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

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Period: 2023/04/01-2023/06/30

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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 2023/04/01 to 2023/06/30, time series velocity field analyses for the GAGE reprocessing analyses (1996-2023). Several earthquakes were investigated this quarter up to 06/15/2023 and one of them, mw4.3 8km WSW of Niland (2.04 km depth) lat/long 33.2008° -115.5900° date 2023/04/30 07:10. Because of the three shallow events we increased the radius of influence from 10.7 to 15 km, and reduced the depth from 8 to 2 km. This event has been designated EQ 70.

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 1974 stations were processed. In addition up to 48 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: March 15, 2023– June 17, 2023

For this report, we generated the statistics using the ~3 months of CWU results between March 15, 2023 and June 17, 2023. 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 1974 stations for CWU analyzed in the finals analysis between March 15, 2023 and June 17, 2023. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.89	0.84	4.61
70%			
CWU	1.12	1.07	5.36
95%			
CWU	2.54	2.59	9.38

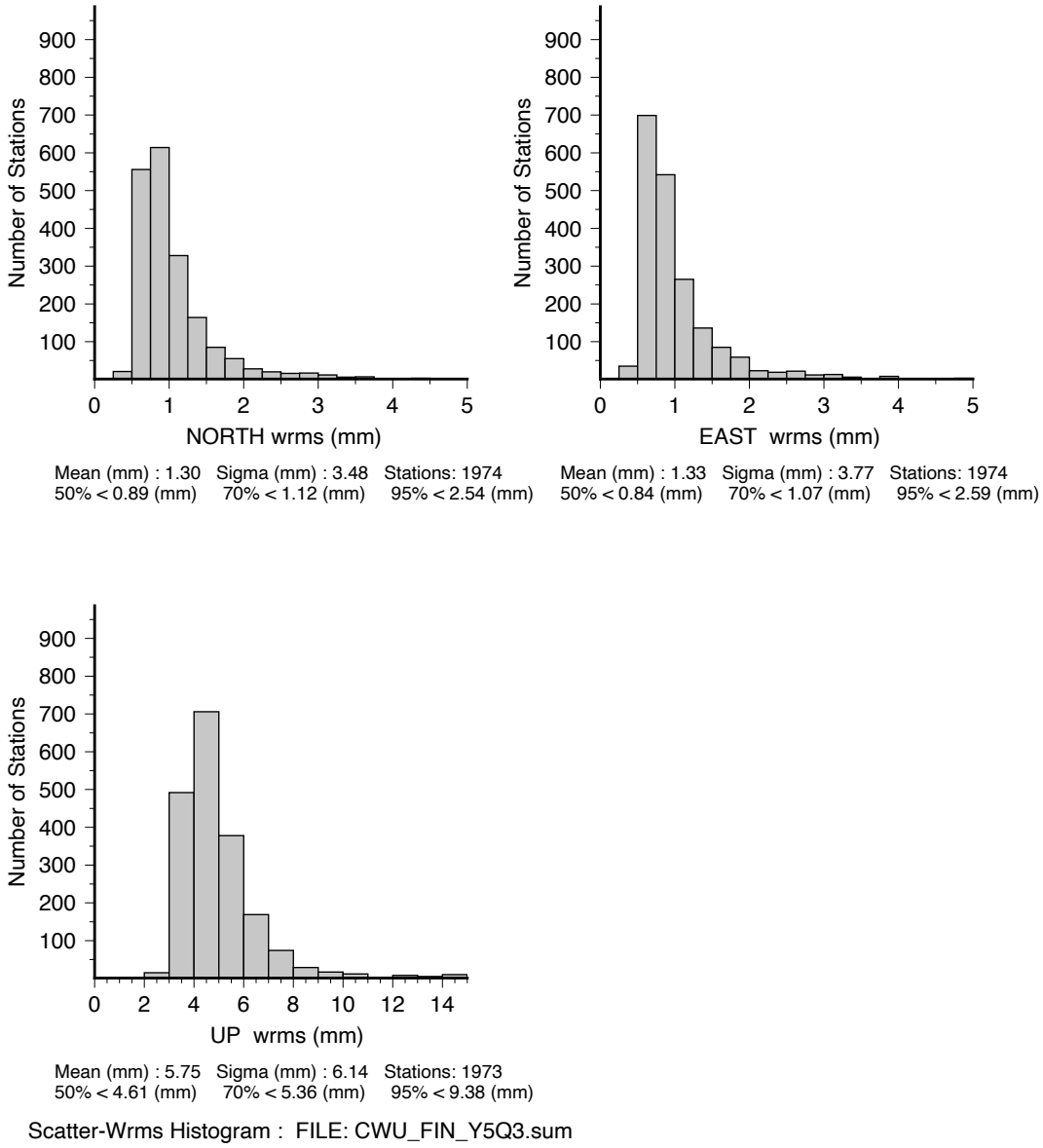

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 1974 stations analyzed between March 15, 2023 and June 17, 2023. Linear trends and annual signals were estimated from the time series.

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 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_Y5Q3.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_Y5Q3.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    95      1.2   0.67      1.7   0.86     6.6   0.73     20.15
 1NSU    95      1.0   0.60      1.1   0.68     5.4   0.73     19.41
 1ULM    95      1.0   0.61      1.1   0.67     6.6   0.90     20.01
 AB02    84      1.3   0.61      1.3   0.88     4.4   0.63     16.04
…
 ZDV1    94      0.9   0.47      0.8   0.50     5.9   0.78     20.04
 ZKC1    94      0.8   0.43      0.9   0.55     5.0   0.65     20.04
 ZLA1    94      1.3   0.70      1.0   0.66     5.1   0.68     20.27
 ZLC1    94      1.0   0.53      0.7   0.47     5.3   0.72     20.27
 ZME1    94      0.9   0.53      1.0   0.61     5.3   0.74     20.51
 ZMP1    94      0.9   0.44      0.7   0.46     5.7   0.76     20.42
 ZNY1    94      0.9   0.48      0.8   0.54     3.9   0.53     20.96
 ZOA1    79      0.7   0.36      0.6   0.39     4.3   0.58     20.42
 ZSE1    94      1.1   0.50      0.7   0.49     7.5   1.01     20.61
```

Table 2: RMS scatter of the position residuals for the CWU solution between March 15, 2023 and June 17, 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	0.80	0.78	4.23	825
NUCLEUS	0.74	0.69	4.04	179
GAMA	0.82	0.83	5.22	14
COCONet	1.37	1.58	6.49	69
USGS_SCIGN	0.81	0.72	4.19	111
Expanded	1.00	0.95	5.17	776
70%				
PBO	1.00	0.97	4.75	
NUCLEUS	0.86	0.79	4.36	
GAMA	0.84	0.88	5.29	
COCONet	1.63	1.86	7.86	

USGS_SCIGN	1.00	0.92	4.71
Expanded	1.21	1.17	5.88
95%			
PBO	2.31	2.24	8.49
NUCLEUS	1.57	1.32	5.71
GAMA	1.09	1.16	5.74
COCONet	3.31	5.77	14.26
USGS_SCIGN	1.58	1.55	7.08

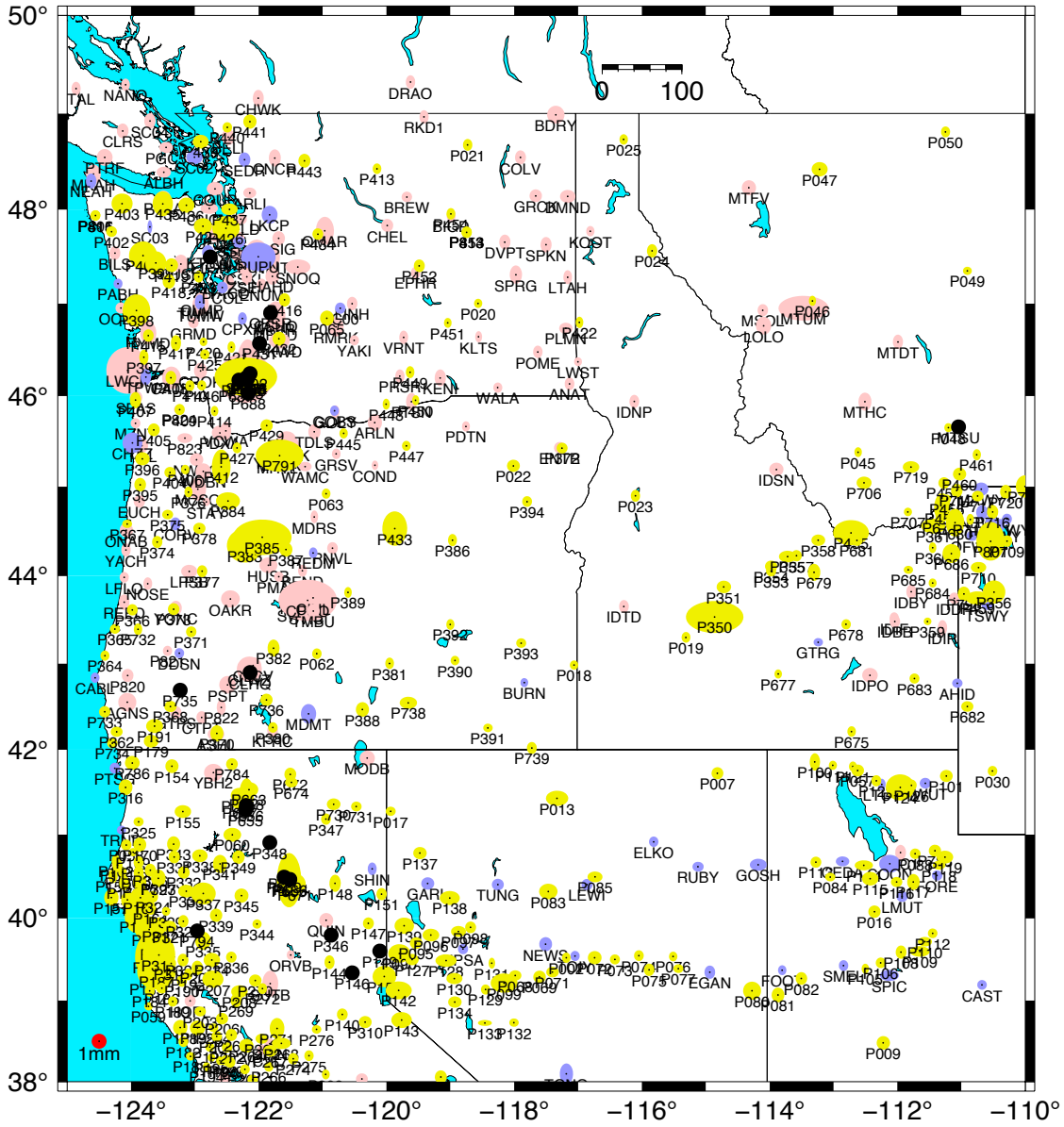

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1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

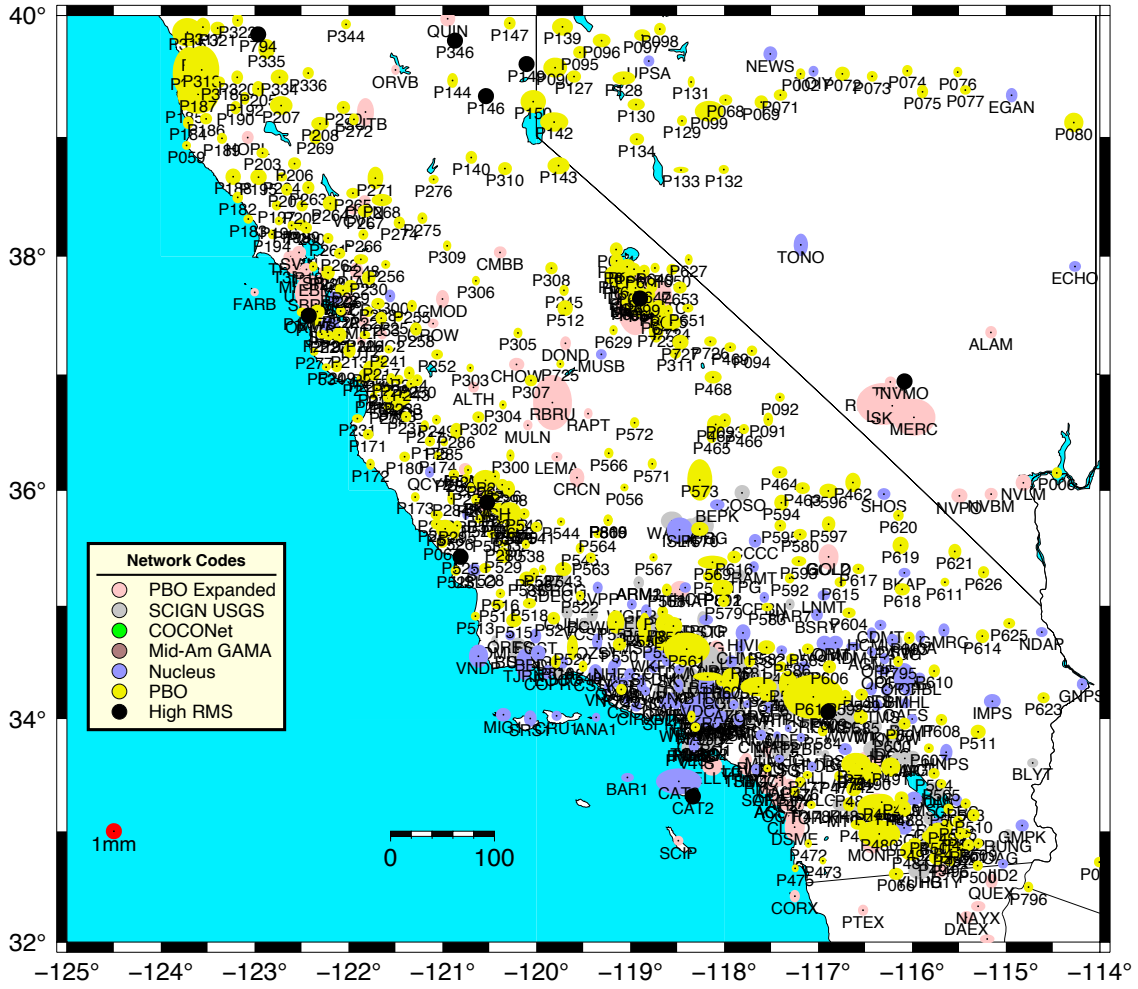

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

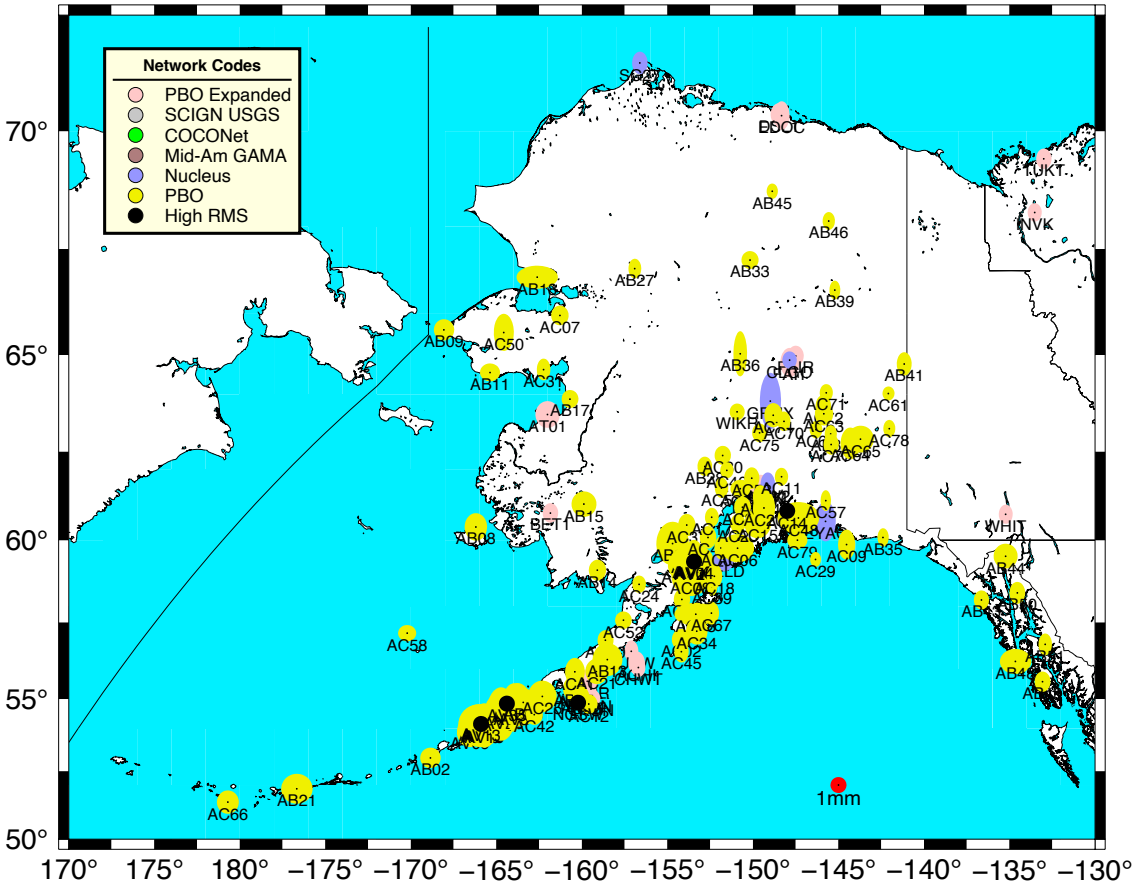

Figure 4: Same as Figure 4 except for the Alaskan region.

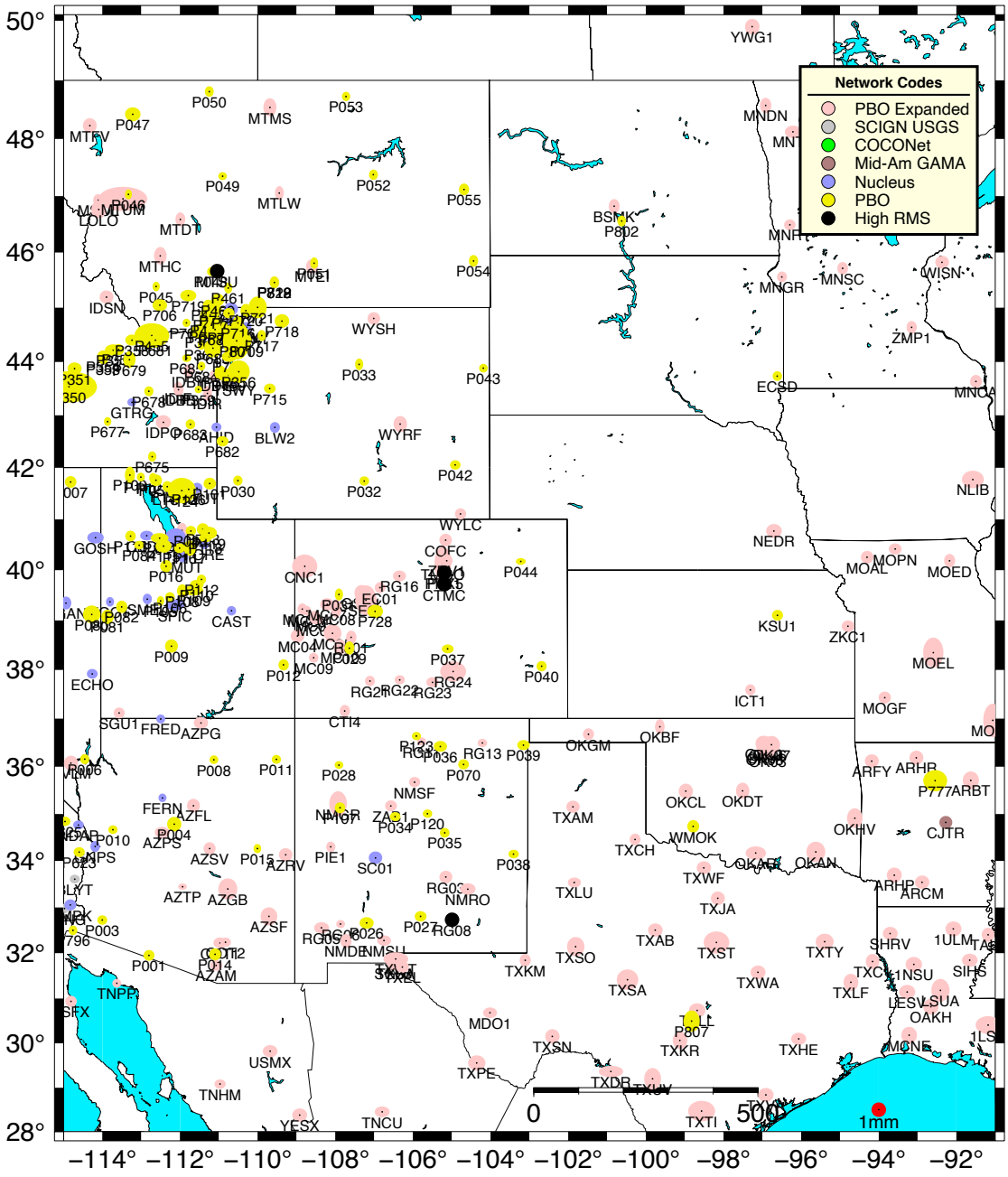

Figure 5: Same as Figure 4 except for the Central United States

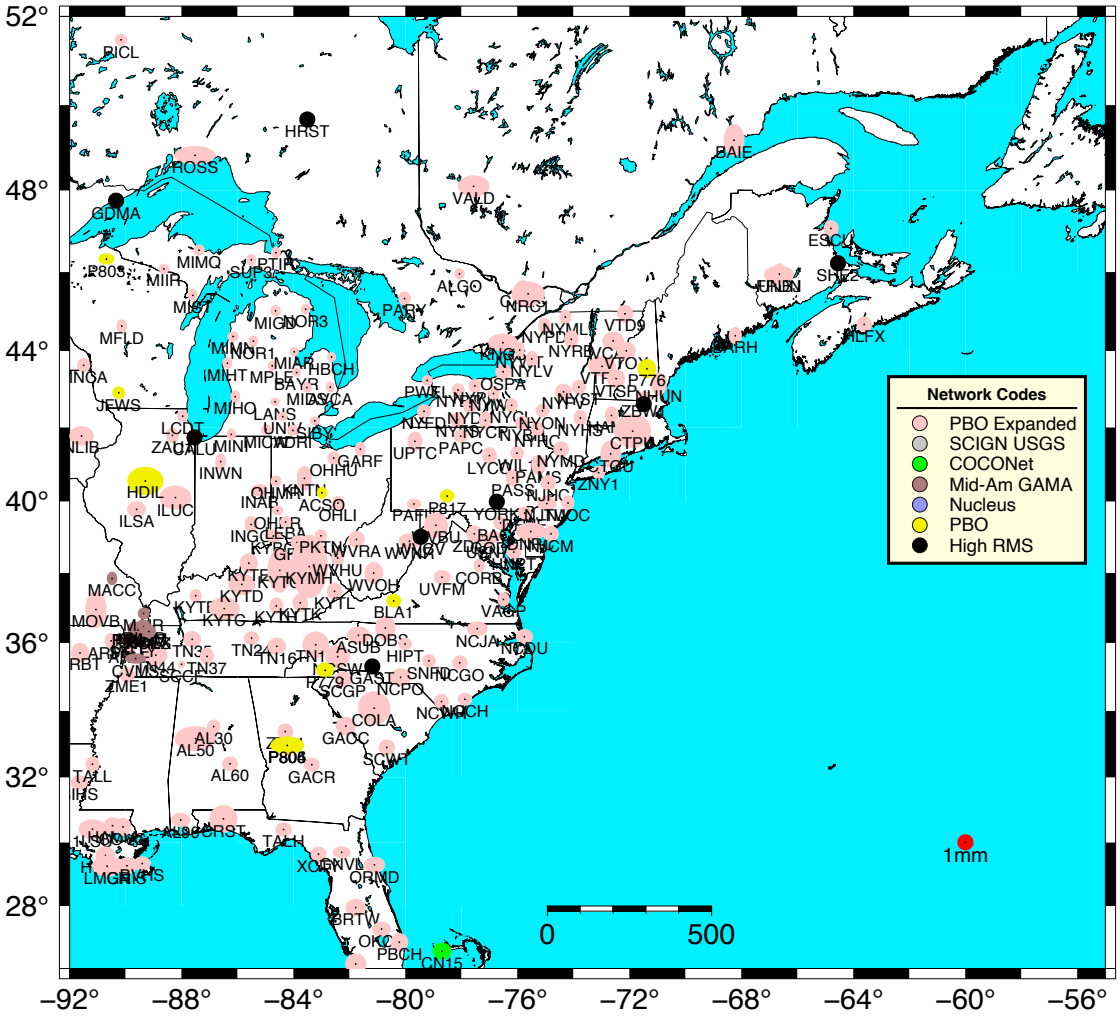

Figure 6: Same as Figure 4 except for the Eastern United States

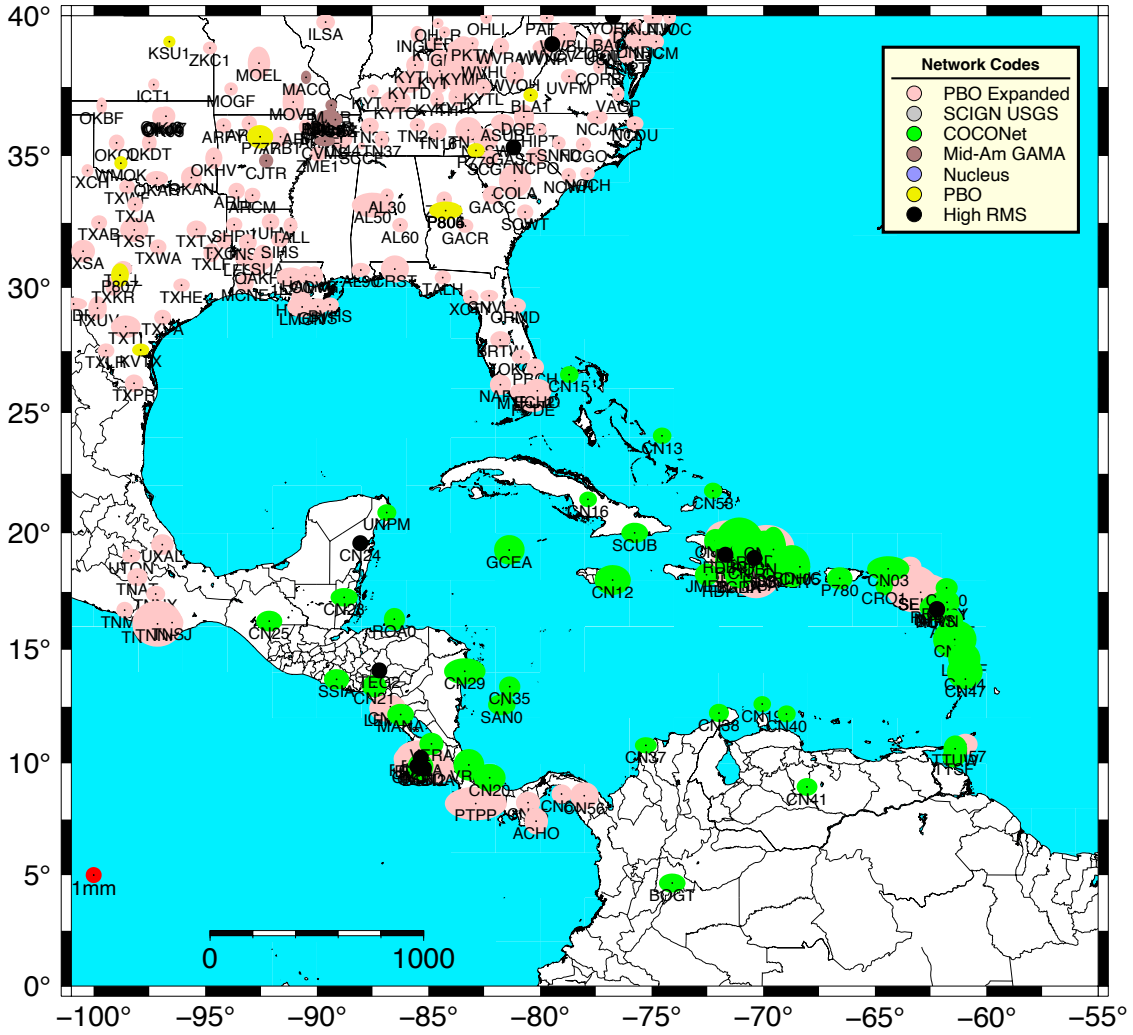

Figure 7: Same as Figure 4 except for the Caribbean region.

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 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_230617.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_230617.snpvel.

Table 3: Statistics of the fits of 2719 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and June 17, 2023.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.41	1.37	6.23
70%			
CWU	1.77	1.74	7.07
95%			
CWU	3.91	3.65	11.70

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.

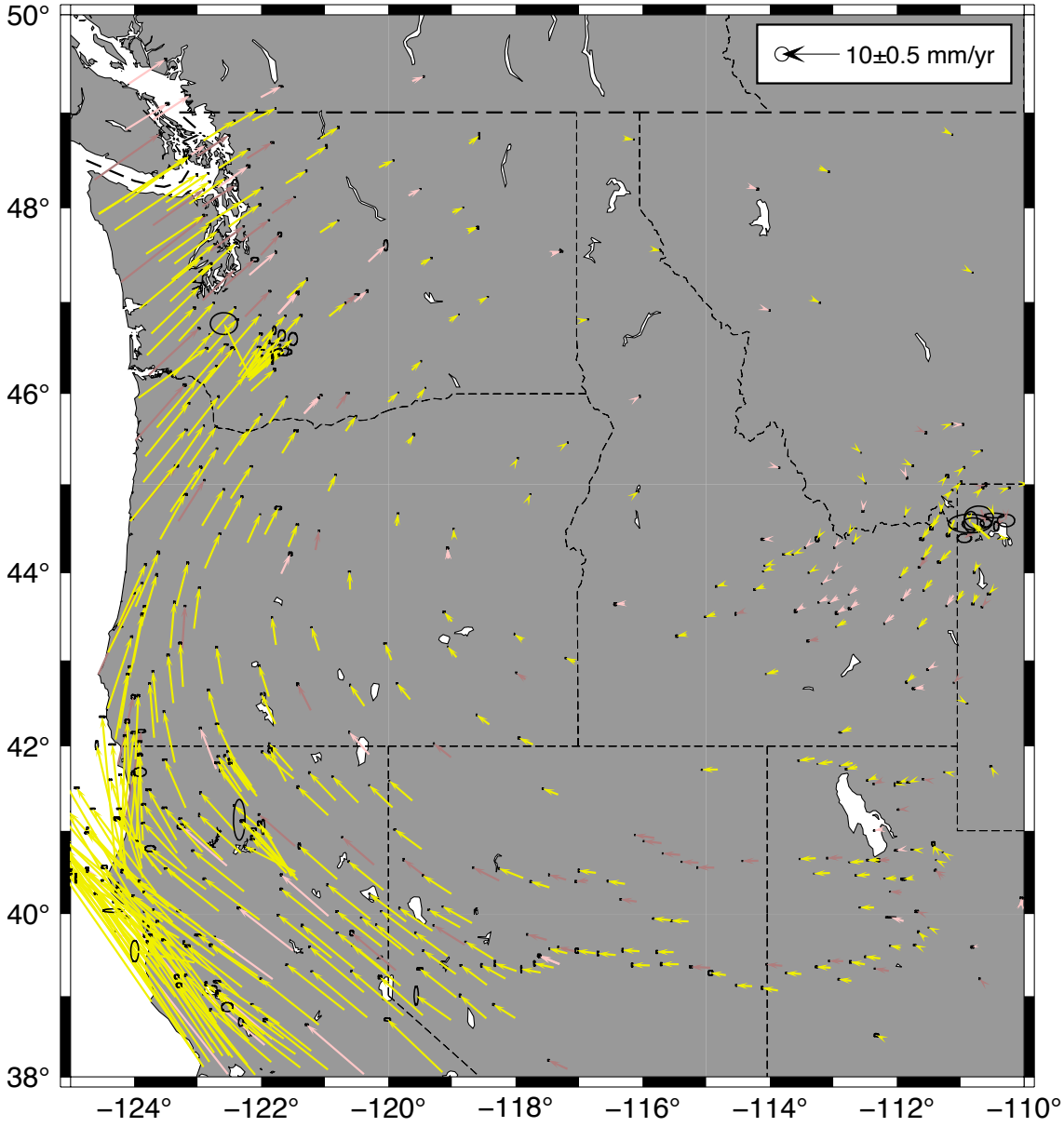

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

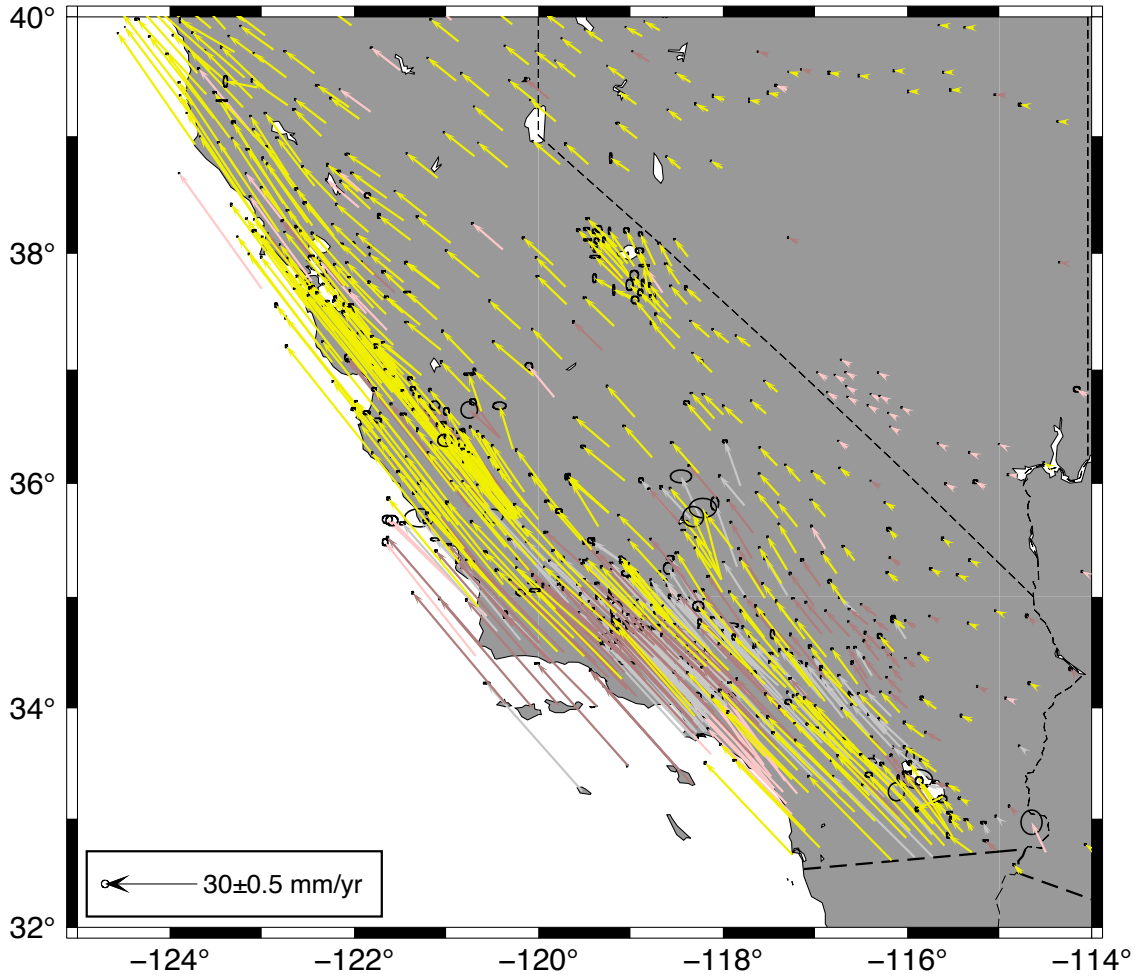

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

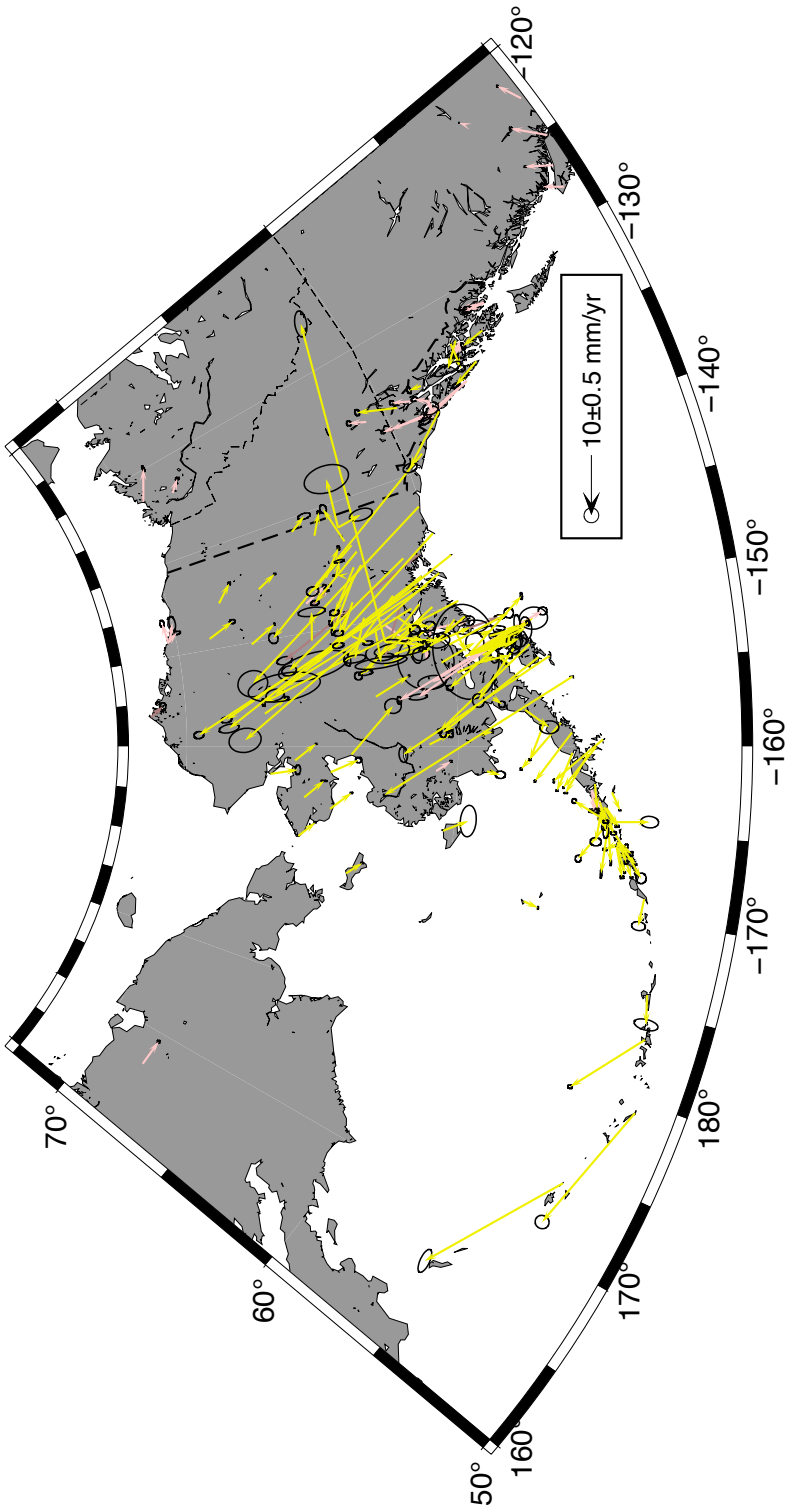

Figure 10: Same as Figure 8 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

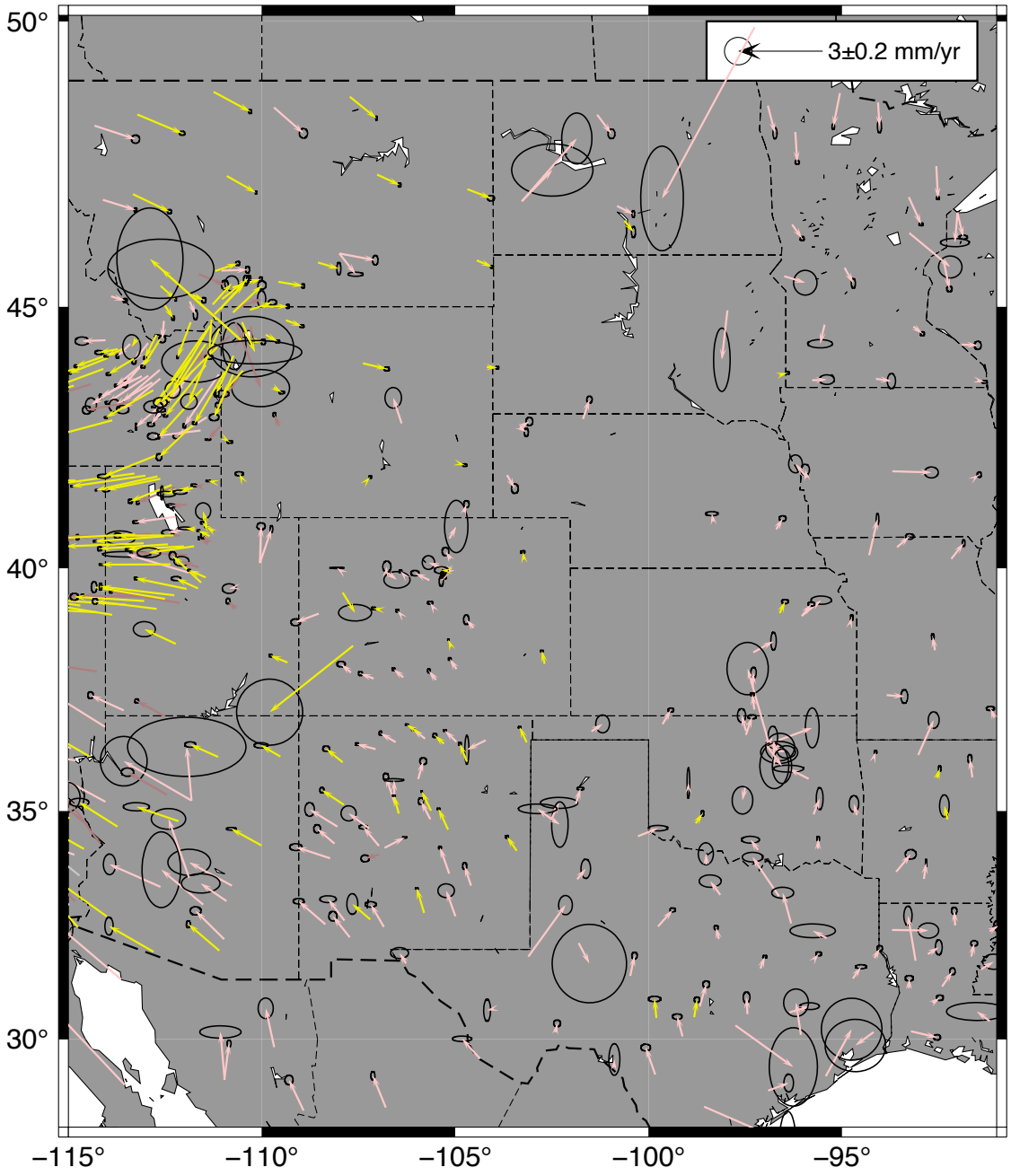

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

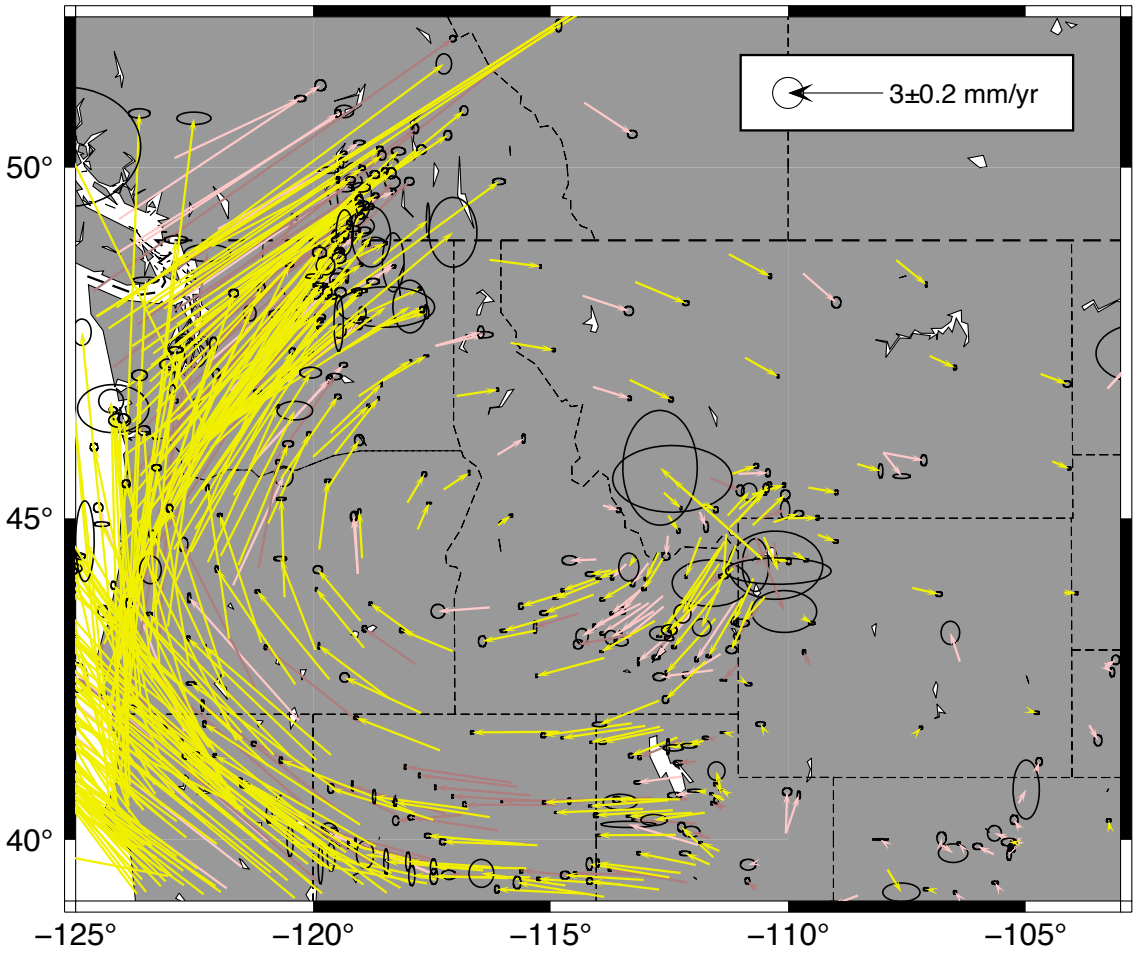

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

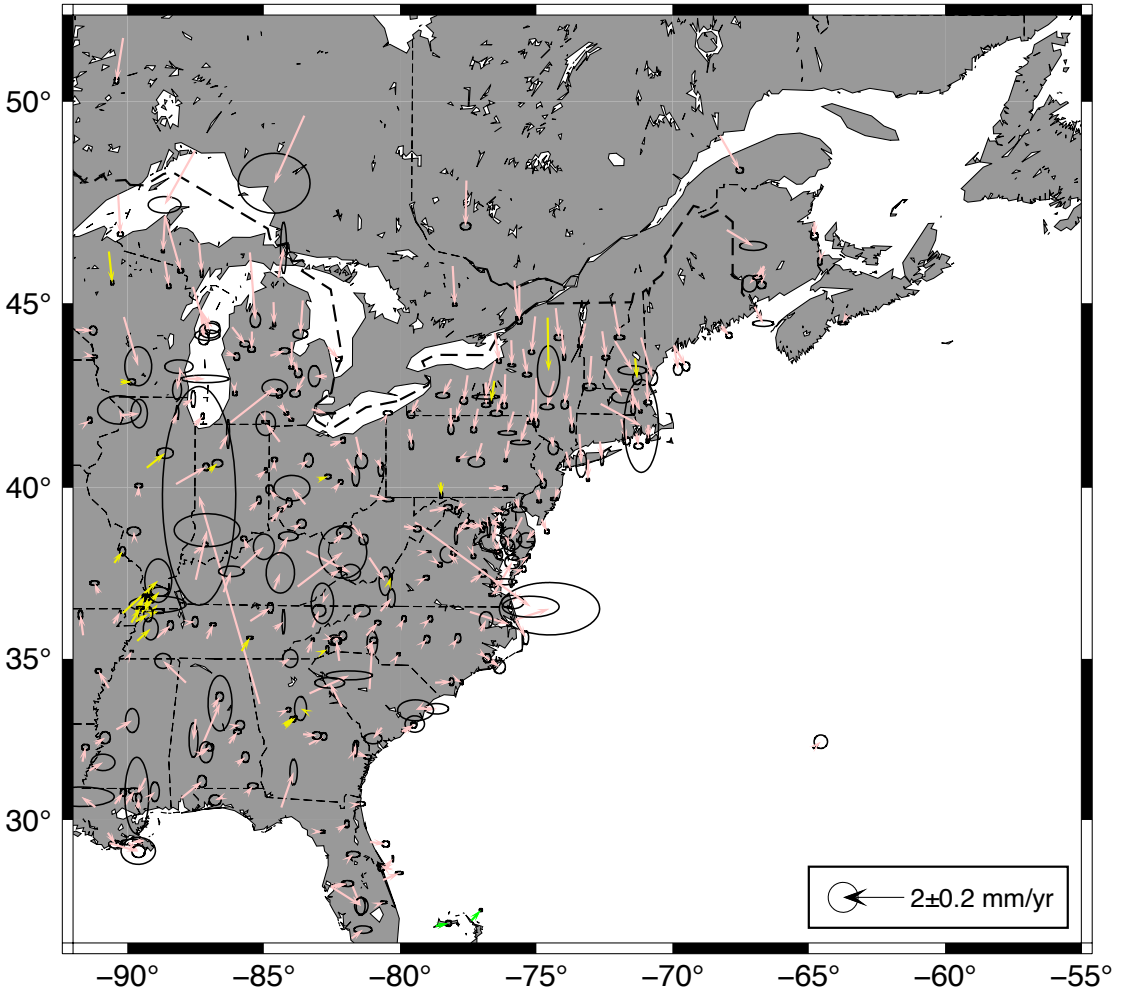

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

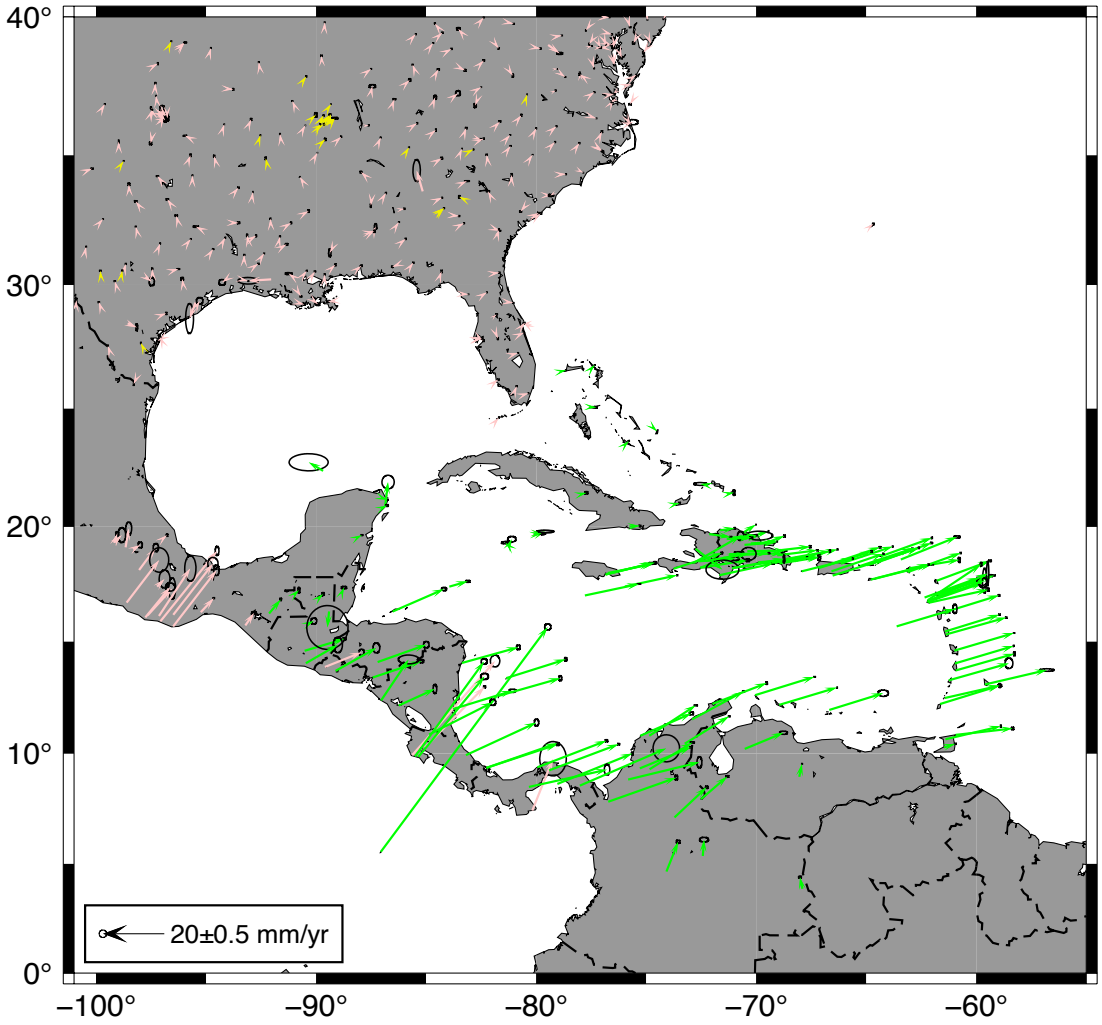

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2023/03/15-2023/06/15

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 29 earthquakes examined during this quarter, only 1 generated co-seismic offsets greater than 1 mm. This event, a mw4.3 8km WSW of Niland (2.04 km depth) lat/long 33.2008° -115.5900° date 2023/04/30 07:10. Because of the three shallow events, we increased the radius of influence from 10.7 to 15 km, and reduced the depth from 8 to 2 km. This event has been designated EQ 70. Co-seismic offsets have been sent to UNAVCO via LDM.

Antenna and other discontinuity events.

Antenna swaps at 27 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
P655		East offset in rapids. Height change as well. New antenna? http://geoweb.mit.edu/~tah/ACC_PBO/P655.CWUOFF.png
TNIF	N	Change in position after gap. Could be slow slip (Mexico site https://www.unavco.org/instrumentation/networks/status/nota/overview/tnif http://geoweb.mit.edu/~tah/ACC_PBO/TNIF.CWUOFF.png
VRNT		Jump in height plus a 2015 unknown jump. PANGA site. http://geoweb.mit.edu/~tah/ACC_PBO/VRNT.CWUOFF.png
		2023-05-05
SHE2		North offsets in rapids but seen before. Height has no outliers? Site near Nova Scotia Canada. http://geodesy.unr.edu/NGLStationPages/stations/SHE2.sta http://geoweb.mit.edu/~tah/ACC_PBO/SHE2.CWUOFF.png
		2023-05-12
CTMC		Looks like antenna/receiver failure. Site near Golden CO. CORS site. New antenna may be bad. http://geoweb.mit.edu/~tah/ACC_PBO/CTMC.CWUOFF.png

P219	N	Large East seasonal. ±10 mm range, Near Menlo Park. http://geoweb.mit.edu/~tah/ACC_PBO/P219.CWUOFF.png
		2023-05-19
CNG2	U	Site in Nicaragua. Long gap. Earthquake 2016/09/15 Mw 5.7 9.2 km away offsets the site and may have post-seismic motion (needs 1000-day time log time) http://geoweb.mit.edu/~tah/ACC_PBO/CNG2.CWURAW.png
		2023-05-26
P503	N	Break in rapids on 2023/05/16. No meta data change in UNAVCO log. Antenna change on 2023/04/13 although data starts after gap a few days before this. http://geoweb.mit.edu/~tah/ACC_PBO/P503.CWUOFF.png
		2023-06-13
LOMP	U	Restarted after gap since mid-2022. New antenna and height offset (not yet updated in processing). Earlier strange east jumps in 2017 and 2018. Site near Vandenberg, CA. Added to UNKN list. http://geoweb.mit.edu/~tah/ACC_PBO/LOMP.CWUOFF.png
P317	N	Heights have started to drop but seems to have recovered. Site north of town of Mendocino. (UNR has problems with this and nearby stations). http://geoweb.mit.edu/~tah/ACC_PBO/P315.CWUOFF.png
PALG	U	New antenna with no meta update in processing most likely. Between San Diego and LA (inland). http://geoweb.mit.edu/~tah/ACC_PBO/PALG.CWUOFF.png
SAJU		Costa Rica; large postseismic but also small slow slip events? http://geoweb.mit.edu/~tah/ACC_PBO/SAJU.CWUOFF.png
WVCV		CORS site in West Virginia. New antenna installed recently seems to be broken. http://geoweb.mit.edu/~tah/ACC_PBO/WVCV.CWUOFF.png
YUHG	U	New antenna but not in meta data. Site on Mexican border near Mexicali. http://geoweb.mit.edu/~tah/ACC_PBO/YUHG.CWUOFF.png
		2023-06-16
ALTH		California site near Fresno. Lots of systematics and unknown break in height (80 mm) in April 2016. SOPAC log file. http://geoweb.mit.edu/~tah/ACC_PBO/ALTH.CWUOFF.png
IND1	U	Jump in East after 1 month gap In data. No new entries in UNAVCO log file. http://geoweb.mit.edu/~tah/ACC_PBO/IND1.CWUOFF.png
P124	N	Systematic in North with recent run off in last month. Site near Salt Lake city (great Salt lake filling with water?). http://geoweb.mit.edu/~tah/ACC_PBO/P124.CWUOFF.png
		2023-06-23 Not in Monthly
COLA		Could be vegetation growth since 2020 or a bad antenna. CORS site in South Carolina. http://geoweb.mit.edu/~tah/ACC_PBO/COLA.CWUOFF.png
DTPG	U	Site in Mojave Desert. Strange Ridgecrest post-seismic. http://geoweb.mit.edu/~tah/ACC_PBO/DTPG.CWUOFF.png
GDMA		Sites seems to failing since late 2021. CORS site in Minnesota on Lake

		Superior. Worst data is being deleted from plots. http://geoweb.mit.edu/~tah/ACC_PBO/GDMA.CWUOFF.png
TNNP	N	Site maybe failing. Outliers in rapids and some finals. Site in Oaxaca, Mexico so slow slip events as well. http://geoweb.mit.edu/~tah/ACC_PBO/TNNP.CWUOFF.png
		2023-06-30
CALU		CORS site in Chicago IL. Sites seems to break starting April 2023. http://geoweb.mit.edu/~tah/ACC_PBO/CALU.CWUOFF.png
CN18	N	Restart after long gap. Site in Honduras, Probable large postseismic. http://geoweb.mit.edu/~tah/ACC_PBO/CN18.CWUOFF.png
P412	N	Site in Oregon with slow slop events. Recent oscillations in all three components. Similar but smaller event happened last year as well. Based on pictures it could be a Bush growing next to the antenna. https://www.unavco.org/instrumentation/networks/status/nota/photos/p412#gallery-5 http://geoweb.mit.edu/~tah/ACC_PBO/P412.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 48 stations in the ANET region for CWU analyzed in the final orbit analysis between March 15, 2023 and June 17, 2023.

CWU	North (mm)	East (mm)	Up (mm)
Median ANET	1.29	1.27	6.19
70% ANET	1.52	1.36	7.11
95% ANET	2.40	2.00	10.07

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

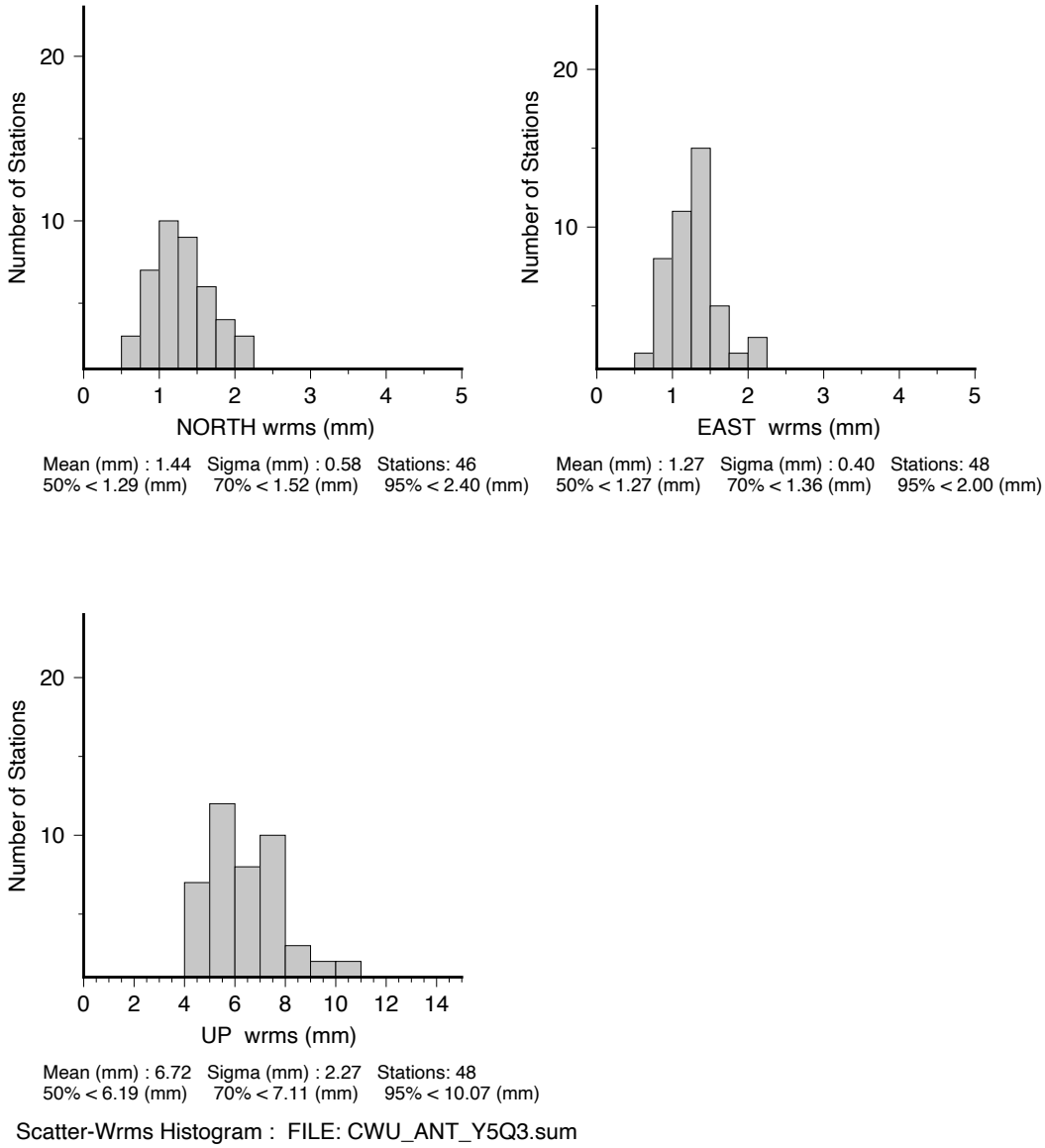

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 50 stations in Antarctica analyzed between March 15, 2023 and June 17, 2023. Linear trends and annual signals were estimated from the time series.

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