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

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Period: 2023/07/01-2023/09/30

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Summary

Under the GAGE2 Facility Data Analysis sub-award, MIT has been processing SINEX files from Central Washington University (CWU) and aligning them to the GAGE NAM14 reference frame. In this report, we show analyses of the data processing for the period 2023/07/01 to 2023/09/30, time series velocity field analyses for the GAGE reprocessing analyses (1996-2023). Several earthquakes were investigated this quarter up to 09/15/2023 and one of them, a mww7.2 98 km S of Sand Point (32.571 km depth) lat/long 54.4596° -160.7604° date 2023/07/16 time 06:49 generated co-seismic displacements greater than 1 mm. This event has been designated EQ 71.

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. These solutions are in the 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, 1989 stations were processed. In addition, up to 28 sites were processed in the ANET solutions, 20 less than last quarter. There were fluctuations in the number of stations processed as data systems were updated at EarthScope.

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

Each week, we also process the Supplemental (12-week latency) and six-month 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, 2023– September 23, 2023

For this report, we generated the statistics using the ~3 months of CWU results between June 15, 2023, and September 23, 2023. These results are summarized in Table 1 and Figure 1.

For the three months of the final position time series generated, 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 1989 stations for CWU analyzed in the finals analysis between June 15, 2023, and September 23, 2023. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.99	0.93	4.47
70%			
CWU	1.21	1.12	5.23
95%			
CWU	2.26	2.27	8.73

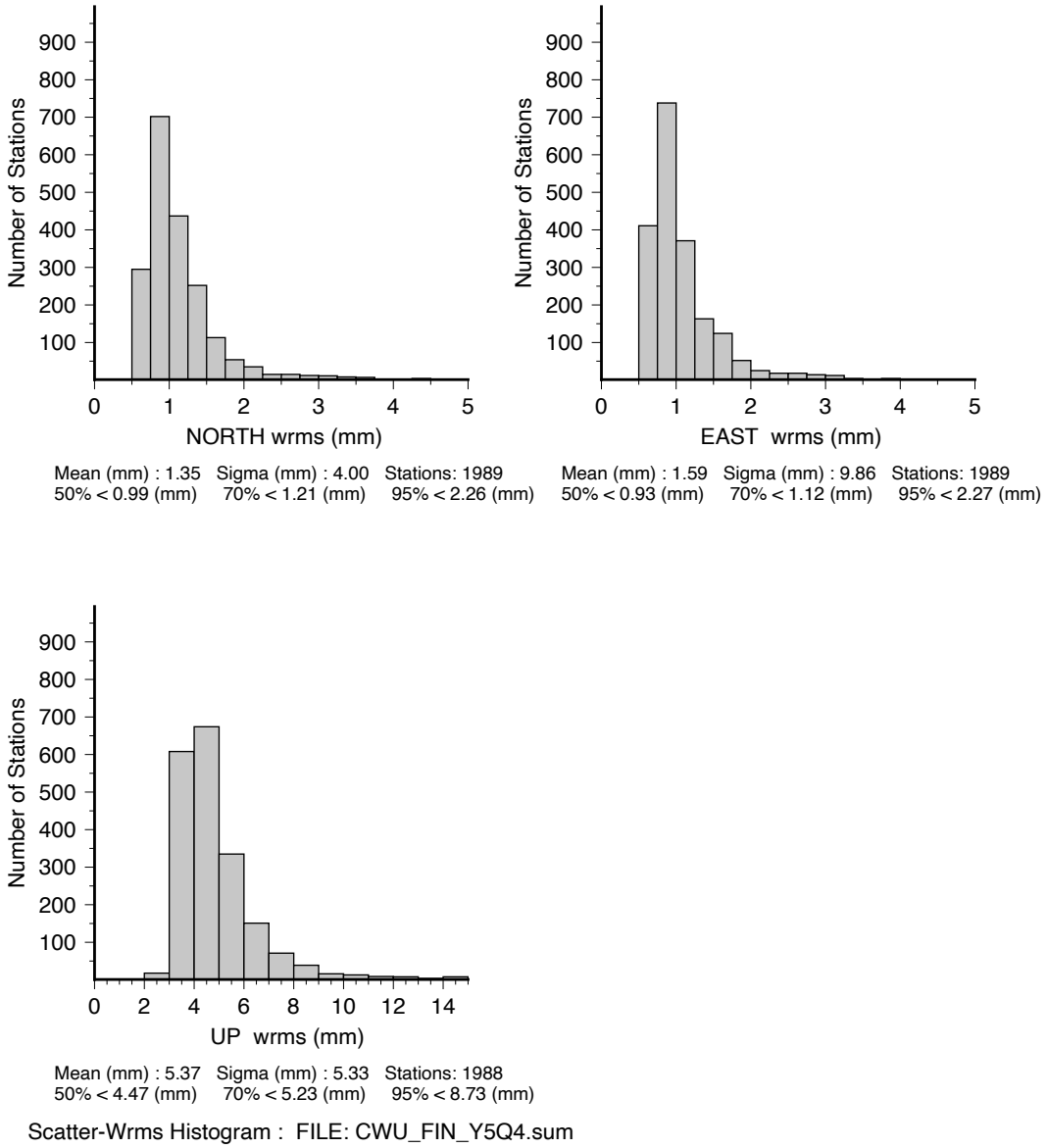

Figure 1: CWU solution histograms of the North, East, and Up RMS scatters of the position residuals for 1989 stations analyzed between June 15, 2023 and September 23, 2023. Linear trends and annual signals were estimated from the time series.

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 three 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_Y5Q4.tab. There are 1974 stations in the file for sites that have at least 2 measurements during the month.

Table 1: Head and tail of WRMS scatter summary file CWU_FIN_Y5Q1.tab.

```
Tabular Position RMS scatters created from CWU_FIN_Y5Q4.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      1.4   0.77      1.8   0.89     7.1   0.77     20.42
 1NSU    98      1.2   0.69      1.2   0.69     5.4   0.72     19.67
 1ULM    99      1.1   0.62      1.2   0.71     5.2   0.69     20.28
 7ODM    34      0.8   0.37      0.9   0.48     5.1   0.60     22.42
…
 ZDV1    99      1.0   0.52      1.0   0.62     6.2   0.81     20.31
 ZKC1    99      1.2   0.64      0.9   0.54     5.6   0.73     20.31
 ZLA1    99      1.1   0.60      1.1   0.69     4.6   0.60     20.53
 ZLC1    99      1.1   0.54      0.9   0.61     4.8   0.62     20.53
 ZME1    99      1.1   0.61      1.1   0.64     5.3   0.71     20.78
 ZMP1    99      1.0   0.48      0.9   0.59     5.8   0.75     20.69
 ZNY1    99      1.0   0.50      1.1   0.72     3.5   0.47     21.22
 ZOA1    98      0.7   0.36      0.7   0.46     4.2   0.57     20.69
 ZSE1    99      0.9   0.43      0.9   0.59     7.5   0.98     20.88
```

Table 2: RMS scatter of the position residuals for the CWU solution between June 15, 2023, and September 23, 2023, 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	0.89	0.87	4.02	838
NUCLEUS	0.85	0.82	4.03	179
GAMA	1.04	1.11	5.28	12
COCONet	1.56	1.69	7.66	71
USGS_SCIGN	0.94	0.89	4.38	115
Expanded	1.12	1.03	5.13	774
70%				
PBO	1.06	0.99	4.45	
NUCLEUS	0.94	0.92	4.41	
GAMA	1.12	1.13	5.84	
COCONet	1.86	1.97	8.40	

USGS_SCIGN	1.19	1.09	5.14
Expanded	1.31	1.31	5.84
95%			
PBO	1.94	1.69	6.35
NUCLEUS	1.77	1.31	5.64
GAMA	1.21	1.25	6.38
COCONet	4.27	7.32	16.04
USGS_SCIGN	2.06	1.65	8.92

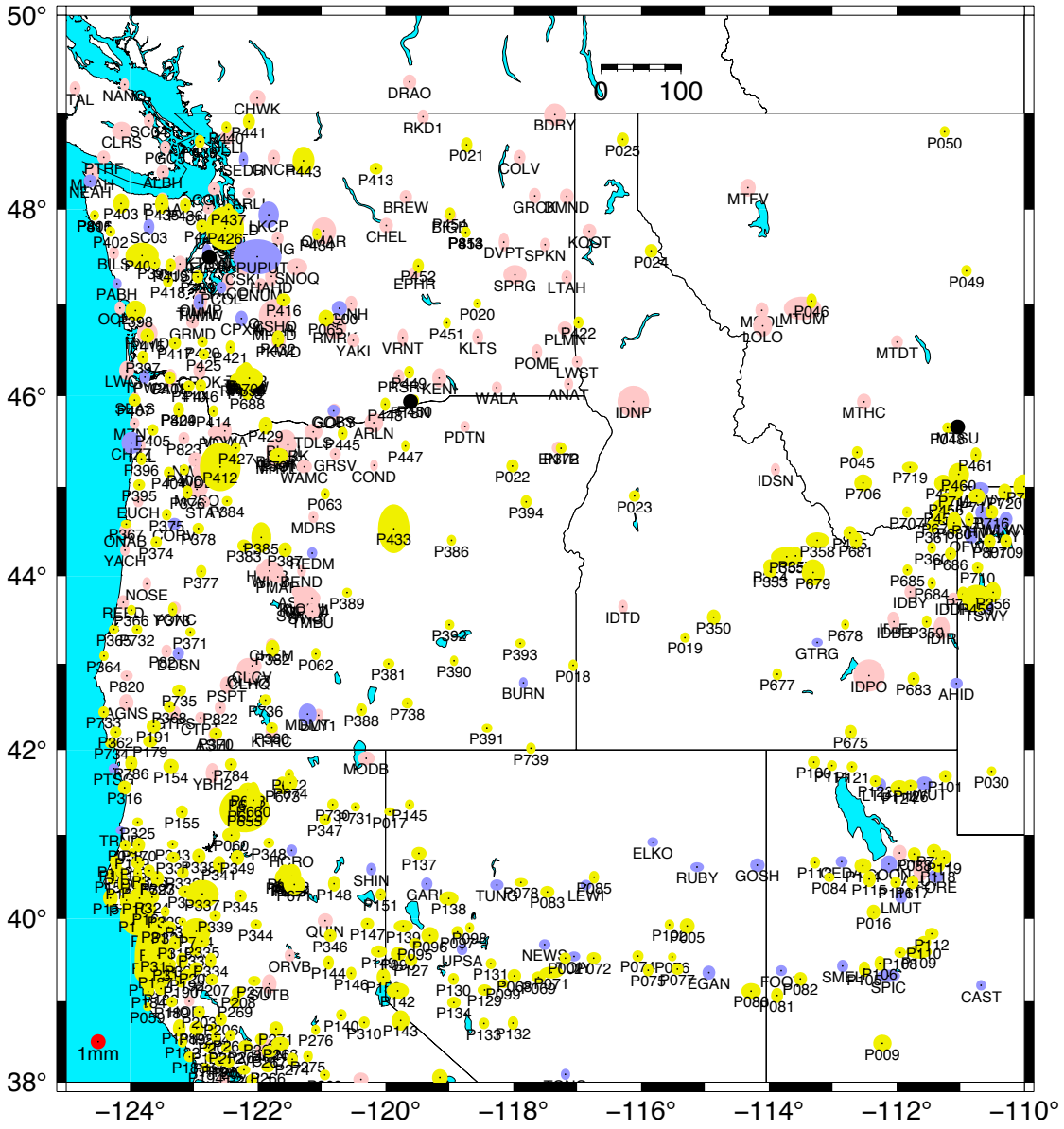

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1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

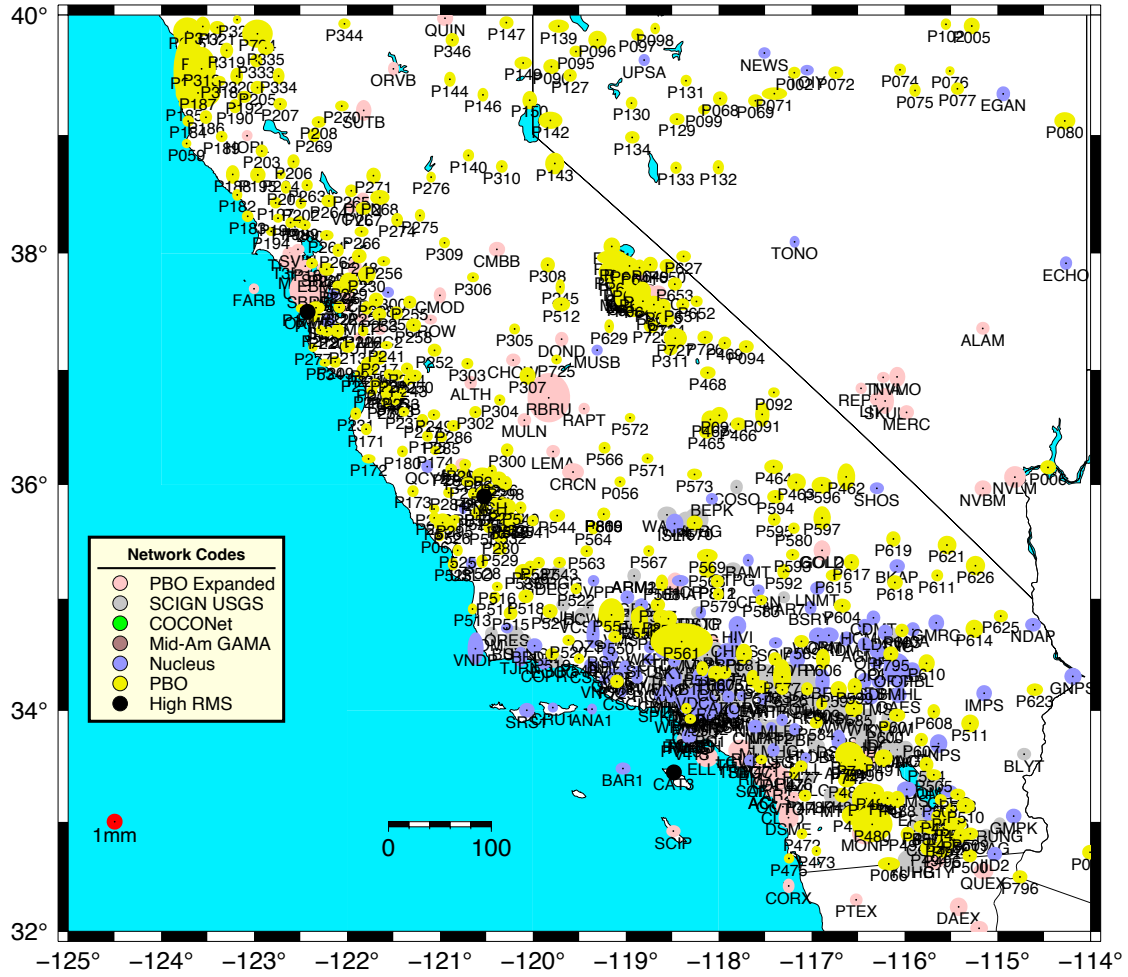

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

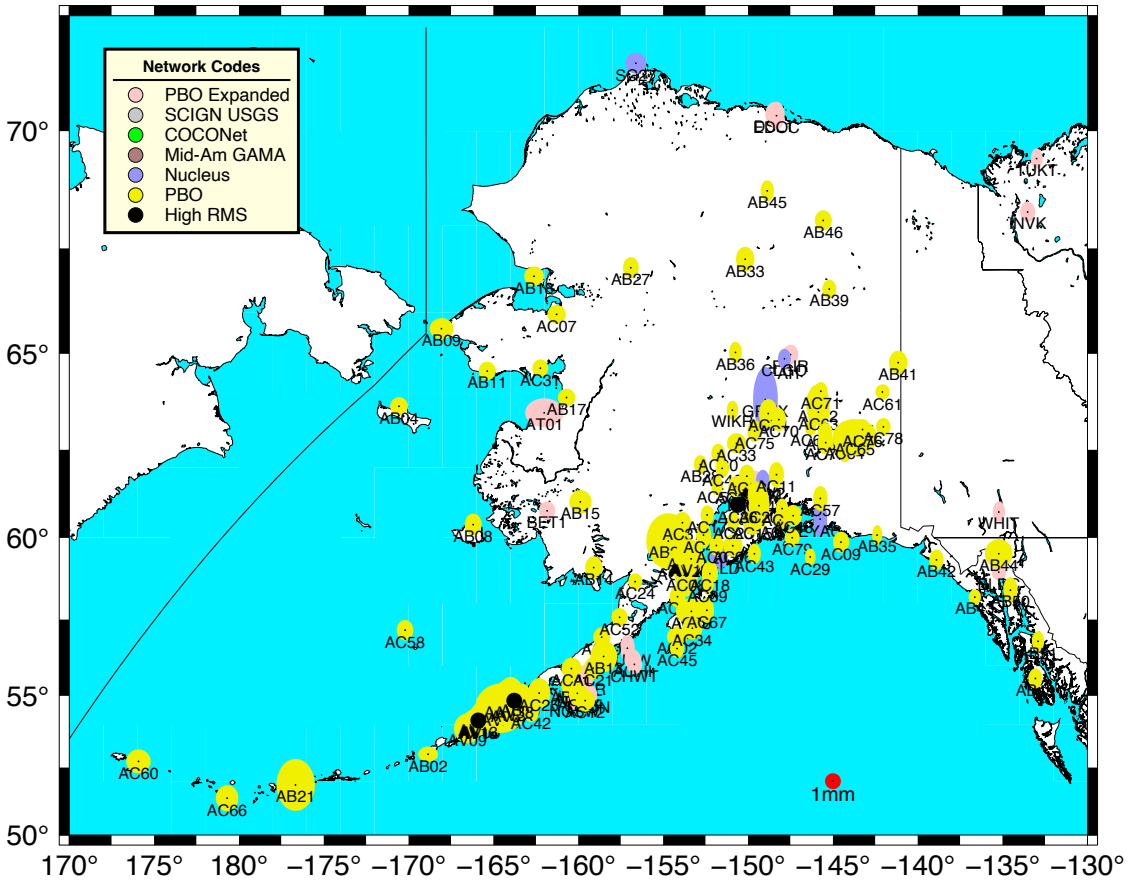

Figure 4: Same as Figure 4 except for the Alaskan region.

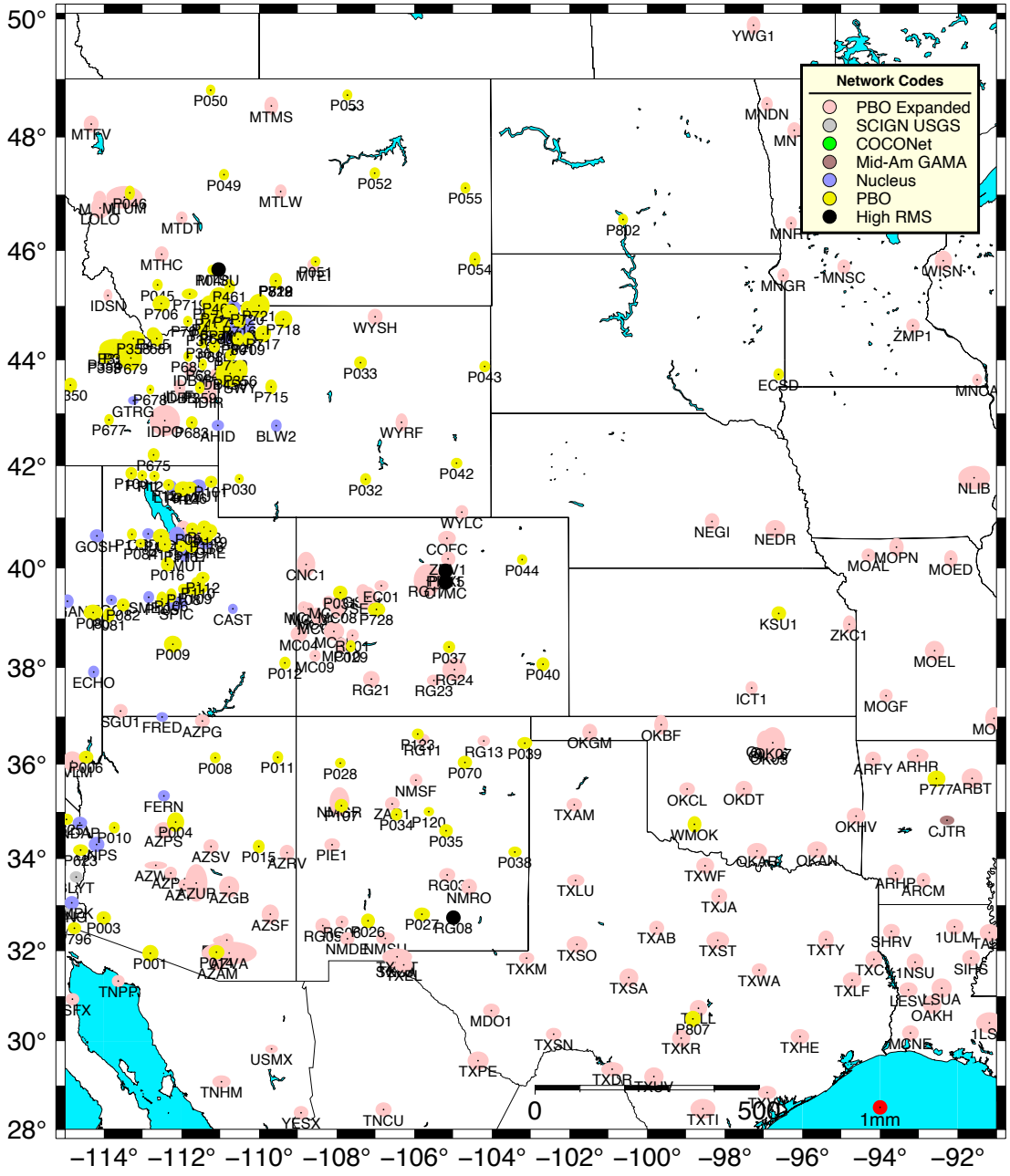

Figure 5: Same as Figure 4 except for the Central United States

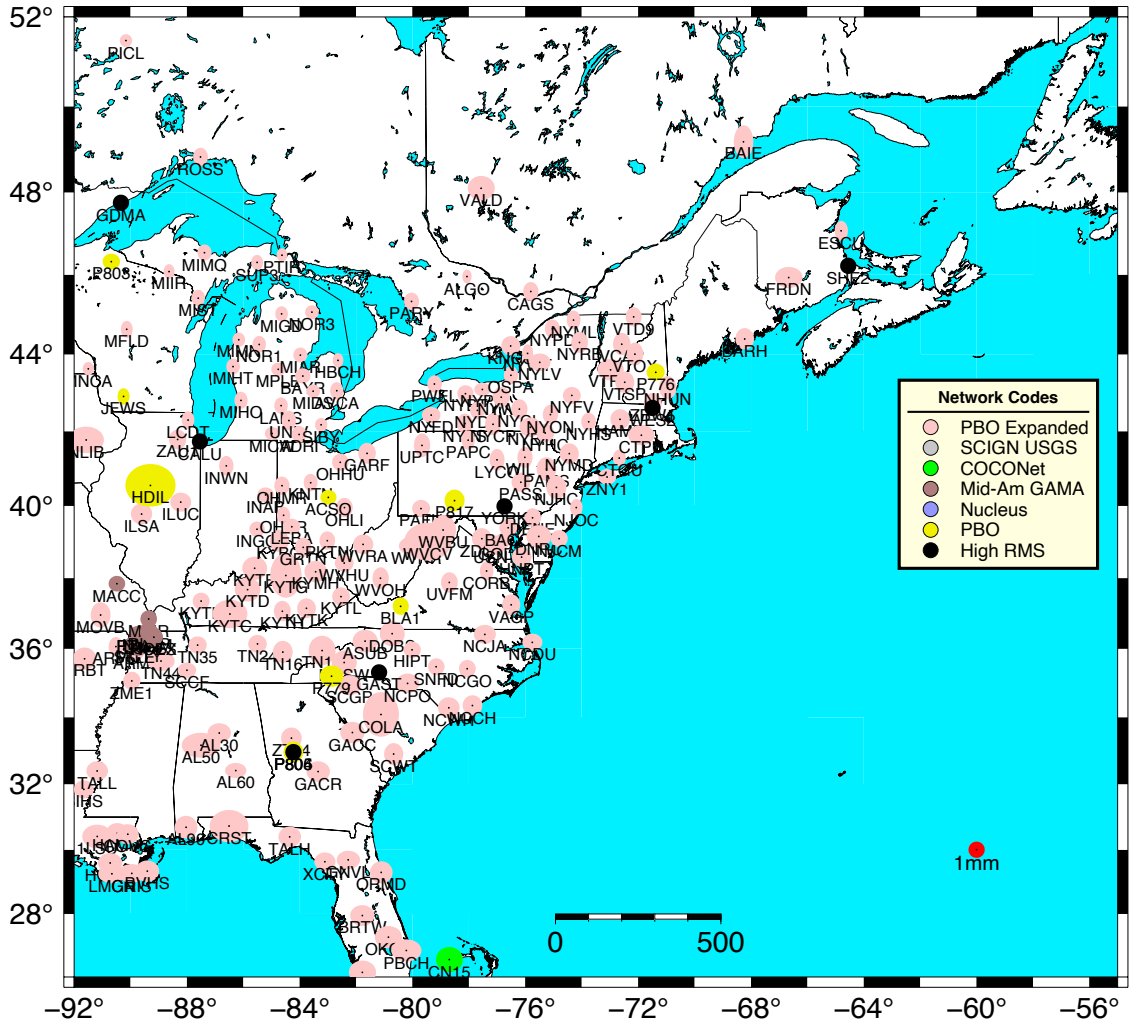

Figure 6: Same as Figure 4 except for the Eastern United States

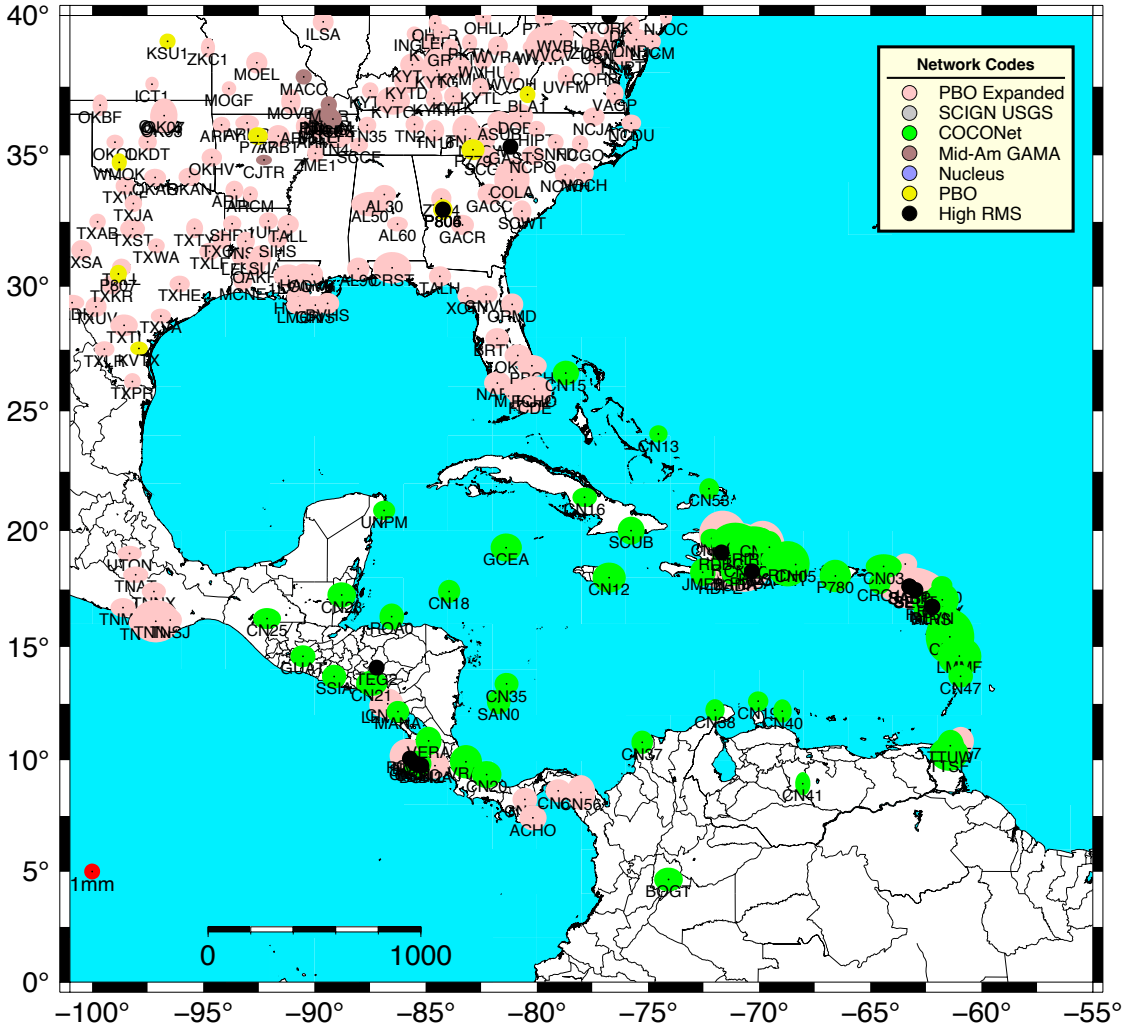

Figure 7: Same as Figure 4 except for the Caribbean region.

GLOBK Apriori coordinate file and earthquake files

As part of the quarterly analysis, we run a 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 estimate 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 2719 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_230923.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_nam14_230923.snpvel.

Table 3: Statistics of the fits of 2718 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and September 23, 2023.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.41	1.37	6.24
70%			
CWU	1.78	1.74	7.10
95%			
CWU	3.96	3.66	11.65

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.

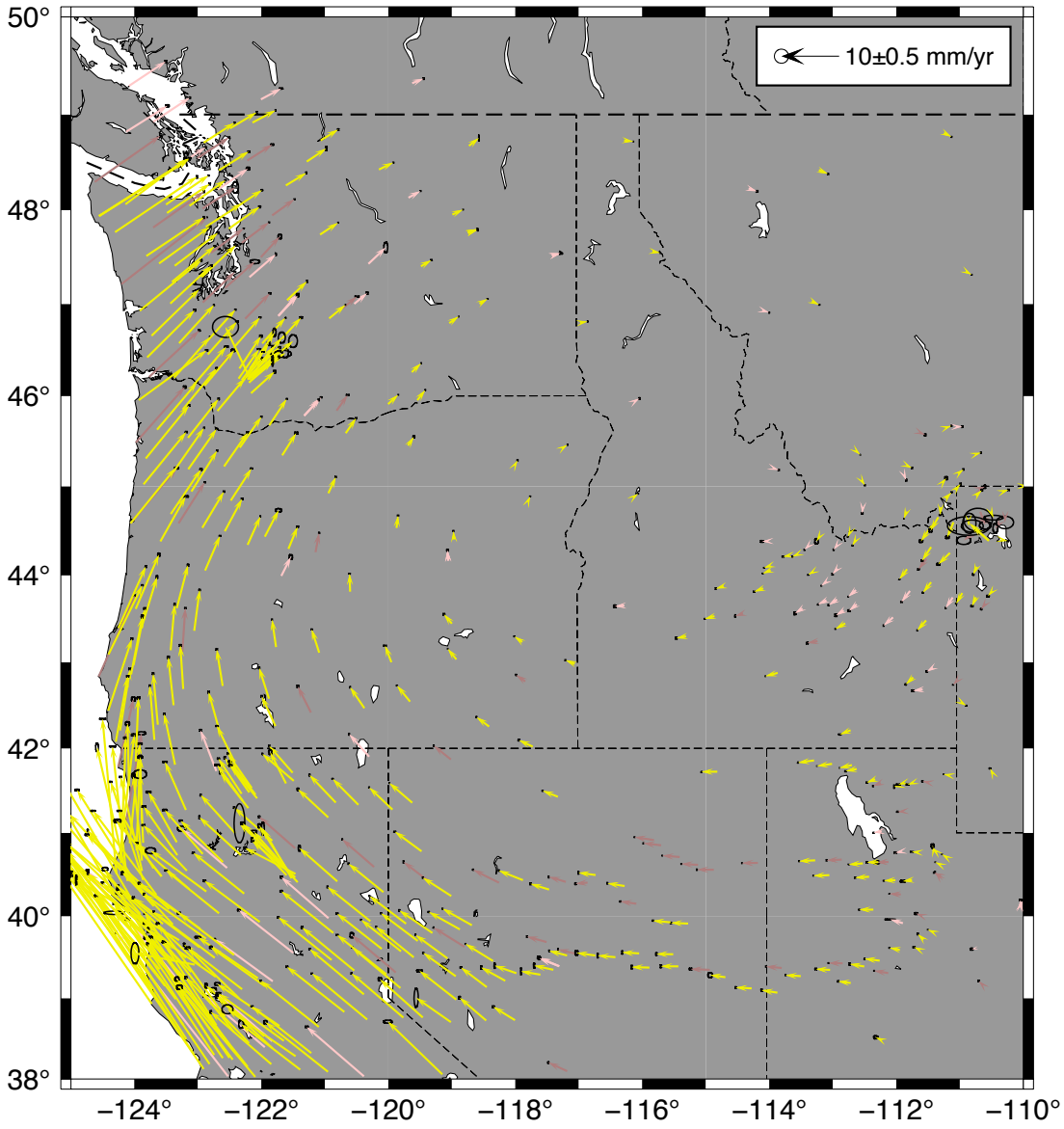

Figure 8: Velocity field estimates for the Pacific northwest from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

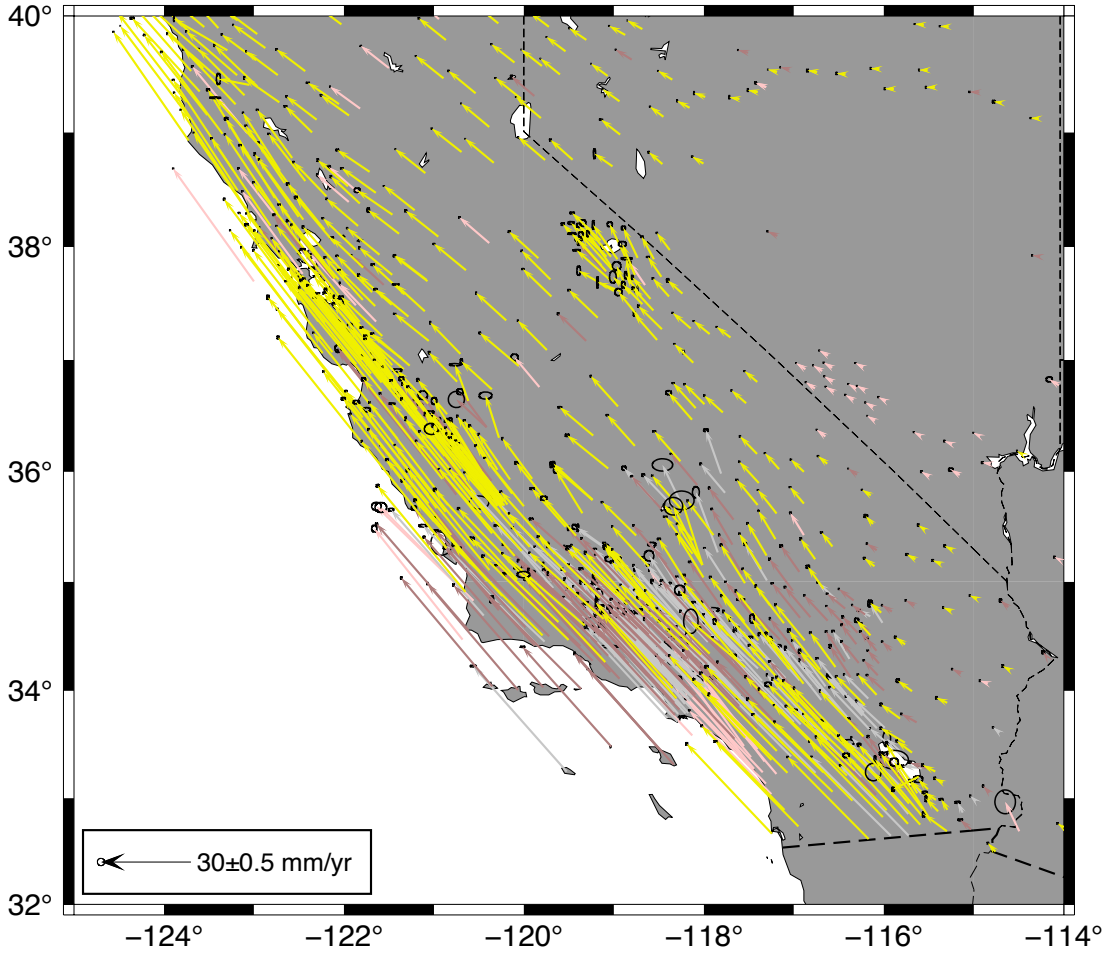

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

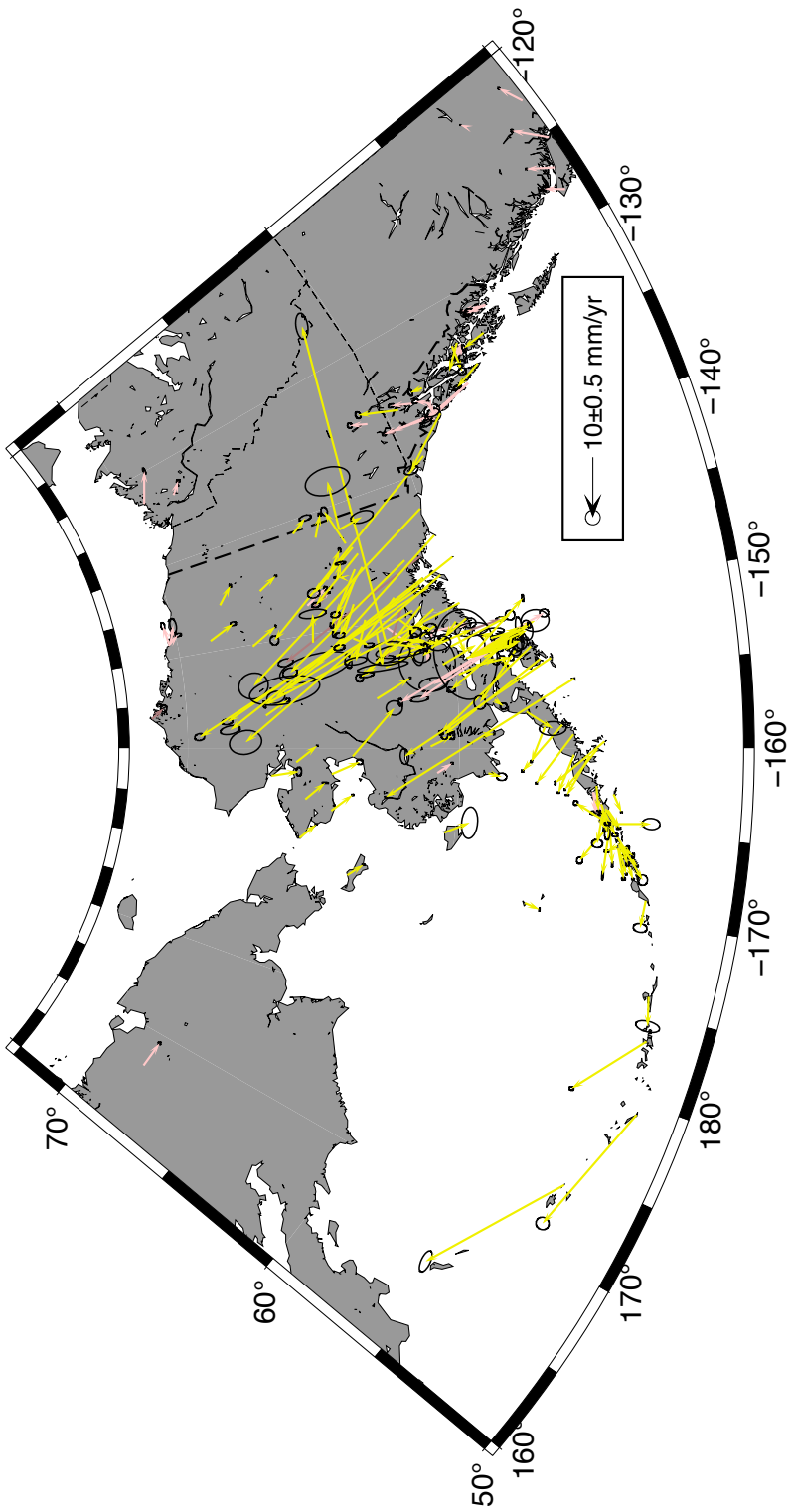

Figure 10: Same as Figure 8 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

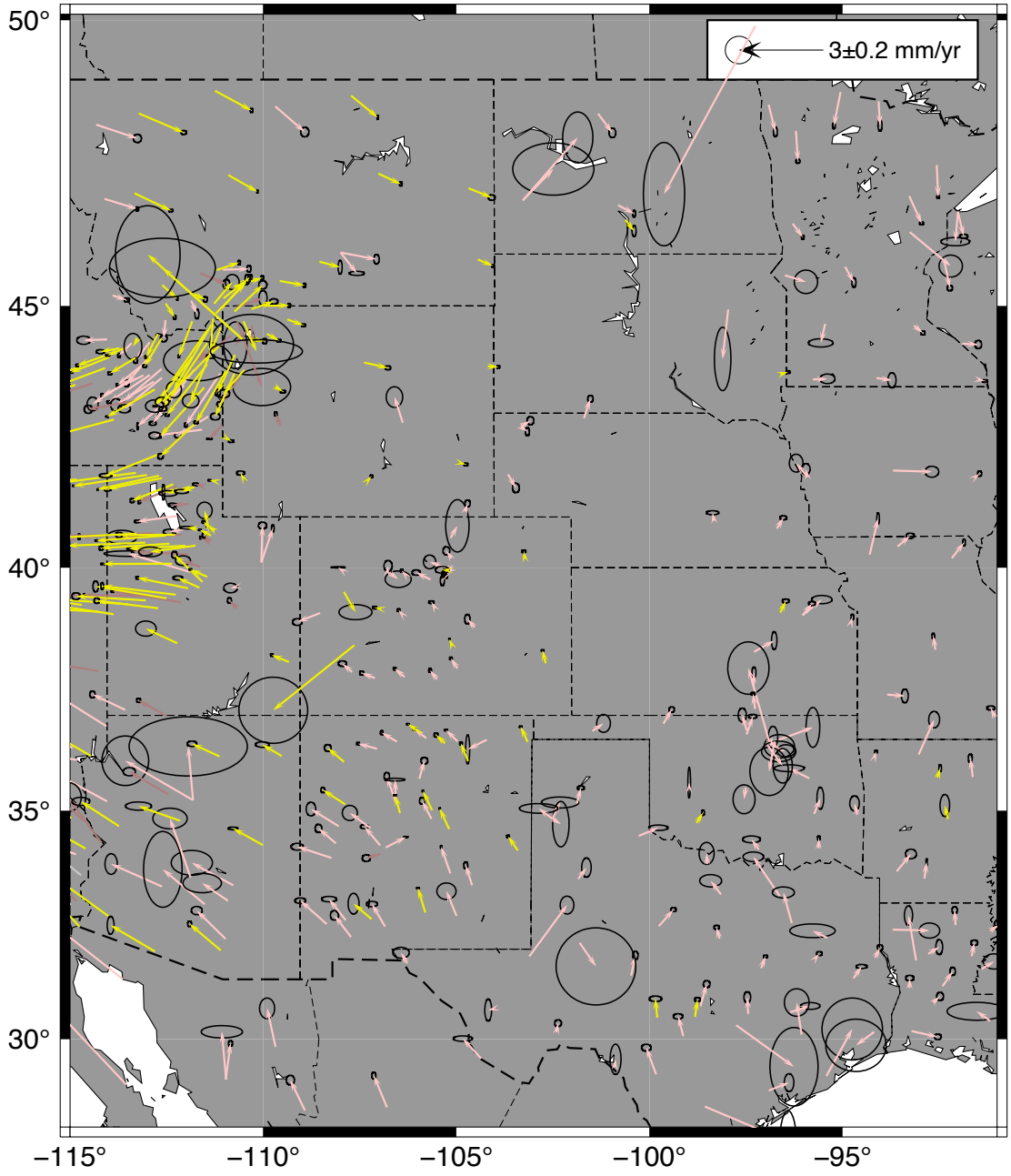

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

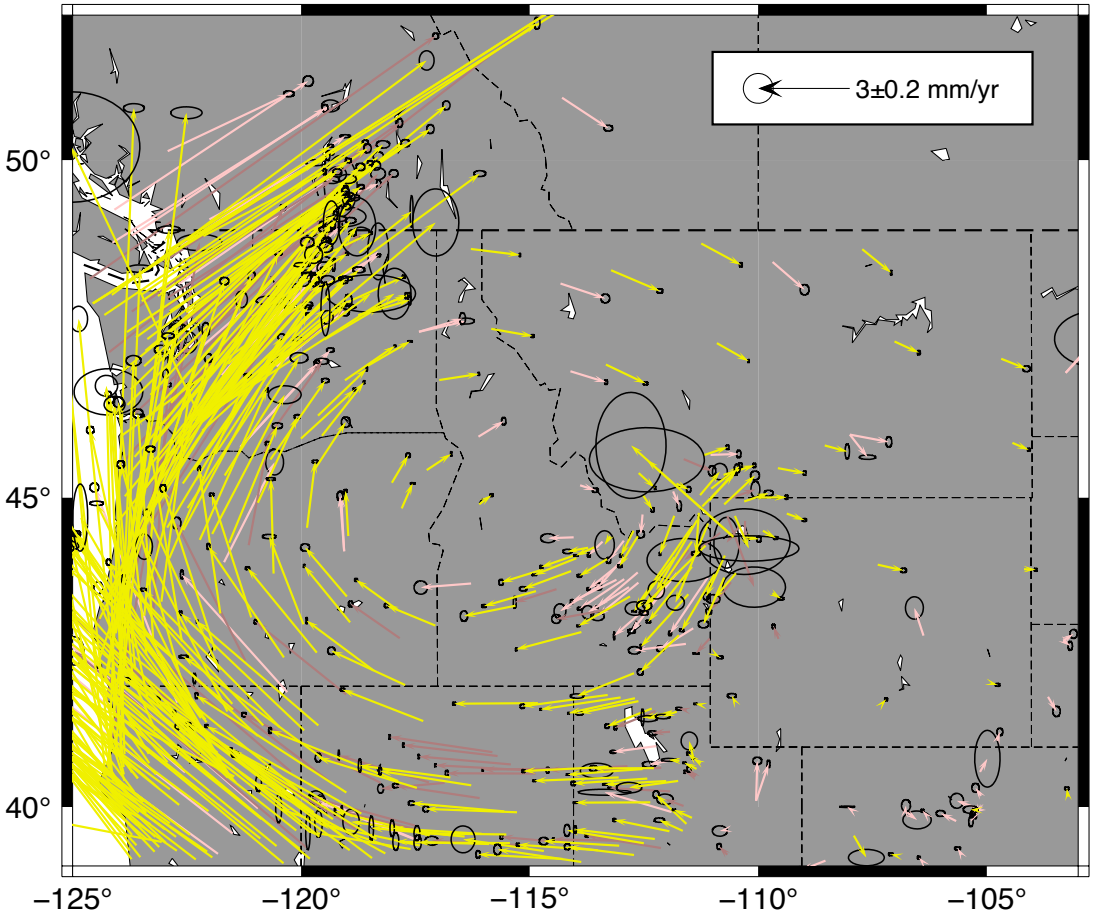

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

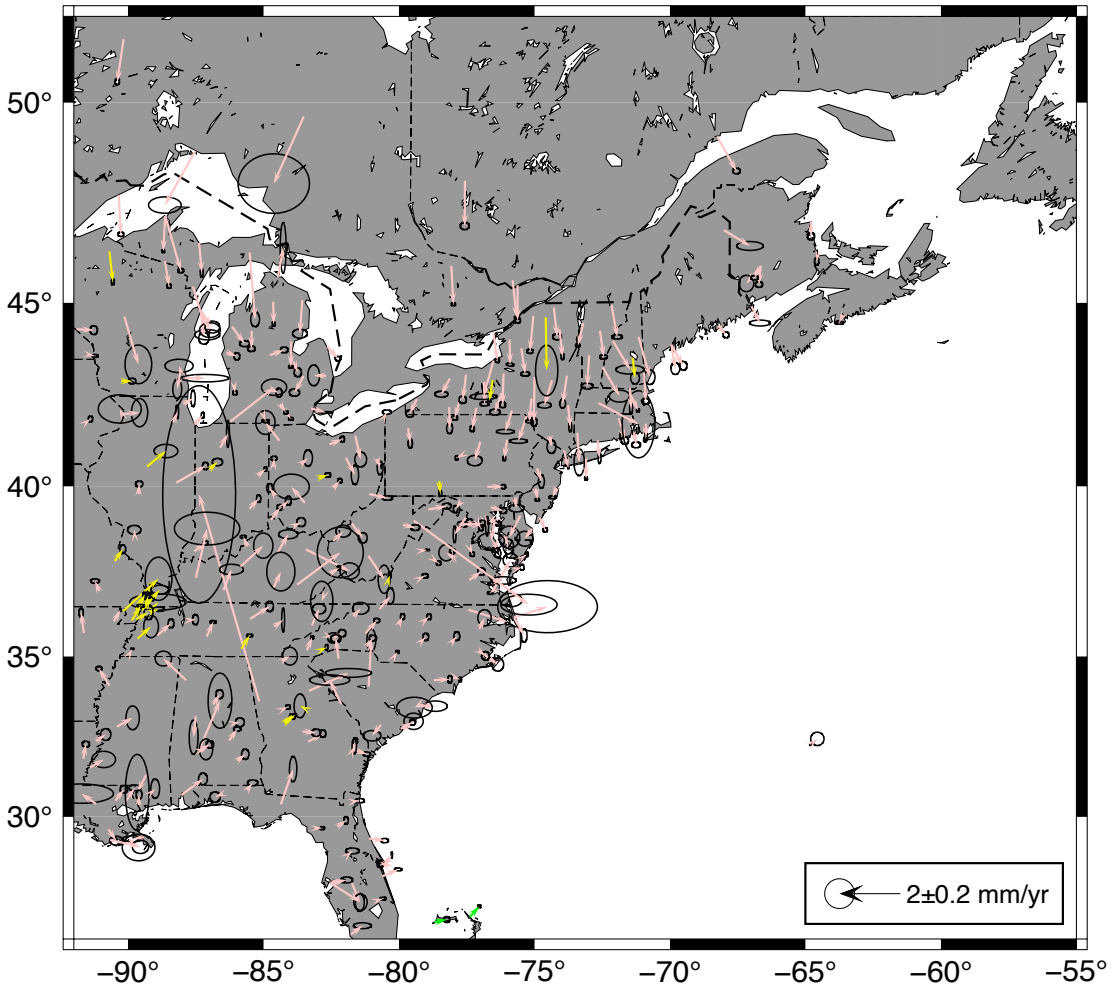

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

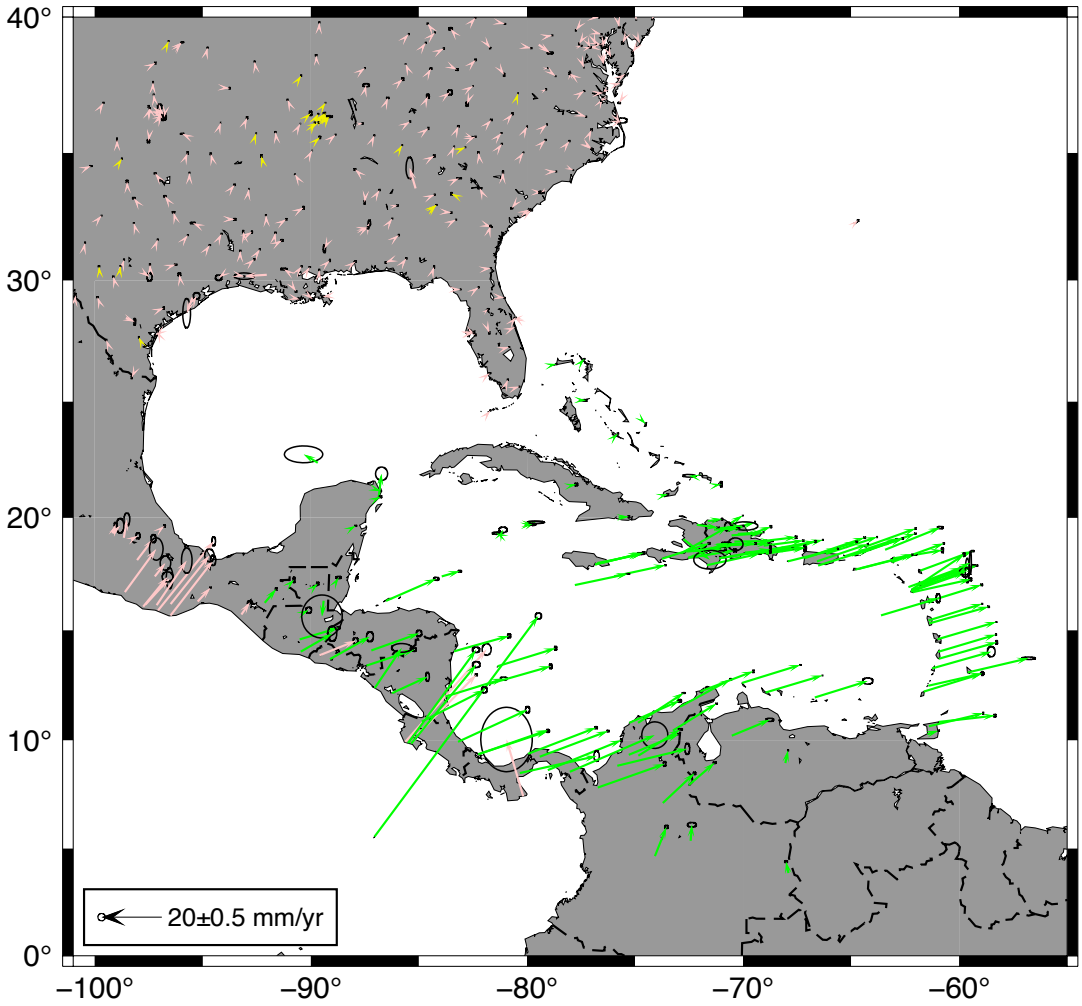

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2023/06/15-2023/09/15

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 21 earthquakes examined during this quarter, only 1 generated co-seismic offsets greater than 1 mm. This event, a mww7.2 98 km S of Sand Point (32.571 km depth) lat/long 54.4596° -160.7604° date 2023/07/16 time 06:49 generated co-seismic displacements greater than 1 mm. This event has been designated EQ 71. Co-seismic offsets have been sent to UNAVCO via LDM.

Antenna and other discontinuity events.

Antenna swaps at 35 sites have been added to the list of offsets that are estimated when fitting velocities and other parameters to the CWU time series. These offsets were spread throughout the quarter.

Anomalous sites

The following sites have been noted as having anomalous motions during this quarter. We updated the ACC_GAGE web site to show times of earthquakes, antenna changes and offsets for unknown reasons. Plots for CWU are now generated with and without offsets (computed from the Kalman filter time series analysis) remove. The landing page for http://geoweb.mit.edu/~tah/ACC_GAGE/ now has the following explanation.

NOTA RAPID Solution Outlier sites for PROD ID 20230120183013

Analyses from Central Washington University (CWU). Series are:
NMT -- Old plots from New Mexico Tech Analyses (Ends 9/15/2018).
PBO -- Old plots from Combined NMT+CWU analyses (Ends 9/15/2108).
CWURAW -- Raw time series with linear trend removed
CWUOFF -- Time series with linear trend and offsets from cwu.kalts_nam14.off removed
Vertical lines denote times of offsets in time series:
Purple, solid: Earthquakes (OffEq ! EQ)
Blue, dotted: Antenna changes (Break ! AN)
Cyan, dashed: Breaks for unkown reasons (Break ! UN)

N after site name means NOTA operated site, U means UNAVCO/Earthscope log file.
The table below includes new and old style plots (update was made that the end of the quarter).

Site	N	Issues related to site
		2023-07-18
YORK		CORS site in Pennsylvania. Antenna probably failed starting 12/1/2022. http://geoweb.mit.edu/~tah/ACC_PBO/YORK.CWUOFF.png
		2023-07-21 not in monthly
AV15	U	Site on Akutan, AK shows offset in North (10mm). See what happens. Isolated data point. Now back to normal. http://geoweb.mit.edu/~tah/ACC_PBO/AV15.CWUOFF.png
P271	N	Strong annuals in North and height. North might be antenna problem. Site near Sacramento. Previously noted. http://geoweb.mit.edu/~tah/ACC_PBO/P271.CWUOFF.png
SEUS	U	Site on Sint Eustatius Caribbean island. East is "noisy" recently but other sites SEUB, SEUH and SEUT show similar changes but they are not all exactly the same. In the rapids, some days match very well but other days do not. Disturbed weather on the island? Somewhat similar behavior each July. http://geoweb.mit.edu/~tah/ACC_PBO/SEUS.CWUOFF.png
		2023-08-02
ANDC		Offset from EQ71. Many other stations also show offsets. Easily seen

		here because this is new station. http://geoweb.mit.edu/~tah/ACC_PBO/ANDC.CWUOFF.png
WES2		Failed antenna/receiver since June 2022. Three values between 2023/7/28 and 2023/7/30 that are 1.5, 0.5, 0.8 meters off in east, north and up. http://geoweb.mit.edu/~tah/ACC_PBO/WES2.CWUOFF.png
		2023-08-11
ELSR		PANGA site getting noisier starting after antenna change in March 2022. http://geoweb.mit.edu/~tah/ACC_PBO/ELSR.CWUOFF.png
SCWT		CORS site. Recent rapids show outliers with increased error bars. Something failing? Site in South Carolina. Stopped sending data 2023/08/09. http://geoweb.mit.edu/~tah/ACC_PBO/SCWT.CWUOFF.png
		2023-08-17Not in monthly
AZFL		CORS site in Flagstaff AZ; gap in data and most recent rapid has 160 mm East offset. Unknown break 2022/04/12 added. See what happens. http://geoweb.mit.edu/~tah/ACC_PBO/AZFL.CWUOFF.png
MTSU		CORS site in Montana near P048. Looks like failed antenna after swap in 2022. http://geoweb.mit.edu/~tah/ACC_PBO/MTSU.CWUOFF.png
		2023-08-25
KAGA	U	West coast Greenland site. Height increase and West motion in rapids. Fast un-loading event? Check later to see if status changes. New antenna seems to be issue. http://geoweb.mit.edu/~tah/ACC_PBO/KAGA.CWUOFF.png
MARG	U	Also west coast of Greenland but further north than KAGA. Height increase similar KAGA but sites in between show not anomaly. http://geoweb.mit.edu/~tah/ACC_PBO/MARG.CWUOFF.png
		2023-09-01
KBUG	U	Site in Greenland with height outlier in rapids. Could be snow? Check again later. Similar to jump at MARG and KAGA but later. New antennas being installed but no log updates but antenna change at KAGA not reported. http://geoweb.mit.edu/~tah/ACC_PBO/KBUG.CWUOFF.png
		2023-09-15
IDPO		Site in Idaho near Idaho Falls. Seems to be offset on 2023/07/25 with possibly another one on 2023/09/12. No meta data update (antenna change at the end of 2022). Had been very linear site. http://geoweb.mit.edu/~tah/ACC_PBO/IDPO.CWUOFF.png
P644		Near Mammoth Lake: Very systematic (not noted previously). P642 similar, but P643 between is not a systematic. http://geoweb.mit.edu/~tah/ACC_PBO/P644.CWUOFF.png
		2023-10-06 Not in monthly
GRSV		PANGA site. Jump in height looks like an antenna change but no log file update. http://geoweb.mit.edu/~tah/ACC_PBO/GRSV.CWUOFF.png
P711	N	Yellowstone site showing decadal systematics. http://geoweb.mit.edu/~tah/ACC_PBO/P711.CWUOFF.png

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 28 stations in the ANET region for CWU analyzed in the final orbit analysis between June 15, 2023 and September 23, 2023.

CWU	North (mm)	East (mm)	Up (mm)
Median			
ANET	1.33	1.17	6.01
70%			
ANET	1.54	1.40	6.27
95%			
ANET	2.02	2.15	6.92

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

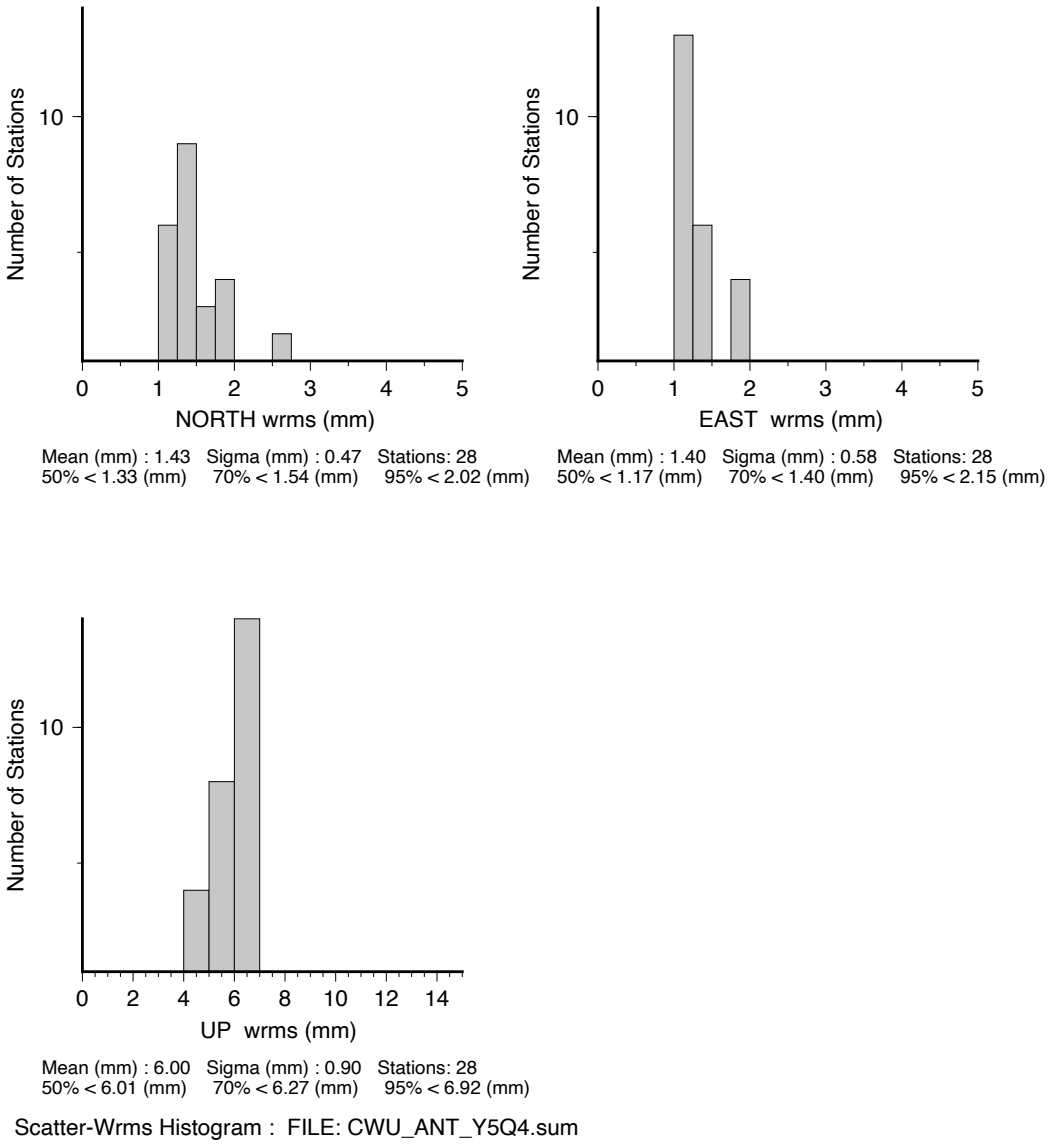

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 50 stations in Antarctica analyzed between June 15, 2023 and September 23, 2023. Linear trends and annual signals were estimated from the time series.

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