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

Thomas Herring and Mike Floyd

Period: 2022/10/01-2022/12/31

Table of Contents

Summary

Under the GAGE2 Facility Data Analysis subaward, MIT has been processing SINEX files 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 2022/09/15 to 2022/12/31, time series velocity field analyses for the GAGE reprocessing analyses (1996-2022). Several earthquakes were investigated this quarter up to 12/15/2022 and none of them generated observable offsets.

Analysis files (pbo format velocity files and offset files) are generated monthly and sent via LDM in the middle of each month. A full SINEX based annual velocity field will be generated in early January 2023 and reported on separately. This report along with the ancillary files will be posted to the UNAVCO derived data products page (https://www.unavco.org/data/gps-gnss/derived-products/derived-products.html).

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 1984 stations were processed. In addition up to 47 sites were processed in the ANET solutions, 13 more 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: September 15, 2022– December 31, 2022

For this report, we generated the statistics using the ~3 months of CWU results between September 15, 2022 and December 31, 2022. 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 1984 stations for CWU analyzed in the finals analysis between September 15, 2022 and December 31, 2022. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.91	0.89	5.68
70%			
CWU	1.19	1.14	6.33
95%			
CWU	2.55	2.45	10.16

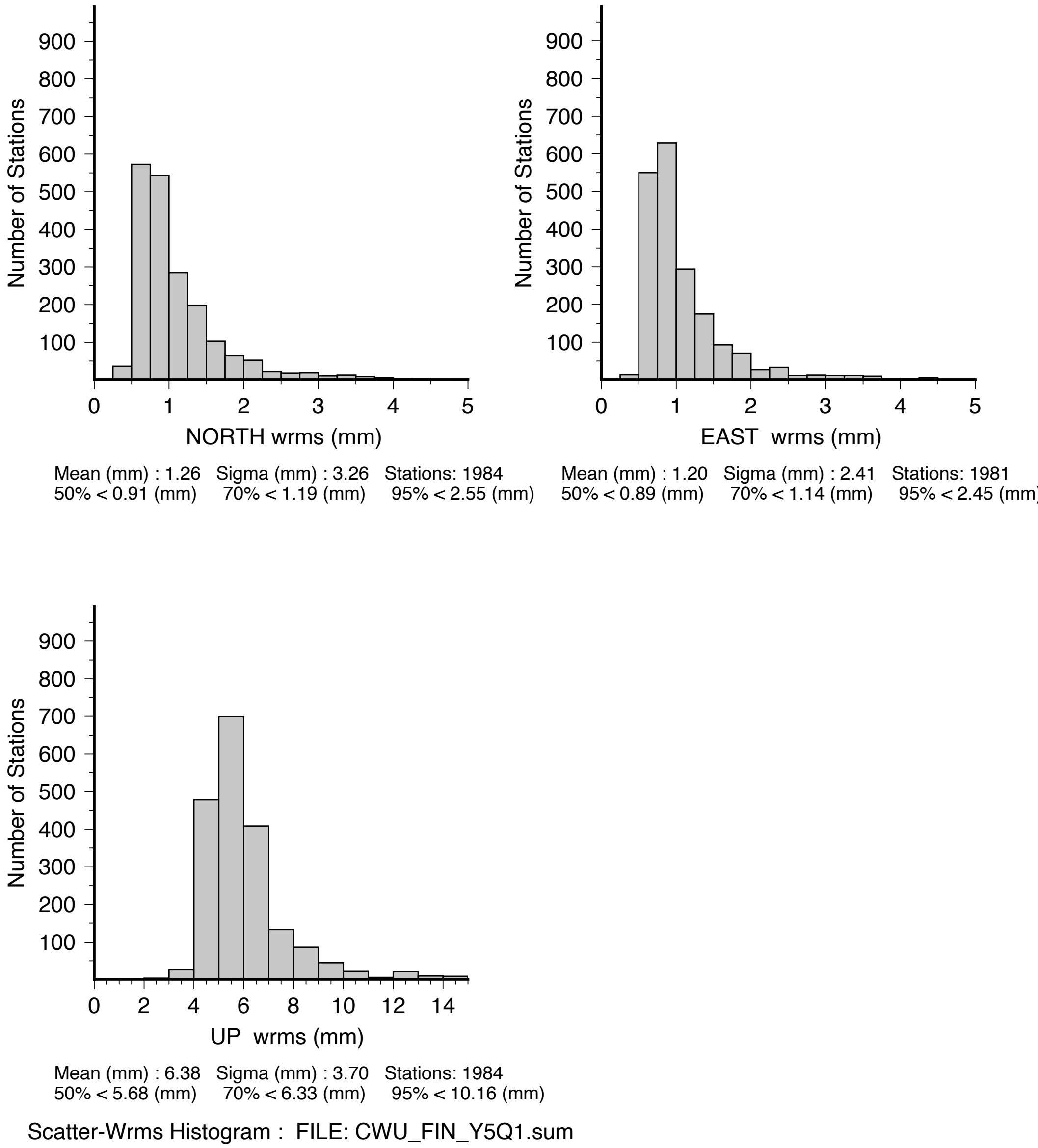

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 1984 stations analyzed between September 15, 2022 and December 31, 2022. Linear trends and annual signals were estimated from the time series.

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_Y5Q1.tab.

There are 1984 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_Y5Q1.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   104      1.1   0.58      1.4   0.69     5.9   0.65     19.69
 1NSU   105      1.0   0.61      1.0   0.61     5.7   0.76     18.95
 1ULM   104      0.8   0.50      1.0   0.63     4.9   0.66     19.55
 AB01    80      2.5   1.18      1.9   1.30     5.8   0.82     15.54
...
 ZDV1   105      0.8   0.45      0.6   0.41     6.1   0.80     19.58
 ZKC1   106      0.9   0.48      1.1   0.70     6.3   0.83     19.58
 ZLA1   106      1.0   0.56      0.9   0.58     5.7   0.76     19.81
 ZLC1   106      0.8   0.39      0.8   0.49     6.6   0.88     19.81
 ZME1   106      0.9   0.53      0.8   0.53     6.7   0.91     20.05
 ZMP1   106      0.8   0.41      0.9   0.61     5.5   0.74     19.96
 ZNY1   106      0.9   0.48      0.7   0.48     6.0   0.80     20.50
 ZOA1   106      0.7   0.40      0.8   0.57     6.6   0.91     19.96
 ZSE1   106      1.1   0.50      1.0   0.64     6.4   0.86     20.15
```

Table 2: RMS scatter of the position residuals for the CWU solution between September 15, 2022 and December 31, 2022 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	0.82	5.47	839
NUCLEUS	0.73	0.73	5.02	183
GAMA	0.76	0.86	5.36	14
COCONet	1.49	1.61	7.35	72
USGS_SCIGN	0.79	0.74	4.84	111
Expanded	1.04	1.02	6.03	767
70%				
PBO	1.02	1.01	6.06	
NUCLEUS	0.86	0.83	5.49	
GAMA	0.78	0.87	5.41	
COCONet	1.65	1.84	7.95	

USGS_SCIGN	0.98	0.88	5.05
Expanded	1.32	1.26	6.73
95%			
PBO	2.29	2.27	9.38
NUCLEUS	1.77	1.41	8.67
GAMA	1.11	0.99	5.91
COCONet	2.64	2.85	13.26
USGS_SCIGN	1.59	1.50	6.65
Expanded	3.22	3.15	12.03

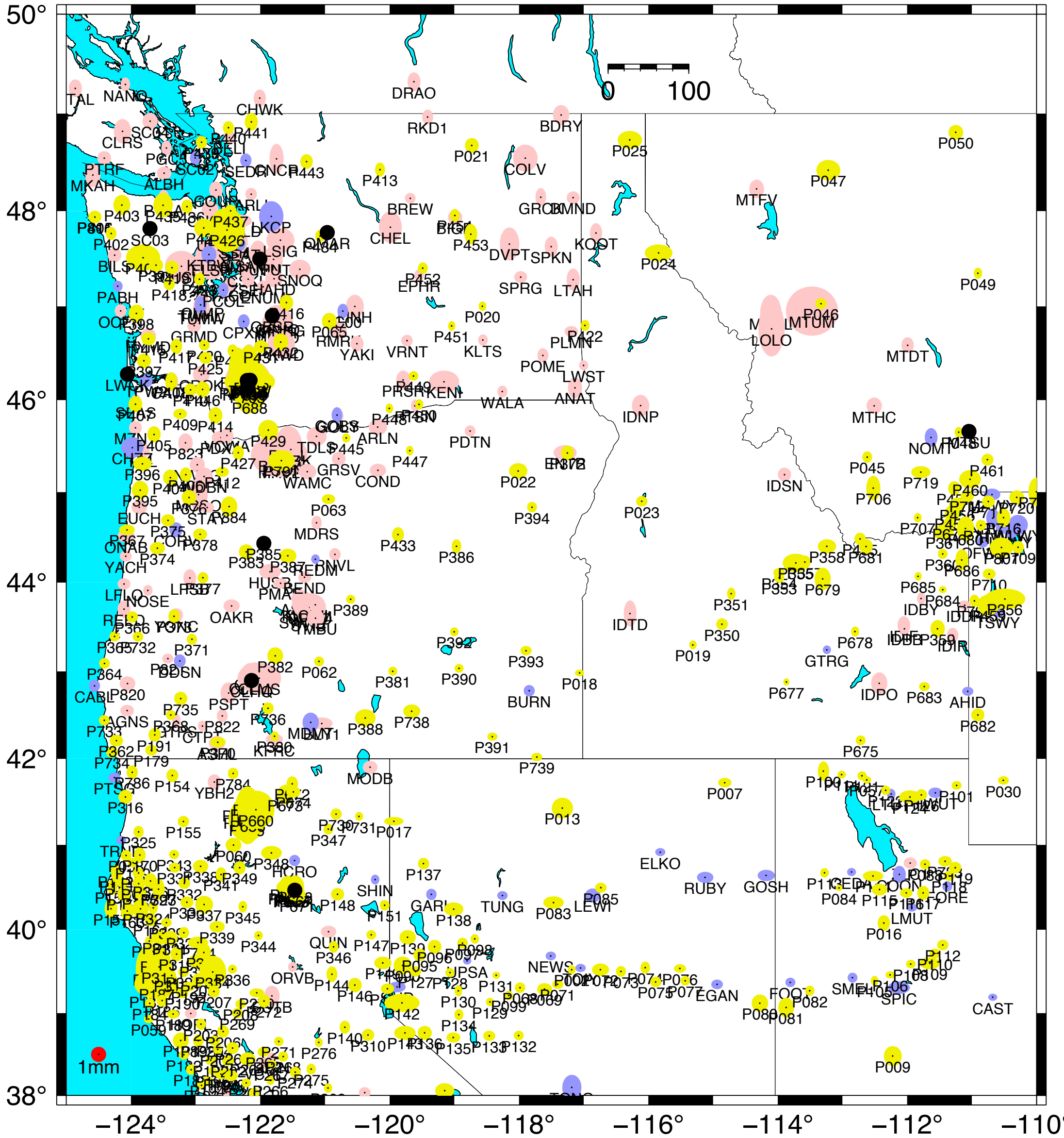

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1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

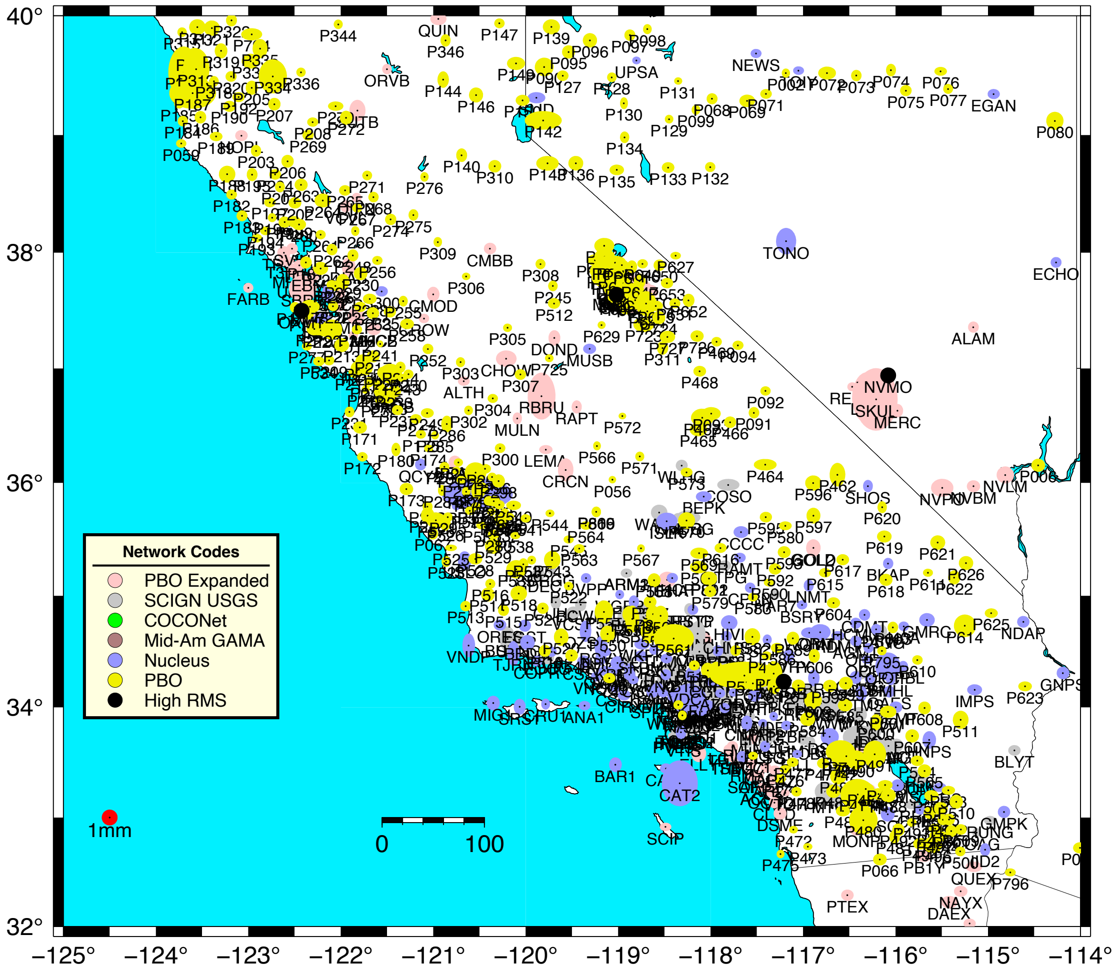

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

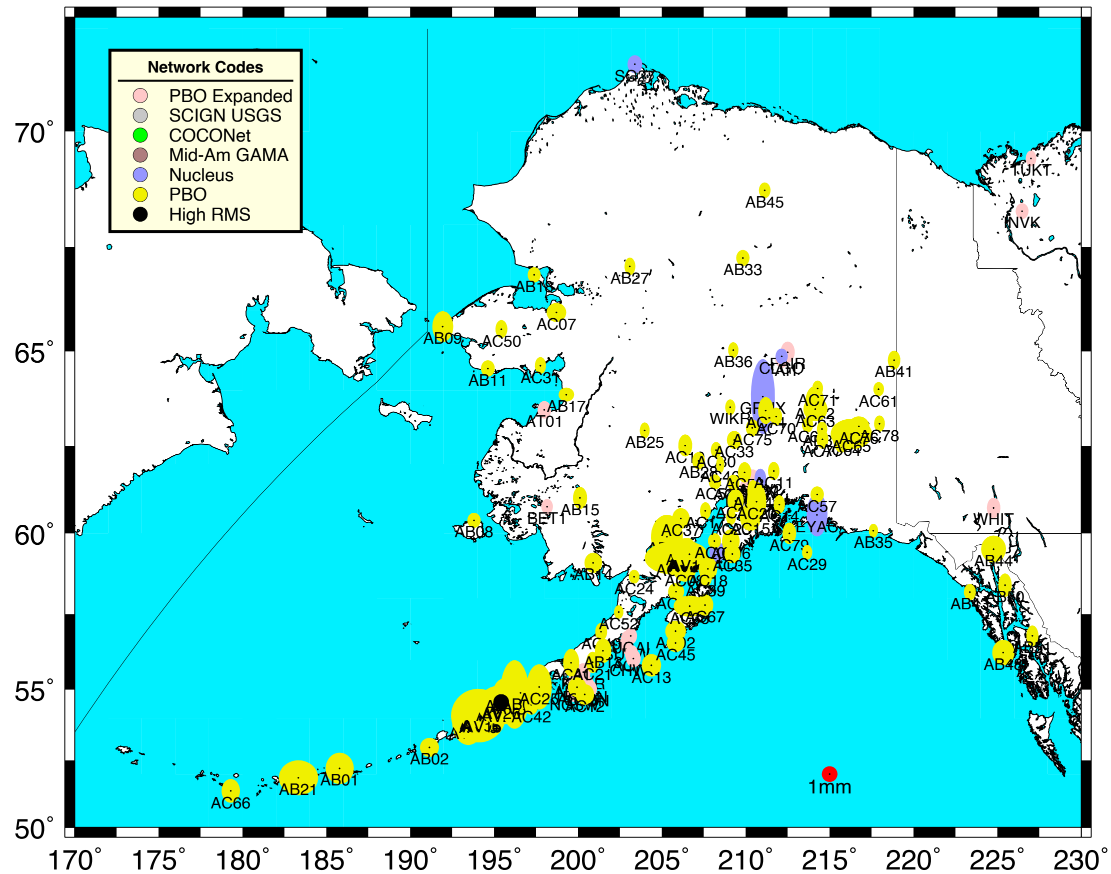

Figure 4: Same as Figure 4 except for the Alaskan region.

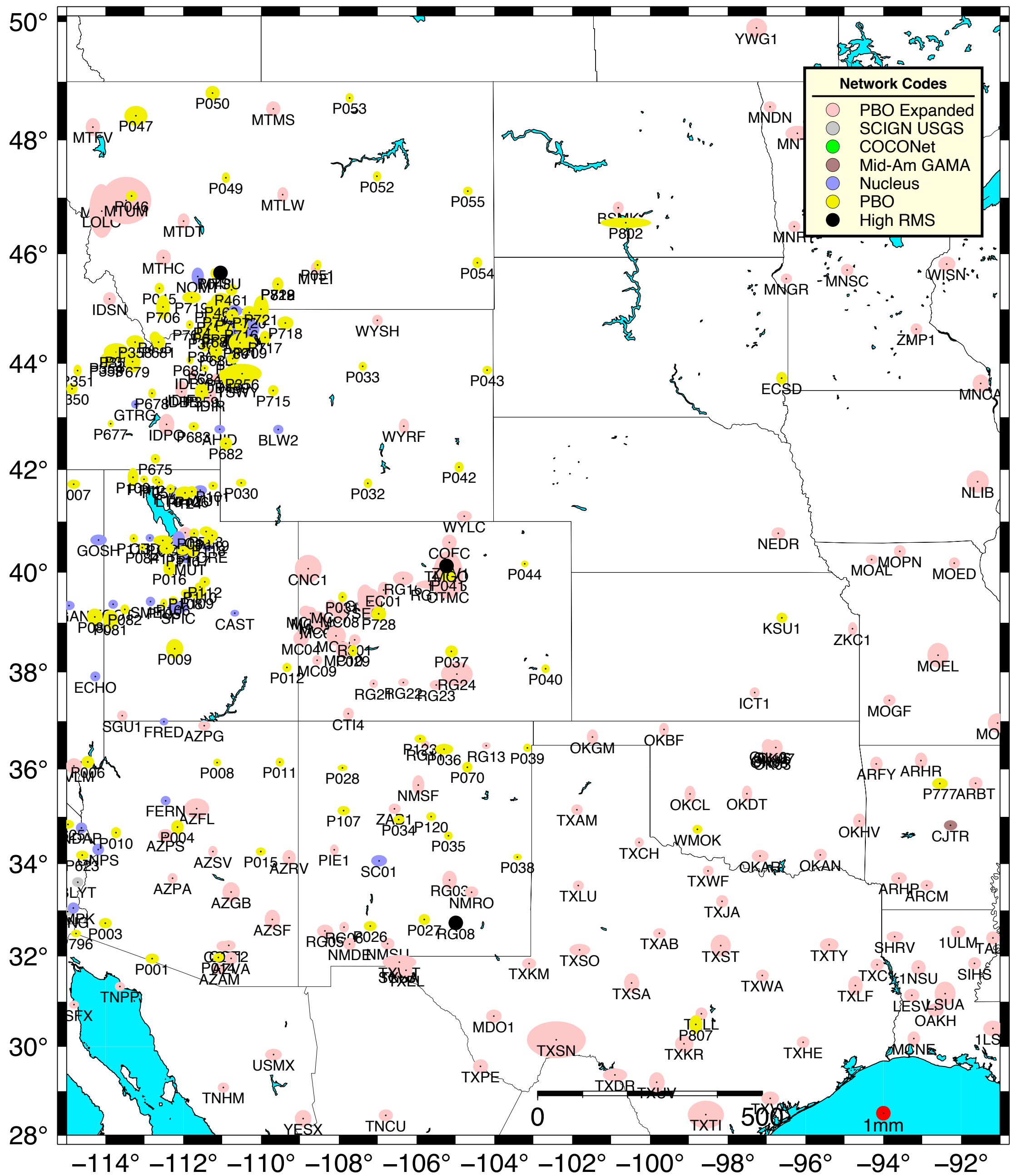

Figure 5: Same as Figure 4 except for the Central United States

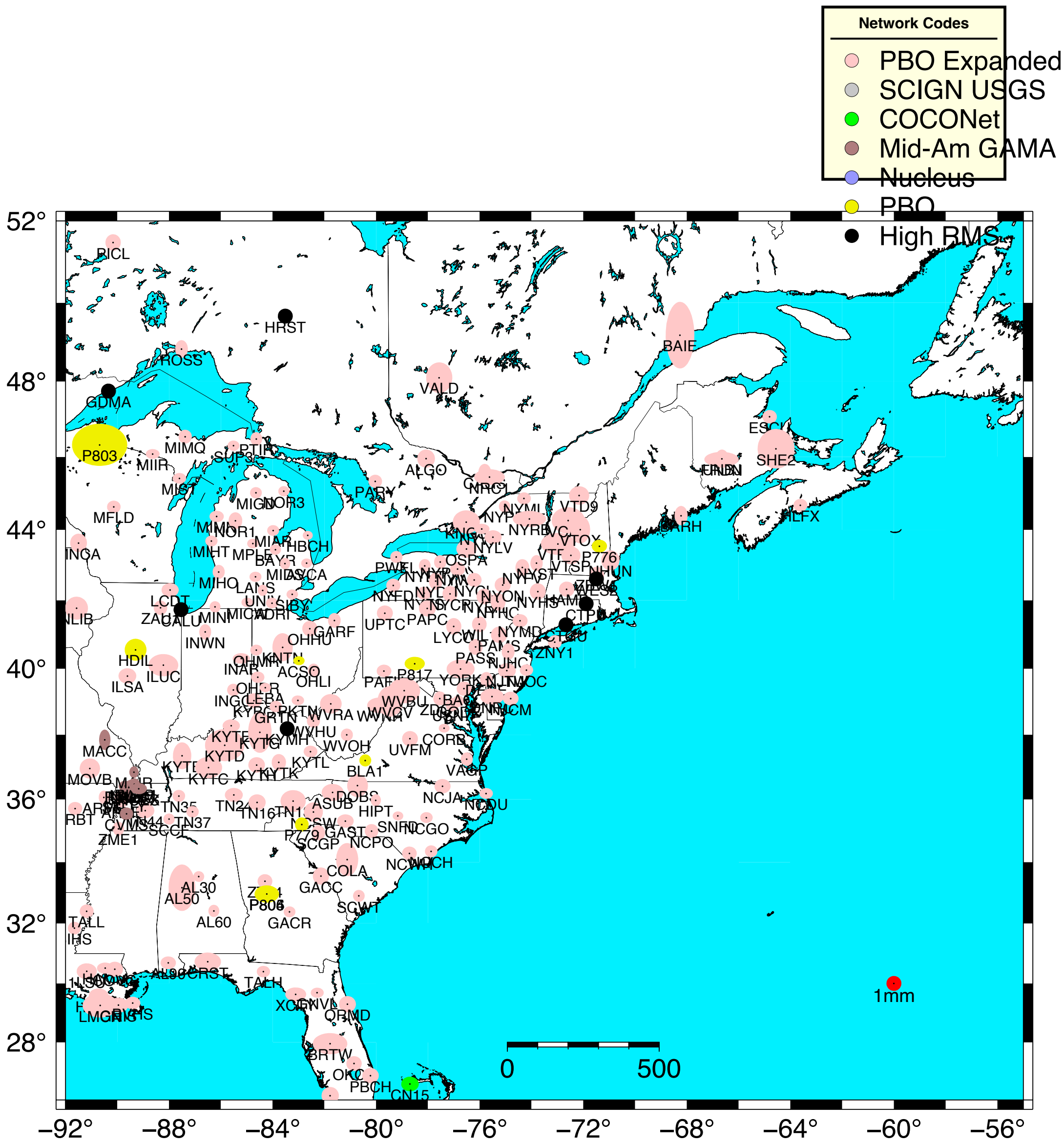

Figure 6: Same as Figure 4 except for the Eastern United States

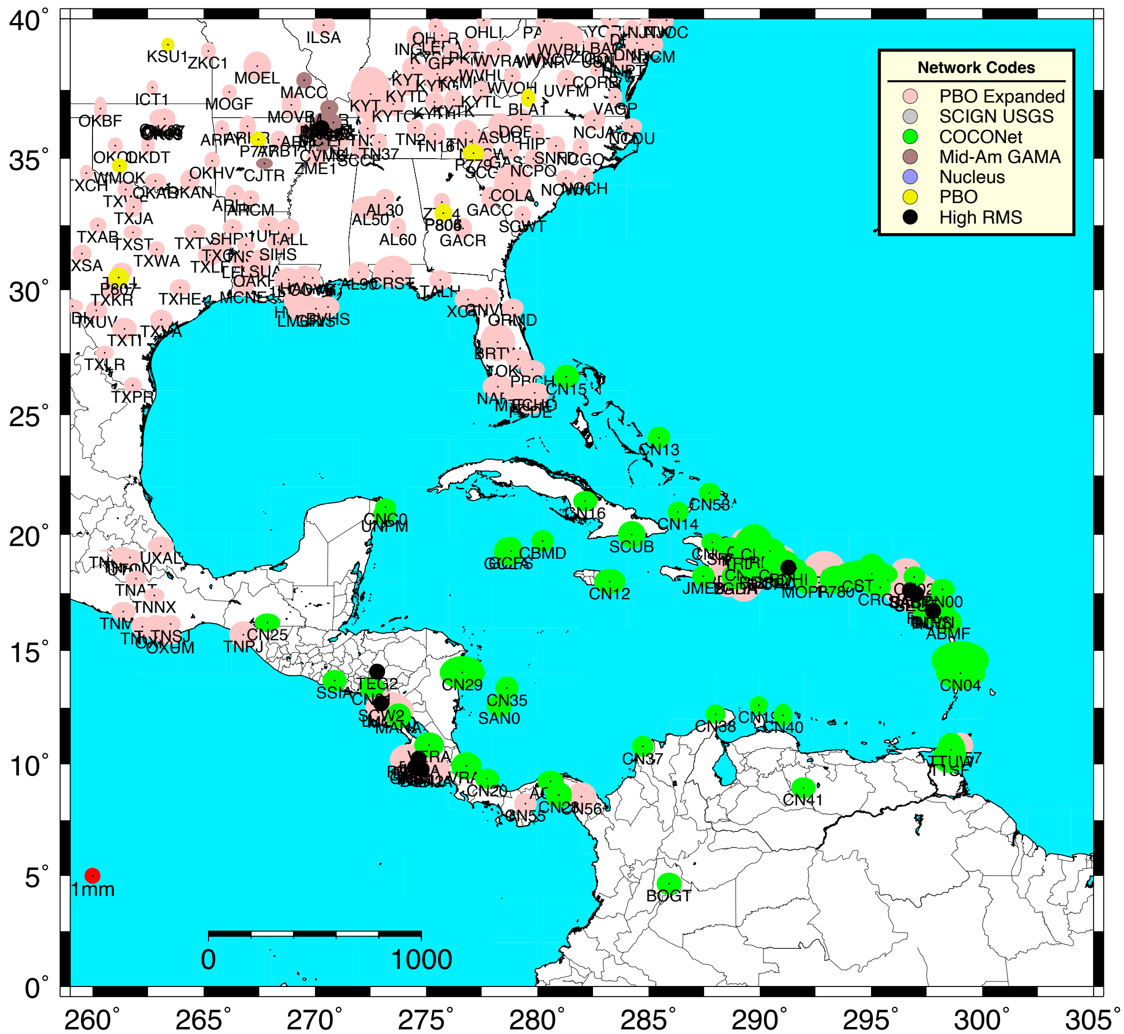

Figure 7: Same as Figure 4 except for the Caribbean region.

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 2709 stations in the CWU solution (37 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_221231.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_221231.snpvel.

Table 3: Statistics of the fits of 2709 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and December 31, 2022.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.40	1.36	6.21
70%			
CWU	1.76	1.72	7.07
95%			
CWU	3.92	3.65	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.

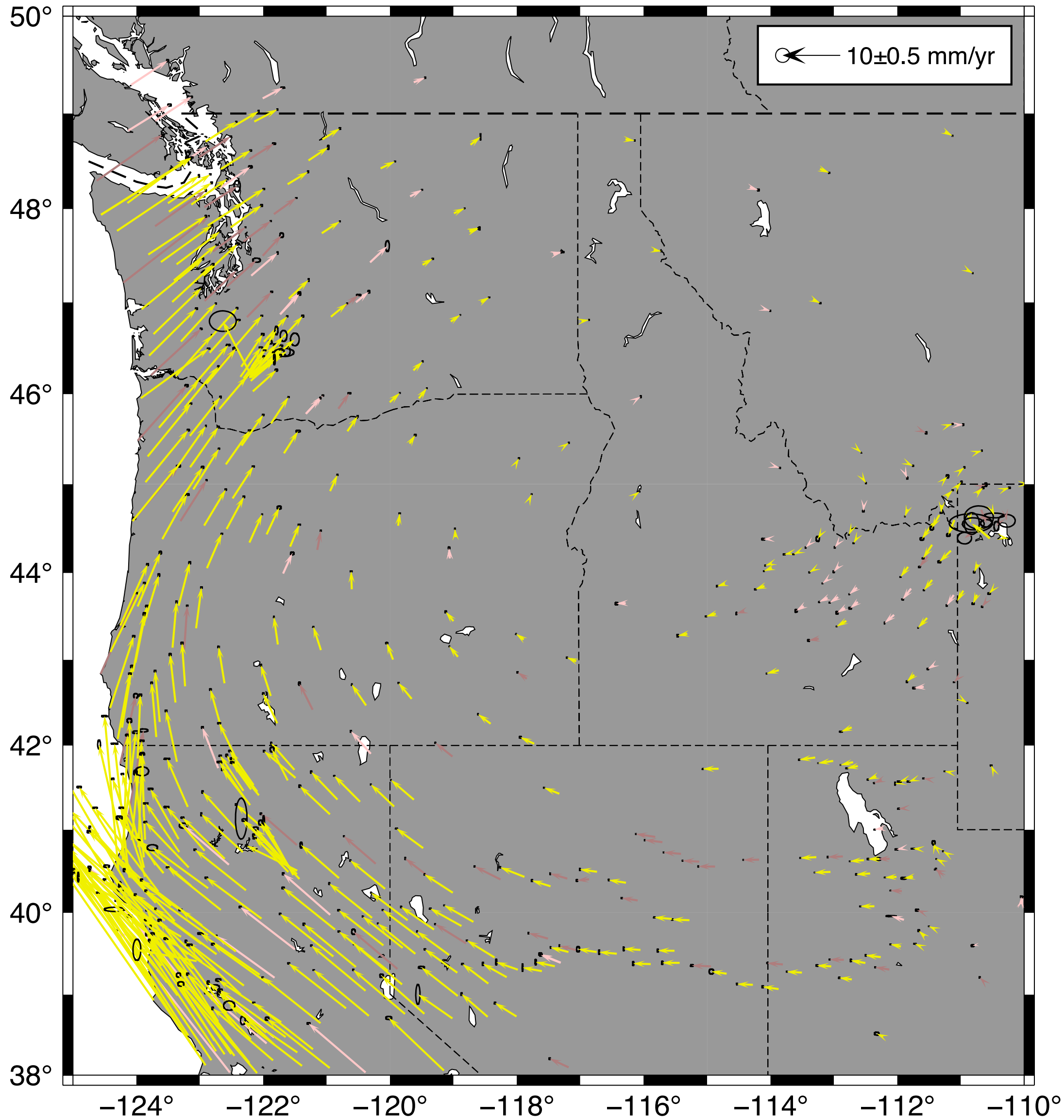

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

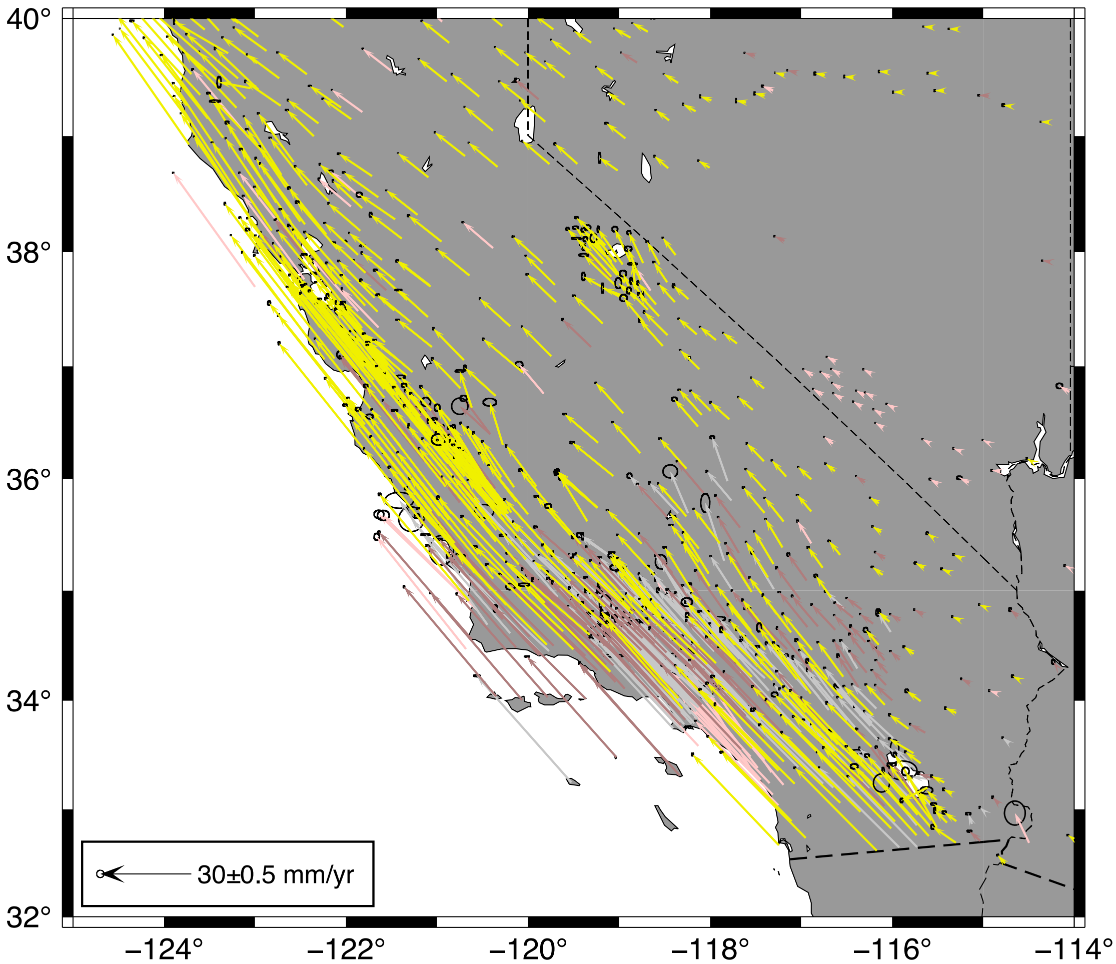

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

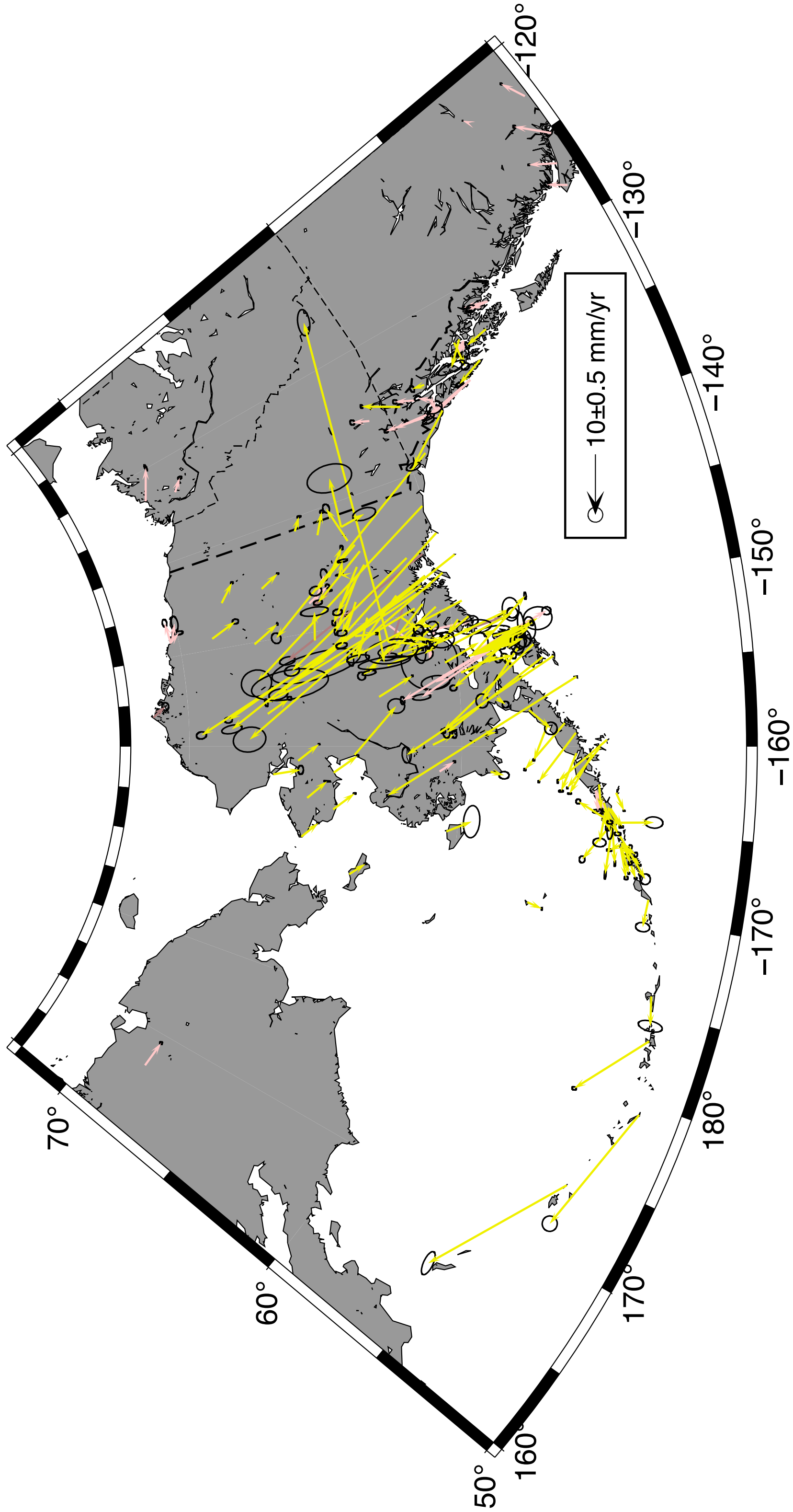

Figure 10: Same as Figure 8 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

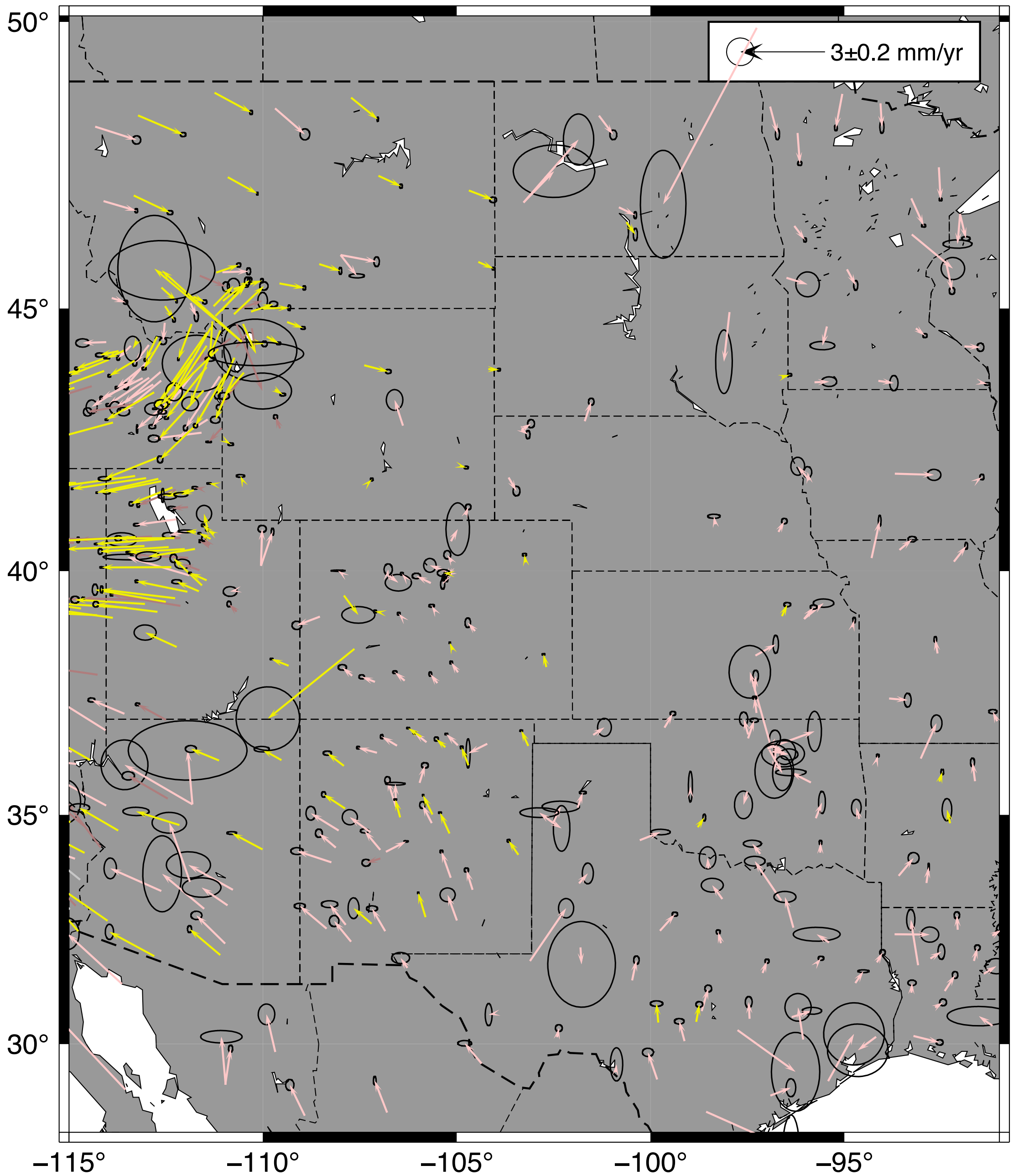

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

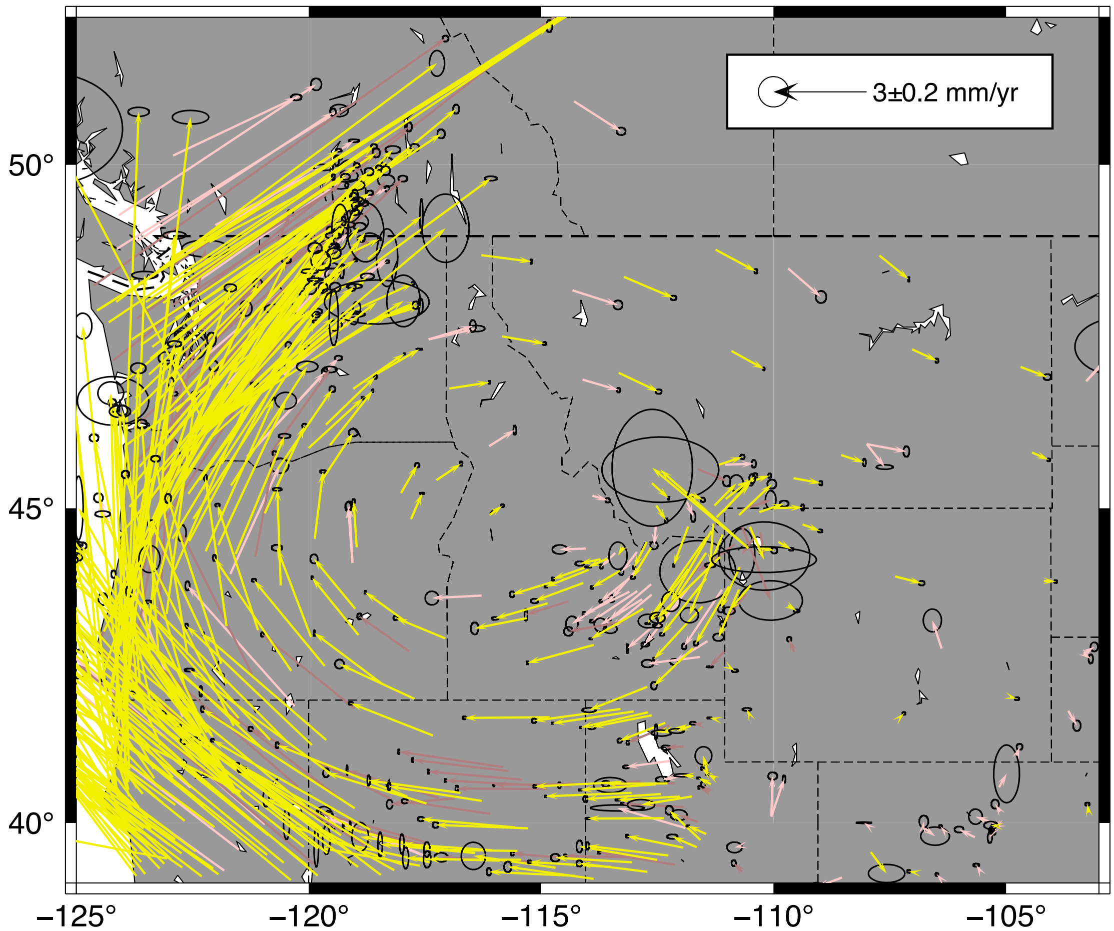

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

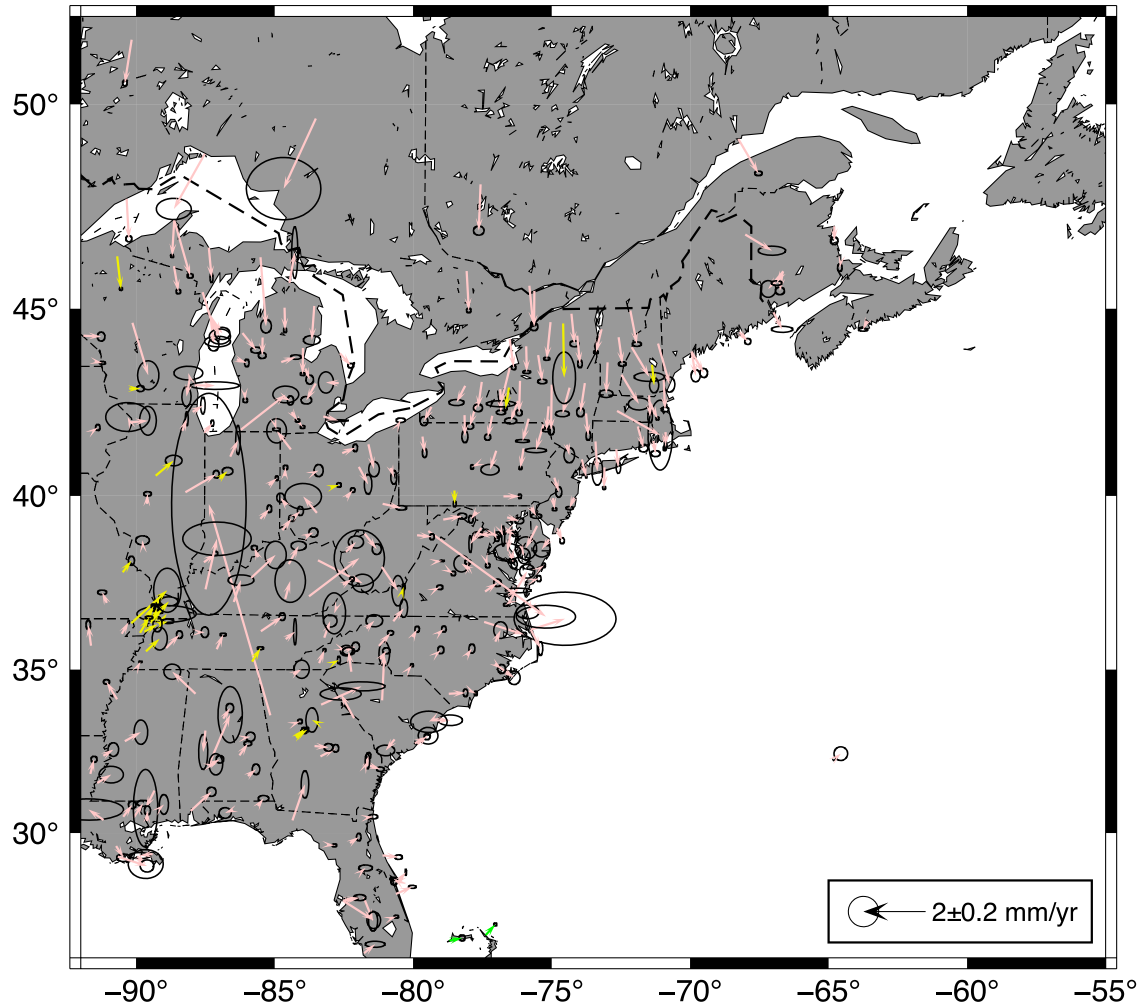

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

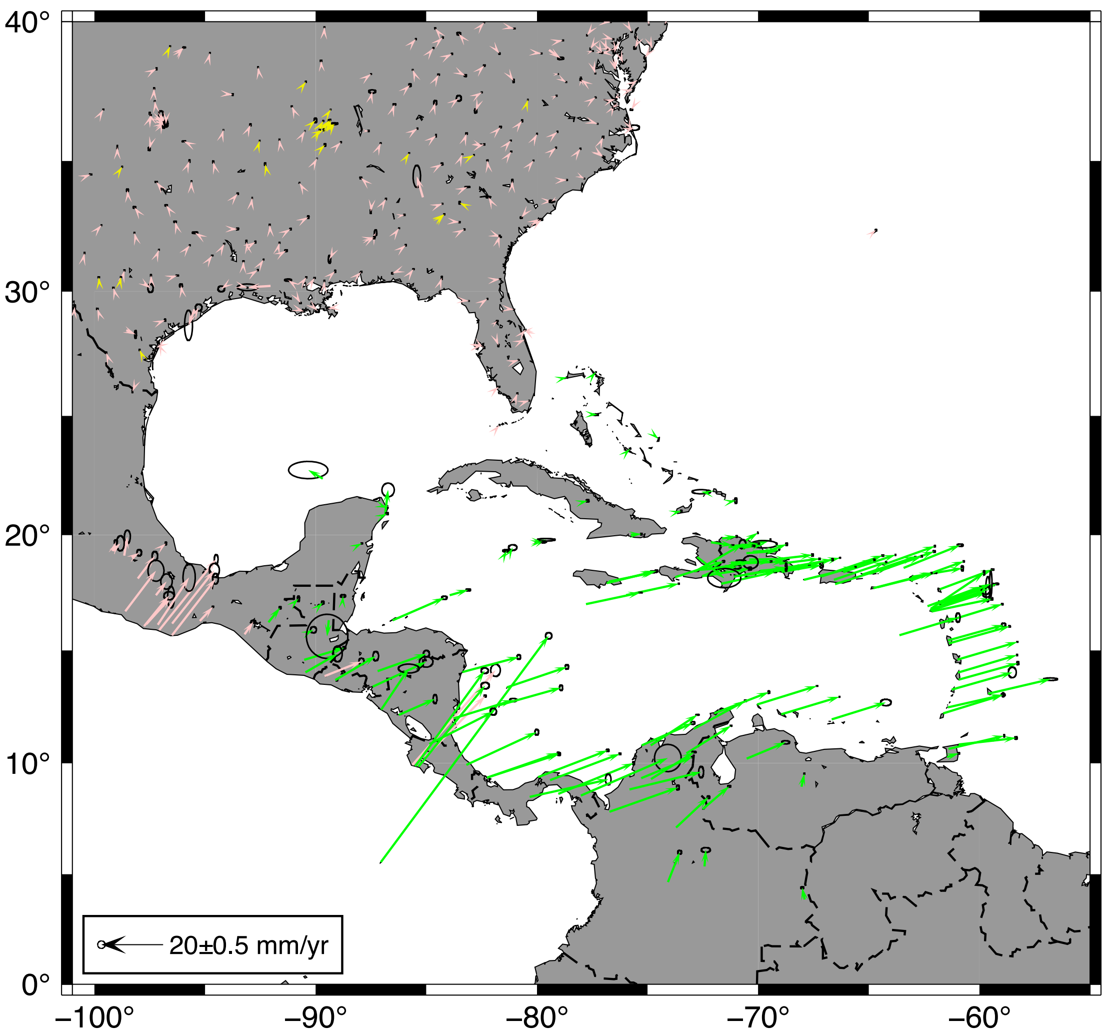

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2022/05/15-2022/12/15

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 32 earthquakes examined during this quarter, none generated displacements more than 1 mm.

Antenna and other discontinuity events.

Antenna swaps at 41 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
The table below includes new and old style plots (update was made that the end of the quarter).

Site/s	**Issues related to site**
10/14/22	
BEND	Offsets in NE but not meta data change. PANGA site in Oregon (in Bend). http://geoweb.mit.edu/~tah/ACC_PBO/BEND.CWU.jpg
10/23/22	Not Reported
AV11	Post-seismic from 2018 01 23 earthquake (EQ44)? Skewness and snow effects? http://geoweb.mit.edu/~tah/ACC_PBO/AV11.CWU.jpg
KNOL	Site near Mammoth Lakes showing systematics. To be expected. http://geoweb.mit.edu/~tah/ACC_PBO/KNOL.CWU.jpg
10/28/22	
AC58	Back online after gap since 2021. East of offset but no metadata update. Long term curvature in east. Site in back arc of Aleutian arc. http://geoweb.mit.edu/~tah/ACC_PBO/AC58.CWU.jpg
BRSP	New site since 2021. Looks like snow. Site near Mt. Hood. Some long term systematics in height. Useful case for “correcting/removing” for snow. http://geoweb.mit.edu/~tah/ACC_PBO/BRSP.CWU.jpg
ELSC	New antenna. Processing meta data not updated yet. http://geoweb.mit.edu/~tah/ACC_PBO/ELSC.CWU.jpg
KYTB	CORS site in Madisonville KY. Lots of “vegetation” effects. New antenna

	just installed. http://geoweb.mit.edu/~tah/ACC_PBO/KYTB.CWU.jpg
MTUM	Site in Montana. Maybe bad antenna. http://geoweb.mit.edu/~tah/ACC_PBO/MTUM.CWU.jpg
MUIR	On Mt. Rainer. Lots of snow and volcano effects. Large offset in 2012 that seems to be related to ANSS(ComCat) usp000juhz mww7.8 206 km SW of Prince Rupert lat/long 52.7880 -132.1010 date/time 2012 10 28 03 05 but seems too far away. Seems to be slow-slip http://geoweb.mit.edu/~tah/ACC_PBO/MUIR.CWU.jpg
P694	Snow and systematics (P690 and P693 also similar). On Mt. St,. Helens. http://geoweb.mit.edu/~tah/ACC_PBO/P694.CWU.jpg
11/4/22	
MTFV	CORS site. Looks like antenna change but no new log yet. http://geoweb.mit.edu/~tah/ACC_PBO/MTFV.CWU.jpg
SHOS	East offset. Site near Death Valley with strong Ridgecrest postseismic. No meta change at UNAVCO. Scatter looks less than error bars except for outliers.. http://geoweb.mit.edu/~tah/ACC_PBO/SHOS.CWU.jpg
11/14/22	
CLQH	Site near Craton Lake, Oregon showing deformation. http://geoweb.mit.edu/~tah/ACC_PBO/CLHQ.CWU.jpg
P219	Near coast south of San Francisco. Very seasonal in east but not clear why. Nearby sites don't seem to show but difficult to see because nearby site plots are not detrended. http://geoweb.mit.edu/~tah/ACC_PBO/P219.CWU.jpg
P303	Strong height hydrology signal. Site north-west of Fresno CA. http://geoweb.mit.edu/~tah/ACC_PBO/P303.CWU.jpg
P802	10 mm east offset but no antenna change. Change coincides with POLARX5 firmware update from 5.4.0-patch1 to 5.5.0. Site in North Dakota. http://geoweb.mit.edu/~tah/ACC_PBO/P802.CWU.jpg
AV35	East offset but no meta data change. Could be snow but no height change. http://geoweb.mit.edu/~tah/ACC_PBO/AV35.CWU.jpg
11/16/22	
MHCB	Near San Jose. No rapids and site might have been displaced and replaced with MHC2 (based in UNR time series)
11/18/22	
LCDT	CORS site: Looks like new antenna but no new log yet. http://geoweb.mit.edu/~tah/ACC_PBO/LCDT.CWU.jpg
BRTW	Site in Florida. Lots of outliers in recent years but there seems to a core of good results. http://geoweb.mit.edu/~tah/ACC_PBO/BRTW.CWU.jpg
PAMS	Site in Pennsylvania. Looks like new antenna with no new log file. CORS site. http://geodesy.unr.edu/NGLStationPages/stations/PAMS.sta
PAPC	Site in Pennsylvania. Looks like new antenna with no new log file. CORS site. This sites shows height outliers in the past so maybe outlier. Check later. http://geoweb.mit.edu/~tah/ACC_PBO/PAPC.CWU.jpg

VTSP	Similar to site above (including single outliers in height). CORS sites in Vermont. http://geoweb.mit.edu/~tah/ACC_PBO/VTSP.CWU.jpg
WIL1	Similar to above. CORS sites in Wike Barre Pennsylvania. http://geoweb.mit.edu/~tah/ACC_PBO/WIL1.CWU.jpg
11/25/22	
BIGD	Site in central Washington State Strong east annual starting 2014 (not clearly seen at P454 2.3 km away). Site near major rivers and dams. Offset in East. Maybe new antenna. http://geoweb.mit.edu/~tah/ACC_PBO/BIGD.CWU.jpg
12/3/22	
BALD	Large signal from Mammoth Lakes. http://geoweb.mit.edu/~tah/ACC_PBO/BALD.CWU.jpg
HOTK	Also Mammoth Lakes. http://geoweb.mit.edu/~tah/ACC_PBO/HOTK.CWU.jpg
OLVN	Monserrat: Strong east skew. http://geoweb.mit.edu/~tah/ACC_PBO/OLVN.CWU.jpg
P270	Rapid drop in height with an increased seasonal signal. http://geoweb.mit.edu/~tah/ACC_PBO/P270.CWU.jpg
P711	Site near Yellowstone; large signals. http://geoweb.mit.edu/~tah/ACC_PBO/P711.CWU.jpg
RBRU	Annual in north started 2019. Near Fresno CA. P307 may show something similar. http://geoweb.mit.edu/~tah/ACC_PBO/RBRU.CWU.jpg
RNCH	Growing East annual. Near Parkfield. http://geoweb.mit.edu/~tah/ACC_PBO/RNCH.CWU.jpg
12/17/22	Not reported in GAGE telecon
AC23	Running off in East and dropping in height. http://geoweb.mit.edu/~tah/ACC_PBO/AC23.CWU.png
FS82	Site near Anchorage; subsiding rapidly; FS63 nearby similar but less magnitude. http://geoweb.mit.edu/~tah/ACC_PBO/FS82.CWU.png
OBSR	Site on Mt. Rainier; rapid offsets in Earth. Recent jump has been seen in the past. http://geoweb.mit.edu/~tah/ACC_PBO/OBSR.CWU.png
P703	North of Portland, run off in North, East, and height excursion due to snow (seen in site photo). http://geoweb.mit.edu/~tah/ACC_PBO/P703.CWU.png
12/23/22	Not included in monthly report
AC49	Mid-way between LA and San Diego; Post-seismic from RidgeCrest. http://geoweb.mit.edu/~tah/ACC_PBO/ACSB.CWU.png
CABA	Equipment seems to be failing since mid-2022. http://geoweb.mit.edu/~tah/ACC_PBO/CABA.CWU.png
CLHQ	Snow on Crater Lake site. http://geoweb.mit.edu/~tah/ACC_PBO/CLHQ.CWU.png
FLIN	Canadian site: Annual height signal developing. http://geoweb.mit.edu/~tah/ACC_PBO/FLIN.CWU.png

MKEA	Offsets in East and North in rapids. http://geoweb.mit.edu/~tah/ACC_PBO/MKEA.CWU.png
MNJC	New Mexico site. 10 mm offset in east in rapids. http://geoweb.mit.edu/~tah/ACC_PBO/MNJC.CWU.png
P385	Site between Eugene and Bend OR, east motion started in early 2022. Could be failing antenna. http://geoweb.mit.edu/~tah/ACC_PBO/P385.CWU.png
P803	Site near Lake Superior. Offsets in east and north but no antenna change in logs. http://geoweb.mit.edu/~tah/ACC_PBO/P803.CWU.png
RDF2	Site in Dominican Republic. Lots of systematics. http://geoweb.mit.edu/~tah/ACC_PBO/RDF2.CWU.png
12/24/22	
AC40	East has jump in rapids. http://geoweb.mit.edu/~tah/ACC_PBO/AC40.CWUOFF.png
AC41	Similar offsets in east and north. Snow? No apparent earthquakes. http://geoweb.mit.edu/~tah/ACC_PBO/AC41.CWUOFF.png
LSIG	Added UNKNOWN break 2021/10/30. Clear in North. No meta data change. http://geoweb.mit.edu/~tah/ACC_PBO/LSIG.CWUOFF.png
P170	Antenna change in log looks like wrong date. http://geoweb.mit.edu/~tah/ACC_PBO/P170.CWUOFF.png
BAMF	Possible snow in rapids. Site on Vancouver Island. http://geoweb.mit.edu/~tah/ACC_PBO/BAMF.CWUOFF.png
HOLB	East offset of 10 mm in rapids. http://geoweb.mit.edu/~tah/ACC_PBO/HOLB.CWUOFF.png
OCEN	East jump 20m mm in rapids. http://geoweb.mit.edu/~tah/ACC_PBO/OCEN.CWUOFF.png
P397	15 mm jump North in rapids. Site in Cascadia near Portland. Has outliers in the past. http://geoweb.mit.edu/~tah/ACC_PBO/P397.CWUOFF.png
P403	20 mm North deviation. Site near Seattle. http://geoweb.mit.edu/~tah/ACC_PBO/P403.CWUOFF.png
TMGO	Looks like failing antenna or tree growth. Site near Longmont CO. http://geoweb.mit.edu/~tah/ACC_PBO/TMGO.CWUOFF.png
TPW2	Offset in east in rapid. Site near Astoria, WA. http://geoweb.mit.edu/~tah/ACC_PBO/TPW2.CWUOFF.png
WVBU	Jump in height recently but seems a have failed antenna starting mid-2018. http://geoweb.mit.edu/~tah/ACC_PBO/WVBU.CWUOFF.png
12/30/22	
GSC1	Jumps in North and East is rapids. Site in Colorado. http://geoweb.mit.edu/~tah/ACC_PBO/GSC1.CWUOFF.png
LONG	Sites seems to be degrading since 2006. Site east of LA. http://geoweb.mit.edu/~tah/ACC_PBO/LONG.CWUOFF.png
MC07	Site in Colorado. Strong systematics. http://geoweb.mit.edu/~tah/ACC_PBO/MC07.CWUOFF.png

NGSW	New site. Starting to "run away" in North and east to a lesser extent. Site in Aleutians in Alaska. http://geoweb.mit.edu/~tah/ACC_PBO/NGSW.CWUOFF.png
TXSO	Systematics mostly in North and East. Site in central Texas. http://geoweb.mit.edu/~tah/ACC_PBO/TXSO.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 September 15, 2022 and December 31, 2022.

CWU	North (mm)	East (mm)	Up (mm)
Median ANET	1.17	1.08	5.92
70% ANET	1.41	1.23	6.39
95% ANET	1.94	1.70	8.12

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

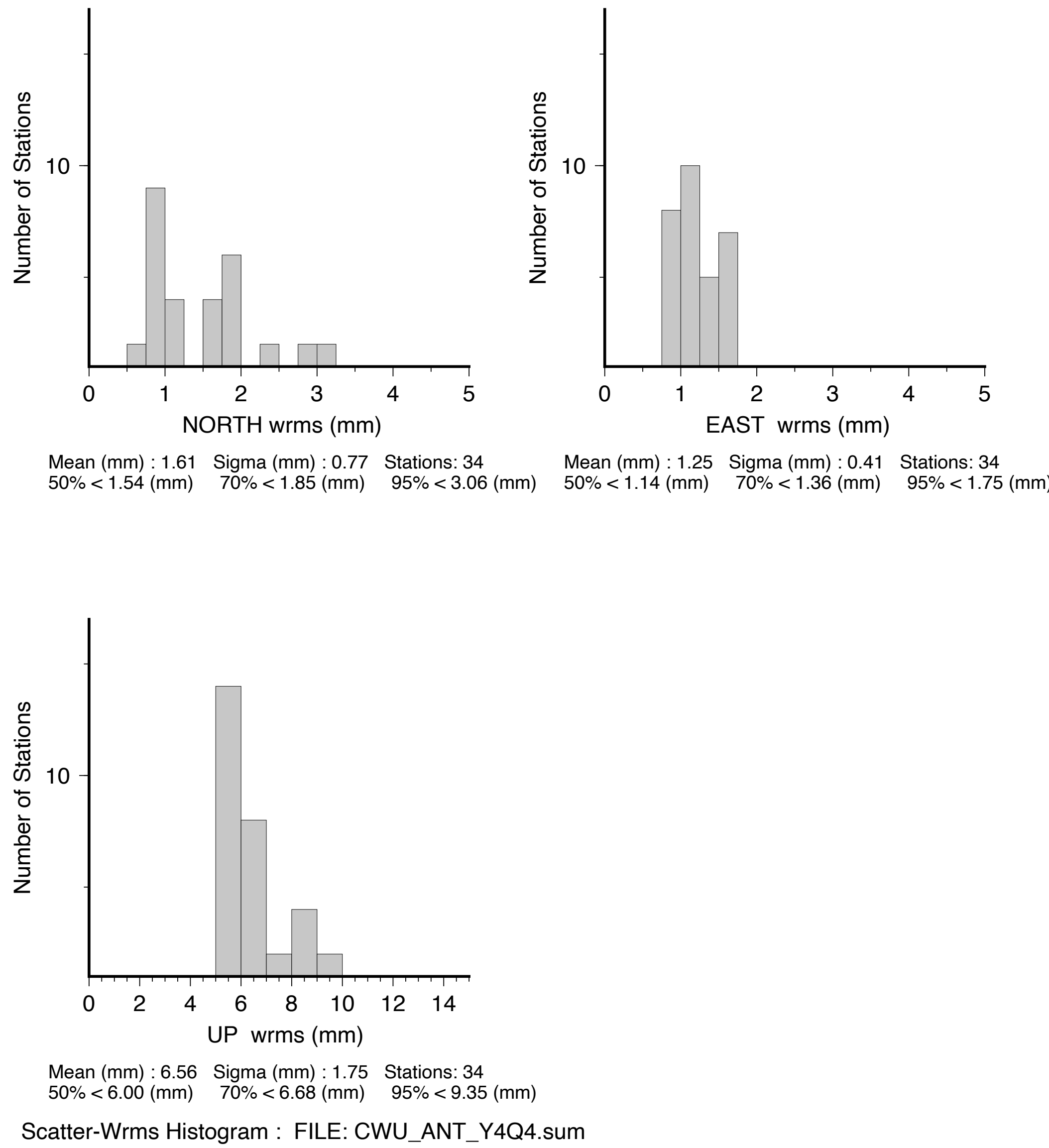

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 34 stations in Antarctica analyzed between September 15, 2022 and December 31, 2022. Linear trends and annual signals were estimated from the time series.

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