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

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Period: 2019/07/01-2019/09/30

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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 2019/03/16 to 2019/09/30, time series velocity field analyses for the GAGE reprocessing analyses (1996-2019). Several earthquakes were investigated this quarter but none generated coseismic displacements > 1mm.

Associated with report, event files, pbovel files and offset files have been queued to LDM with time tag 20191008100035.

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

ITRF2014 transition

The ITRF2014 re-processing analysis has been completed and the transition from the NAM08 system to NAM14 has been completed. The primary SINEX and time series products are generated in the NAM14 reference frame. Currently time series rotated into the IGS14, NAM08 and IGS08 systems are being generated and distributed. The NAM08 and IGS08 distributions will likely be discontinued during the next quarter.

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 2099 stations were processed which is 10 more than last quarter. In addition up to 58 sites were processed in the ANET solutions.

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, 2019– September 21, 2019

For this report, we generated the statistics using the ~3 months of CWU results between June 15, 2019 and September 21, 2019. 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 2099 stations for CWU analyzed in the finals analysis between June 15, 2019 and September 21, 2019. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.06	0.95	4.62
70%			
CWU	1.24	1.13	5.27
95%			
CWU	2.12	2.06	8.53

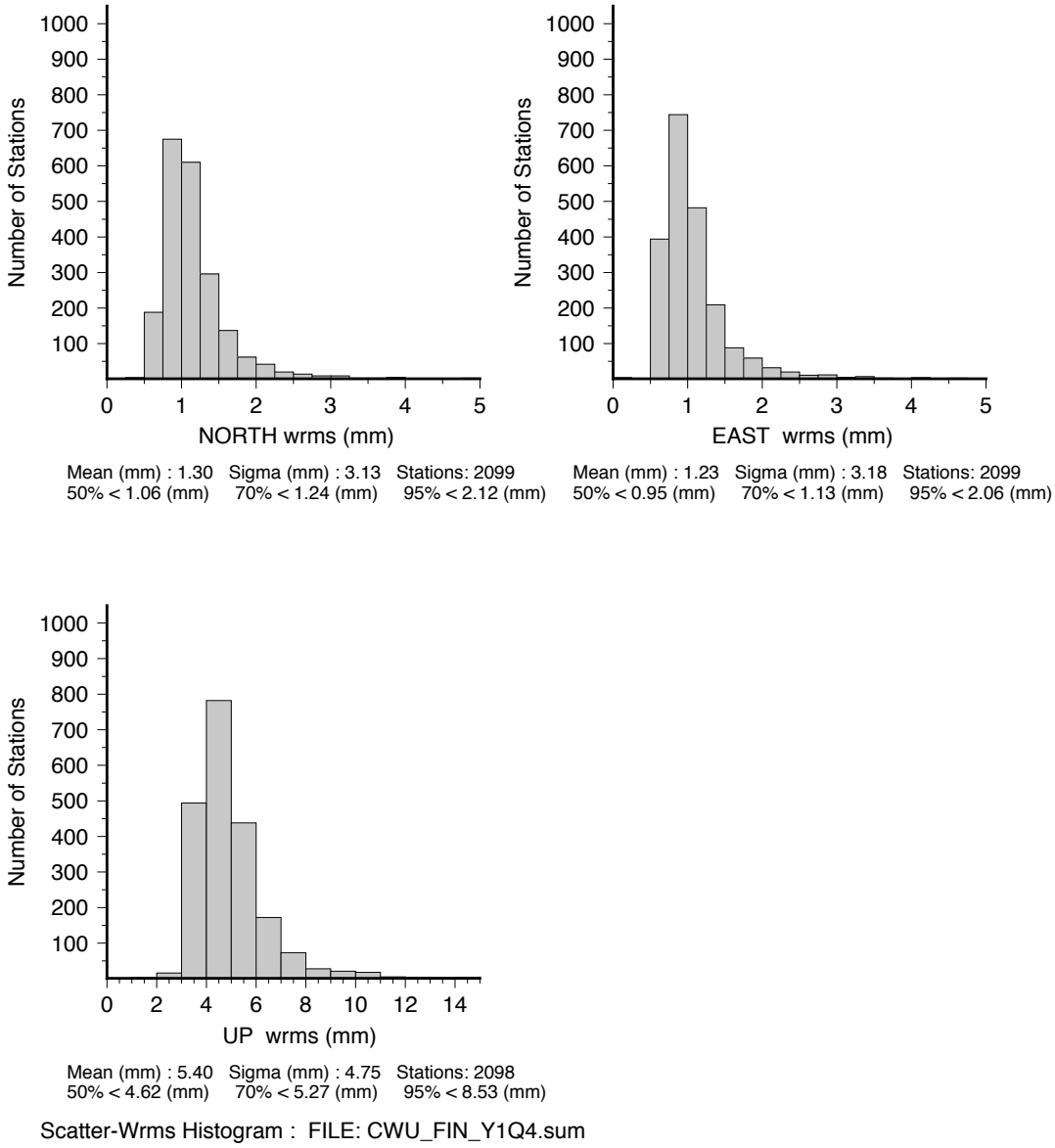

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 2099 stations analyzed between June 15, 2019 and September 21, 2019. Linear trends and annual signals were estimated from the time series.

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_Y1Q4.tab.

There are 2099 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_Y1Q4.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    99       1.5   0.76      1.8   0.89     8.7   0.91     16.41
 1NSU    99       1.2   0.65      1.1   0.68     6.2   0.81     15.67
 1ULM    99       1.0   0.55      1.3   0.76     5.8   0.75     16.27
 7ODM    92       1.1   0.55      0.8   0.52     4.5   0.61     18.41
…
 ZDV1    98       1.5   0.70      1.1   0.67     5.8   0.79     16.30
 ZKC1    98       1.1   0.55      1.2   0.72     5.8   0.76     16.30
 ZLA1    97       1.3   0.65      1.0   0.63     5.8   0.78     16.30
 ZLC1    97       1.5   0.71      1.0   0.59     4.5   0.61     16.53
 ZME1    98       1.4   0.73      1.2   0.71     6.2   0.79     16.53
 ZMP1    97       1.4   0.61      0.9   0.58     6.2   0.83     16.77
 ZNY1    95       1.2   0.56      1.1   0.67     4.2   0.56     16.68
 ZOA1    94       0.9   0.43      0.7   0.47     4.7   0.66     17.22
 ZSE1    93       1.1   0.51      0.9   0.53     4.7   0.65     16.68
 ZTL4    94       1.2   0.63      1.2   0.71     6.3   0.82     16.88
```

Table 2: RMS scatter of the position residuals for the CWU solution between June 15, 2019 and September 21, 2019 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	0.97	0.88	4.23	869
NUCLEUS	0.88	0.85	4.21	198
GAMA	1.06	1.03	5.40	15
COCONet	1.51	1.62	6.61	79
USGS_SCIGN	0.94	0.87	4.39	124
Expanded	1.17	1.06	5.12	814
70%				
PBO	1.13	1.01	4.70	
NUCLEUS	1.00	0.95	4.56	
GAMA	1.09	1.07	5.83	
COCONet	1.71	1.95	7.69	
USGS_SCIGN	1.09	1.04	4.84	
Expanded	1.32	1.24	5.72	

95%			
PBO	2.05	1.84	6.83
NUCLEUS	1.58	1.48	6.61
GAMA	1.31	1.22	7.25
COCONet	2.88	3.64	12.01
USGS_SCIGN	2.12	1.85	8.10
Expanded	2.08	2.09	9.47

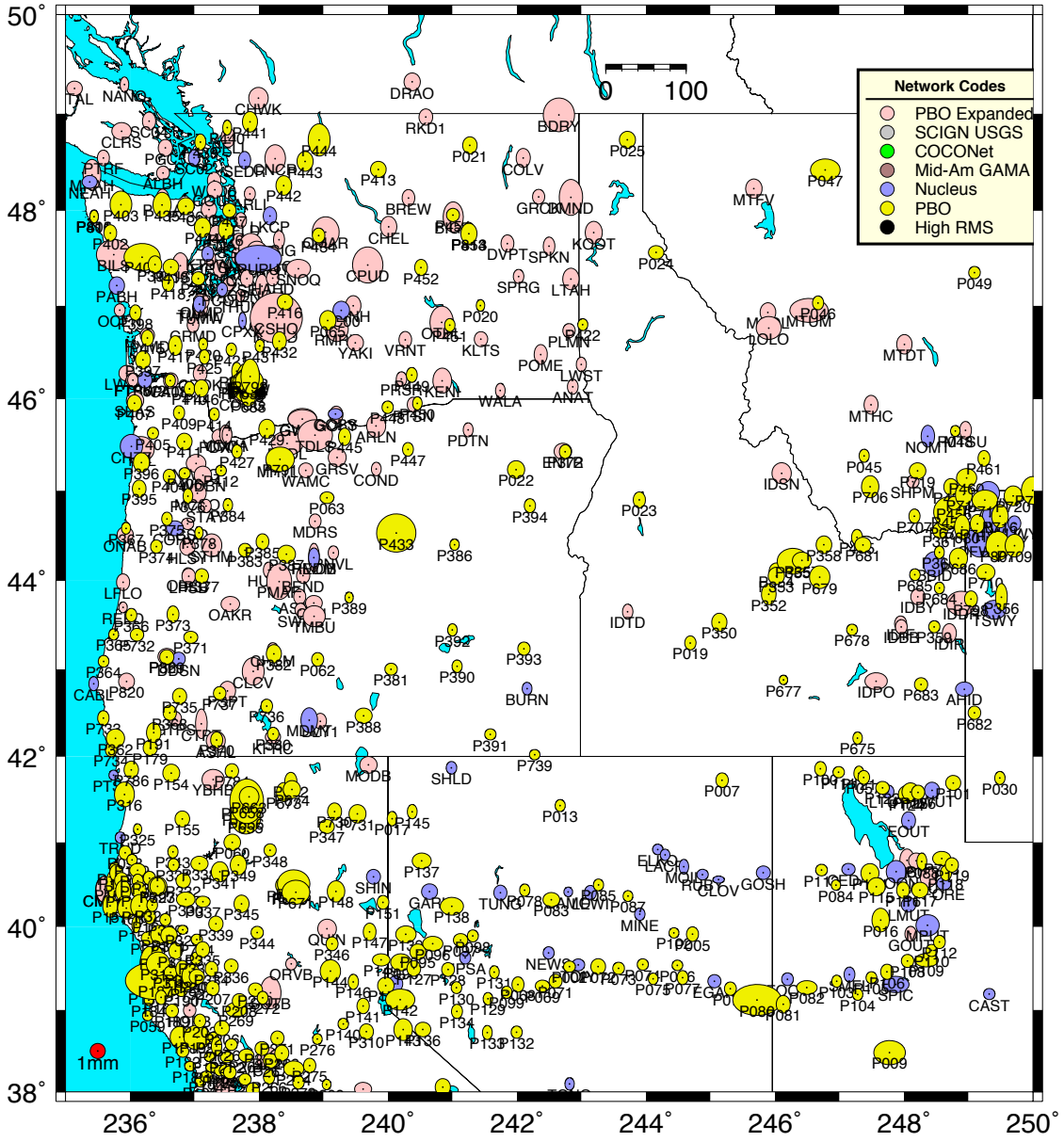

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1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

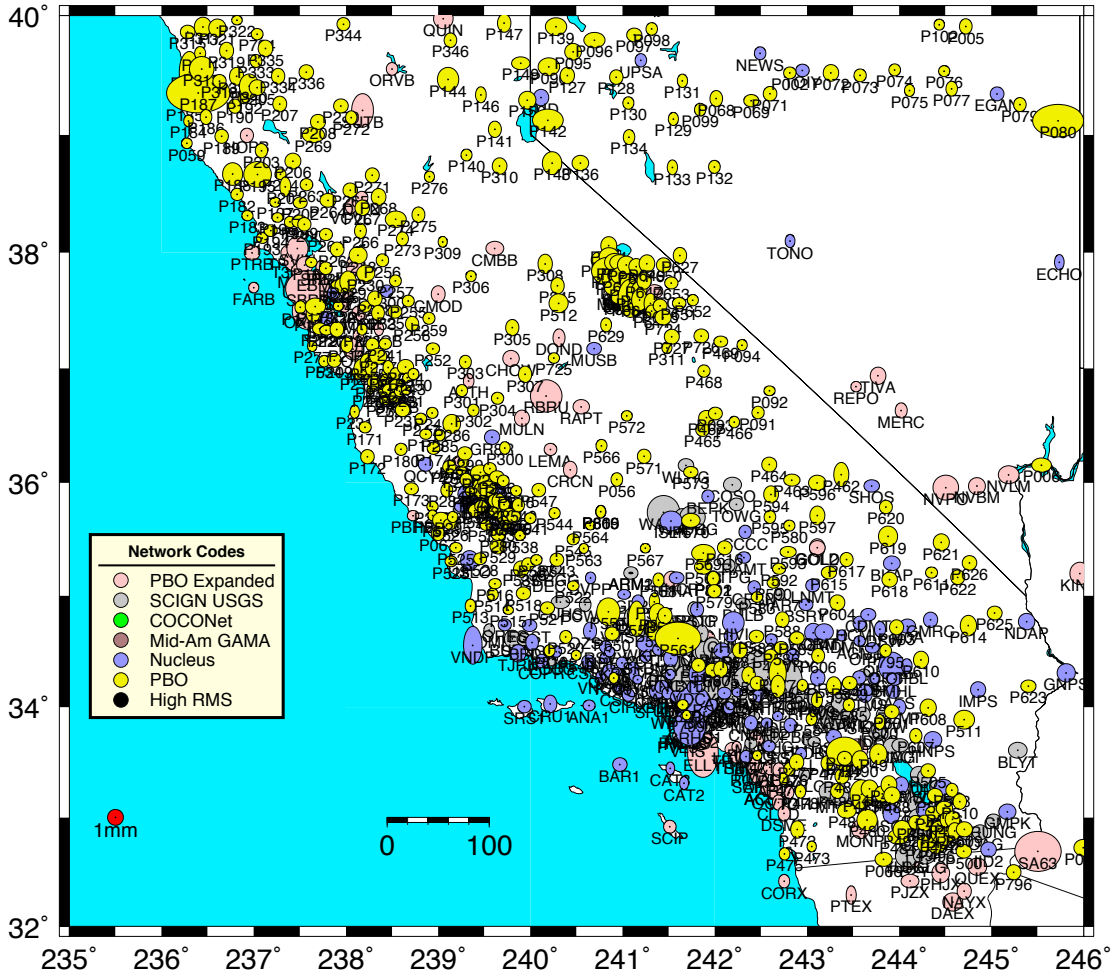

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

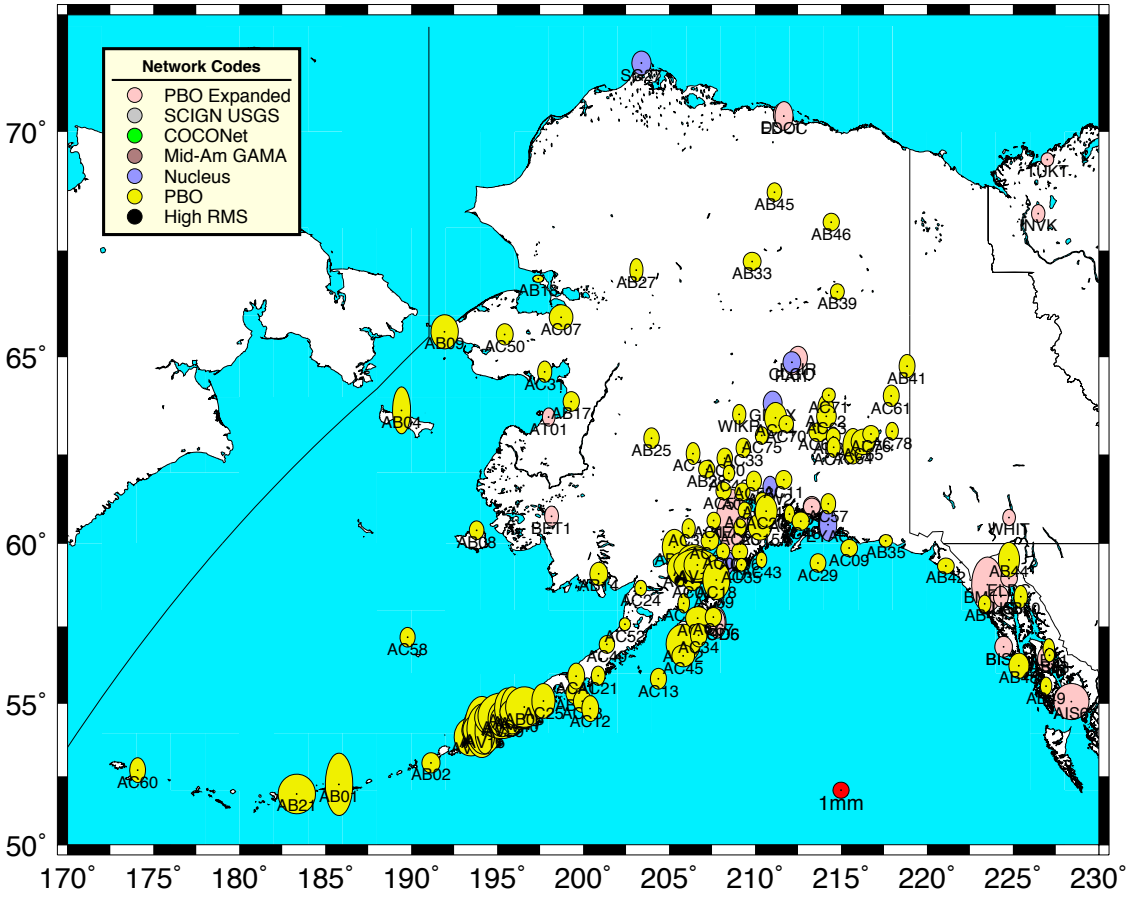

Figure 4: Same as Figure 4 except for the Alaskan region.

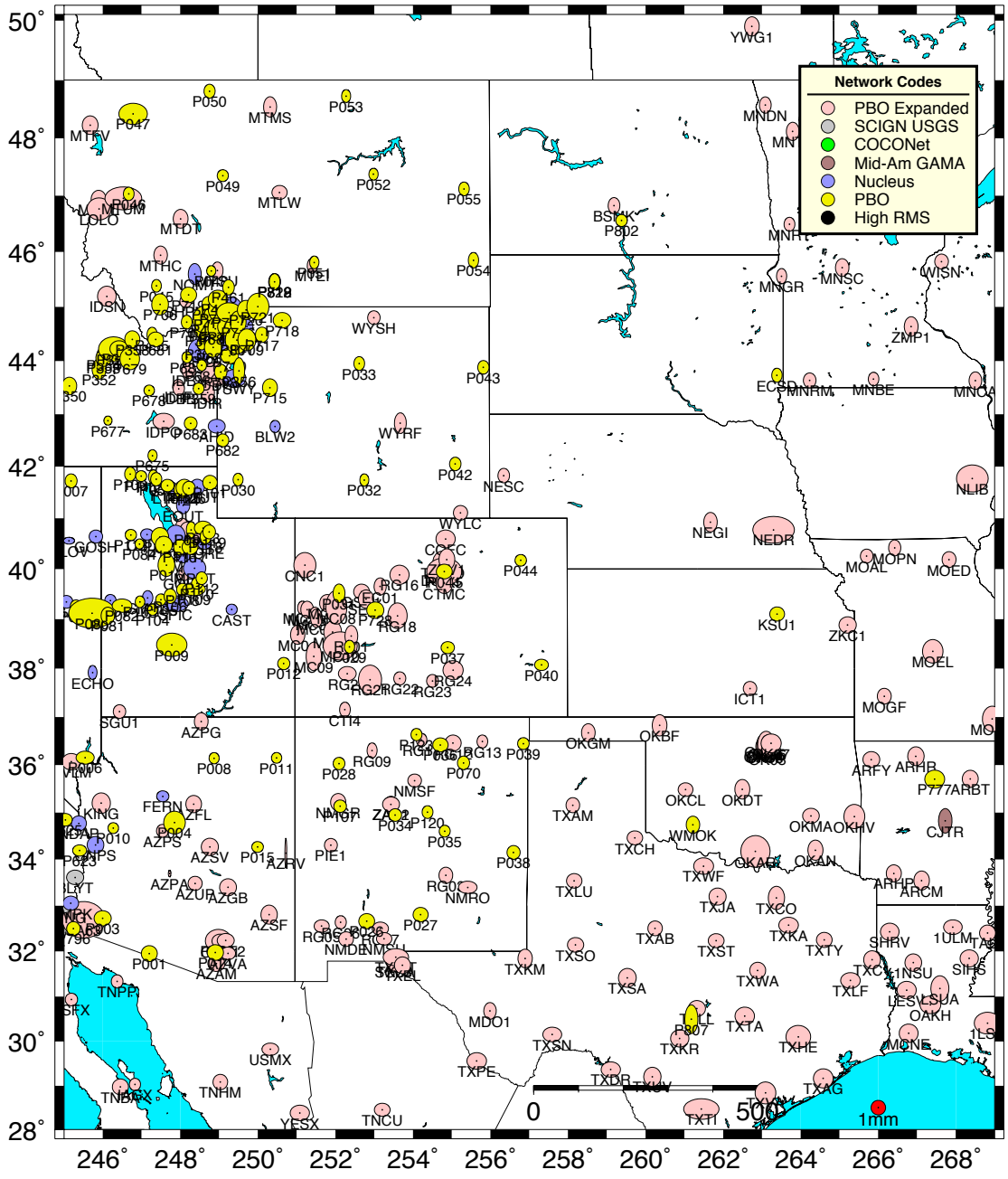

Figure 5: Same as Figure 4 except for the Central United States

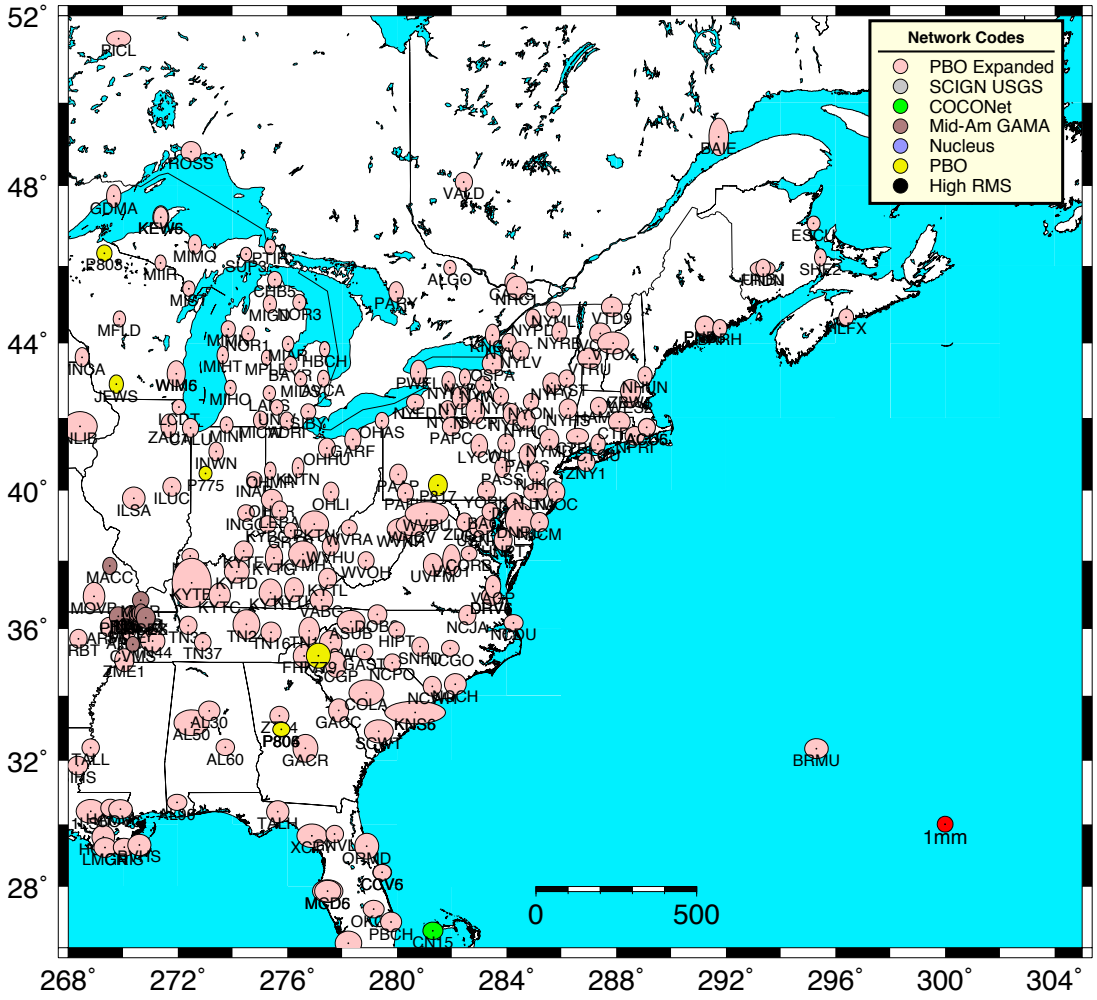

Figure 6: Same as Figure 4 except for the Eastern United States

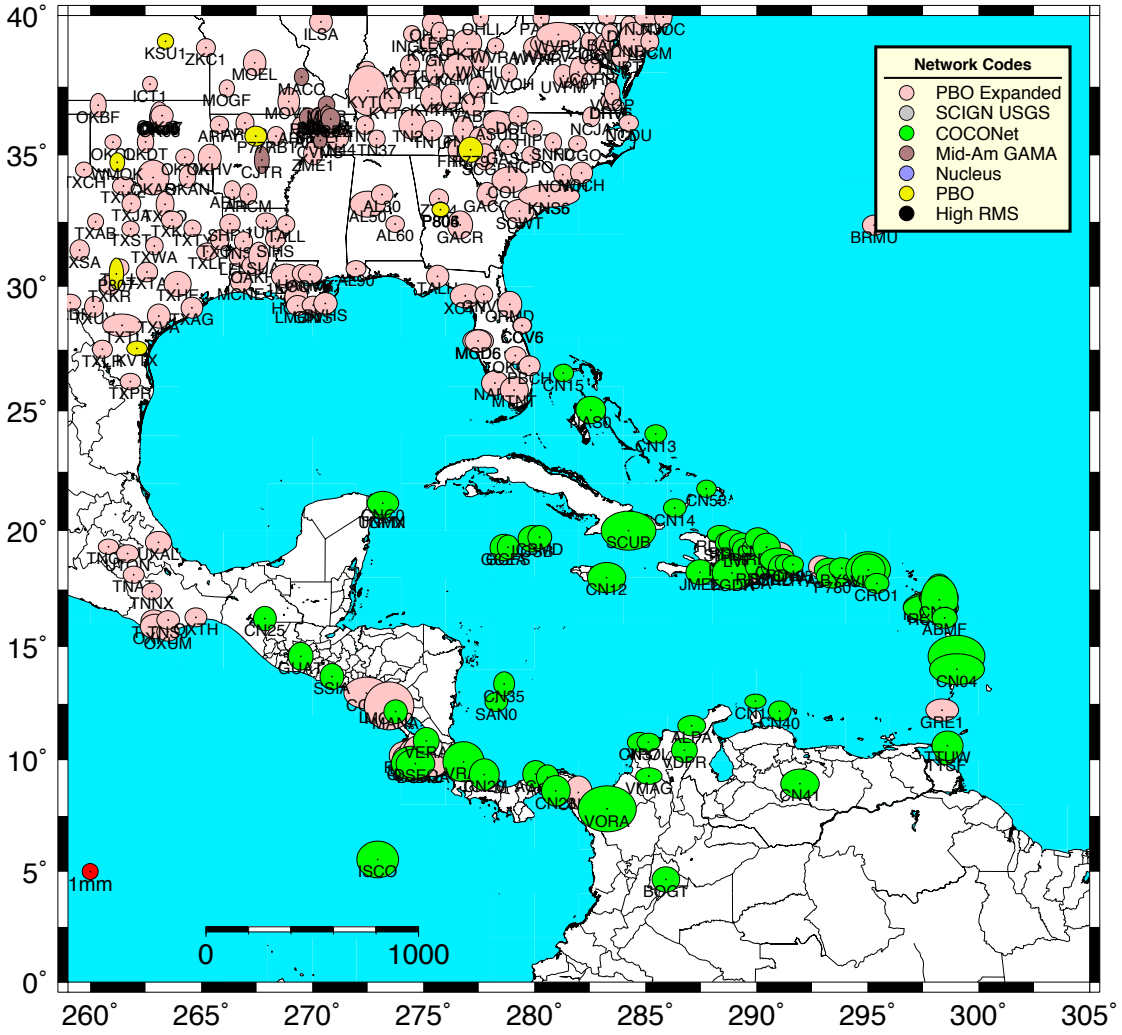

Figure 7: Same as Figure 4 except for the Caribbean region.

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_PBO_eqs.eq All_PBO_ants.eq All_PBO_unkn.eq. The GLOBK apriori coordinate file All_PBO_nam14.apr is the current estimates based on data analysis in this quarterly report. Currently this file defines the definitive coordinates and velocities of the NAM14 system. We now also include All_CWU_nam14.apr which includes recently added sites that do not appear in the PBO apriori file based on the combination of NMT and CWU analyses.

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 2624 stations in the CWU solution. The statistics of the fits to results are shown in Table 3. 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_190921.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_190622.snpvel.

Table 3: Statistics of the fits of 2624 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and September 21, 2019

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.39	1.34	6.12
70%			
CWU	1.75	1.68	6.96
95%			
CWU	3.78	3.54	12.44

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.

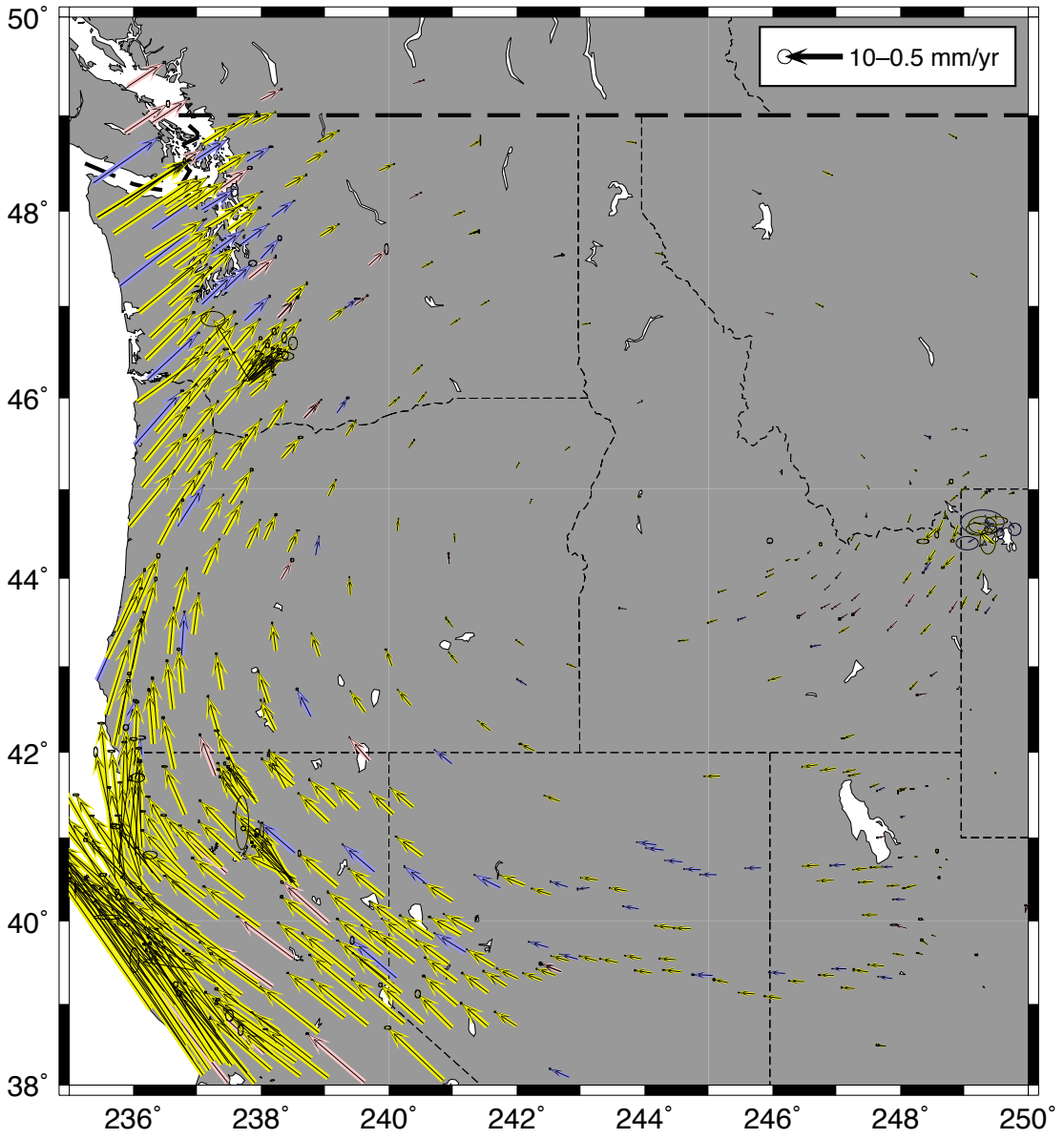

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

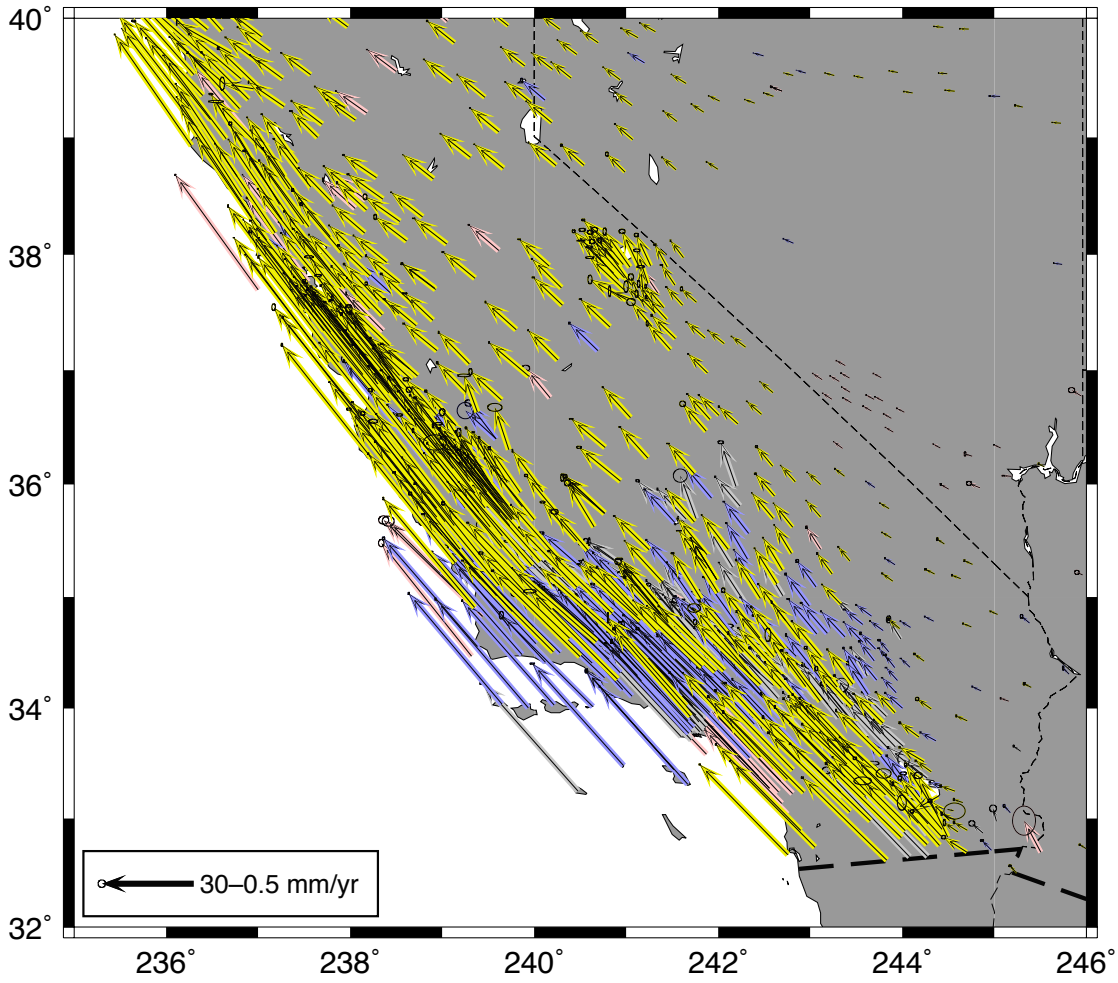

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

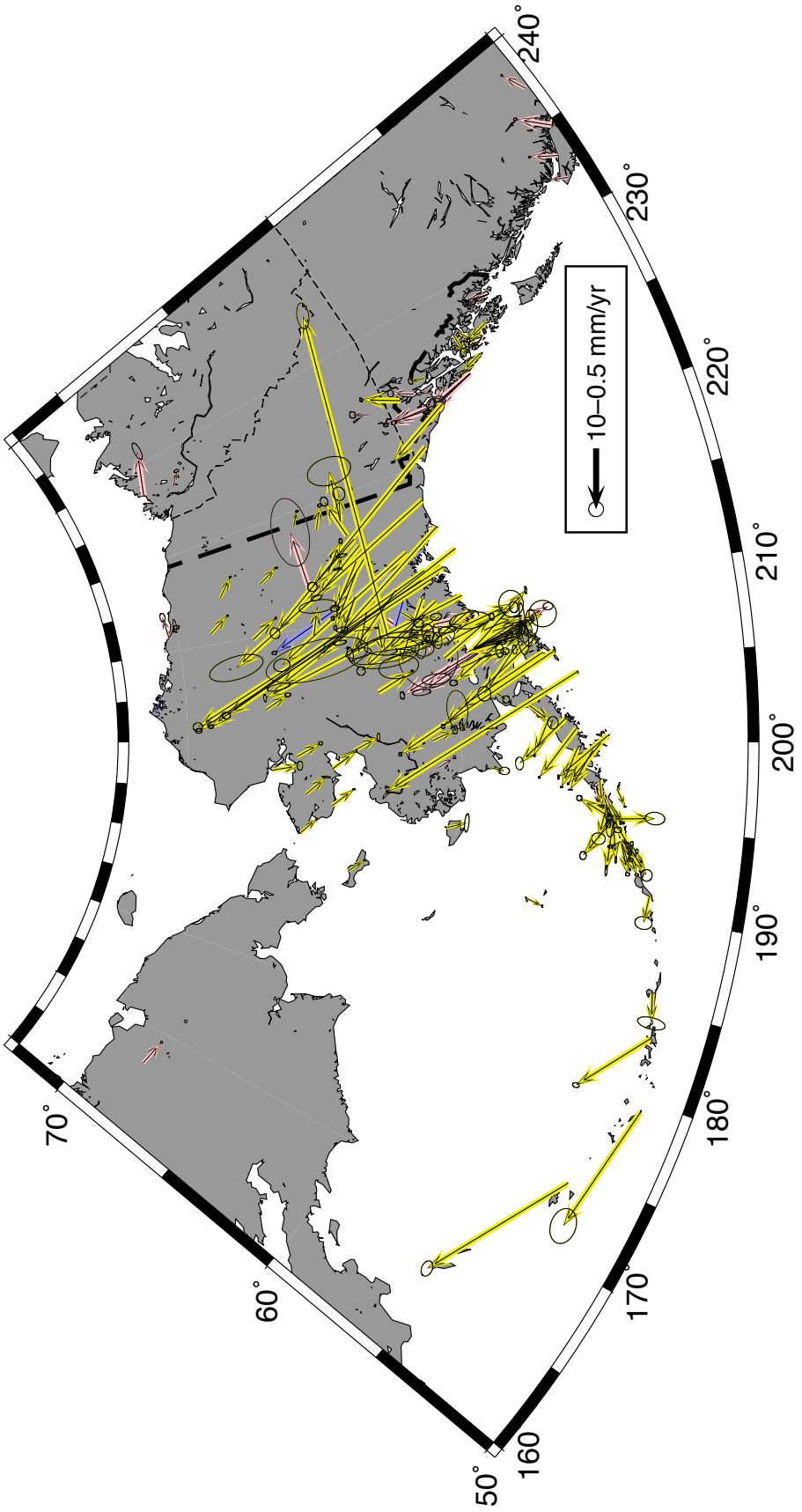

Figure 10:

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

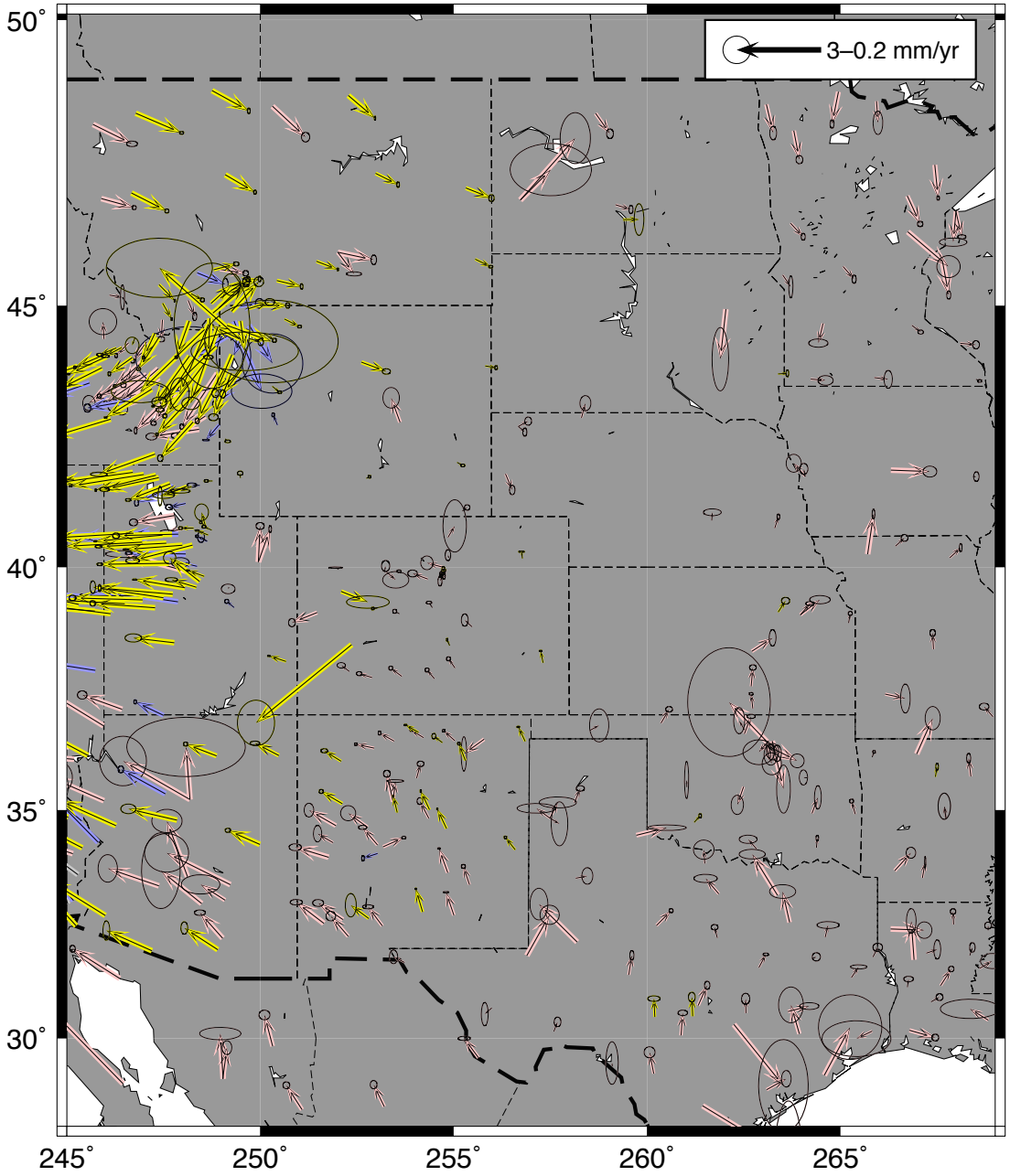

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

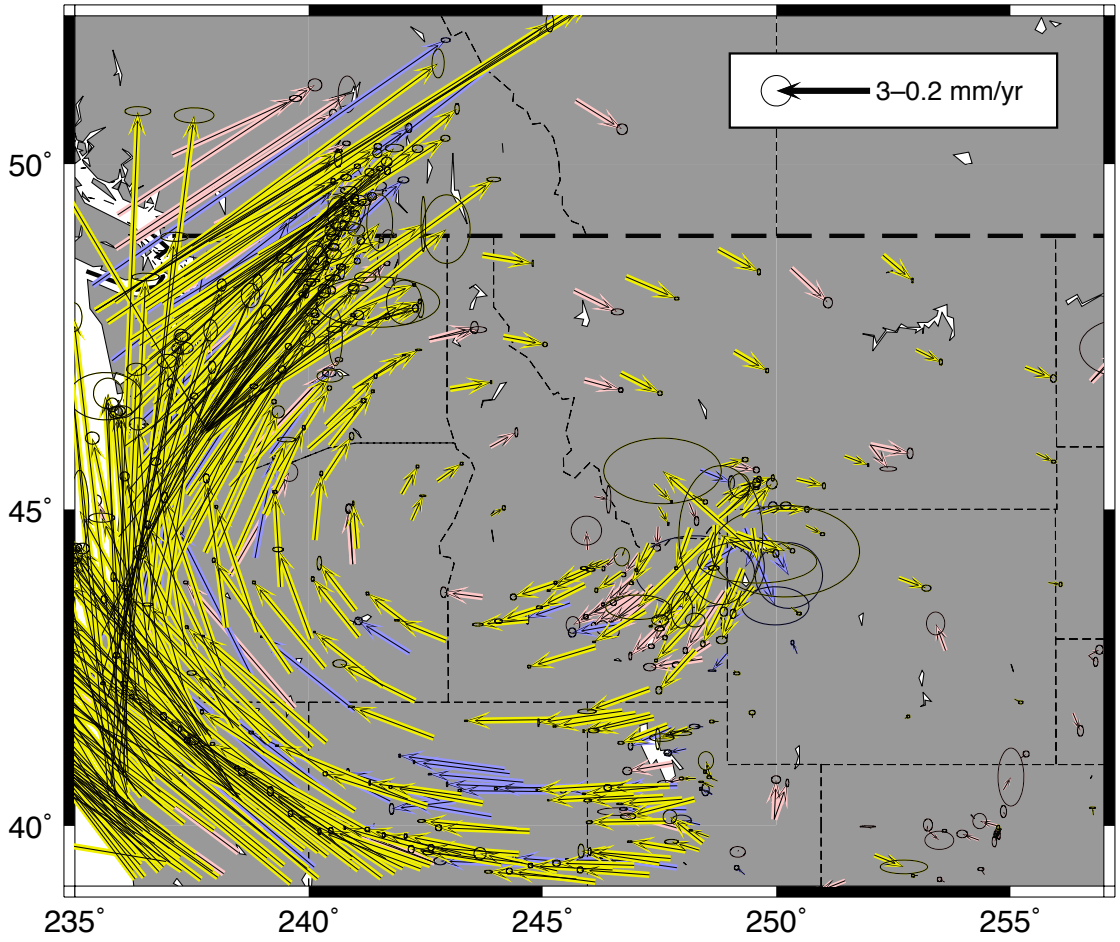

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

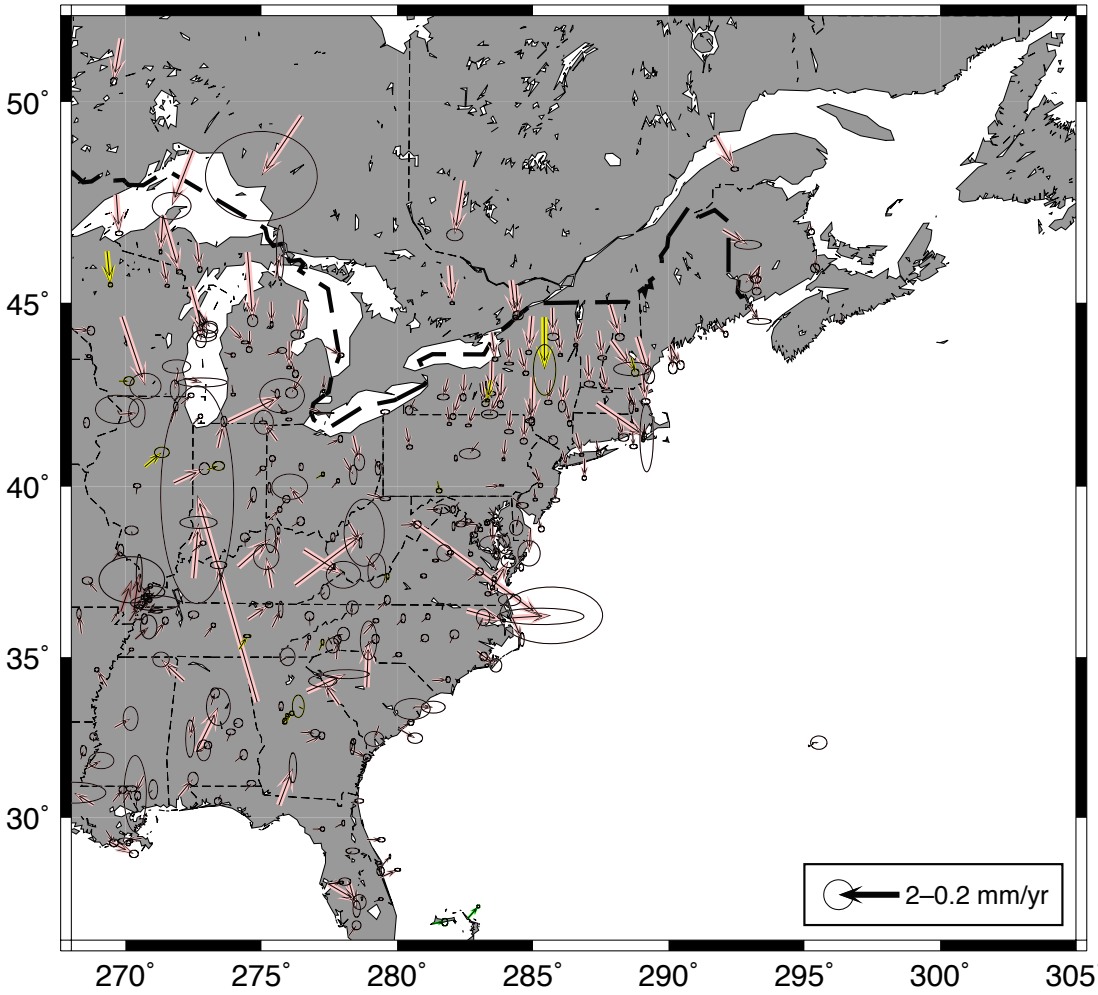

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

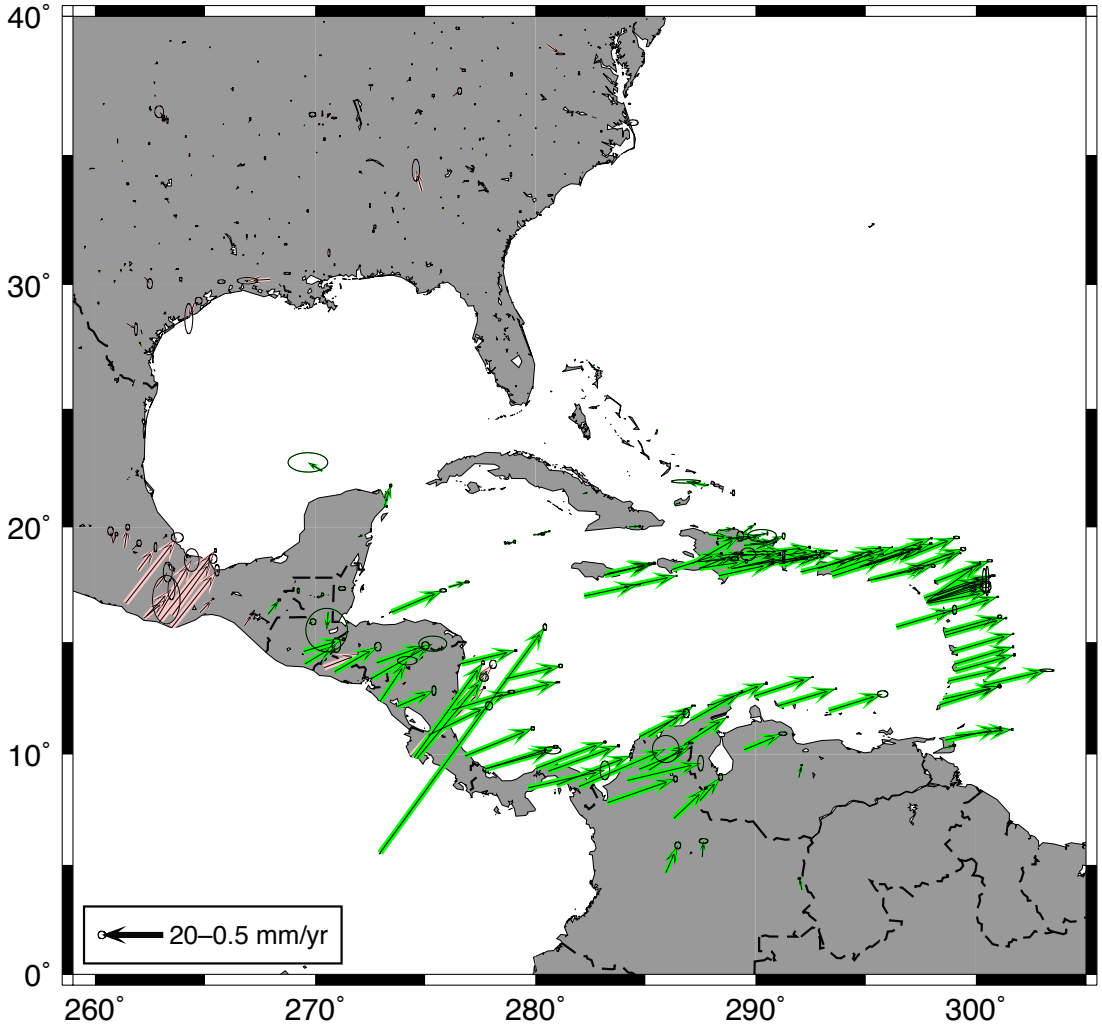

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2019/06/15-2019/09/15

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 117 earthquakes examined during this quarter, 2 new earthquakes which would displace sites by more than 1 mm were detected. The two earthquakes were associated with the Ridgecrest two main shocks. These have been assigned earthquake codes of 48 and 49. The radius of influence of the July 4, Mw 6.4 was increased from 82 km (algorithm default) to 100 km. For the July 6, Mw 7.1, its radius was increased from 237 km to 250 km and a logarithmic postseismic term was added by the time series changes after the first 2 months following the event..

```
ANSS(ComCat) ci38443183 nmw6.4 12km SW of Searles Valley (10.71 km)
```

```
Location and date   35.7052 -117.5060    2019 07 04 17 34
ANSS(ComCat) ci38457511 mw7.1 18km W of Searles Valley (8 km depth)
Location and date  35.7695 -117.5993     2019 07 06 03
```

Event files were generated for these events. The rapid orbit event file, was generated with both events merged and the standard two days before and after the events. The final orbit event was generated for each event separately with only 1 day before and after the events since there was only 1 full of data between the two events. A special MIT GAMIT solution was run with the earthquake days divided into segments before and starting 10 minutes after each event. These results were sent to UNAVCO as event files. They were also posted to https://response.scec.org/node/395#comment-1230 so that the community could use the results.

All event files and plots have been queued to LDM with time-tag 20191008100035.

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 58 stations in the ANET region for CWU analyzed in the final orbit analysis between June 15, 2019 and September 21, 2019.

CWU	North (mm)	East (mm)	Up (mm)
Median (50%)	1.24	1.04	5.63
70%	1.48	1.31	6.20
95%	2.19	4.17	12.72

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

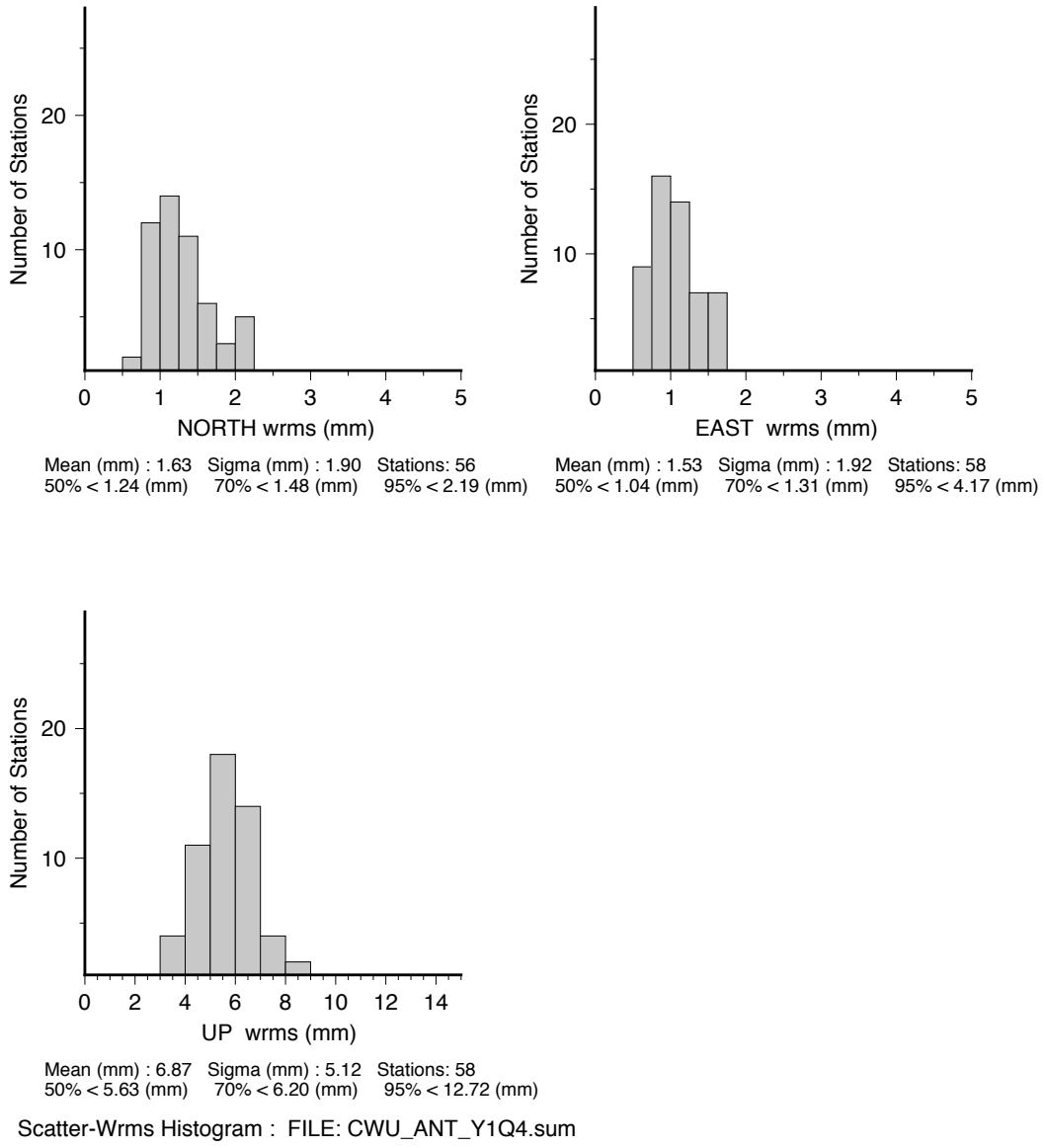

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 58 stations in Antarctica analyzed between June 15, 2019 and September 21, 2019. Linear trends and annual signals were estimated from the time series.

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