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

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Period: 2021/04/01-2021/06/30

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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 2021/03/15 to 2021/06/30, time series velocity field analyses for the GAGE reprocessing analyses (1996-2021). Several earthquakes were investigated this quarter but only one of them associated with the swarm near the Brawley seismic zone (Calipatria swarm) 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 1959 stations were processed which is 14 more than last quarter due to new stations being added to the analyses. In addition up to 46 sites were processed in the ANET solutions, 5 less than last quarter. There has been a declining number of ANET sites due to lack of access to sites for maintenance.

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, 2021– June 26, 2021

For this report, we generated the statistics using the ~3 months of CWU results between March 15, 2021 and June 26, 2021. 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 1959 stations for CWU analyzed in the finals analysis between March 15, 2021 and June 26, 2021. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.90	0.84	4.60
70%			
CWU	1.10	1.03	5.30
95%			
CWU	2.14	2.13	8.46

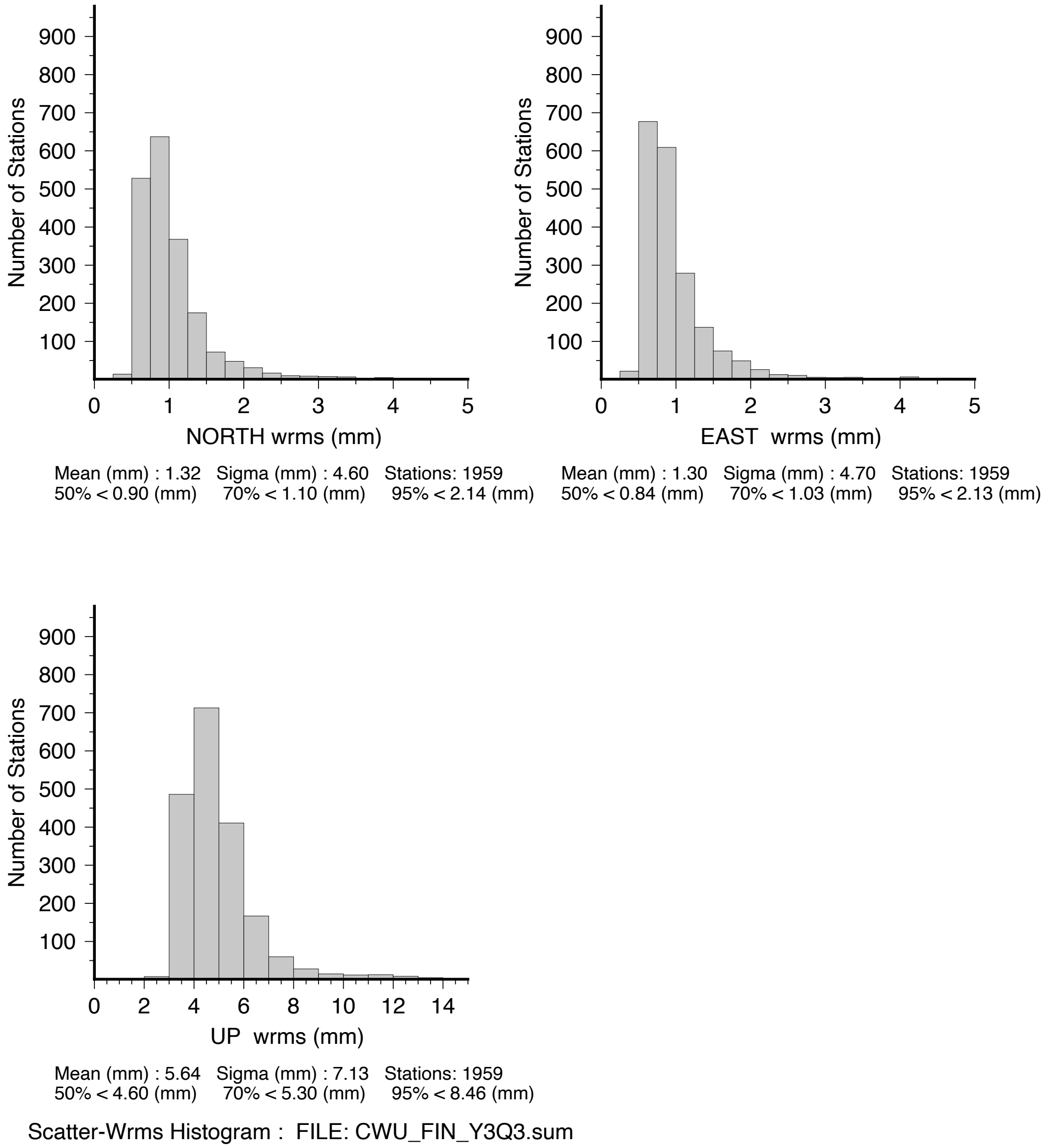

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 1959 stations analyzed between March 15, 2021 and June 26, 2021. Linear trends and annual signals were estimated from the time series.

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_Y3Q3.tab.

There are 1959 stations in the file for sites that have at least 2 measurements during the month.

```
Tabular Position RMS scatters created from CWU_FIN_Y3Q3.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   101      1.4   0.72      1.6   0.78     8.7   0.90      18.18
 1NSU   104      1.0   0.58      1.1   0.67     5.9   0.78      17.43
 1ULM   103      1.0   0.56      0.9   0.59     5.5   0.73      18.03
 AB02    79      1.2   0.57      1.3   0.87     3.7   0.54      14.09
…
 ZDC1   101      1.0   0.52      1.0   0.68     5.4   0.71      18.06
 ZDV1   101      0.8   0.42      0.9   0.56     5.2   0.69      18.06
 ZKC1   101      1.0   0.54      0.8   0.50     5.7   0.74      18.06
 ZLA1   100      1.1   0.62      1.1   0.70     4.9   0.64      18.06
 ZLC1   101      0.8   0.42      0.7   0.46     4.6   0.62      18.29
 ZME1   101      1.2   0.64      0.9   0.58     5.9   0.77      18.29
 ZMP1   101      0.9   0.47      0.8   0.50     6.1   0.82      18.54
 ZNY1   101      1.1   0.56      0.8   0.50     5.6   0.74      18.45
 ZSE1   101      0.8   0.38      0.7   0.48     4.8   0.66      18.45
 ZTL4   101      1.0   0.57      1.0   0.66     6.3   0.83      18.64
```

Table 2: RMS scatter of the position residuals for the CWU solution between March 15, 2021 and June 26, 2021 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	0.76	4.24	823
NUCLEUS	0.76	0.74	4.13	194
GAMA	0.87	0.82	5.31	15
COCONet	1.36	1.49	6.37	64
USGS_SCIGN	0.79	0.77	4.11	107
Expanded	1.02	0.95	5.27	756
70%				
PBO	0.97	0.92	4.62	
NUCLEUS	0.86	0.82	4.51	
GAMA	0.90	0.85	5.50	
COCONet	1.63	1.61	6.91	
USGS_SCIGN	1.04	1.00	4.68	
Expanded	1.22	1.14	5.92	
95%				

PBO	1.88	1.88	6.63
NUCLEUS	1.58	1.22	6.25
GAMA	1.02	0.94	6.26
COCONet	4.28	7.45	15.92
USGS_SCIGN	1.53	1.47	7.25
Expanded	2.43	2.52	10.06

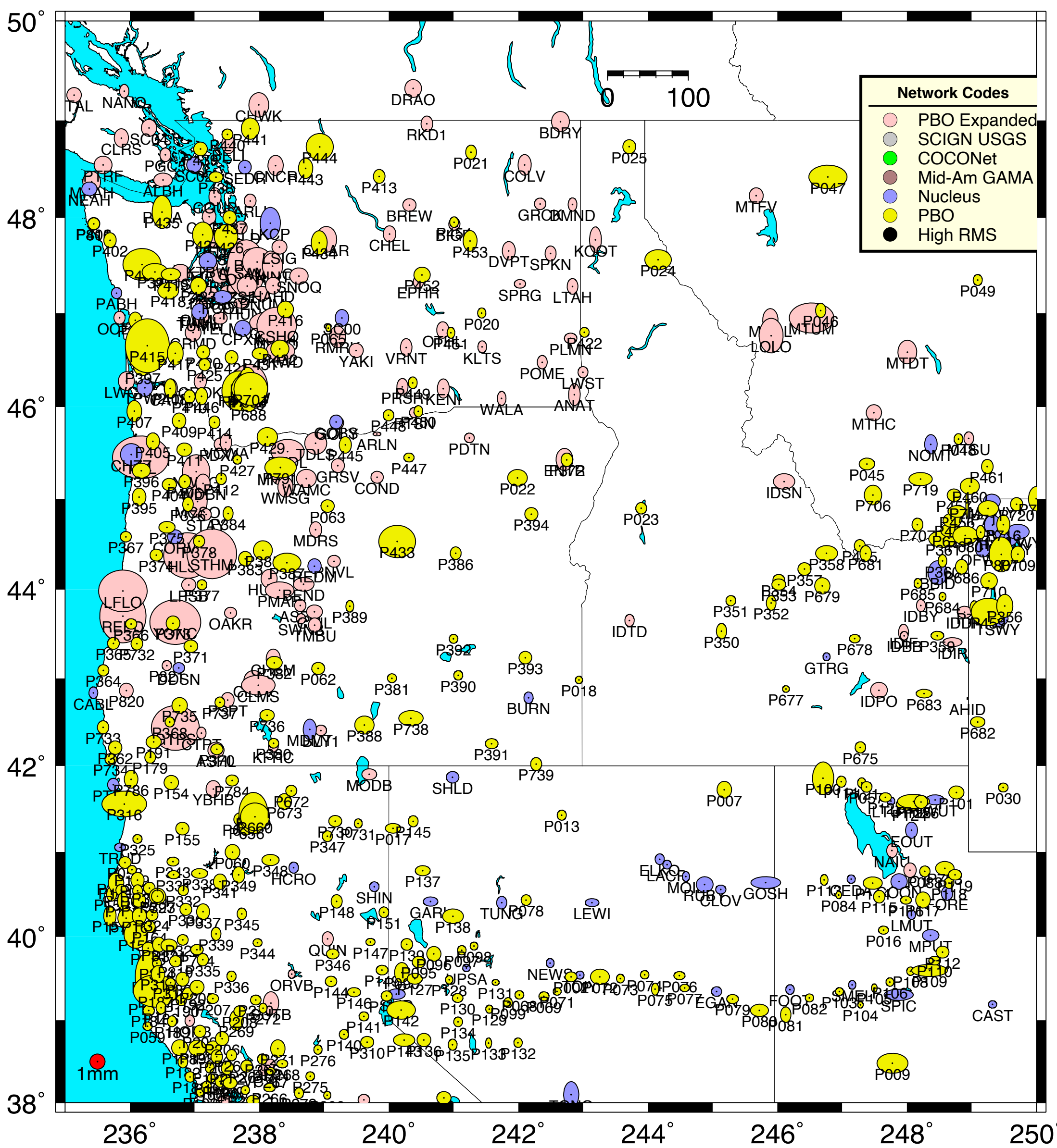

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1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

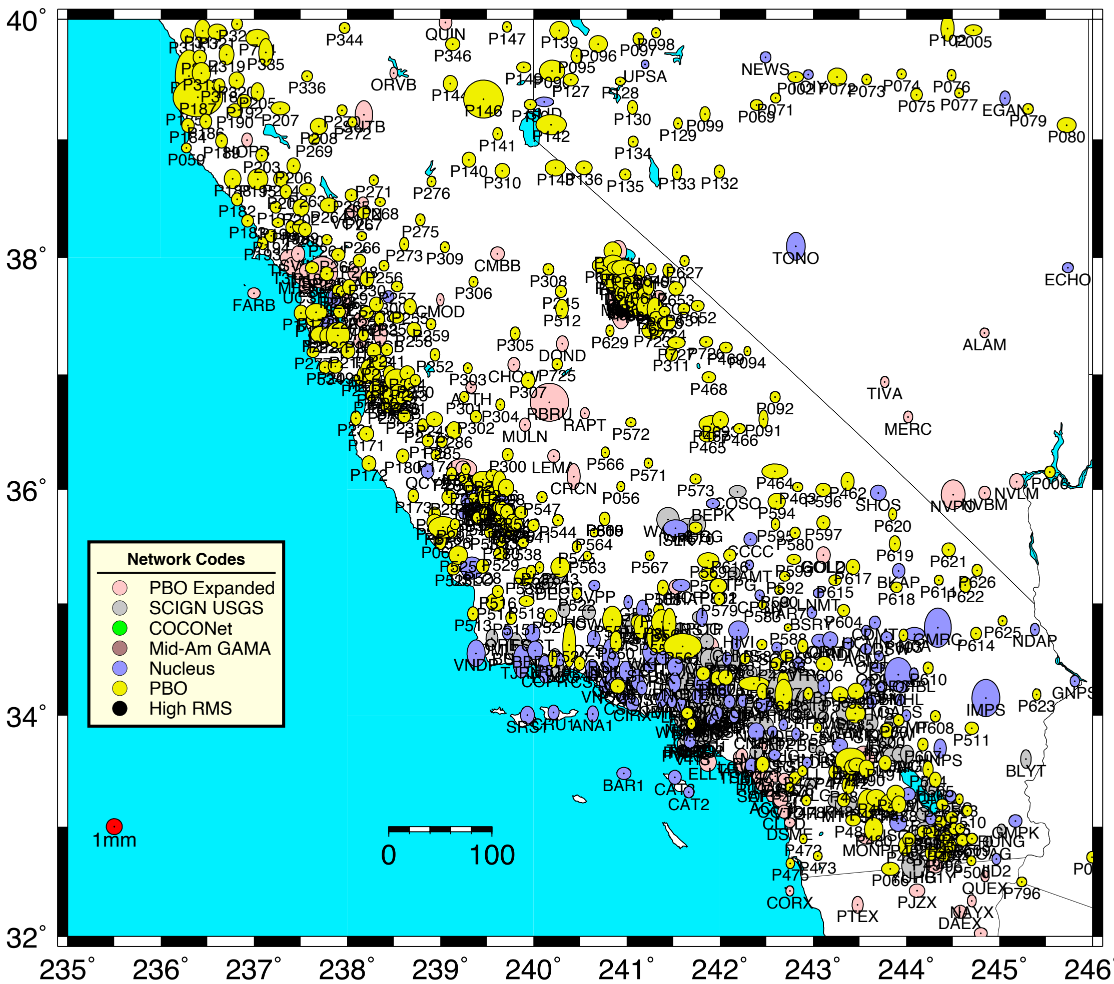

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

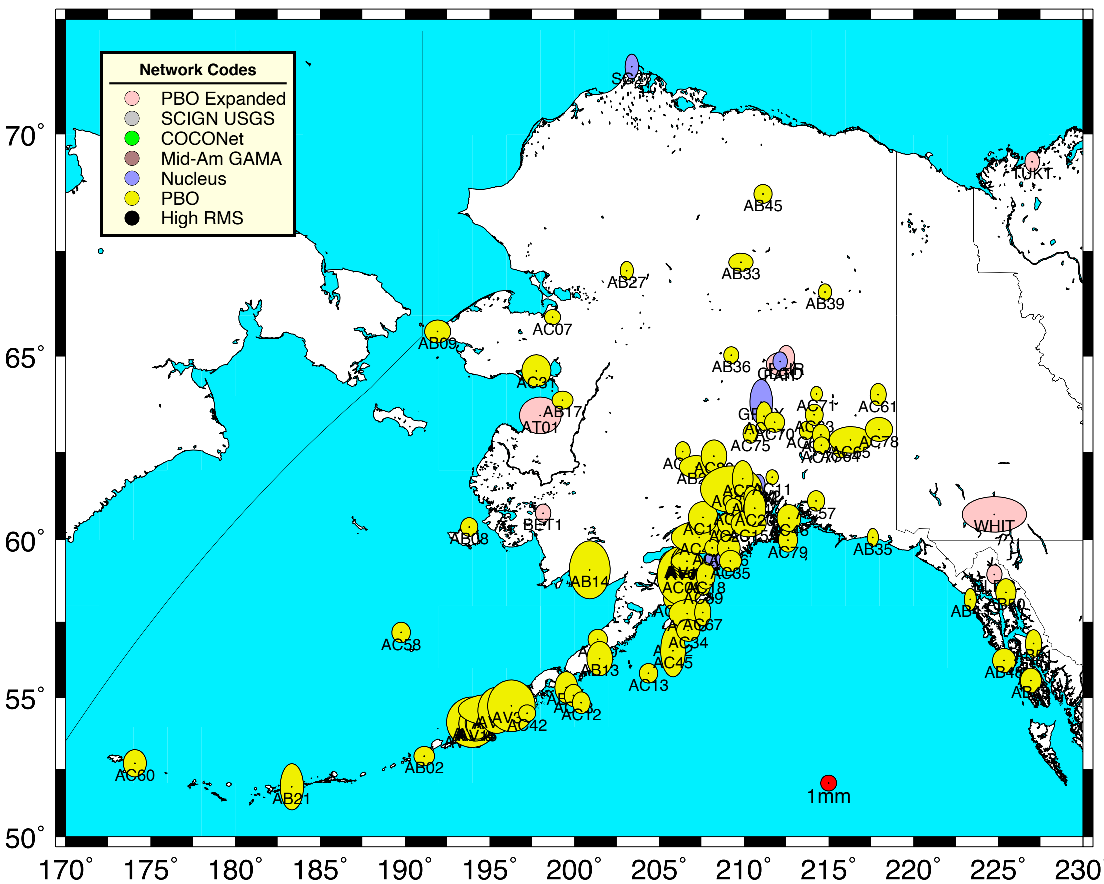

Figure 4: Same as Figure 4 except for the Alaskan region.

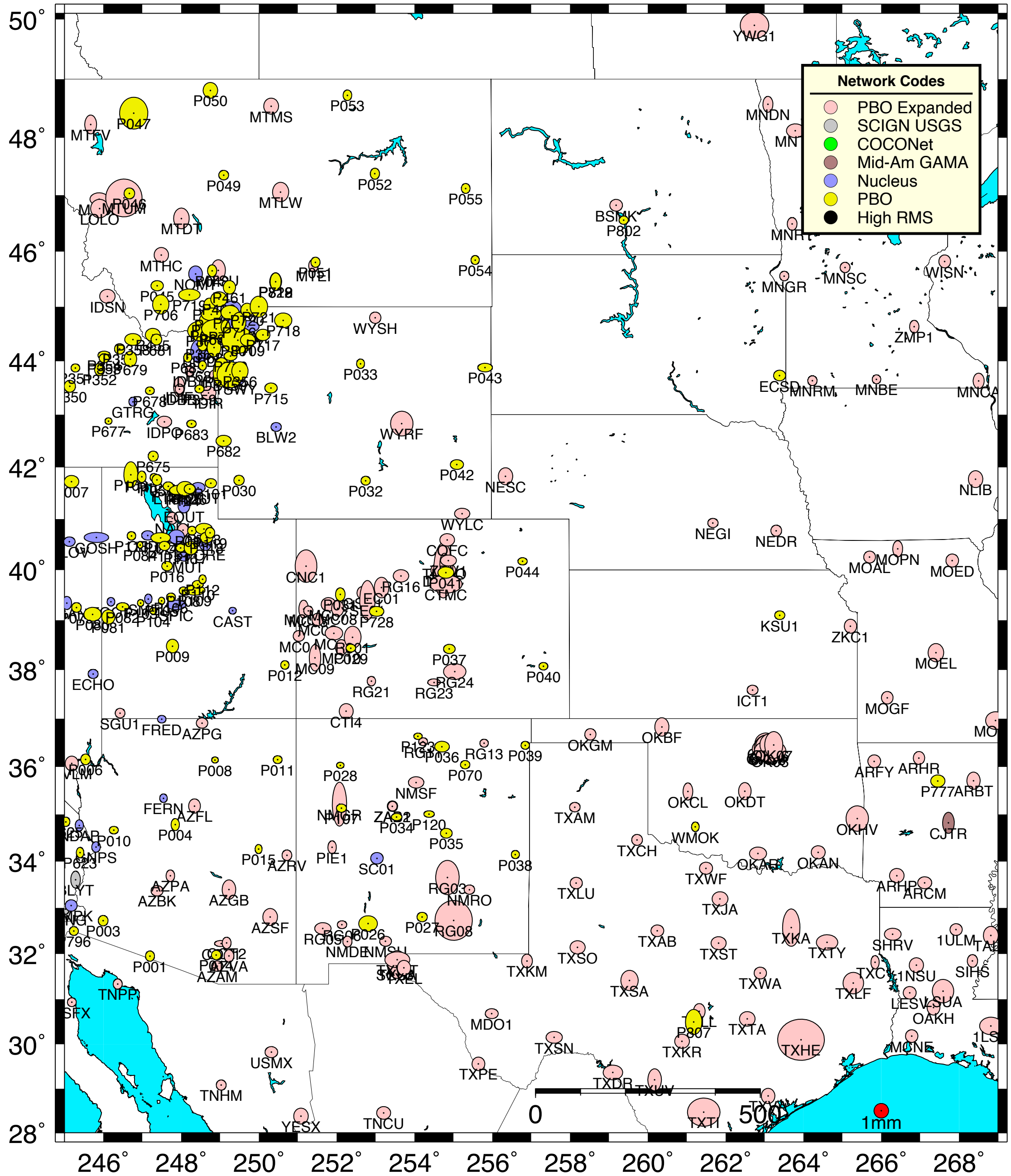

Figure 5: Same as Figure 4 except for the Central United States

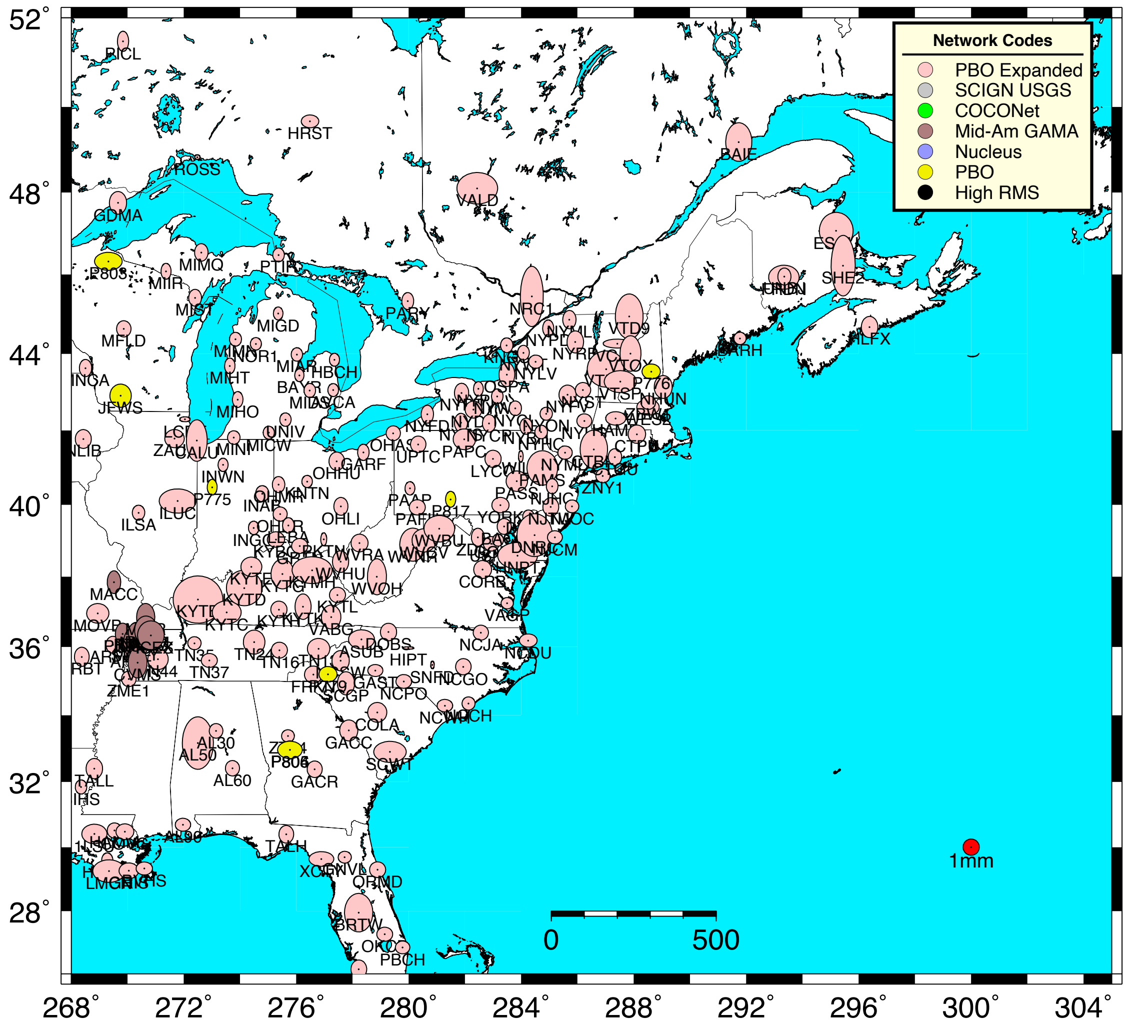

Figure 6: Same as Figure 4 except for the Eastern United States

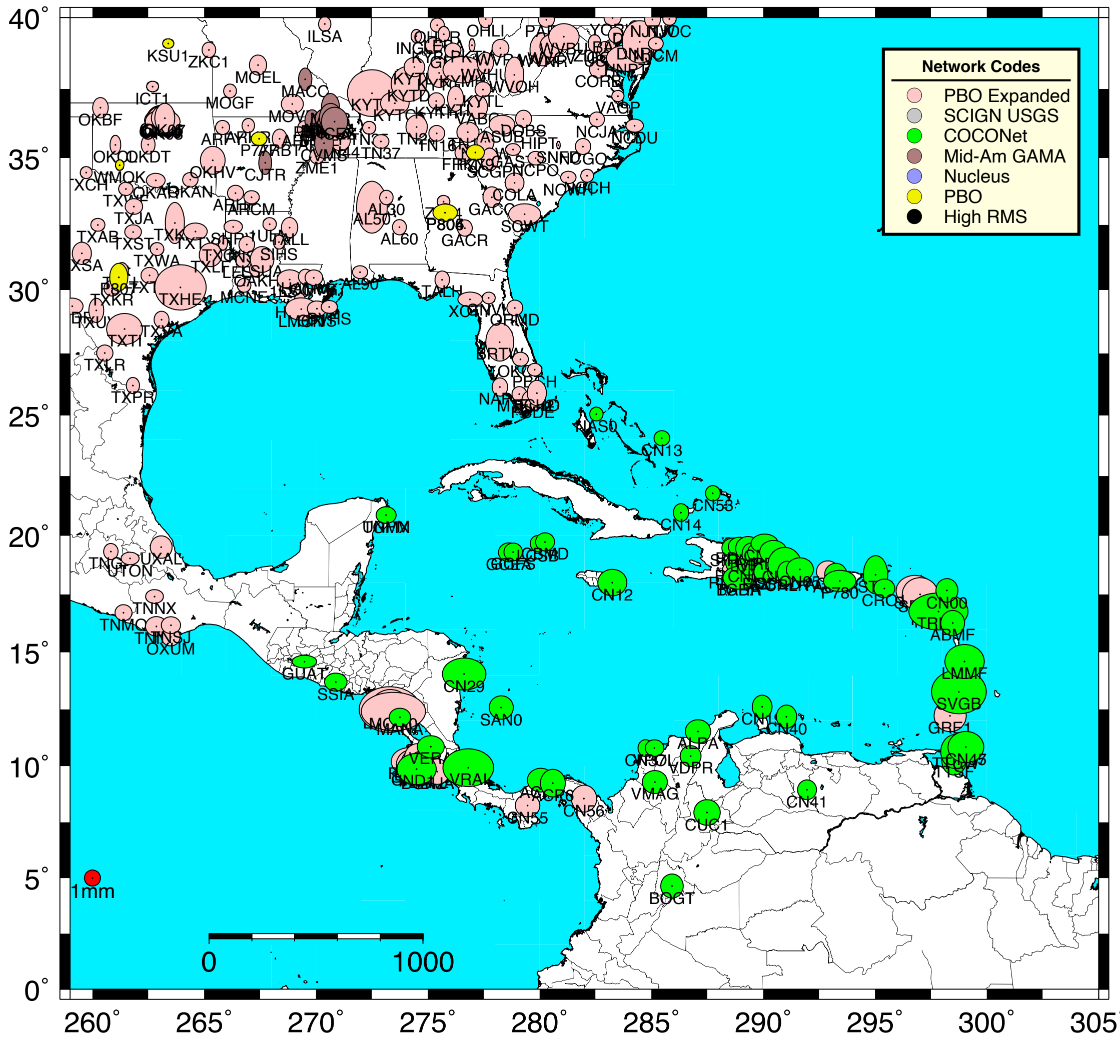

Figure 7: Same as Figure 4 except for the Caribbean region.

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 2657 stations in the CWU solution (5 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_210626.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_210626.snpvel.

Table 3: Statistics of the fits of 2657 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and June 26, 2021.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.40	1.35	6.16
70%			
CWU	1.76	1.70	7.01
95%			
CWU	3.92	3.63	11.64

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.

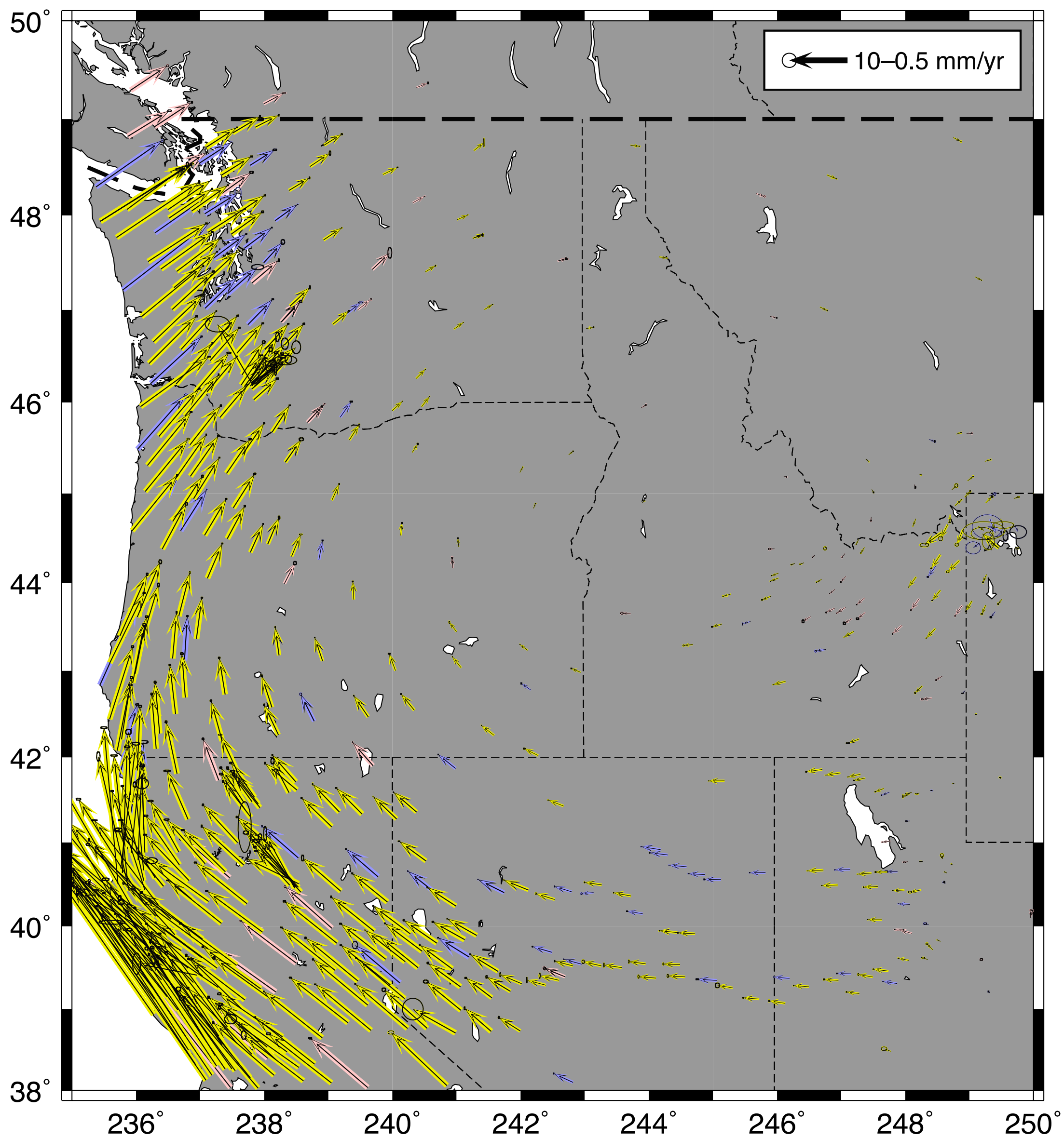

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

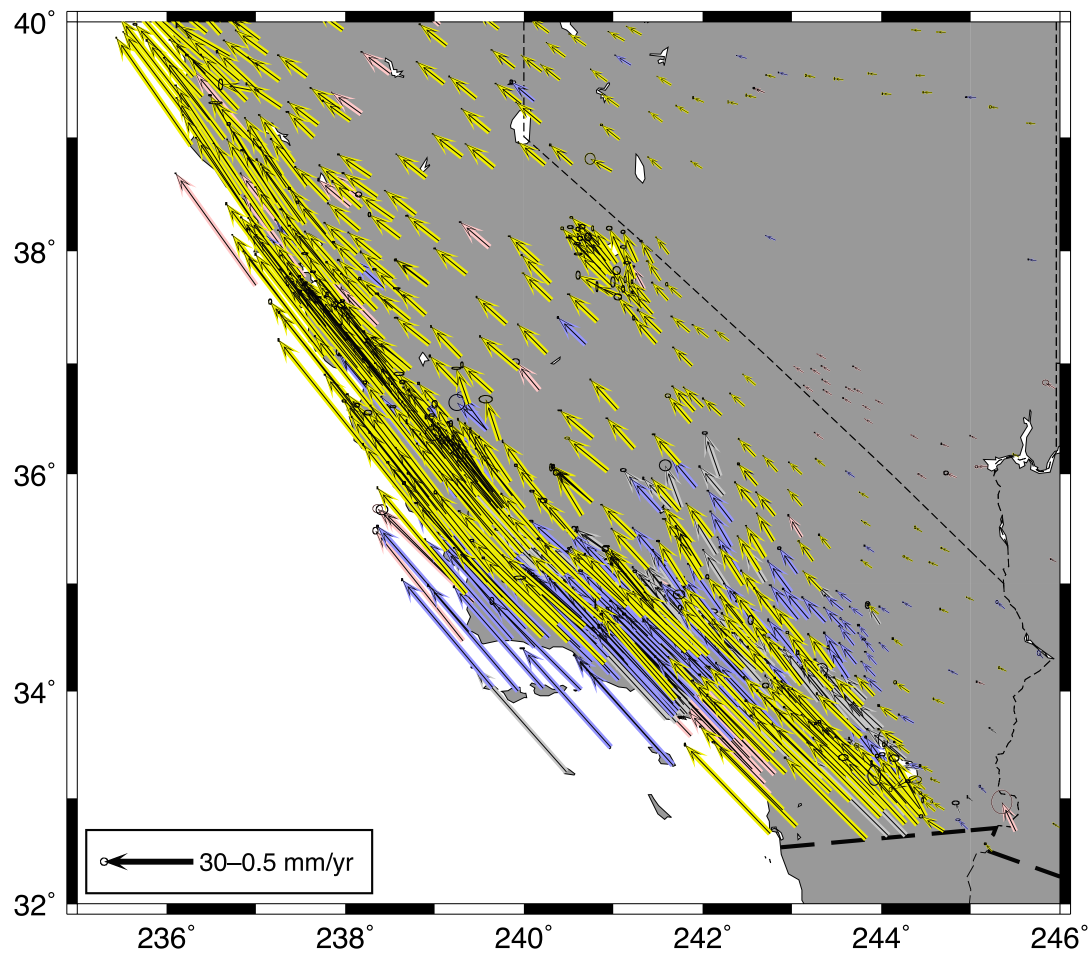

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

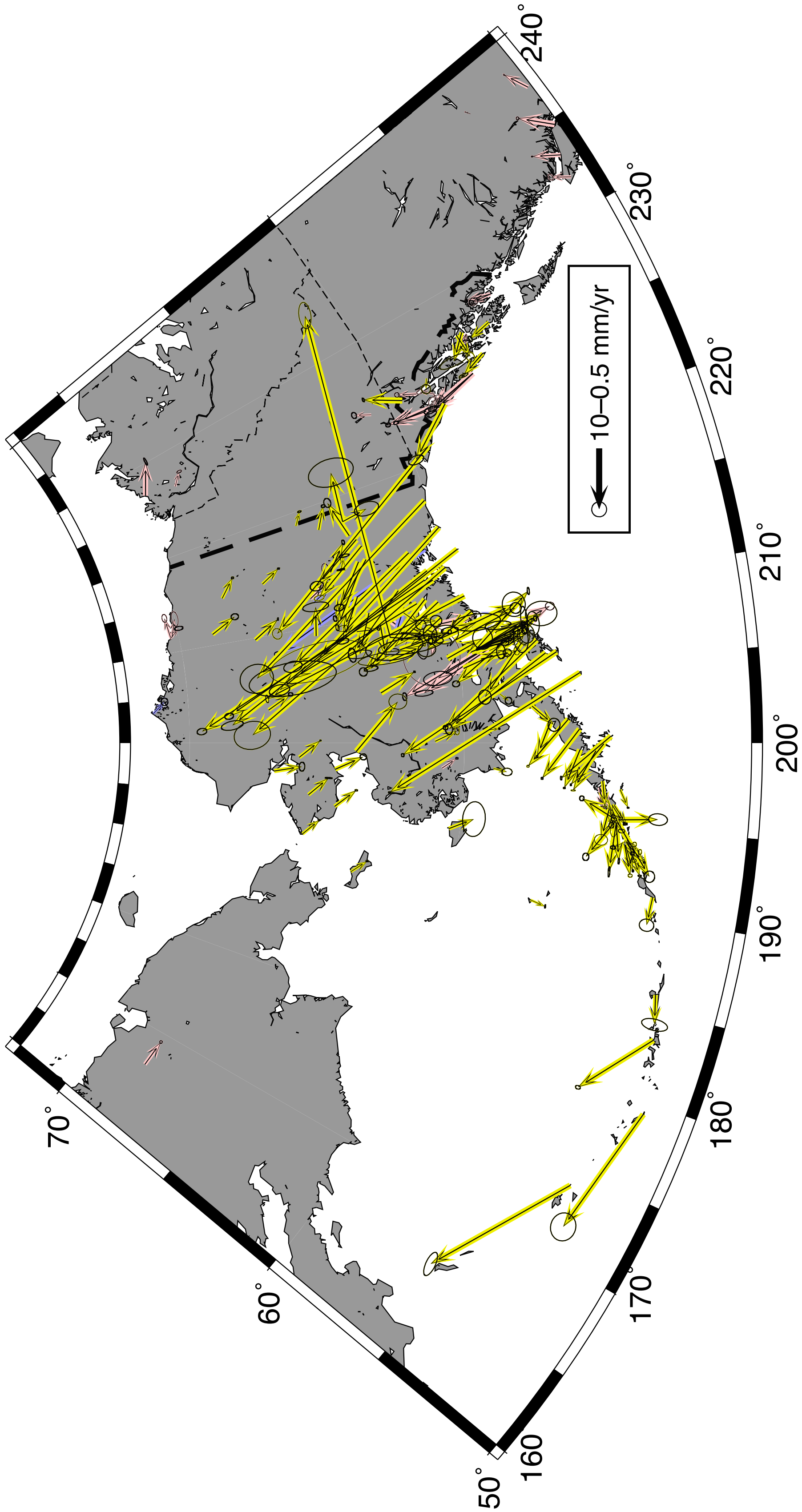
10–0.5 mm/yr
240°
230°
220°
210°
200°
190°
180°
170°
160°
50°
60°
70°

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

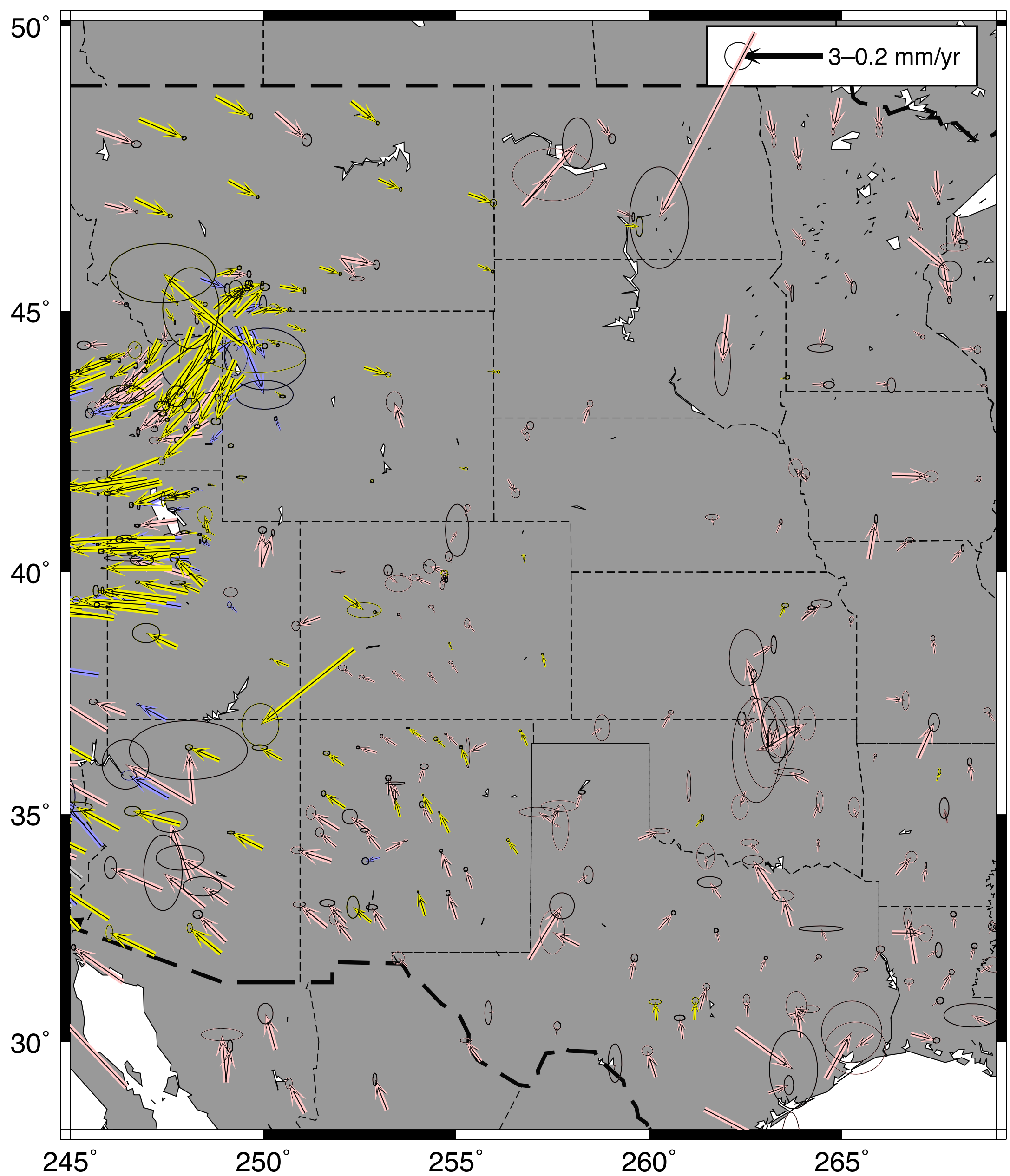

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

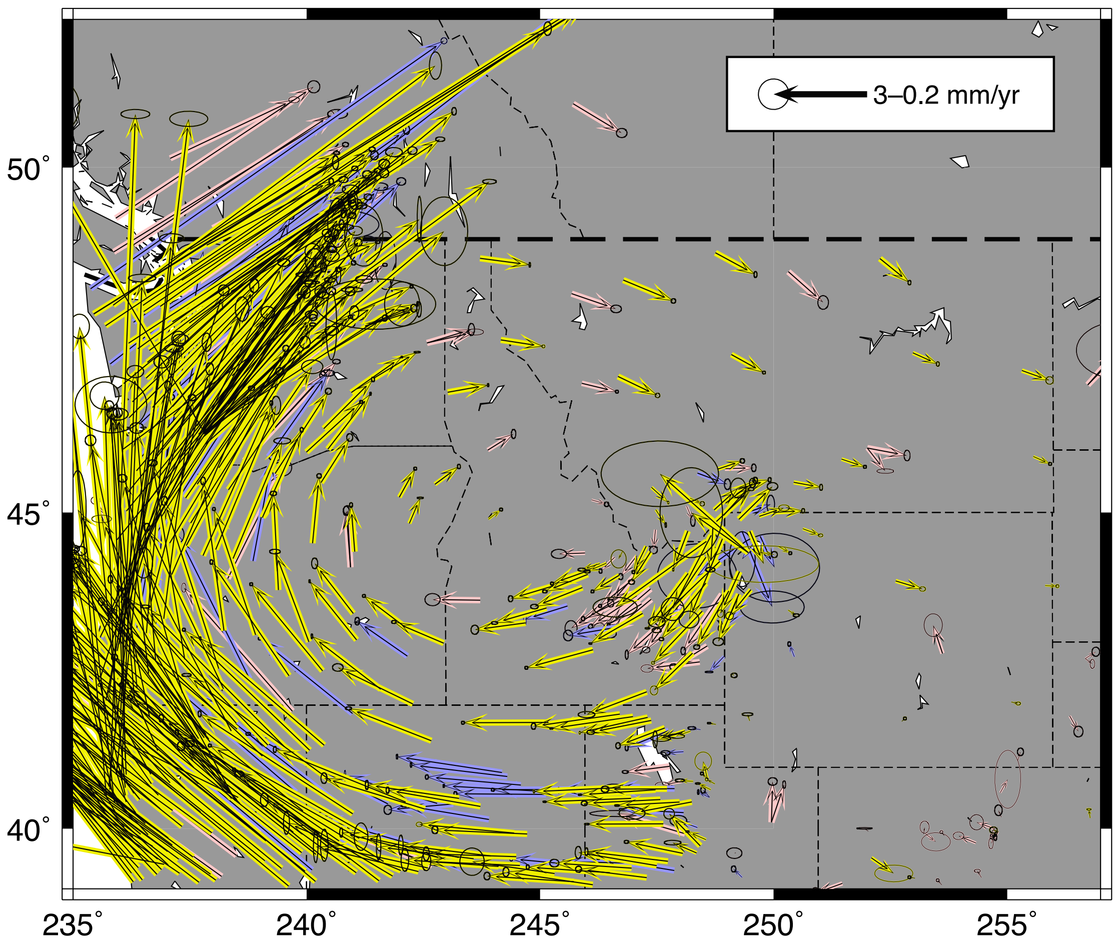

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

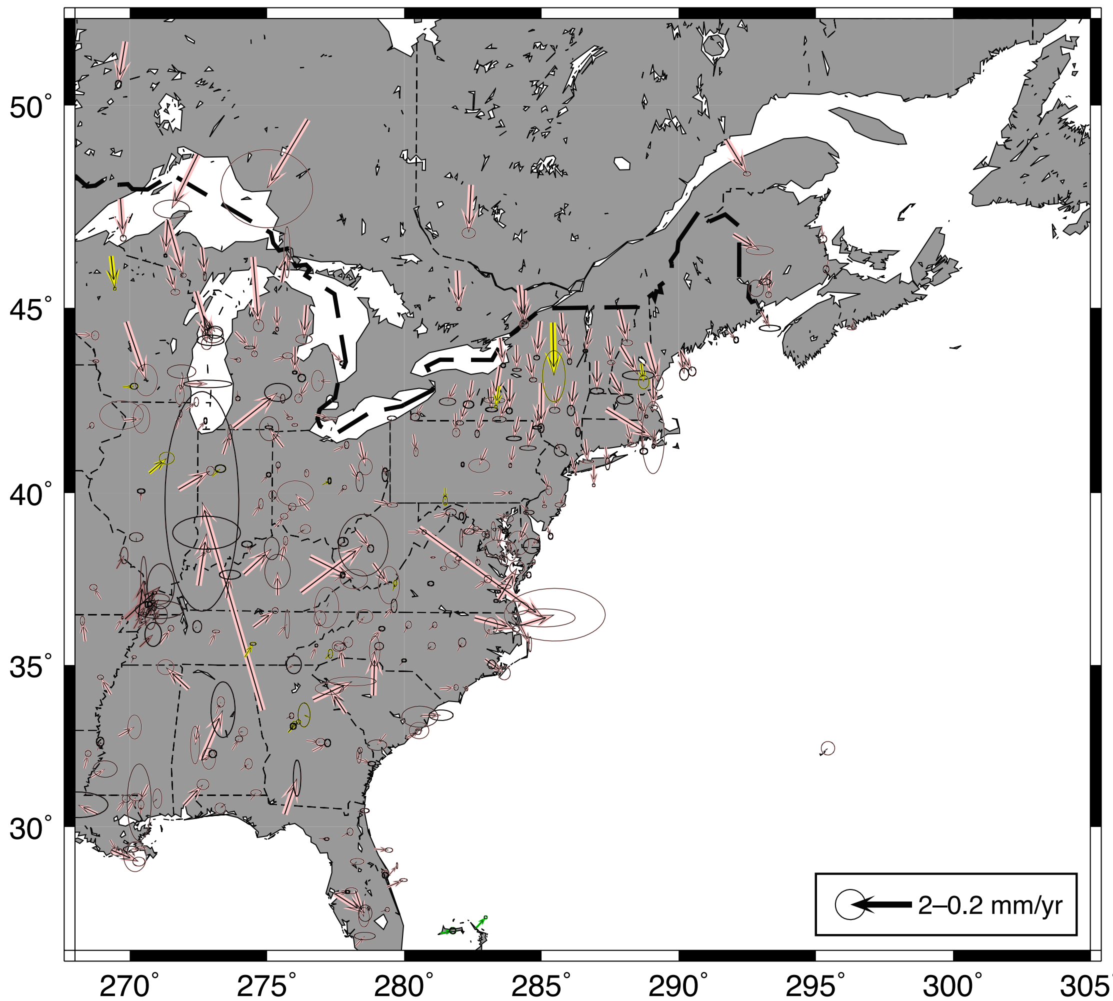

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

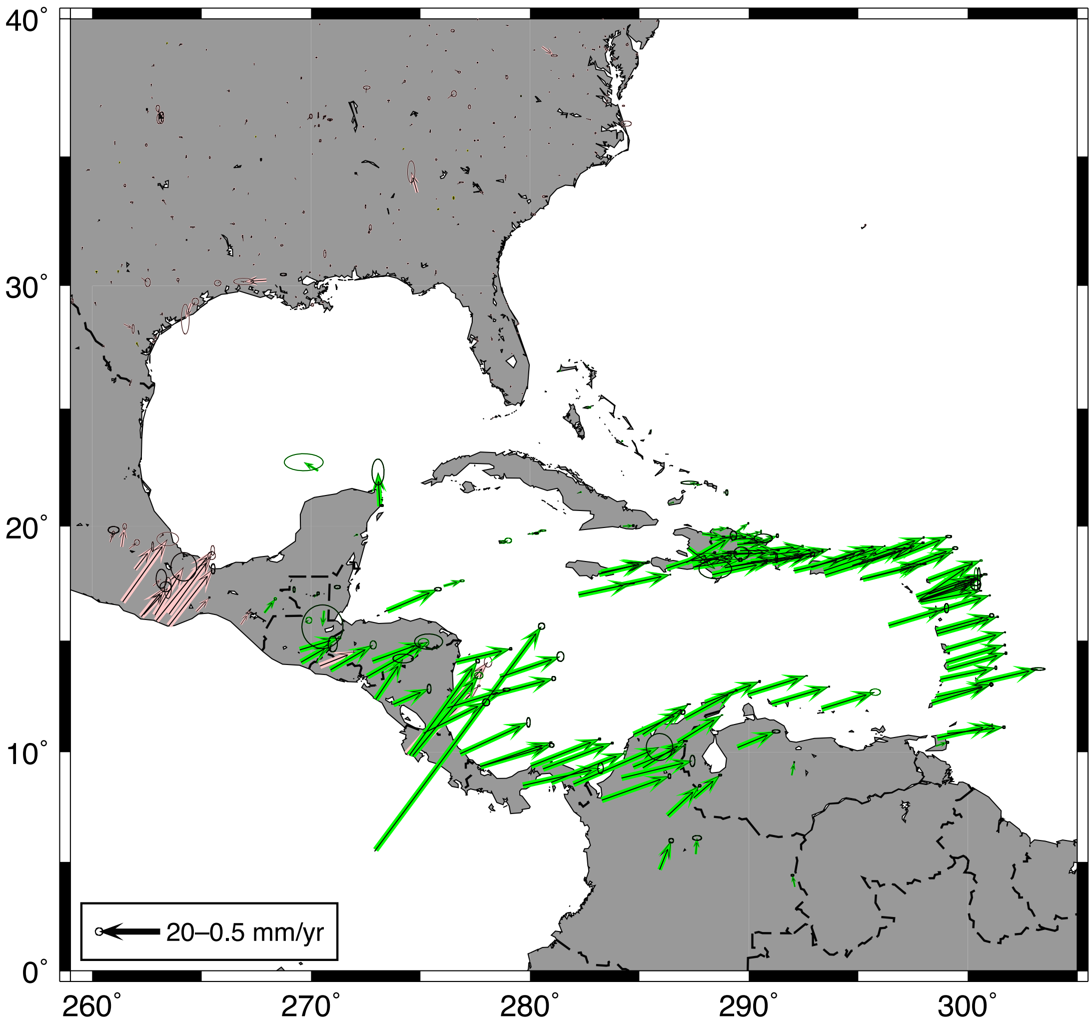

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2021/03/15-2021/06/30

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 40 earthquakes examined during this quarter only one generated displacements more than 1 mm. The event, designate EQ60 is ANSS(ComCat) ci39919392 Mw5.2 2021-06-05 17:56 / It is the largest event in the Brawley Seismic zone/ Calipatria swarm. Co-seismic offsets were generated and EQ60 added to the earthquake file. Rapid and final event files were generated and sent to UNAVCO via LDM. For the final event file, the radius of influence of the event was increased from 19.7 to 25 km to accommodate sites that appear to small, millimeter level displacements. Other large events in the sequence may have also displaced individual sites and the co-seismic offsets from the swarm should be considered the cumulative effects of all events. The final's co-seismic offsets are shown in Figure 15.

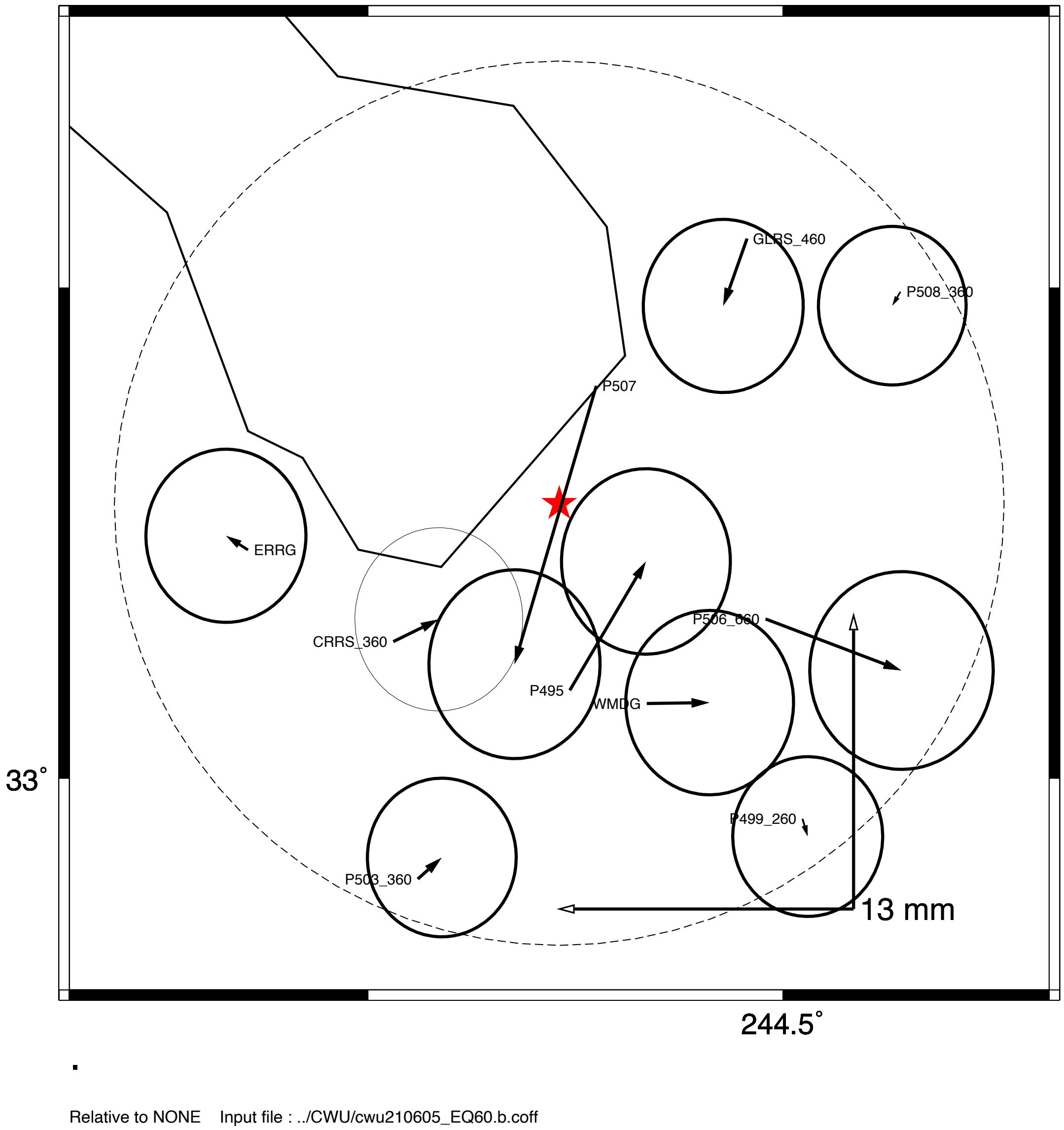

Figure 15: Coseismic offsets from the GAGE event 60: ANSS(ComCat) ci3991939 mw5.2 11km W of Calipatria (5.78 km depth) ϕ 33.1400 λ -115.6348 date 2021 06 05 time 17:56 UTC. A rapid and final event files prepared and sent.

Antenna and other discontinuity events.

Antenna swaps at 30 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
2021-04-01	
PUMO	Change in height trend after 2012/09/15 (EQ21) earthquake. Nearby EQ20 (2012/08/27) may have impact too. LEPA similar plus other sites. http://geoweb.mit.edu/~tah/ACC_PBO/PUMO.CWU.jpg
AC14	Postseismic north from EQ 44 ANSS(ComCat) us2000cmy3 mww7.9 280km SE of Kodiak 56.0464 -149.0728 2018 01 23 09 32. http://geoweb.mit.edu/~tah/ACC_PBO/AC14.CWU.jpg
AB07	Large co-seismics from EQ 56 ANSS(ComCat) us7000asvb mww7.8 105 km SSE of Perryville 55.0298 -158.5217. Aftershock EQ 59 ANSS(ComCat) us6000c9hg mww7.6 97 km SE of Sand Point 54.6172 -159.6352 2020 10 19 20 55 offset in East on 2020 10 20; amplitude -10 mm. http://geoweb.mit.edu/~tah/ACC_PBO/AB07.CWU.jpg
	Comment: Important sites in snowy regions: How do extract data not affected by snow so that tectonic results can be used?
2021-04-09 Reported in monthly telecon to here.	
P177	~20 mm East shift with switch from TRM29659.0 to TRM59800.99 antenna on 2021/094. http://geoweb.mit.edu/~tah/ACC_PBO/P177.CWU.jpg
2021-04-16	
VTOX	Started developing annual in height and north in 2017. Antenna or vegetation maybe issue. Site in New Hampshire. No photos. http://geoweb.mit.edu/~tah/ACC_PBO/VTOX.CWU.jpg
SVBG	Displaced by 04/09/2021 volcanic eruption. Data quality changes during 2020 for unknown reason. NetR9 installed late 2016 and quality improves dramatically after Jan 19, 2021. http://geoweb.mit.edu/~tah/ACC_PBO/SVGB.CWU.jpg
4/30/21	
GHRP	Large north excursion starting 2007 and ending in 2013 with 40 mm jump. Not obviously related to antenna changes. No earthquakes. http://geoweb.mit.edu/~tah/ACC_PBO/GHRP.CWU.jpg
5/7/21	
NRC1	Noisy patches: Off in north in rapids (outliers like this in the past as well). http://geoweb.mit.edu/~tah/ACC_PBO/NRC1.CWU.jpg
5/15/21	
PMKZ	Possible earthquake effect from magnitude 4.8 on 2021/04/27. PMKZ only site possible effected but there is no clear offset at the time of the earthquake but there is a change in rate at about this date. The is a newer site which shows systematics and the change may be unrelated to the earthquake.

	http://geoweb.mit.edu/~tah/ACC_PBO/PMKZ.CWU.jpg
5/24/21	
AC23	Systematic in North in particular. Amplitude ±10 mm, Starting to move west for last 2 years. http://geoweb.mit.edu/~tah/ACC_PBO/AC23.CWU.jpg
RG24	Skewed in East. Outliers 15-30 mm West. http://geoweb.mit.edu/~tah/ACC_PBO/RG24.CWU.jpg
SFMD	Maybe something happening in North recently. http://geoweb.mit.edu/~tah/ACC_PBO/SFDM.CWU.jpg
WGPP	Ridge Crest offset of -4 mm East offset 2019/07/06. Longer term systematics in all components. http://geoweb.mit.edu/~tah/ACC_PBO/WGPP.CWU.jpg
VTSP	Large annual in east starting 2018. Deviation ~10 mm. http://geoweb.mit.edu/~tah/ACC_PBO/VTSP.CWU.jpg
5/28/21	
HJOR	Strong East annual (5 mm peak-peak). Height annual as well. http://geoweb.mit.edu/~tah/ACC_PBO/HJOR.CWU.jpg
CSDH	13 cm jump in height on re-start 21/05/28 (gap from 21/05/12). No new log but could be antenna change. http://geoweb.mit.edu/~tah/ACC_PBO/CSDH.CWU.jpg
IMPS	Noise level increase at start of 2021, North offset of 50 mm 21/05/29 but error is some larger than normal. Before change, error bars look large compared to scatter compared to other sites. http://geoweb.mit.edu/~tah/ACC_PBO/IMPS.CWU.jpg
6/12/21	
GVRS	Strange north dip from 2010-2018, span of estimates with larger error bars (missing data?) and now rebound. Noticed due to 100 mm height jump in rapids. New antenna 2021 155 from TPSCR.G3 to TWIVC6150 http://geoweb.mit.edu/~tah/ACC_PBO/GVRS.CWU.jpg
LMNL	Restarted after 1 year gap. Large post-seismic from EQ_ID 21 ANSS(ComCat) usp000jrsw EQ_DEF mww7.6 Costa Rica. Looks OK on trend. http://geoweb.mit.edu/~tah/ACC_PBO/LMNL.CWU.jpg
MILK	Similar height jump as GVRS with antenna changes from TRM55971.00 to TWIVC6150 on 2021 156. http://geoweb.mit.edu/~tah/ACC_PBO/MILK.CWU.jpg
P507	Earthquake swarm: EQ_ID B2 ANSS(ComCat) ci39919392 mw5.2 11km W of Calipatria 2021/06/05 17:56, about -10 mm N. P495 also displaced. New EQ entry created. Maybe 20201/06/12 ANSS(ComCat) ci39936192 mw4.3 13km WSW of Niland (2.21 km depth) 2021/06/12 04:40 may displace too (no rapid yet). Event EQ60 created. http://geoweb.mit.edu/~tah/ACC_PBO/P507.CWU.jpg
ROCK	Jump in height 140 mm. Antenna change to TWIVC6150. http://geoweb.mit.edu/~tah/ACC_PBO/ROCK.CWU.jpg

7/2/21	
DMND	10 mm East jump. PANGA site, not meta data change in log file. http://geoweb.mit.edu/~tah/ACC_PBO/DMND.CWU.jpg
7/14/21	
AC41	Continued post-seismic after gaps in data from EQ 56 ANSS(ComCat) us7000asvb mww7.8 105 km SSE of Perryville 2020/07/22 06:13. http://geoweb.mit.edu/~tah/ACC_PBO/AC41.CWU.jpg
P499	Change in trend starting around 2021/04/22, seen as P503 as well possibly. P508? Swarm related although starts earlier. http://geoweb.mit.edu/~tah/ACC_PBO/P499.CWU.jpg http://geoweb.mit.edu/~tah/ACC_PBO/P503.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 46 stations in the ANET region for CWU analyzed in the final orbit analysis between March 15, 2021 and June 26, 2021.

CWU	North (mm)	East (mm)	Up (mm)
Median ANET	1.29	1.12	5.90
70% ANET	1.49	1.40	6.60
95% ANET	2.73	6.72	11.16

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

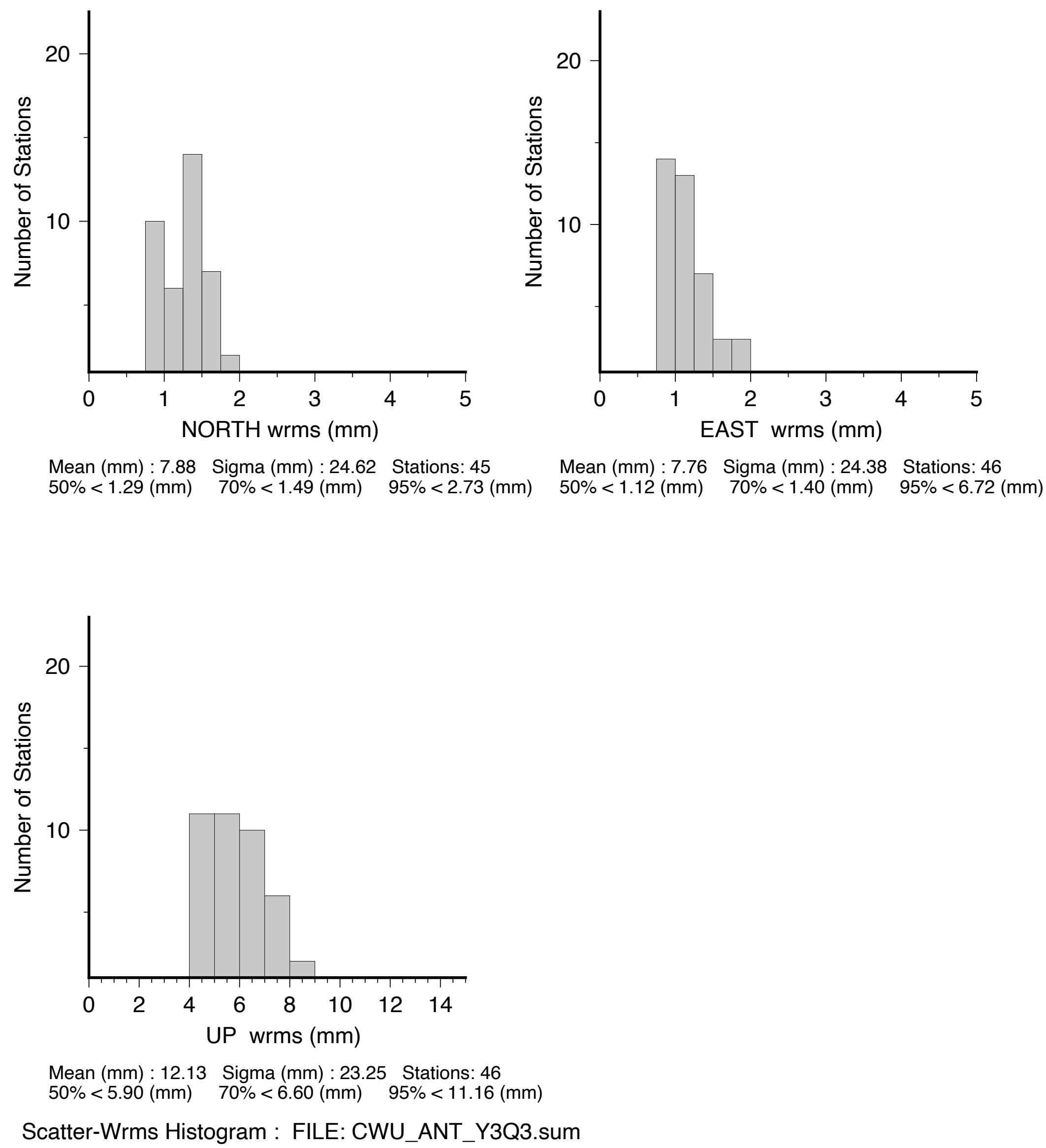

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 51 stations in Antarctica analyzed between March 15, 2021 and June 26, 2021. Linear trends and annual signals were estimated from the time series.

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