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

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Period: 2021/07/01-2021/09/30

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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 2021/06/15 to 2021/09/30, 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 1958 stations were processed which is 1 less than last quarter. In addition up to 34 sites were processed in the ANET solutions, 12 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: June 15, 2021– September 18, 2021

For this report, we generated the statistics using the ~3 months of CWU results between June 15, 2021 and September 18, 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 1958 stations for CWU analyzed in the finals analysis between June 15, 2021 and September 18, 2021. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.98	0.91	4.60
70%			
CWU	1.20	1.09	5.26
95%			
CWU	2.05	1.95	8.02

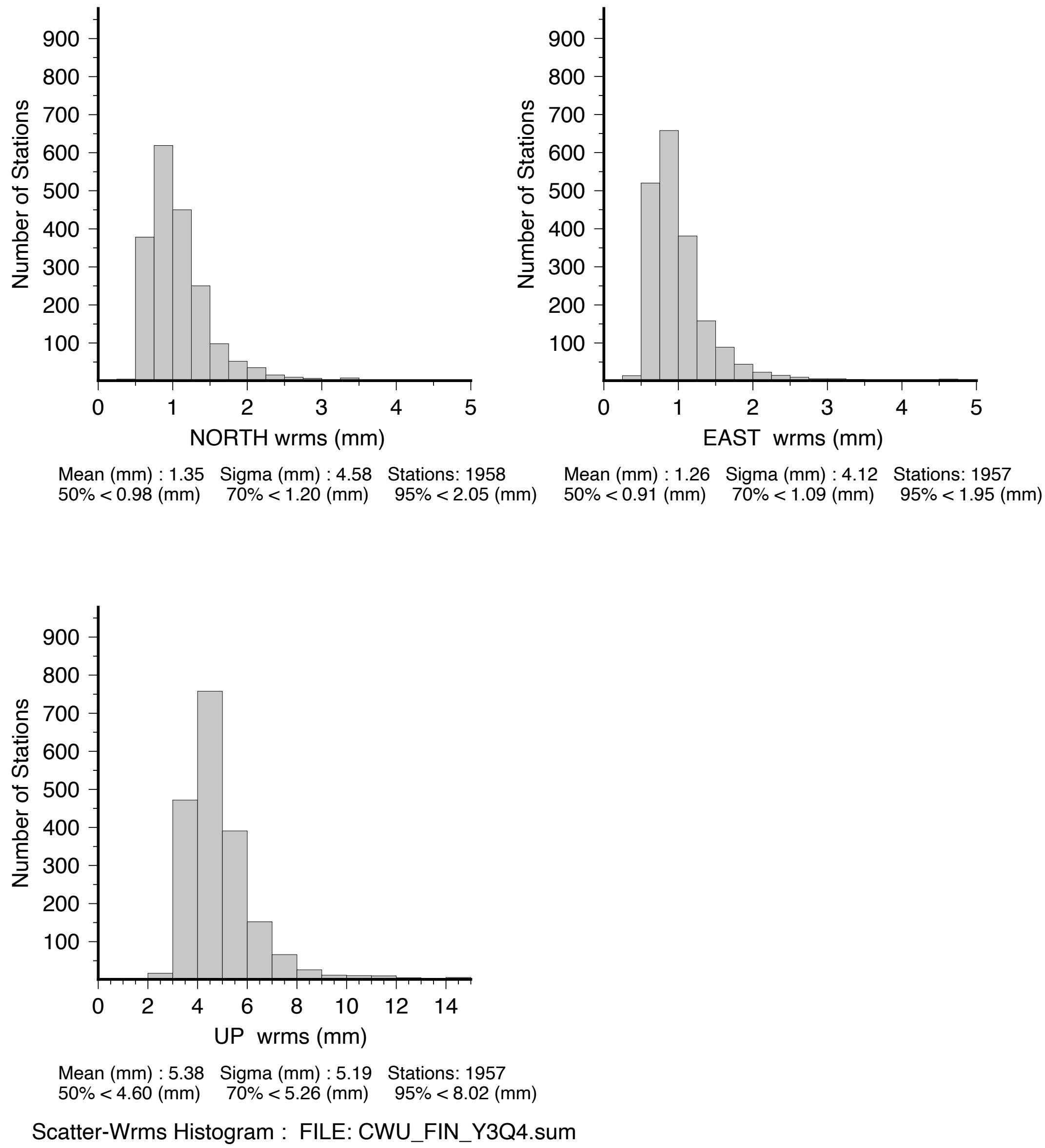

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 1958 stations analyzed between June 15, 2021 and September 18, 2021. Linear trends and annual signals were estimated from the time series.

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_Y3Q4.tab.

There are 1958 stations in the file for sites that have at least 2 measurements during the month.

```
Tabular Position RMS scatters created from CWU_FIN_Y3Q4.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    95      1.4   0.71      1.8   0.86     8.4   0.87     18.41
 1NSU    96      1.2   0.66      1.0   0.59     5.5   0.71     17.66
 1ULM    95      1.2   0.69      1.5   0.92     5.0   0.64     18.26
 AB02    95      1.3   0.61      1.4   0.93     4.4   0.62     14.32
…
 ZDV1    95      1.0   0.51      0.9   0.55     5.8   0.74     18.29
 ZKC1    94      1.1   0.54      1.0   0.63     6.1   0.79     18.29
 ZLA1    96      1.1   0.57      1.0   0.60     5.0   0.65     18.52
 ZLC1    95      0.9   0.44      1.2   0.73     5.4   0.69     18.52
 ZME1    95      1.2   0.67      0.8   0.52     5.0   0.65     18.77
 ZMP1    95      1.0   0.49      1.1   0.72     5.8   0.74     18.68
 ZNY1    96      1.3   0.63      0.6   0.32     2.8   0.35     19.15
 ZOA1    10      0.5   0.23      1.0   0.65     5.0   0.67     18.68
 ZSE1    96      1.0   0.48      1.0   0.64     6.0   0.78     18.87
 ZTL4    95      1.1   0.63      0.0   0.00     0.0   0.00      0.00
```

Table 2: RMS scatter of the position residuals for the CWU solution between June 15, 2021 and September 18, 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	0.86	0.81	4.26	828
NUCLEUS	0.80	0.78	4.17	199
GAMA	1.10	1.11	5.15	15
COCONet	1.52	1.62	6.94	63
USGS_SCIGN	0.86	0.80	4.32	107
Expanded	1.14	1.05	5.22	746
70%				
PBO	1.03	0.96	4.64	
NUCLEUS	0.92	0.88	4.53	
GAMA	1.20	1.16	5.43	
COCONet	1.86	1.88	7.63	

USGS_SCIGN	1.00	0.98	4.91
Expanded	1.30	1.24	5.86
95%			
PBO	1.86	1.54	6.18
NUCLEUS	1.58	1.28	6.14
GAMA	1.29	1.19	5.81
COCONet	3.41	4.71	17.25
USGS_SCIGN	1.63	1.44	6.65
Expanded	2.05	2.20	9.49

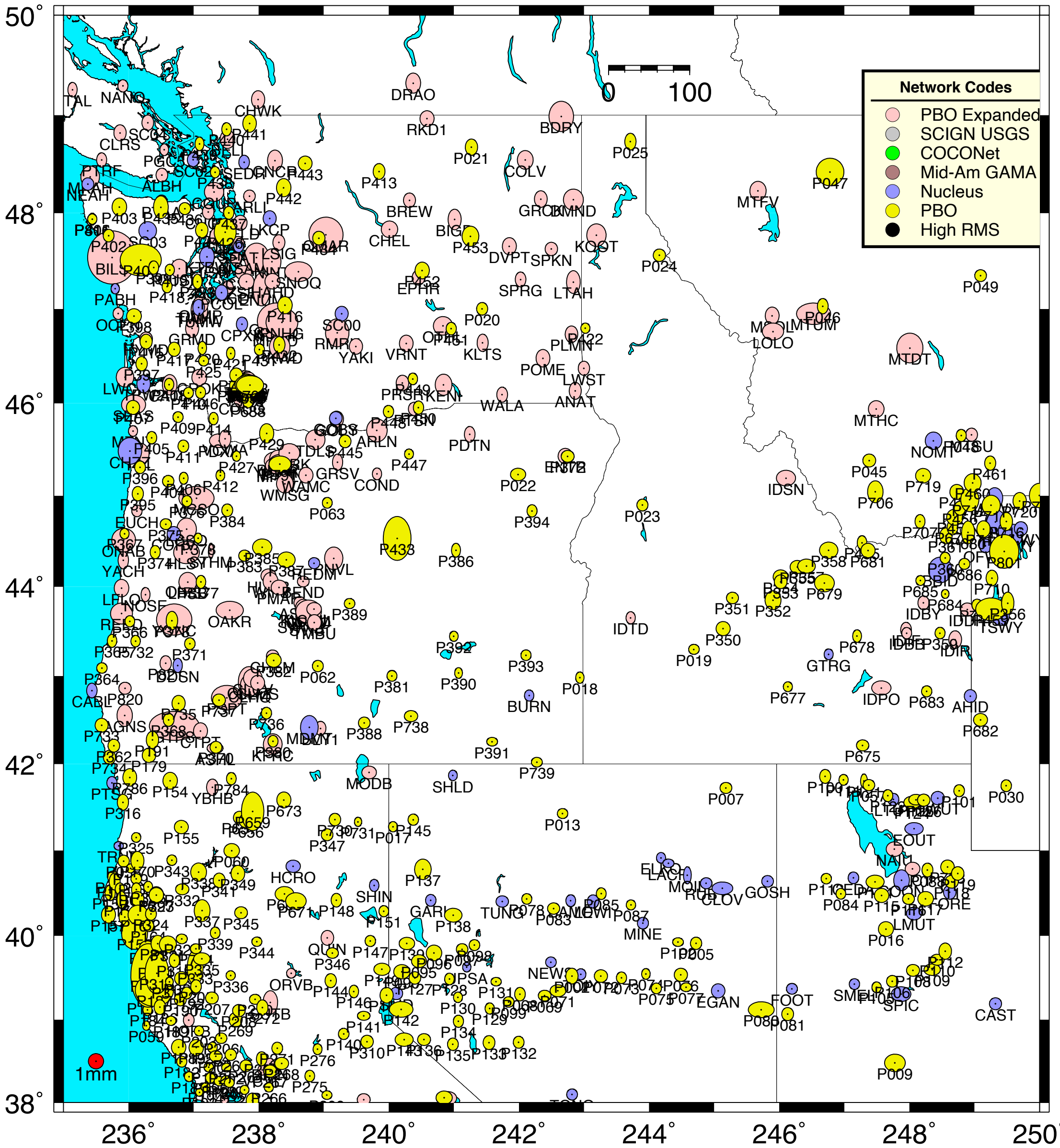

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1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

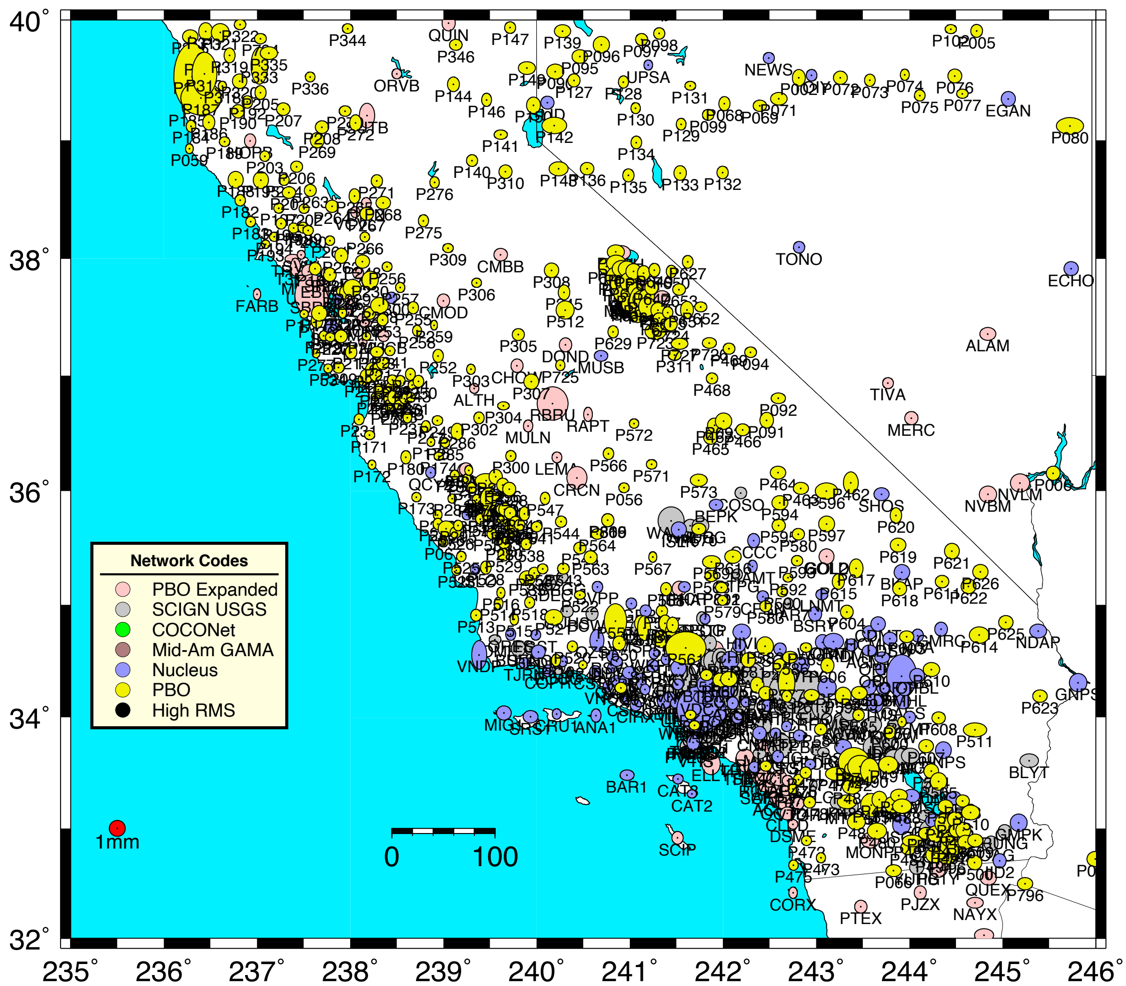

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

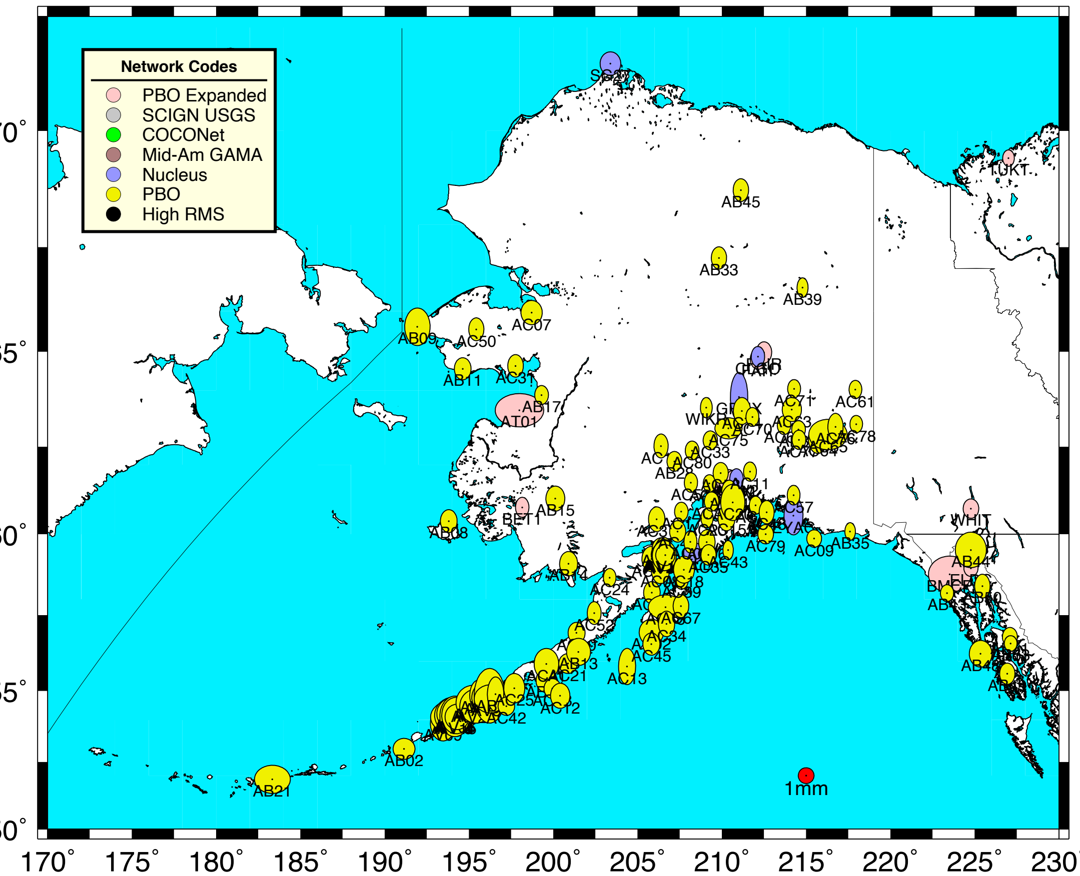

Figure 4: Same as Figure 4 except for the Alaskan region.

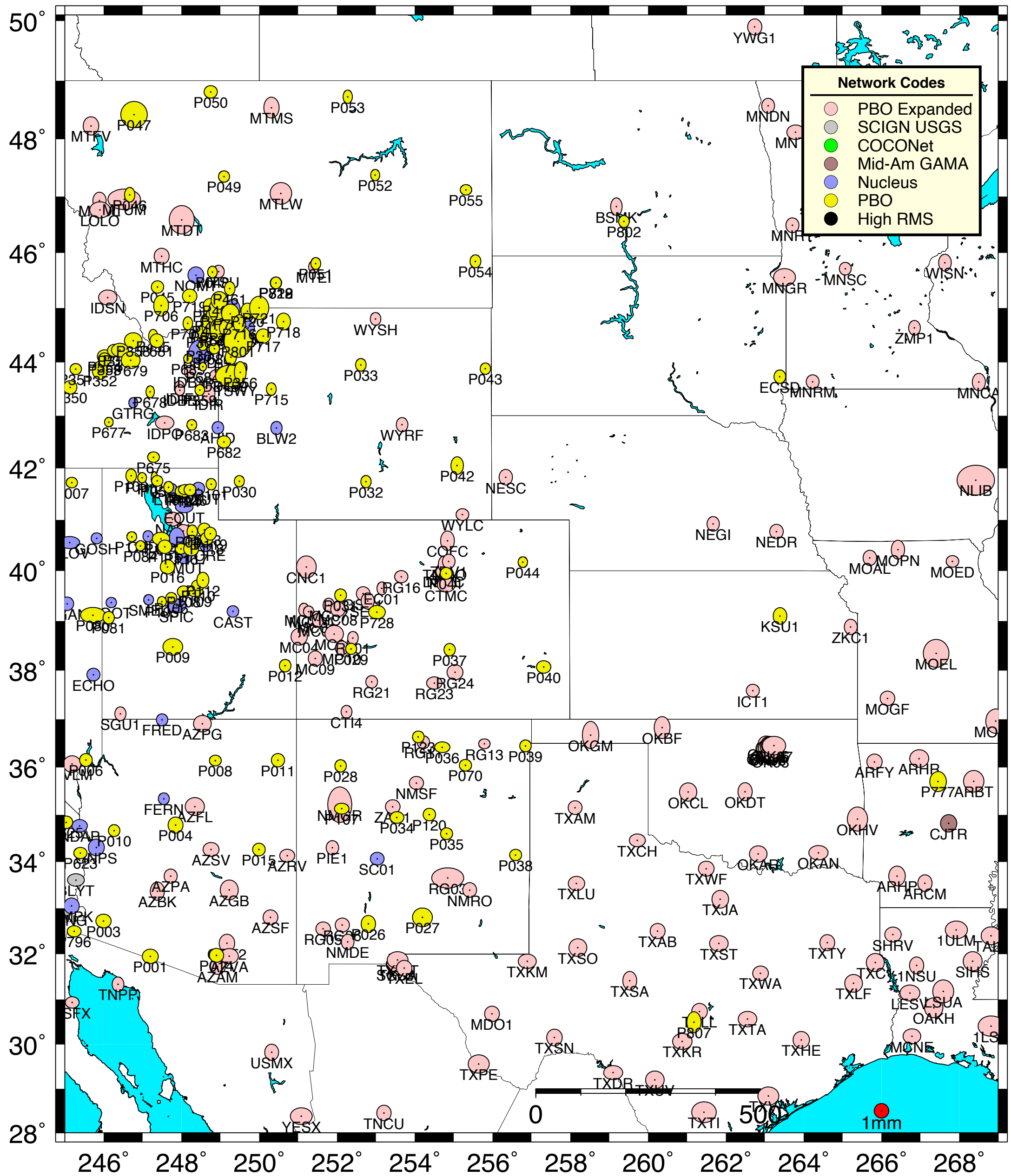

Figure 5: Same as Figure 4 except for the Central United States

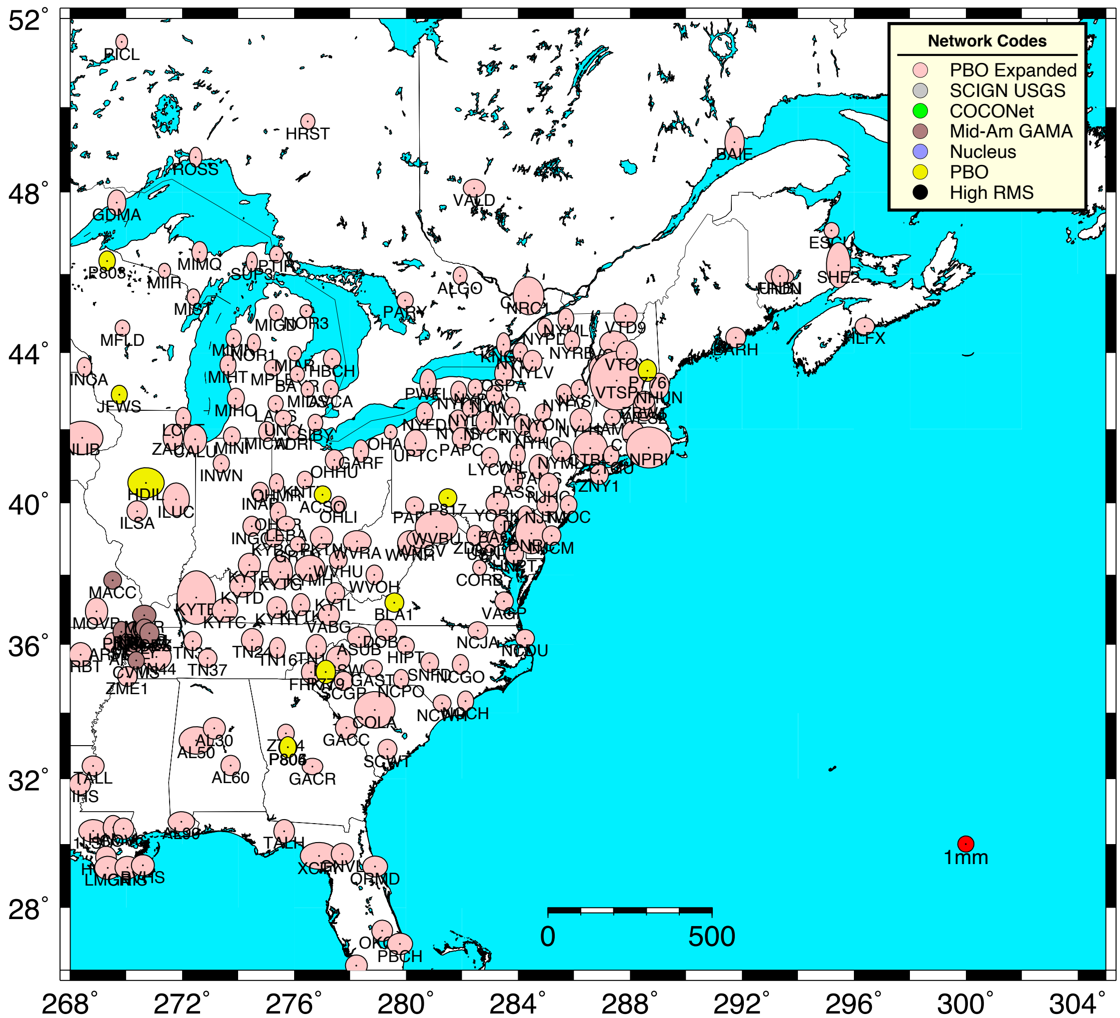

Figure 6: Same as Figure 4 except for the Eastern United States

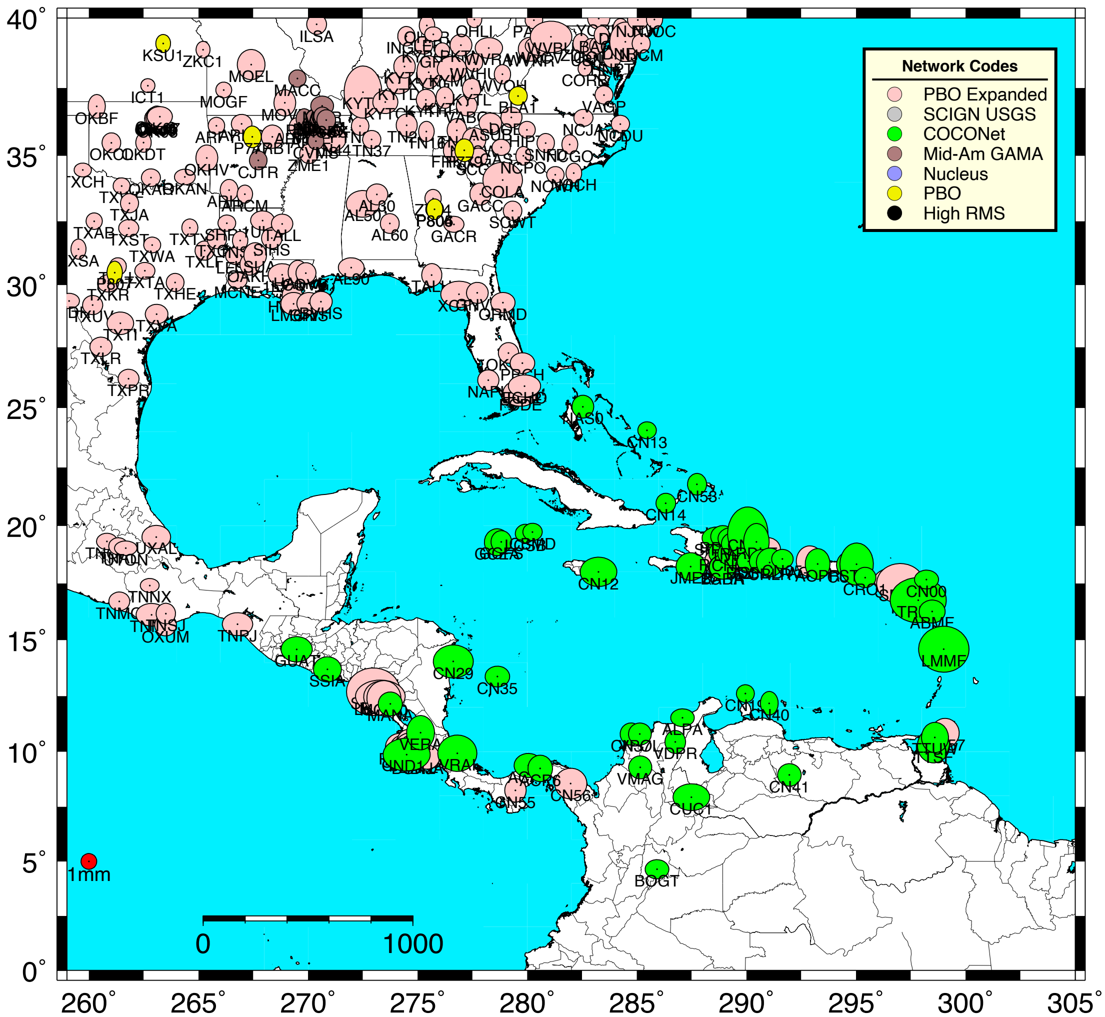

Figure 7: Same as Figure 4 except for the Caribbean region.

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 2660 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_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 2660 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and September 18, 2021.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.40	1.35	6.17
70%			
CWU	1.76	1.70	7.02
95%			
CWU	3.90	3.59	11.60

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.

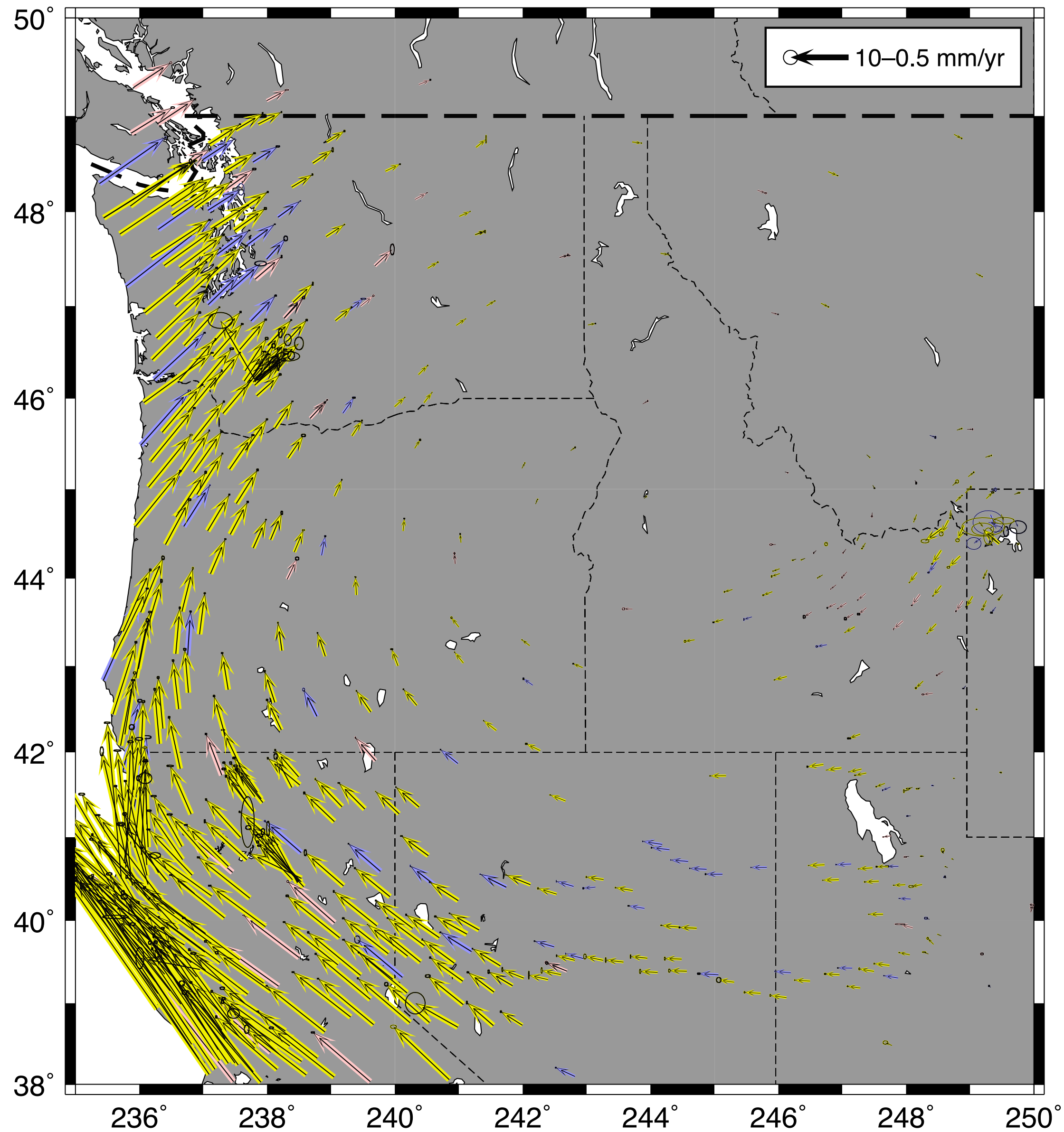

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

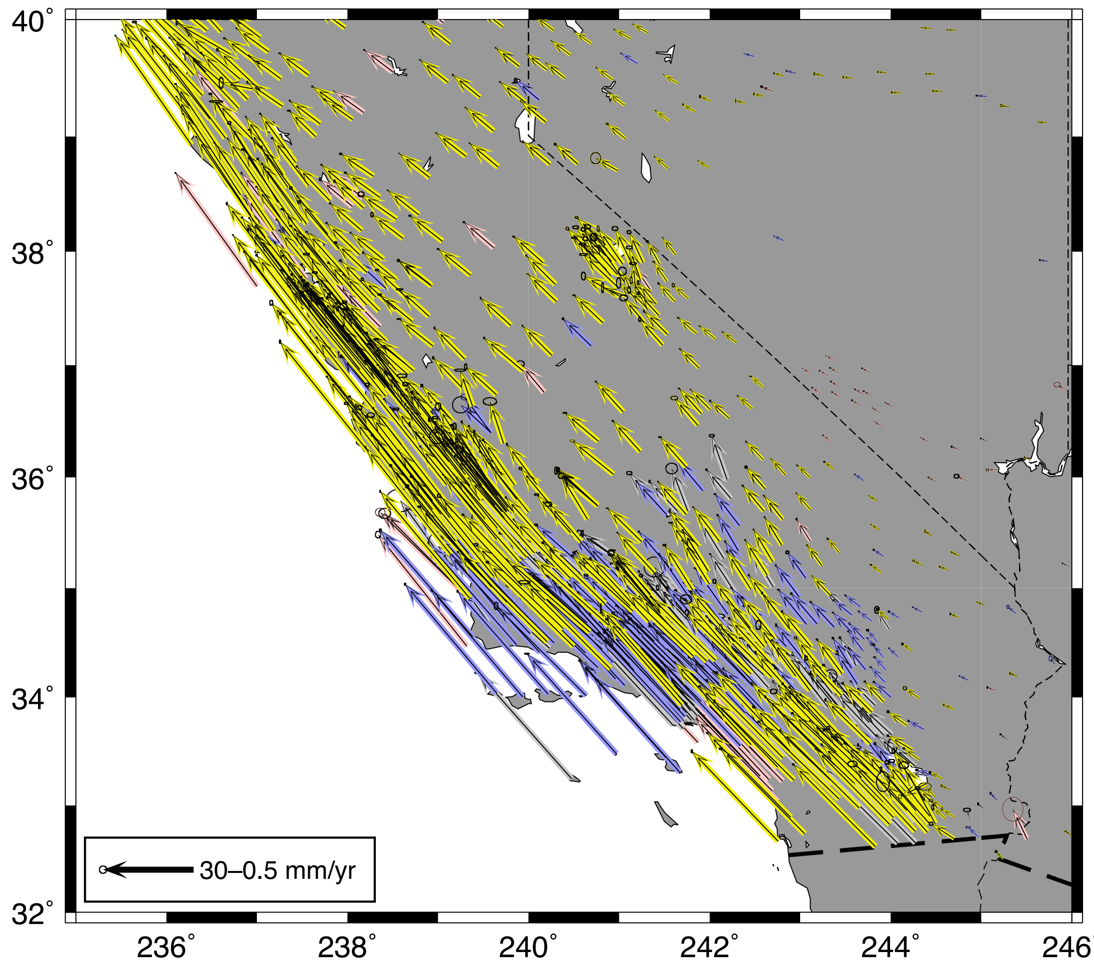

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

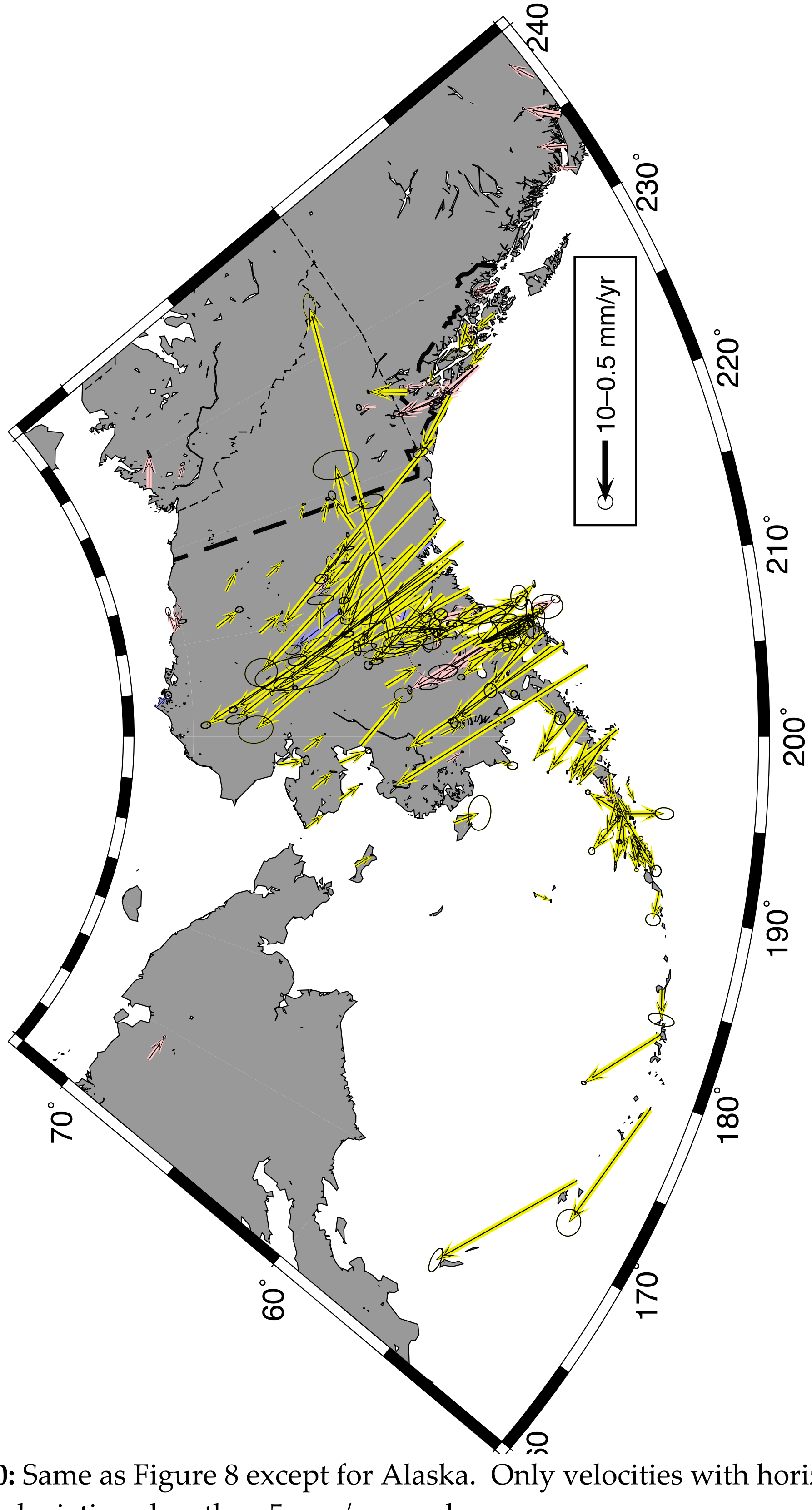

Figure 10: Same as Figure 8 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

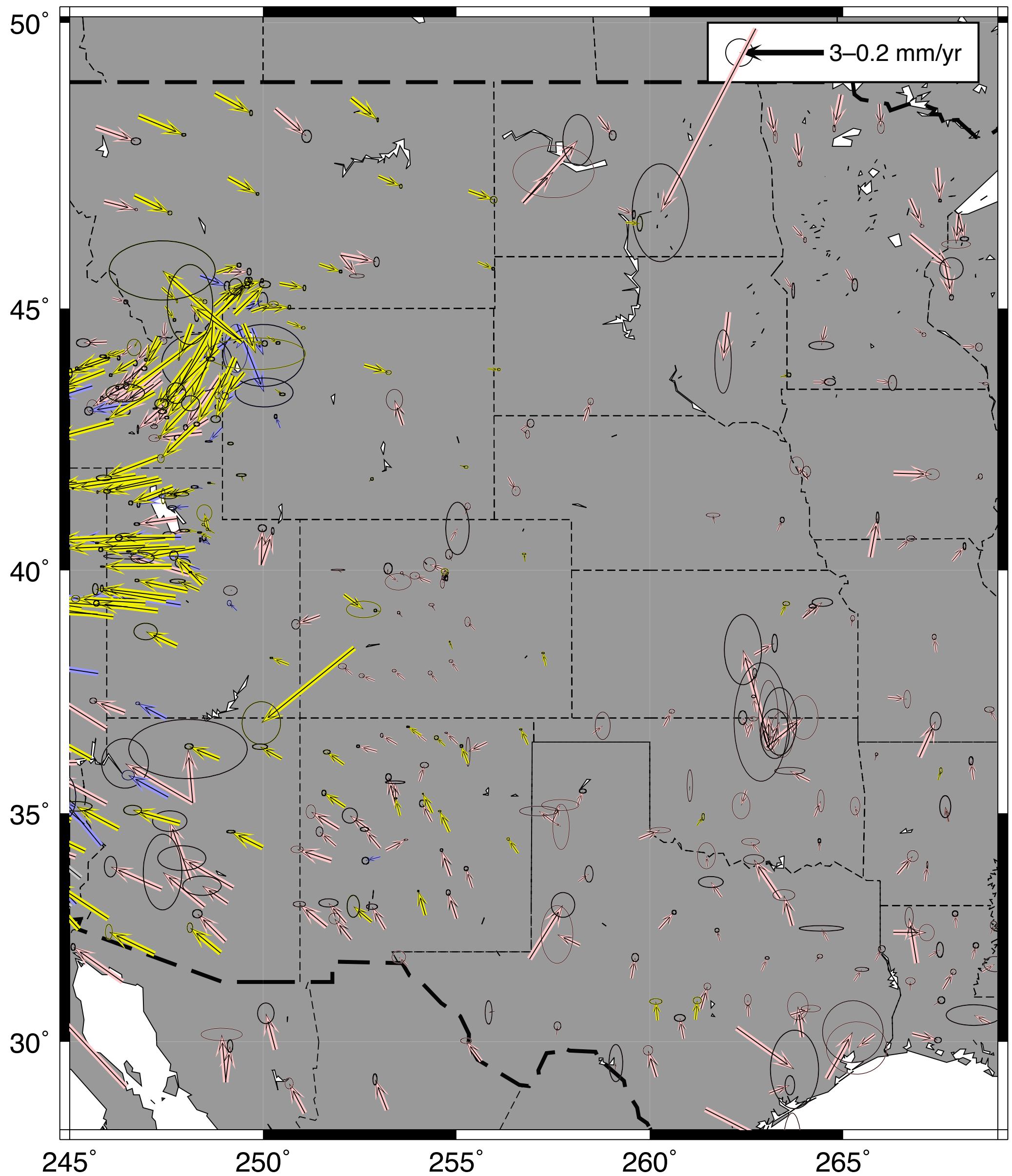

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

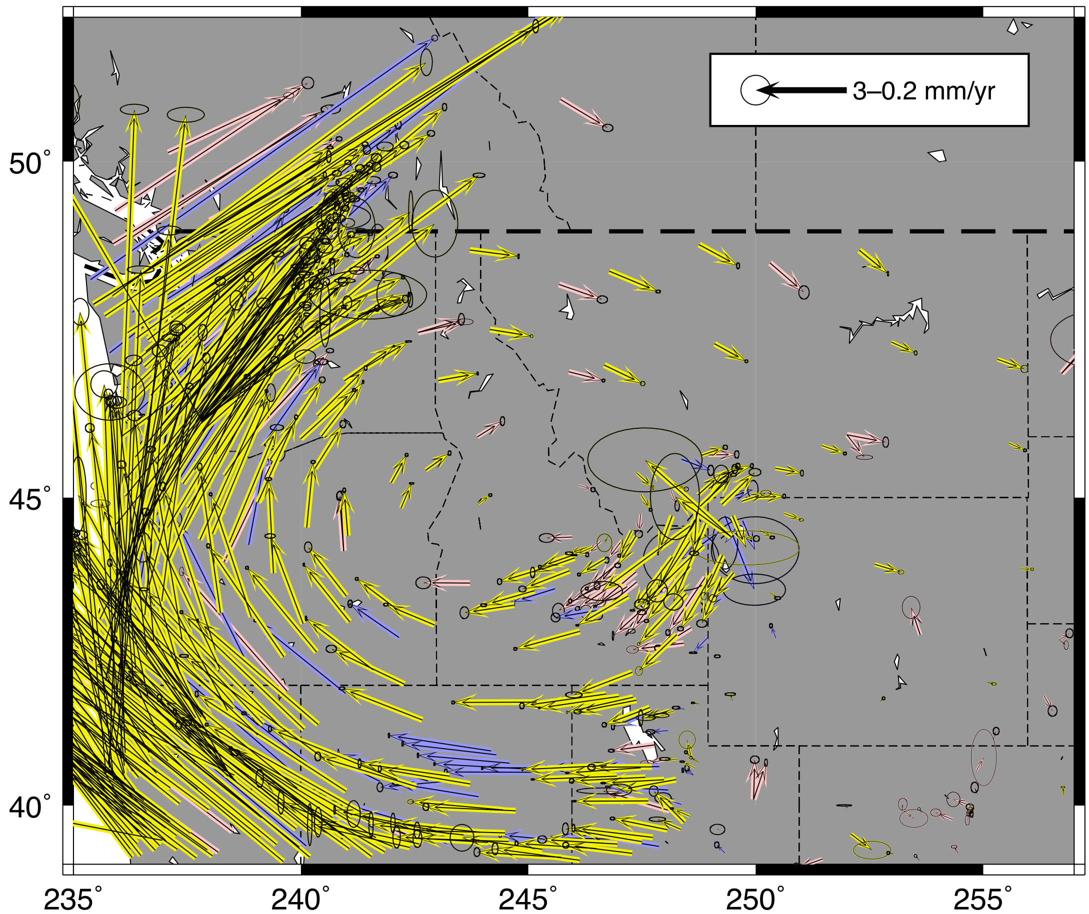

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

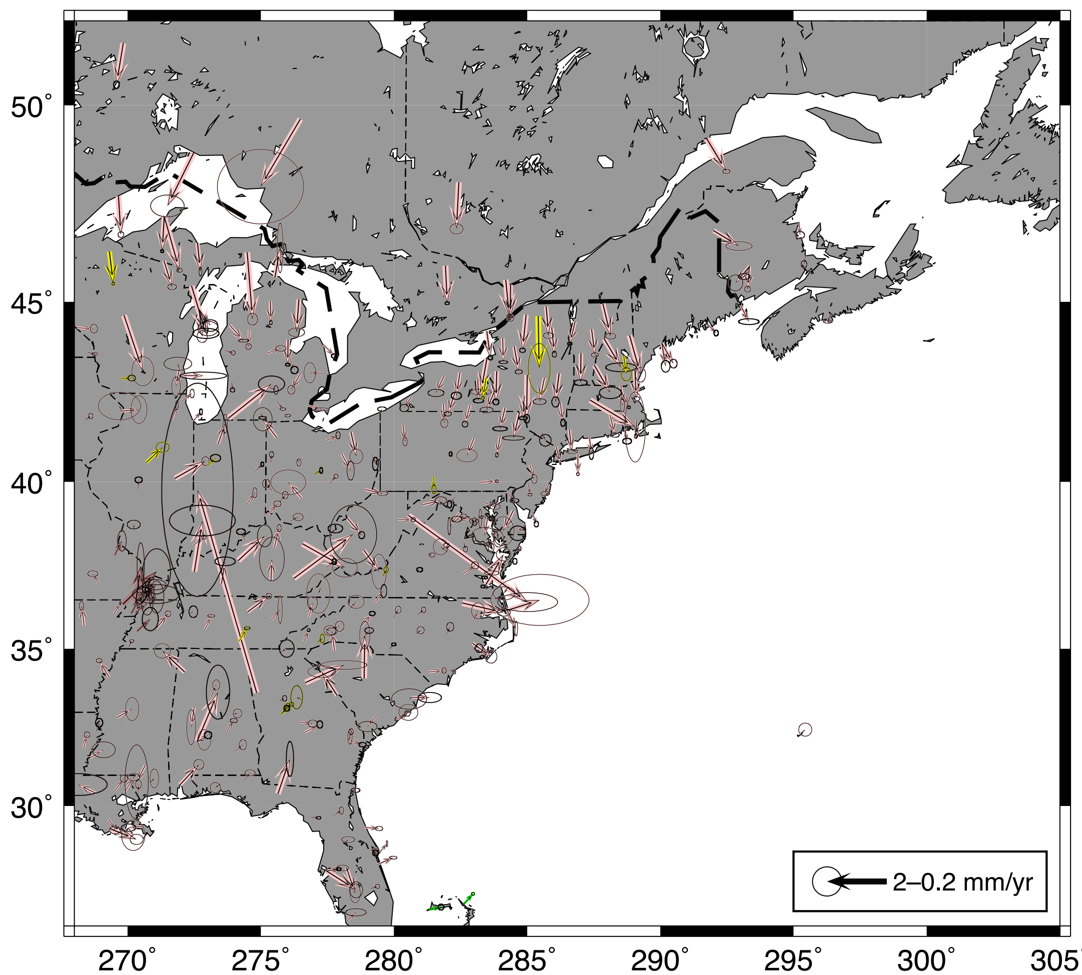

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

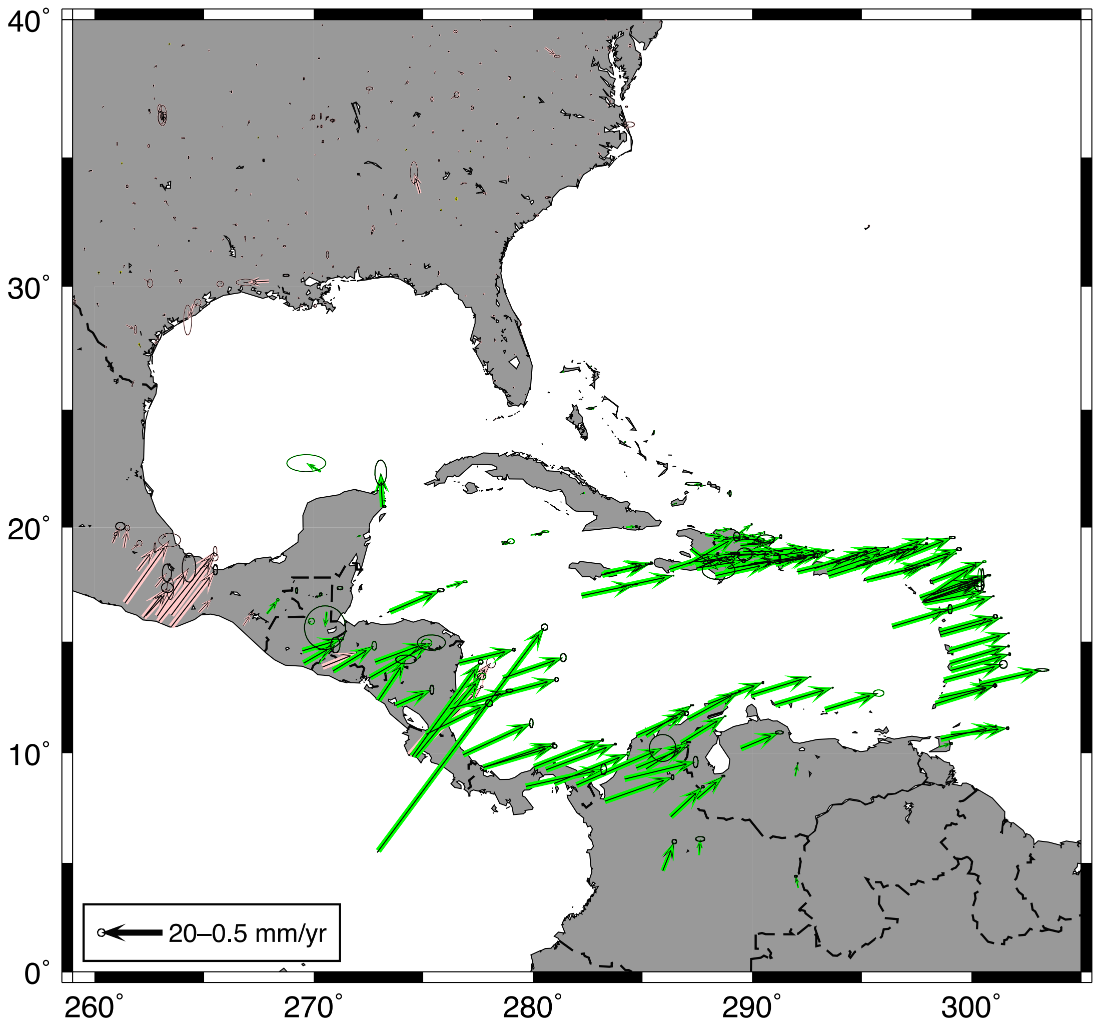

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2021/06/15-2021/09/30

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 29 earthquakes examined during this quarter and three generated displacements more than 1 mm. These events are EQ61 ANSS(ComCat) ak0219neiszm, mww8.2 104 km SE of Perryville latitude/longitude 55.3248 -157.8414 Date/Time 2021/07/29 06:16; EQ62 ANSS(ComCat) us6000f65h mww7.2 Nippes latitude/longitude 18.4079 -73.4753 Date/Time 2021/08/14 12:30; and EQ63 ANSS(ComCat) nc73584926 mw6.0 Antelope Valley latitude/longitude 38.5075 -119.4998 Date/Time 2021/07/08 22:50. A post-seismic signal can be seen for EQ61 and a logarithmic postseismic term with a 10-day decay time was added. EQ63 was not identified at first and was added

21/08/30 and its radius of influence was updated from 47.1 to 60 km to accommodate the offsets seen at sites in the region.

Co-seismic offsets were generated and EQ61
Rapid and final event files were generated and sent to UNAVCO via LDM. The Kalman filter estimates of the co-seismic offsets are shown in Figure 15.

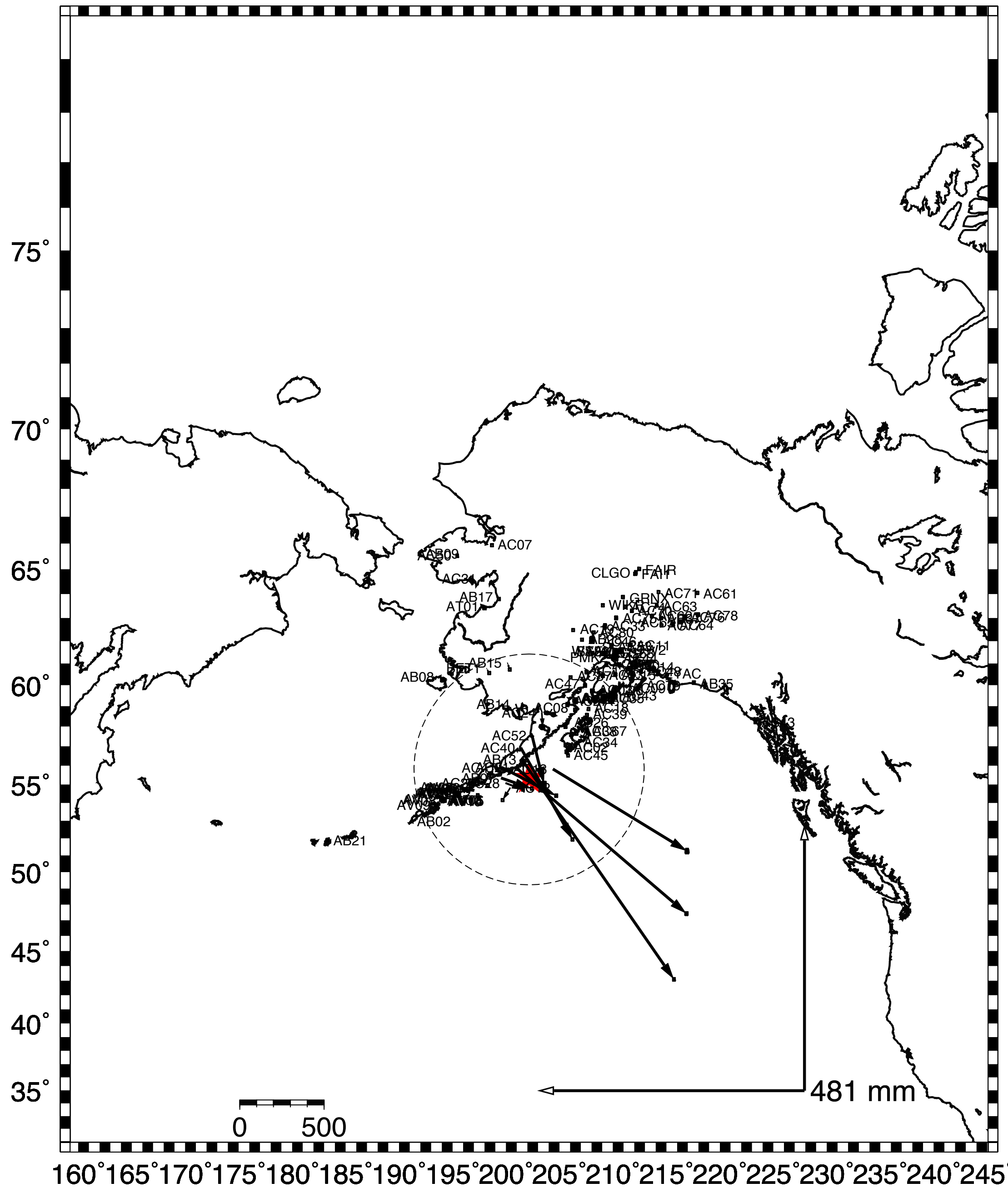

Figure 15: Coseismic offsets from the GAGE event 61: ANSS(ComCat) ak0219neiszm, mww8.2 104 km SE of Perryville latitude/longitude 55.3248 -

157.8414 Date/Time 2021/07/29 06:16. A rapid and final event files prepared and sent.

The postseismic effects seem to be isolated to a few stations with the largest co-seismic offsets. Some sites (e.g., AC21 have not reported that much data since the earthquake). The coseismic offsets for events EQ62 and EQ63 are shown in Figures 16 and 17. These results are from the Kalman filter analysis which provides the lowest standard deviation estimates.

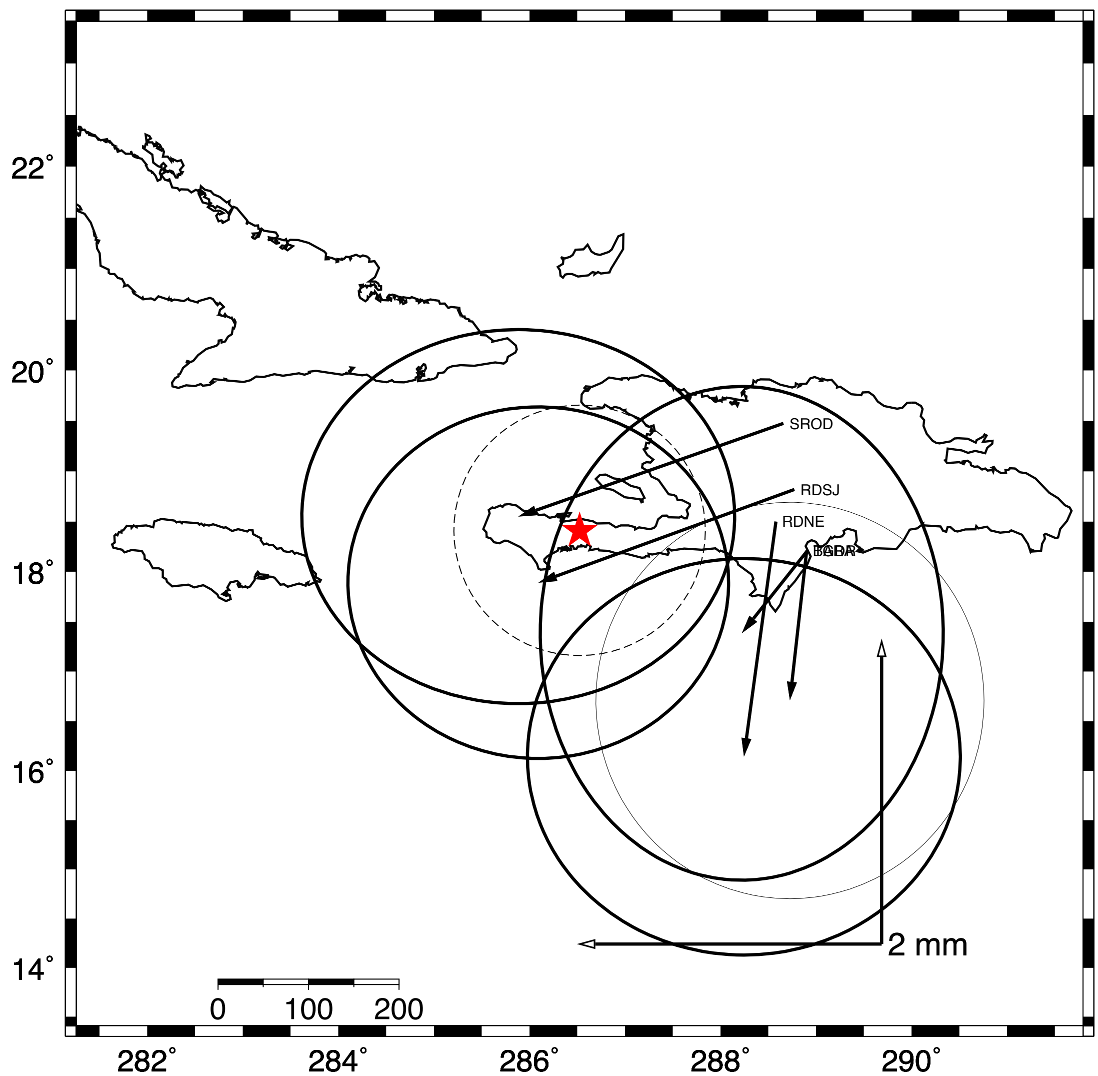

Figure 16: Coseismic offsets from the GAGE event EQ62 ANSS(ComCat) us6000f65h mww7.2 Nippes latitude/longitude 18.4079 -73.4753 Date/Time 2021/08/14 12:30.

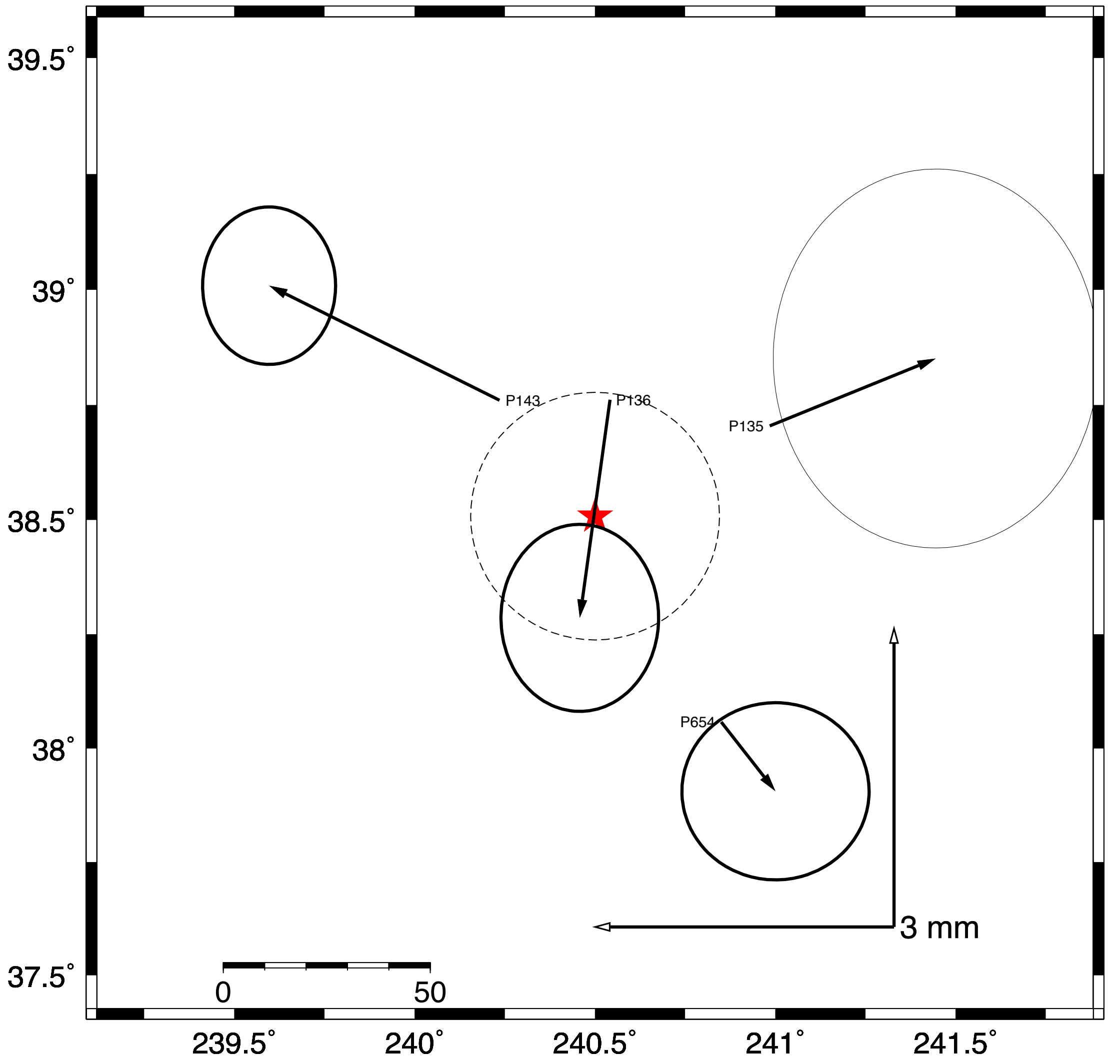

Figure 17: Coseismic offsets from the GAGE event and EQ63 ANSS(ComCat) nc73584926 mw6.0 Antelope Valley latitude/longitude 38.5075 -119.4998 Date/Time 2021/07/08 22:50.

Antenna and other discontinuity events.

Antenna swaps at 54 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

7/16/21	
TILC	Skewed in North, large >50 cm jump in height on 2008 7 27. Added to unknown list. http://geoweb.mit.edu/~tah/ACC_PBO/TILC.CWU.jpg
7/23/21	
DYH2	>5 mm East shift with switch to TWIVC6150 antenna. http://geoweb.mit.edu/~tah/ACC_PBO/DYH2.CWU.jpg
MORP	East jump of +20 mm centered on 2021/07/14. Smaller north jump. No meta data change in EPN log. Seems to be removed on 2020/08/02. http://geoweb.mit.edu/~tah/ACC_PBO/MORP.CWU.jpg
7/31/21	
CVHS	120 mm height jump associated with 2021/07/22 (doy 203) change to TWIVC6150 antenna. http://geoweb.mit.edu/~tah/ACC_PBO/CVHS.CWU.jpg
OAKR	Noisy results (height sigma ±30 mm instead of ±7 mm) from June 13 to July 26, 2021. Antenna change on June 08 in PANGA log; no logged change after that date. http://geoweb.mit.edu/~tah/ACC_PBO/OAKR.CWU.jpg
OKHV	Antenna change to LEIAR10 from LEIAT502 on day 182, 2021. 10 cm height change. Also in North, 2020/05/05 offset that looks like earthquake with post-seismic. http://geoweb.mit.edu/~tah/ACC_PBO/OKHV.CWU.jpg
P071	Offset in East (-15 mm) and North (+5mm) associated with receiver change to SEPT POLARX5 from TRIMBLE NETRS on 2021 day 201 (07/20) http://geoweb.mit.edu/~tah/ACC_PBO/P071.CWU.jpg
PNVL	Same as OAKR. Position sigma's improve on July 27, 2021. http://geoweb.mit.edu/~tah/ACC_PBO/PNVL.CWU.jpg
PSPT	Same as OAKR and PNVL. Position sigma's improve on July 29, 2021. These seem to be associated with RTCM data telemetry. http://geoweb.mit.edu/~tah/ACC_PBO/PSPT.CWU.jpg
8/7/21	
AB02	Change in rate in East starting early 2021. http://geoweb.mit.edu/~tah/ACC_PBO/AB02.CWU.jpg
AC62	Large -10 to 30 mm "quadratic" east component since 2005. AC64 as well. AC71 opposite sign. http://geoweb.mit.edu/~tah/ACC_PBO/AC62.CWU.jpg
AC65	Quadratic like AC62 but large East annual 2009-2016. http://geoweb.mit.edu/~tah/ACC_PBO/AC65.CWU.jpg
AC78	Annual coherent spikes in North. http://geoweb.mit.edu/~tah/ACC_PBO/AC78.CWU.jpg
BRTW	Lots of outliers in height since 2016 but core seems OK. Maybe group that sits low with a drift after April 2020. http://geoweb.mit.edu/~tah/ACC_PBO/AC78.CWU.jpg
GRNX	Highly skewed in North; only slight skew in height. http://geoweb.mit.edu/~tah/ACC_PBO/GRNX.CWU.jpg

P271	Annual starting in North in 2012; large height annual and long term systematics. http://geoweb.mit.edu/~tah/ACC_PBO/P271.CWU.jpg
8/13/21	
TEG2	Data restarted in 2021 after 3-year gap but is now very noisy. http://geoweb.mit.edu/~tah/ACC_PBO/TEG2.CWU.jpg
WCHS	90 mm vertical jump 21/08/11. Switch to TWIVC6150 antenna. http://geoweb.mit.edu/~tah/ACC_PBO/WCHS.CWU.jpg
8/20/21	
AC13	Large post-seismic from EQ_ID 61 ANSS(ComCat) ak0219neiszm. Initial estimate North: OffLn 2021 7 29 6 16 dOf 10.0 -133.72 +- 1.69 mm Log 2021 7 29 6 16 dOf 10.0 -72.56 +- 2.01 mm East: OffLn 2021 7 29 6 16 dOf 10.0 -133.72 +- 1.69 mm Log 2021 7 29 6 16 dOf 10.0 -72.56 +- 2.01 mm http://geoweb.mit.edu/~tah/ACC_PBO/AC13.CWU.jpg
KUAQ	Jump in height. Looks like an antenna change but no updated to UNAVCO log file. Gap then jump 21/08/07. http://geoweb.mit.edu/~tah/ACC_PBO/KUAQ.CWU.jpg
P703	Jump in North 21/08/18. No metadata change. Has had isolated jumps like this in the past. http://geoweb.mit.edu/~tah/ACC_PBO/P703.CWU.jpg
TNAL	Came back on line after gap since 2018. Not on trend from earlier data. http://geoweb.mit.edu/~tah/ACC_PBO/TNAL.CWU.jpg
TRNT	Very non-linear behavior with increasing noise since 2019. Located on Monserrat. http://geoweb.mit.edu/~tah/ACC_PBO/TRNT.CWU.jpg
TXSO	Change of trend in north since 2019, in east since early 2021. http://geoweb.mit.edu/~tah/ACC_PBO/TXSO.CWU.jpg
8/28/21	
NOCO	Jump in height 2021 8 23 of ~10 cm. Change to TWIV6150 antenna. http://geoweb.mit.edu/~tah/ACC_PBO/NOCO.CWU.jpg
PAMS	Jump in height 2021 8 26 of ~10 cm. No new metadata 8/29/21. http://geoweb.mit.edu/~tah/ACC_PBO/PAMS.CWU.jpg
9/3/21	
NCJA	North Carolina (UNR) uplift and NE motion starting Jan 2021. http://geoweb.mit.edu/~tah/ACC_PBO/NCJA.CWU.jpg
P135	Nevada: Large NE excursions 2015-2021: Looks like bad antenna. Goes away with antenna change 2021/08/07 http://geoweb.mit.edu/~tah/ACC_PBO/P135.CWU.jpg
RDF2	Dominican Republic. Systematic. Seems local; other sites in region do not show similar behavior. No photos. http://geoweb.mit.edu/~tah/ACC_PBO/RDF2.CWU.jpg
9/10/21	
DRAO	New antenna but UNAVCO and WCDA logs have not been updated. (IGS

	message reported change). http://geoweb.mit.edu/~tah/ACC_PBO/DRAO.CWU.jpg
LEPA	Interesting saw-tooth annual signal plus large postseismic from EQ_ID 21 ANSS(ComCat) usp000jrsw mww7.6 Costa Rica (35 km depth fixed) 10.24172 274.16050 2012/09/05 14:42. http://geoweb.mit.edu/~tah/ACC_PBO/LEPA.CWU.jpg
P656	Very systematic snow signal over multiple years, less in recent years. http://geoweb.mit.edu/~tah/ACC_PBO/P656.CWU.jpg
P711	Long term systematics. Located in Yellowstone. Almost sinusoid in height, half cycle. http://geoweb.mit.edu/~tah/ACC_PBO/P711.CWU.jpg
RNCH	Large annual in East – same amplitude 7 mm in E and U. Maybe be growing with time. http://geoweb.mit.edu/~tah/ACC_PBO/RNCH.CWU.jpg
9/17/21	
KFRC	Antenna change and height jump by 60 mm. No meta data update. PANGA site. http://geoweb.mit.edu/~tah/ACC_PBO/KFRC.CWU.jpg
RKMG	Saddleback Valley SCAL site not in UNAVCO list. Systematic but seems limited to this location based on UNR site. http://geoweb.mit.edu/~tah/ACC_PBO/RKMG.CWU.jpg
SCOR	Change to LEIAR20 antenna with no metadata update. 80 mm height change. http://geoweb.mit.edu/~tah/ACC_PBO/SCOR.CWU.jpg
WILL	Antenna change to SEPCHOKE_B3E6 with not meta data update. 110 mm height change. http://geoweb.mit.edu/~tah/ACC_PBO/WILL.CWU.jpg
9/24/21	
TORP	Antenna change 2021 264. Height offset if metadata not updated. Site itself has interesting systematics. Site near Long Beach (UNR site) and changes are correlated with earthquakes. http://geoweb.mit.edu/~tah/ACC_PBO/TORP.CWU.jpg
WVCV	10 mm North offset 21/09/21. Check to see if it persists. No other components change. http://geoweb.mit.edu/~tah/ACC_PBO/WVCV.CWU.jpg
XCTY	Strange pattern of height outliers with no large increase in errorbars. Started happening in 2017 and comes and goes. http://geoweb.mit.edu/~tah/ACC_PBO/XCTY.CWU.jpg
10/1/21	
ACP1	Rapids have become noisy with possible offset. No meta changes. http://geoweb.mit.edu/~tah/ACC_PBO/ACP1.CWU.jpg
IDIR	Site in Wyoming. ~8 mm offset in East 21/09/29. Nearby site P359 does not show offset. Earlier data shows what looks like an earthquake with post-seismic between 2017/02/20 and 2017/03/06 (data gap) but none found. There was an antenna change 2017/03/09 which is a few days after data starts again. http://geoweb.mit.edu/~tah/ACC_PBO/IDIR.CWU.jpg
MNGR	New Mexico site. Break in east by 6.6 mm on 2021/08/05. No

	earthquakes or recorded meta data change (CORS site). http://geoweb.mit.edu/~tah/ACC_PBO/MNGR.CWU.jpg
10/8/21	
FOXG	Near Palmdale, Large gap and offset when data starts again. New antenna and probably old meta data. http://geoweb.mit.edu/~tah/ACC_PBO/FOXG.CWU.jpg
OK02	Jump on 2021/02/27 seen at OK05 and OK08 at the same time. Does not seem to be an earthquake and does not appear in UNR time series (check combined time series). No meta data changes in processing or logs. http://geoweb.mit.edu/~tah/ACC_PBO/OK02.CWU.jpg
P270	Rapid 50 mm drop in height centered on August 2021; P272 shows small drop and P271 shows much larger vertical over the years with a drop in 8/2021 but not as pronounced relative a seasonal drops as at P270. Site is north of Sacramento CA http://geoweb.mit.edu/~tah/ACC_PBO/P270.CWU.jpg
WMAP	Antenna change to TWIV6150. Large height change when meta data not updated/ http://geoweb.mit.edu/~tah/ACC_PBO/WMAP.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 June 15, 2021 and September 18, 2021.

CWU	North (mm)	East (mm)	Up (mm)
Median ANET	1.47	1.21	5.82
70% ANET	1.71	1.41	7.23
95% ANET	2.01	1.86	8.15

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

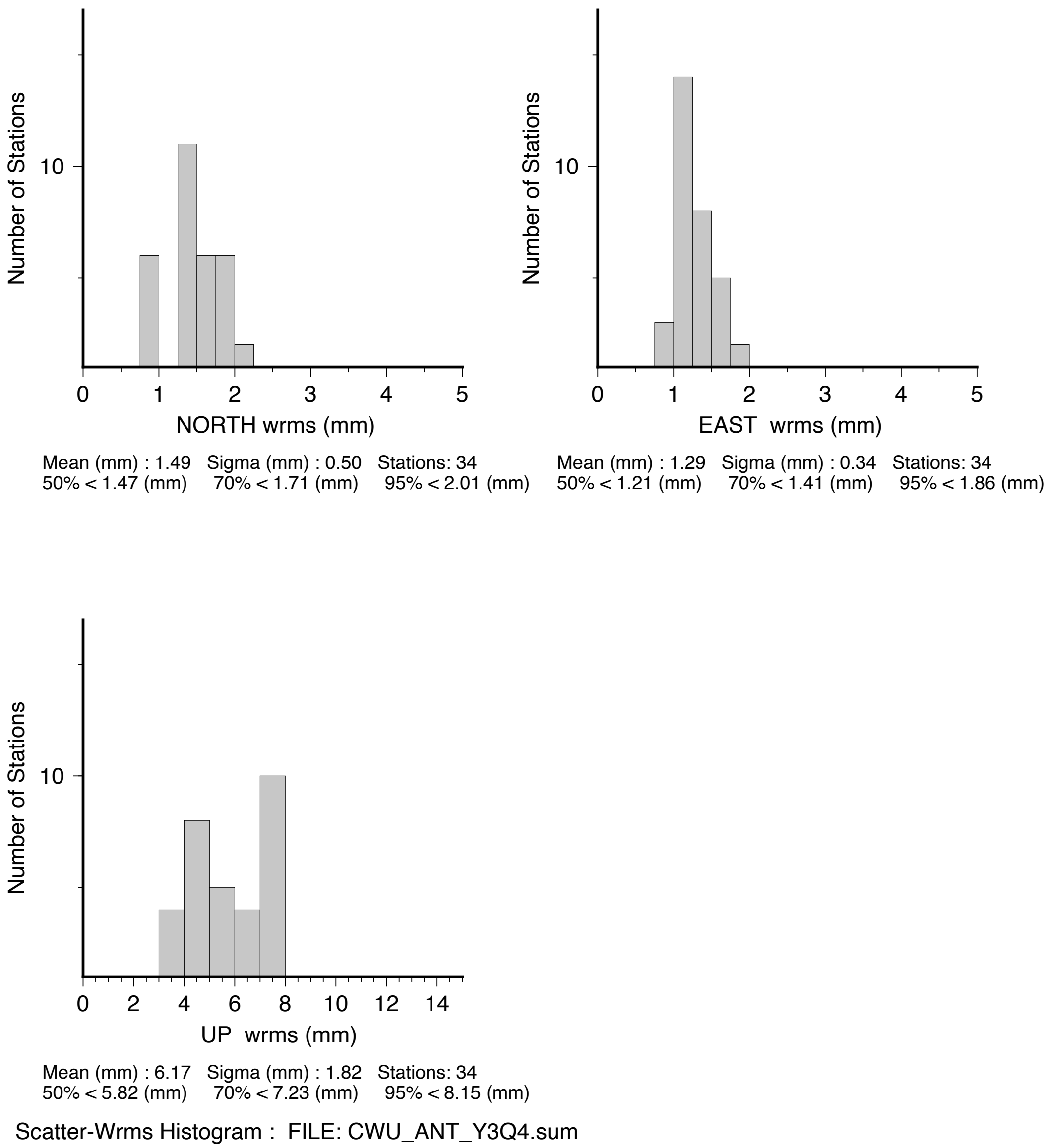

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 34 stations in Antarctica analyzed between June 15, 2021 and September 18, 2021. Linear trends and annual signals were estimated from the time series.

Multi-Analysis Center Time Series

We introduce a new set of time series, combined from several publicly available analysis center products, within the GAGE region of coverage. Five ACs are aligned and combined by simple weighted averaging to produce "union" time series. These five ACs are GAGE (CWU), as reported above, the Jet Propulsion

Laboratory (JPL), Nevada Geodetic Laboratory (University of Nevada, Reno), Scripps Orbital and Permanent Array Center and the U.S. Geological Survey. The GAGE (CWU), JPL, NGL (UNR) and USGS solutions are all processed using Gipsy but the SOPAC solution is processed using GAMIT/GLOBK, lending a critical alternative software package to the products.

The result is that all stations in the complete GAGE solution, including stations that are no longer active, also have a multi-AC solution, where the number of contributing ACs to the combined solution is summarized in Table 5, below.

Number of ACs	1	2	3	4	5	Total
Number of stations	6	545	392	528	1271	2742

Multi-AC combination steps

1. Conversion of individual time series formats to GAGE's ".pos" format
2. Restoration of scale parameter from Gipsy "x"-files where they were used to align Gipsy solutions to the ITRF
3. Relative reweighting of time series data by multiplication of sigmas by a constant value (see Table 6)
4. Network realignment of all time series into the standard GAGE reference frames (i.e. "nam14" and "igs14")
5. Combination of all available time series data by weighted average

Each ingested analysis center distributes their time series products in different formats. The GAGE (CWU) time series are available from https://data.unavco.org/archive/gnss/products/position/ and are already in the standard ".pos" format. The JPL time series are downloaded from http://garner.ucsd.edu/pub/solutions/gipsy/ and are in Gipsy "stacov" format. The NGL (UNR) time series are downloaded from http://geodesy.unr.edu/gps_timeseries/txyz/IGS14/ and are in their ".txyz2"-format (see http://geodesy.unr.edu/gps_timeseries/README_txyz2.txt). SOPAC time series are downloaded from http://garner.ucsd.edu/pub/timeseries/measures/ats/ and https://cddis.nasa.gov/archive/GPS_Explorer/latest/, where the time series used for each site is whichever is more up-to-date between these two archives. The USGS time series are downloaded from https://earthquake.usgs.gov/monitoring/gps/data/itrf2008_xyz_files/.

All downloaded time series are converted to GAGE's ".pos" format with a constant scaling factor applied to all position sigma values, as shown in Table 6. We restore the scale component of the reference frame transformation applied to all JPL, NGL (UNR) and USGS time series, following the discussion in Herring et al. (2015). The Gipsy "x"-files used to do this are downloaded from https://sideshow.jpl.nasa.gov/pub/JPL_GNSS_Products/Final/. Until the USGS analysis center has completed a full reprocessing effort back in time, the "x"-files used for the scale parameter prior to 2018-05-27 (2018-147) for the USGS time series are currently downloaded from https://sideshow.jpl.nasa.gov/pub/JPL_GPS_Products_IGb08/Final/ (J. Svarc, pers. comm.).

AC solution	GAGE (CWU)	JPL	NGL (UNR)	SOPAC	USGS
Sigma factor	1.0	2.3	2.2	1.0	2.1

Table 6: Sigma reweighting factors applied before network realignment of reference frame and combination (sigmas for all data in all components are multiplied by these values).

Finally, each network of time series products has the reference frame realigned by estimating translation and rotation parameters to minimize the deviation between the time series coordinates and the current IGb14 reference frame and the ITRF2014 Plate Motion Model for North America (Altamimi et al., 2017) using all available sites with coordinates defined in the ITRF2014/IGb14 reference frame (ftp://itrf.ign.fr/pub/itrf/itrf2014/ITRF2014-IGS-TRF.SNX.gz and ftp://igs-rf.ign.fr/pub/IGb14/IGb14.snx).

The combination is done by simple weighted average, where the associated uncertainty for each time series point is the inverse of the square root of the sum of the inverse variances. An artifact of this averaging is that it reduces the uncertainty, so we also multiply the formal uncertainty by the square root of the number of contributing solutions on a point-by-point basis in each time series. Several time series are excluded from the combinations because their solutions are not from exactly the same station as the GAGE solution despite having the same ID. These exclusions, or renames to match the GAGE station ID, are listed in Table 7.

AC	Station	Action
NGL (UNR)	MSC1	Renamed MSCG to match other ACs
NGL (UNR)	BARA	Excluded; does not correspond to same ID from other ACs
NGL (UNR)	CALV	Excluded; does not correspond to same ID from other ACs
NGL (UNR)	FTS1	Excluded; does not correspond to

		same ID from other ACs
NGL (UNR)	LIND	Excluded; does not correspond to same ID from other ACs
NGL (UNR)	MLF1	Excluded; does not correspond to same ID from other ACs
NGL (UNR)	NARA	Excluded; does not correspond to same ID from other ACs
NGL (UNR)	PENA	Excluded; does not correspond to same ID from other ACs
NGL (UNR)	STB1	Excluded; does not correspond to same ID from other ACs
NGL (UNR)	THUR	Excluded; does not correspond to same ID from other ACs

Table 7: Station aliases between ACs and action before combination in the GAGE multi-AC 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.

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