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

Thomas Herring and Mike Floyd

Period: 2022/01/01-2022/03/31

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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 2021/12/15 to 2022/03/31, time series velocity field analyses for the GAGE reprocessing analyses (1996-2021). Several earthquakes were investigated this quarter but only one of them, event 65; ANSS(ComCat) nc73666231, mw6.2 7km N of Petrolia, latitude/longitude 40.3902°/-124.2980°, Date/Time 2021/12/20 20:11 generated observable offsets. The radius of influence of this event was increased from 62km to 100km to accommodate the observed displacements.

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 1921 stations were processed which is 28 less than last quarter. In addition up to 47 sites were processed in the ANET solutions, 1 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: December 15, 2021– March 26, 2022

For this report, we generated the statistics using the ~3 months of CWU results between December 15, 2021 and March 26, 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 1921 stations for CWU analyzed in the finals analysis between December 15, 2021 and March 26, 2022. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.90	0.88	5.08
70%			
CWU	1.18	1.11	5.83
95%			
CWU	2.71	2.65	10.98

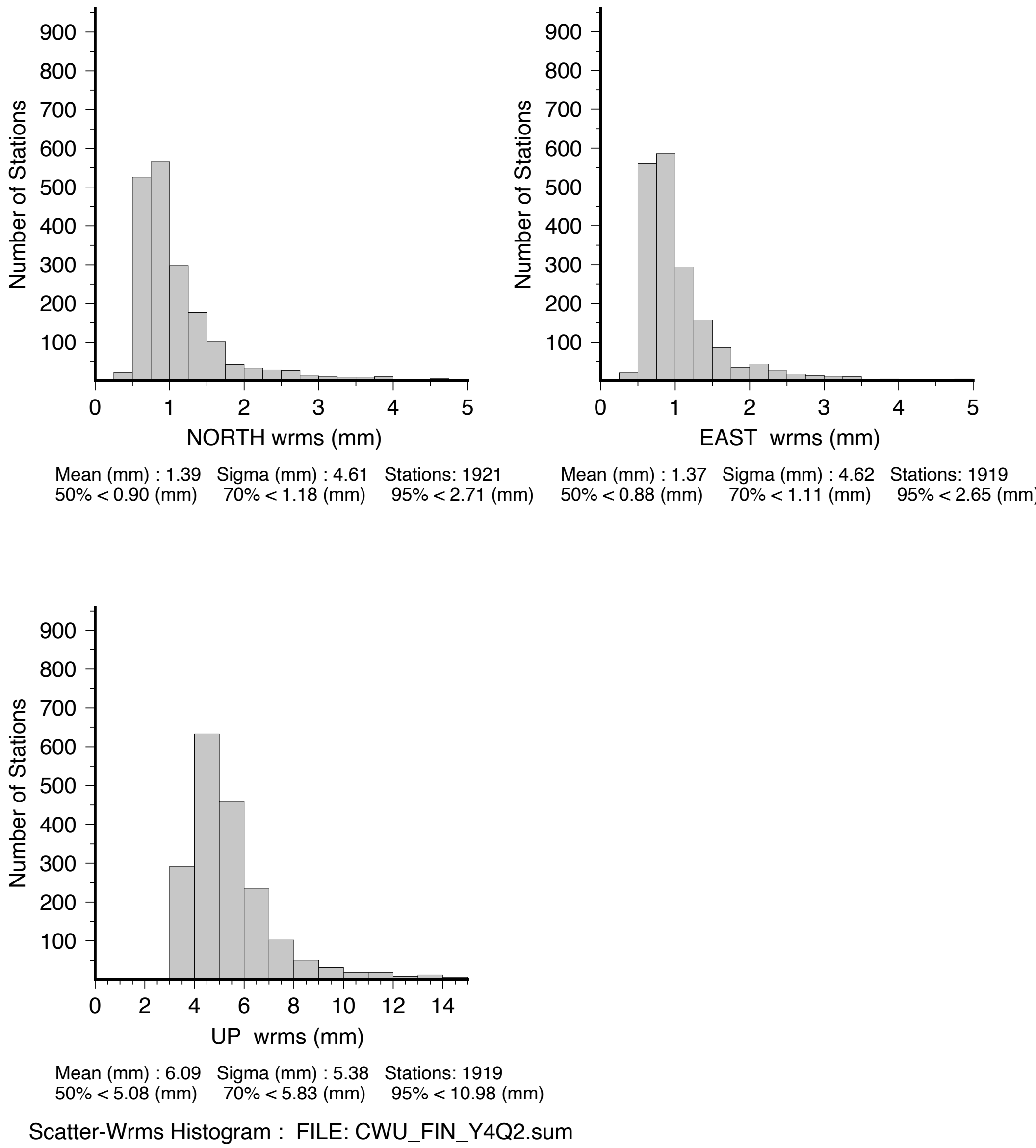

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 1921 stations analyzed between December 15, 2021 and March 26, 2022. Linear trends and annual signals were estimated from the time series.

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_Y4Q2.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_Y4Q2.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    99      1.2   0.61      1.2   0.58     6.0   0.64     18.92
 1NSU   101      0.9   0.50      0.9   0.55     5.9   0.77     18.18
 1ULM   101      0.7   0.41      0.8   0.49     6.1   0.80     18.78
 AB01   102      2.6   1.19      1.7   1.11     6.5   0.90     14.85
…
 ZDV1    97      0.9   0.48      1.2   0.75     5.7   0.74     18.81
 ZKC1    97      0.9   0.47      0.8   0.53     5.2   0.68     18.81
 ZLA1    96      1.0   0.53      0.8   0.48     6.6   0.86     19.04
 ZLC1    97      0.8   0.41      0.7   0.46     6.1   0.82     19.04
 ZME1    98      1.0   0.56      1.0   0.64     6.5   0.87     19.28
 ZMP1    97      0.9   0.42      0.7   0.45     5.8   0.76     19.20
 ZNY1    97      5.6   2.87      1.0   0.66     4.0   0.51     19.73
 ZOA1    86      0.7   0.36      0.7   0.45     5.6   0.75     19.20
 ZSE1    97      0.9   0.43      0.9   0.61     6.5   0.86     19.39
 ZTL4    97      0.8   0.48      0.9   0.59     0.0   0.00      0.00
```

Table 2: RMS scatter of the position residuals for the CWU solution between December 15, 2021 and March 26, 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	0.81	0.81	4.60	804
NUCLEUS	0.77	0.75	4.43	182
GAMA	0.84	0.92	5.70	15
COCONet	1.39	1.52	7.23	63
USGS_SCIGN	0.83	0.79	4.26	112
Expanded	1.02	0.98	5.69	745
70%				
PBO	1.05	1.01	5.18	
NUCLEUS	0.95	0.86	4.84	
GAMA	0.92	1.00	6.15	
COCONet	1.65	1.77	7.74	

USGS_SCIGN	1.00	0.91	4.85
Expanded	1.27	1.23	6.35
95%			
PBO	2.74	2.65	9.57
NUCLEUS	1.73	1.39	7.43
GAMA	1.04	1.12	8.44
COCONet	3.61	5.97	16.42
USGS_SCIGN	1.54	1.38	7.17
Expanded	2.92	2.91	12.22

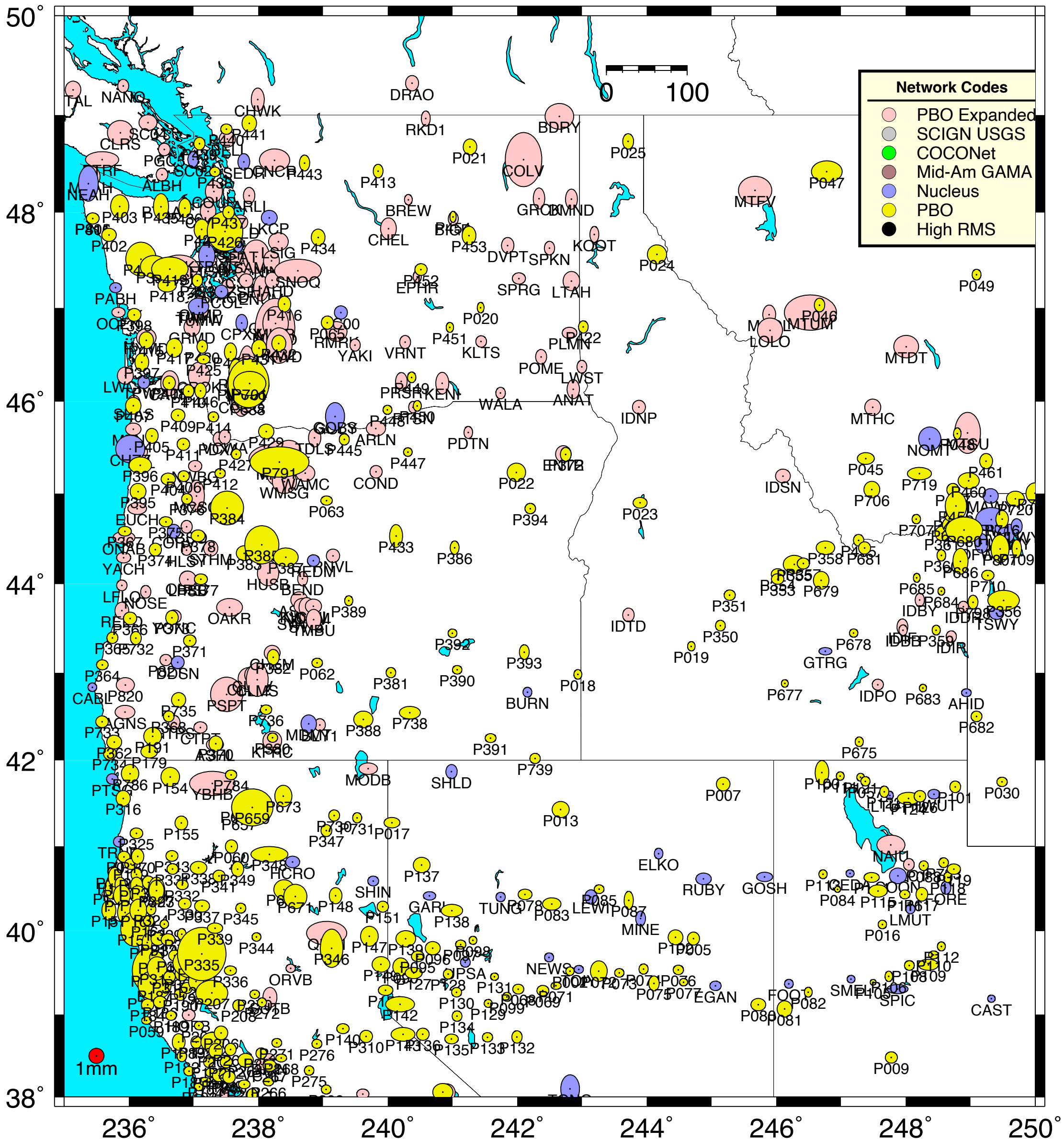

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1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

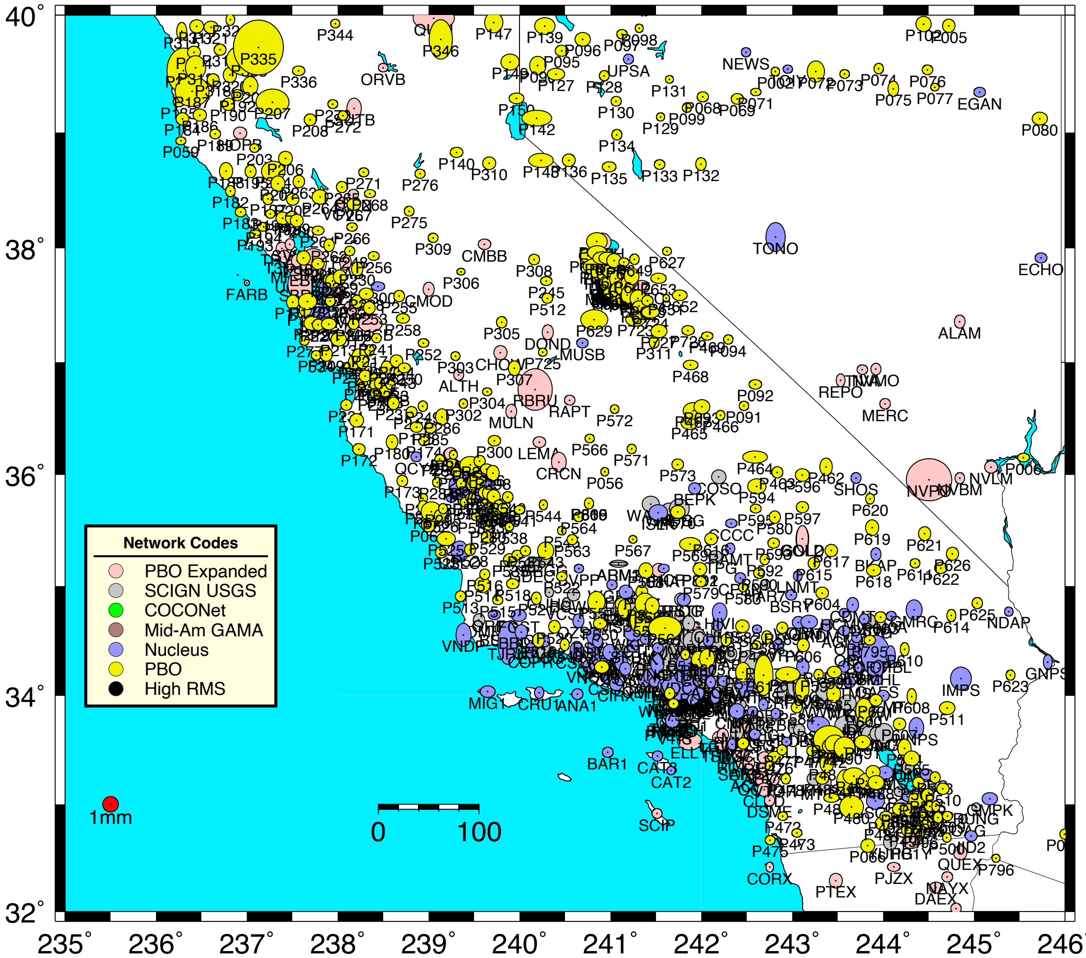

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

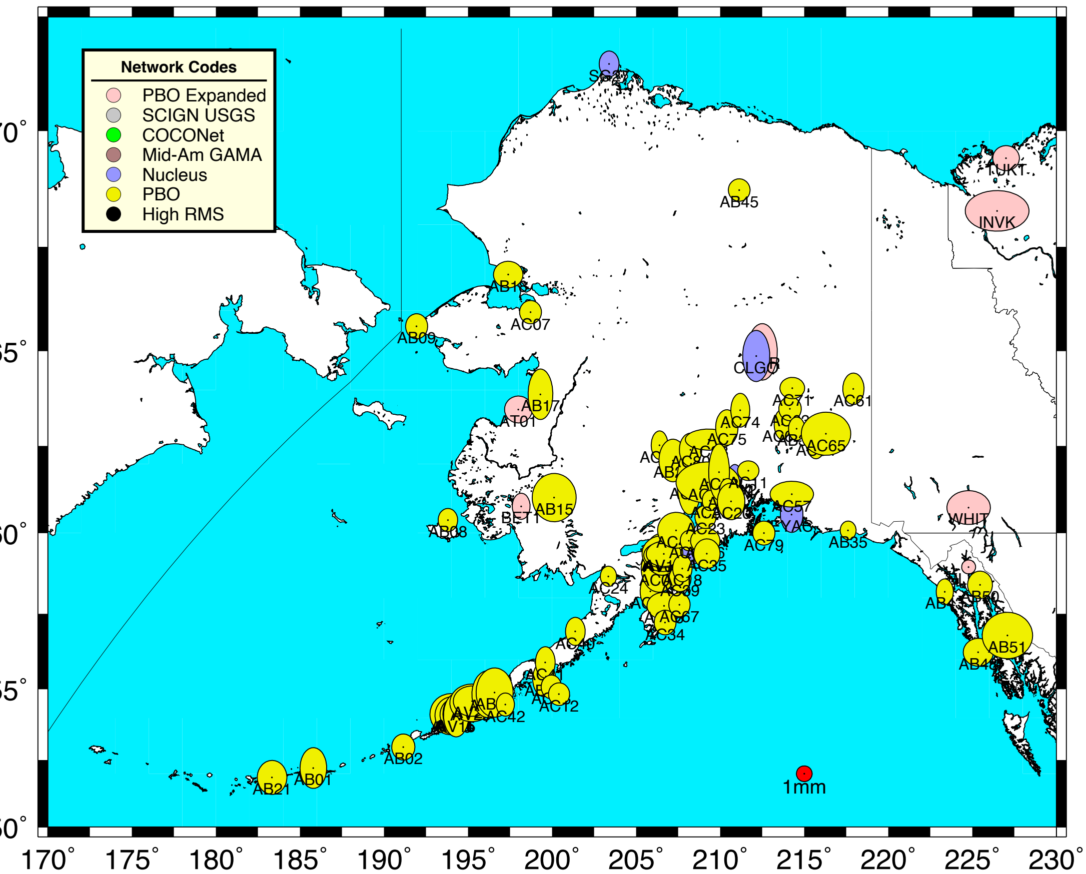

Figure 4: Same as Figure 4 except for the Alaskan region.

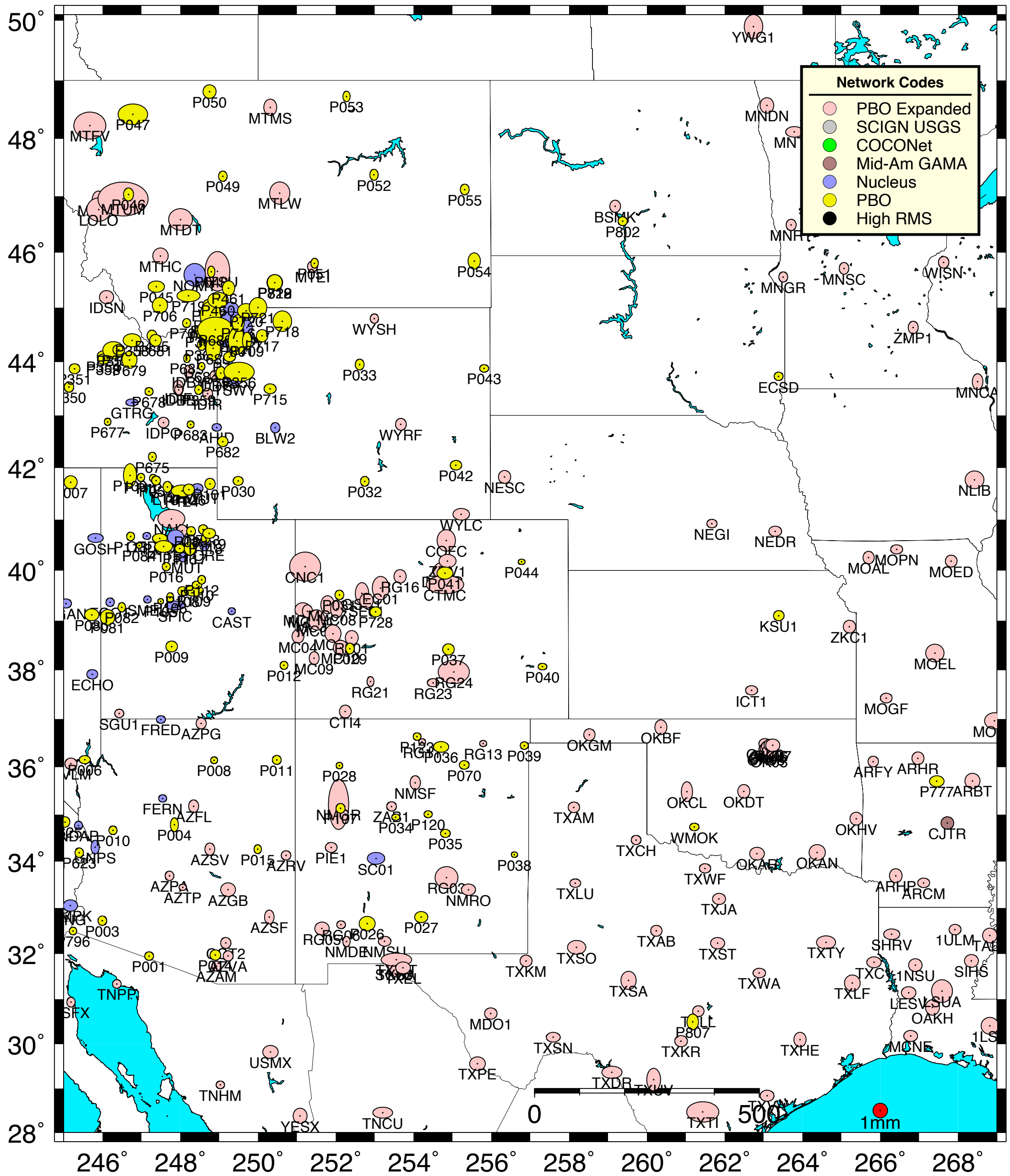

Figure 5: Same as Figure 4 except for the Central United States

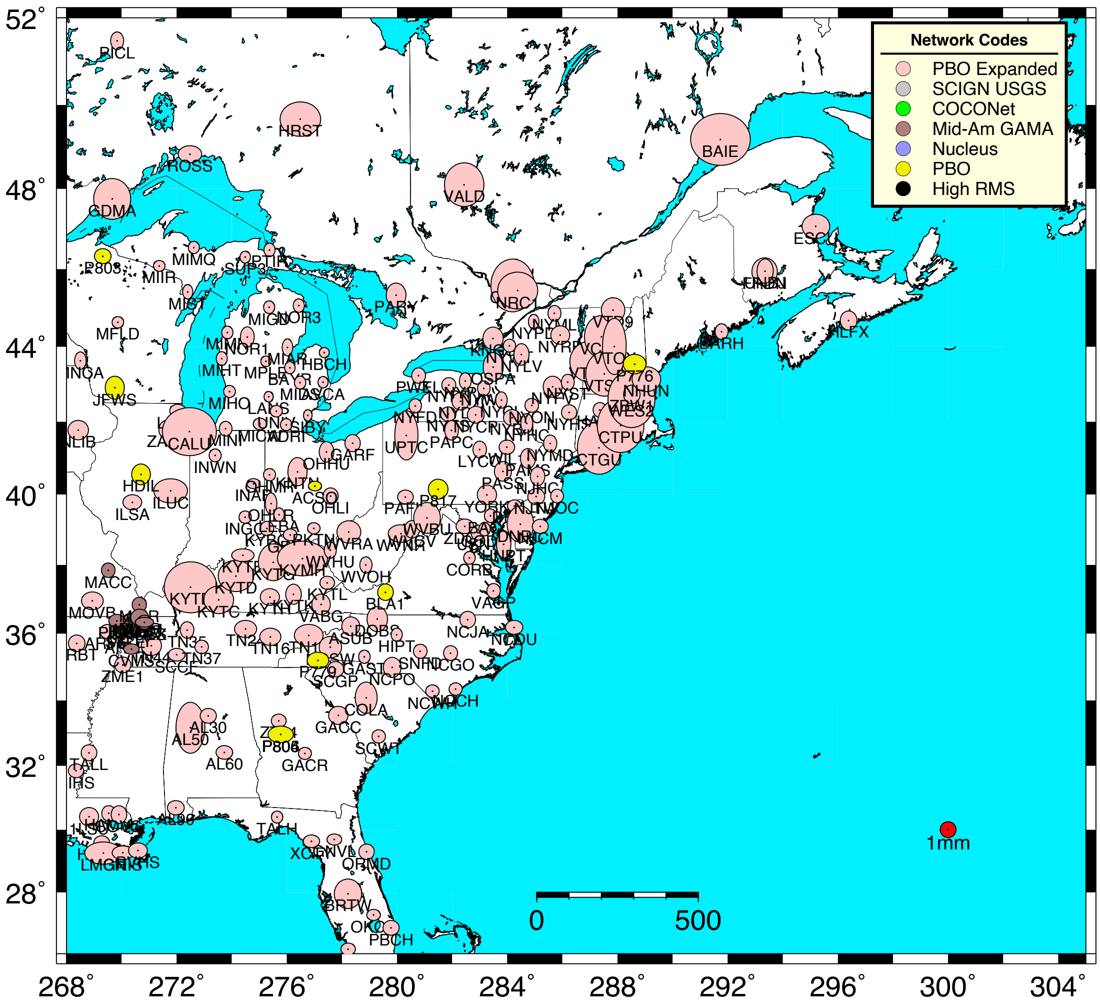

Figure 6: Same as Figure 4 except for the Eastern United States

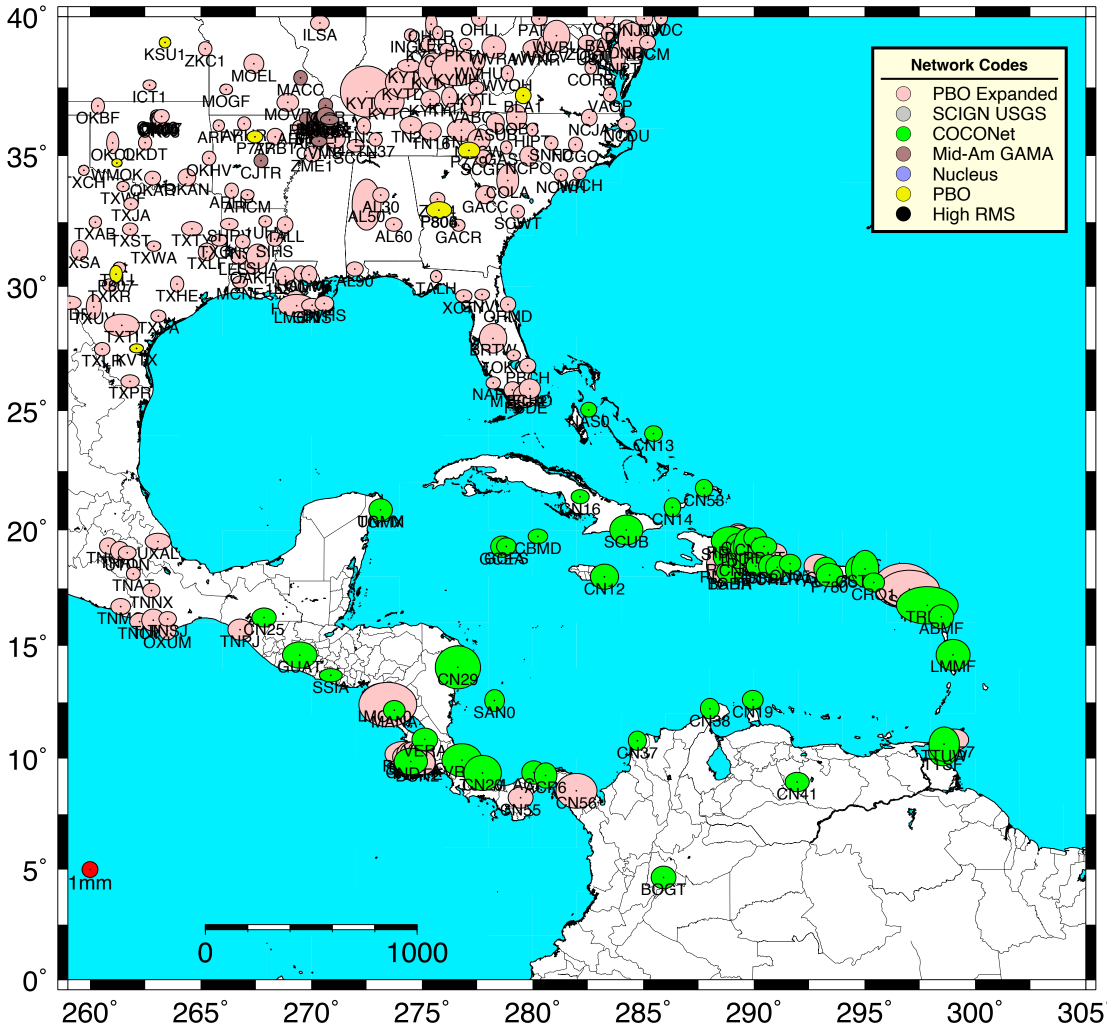

Figure 7: Same as Figure 4 except for the Caribbean region.

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_211218.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 2669 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and March 26, 2022.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.40	1.35	6.18
70%			
CWU	1.75	1.70	7.02
95%			
CWU	3.90	3.62	11.73

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.

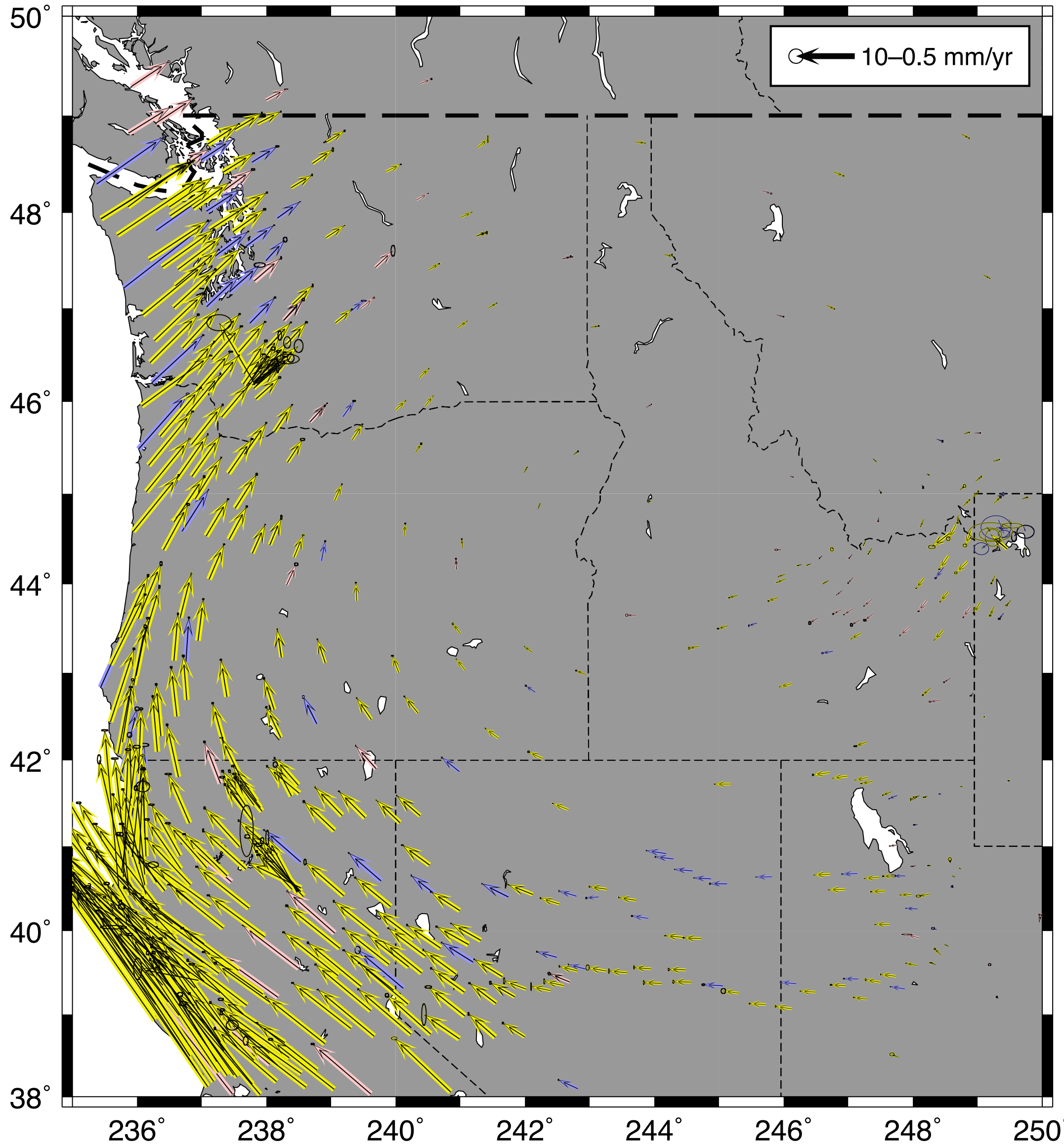

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

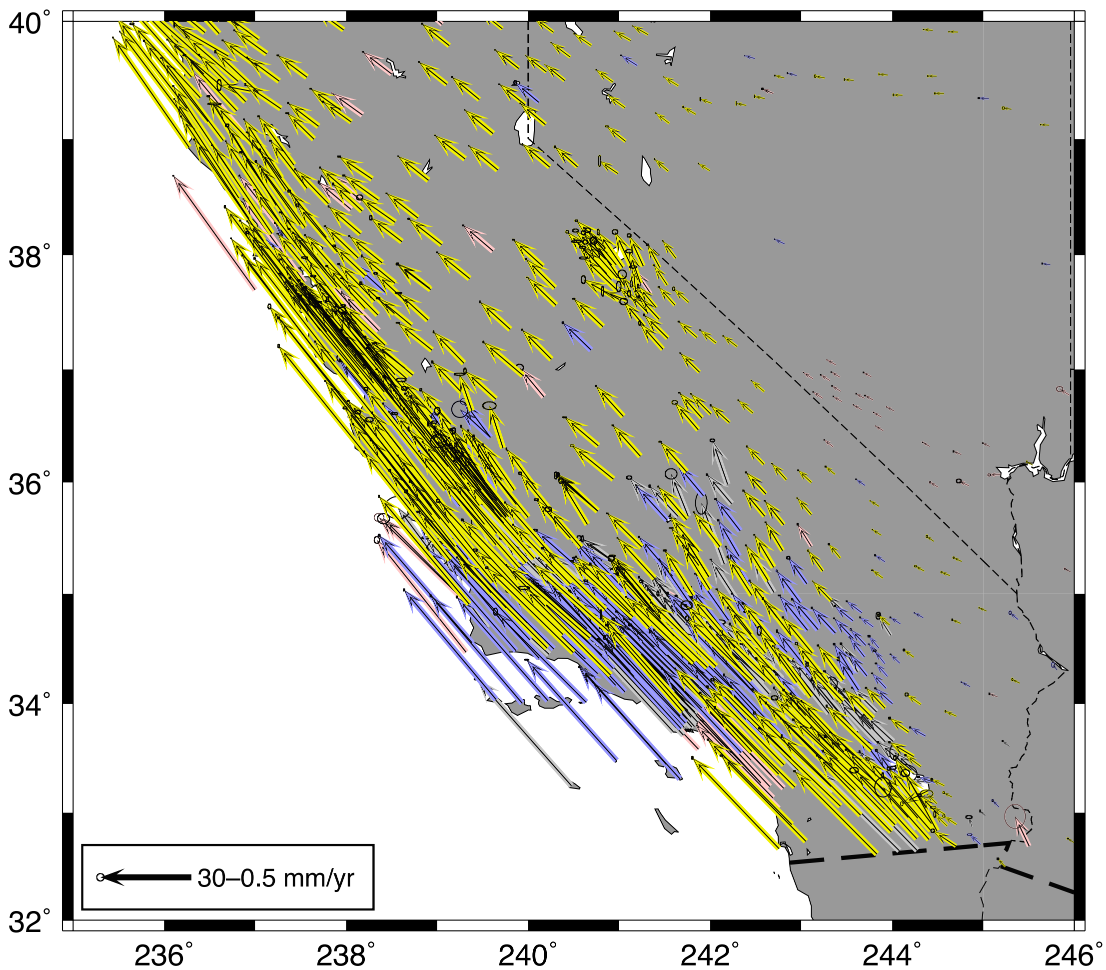

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

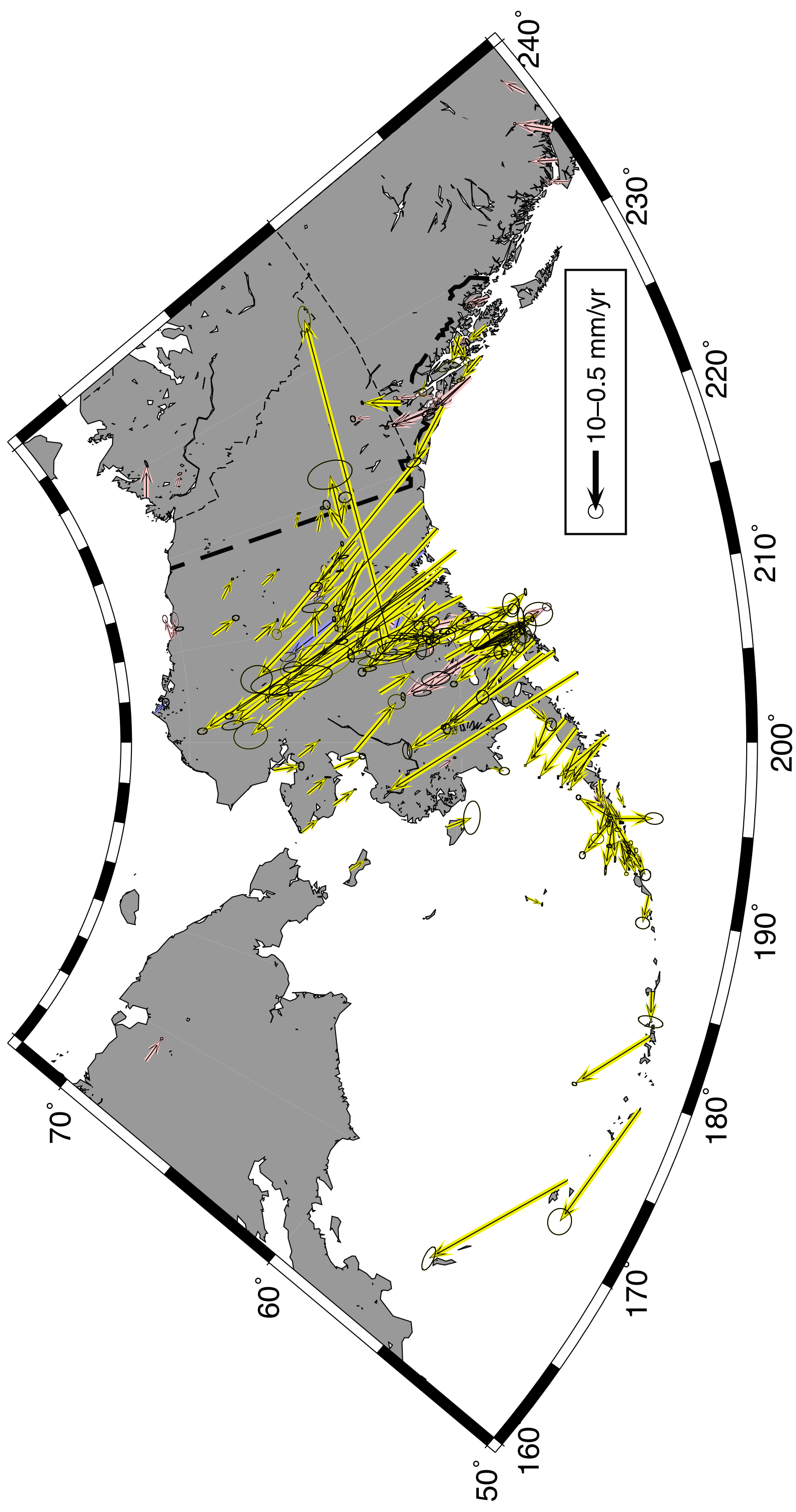

Figure 10: Same as Figure 8 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

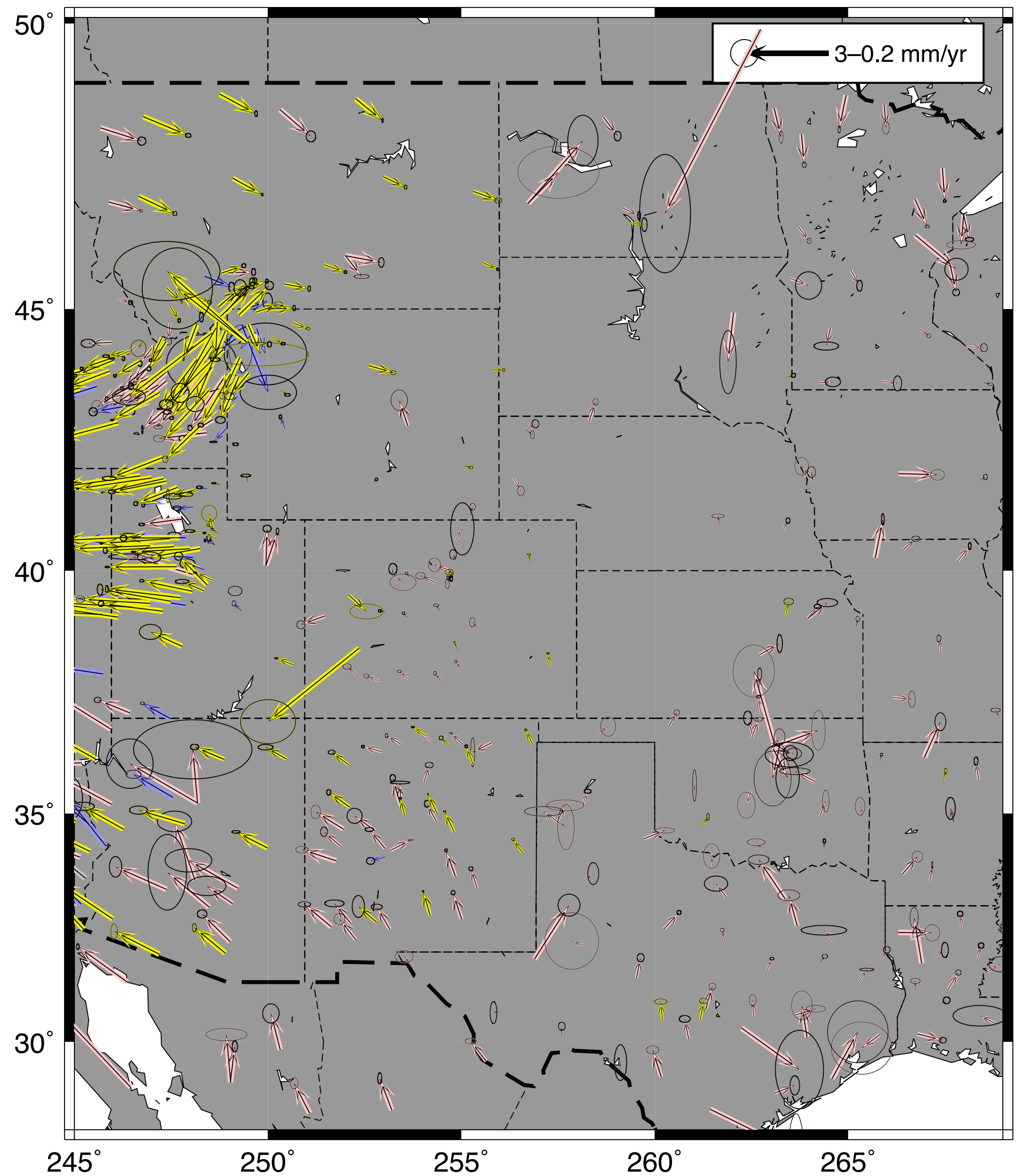

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

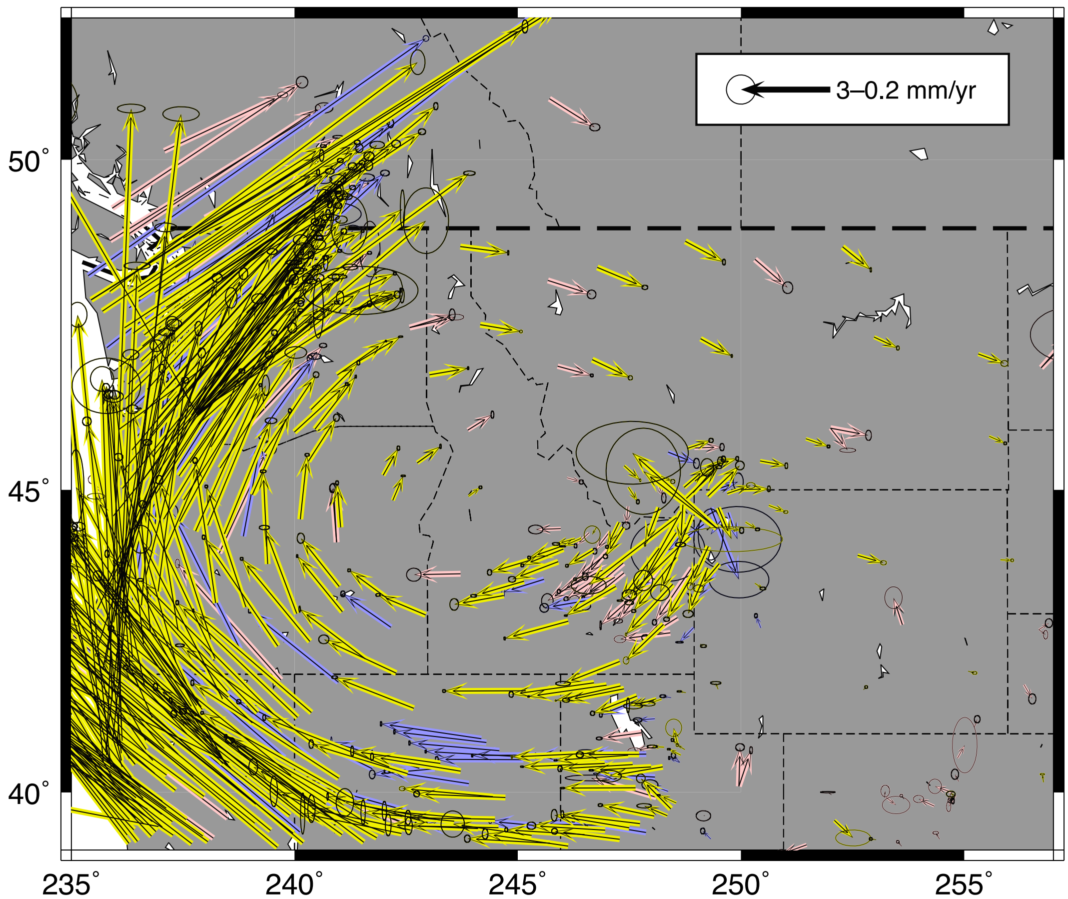

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

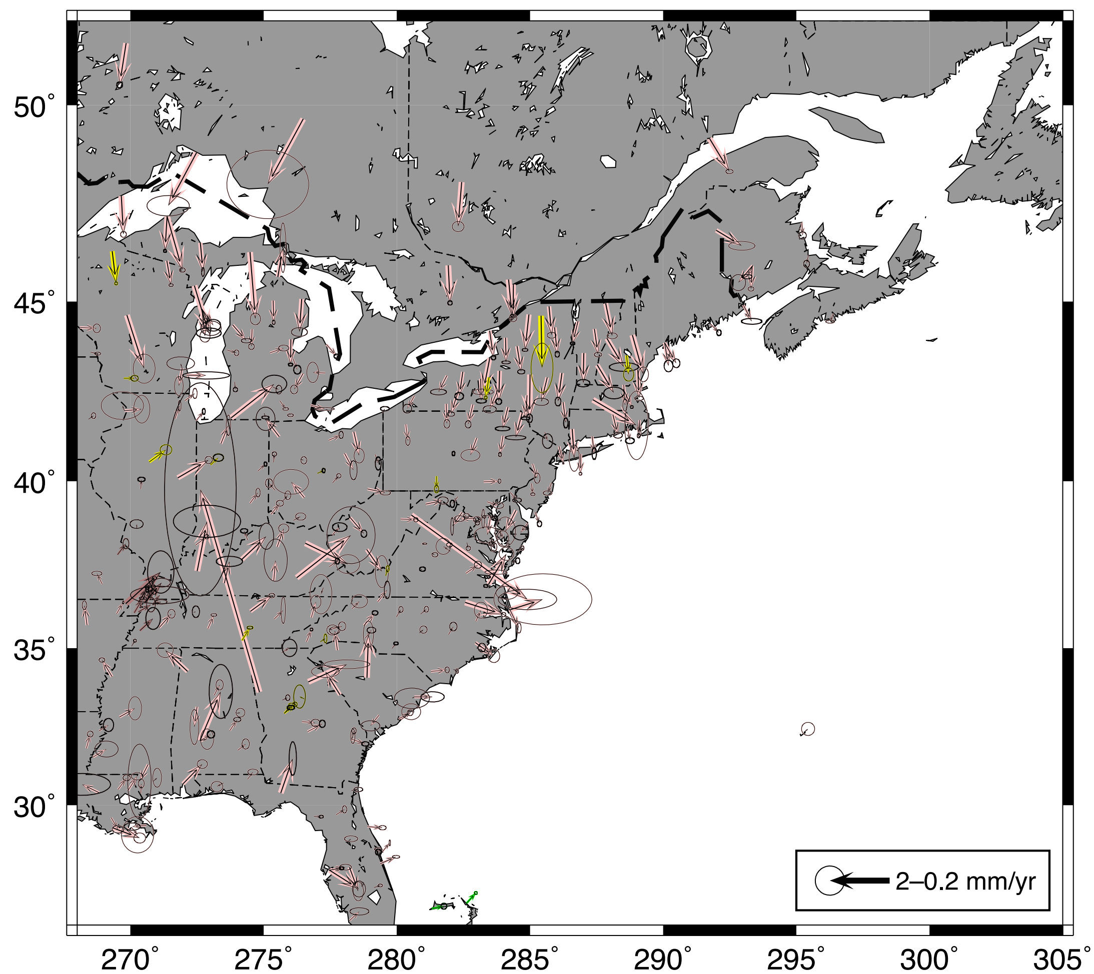

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

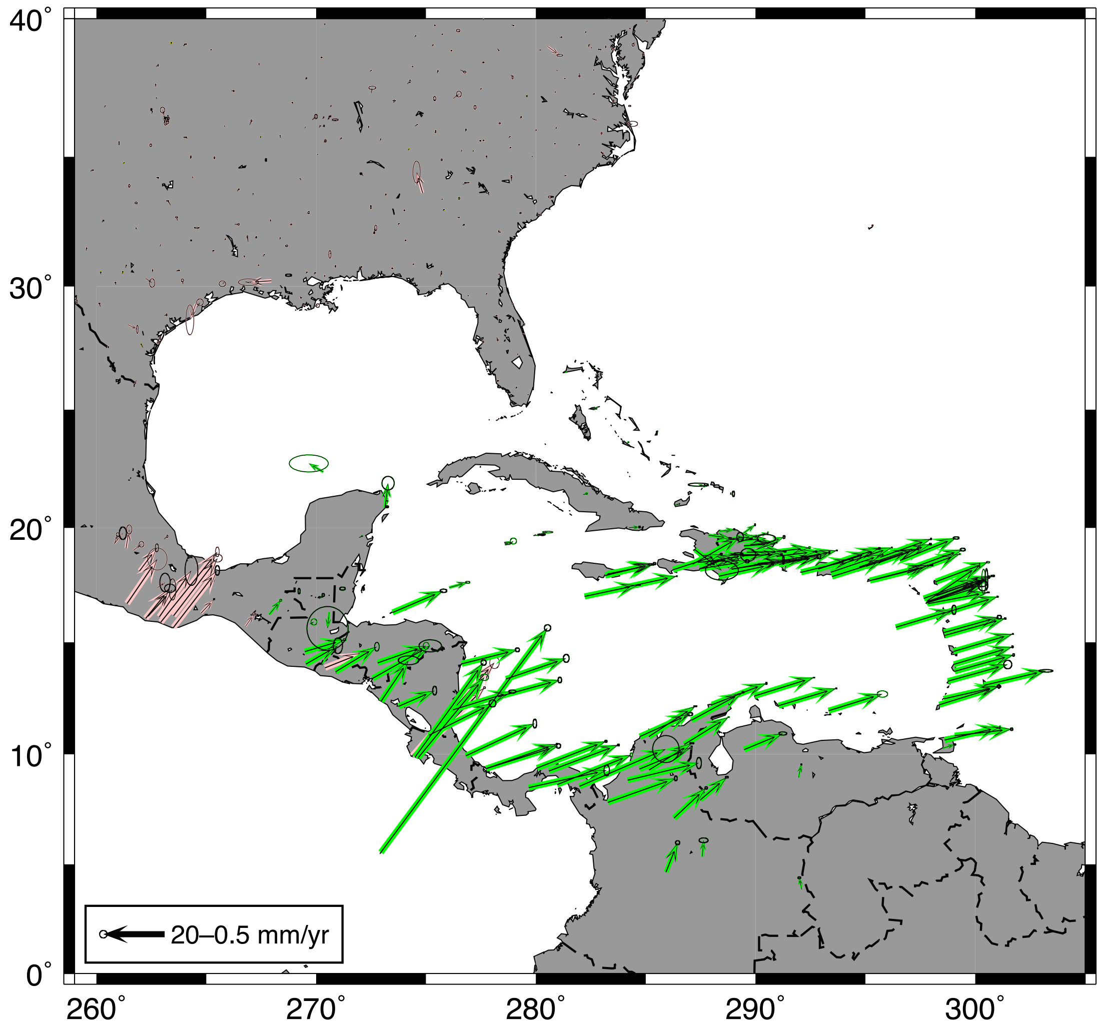

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2021/12/15-2022/03/31

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 30 earthquakes examined during this quarter (same as last quarter) and only one generated displacements more than 1 mm. The event is 65; ANSS(ComCat) nc73666231, mw6.2 7km N of Petrolia, latitude/longitude 40.3902°/-124.2980°, Date/Time 2021/12/20 20:11 generated observable offsets. The radius of influence of this event was increased from 62km to 100km to accommodate the observed displacements.

EQ65 Rapid and Kalman filter event files were generated and sent to UNAVCO via LDM. The Kalman filter estimates of the co-seismic offsets are shown in Figure 15.

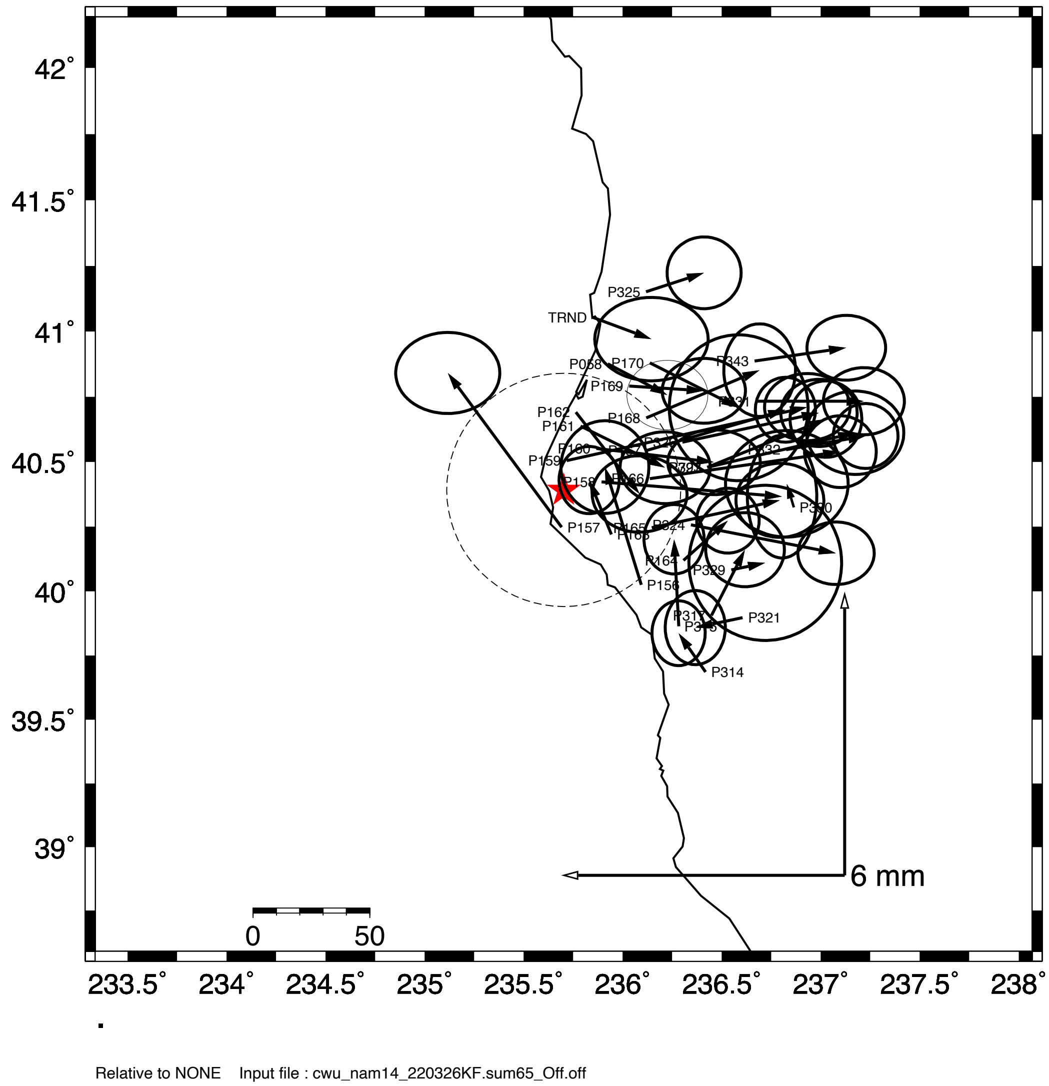

Figure 15: Coseismic offsets from the GAGE event 65; ANSS(ComCat) nc73666231, mw6.2 7km N of Petrolia, latitude/longitude 40.3902°/-124.2980°, Date/Time 2021/12/20 20:11. These results are from the Kalman filter analysis which provides the lowest standard deviation estimates.

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.

Site/s	Issues related to site
1/18/22	
BILS	Washington state near Queets: Very strong East 5 mm (and North, 2mm) annual. Does not appear to be any large lakes. http://geoweb.mit.edu/~tah/ACC_PBO/BILS.CWU.jpg
MOVB	Height jump in rapids. No new meta data. (Missouri) http://geoweb.mit.edu/~tah/ACC_PBO/MOVB.CWU.jpg
NCPO	11 mm in east rapids (North Carolina). http://geodesy.unr.edu/NGLStationPages/stations/NCPO.sta
VTRB	Large N (3mm) and E (4mm) annual (Vermont). Maybe on building. http://geoweb.mit.edu/~tah/ACC_PBO/VTRU.CWU.jpg
1/21/22	
MIMQ	70 mm height jump in rapid. Looks like an antenna change. CORS site , no meta data change. http://geoweb.mit.edu/~tah/ACC_PBO/MIMQ.CWU.jpg
ALGO	North and East offset of 10 mm in on 2021/12/25. No meta data change at UNAVCO or IGSCB. Likely snow. 2022/02/02 position returns to normal. http://geoweb.mit.edu/~tah/ACC_PBO/ALGO.CWU.jpg
1/28/22	
YBHB	14 mm east jump rapid 1/26/2022. Offset persists until mid-February at least. http://geoweb.mit.edu/~tah/ACC_PBO/YBHB.CWU.jpg
2/3/22	
RMRK	PANGA site, 10 cm un-documented height jump 2014/06/05. No meta or earthquake. Added to UNKN list http://geoweb.mit.edu/~tah/ACC_PBO/RMRK.CWU.jpg
2/18/22	Not reported
BAIE	Offset in east in rapids. In Quebec, could be snow. http://geoweb.mit.edu/~tah/ACC_PBO/BAIE.CWU.jpg
PSDM	Height jump in rapid new antenna 2022/047. Also systematics, near large reservoir. Should be fixed by finals. http://geoweb.mit.edu/~tah/ACC_PBO/PSDM.CWU.jpg
2/24/22	
CTBR	Jump 2021/01/15 before switch of receiver 2021/02/10. No antenna changes (2013 break due to antenna). 2021/12/01 change seems to be system failure. http://geoweb.mit.edu/~tah/ACC_PBO/CTBR.CWU.jpg
MONP	Missing data and poor quality starting 2022/02/13. Maybe snow? New unknown breaks seen in time series. http://geoweb.mit.edu/~tah/ACC_PBO/MONP.CWU.jpg
P274	Starts failing 2020/07/21. http://geoweb.mit.edu/~tah/ACC_PBO/P274.CWU.jpg
P485	Lots of outliers. Between Salton sea and coast. Lots like it should be a good site? http://geoweb.mit.edu/~tah/ACC_PBO/P485.CWU.jpg
P510	East jump ~6mm 2022/01/16. Added to unknown list.

	http://geoweb.mit.edu/~tah/ACC_PBO/P510.CWU.jpg
ROSS	Edge of Lake Superior? Strange systematics. No nearby sites (>130 km, near sire THN2). http://geoweb.mit.edu/~tah/ACC_PBO/ROSS.CWU.jpg
TGMX	Tide gauge site in Yucatan. Unknown break 2021/08/19 (>30mm), smaller jump 2020/10/16 (7 mm). http://geoweb.mit.edu/~tah/ACC_PBO/TGMX.CWU.jpg
3/3/22	
LMSG	Gap since 2019. Offset due to new antenna and meta data not updated yet. http://geoweb.mit.edu/~tah/ACC_PBO/LMSG.CWU.jpg
MSOB	New antenna. Meta data not updated in rapids yet? Systematic time series; not in UNAVCO station pages; nearest sites P612, P577 (11-13km). Near Lake Arrowhead (San Bernardino, SCal). http://geoweb.mit.edu/~tah/ACC_PBO/MSOB.CWU.jpg
VCST	Antenna change, no metadata update. Systematic in east. SCal site. http://geoweb.mit.edu/~tah/ACC_PBO/VCST.CWU.jpg
WNRA	Systematic. Near downtown LA. http://geoweb.mit.edu/~tah/ACC_PBO/WNRA.CWU.jpg
ZNY1	CORS site on Long Island. 26 mm Jump North 2/24/2022. No meta updates yet. http://geoweb.mit.edu/~tah/ACC_PBO/ZNY1.CWU.jpg
3/11/22	
AV02	Outliers skewed in East or maybe snow; systematic changes associated with 2018 /01/23 earthquake? Seems to be postseismic. http://geoweb.mit.edu/~tah/ACC_PBO/AV02.CWU.jpg
CUHS	Strong, variable annual signal. (Not in station homepages). http://geoweb.mit.edu/~tah/ACC_PBO/CUHS.CWU.jpg
DIAB	Looks like antenna change; no update to NCEDC log. http://geoweb.mit.edu/~tah/ACC_PBO/DIAB.CWU.jpg
HRST	-30 to 50 mm systematic East mostly deviations. Site north, central Canada (Ontario). http://geoweb.mit.edu/~tah/ACC_PBO/HRST.CWU.jpg
ZLC1	Strong East annual. Near Salt Lake city. From UNR pages, nearby sites show same signal. http://geoweb.mit.edu/~tah/ACC_PBO/ZLC1.CWU.jpg
3/18/22	Not reported
AC27	Probably bad snow build up. Worse than previous years. http://geoweb.mit.edu/~tah/ACC_PBO/AC27.CWU.jpg
P170	Bad antenna for 2017-2021. Seems OK after 2021. http://geoweb.mit.edu/~tah/ACC_PBO/P170.CWU.jpg
P317	Strong east annual signal but also region of slow slip events. http://geoweb.mit.edu/~tah/ACC_PBO/P317.CWU.jpg
3/25/22	
NNVN	Recent drop in height but may be snow (Southern Greenland site). http://geoweb.mit.edu/~tah/ACC_PBO/NNVN.CWU.jpg
YELL	Outliers in east; maybe snow. Similar behavior in Oct 2013. http://geoweb.mit.edu/~tah/ACC_PBO/YELL.CWU.jpg

AT01	Systematic east annual signal; permafrost? St. Michael Alaska site. http://geoweb.mit.edu/~tah/ACC_PBO/AT01.CWU.jpg
4/1/22	
ARM1/2	Large gap and offset on return however large systematic variations. Sitting in sediments. http://geoweb.mit.edu/~tah/ACC_PBO/ARM2.CWU.jpg
P467	Some level of NS skewness. Postseismic from Ridgecrest. http://geoweb.mit.edu/~tah/ACC_PBO/P467.CWU.jpg
VNPS	North jump in rapids. Site North of LA. Not in Unavco station pages. Jumps are antenna and Ridgecrest. http://geoweb.mit.edu/~tah/ACC_PBO/VNPS.CWU.jpg
4/8/22	
ENUM	Rapids showing -10 mm North offset due to antenna change. Unknown break 2015/01/11 probably a failing antenna. Site near Seattle (ETS events?) http://geoweb.mit.edu/~tah/ACC_PBO/ENUM.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 December 15, 2021 and March 26, 2022.

CWU	North (mm)	East (mm)	Up (mm)
Median			
ANET	1.28	1.03	5.65
70%			
ANET	1.44	1.18	6.01
95%			
ANET	1.84	1.62	8.30

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

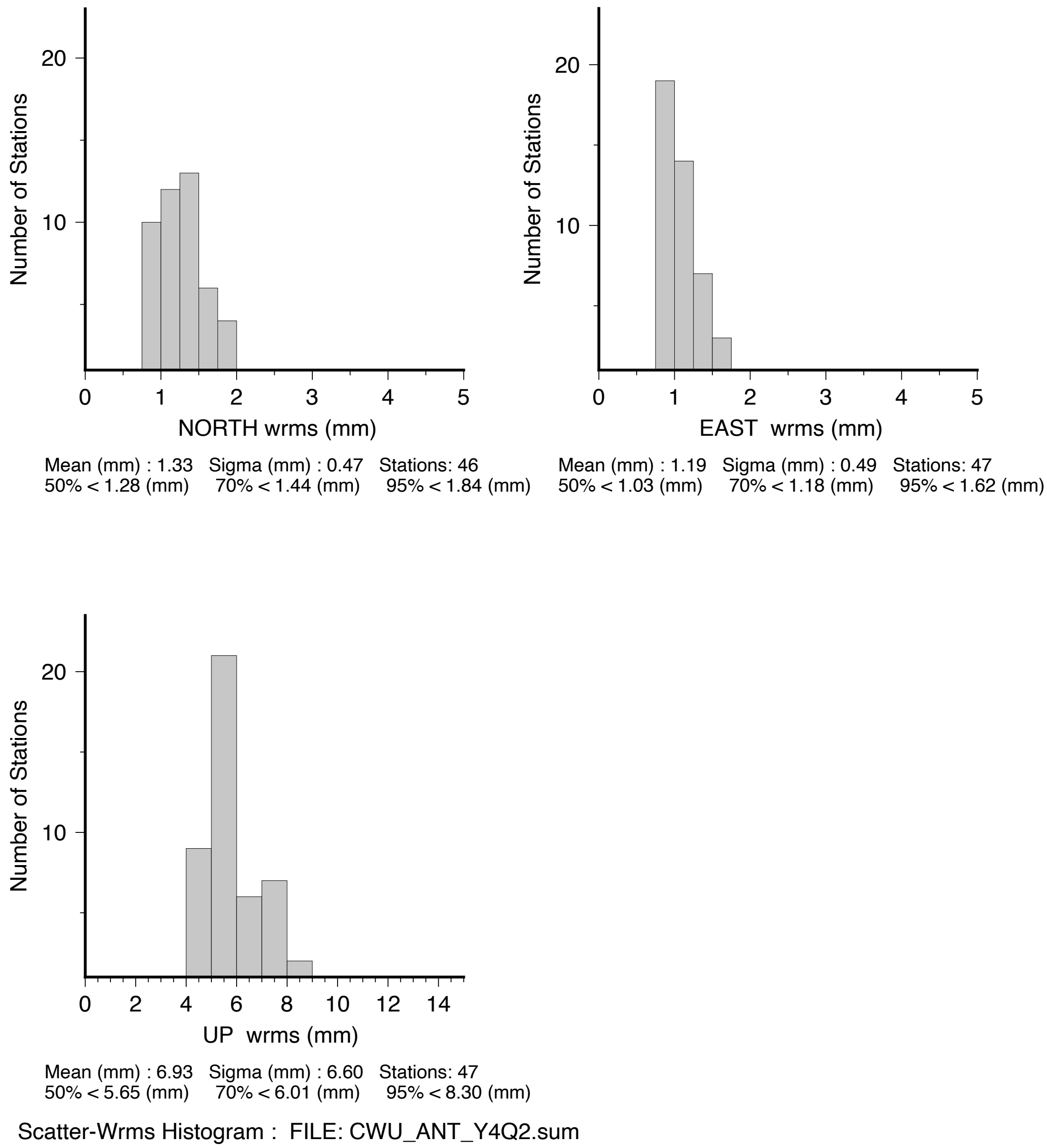

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 47 stations in Antarctica analyzed between December 15, 2021 and March 26, 2022. Linear trends and annual signals were estimated from the time series.

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