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

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Period: 2022/06/01-2022/09/30

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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 NAM14 reference frame. In this report, we show analyses of the data processing for the period 2022/05/15 to 2022/09/30, time series velocity field analyses for the GAGE reprocessing analyses (1996-2022). Several earthquakes were investigated this quarter but only one of them, event 67; ANSS(ComCat) us7000i9bw, mww7.6 37 km SE of Aquila. latitude/longitude 18.3667°/-103.2524° Date/Time 2022/09/19 18:06 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 was generated 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) shortly.

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 1998 stations were processed. In addition up to 34 sites were processed in the ANET solutions, 13 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: May 15, 2022– September 24, 2022

For this report, we generated the statistics using the ~3 months of CWU results between May 15, 2022 and September 24, 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 1998 stations for CWU analyzed in the finals analysis between May 15, 2022 and September 24, 2022. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.94	0.87	4.31
70%			
CWU	1.14	1.07	5.10
95%			
CWU	2.03	2.13	7.98

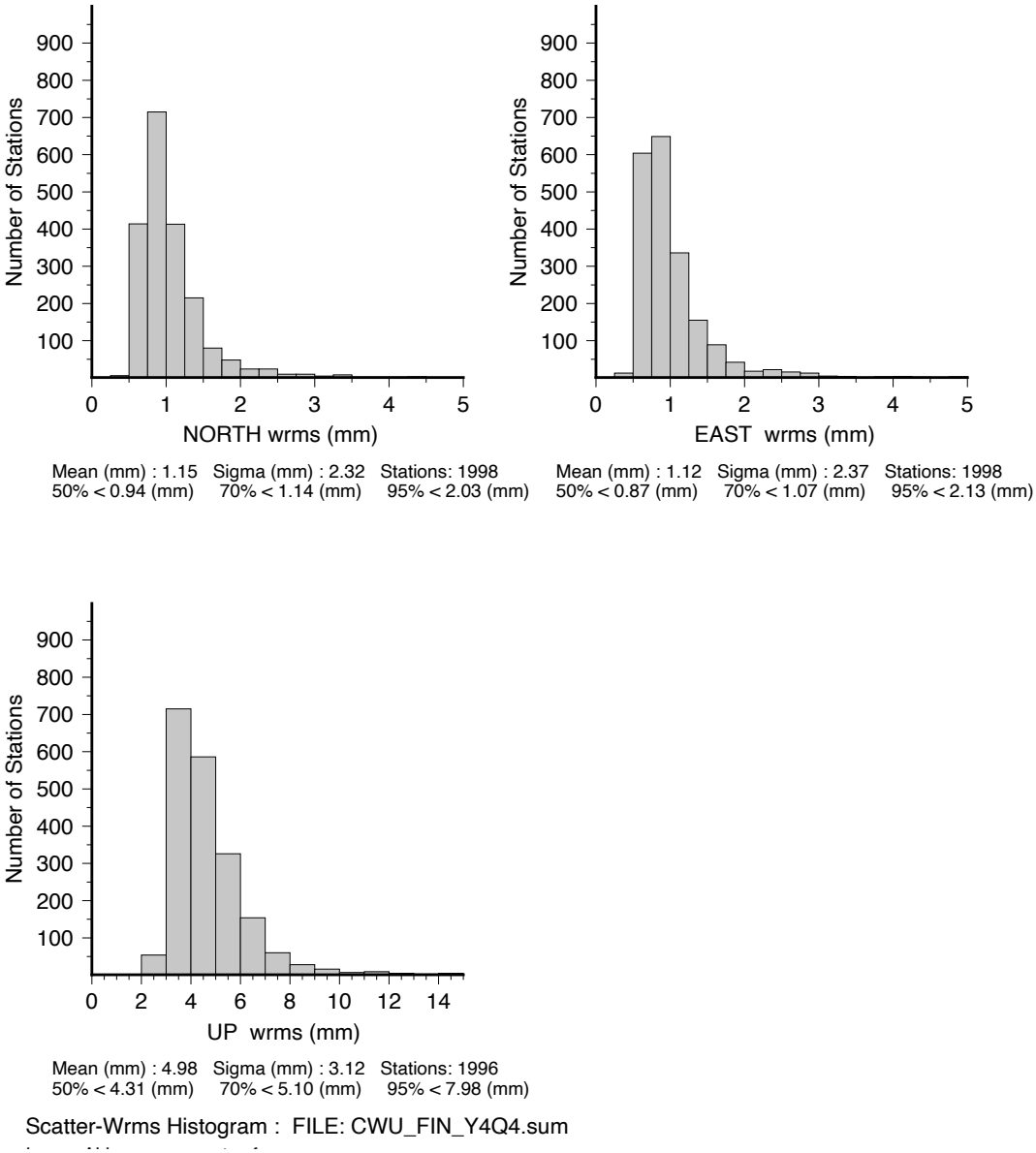

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 1998 stations analyzed between May 15, 2022 and September 24, 2022. Linear trends and annual signals were estimated from the time series.

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_Y4Q4.tab.

There are 1998 stations in the file for sites that have at least 2 measurements during the month.

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abular Position RMS scatters created from CWU_FIN_Y4Q4.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   102      1.5   0.78      1.8   0.91     7.5   0.81     19.42
 1NSU   101      1.0   0.57      1.1   0.69     5.3   0.69     18.68
 1ULM   102      1.1   0.61      1.3   0.81     5.3   0.70     19.28
 AB01   100      2.0   0.92      1.8   1.20     6.4   0.91     15.35
…
 ZDV1   102      0.9   0.46      0.8   0.51     5.5   0.72     19.31
 ZKC1   102      1.1   0.57      0.9   0.60     4.3   0.56     19.31
 ZLA1   102      1.1   0.62      0.8   0.54     4.2   0.56     19.54
 ZLC1   102      0.9   0.48      0.9   0.60     5.2   0.67     19.54
 ZME1   102      1.2   0.68      1.2   0.74     5.6   0.74     19.78
 ZMP1   101      1.0   0.50      0.8   0.50     5.3   0.70     19.69
 ZNY1   102      1.0   0.53      1.0   0.66     3.6   0.48     20.23
 ZOA1   102      0.7   0.37      0.6   0.41     3.9   0.53     19.69
 ZSE1   102      1.0   0.46      0.8   0.56     6.0   0.79     19.89
```

Table 2: RMS scatter of the position residuals for the CWU solution between May 15, 2022 and September 24, 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	0.85	0.78	3.86	843
NUCLEUS	0.82	0.77	3.92	183
GAMA	0.94	0.99	5.05	14
COCONet	1.50	1.60	7.22	68
USGS_SCIGN	0.86	0.82	4.13	117
Expanded	1.08	1.00	5.10	773
70%				
PBO	0.98	0.93	4.31	
NUCLEUS	0.91	0.88	4.29	
GAMA	0.98	1.06	5.26	
COCONet	1.67	1.86	7.88	
USGS_SCIGN	1.03	0.98	4.64	

Expanded 95%	1.25	1.23	5.77
PBO	1.77	1.55	6.01
NUCLEUS	1.32	1.28	5.33
GAMA	1.11	1.14	5.99
COCONet	3.43	4.13	15.20
USGS_SCIGN	1.70	1.44	6.28
Expanded	2.36	2.58	9.79

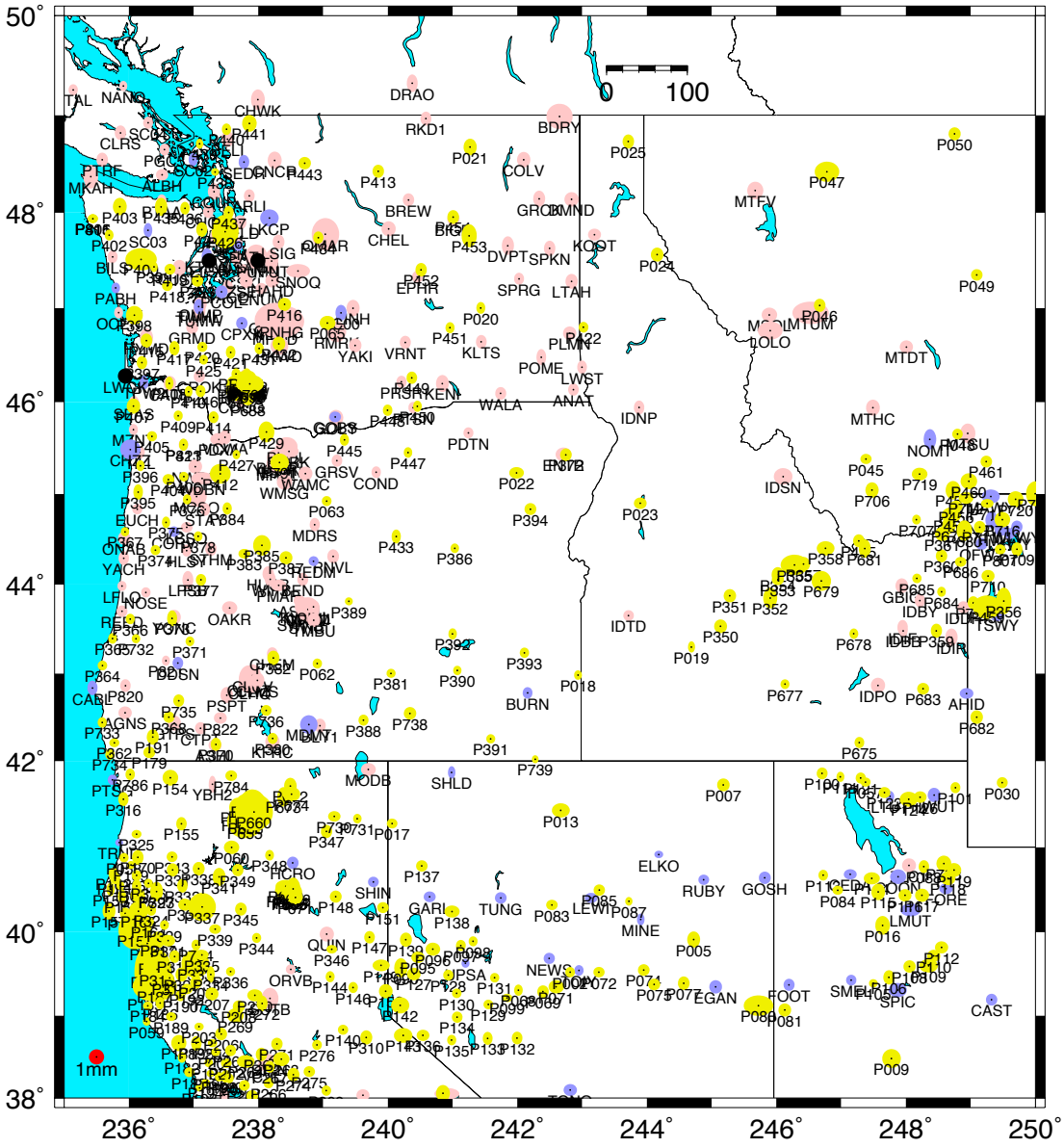

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1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

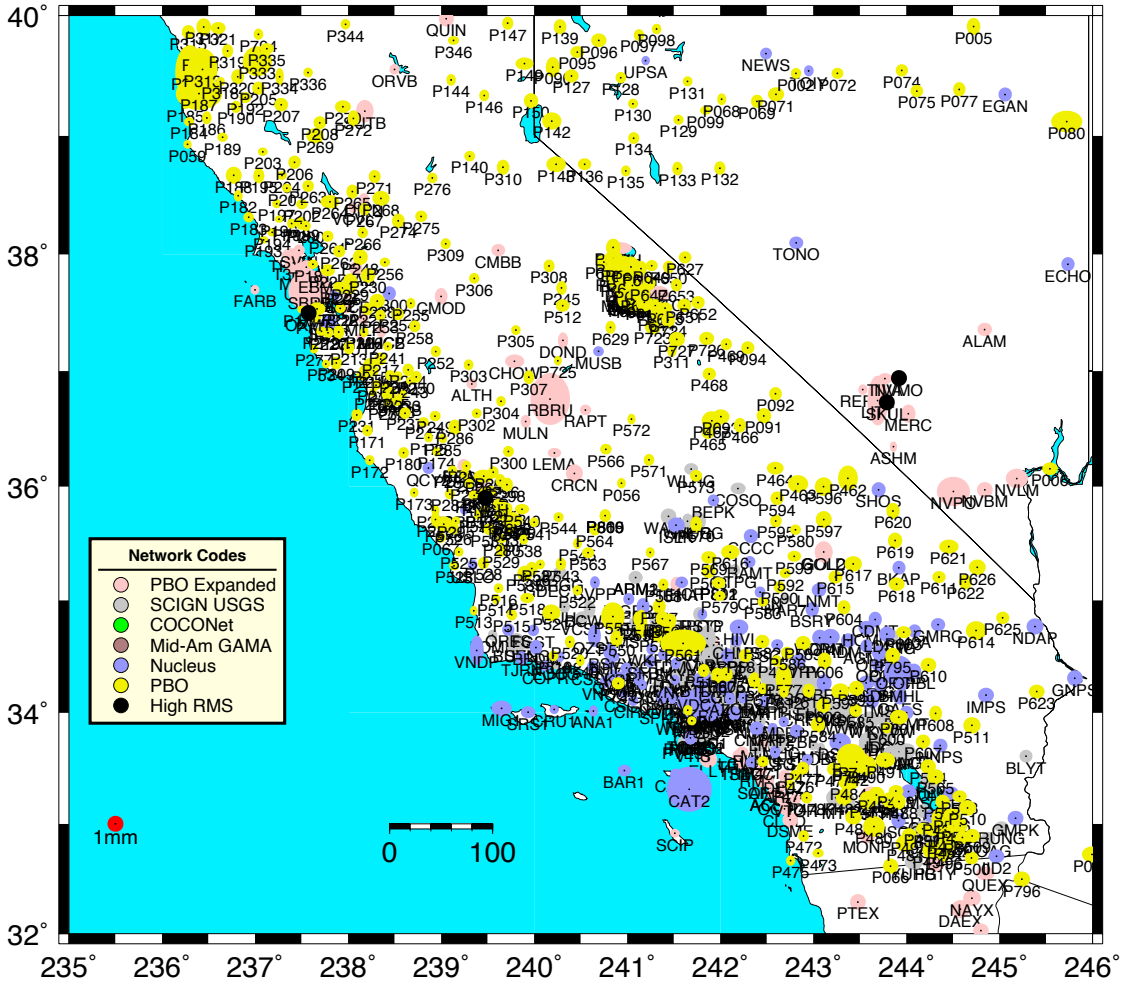

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

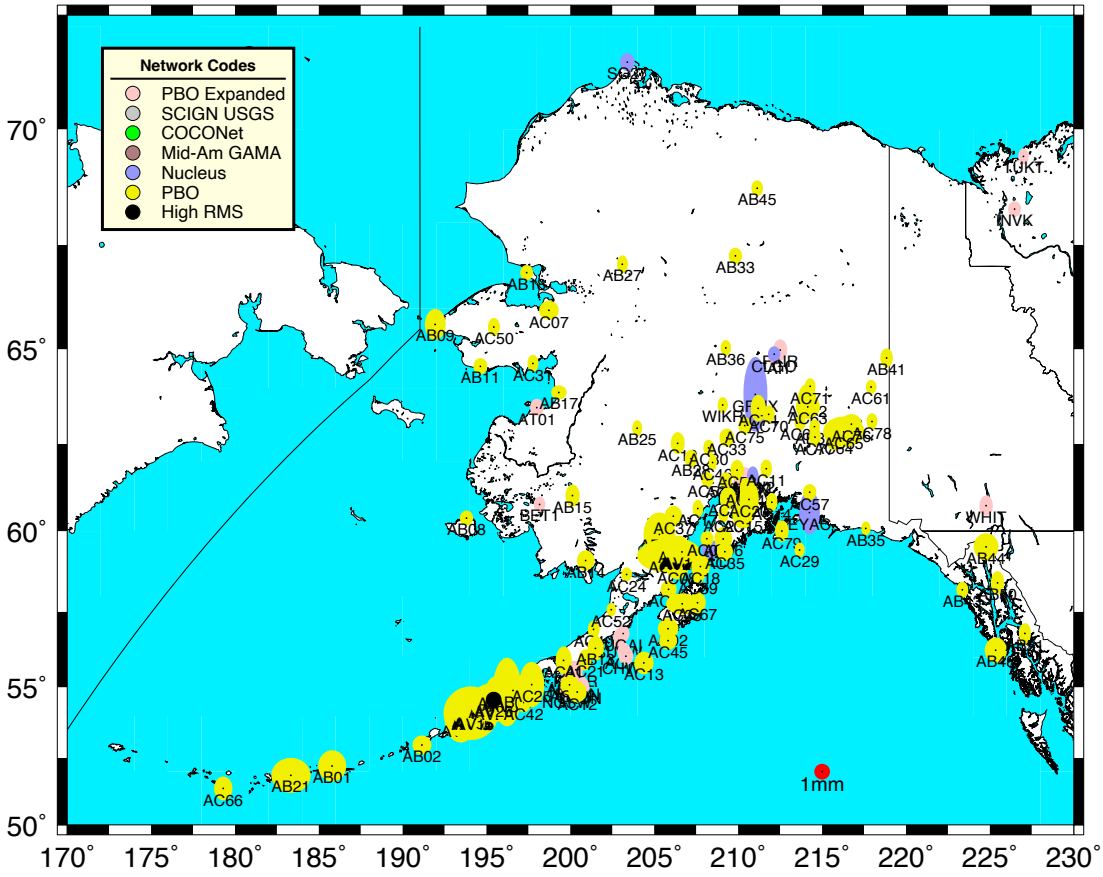

Figure 4: Same as Figure 4 except for the Alaskan region.

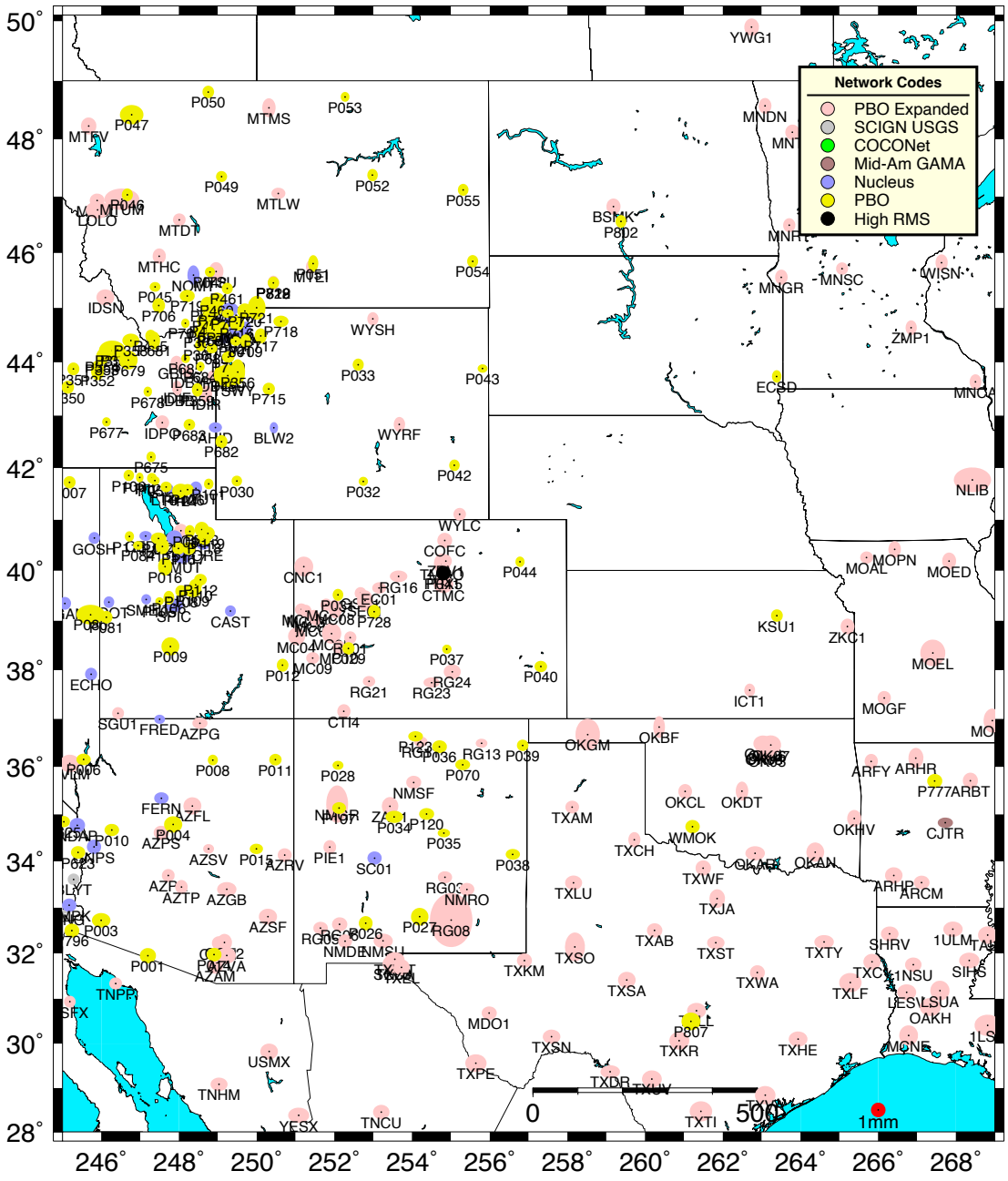

Figure 5: Same as Figure 4 except for the Central United States

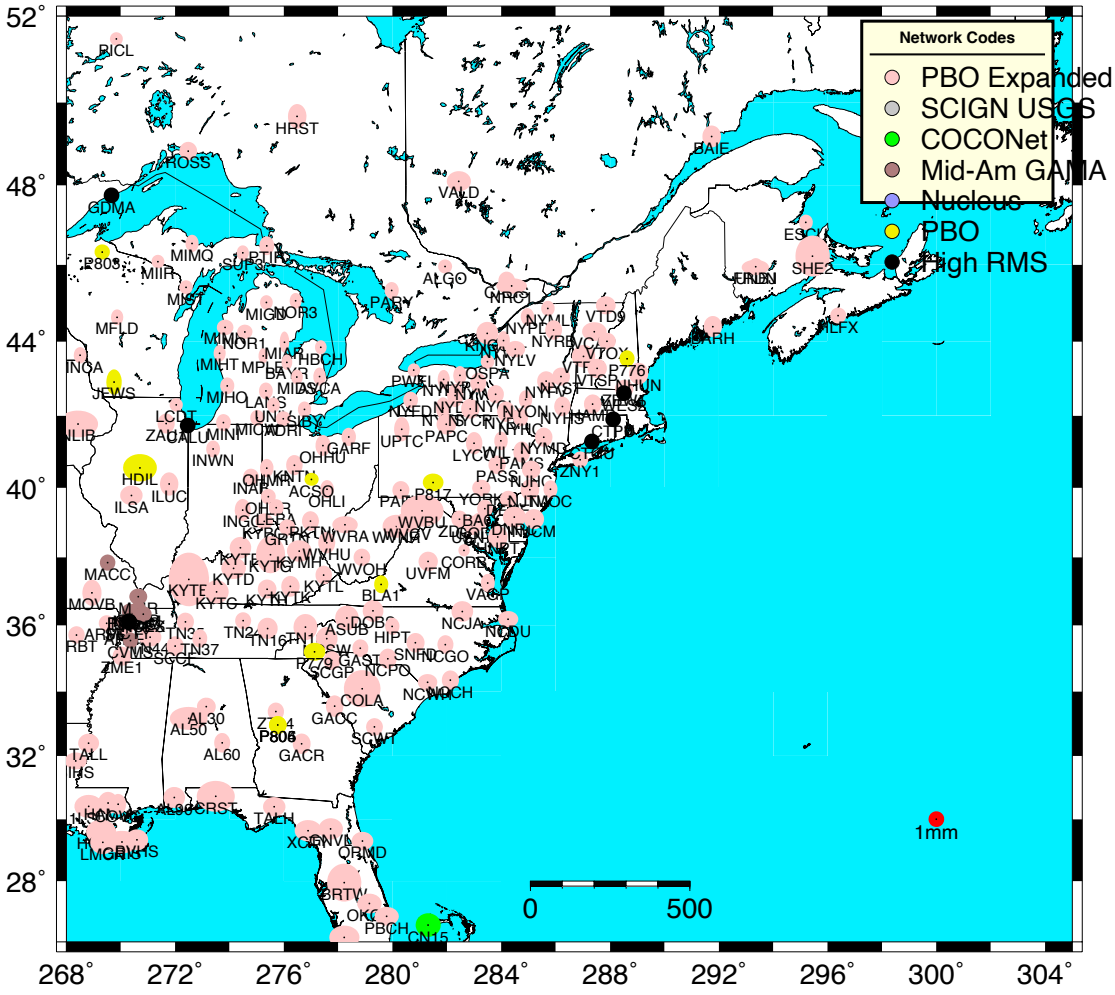

Figure 6: Same as Figure 4 except for the Eastern United States

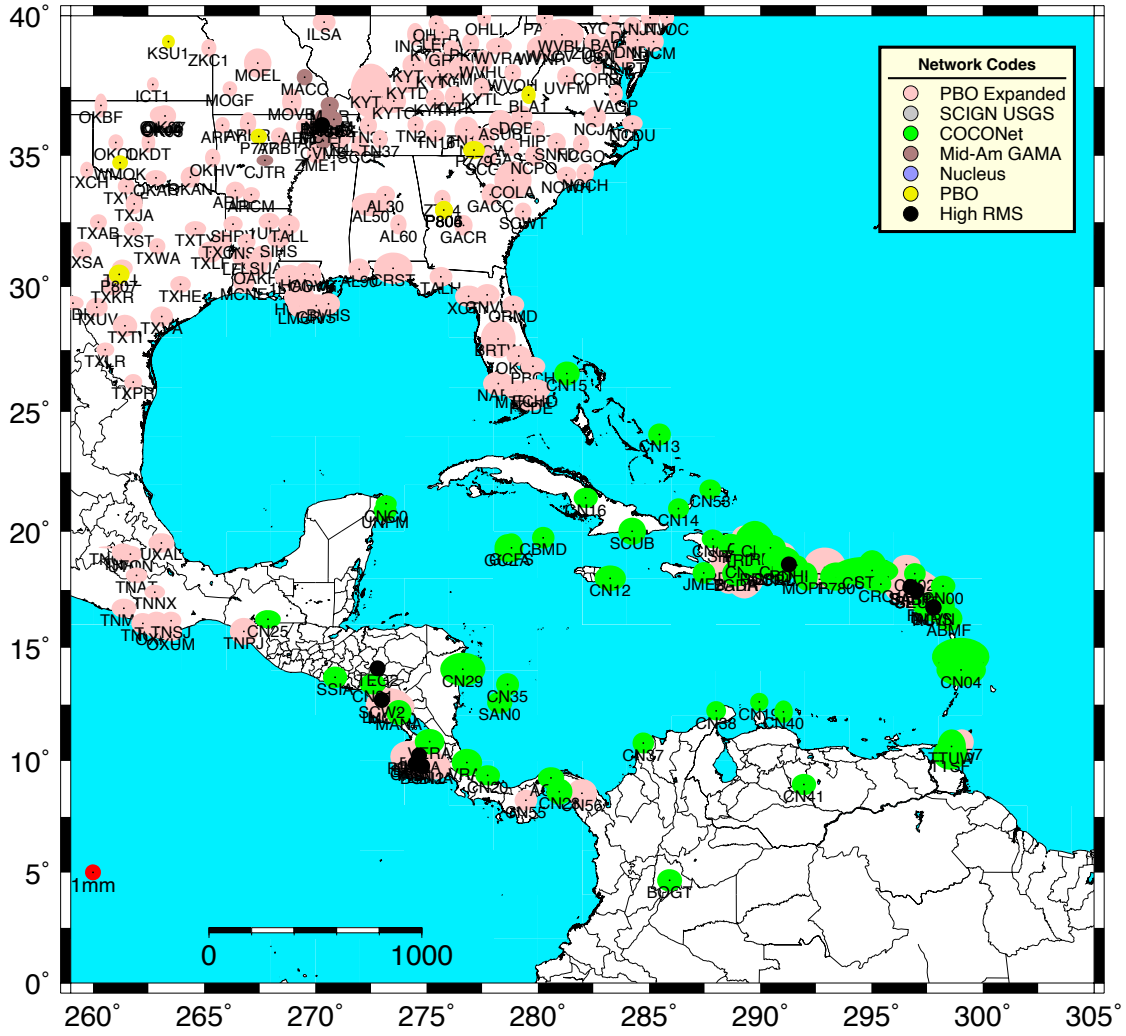

Figure 7: Same as Figure 4 except for the Caribbean region.

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 2705 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_220924.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_211218.snpvel.

Table 3: Statistics of the fits of 2705 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and September 24, 2022.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.40	1.36	6.19
70%			
CWU	1.76	1.71	7.03
95%			
CWU	3.90	3.63	11.58

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.

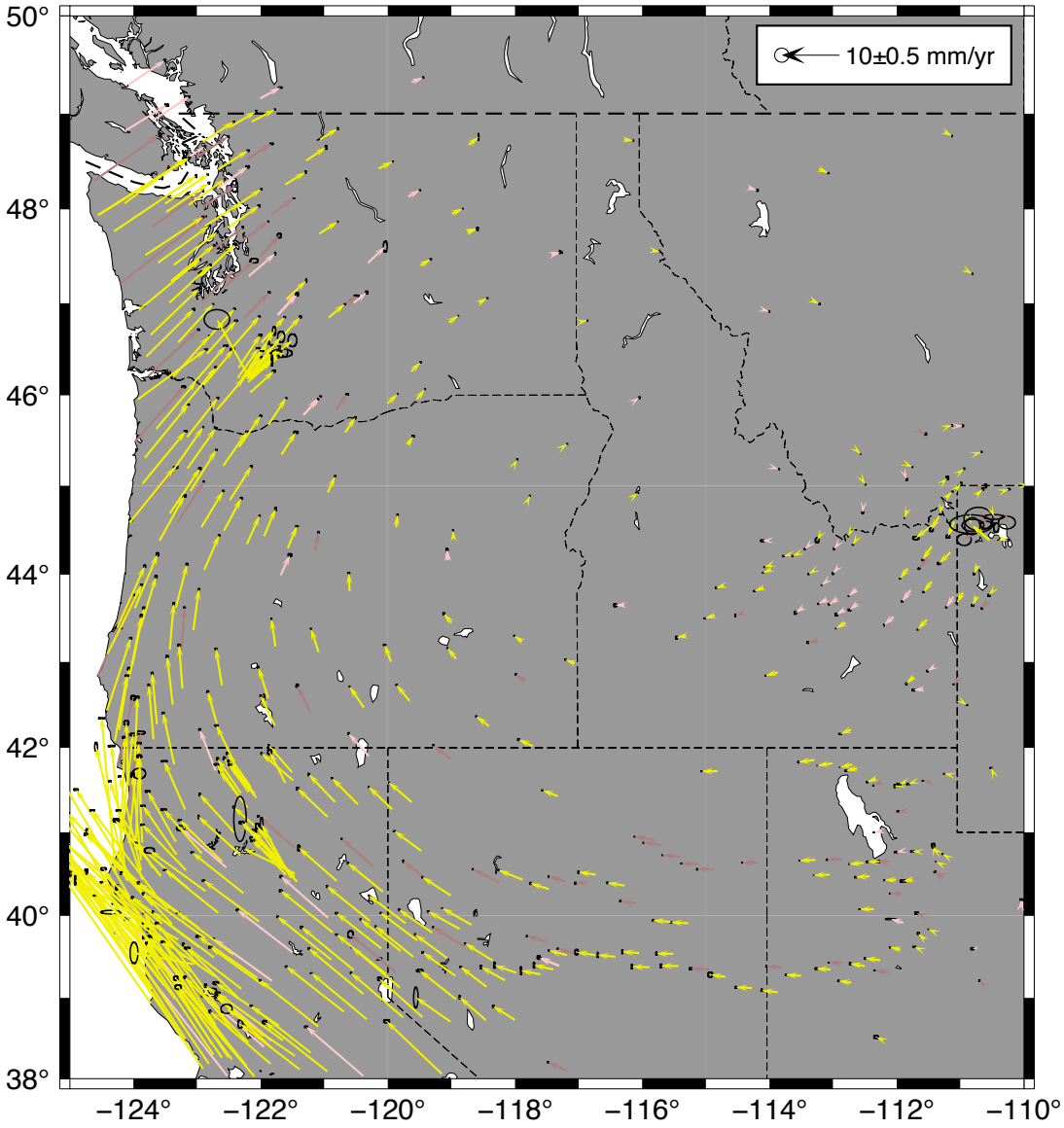

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

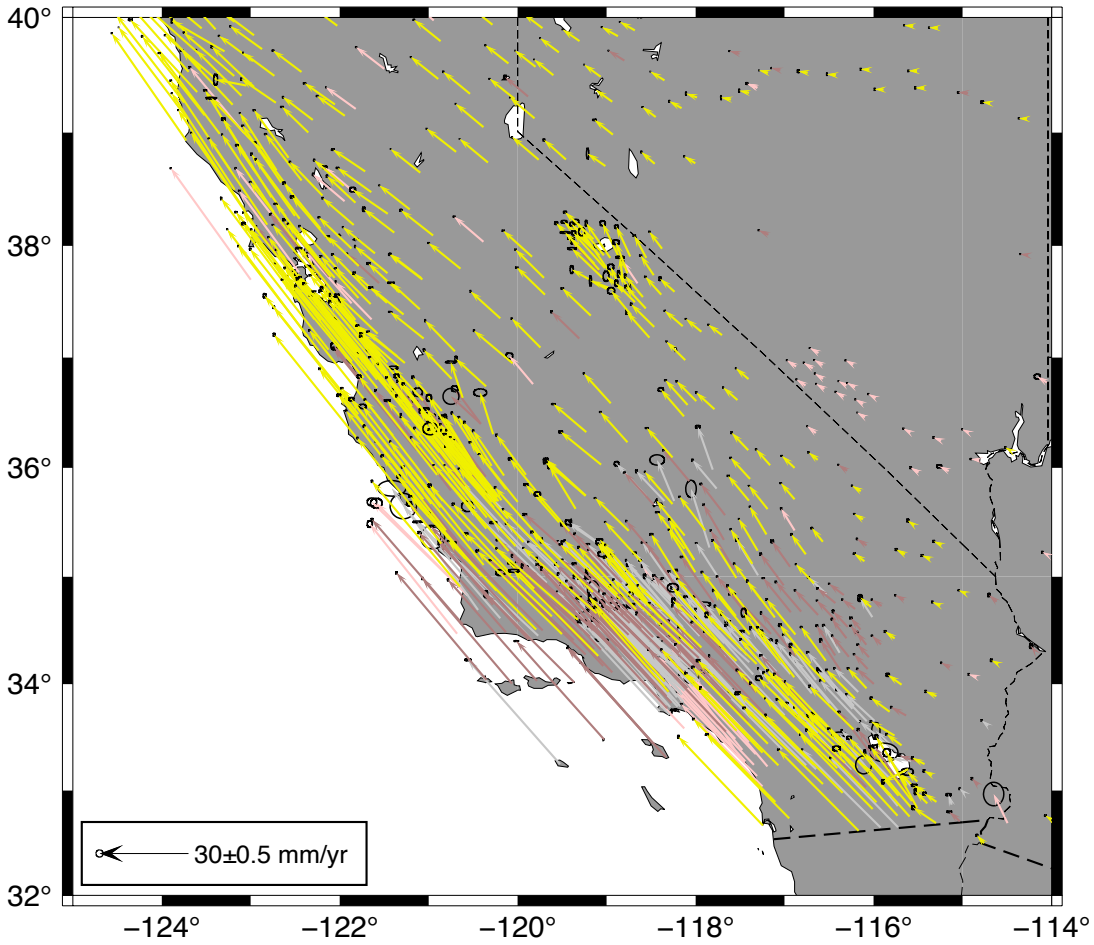

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

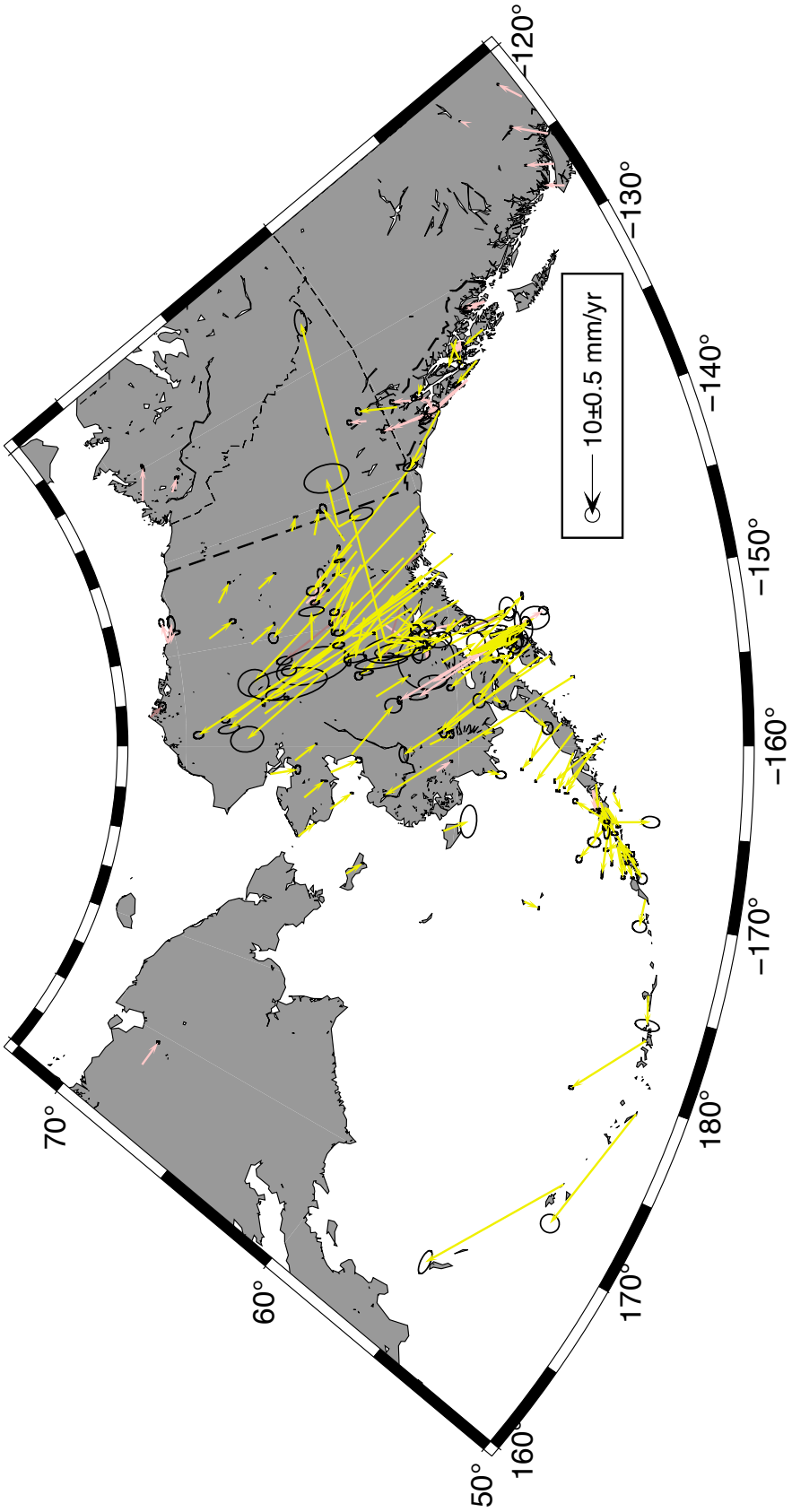

Figure 10:

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

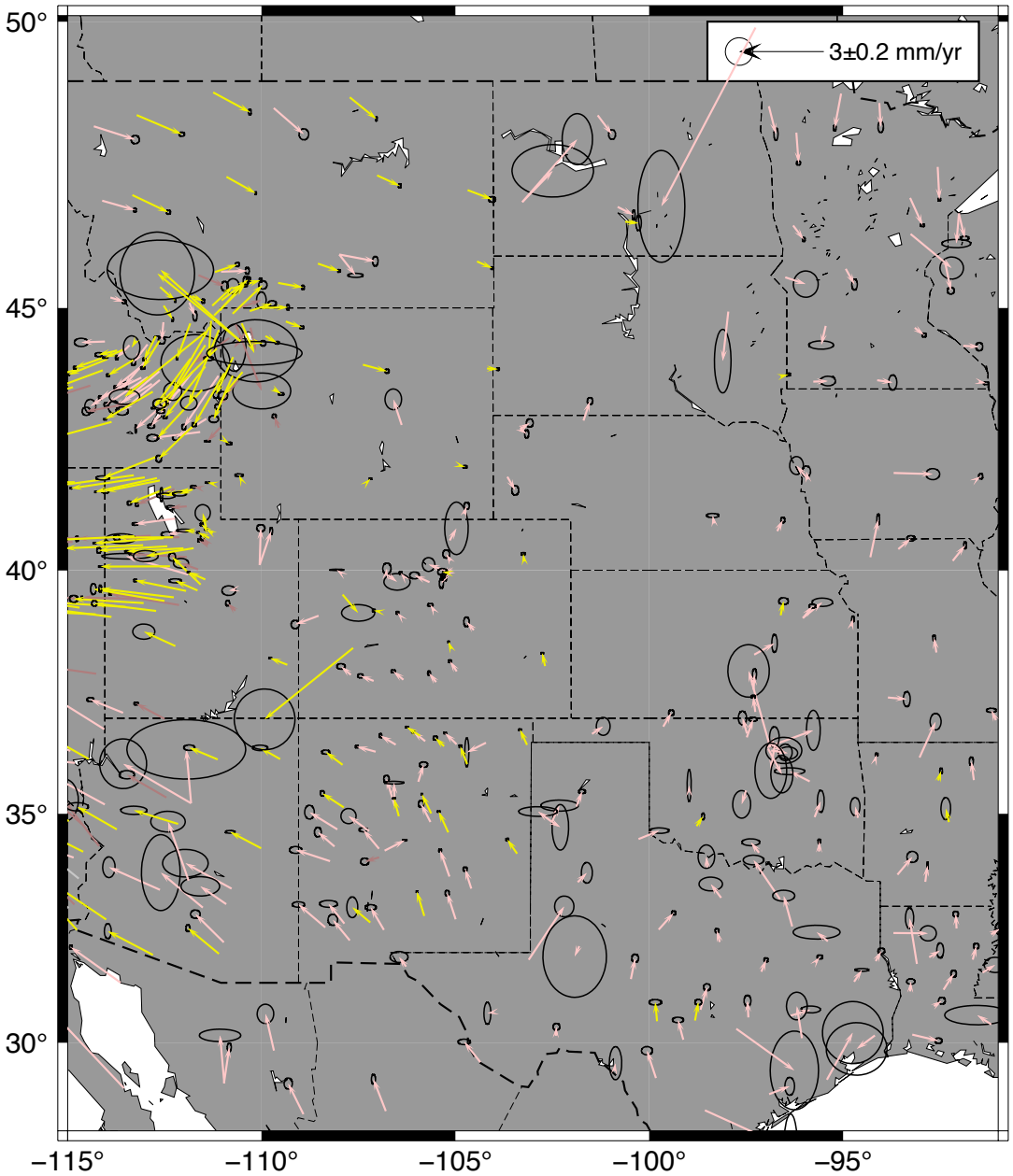

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

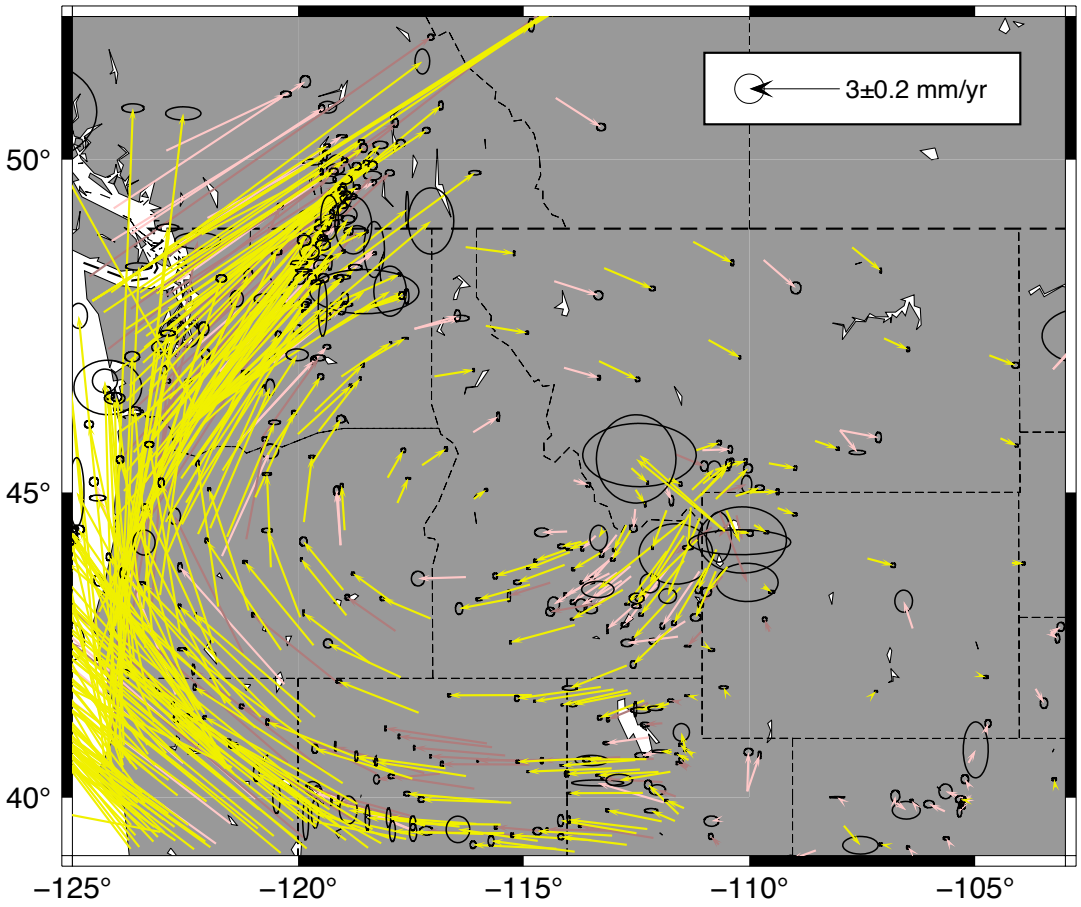

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

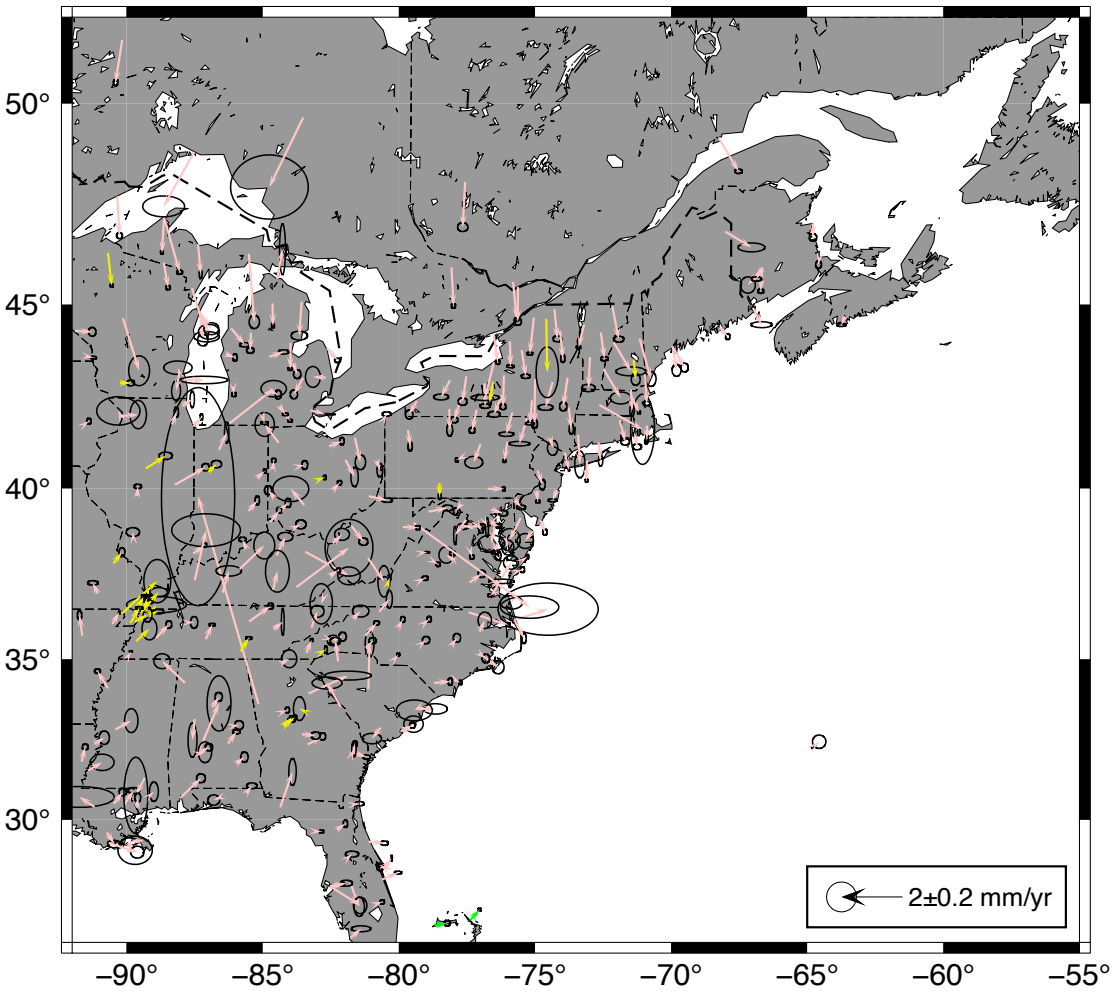

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

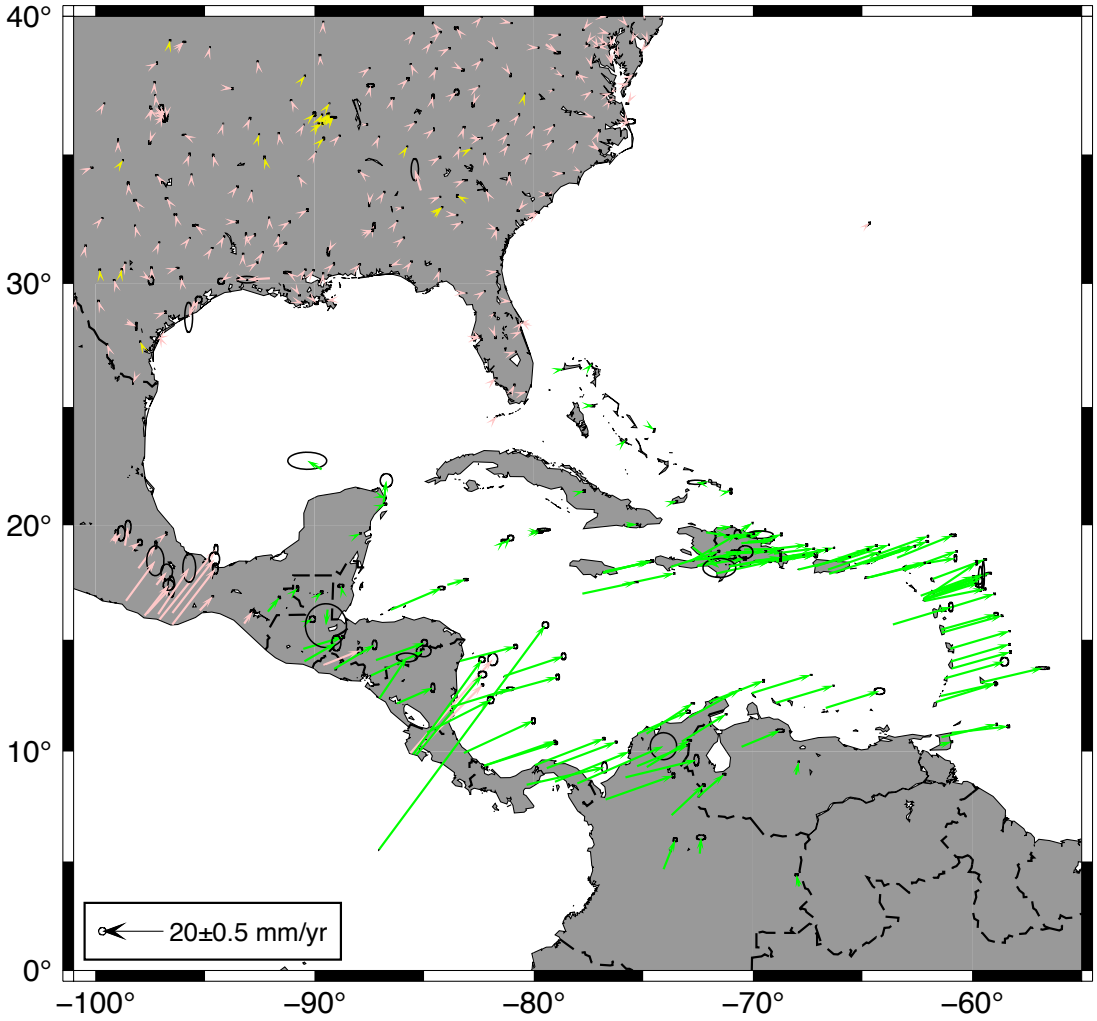

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2022/05/15-2022/09/30

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, only one generated displacements more than 1 mm. Event 67; ANSS(ComCat) us7000i9bw, mww7.6 37 km SE of Aquila. latitude/longitude 18.3667°/-103.2524° Date/Time 2022/09/19 18:06 generated observable offsets. Rapid and final event files have been sent to UNACVO. The Kalman filter estimates will be generated October 16 during our monthly updates. The finals estimates are shown in Figure 15.

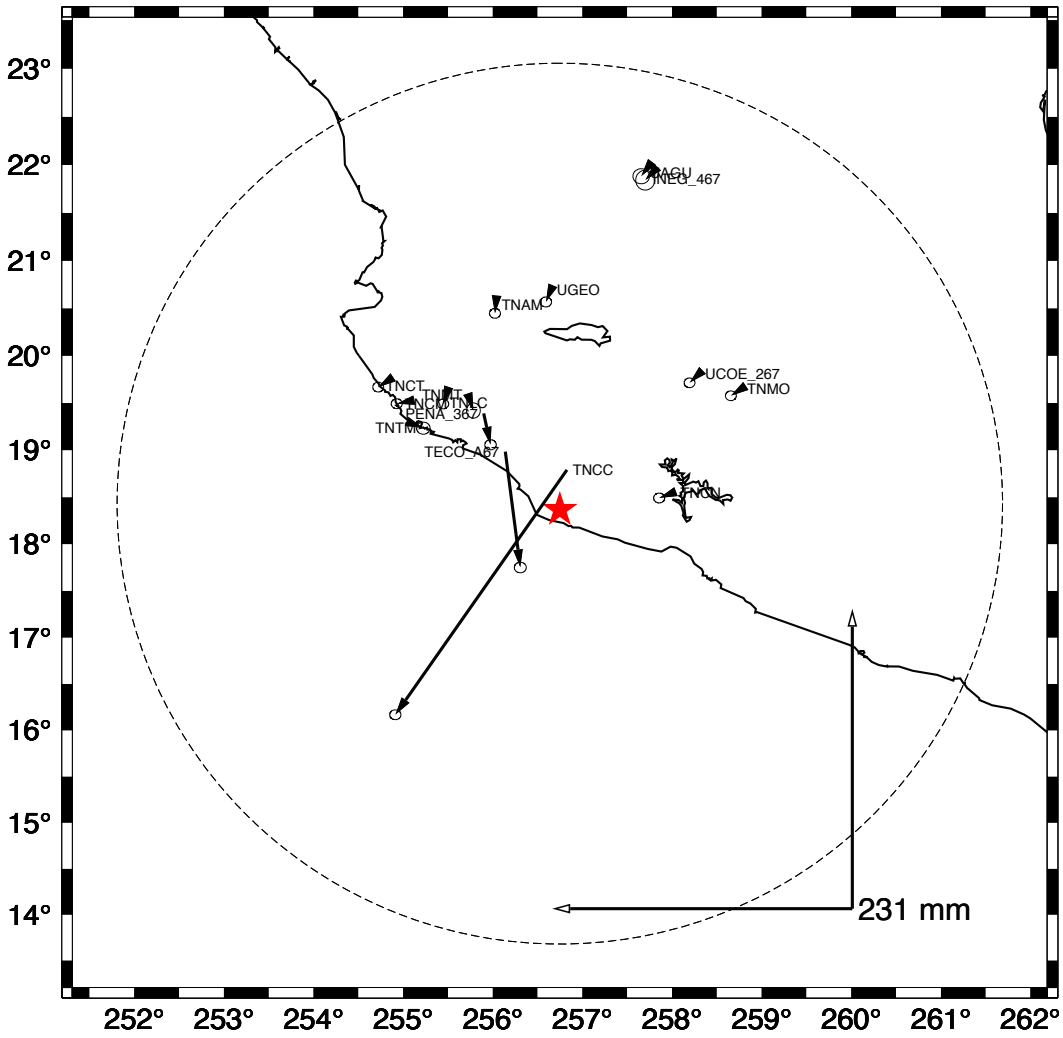

Figure 15: Coseismic offsets from the GAGE event 67; ANSS(ComCat) us7000i9bw, mww7.6 37 km SE of Aquila. latitude/longitude 18.3667°/-103.2524° Date/Time 2022/09/19 18:06. These results are from the finals analysis.

Antenna and other discontinuity events.

Antenna swaps at 40 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.

Site/s	Issues related to site

6/24/22	
LINJ	Example of Ridgecrest post seismic and other longer term changes. http://geoweb.mit.edu/~tah/ACC_PBO/LINJ.CWU.jpg
TILL	Failing antenna between 2019-2021 or tree growth. Strong North annual and slow slip (590 day period) in East. (West of Portland OR) http://geoweb.mit.edu/~tah/ACC_PBO/TILL.CWU.jpg
7/1/22	
KNGS	Offset with antenna change 2022/171. http://geoweb.mit.edu/~tah/ACC_PBO/KNGS.CWU.jpg
OLO1	Variability in time series http://geoweb.mit.edu/~tah/ACC_PBO/OLO1.CWU.jpg
OLO6	Similar variations to OLO1 http://geoweb.mit.edu/~tah/ACC_PBO/OLO6.CWU.jpg
TNMT	Drop in heights in rapids no antenna change in UNAVCO log. Starts 06/15/2022 and drops 100 mm over 4 days. http://geoweb.mit.edu/~tah/ACC_PBO/TNMT.CWU.jpg
TWIW	Strong (variable) annual signal in East and in Height. Site near Mt. St. Helens (not processed by UNR) http://geoweb.mit.edu/~tah/ACC_PBO/TWIW.CWU.jpg
7/8/22	
P307	Accelerating subsidence; does not show variability of P304, P303 intermediate (both in sediments north of Fresno, CA.) http://geoweb.mit.edu/~tah/ACC_PBO/P307.CWU.jpg
WLHG	Systematic variations in East and North; Large gap from 2019 to 2022. Large height in rapids until antenna metadata corrected. http://geoweb.mit.edu/~tah/ACC_PBO/WLHG.CWU.jpg
7/15/22	
P300	Creeping section of San Andreas (see notes on P302 above). http://geoweb.mit.edu/~tah/ACC_PBO/P300.CWU.jpg
7/29/22	
MDRS	Height jump after gap. Looks like new antenna but no update to PANGA log for site. http://geoweb.mit.edu/~tah/ACC_PBO/MDRS.CWU.jpg
POME	Small height from antenna change 2022/201 but large 100 mm change in June 2014 which has no meta data change. Also problem with 2011 antenna change where meta data not updated for several months http://geoweb.mit.edu/~tah/ACC_PBO/POME.CWU.jpg
8/5/22	
AC38	Strongly skewed to south; outliers due to snow as well probably. Located on Unimak Island. http://geoweb.mit.edu/~tah/ACC_PBO/AV38.CWU.jpg
MC07	Near Grand Junction, Colorado; very systematics. MC08 also systematics with outliers (snow?). Not in UNAVCO nota stations. http://geoweb.mit.edu/~tah/ACC_PBO/MC07.CWU.jpg

8/17/22	
AL60	CORS sites; new antenna but no metadata update yet. http://geoweb.mit.edu/~tah/ACC_PBO/AL60.CWU.jpg
LLAS	New antenna. No metadata update yet. Site is north of LA. Post-seismic from Ridgecrest. http://geoweb.mit.edu/~tah/ACC_PBO/LLAS.CWU.jpg
MHCB	Antenna change with no metadata update. CORS site. Large post-seismic from Mw5.5 ANSS(ComCat) nc40204628 2007/10/31. (Already modeled). http://geoweb.mit.edu/~tah/ACC_PBO/MHCB.CWU.jpg
P242	Strong annuals in all components. Seems to be middle of valley floor. Site southe of San Jose. http://geoweb.mit.edu/~tah/ACC_PBO/P242.CWU.jpg
TECO	Unknown offset 2021/12/15. Mostly in north. Site in Mexico. Maybe vegetation growth in height since 2020. http://geoweb.mit.edu/~tah/ACC_PBO/TECO.CWU.jpg
8/26/22	Not reported (No telecon report yet).
AV27	Long gap since start of 2021; heavily affected by snow; Large height offset but no new antenna. Could be snow. http://geoweb.mit.edu/~tah/ACC_PBO/AV27.CWU.jpg
BUEG	Very systematic. Site inland from Vandenberg. Not clear what is happening. http://geoweb.mit.edu/~tah/ACC_PBO/BUEG.CWU.jpg
CABA	Recent rapids are showing transient like behavior in all components. Site in Costa Rica. Site seems to be field. http://geoweb.mit.edu/~tah/ACC_PBO/CABA.CWU.jpg
MCTY	Site in Missouri show rapid east motion (30 mm). Deviations in North starting late 2019. http://geoweb.mit.edu/~tah/ACC_PBO/MCTY.CWU.jpg
9/3/22	
AV06	Small jump in East. Previous outliers like this. http://geoweb.mit.edu/~tah/ACC_PBO/AV06.CWU.jpg
HDIL	General systematic behavior. Site near Peoria in Illinois. http://geoweb.mit.edu/~tah/ACC_PBO/HDIL.CWU.jpg
P271	Really starting to sink. Near Sacramento CA. Site previously noted. North developed annual signal starting in 2012. http://geoweb.mit.edu/~tah/ACC_PBO/P271.CWU.jpg
P810	Dry out as well. Near Bakersfield. http://geoweb.mit.edu/~tah/ACC_PBO/P810.CWU.jpg
PNHG	Not much data, near Mt. Rainier. Seems OK. http://geoweb.mit.edu/~tah/ACC_PBO/PNHG.CWU.jpg
TXSO	CORS site in middle of Texas. Lots of outliers in rapids. Errorbars are not changed. No meta data update. http://geoweb.mit.edu/~tah/ACC_PBO/TXSO.CWU.jpg
UGEO	Data from 200302-20000320 are >100 meters off. Removed from pos file. Site in Guadalajara Mexico. Time series curved. http://geoweb.mit.edu/~tah/ACC_PBO/UGEO.CWU.jpg

9/16/22	
AB22	Restart after 2 year gap; evidence of snow effects but seems to be an offset in North. http://geoweb.mit.edu/~tah/ACC_PBO/AB22.CWU.jpg
P630	Distinct shape for North motions amplitude of almost 20 mm. Superimposed on hold longer 10 year type period signal. Located in Mammoth Lakes. http://geoweb.mit.edu/~tah/ACC_PBO/P630.CWU.jpg
9/23/22	Not reported
IQAL	Site in northern Canada, outliers in east , might be snow but only seen in recent years. http://geoweb.mit.edu/~tah/ACC_PBO/IQAL.CWU.jpg
MORP	Site in England. Probably failing antenna. http://geoweb.mit.edu/~tah/ACC_PBO/MORP.CWU.jpg
P080	Near Nevada/Utah border, skewed in east. http://geoweb.mit.edu/~tah/ACC_PBO/P080.CWU.jpg
TNCC	Offset due to ANSS(ComCat) us7000i9bw mww7.6 37 km SE of Aquila 18.3667°N -103.2524°W 2022/09/19 18:06. -120 mm East offset. http://geoweb.mit.edu/~tah/ACC_PBO/TNCC.CWU.jpg
10/7/22	
CSHQ	Jump in height after gap. No meta data change. Liberty Cap Washington State. Maybe snow. http://geoweb.mit.edu/~tah/ACC_PBO/CSHQ.CWU.jpg
ENTR	Height change but no meta data update. PANGA site. http://geoweb.mit.edu/~tah/ACC_PBO/ENTR.CWU.jpg
TNAM	10 mm excursion in North. Annual in height developed in height starting 2019? Site near Guadalajara Mexico. http://geoweb.mit.edu/~tah/ACC_PBO/TNAM.CWU.jpg
TNCN	Offset from 22/09/19 Mw7.6 earthquake. Just came back online. http://geoweb.mit.edu/~tah/ACC_PBO/TNCN.CWU.jpg
UAGU	Long term systematics with height rate change 2015. Just came back online. http://geoweb.mit.edu/~tah/ACC_PBO/UAGU.CWU.jpg

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 34 stations in the ANET region for CWU analyzed in the final orbit analysis between May 15, 2022 and September 24, 2022.

CWU	North (mm)	East (mm)	Up (mm)
Median			
ANET	1.54	1.14	6.00
70%			
ANET	1.85	1.36	6.68
95%			
ANET	3.06	1.75	9.35

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

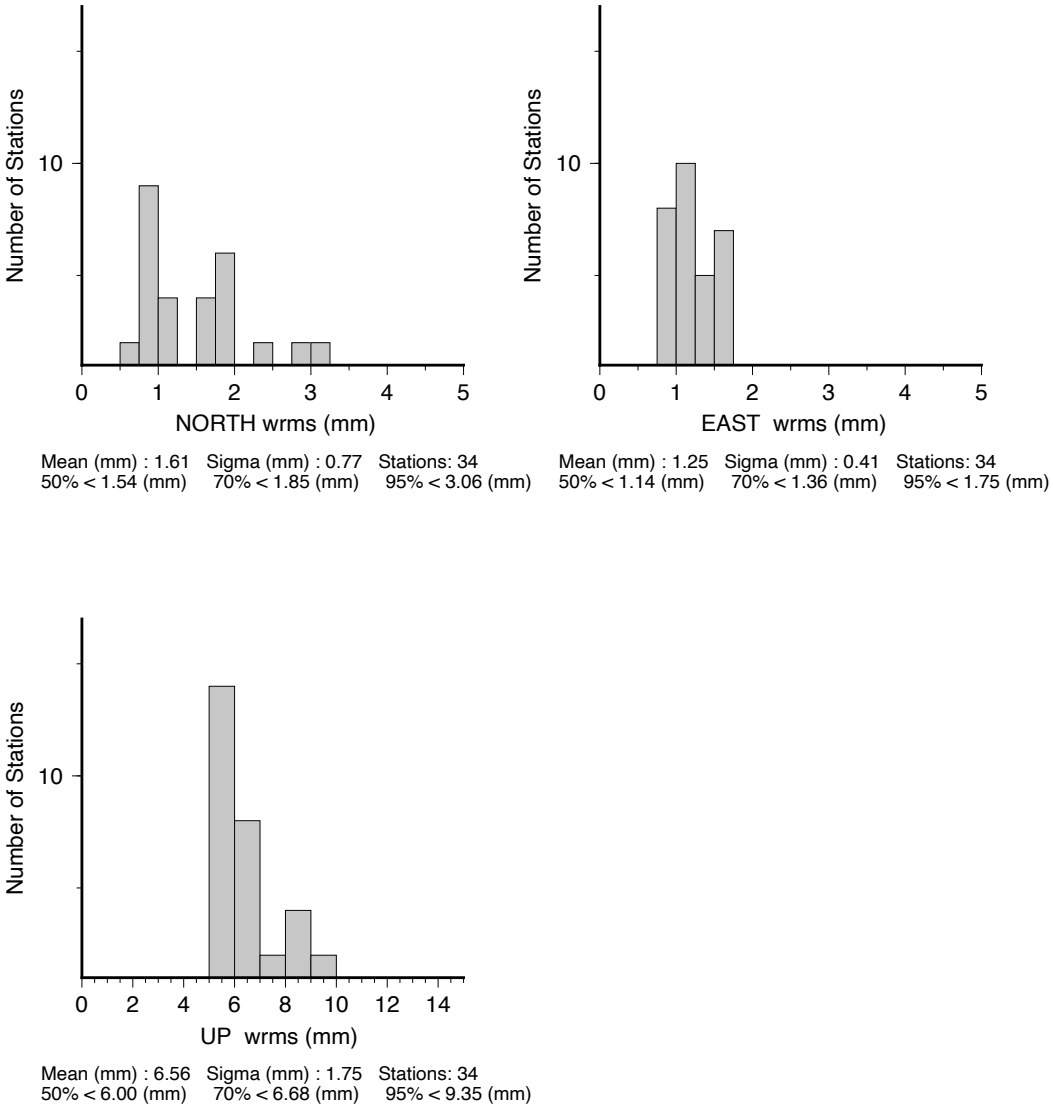

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 34 stations in Antarctica analyzed between May 15, 2022 and September 24, 2022. Linear trends and annual signals were estimated from the time series.

References

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