss this quarter is similar to last quarter. In addition up to 56 sites were processed in the ANET solutions, 4 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: March 15, 2020– June 13, 2020

For this report, we generated the statistics using the ~3 months of CWU results between March 15, 2020 and June 13, 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 2006 stations for CWU analyzed in the finals analysis between March 15, 2020 and June 13, 2020. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.94	0.86	4.49
70%			
CWU	1.14	1.07	5.16
95%			
CWU	2.03	1.99	8.02

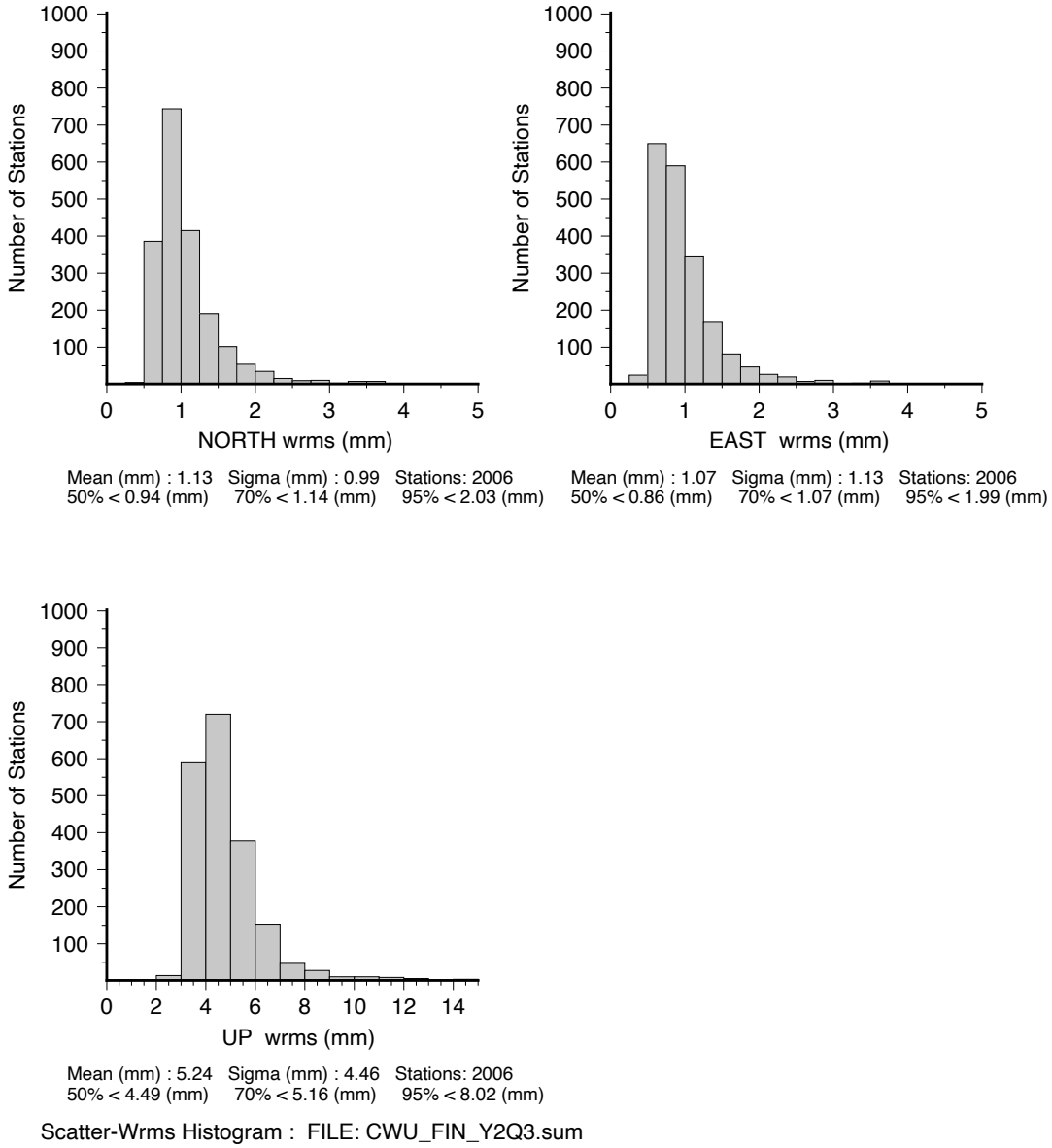

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 2006 stations analyzed between March 15, 2020 and June 13, 2020. Linear trends and annual signals were estimated from the time series.

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_Y2Q3.tab.

There are 2006 stations in the file for sites that have at least 2 measurements during the month. The contents of the files are of this form:

```
Tabular Position RMS scatters created from CWU_FIN_Y2Q3.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    84       1.1   0.33       1.3   0.39      5.2   0.32     17.12
 1NSU    84       1.0   0.34       1.0   0.37      6.0   0.46     16.38
 1ULM    84       0.9   0.30       1.0   0.39      5.1   0.39     16.98
 7ODM    84       0.9   0.30       0.7   0.25      3.8   0.30     19.13
…
 ZDV1    84       1.0   0.29       1.1   0.43      5.1   0.41     17.01
 ZKC1    84       0.8   0.24       0.7   0.28      5.3   0.40     17.01
 ZLA1    83       1.6   0.52       1.1   0.41      4.5   0.36     17.01
 ZLC1    83       0.8   0.24       0.8   0.30      5.3   0.42     17.24
 ZME1    84       1.1   0.35       0.9   0.35      4.7   0.35     17.24
 ZMP1    84       0.8   0.23       0.6   0.22      5.8   0.45     17.48
 ZNY1    84       0.9   0.26       0.9   0.33      5.4   0.42     17.39
 ZOA1    84       0.7   0.22       0.6   0.24      3.5   0.28     17.93
 ZSE1    84       0.8   0.22       0.8   0.30      4.0   0.32     17.39
 ZTL4    83       1.1   0.35       1.0   0.36      6.2   0.48     17.59
```

Table 2: RMS scatter of the position residuals for the CWU solution between March 15, 2020 and June 13, 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	0.88	0.79	4.16	843
NUCLEUS	0.85	0.78	4.04	203
GAMA	0.88	0.90	5.47	13
COCONet	1.25	1.37	5.71	72
USGS_SCIGN	0.88	0.84	4.01	109
Expanded	1.03	0.96	4.97	766
70%				
PBO	1.06	0.98	4.64	
NUCLEUS	0.97	0.91	4.45	
GAMA	0.95	0.96	5.85	
COCONet	1.44	1.49	6.58	
USGS_SCIGN	1.07	1.01	4.39	
Expanded	1.24	1.16	5.60	
95%				

PBO	1.87	1.81	6.56
NUCLEUS	1.58	1.49	6.31
GAMA	1.01	1.01	7.00
COCONet	1.89	2.41	10.01
USGS_SCIGN	1.88	1.73	7.00
Expanded	2.21	2.07	9.42

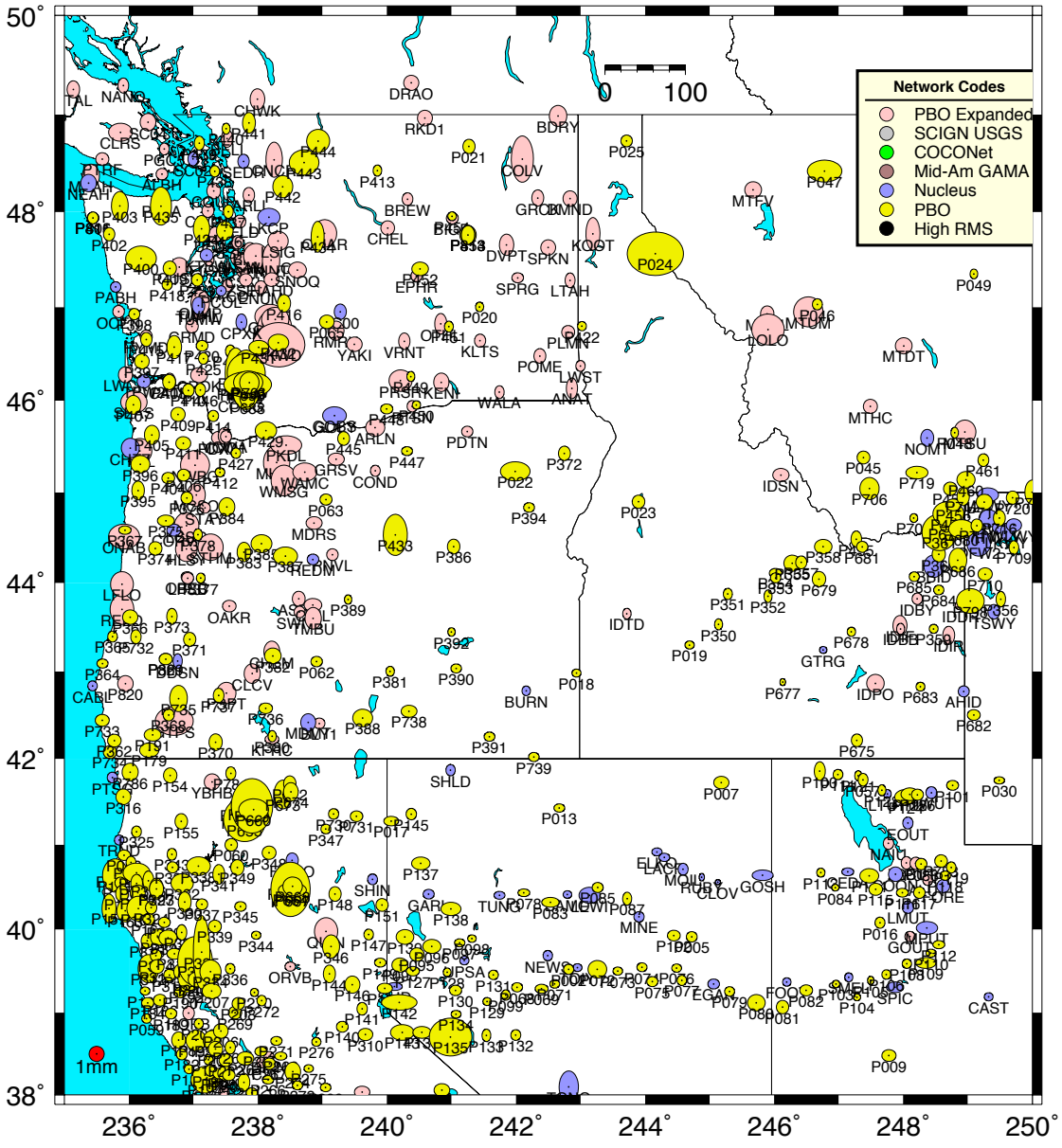

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1 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.

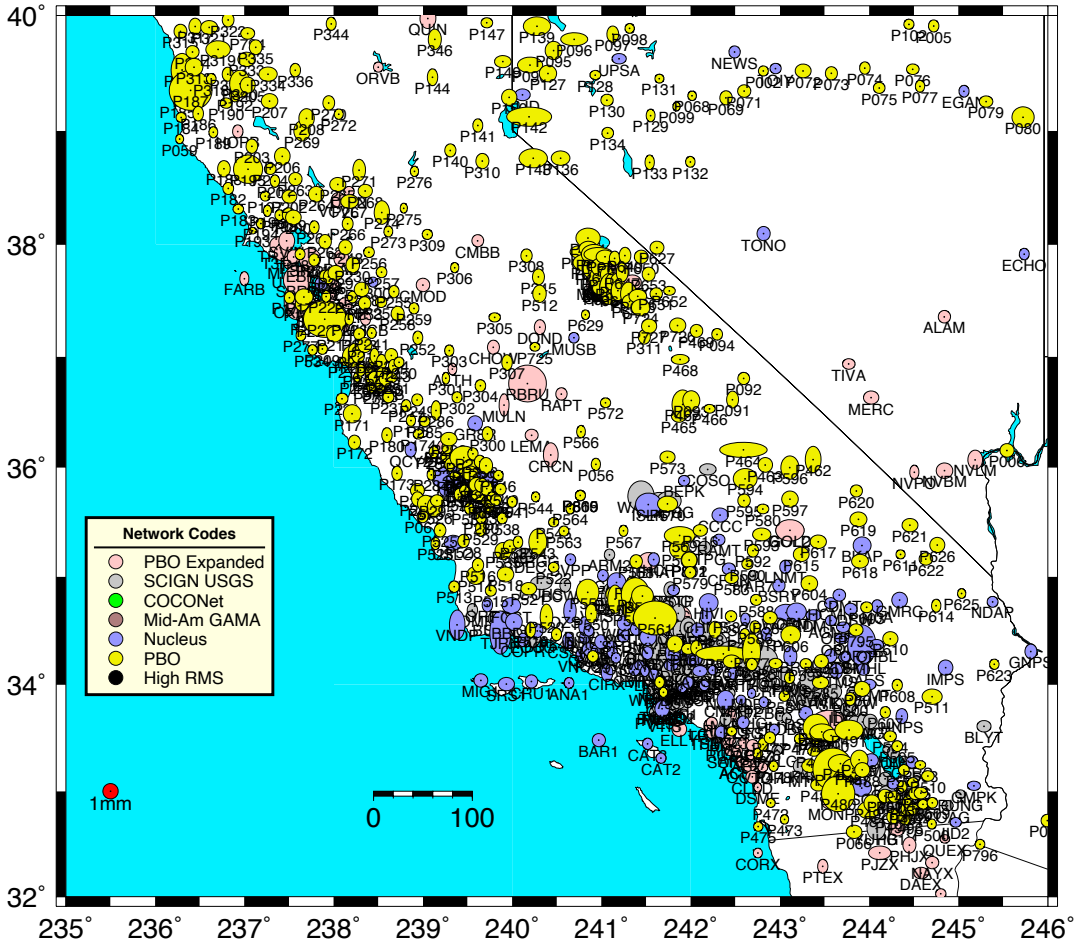

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

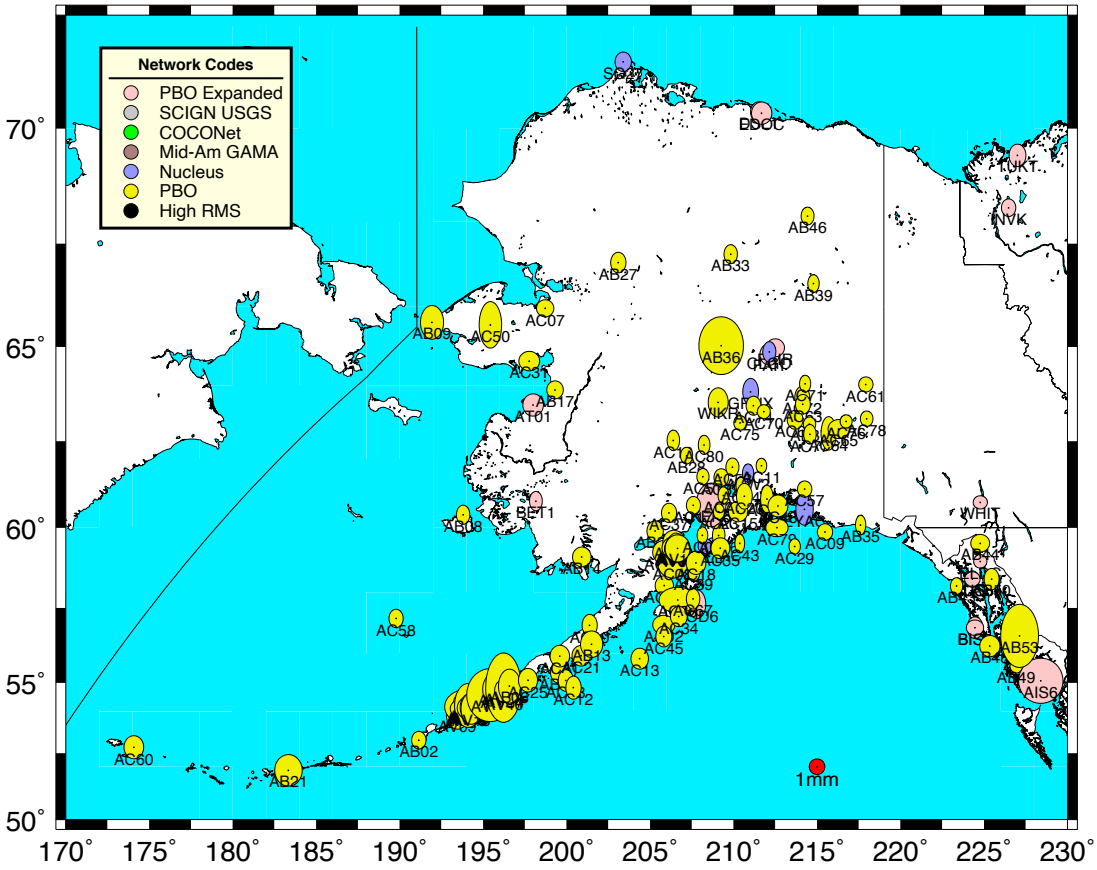

Figure 4: Same as Figure 4 except for the Alaskan region.

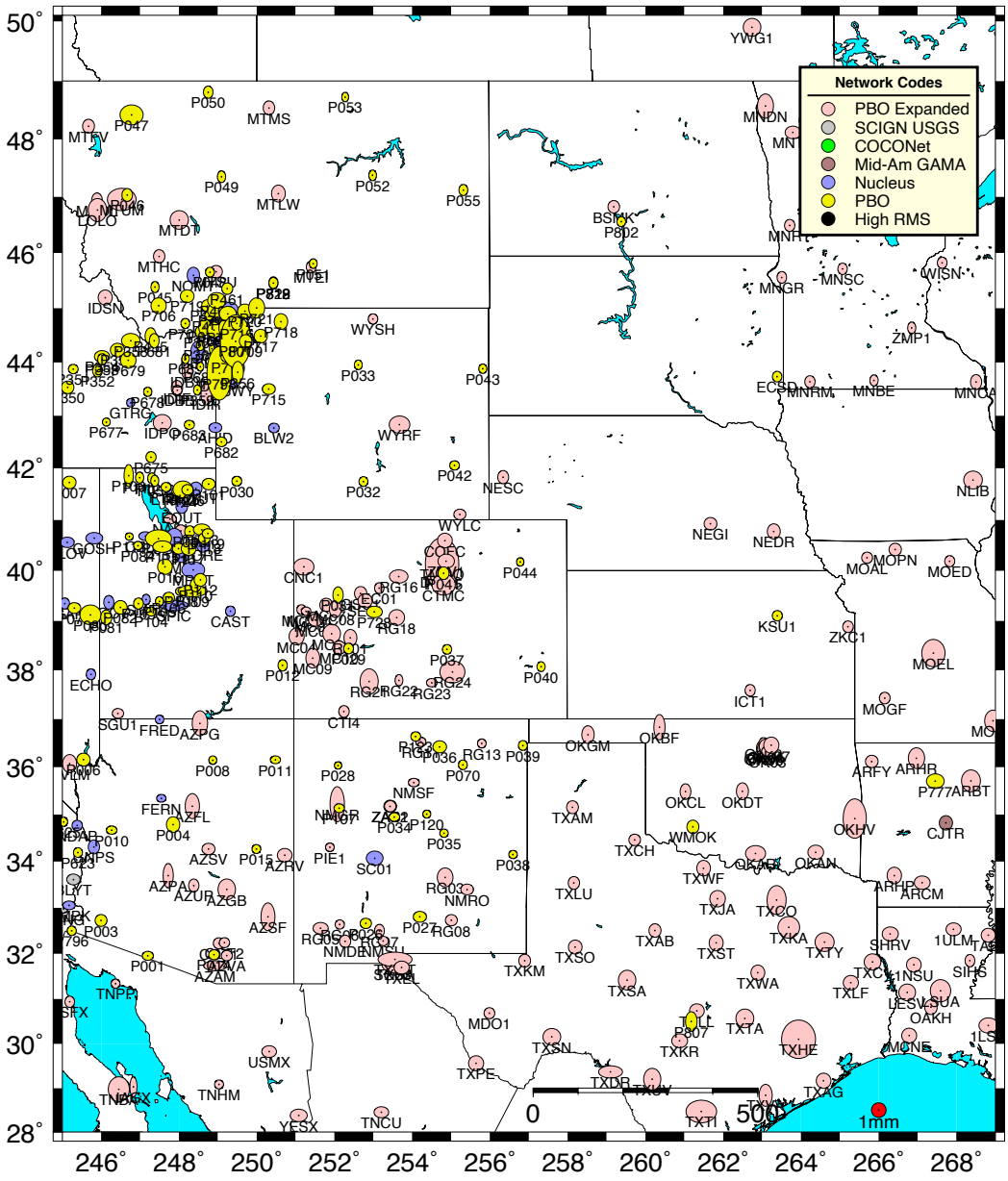

Figure 5: Same as Figure 4 except for the Central United States

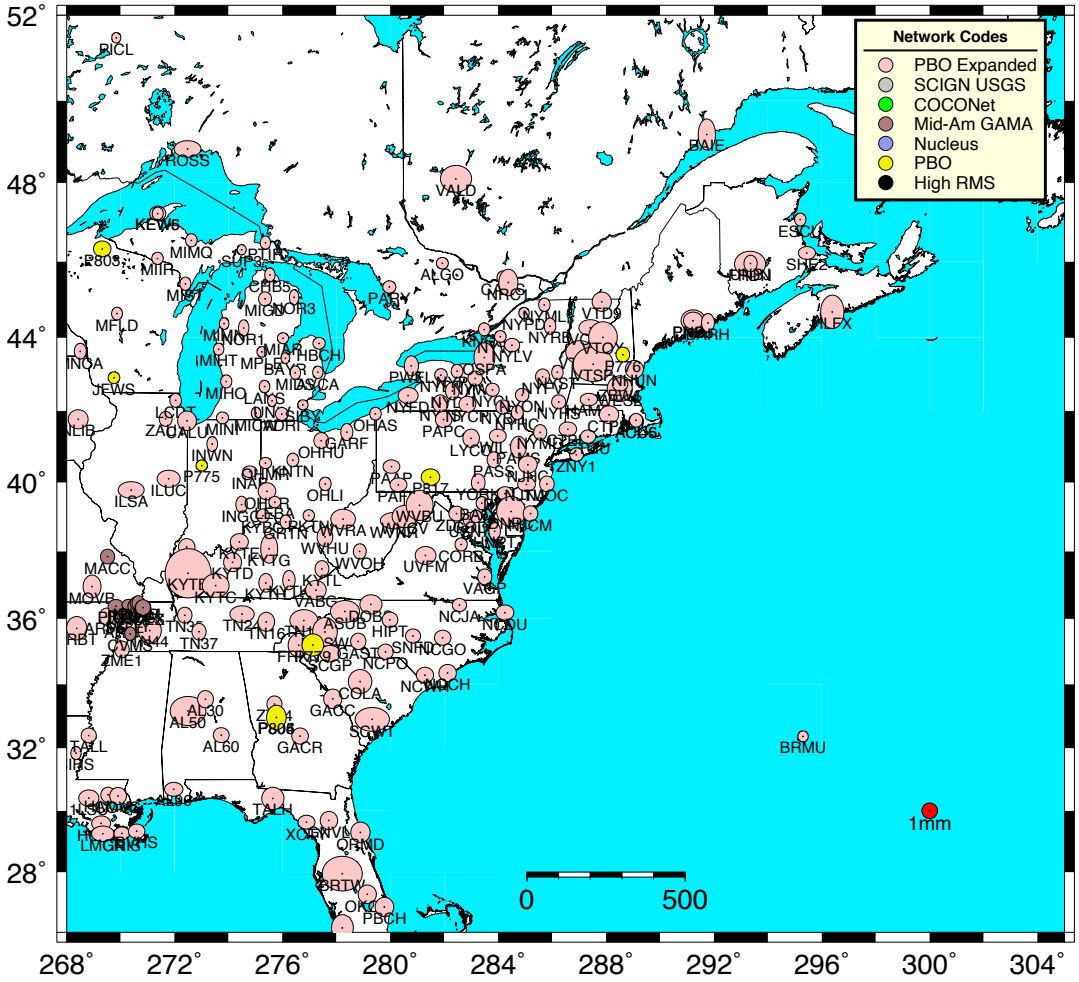

Figure 6: Same as Figure 4 except for the Eastern United States

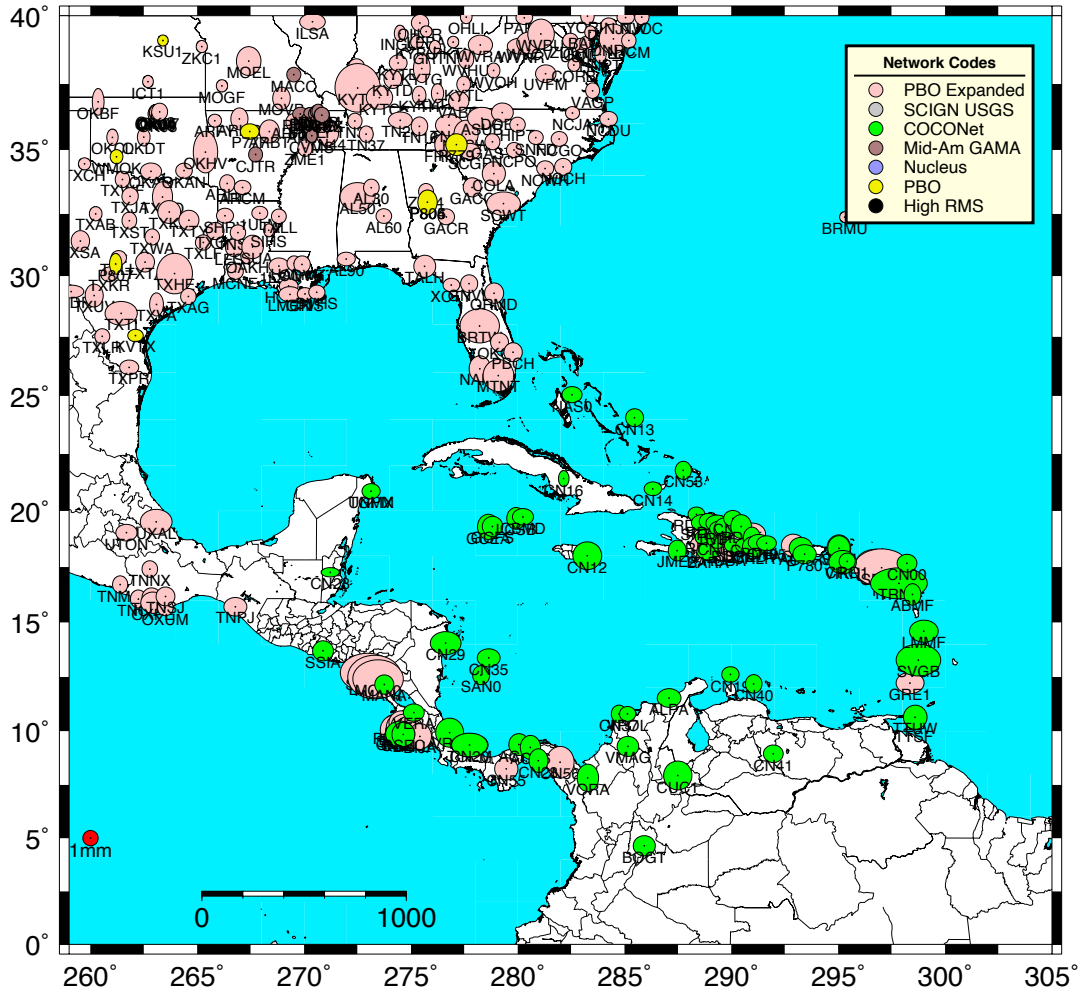

Figure 7: Same as Figure 4 except for the Caribbean region.

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_200613.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_200613.snpvel.

Table 3: Statistics of the fits of 2630 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and June 13, 2020.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.40	1.35	6.13
70%			
CWU	1.75	1.68	6.97
95%			
CWU	3.78	3.58	11.44

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.

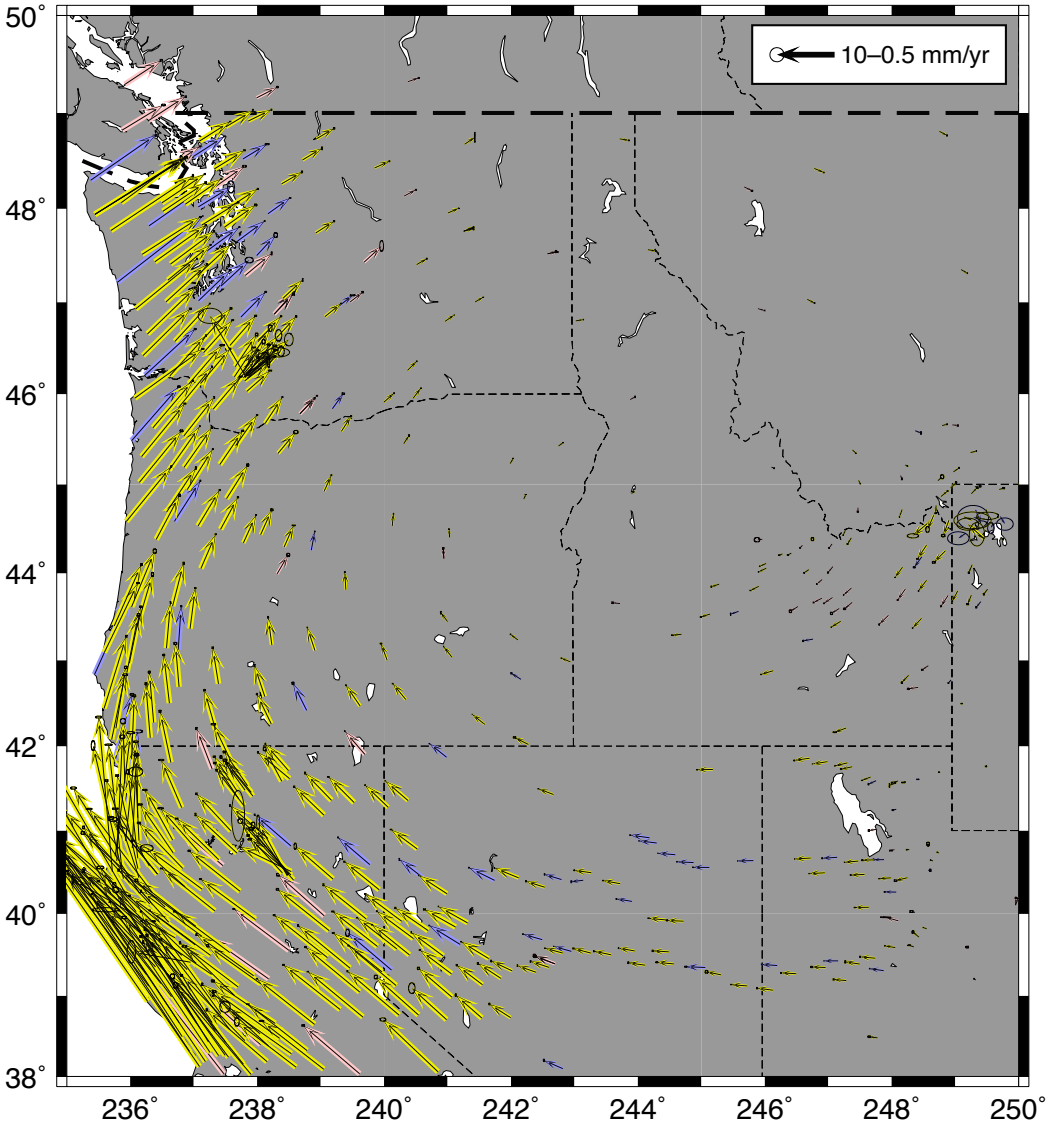

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

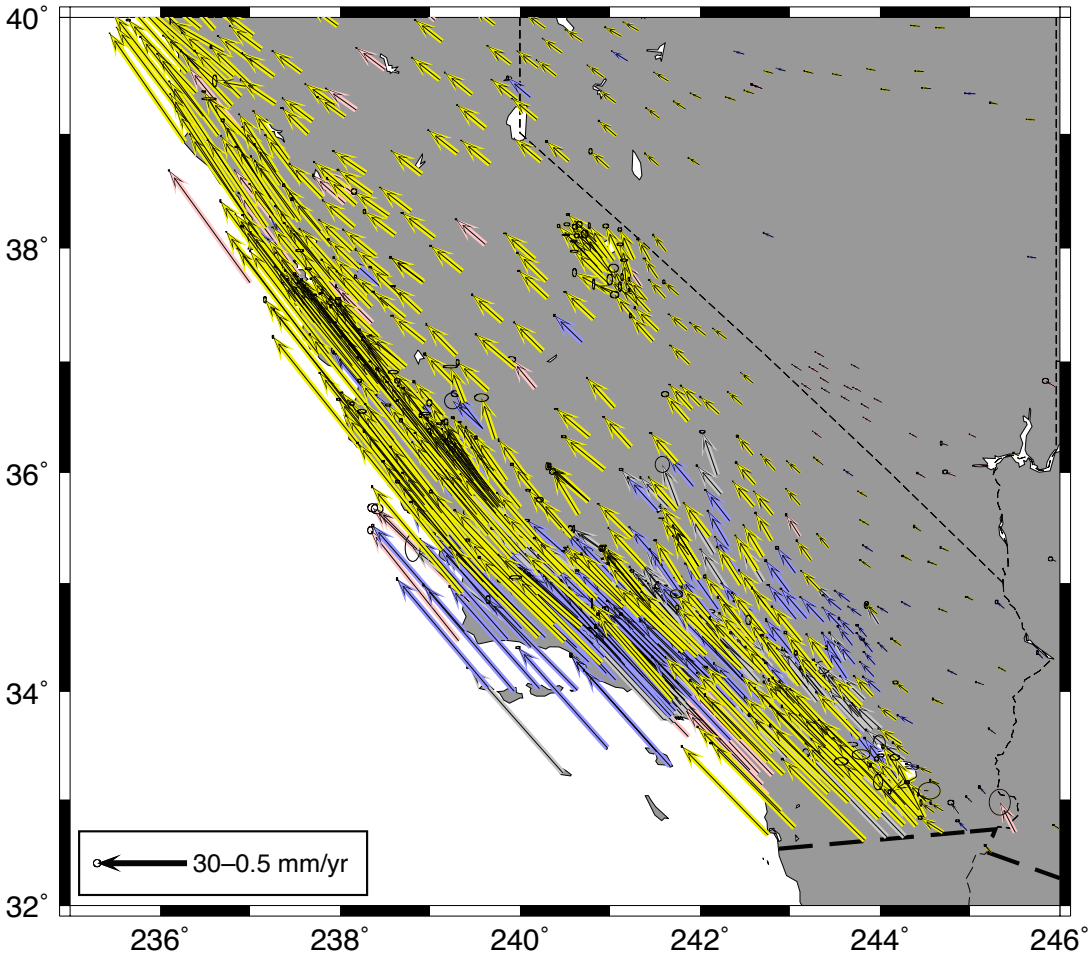

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

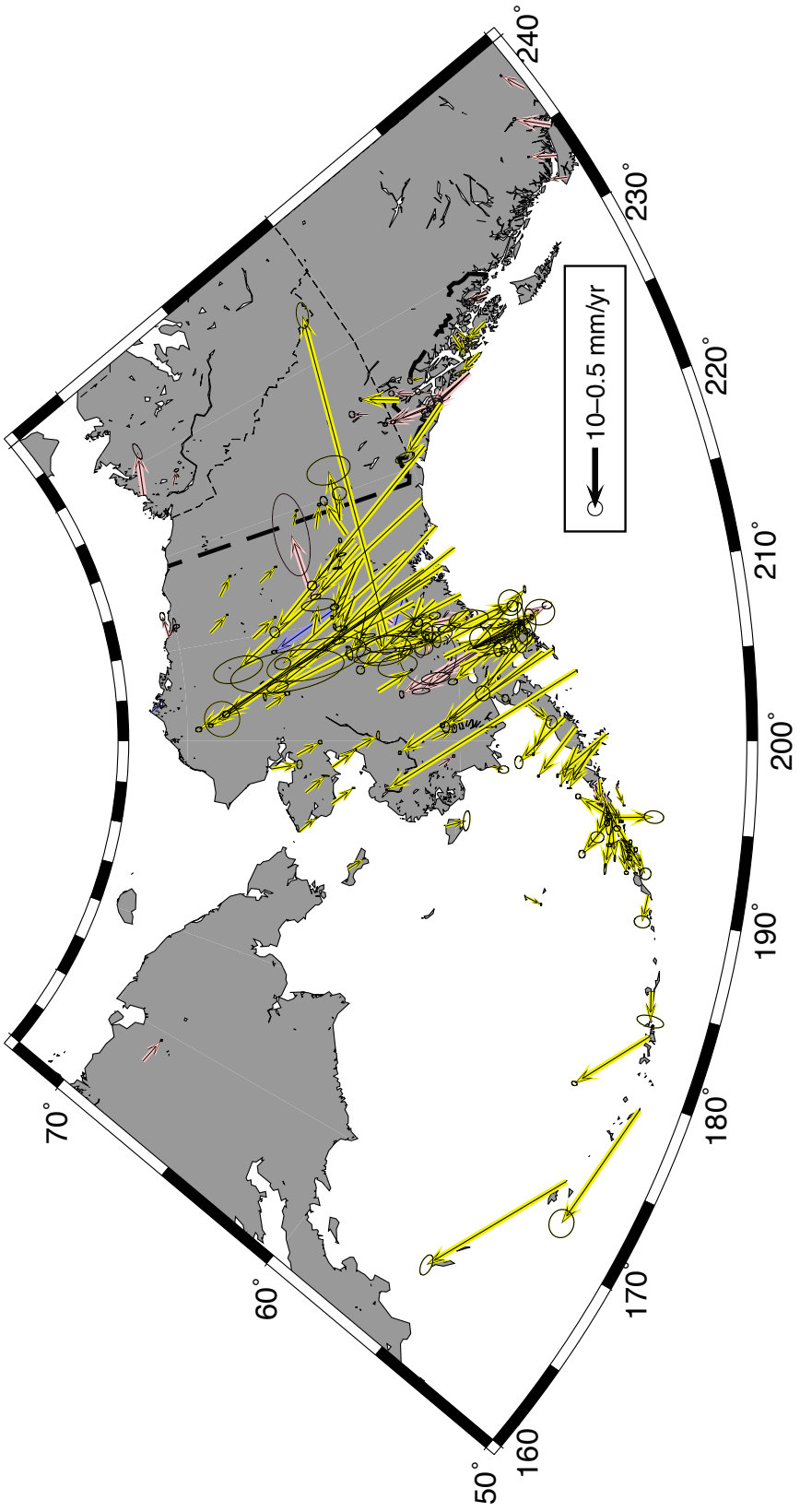

Figure 10:

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

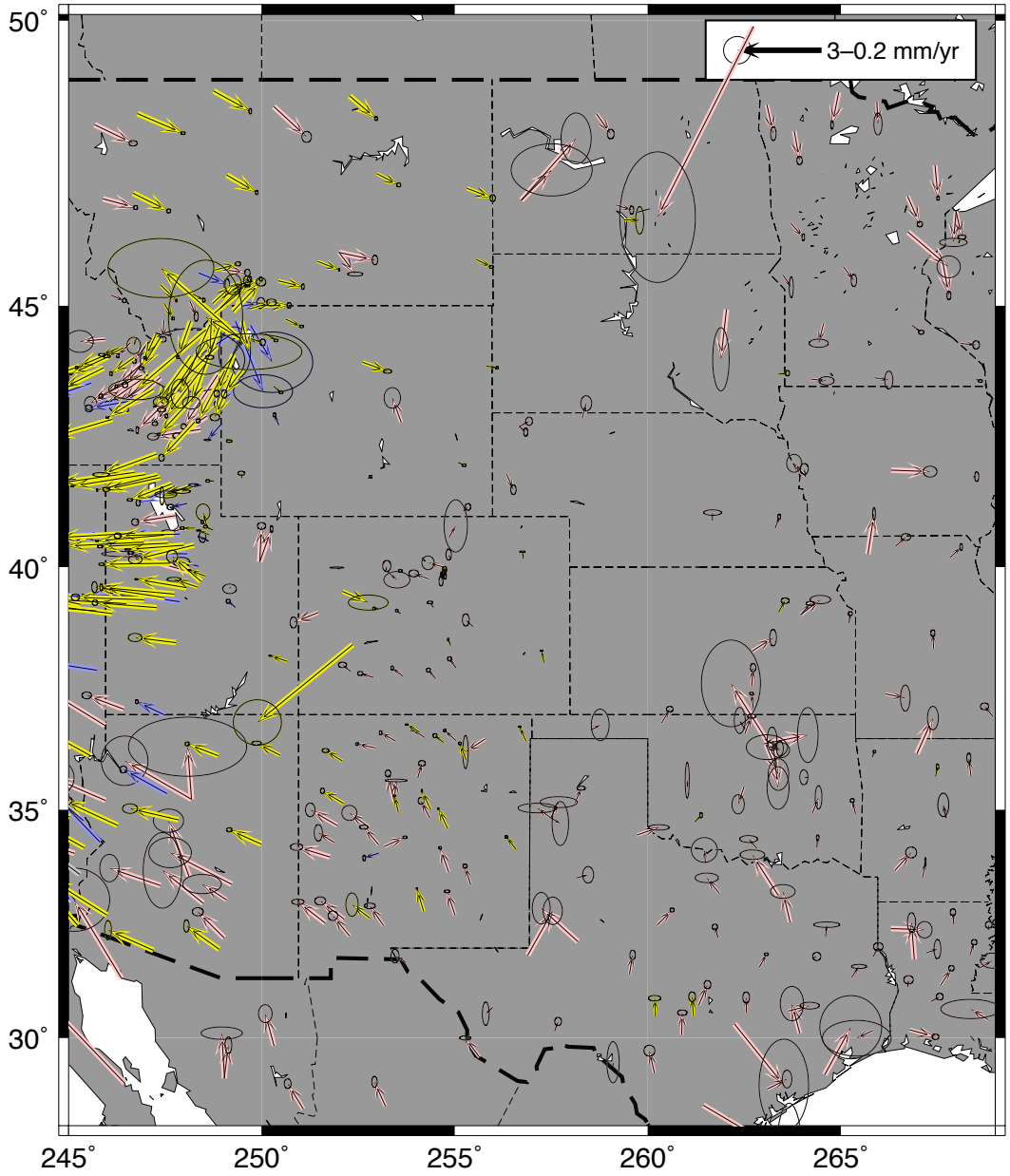

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

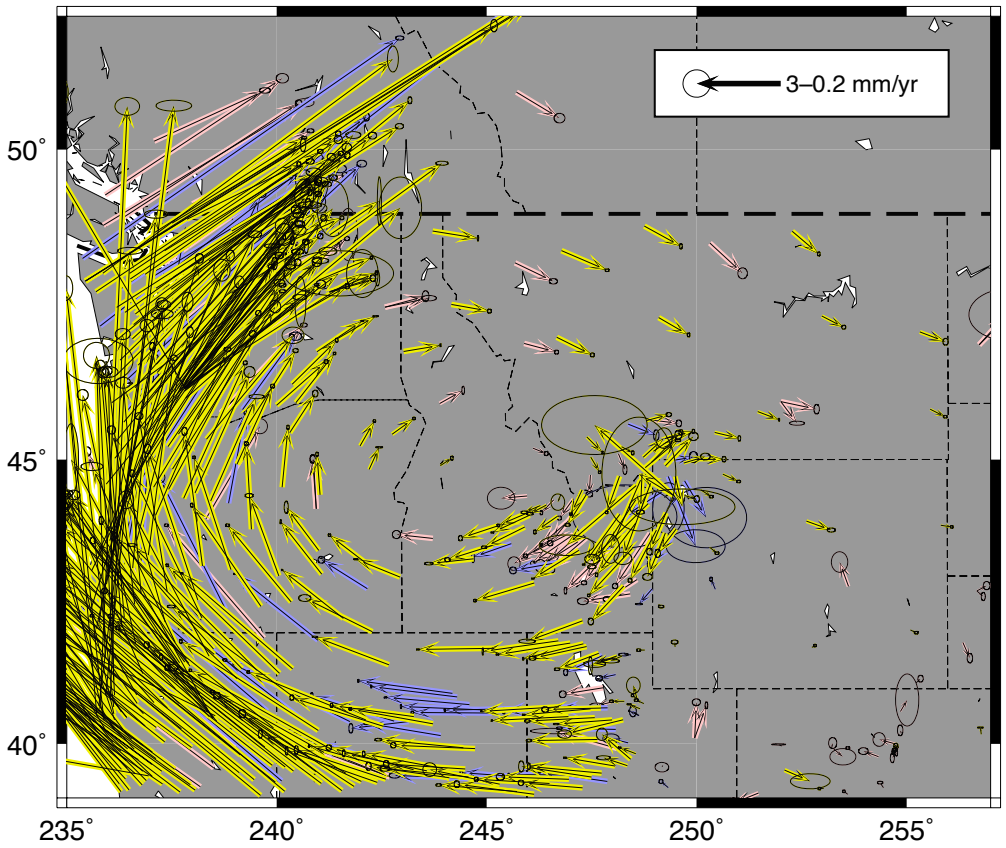

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

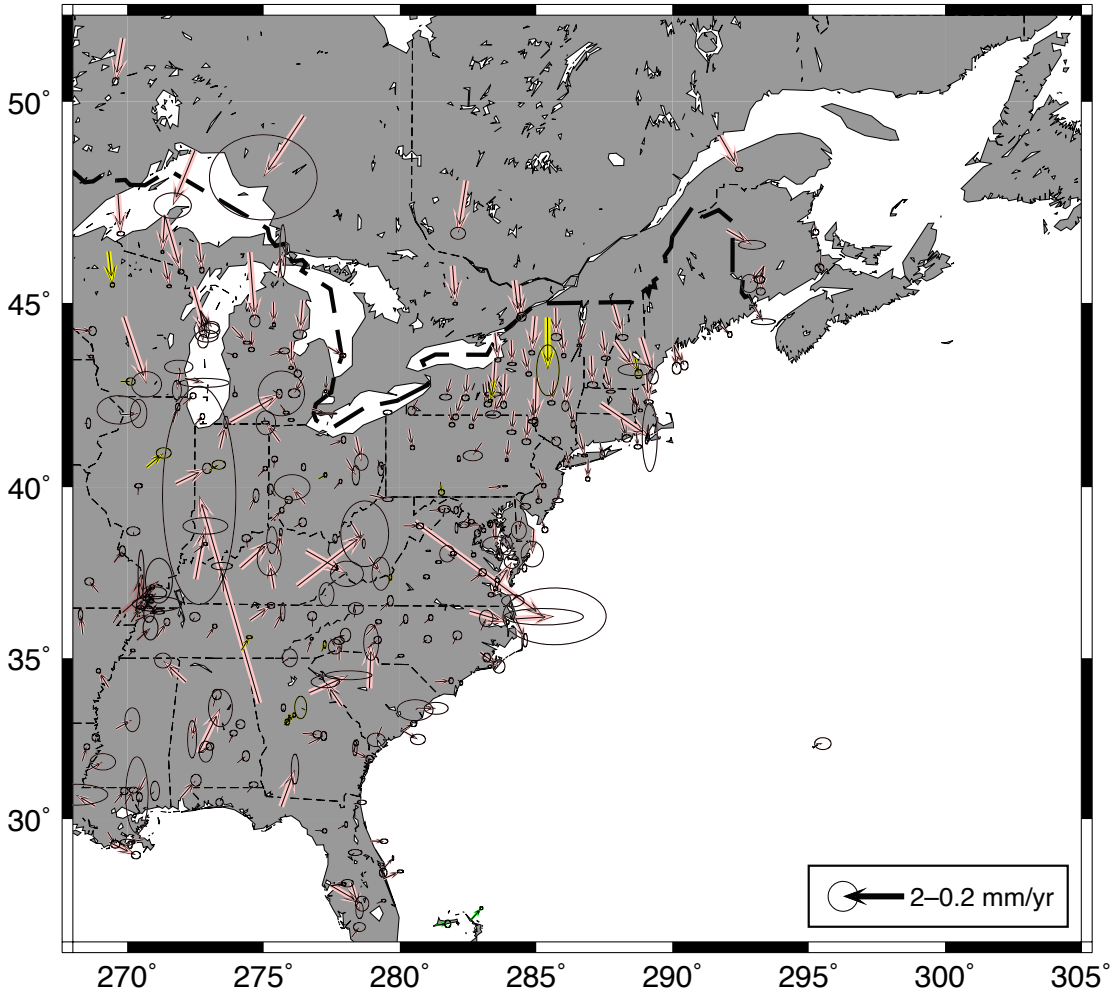

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

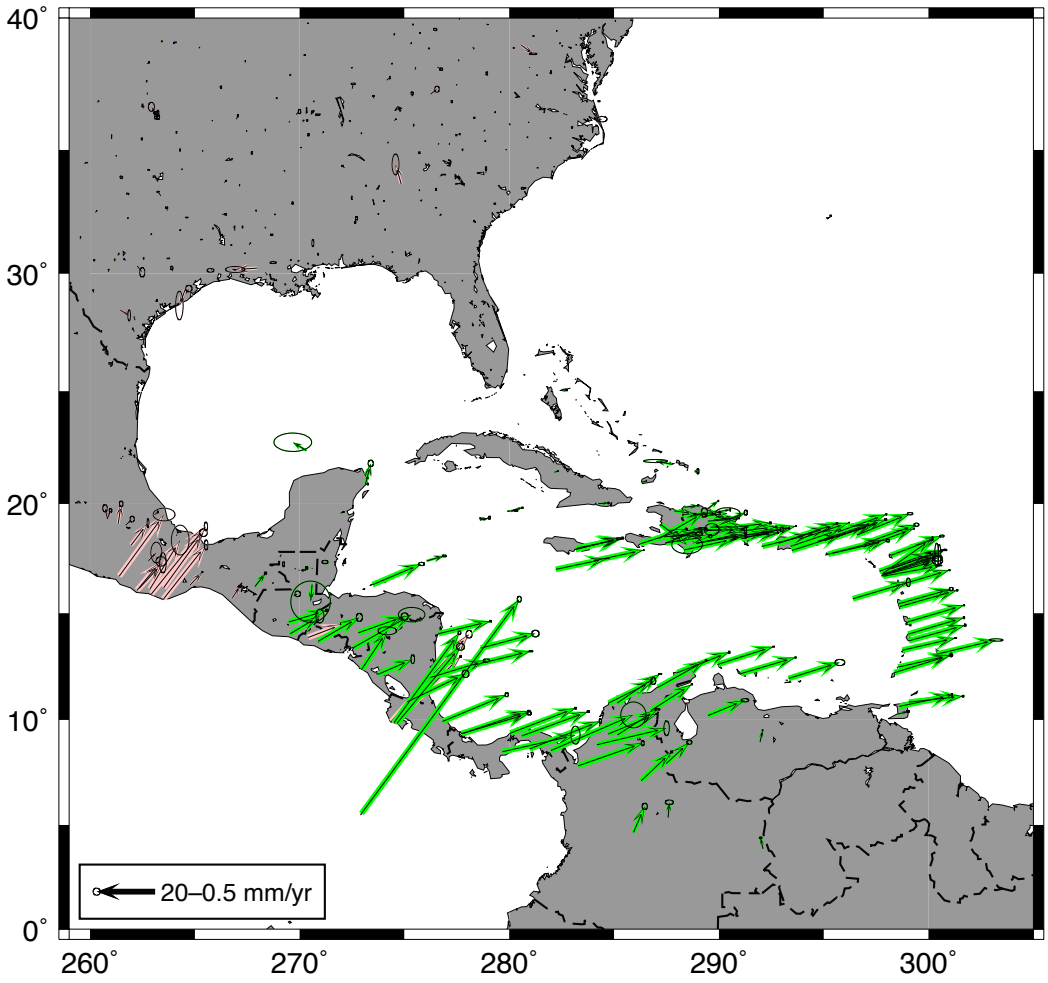

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2020/03/15-2020/06/30

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 41 earthquakes examined during this quarter, 4 earthquakes generated displacements more than 1 mm. These have been designated events 52, 53, 54 and 55. Event 52 occurred on the last day of last quarter and was no reported on at that time. Event files have been sent to UNAVCO for both rapid (initial) and final orbit processing (except events 54 and 55 for which finals are not yet available). The events also appear in the Kalman filter timeseries offset estimates. The four events that generated co-seismic offsets are the ANSS(ComCat) us70008jr5 Mw 6.5 70km W of Challis epicenter ϕ 44.4906 λ -115.1176 data 2020 03 31 time 23:53 UTC (EQ 52); ANSS(ComCat) nn00725272 ml6.5 56km W of Tonopah ϕ 38.1589 λ -117.8749 date 2020 05 15 time 11:04 UTC (EQ53); ANSS(ComCat) us6000ah9t mww7.4 20km ENE of Santa Maria

Xadani ϕ 16.0291 λ -95.9010 date 2020 06 23 time 15:30 UTC (EQ54) and ANSS(ComCat) ci39493944 mw5.8 18km SSE of Lone Pine ANSS(ComCat) us70008jr5 ϕ 36.4468 λ -117.9752 date 2020 06 24 time 17:41 UTC (EQ55).

The event co-seismic offsets are shown in Figures 15-18.

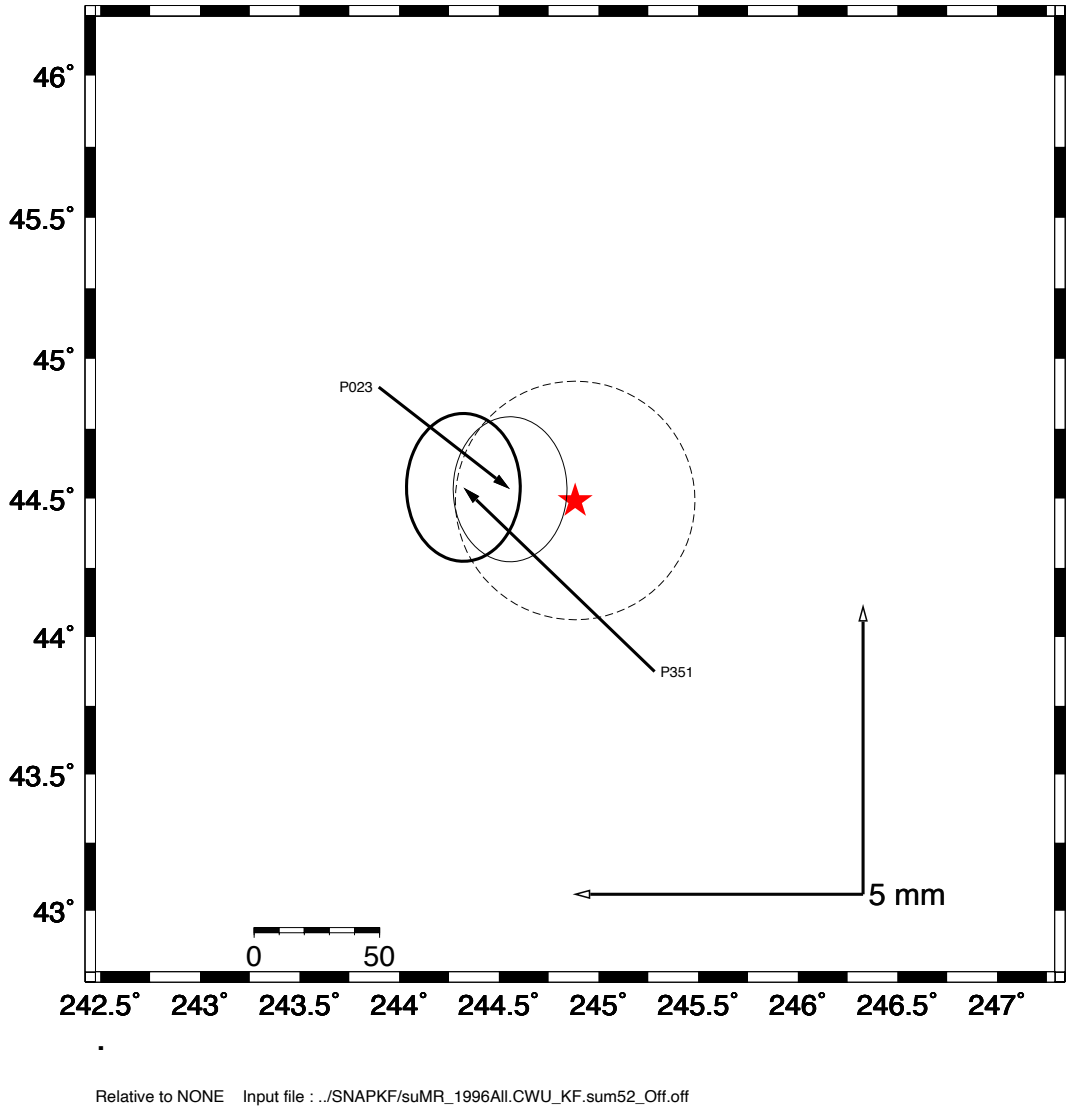

Figure 15: Coseismic offsets from the GAGE event 52 ANSS(ComCat) us70008jr5 Mw 6.5 70km W of Challis epicenter ϕ 44.4906 λ -115.1176 data 2020 03 31 time 23:53 UTC. Kalman filter estimate based on finals processing.

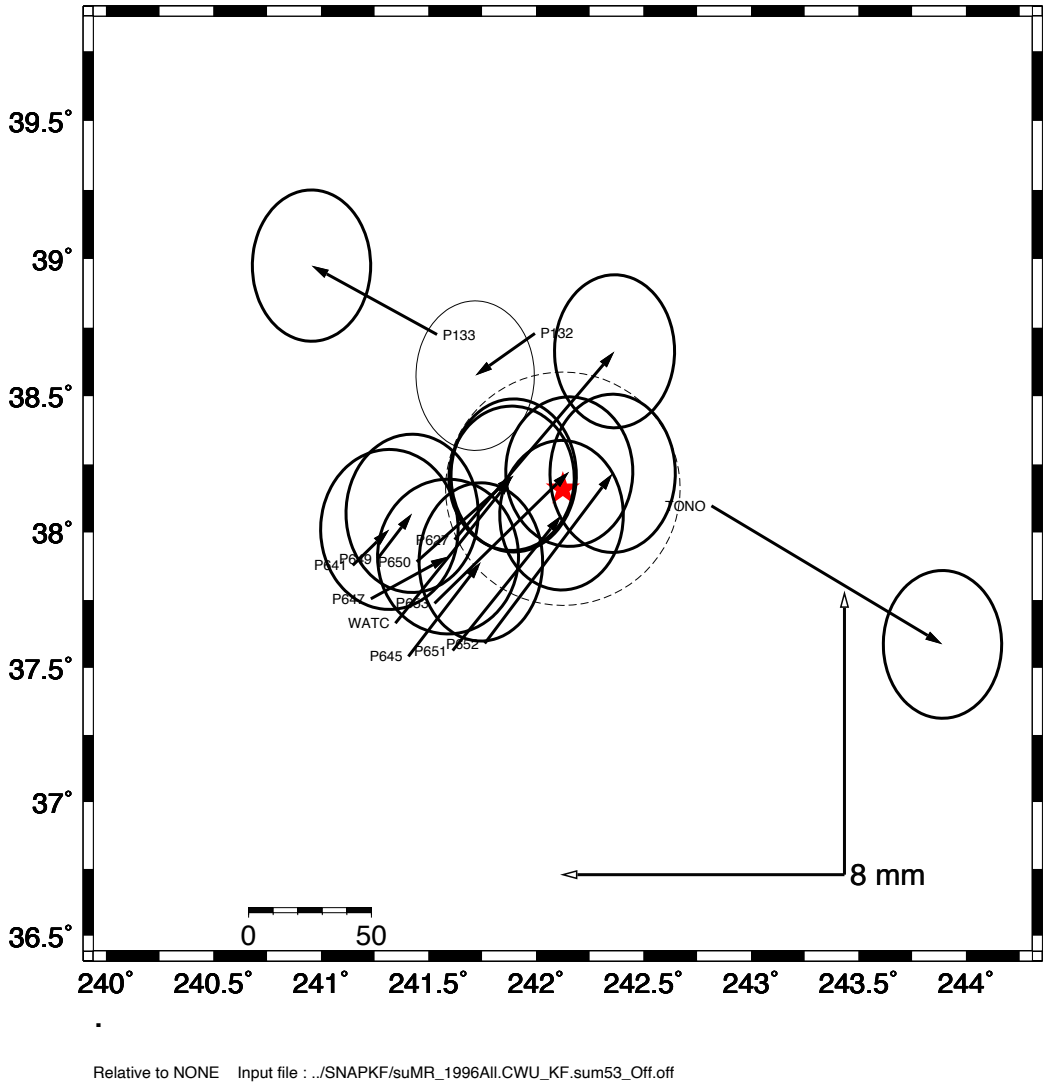

Figure 16: Coseismic offsets from the GAGE event 53. ANSS(ComCat) nn00725272 ml6.5 56km W of Tonopah ϕ 38.1589 λ -117.8749 date 2020 05 15 time 11:04 UTC Kalman filter estimate based on finals processing

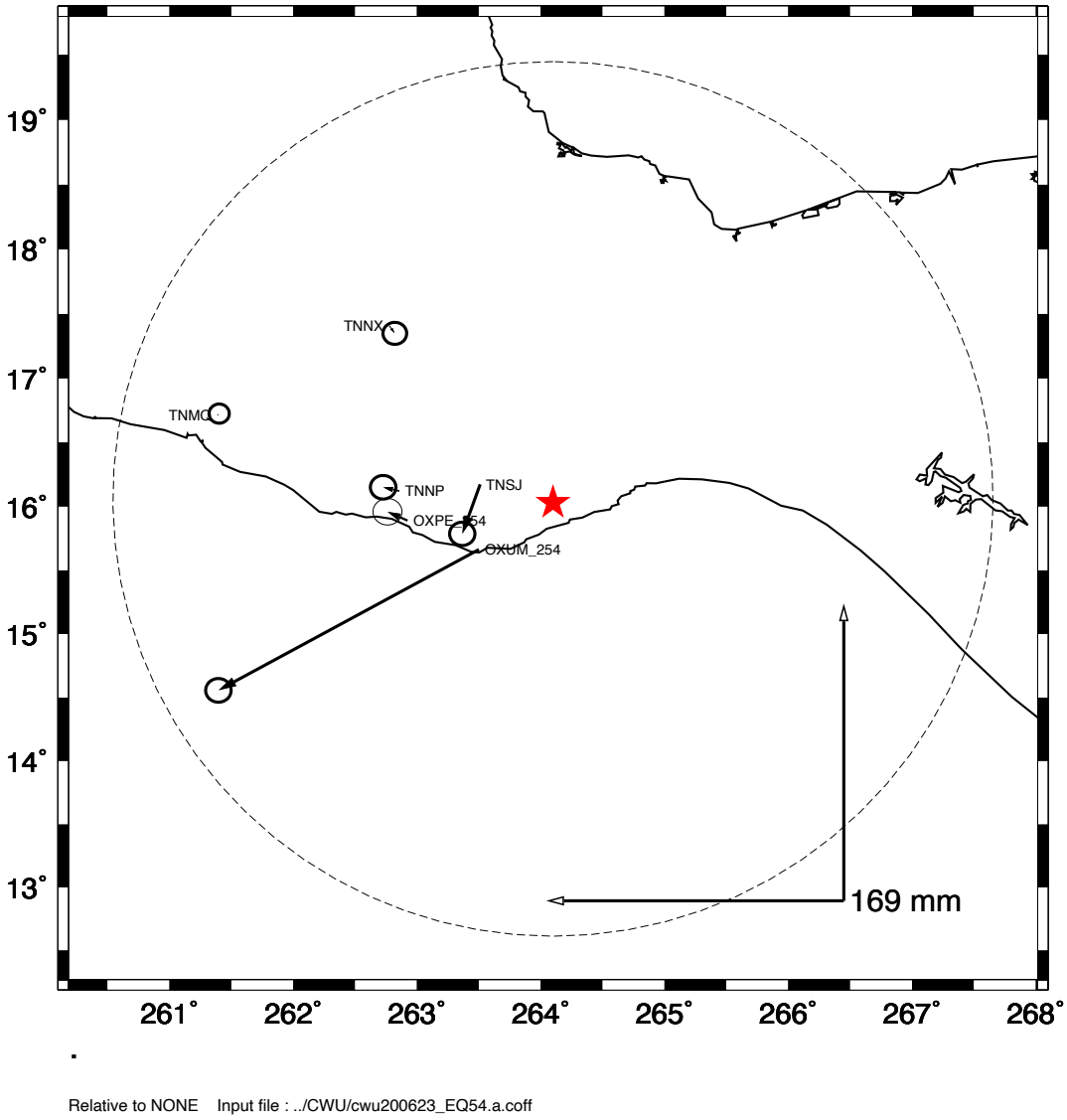

Figure 17: Coseismic offsets from the GAGE event 54. ANSS(ComCat) us6000ah9t mww7.4 20km ENE of Santa Maria Xadani ϕ 16.0291 λ -95.9010 date 2020 06 23 time 15:30 UTC. Rapid processing based on 2-days of data before and after the event excluding the day of the event.

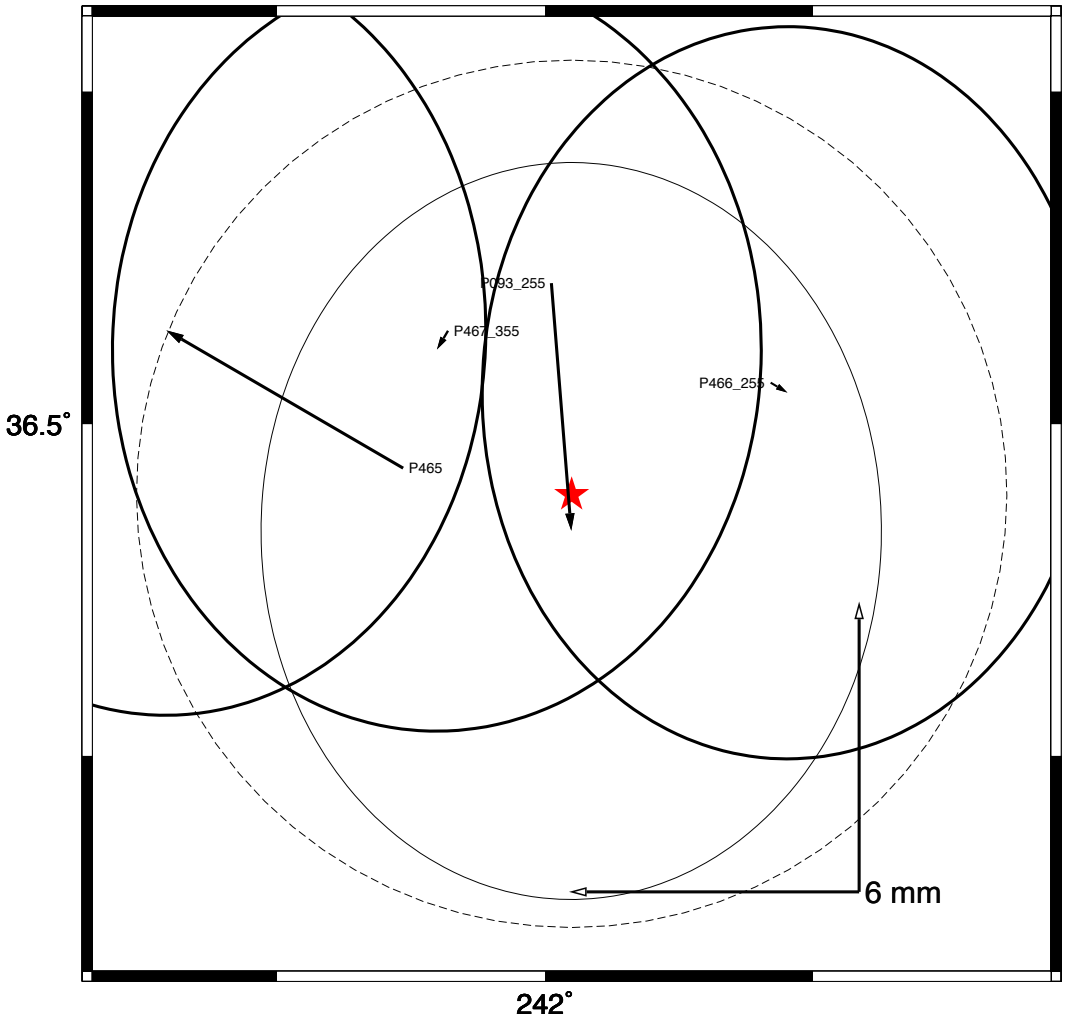

Figure 18: Coseismic offsets from the GAGE event 55. ANSS(ComCat) ci39493944 mw5.8 18km SSE of Lone Pine ANSS(ComCat) us70008jr5 ϕ 36.4468 λ -117.9752 date 2020 06 24 time 17:41 UTC. Rapid processing based on 2-days of data before and after the event excluding the day of the event.

Antenna and other discontinuity events.

Antenna swaps at 18 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 March and April 2020. No meta data changes were recorded in May 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 56 stations in the ANET region for CWU analyzed in the final orbit analysis between March 15, 2020 and June 13, 2020.

CWU	North (mm)	East (mm)	Up (mm)
ANET	1.08	1.03	5.39
ANET	1.29	1.16	5.87
ANET	1.91	2.05	9.46

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

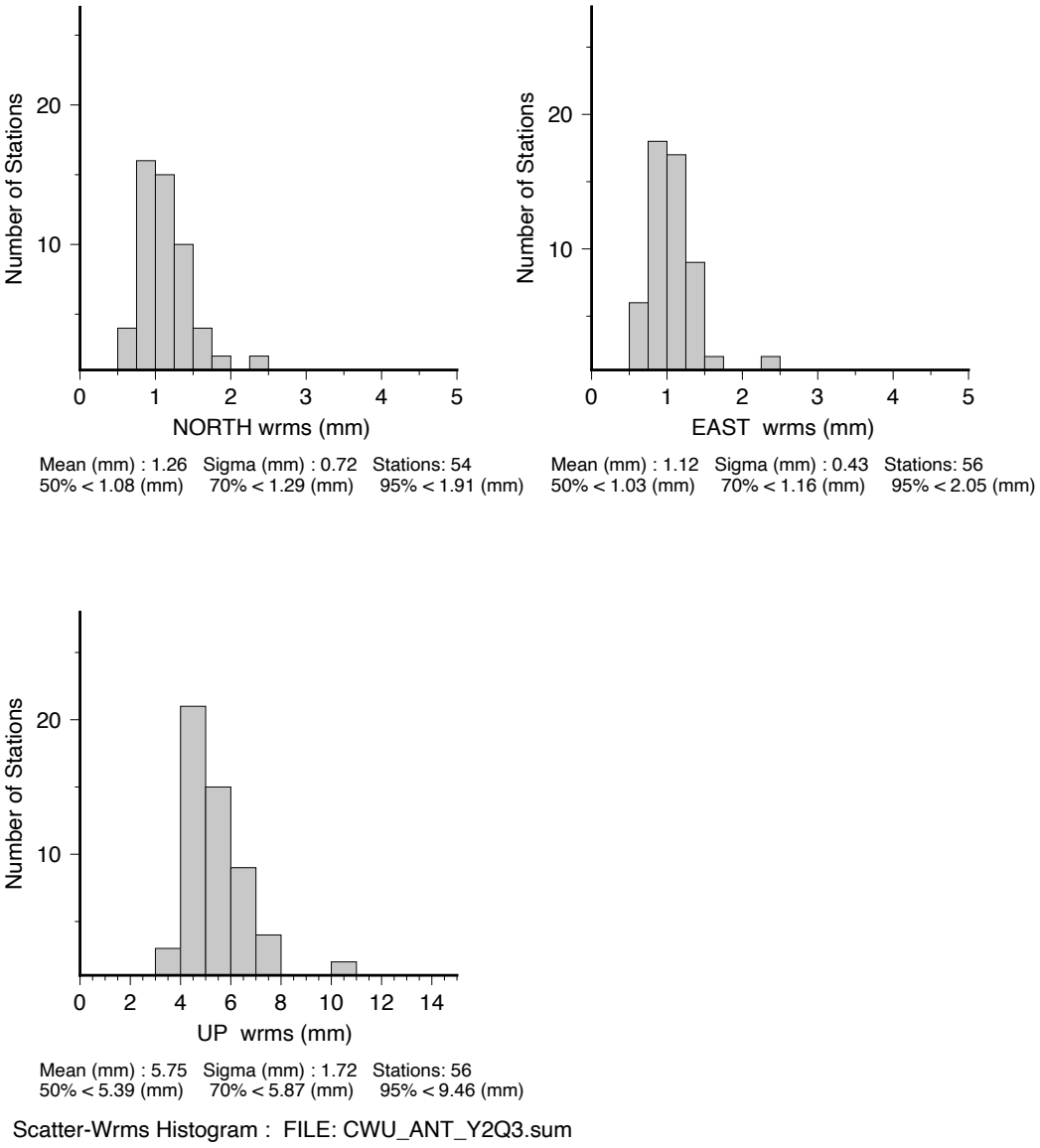

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 60 stations in Antarctica analyzed between March 15, 2020 and June 13, 2020. Linear trends and annual signals were estimated from the time series.

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