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

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Period: 2024/01/01-2024/03/31

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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 2024/01/01 to 2024/03/31, as well as time series velocity field analyses for the GAGE reprocessing analyses (1996-2024). Several earthquakes were investigated this quarter up to 2024/03/15, and none of them generated any detectable co-seismic offsets.

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, 1947 stations were processed. In addition, up to 47 sites were processed in the ANET solutions, 8 more than last quarter. The number of stations processed fluctuated 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.
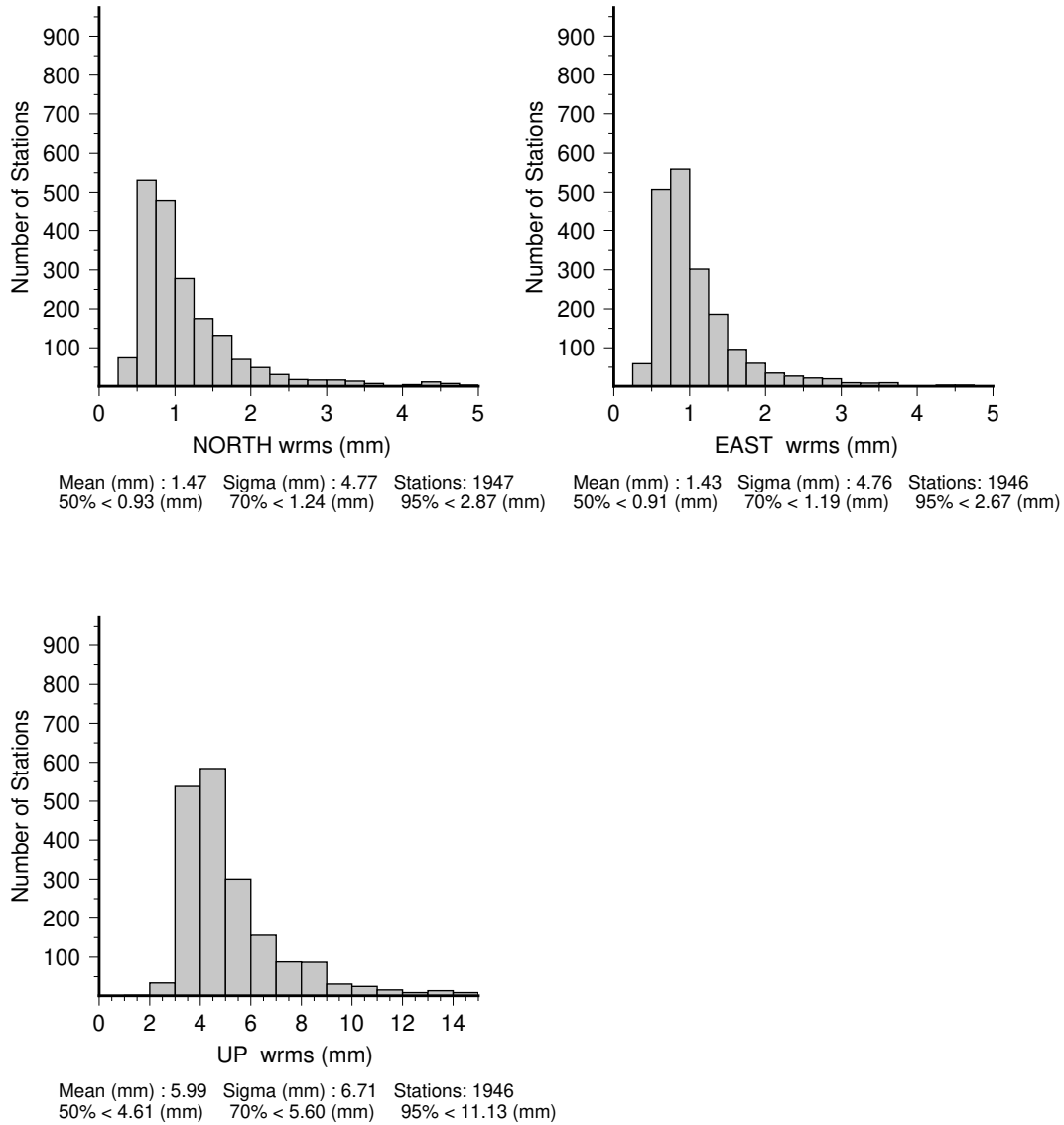
Analysis of Final products: December 15, 2023– March 23, 2024

For this report, we generated the statistics using the ~3 months of CWU results between December 15, 2023, and March 23, 2024. 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 1947 stations for CWU analyzed in the finals analysis between December 15, 2023, and March 23, 2024. Figure 1 shows histograms of the RMS scatters.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.93	0.91	4.61
70%			
CWU	1.24	1.19	5.60
95%			
CWU	2.87	2.67	11.13

Mean (mm) : 1.47   Sigma (mm) : 4.77   Stations: 1947
50% < 0.93 (mm)   70% < 1.24 (mm)   95% < 2.87 (mm)

Mean (mm) : 1.43   Sigma (mm) : 4.76   Stations: 1946
50% < 0.91 (mm)   70% < 1.19 (mm)   95% < 2.67 (mm)

Mean (mm) : 5.99   Sigma (mm) : 6.71   Stations: 1946
50% < 4.61 (mm)   70% < 5.60 (mm)   95% < 11.13 (mm)

Scatter-Wrms Histogram : FILE: CWU_FIN_Y6Q2.sum

Figure 1: CWU solution histograms of the North, East, and Up RMS scatters of the position residuals for 1947 stations analyzed between December 15, 2023 and March 23, 2024. 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_Y6Q2.tab. There are 1974 stations in the file for sites with at least two measurements during the month.

Table 1: Head and tail of WRMS scatter summary file CWU_FIN_Y6Q1.tab.
```
Tabular Position RMS scatters created from CWU_FIN_Y6Q2.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     46     1.2    0.67     1.2    0.61     6.8    0.76      20.92
 1NSU     47     0.9    0.56     1.1    0.63     4.6    0.62      20.17
 1ULM     47     0.7    0.39     0.8    0.47     4.1    0.56      20.77
 7ODM     47     1.2    0.65     0.8    0.51     4.0    0.52      22.83
TAHMac[1542]  tail  CWU_FIN_Y6Q2.tab
 ZDV1     46     0.7    0.34     0.7    0.42     4.5    0.59      20.80
 ZKC1     46     1.0    0.52     0.9    0.56     4.5    0.58      20.80
 ZLA1     42     1.0    0.52     0.8    0.53     5.4    0.68      20.80
 ZLC1     46     0.8    0.39     0.7    0.45     4.6    0.60      21.03
 ZME1     46     1.1    0.59     0.9    0.52     5.6    0.75      21.03
 ZMP1     46     0.9    0.45     0.8    0.49     4.6    0.61      21.28
 ZNY1     46     0.9    0.45     1.1    0.68     4.2    0.55      21.19
 ZOA1     39     1.0    0.50     0.9    0.61     5.3    0.68      21.72
 ZSE1     46     0.8    0.38     0.9    0.57     4.7    0.62      21.19
 ZTL4     46     1.1    0.61     1.2    0.72     9.5    1.25      21.38
```

Table 2: RMS scatter of the position residuals for the CWU solution between December 15, 2023, and March 23, 2024, 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	0.83	0.87	4.27	810
NUCLEUS	0.79	0.75	4.08	184
GAMA	0.60	0.72	4.55	10
COCONet	1.39	1.46	6.89	68
USGS_SCIGN	0.91	0.81	3.94	114
Expanded	1.00	0.98	5.25	761
70%				
PBO	1.19	1.12	4.97	
NUCLEUS	0.96	0.89	4.52	
GAMA	0.62	0.77	4.66	

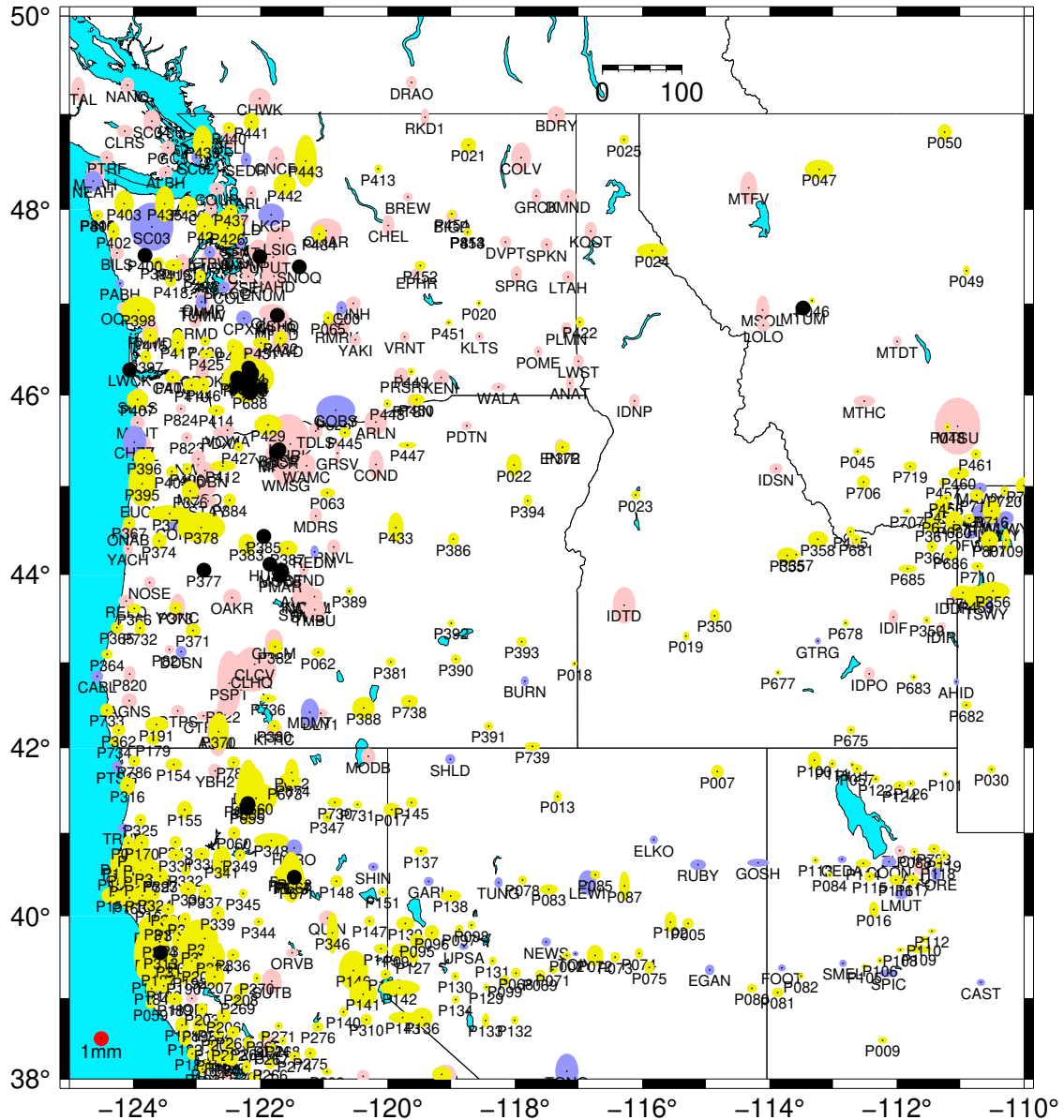|			
COCONet	1.65	1.87	8.40
USGS_SCIGN	1.08	0.98	4.54
Expanded	1.33	1.24	6.27
95%			
PBO	2.88	2.56	11.03
NUCLEUS	2.06	1.62	8.12
GAMA	0.73	0.89	5.48
COCONet	2.64	5.32	14.65
USGS_SCIGN	2.00	1.67	6.88

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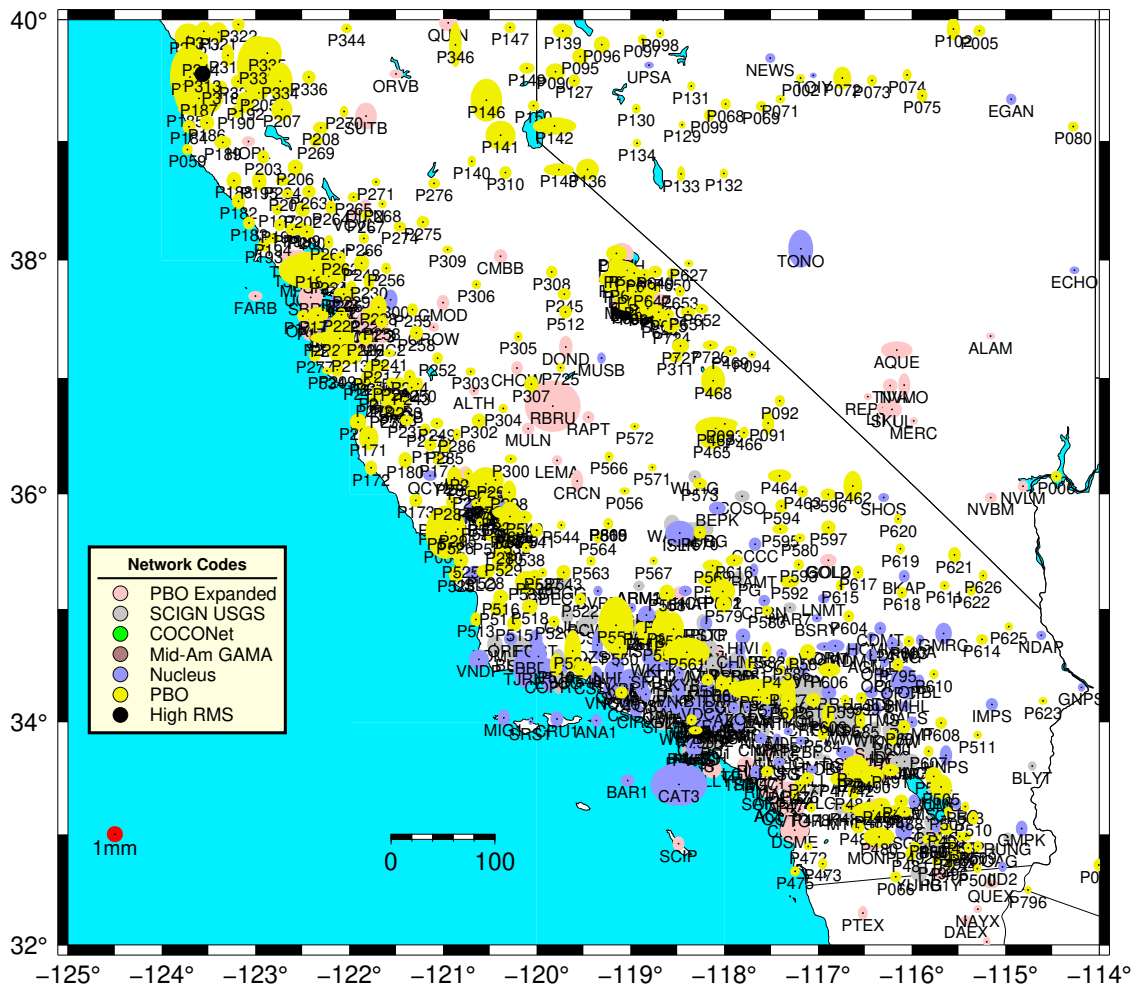
Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.
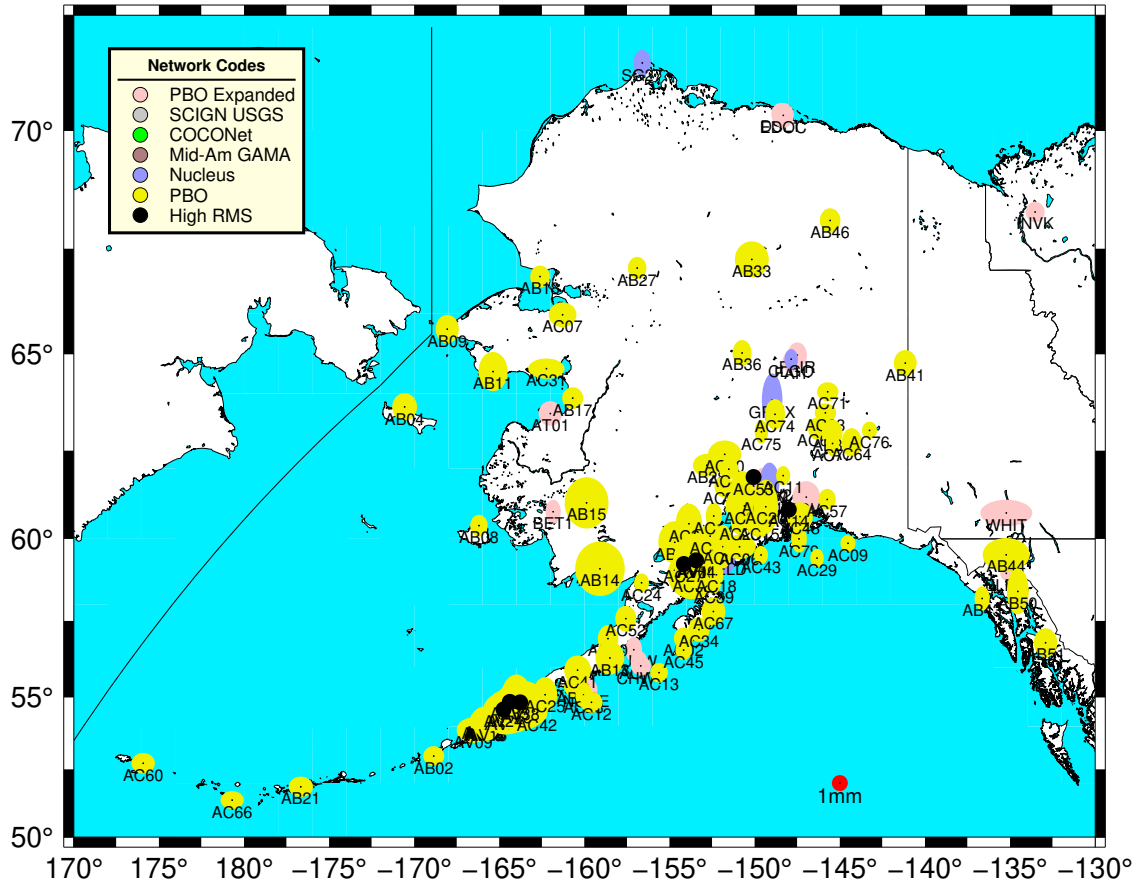
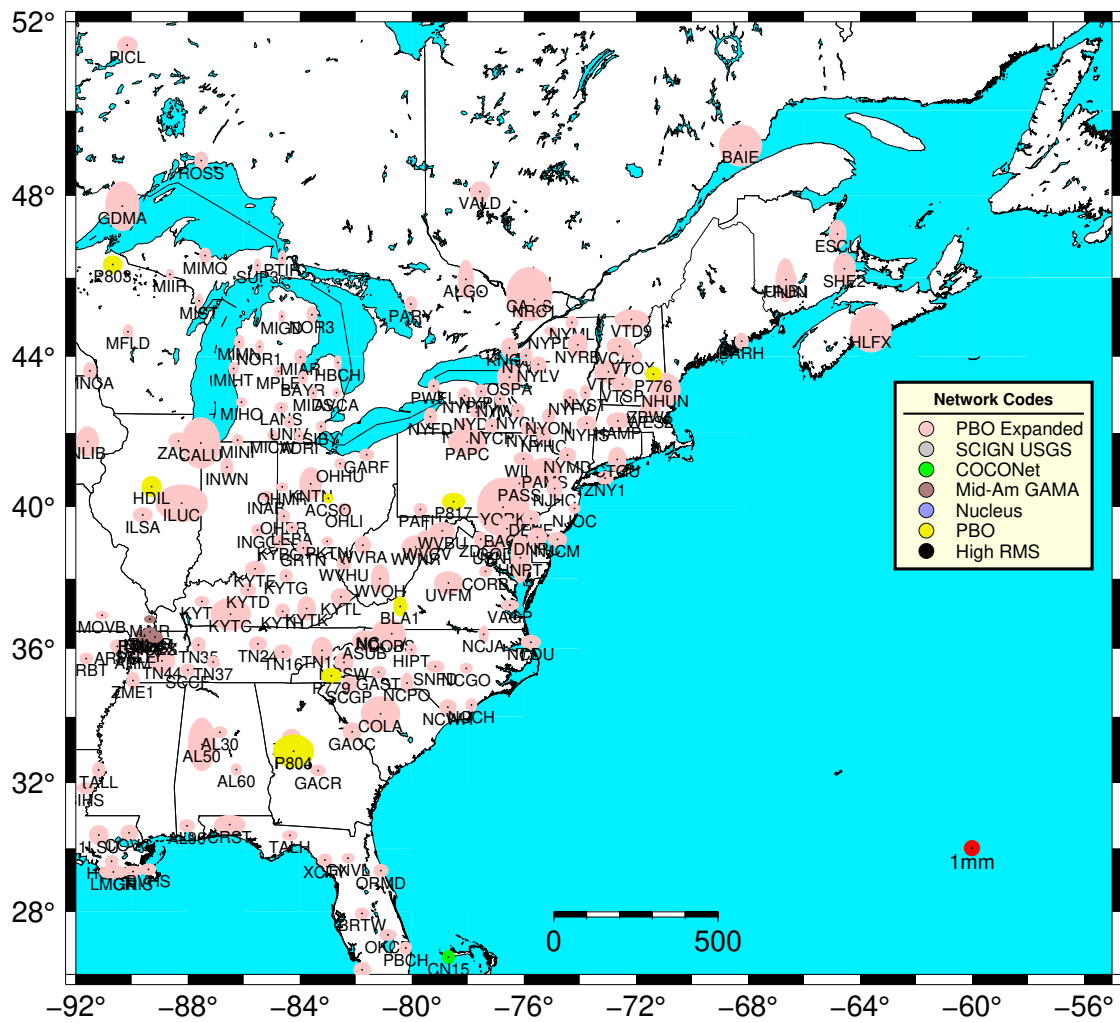**Figure 4**: Same as Figure 4 except for the Alaskan region.

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

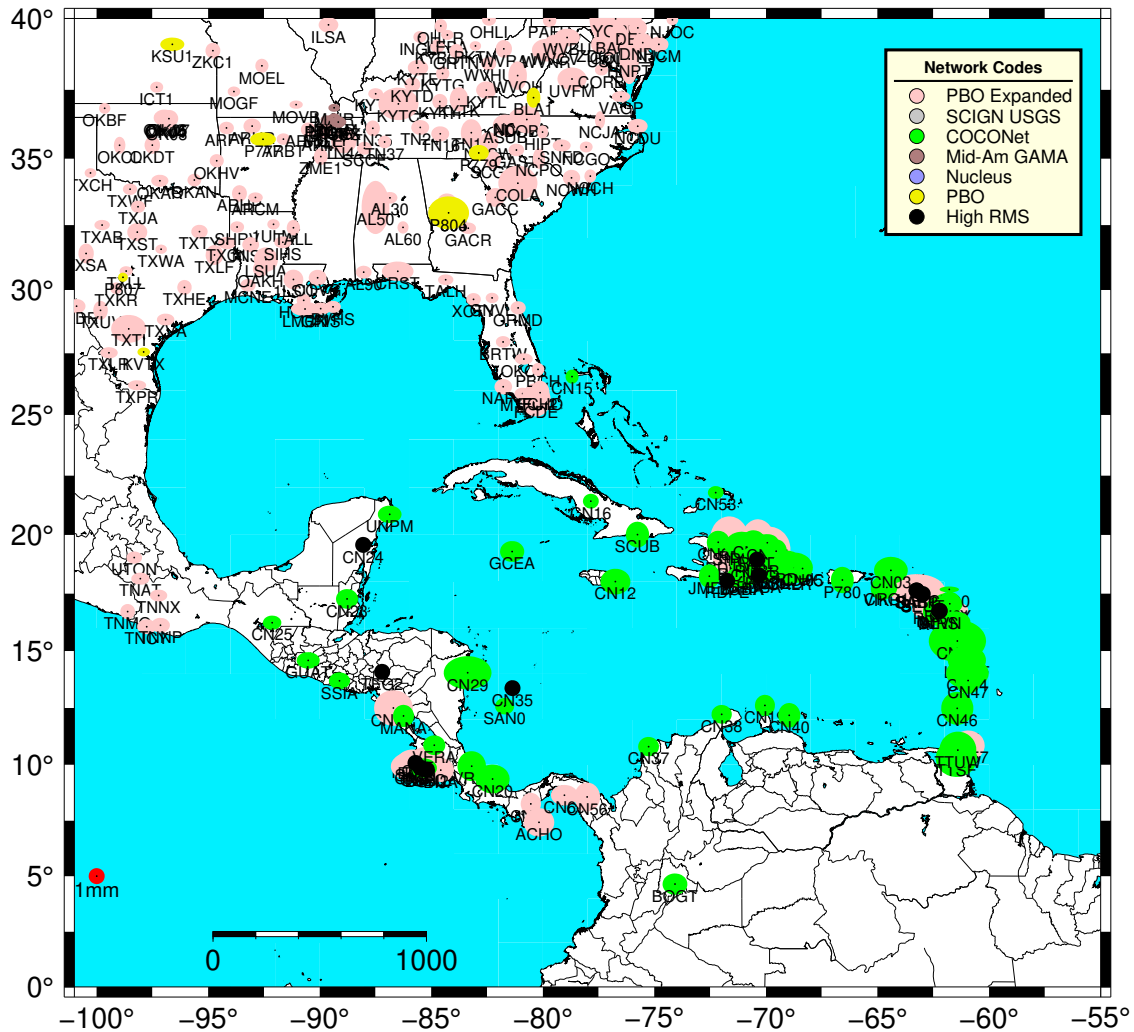**Figure 6:** Same as Figure 4 except for the Eastern United States

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 2728 stations in the CWU solution (same as 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_240323.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_240323.snpvel.

Table 3: Statistics of the fits of 2728 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and March 23, 2024.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.41	1.38	6.25
70%			
CWU	1.79	1.74	7.13
95%			
CWU	4.08	3.70	11.68

In Figures 8-14, different tolerances are used for maximum standard deviation in each figure 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.
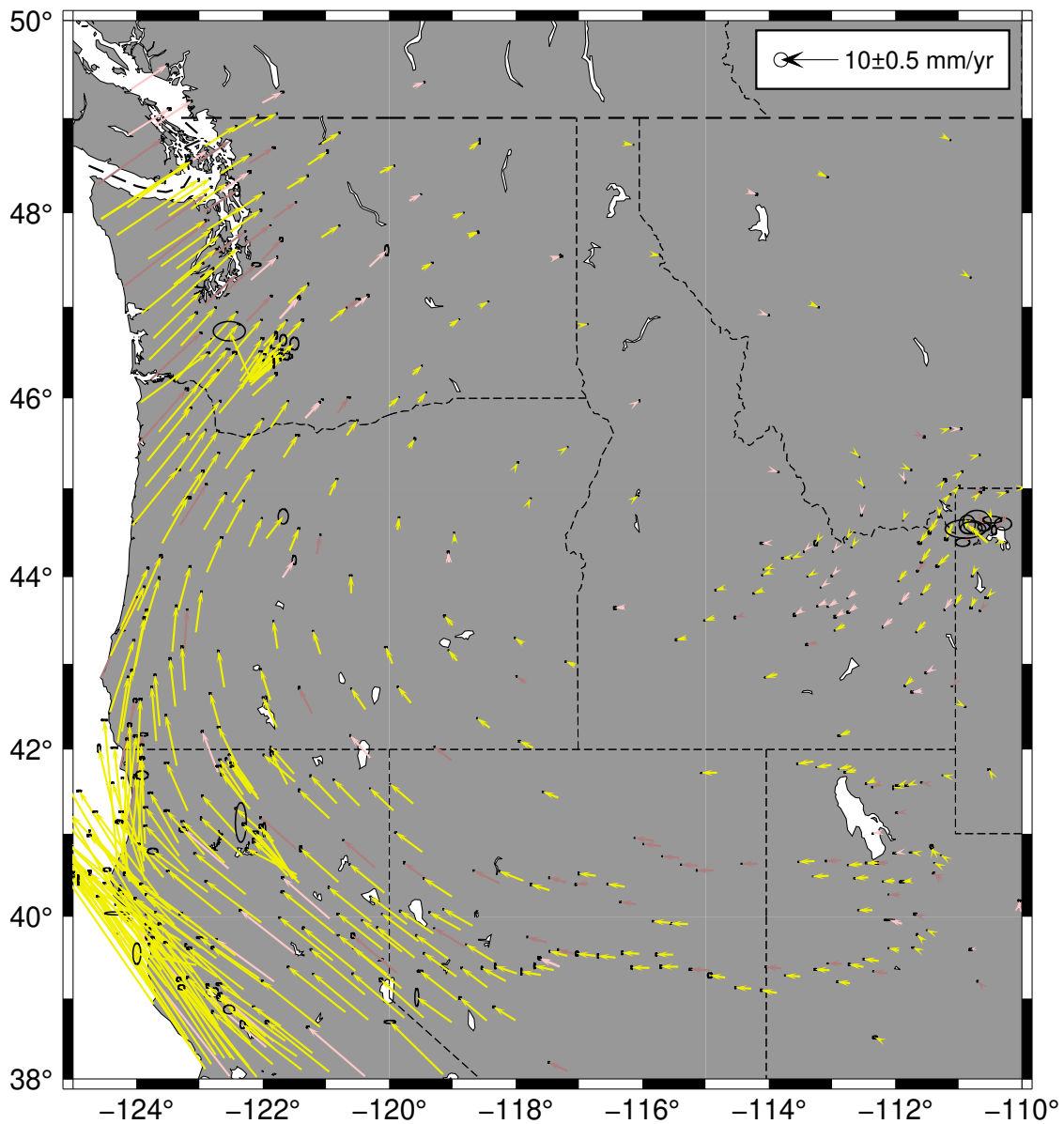
Figure 8: Velocity field estimates for the Pacific northwest from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal standard deviations less than 2 mm/yr are shown (this value is reduced from previous reports due to the improved velocity sigmas).
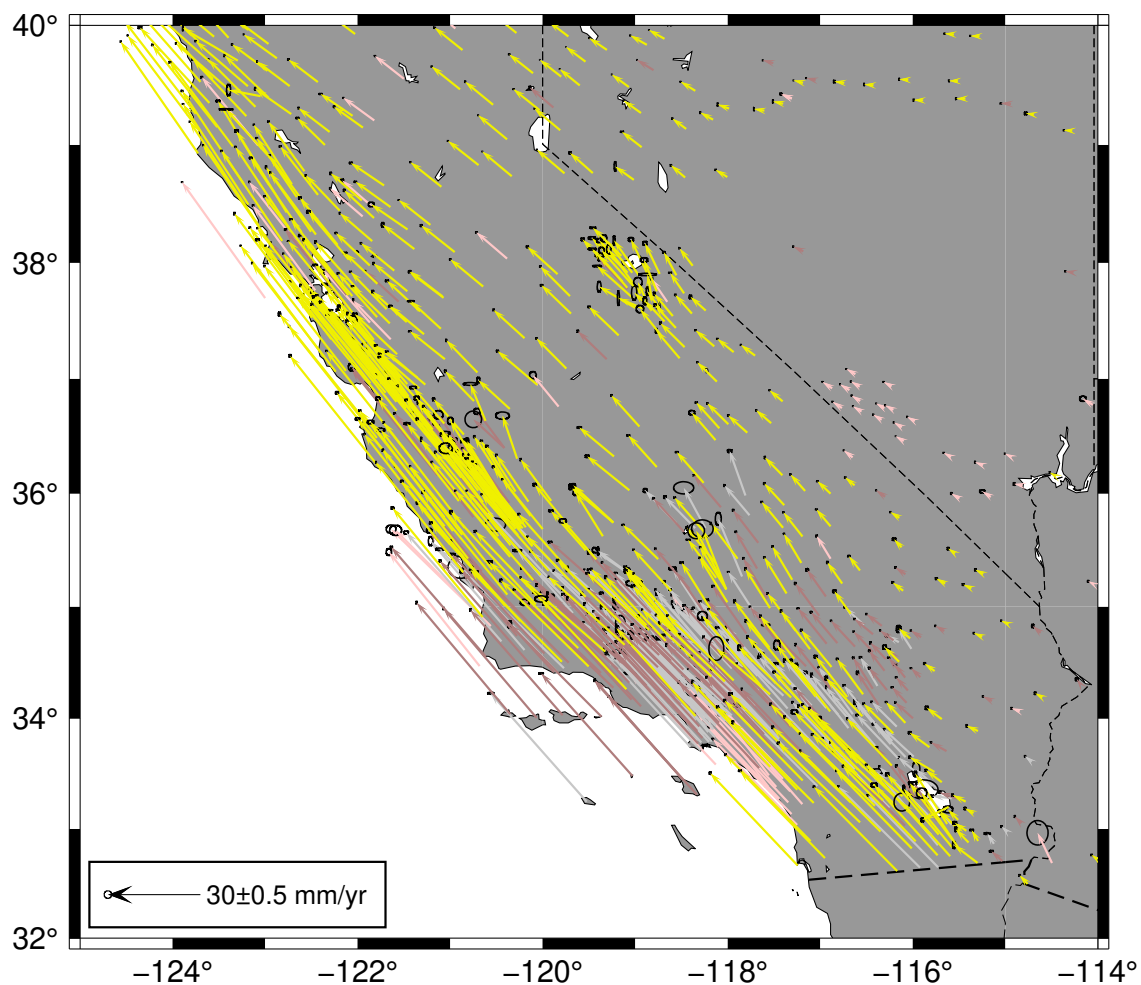
Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.
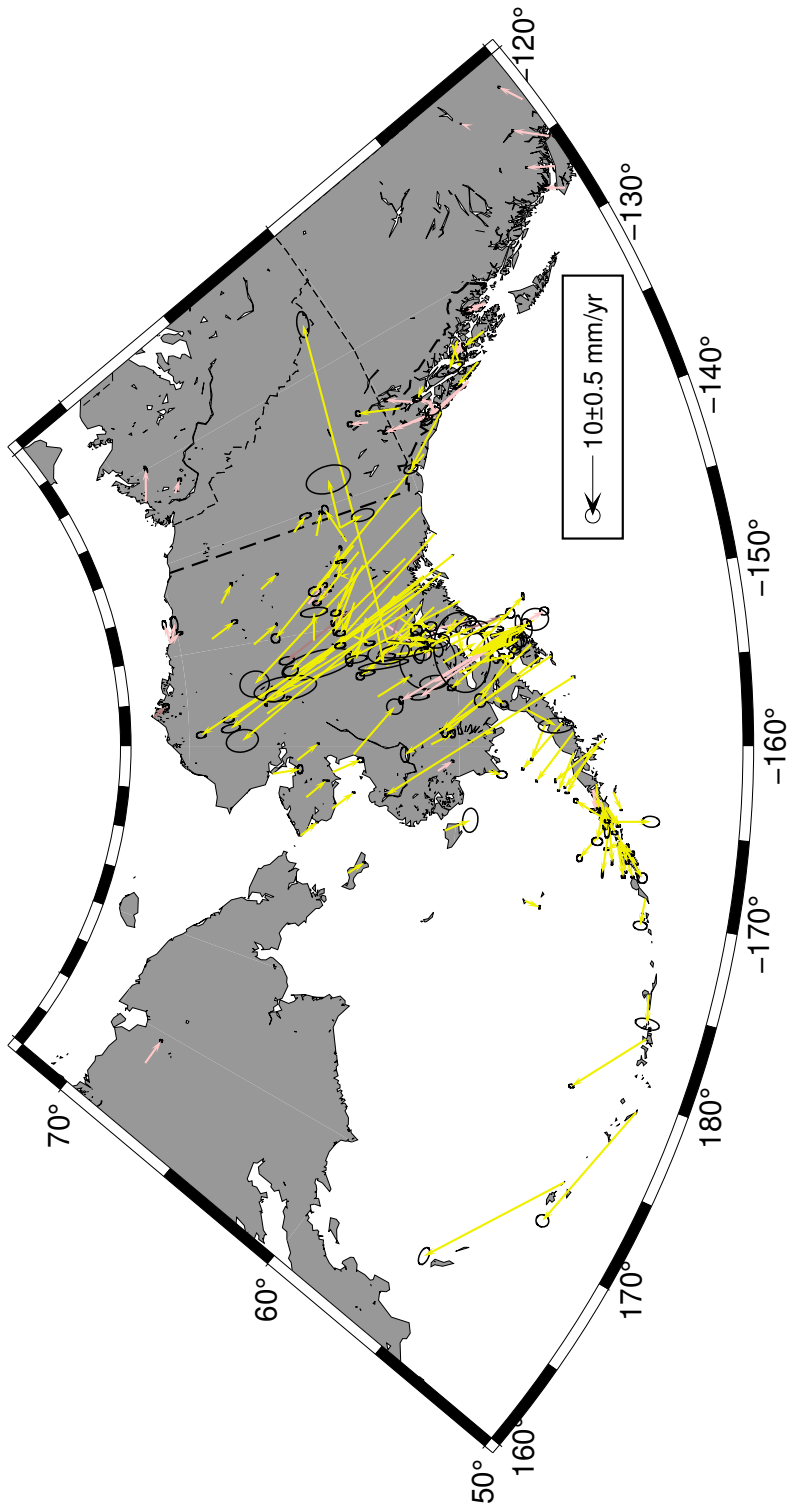
Figure 10: Same as Figure 8 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown
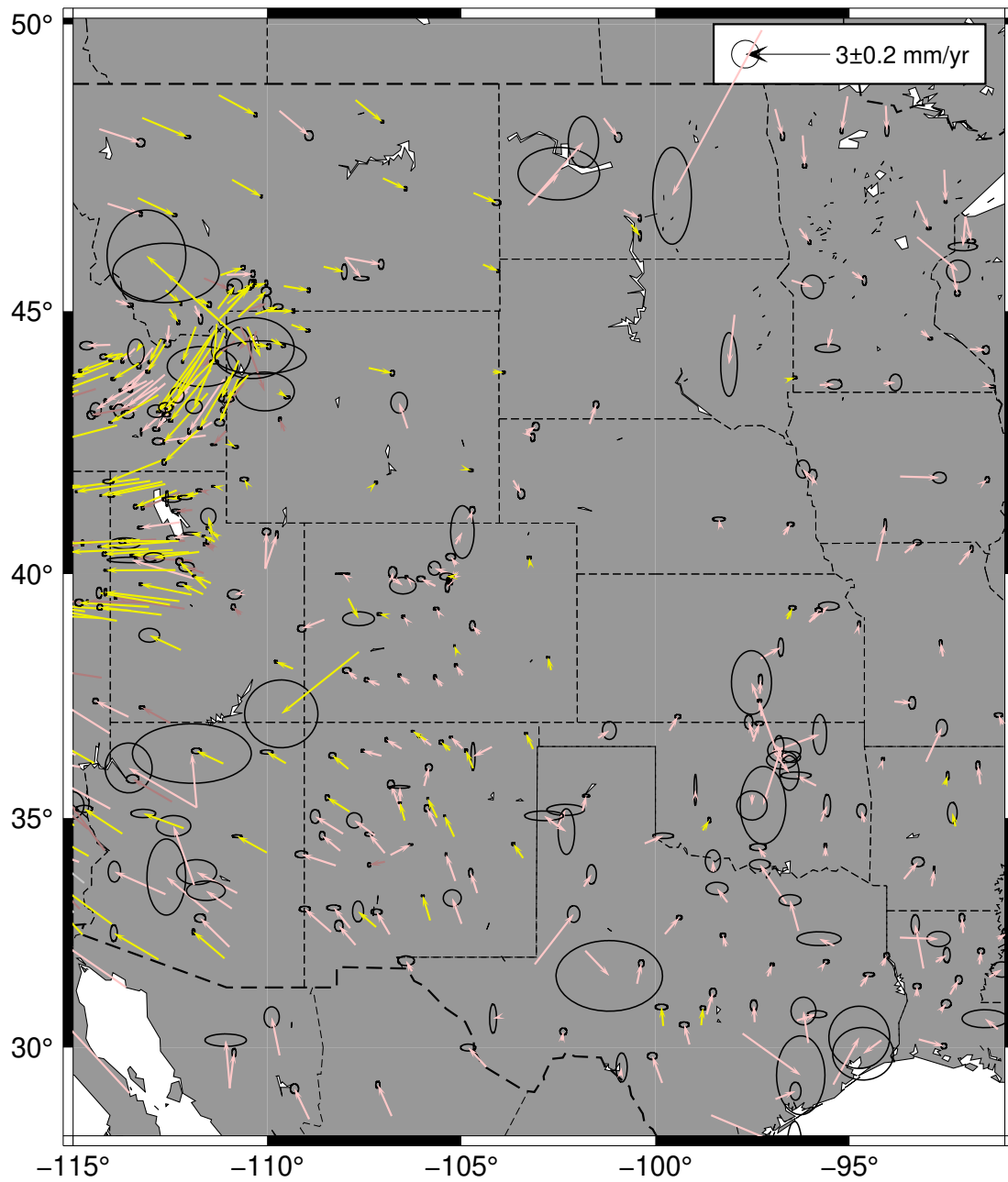
Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.
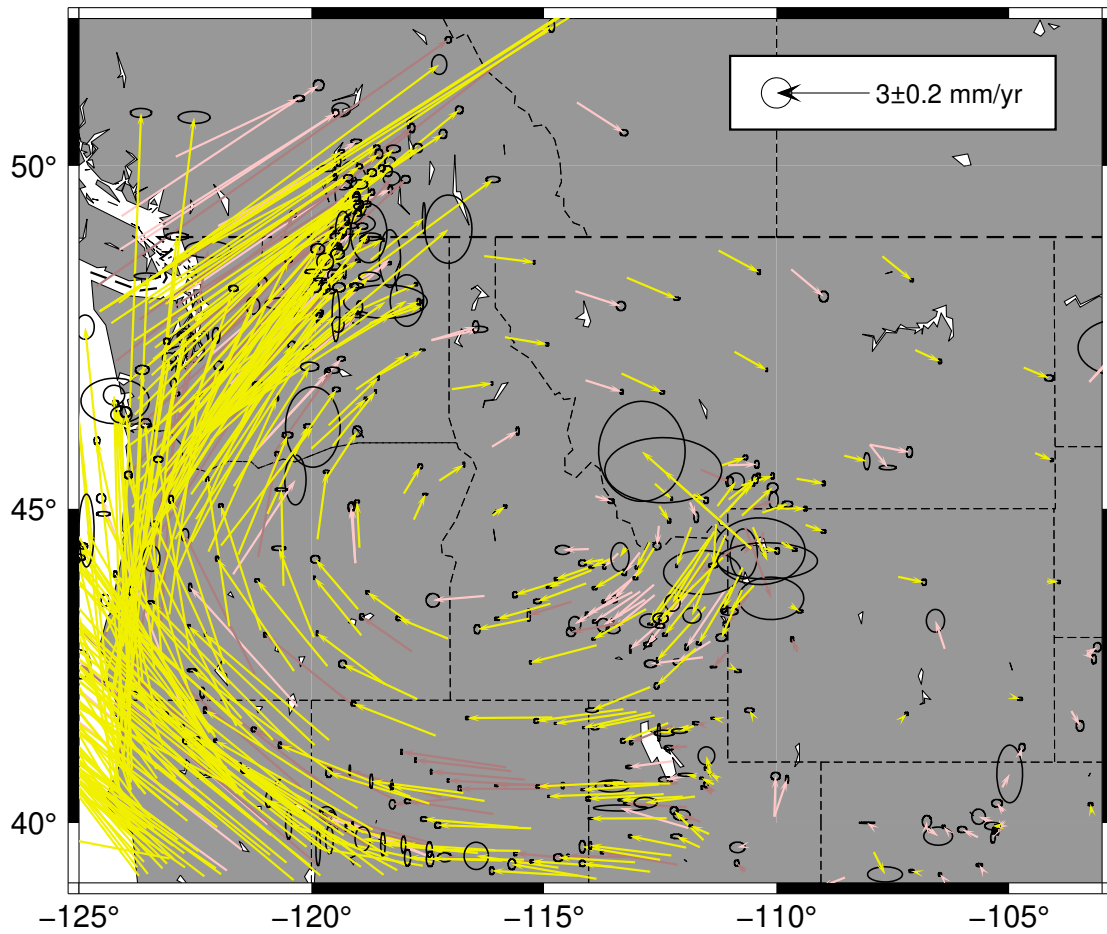
Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.
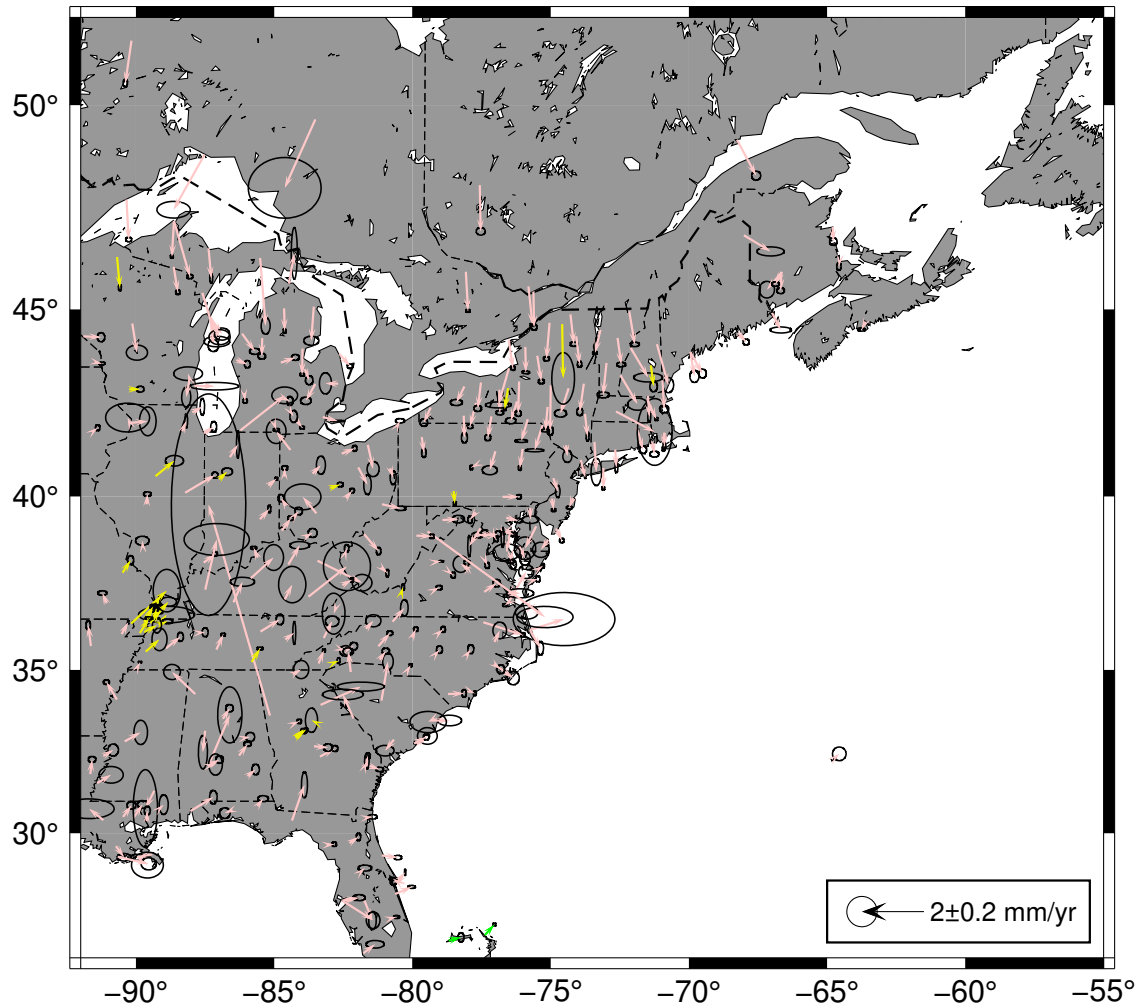
Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.
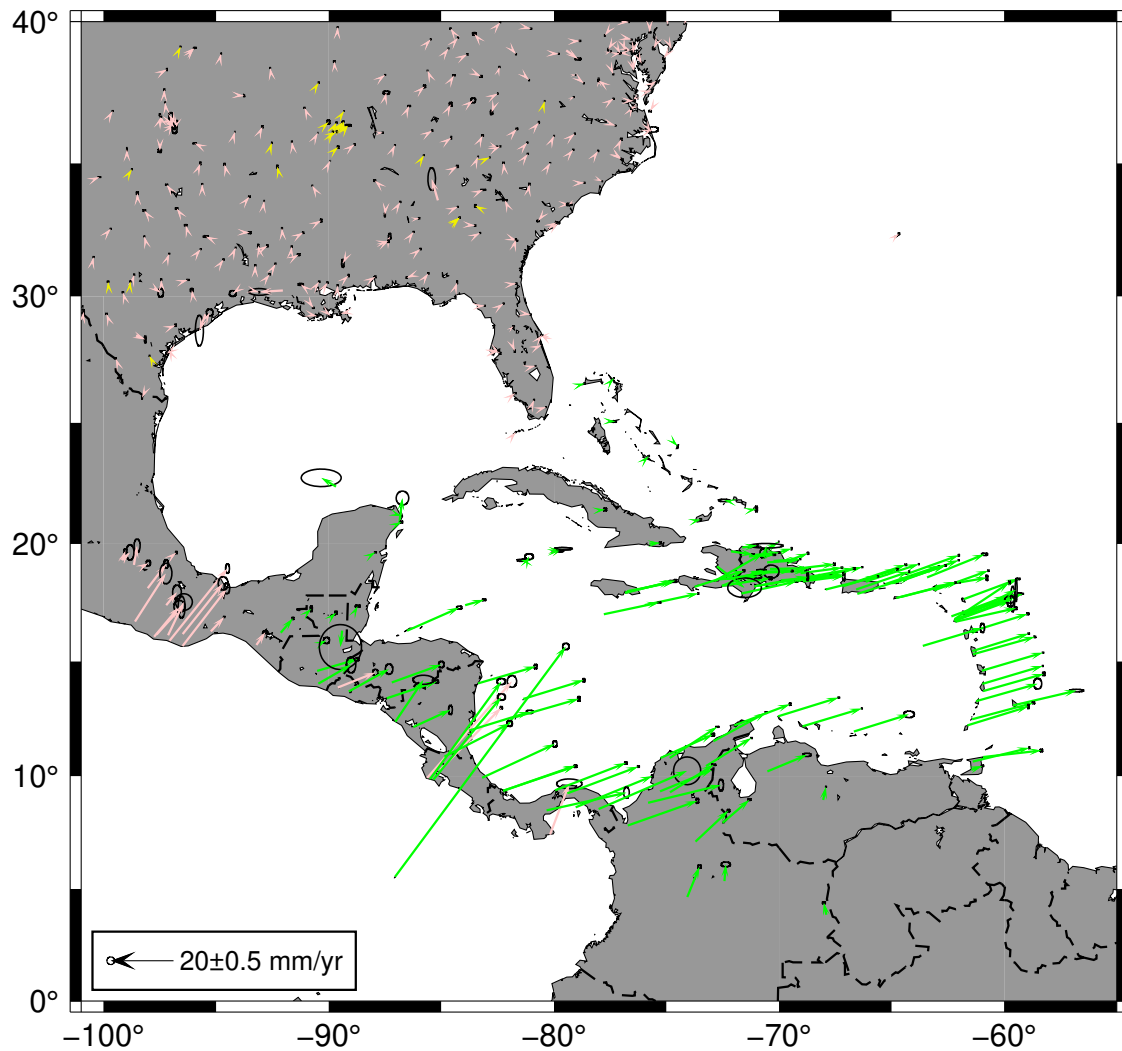
Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2023/12/15-2024/03/15

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 22 earthquakes examined during this quarter, none generated co-seismic offsets greater than 1 mm.

Antenna and other discontinuity events.

Antenna swaps at 28 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 website 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) removed. 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
		2024-02-23.
HAMM		CORS site in Louisiana, east jump in rapids ~20 mm. See if it persists. Persisting, firmware change on day of offset. TRM Alloy. http://geoweb.mit.edu/~tah/ACC_GAGE/HAMM.CWUOFF.png
PVHS	U	New antenna day 2024 47, Processing not updated yet. Check later to see if fixed. Fixed later. OK when finals get done. 5 mm North offset after metadata updated. http://geoweb.mit.edu/~tah/ACC_GAGE/PVHS.CWUOFF.png
SILK	U	Same antenna update, not in processing. Fixed with new antenna used but an east offset still likely. Small residual offset (~3 mm) http://geoweb.mit.edu/~tah/ACC_GAGE/SILK.CWUOFF.png
WLHG	U	Site north of Ridgecrest in CA. Lots of systematics with possible jump after gap in data. http://geoweb.mit.edu/~tah/ACC_GAGE/WLHG.CWUOFF.png
		2024-03-01
AB14	N	Snow but large post-seismics from EQ_ID 56 ANSS(ComCat) us7000asvb mww7.8 (2020/07/22) and EQ_ID 61 ANSS(ComCat) ak0219neiszm m22 8.2 (2021/97/29). This site 790 and 690 km from the epicenters.

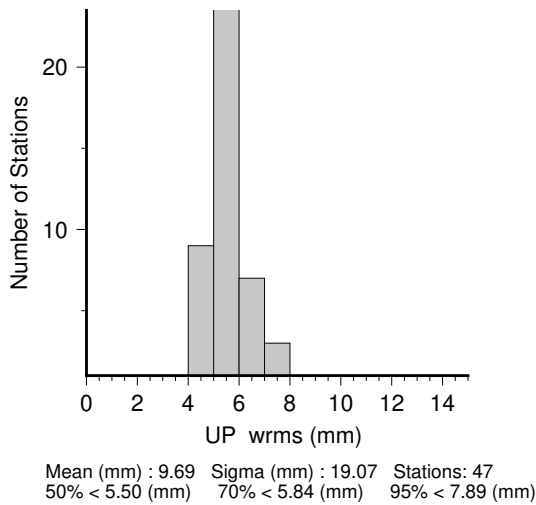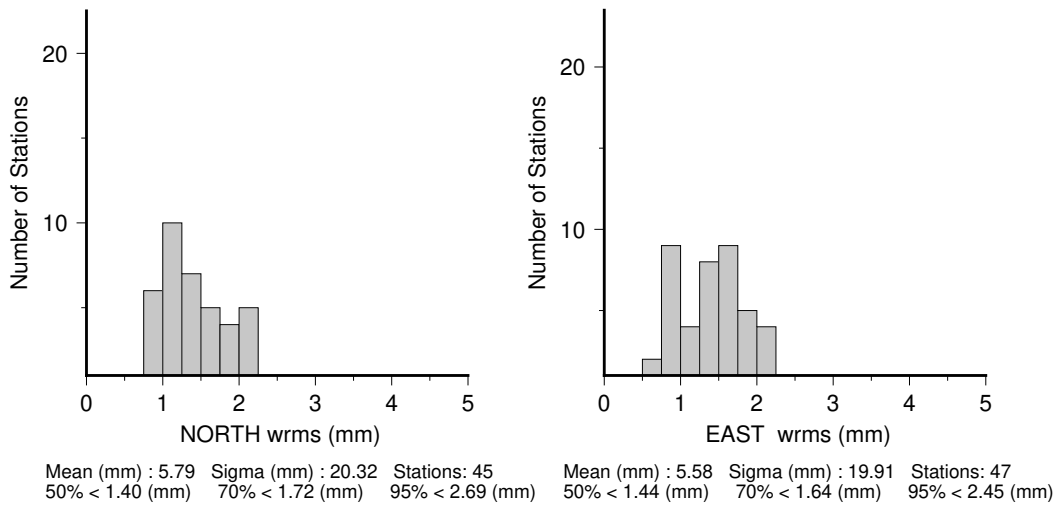|		
		http://geoweb.mit.edu/~tah/ACC_GAGE/AB14.CWUOFF.png
BUEG	U	New antenna 2024-054 not fixed in rapids yet. Two earlier unknown breaks added to unkn list. http://geoweb.mit.edu/~tah/ACC_GAGE/BUEG.CWUOFF.png
QUAD		WCDA site in British Columbia. Maybe new antenna but no log update. Earlier unknown breaks added. http://geoweb.mit.edu/~tah/ACC_GAGE/QUAD.CWUOFF.png
		2024-03-08
QUEX	U	Looks like antenna change, 10 mm in NE. Site in Baja California. No log update since 2020. http://geoweb.mit.edu/~tah/ACC_GAGE/QUEX.CWUOFF.png
		2024-03-15
EOCG	U	Systematic variations in North and East. Site near Santa Barbara. Some breaks for unknown reasons and one PCV model change. http://geoweb.mit.edu/~tah/ACC_GAGE/EOCG.CWUOFF.png
		2024-03-29 Not in monthly.
AB09	N	East offset by ~10 mm. Larger than earlier deviations. Site in Alaska. Revisit later to see if persists. http://geoweb.mit.edu/~tah/ACC_GAGE/AB09.CWUOFF.png
HAR7		Antenna change, metadata not updated yet. Should be OK by finals. http://geoweb.mit.edu/~tah/ACC_GAGE/HAR7.CWUOFF.png
ROSS		CORS site on Lake Superior. Lots of systematics in North and East. http://geoweb.mit.edu/~tah/ACC_GAGE/ROSS.CWUOFF.png
SHE2		Site on coast of New Brunswick. Lots of NE outliers but height looks good. NRCAN site. Information about site a https://webapp.csrs-scrs.nrcan-rncan.gc.ca/geod/data-donnees/station/report-rapport.php?id=M061001 It is a concrete pillar. http://geoweb.mit.edu/~tah/ACC_GAGE/SHE2.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 47 stations in the ANET region for CWU analyzed in the final orbit analysis between December 15, 2023 and March 23, 2024.

CWU	North (mm)	East (mm)	Up (mm)

Median			
ANET	1.40	1.44	5.50
70%			
ANET	1.72	1.64	5.84
95%			
ANET	2.69	2.45	7.89

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

Mean (mm) : 5.79   Sigma (mm) : 20.32   Stations: 45
50% < 1.40 (mm)   70% < 1.72 (mm)   95% < 2.69 (mm)

Mean (mm) : 5.58   Sigma (mm) : 19.91   Stations: 47
50% < 1.44 (mm)   70% < 1.64 (mm)   95% < 2.45 (mm)

Mean (mm) : 9.69   Sigma (mm) : 19.07   Stations: 47
50% < 5.50 (mm)   70% < 5.84 (mm)   95% < 7.89 (mm)

Scatter-Wrms Histogram : FILE: CWU_ANT_Y6Q2.sum

No index entries found.**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 December 15, 2023 and March 23, 2024. 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/ggx147