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

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Period: 2022/04/01-2022/06/30

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 2022/02/15 to 2022/06/30, time series velocity field analyses for the GAGE reprocessing analyses (1996-2022). Several earthquakes were investigated this quarter but only one of them, event 66; ANSS(ComCat) us6000hf75, mww6.6 55 km WSW of Masachapa lat/long 11.5537° -86.9604° on 2022/04/21 07:43 UTC 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 2010 stations were processed, which is 89 more than last quarter. In addition up to 47 sites were processed in the ANET solutions, the same as 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, 2022– June 24, 2022

For this report, we generated the statistics using the ~3 months of CWU results between March 15, 2022 and June 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 2010 stations for CWU analyzed in the finals analysis between March 15, 2022 and June 24, 2022. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.93	0.89	4.80
70%			
CWU	1.11	1.10	5.36
95%			
CWU	1.96	2.19	8.02

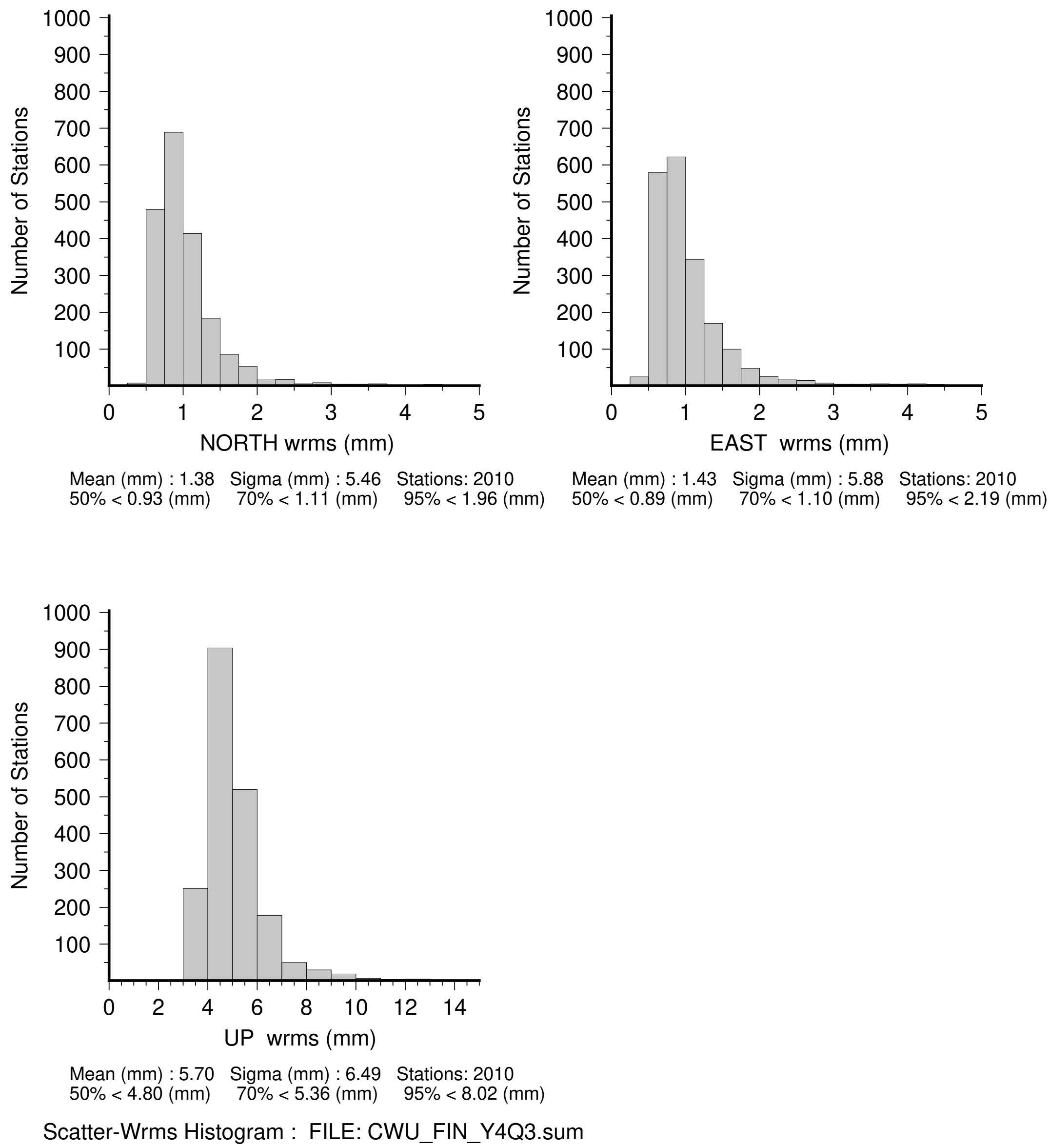

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 2010 stations analyzed between March 15, 2022 and June 24, 2022. Linear trends and annual signals were estimated from the time series.

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_Y4Q3.tab.

There are 1921 stations in the file for sites that have at least 2 measurements during the month.

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Tabular Position RMS scatters created from CWU_FIN_Y4Q3.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   107      1.1   0.60      1.4   0.68     6.5   0.71     19.42
 1NSU   107      0.9   0.53      1.0   0.59     4.8   0.62     18.68
 1ULM   107      0.9   0.50      1.2   0.73     5.2   0.69     19.28
 AB01   107      1.8   0.86      1.2   0.84     5.3   0.75     15.35
…
 ZDV1   102      0.9   0.46      1.1   0.72     6.0   0.79     19.31
 ZKC1   102      1.1   0.57      0.9   0.57     6.7   0.86     19.31
 ZLA1   102      1.1   0.60      1.0   0.65     5.6   0.73     19.31
 ZLC1   102      0.8   0.40      0.8   0.51     5.5   0.72     19.54
 ZME1   103      1.3   0.73      1.1   0.71     5.0   0.65     19.54
 ZMP1   102      0.9   0.44      0.9   0.55     5.9   0.79     19.78
 ZNY1   102      0.9   0.48      0.9   0.60     6.0   0.77     19.69
 ZOA1   102      0.8   0.40      0.7   0.47     4.6   0.61     20.23
 ZSE1   102      1.0   0.47      0.9   0.62     4.7   0.63     19.69
 ZTL4   102      0.9   0.52      1.1   0.70     5.2   0.68     19.89
```

Table 2: RMS scatter of the position residuals for the CWU solution between March 15, 2022 and June 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	0.84	0.82	4.49	841
NUCLEUS	0.76	0.77	4.45	183
GAMA	0.89	0.93	5.07	15
COCONet	1.28	1.48	6.44	69
USGS_SCIGN	0.84	0.82	4.47	117
Expanded	1.02	1.00	5.17	785
70%				
PBO	1.02	0.99	4.90	
NUCLEUS	0.87	0.88	4.83	
GAMA	0.90	0.99	5.23	
COCONet	1.40	1.67	6.84	

USGS_SCIGN	1.03	0.95	5.06
Expanded	1.19	1.20	5.72
95%			
PBO	1.83	1.87	6.80
NUCLEUS	1.26	1.27	5.86
GAMA	1.10	1.07	6.14
COCONet	2.19	4.13	14.82
USGS_SCIGN	1.73	1.94	7.70
Expanded	2.25	2.66	9.28

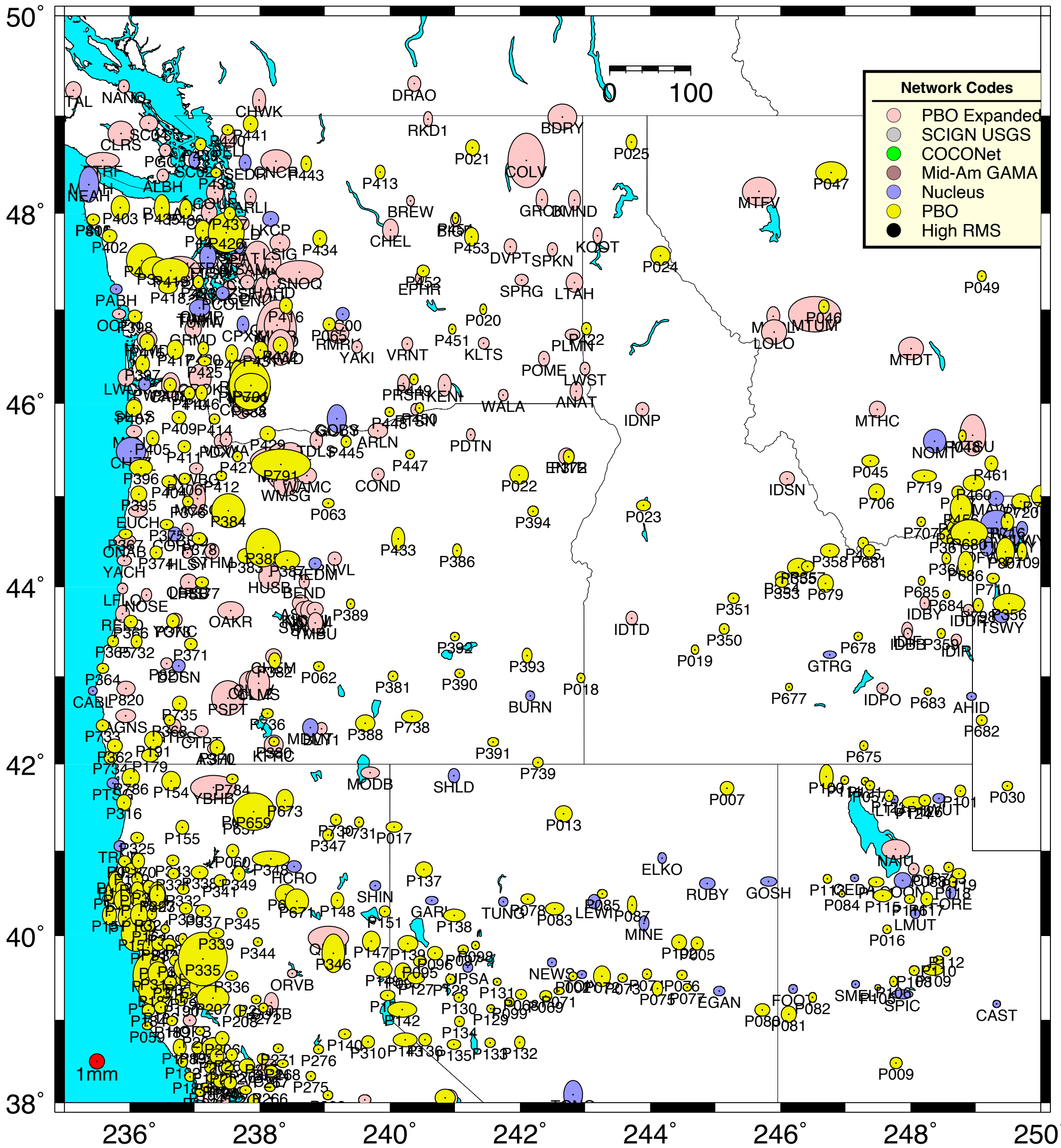

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1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

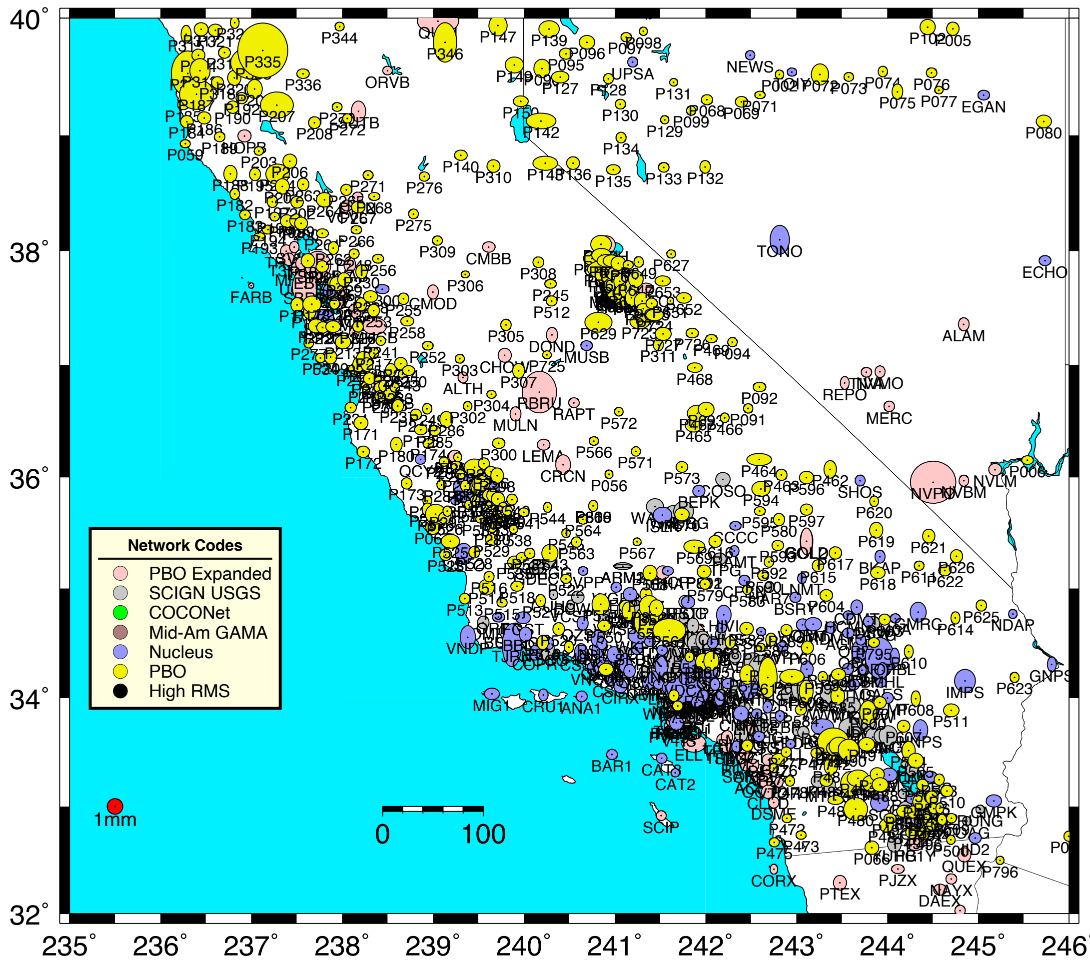

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

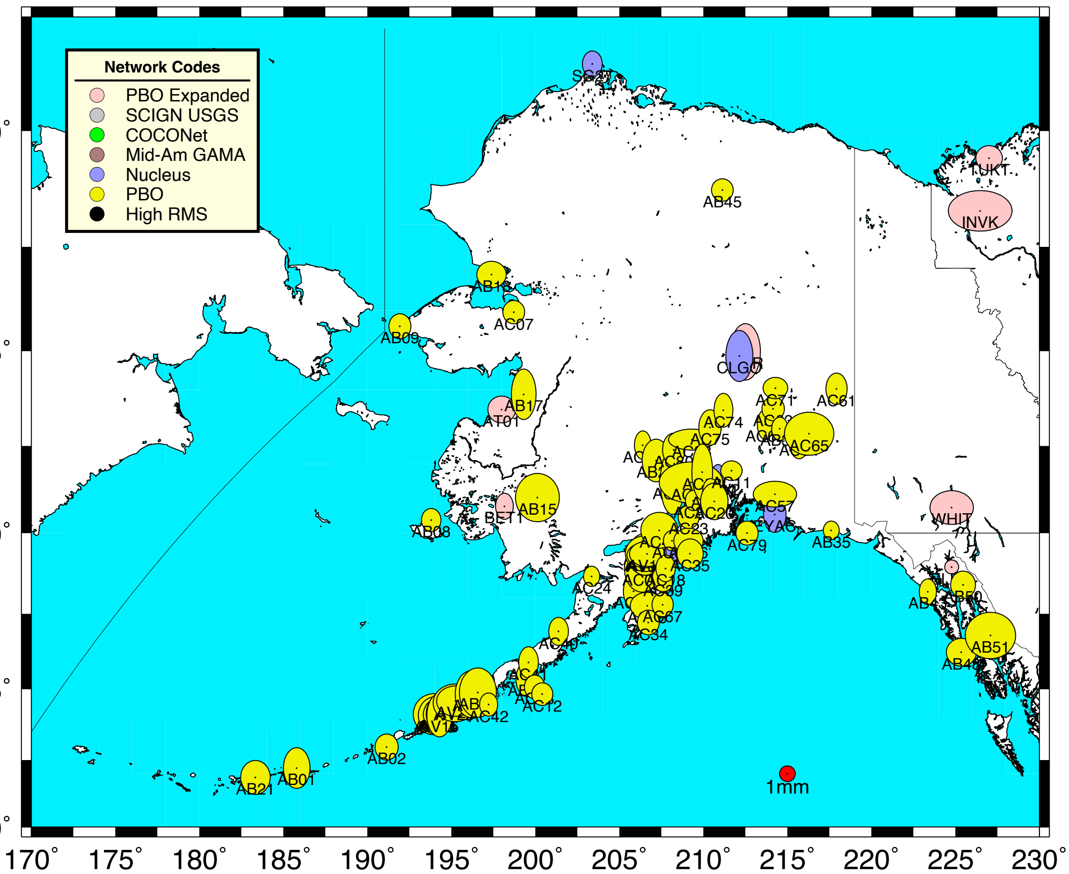

Figure 4: Same as Figure 4 except for the Alaskan region.

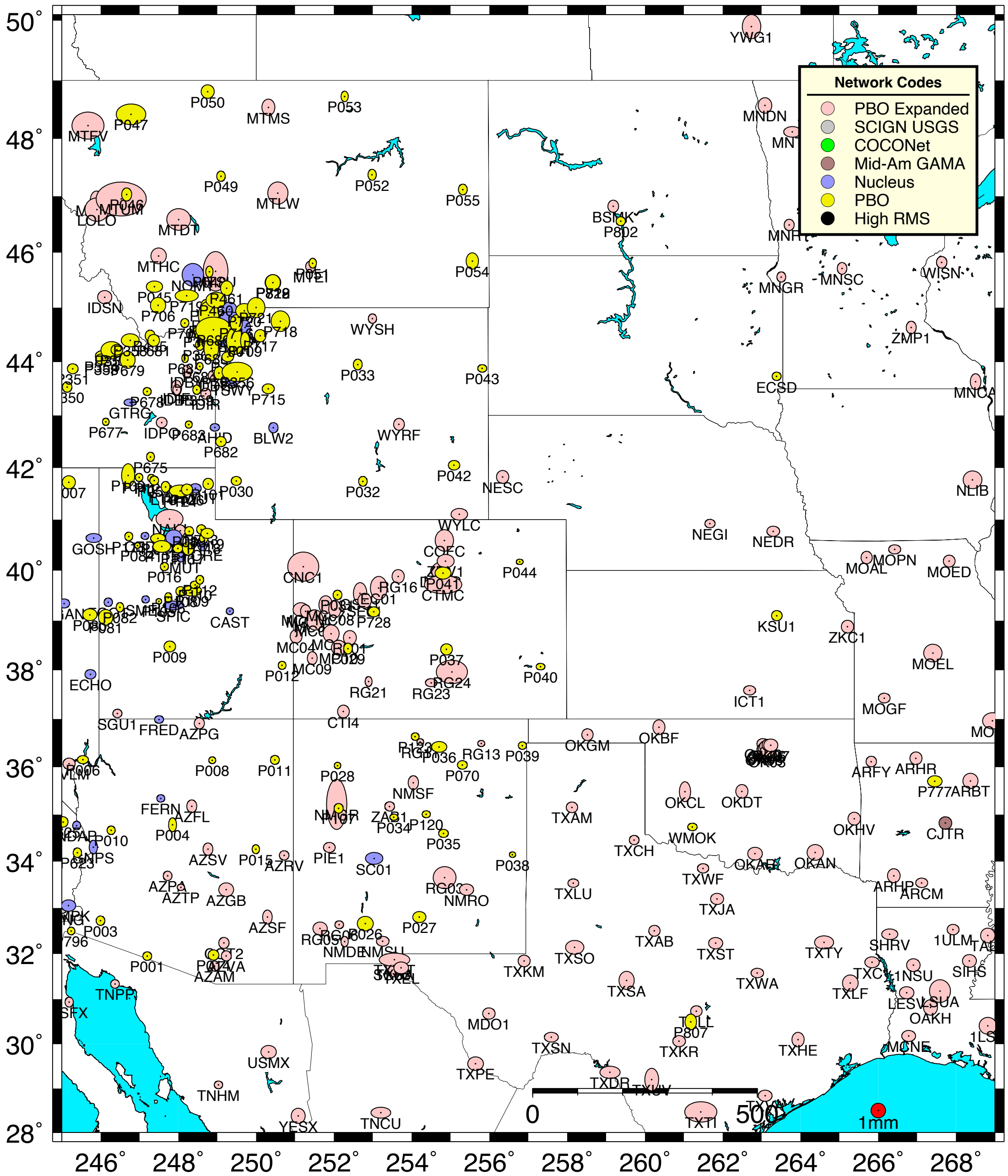

Figure 5: Same as Figure 4 except for the Central United States

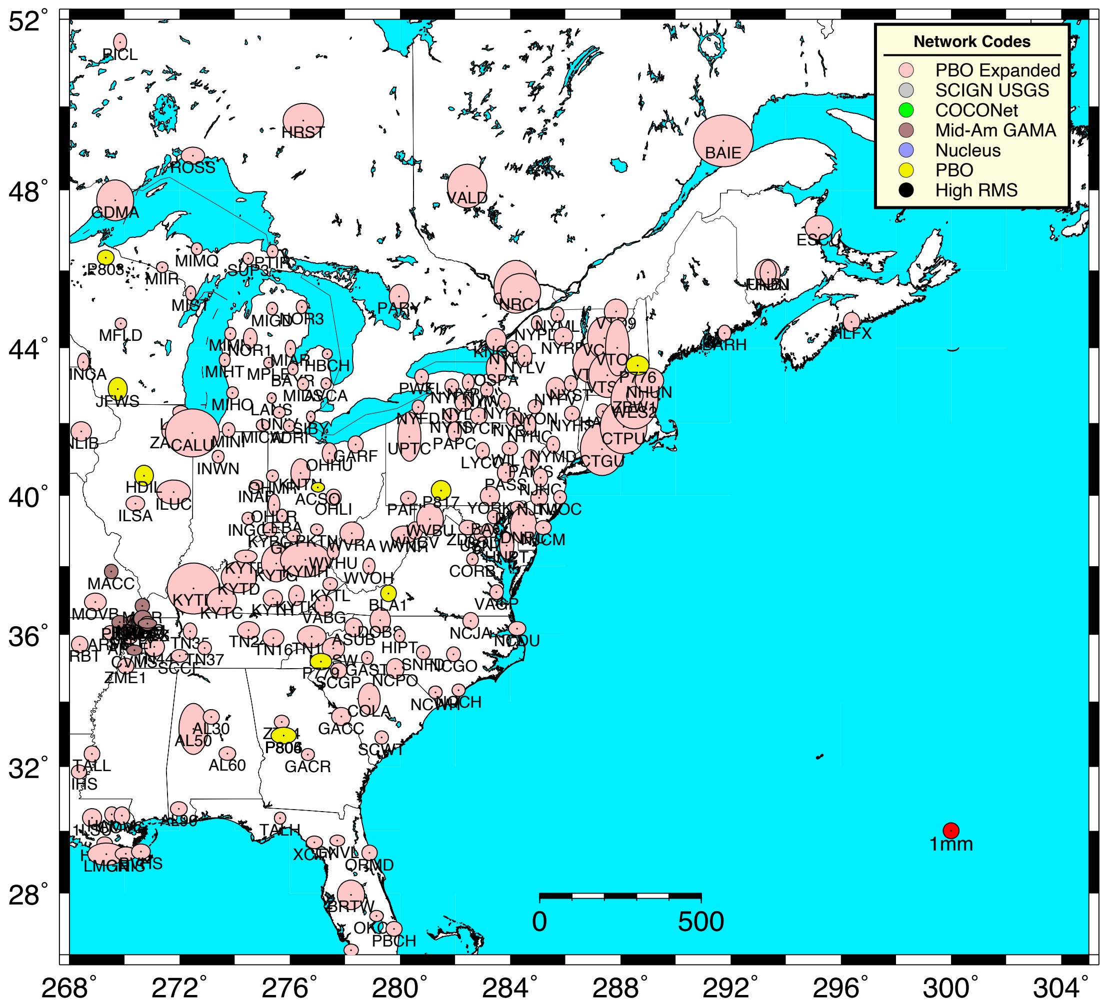

Figure 6: Same as Figure 4 except for the Eastern United States

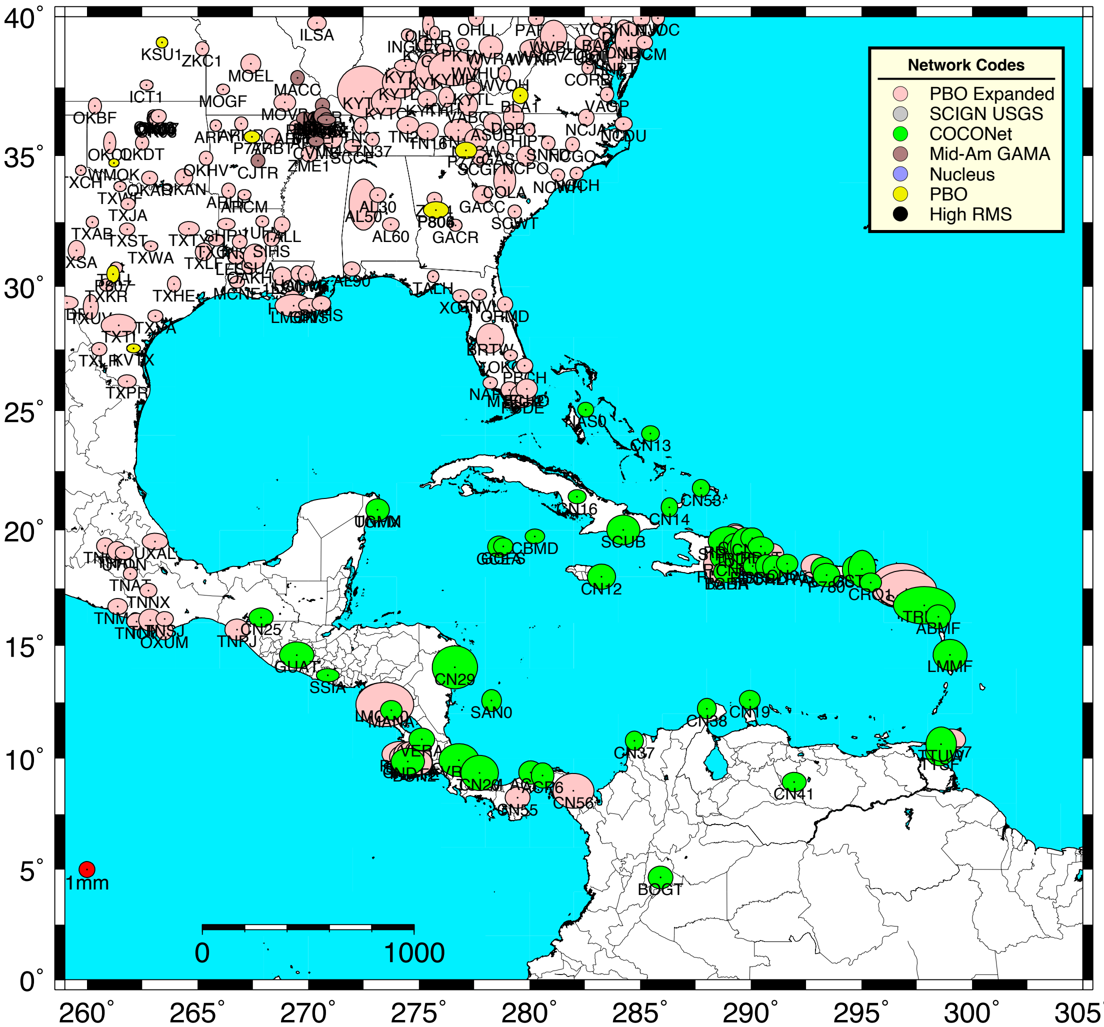

Figure 7: Same as Figure 4 except for the Caribbean region.

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 2669 stations in the CWU solution (3 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_220624.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_220624.snpvel.

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

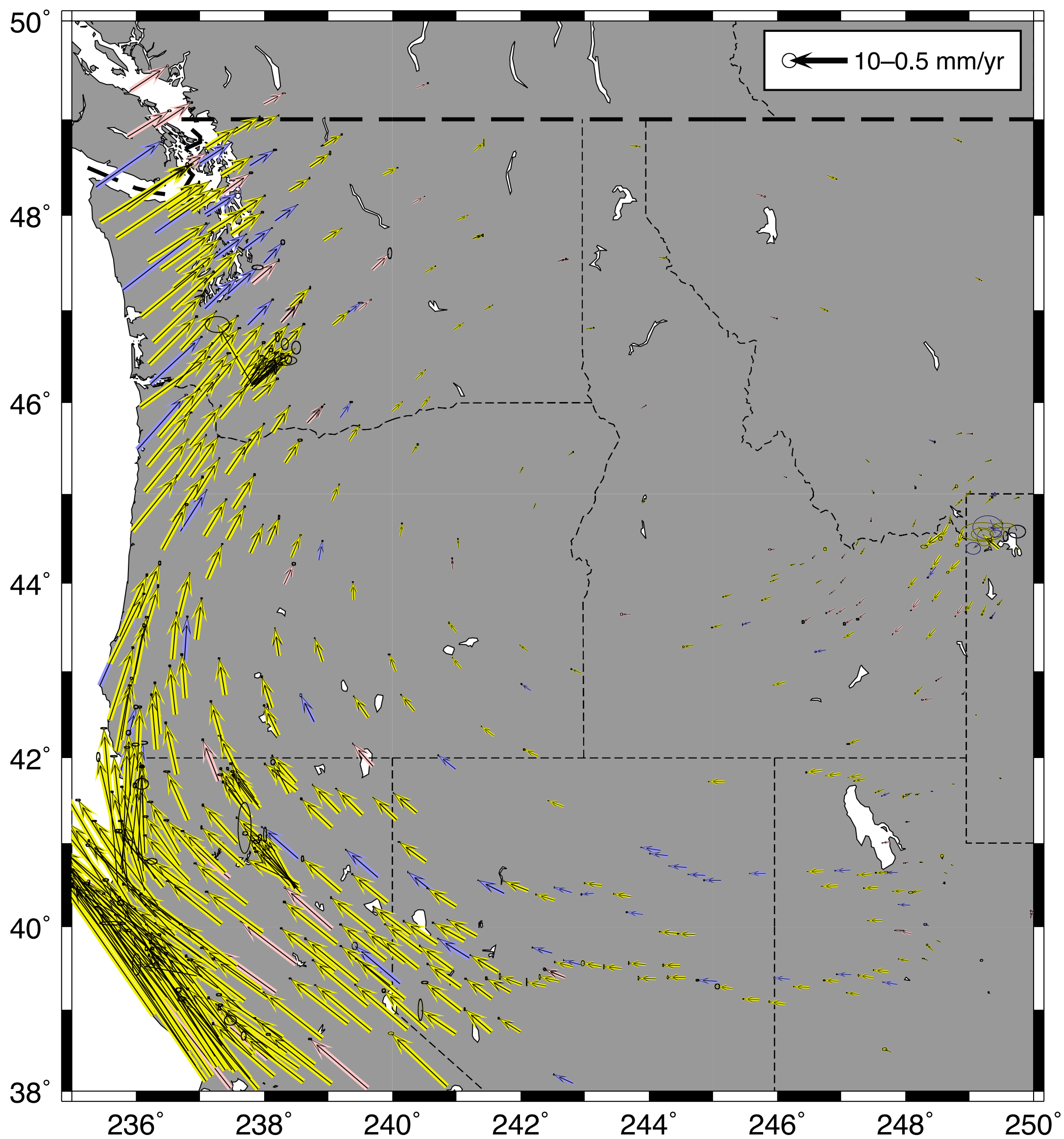

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

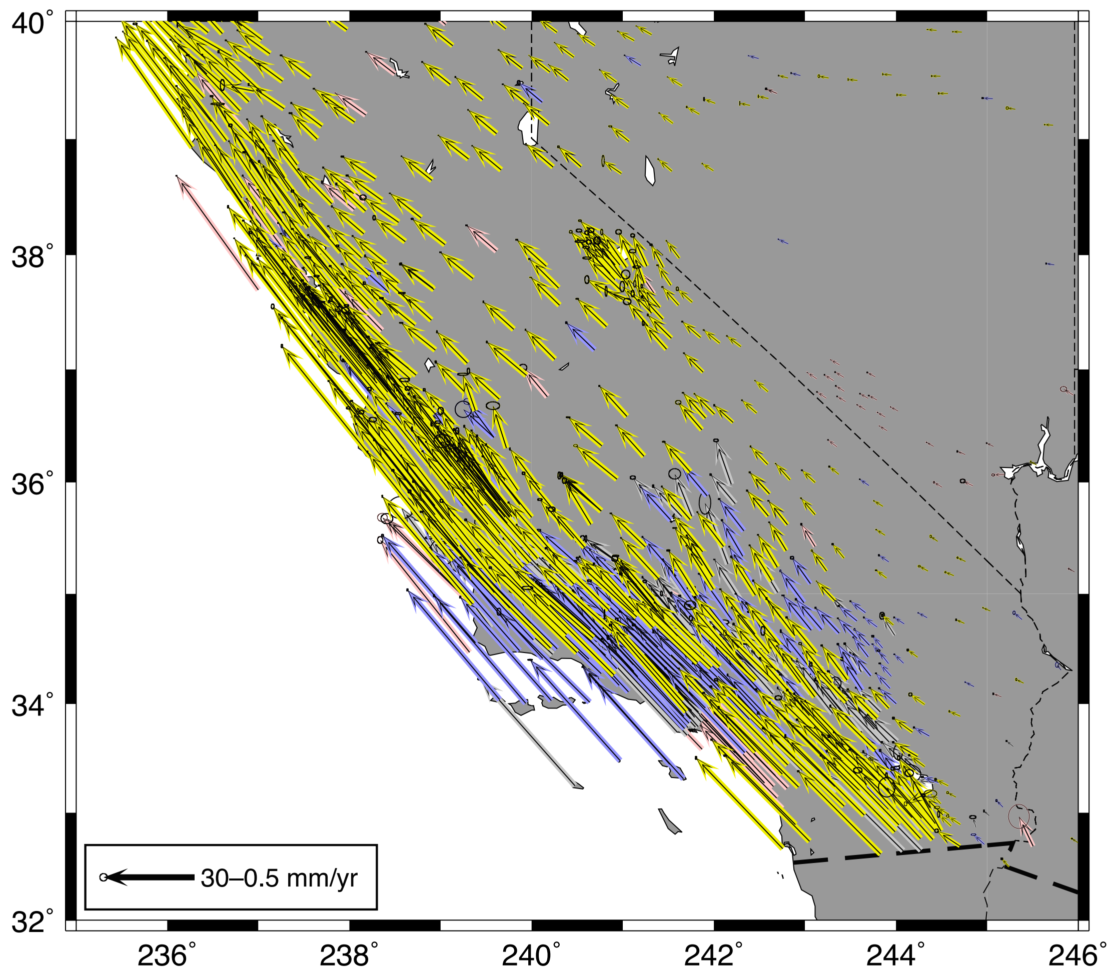

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

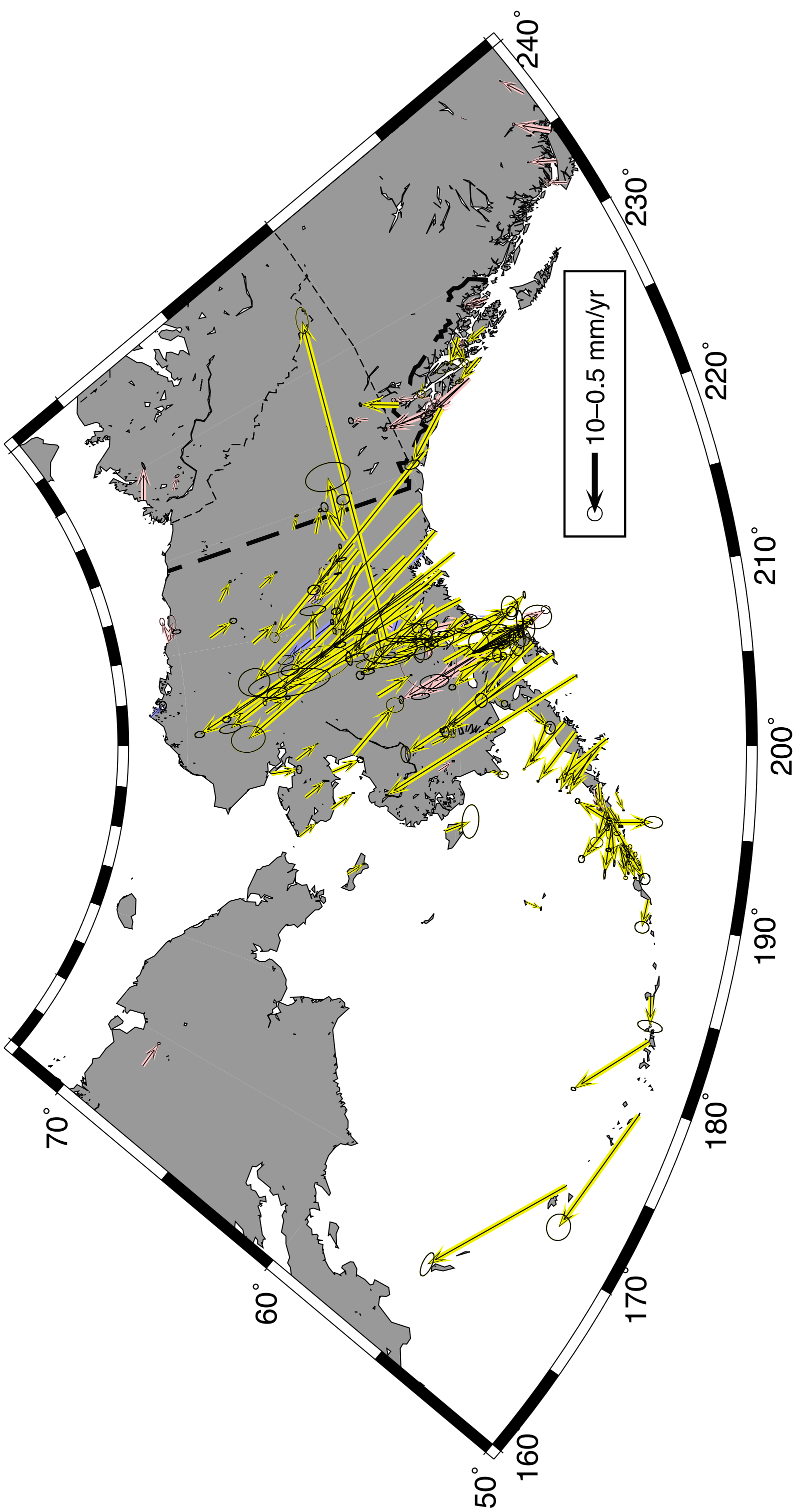

Figure 10: Same as Figure 8 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

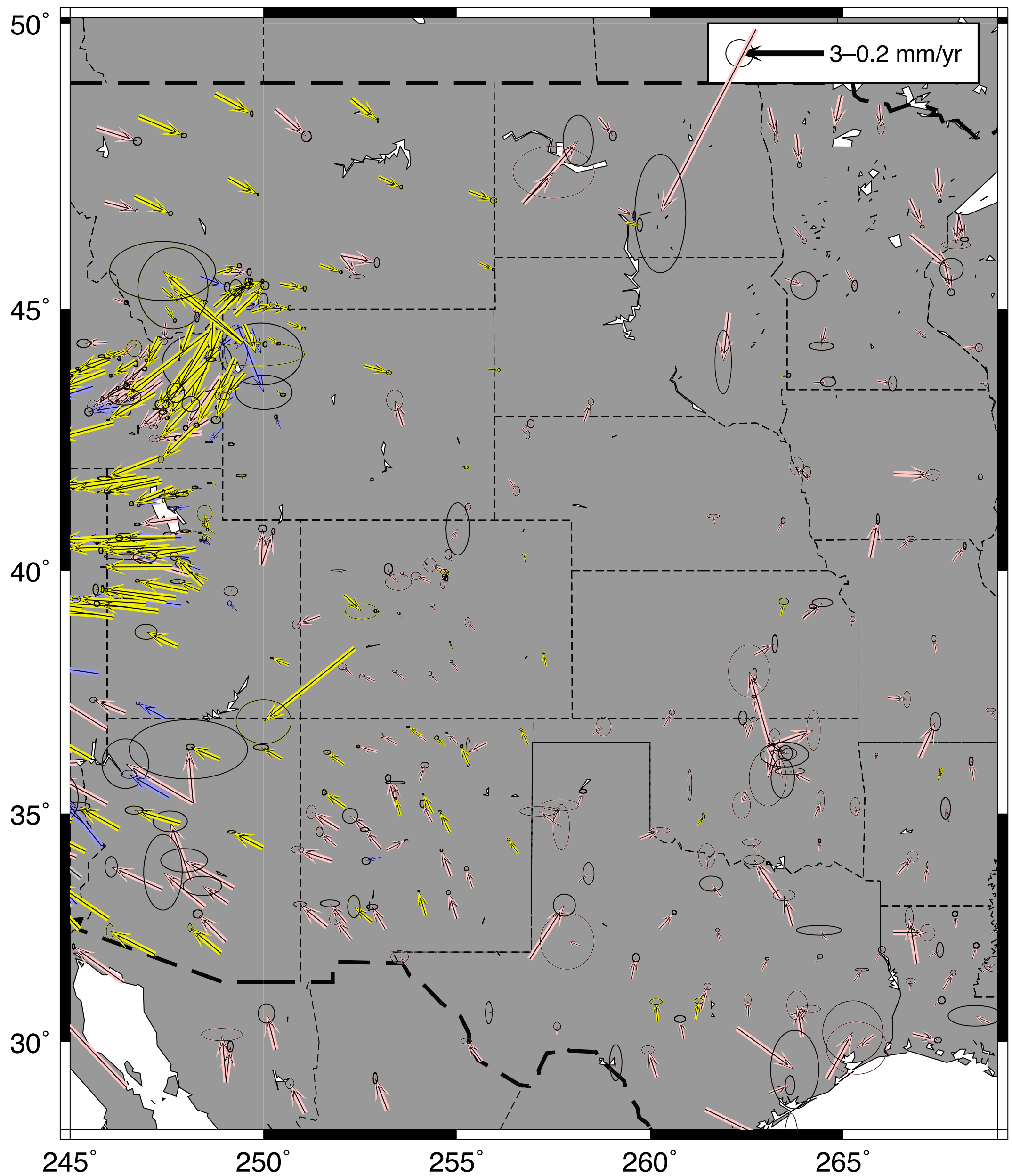

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

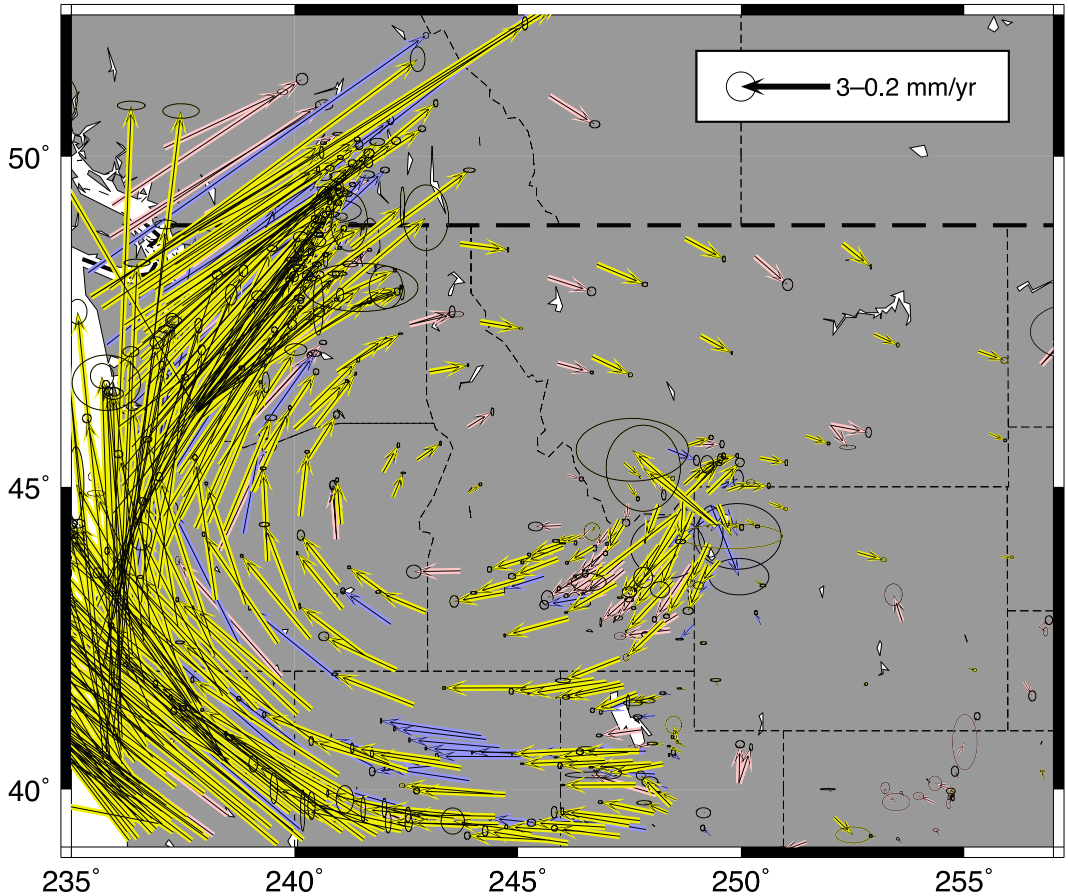

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

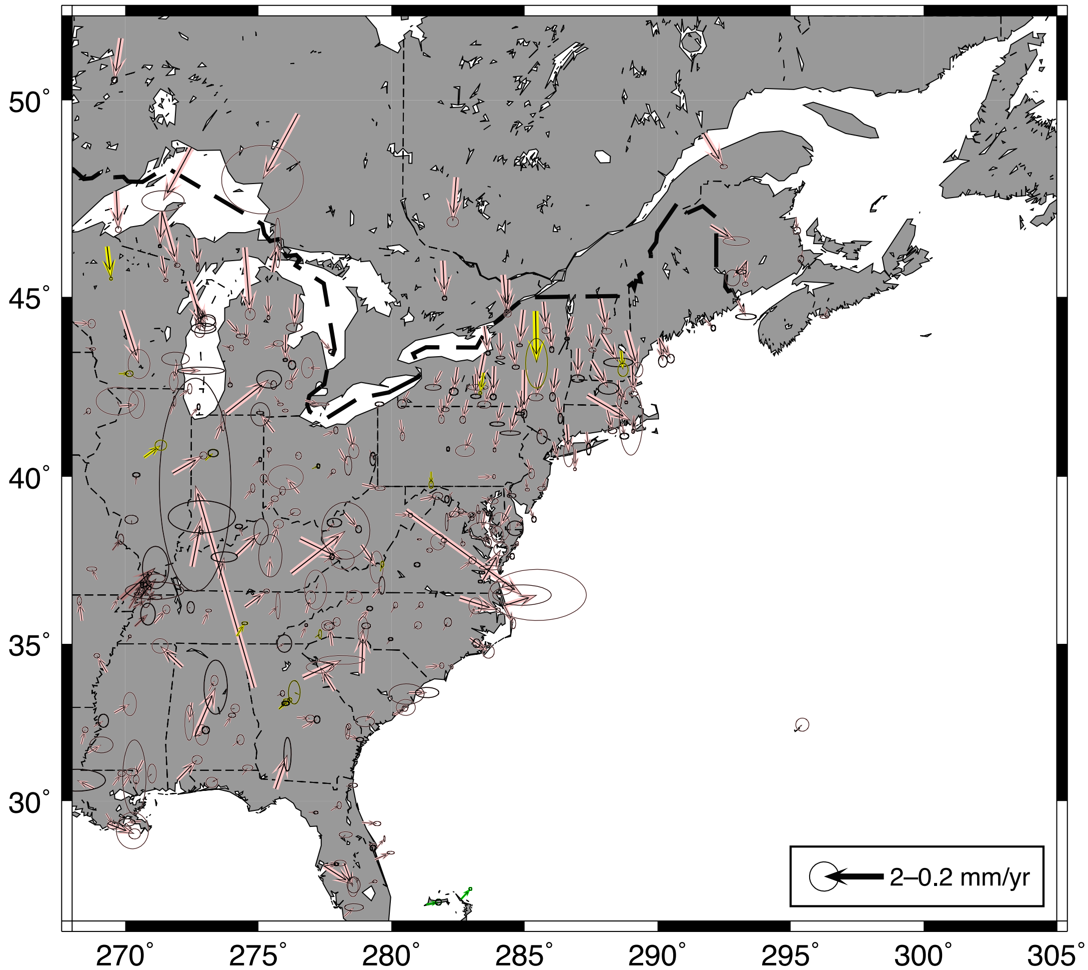

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

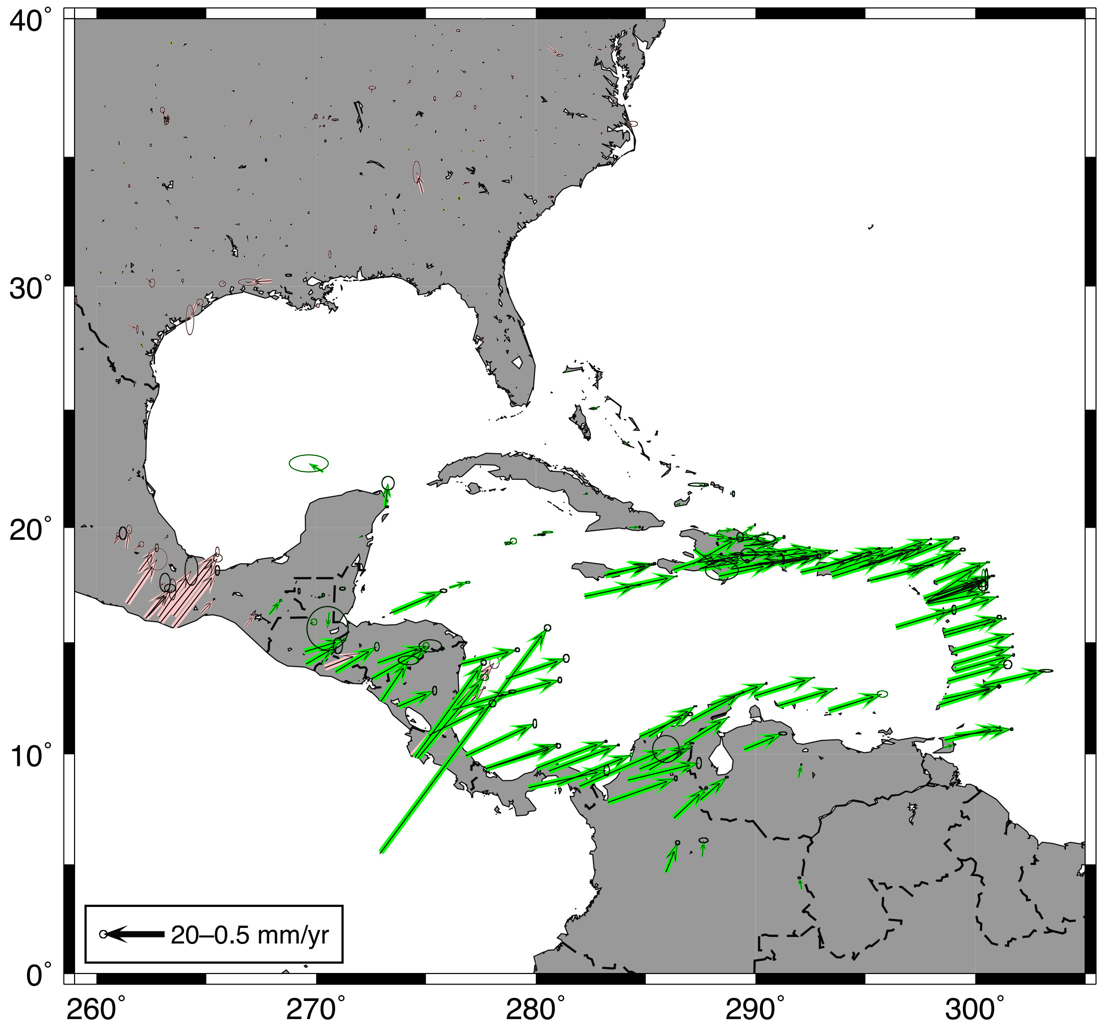

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2022/02/15-2022/06/30

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 24 earthquakes examined during this quarter (same as last quarter) and only one generated displacements more than 1 mm. The event is event 66; ANSS(ComCat) us6000hf75, mww6.6 55 km WSW of Masachapa lat/long 11.5537° -86.9604° on 2022/04/21 07:43 UTC generated observable offsets. The Kalman filter estimates of the co-seismic offsets are shown in Figure 15.

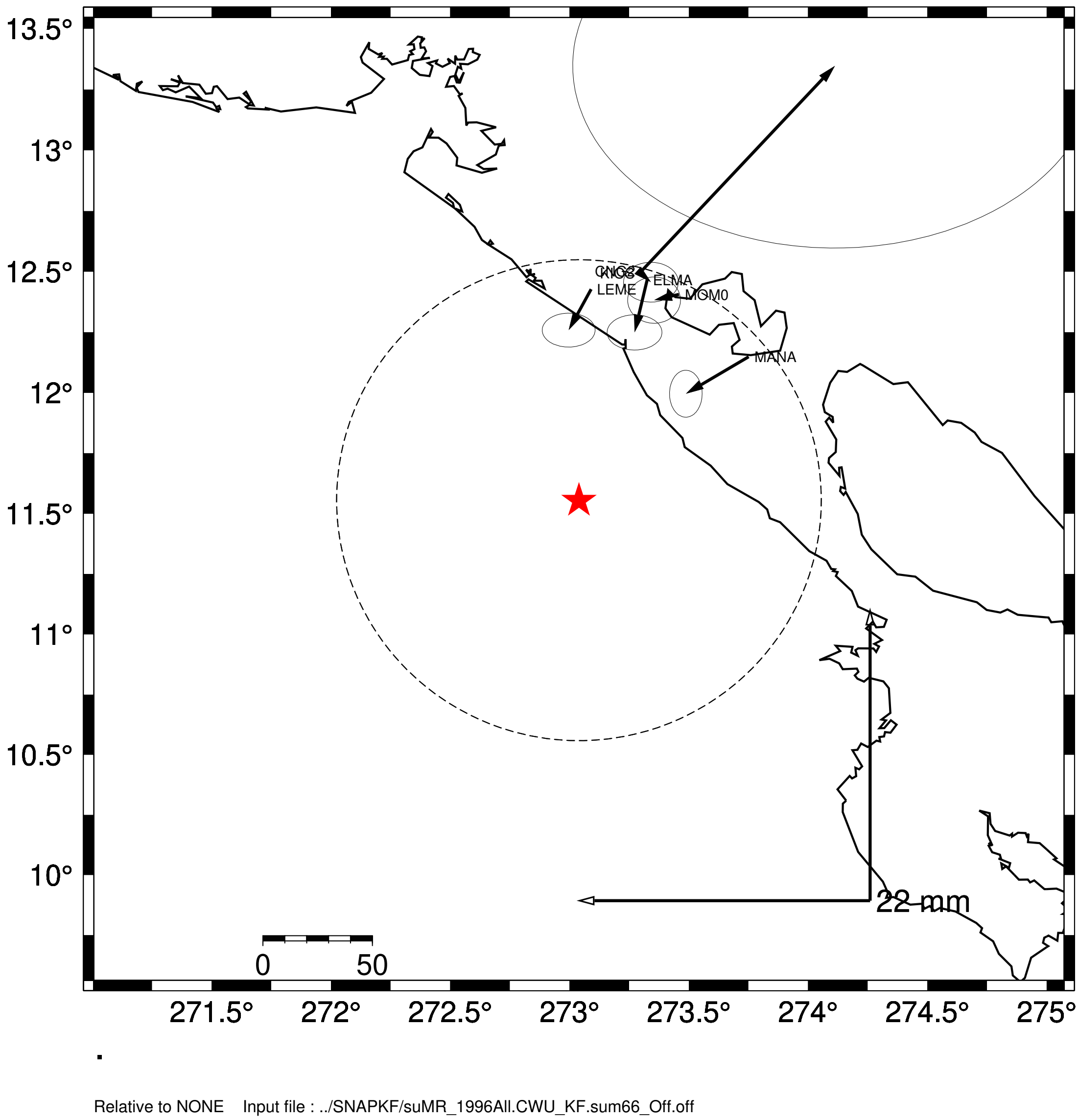

Figure 15: Coseismic offsets from the GAGE event 66; ANSS(ComCat) us6000hf75, mww6.6 55 km WSW of Masachapa lat/long 11.5537° -86.9604° on 2022/04/21 07:43 UTC. These results are from the Kalman filter analysis which provides the lowest standard deviation estimates.

Antenna and other discontinuity events.

Antenna swaps at 44 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
4/15/22	
CN02	Gap since 2018 and new position does not look consistent with old values. New receiver (same type) but no antenna change http://geoweb.mit.edu/~tah/ACC_PBO/CN02.CWU.jpg
EOCG	Site near Santa Barbara, CA. Looks like could be landslide? http://geoweb.mit.edu/~tah/ACC_PBO/EOCG.CWU.jpg
JR01	Site near Mt. St. Helens (not in UNAVCO station pages). Systematic and annual in East coordinates (and height). http://geoweb.mit.edu/~tah/ACC_PBO/JR01.CWU.jpg
OXPE	Back after gap of about a year. Long period slow slip events. http://geoweb.mit.edu/~tah/ACC_PBO/OXPE.CWU.jpg
4/22/22	Not Reported
P356	Annual in North becomes more pronounced starting in 2020, starting to see in east as well. Change seems to coincide with receiver and antenna change. Not a break. http://geoweb.mit.edu/~tah/ACC_PBO/P356.CWU.jpg
4/29/22	
KRAC	Near Mammoth Lakes with large multi-year systematics. http://geoweb.mit.edu/~tah/ACC_PBO/KRAC.CWU.jpg
5/21/22	Not reported
AV20	Most likely snow. Seems very bad in Apr/May, 2022. http://geoweb.mit.edu/~tah/ACC_PBO/AV20.CWU.jpg
CRCN	In Great Valley near Corcoran, CA. Ground water effects. http://geoweb.mit.edu/~tah/ACC_PBO/CRCN.CWU.jpg
OXMT	North trending off by -80 in last year. East and height picking up annual signals. Site South of San Francisco. http://geoweb.mit.edu/~tah/ACC_PBO/OXMT.CWU.jpg
P791	Site moved by snow in 2012? Annual peaks in North since 2020. Tall mast on drilled braced monument. Near Portland, OR. http://geoweb.mit.edu/~tah/ACC_PBO/P791.CWU.jpg
P801	Yellowstone site with systematics and snow. http://geoweb.mit.edu/~tah/ACC_PBO/P801.CWU.jpg
RG08	Bad antenna since 2021? http://geoweb.mit.edu/~tah/ACC_PBO/RG08.CWU.jpg
SEPR	Very systematic. Start 2021. Near Mt. St. Helens. http://geoweb.mit.edu/~tah/ACC_PBO/SEPR.CWU.jpg
SNOG	Restarted after gap from 2019. Position is offset. http://geoweb.mit.edu/~tah/ACC_PBO/SNOG.CWU.jpg
5/31/22	
P812	Outliers in rapids similar to earlier example. Data mostly smooth but with east (mostly) outliers. CalCity monument test site.

	http://geoweb.mit.edu/~tah/ACC_PBO/P812.CWU.jpg
6/3/22	
GZKA	New station; large outlier in east and some N and U motion associated with it. Keep an eye on site. http://geoweb.mit.edu/~tah/ACC_PBO/GZKA.CWU.jpg
KYMH	Failed antenna starting 2016. Reported in 10/2020. http://geoweb.mit.edu/~tah/ACC_PBO/KYMH.CWU.jpg
PWEL	New antenna 2022-150. http://geoweb.mit.edu/~tah/ACC_PBO/PWEL.CWU.jpg
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

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 March 15, 2022 and June 24, 2022.

CWU	North (mm)	East (mm)	Up (mm)
Median ANET	1.19	1.06	6.14
70% ANET	1.45	1.18	6.49
95% ANET	2.00	1.68	7.55

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

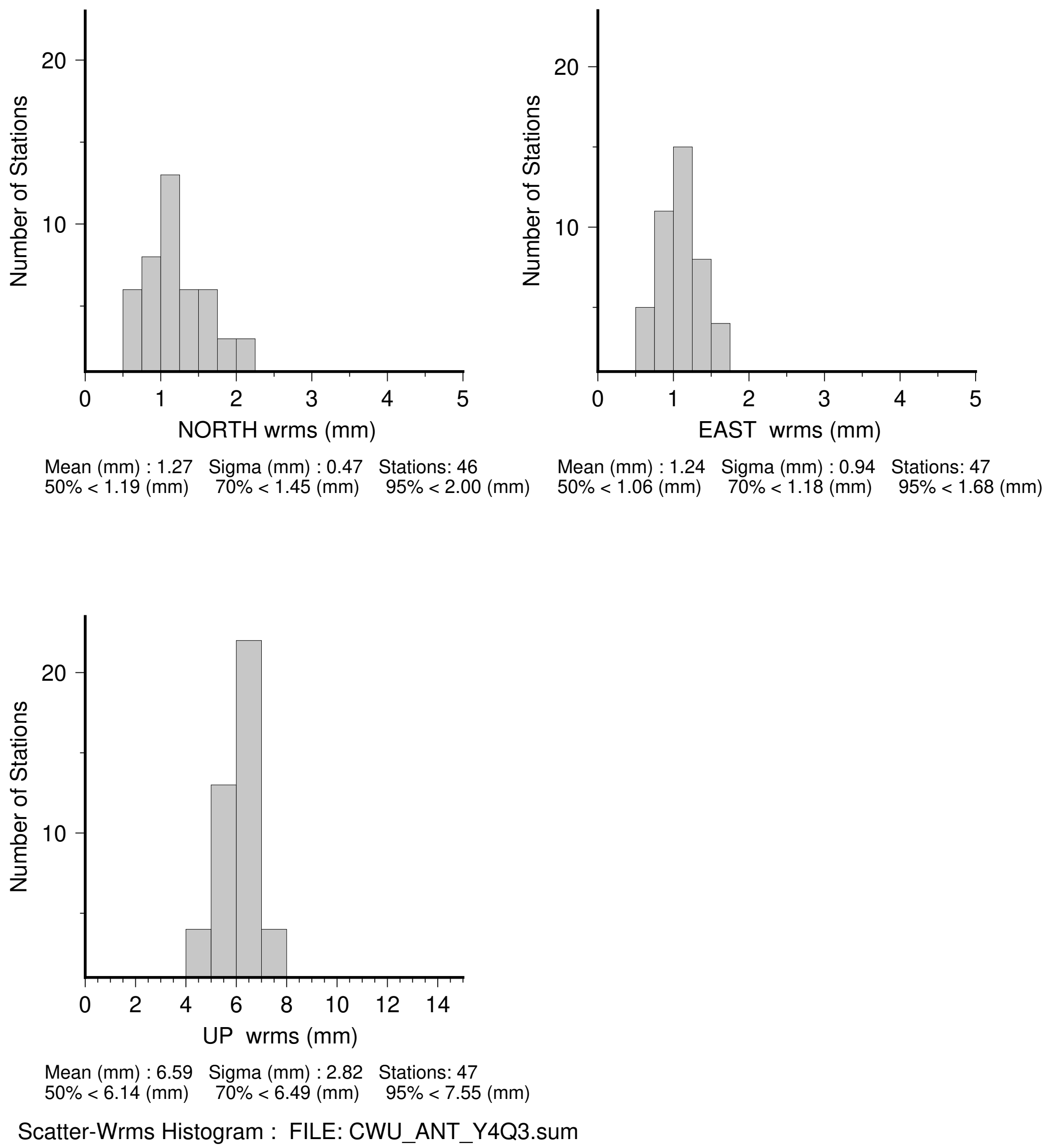

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 47 stations in Antarctica analyzed between March 15, 2022 and June 24, 2022. Linear trends and annual signals were estimated from the time series.

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