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

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Period: 2021/10/01-2021/12/31

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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 2021/09/15 to 2021/12/31, time series velocity field analyses for the GAGE reprocessing analyses (1996-2021). Several earthquakes were investigated this quarter but only one of them, event 64; ANSS(ComCat) ak021d1u1nos mww6.9 114 km E of Chignik latitude/longitude 56.2584 -156.5532, Date/Time 2021/10/11 09:11 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 1949 stations were processed which is 9 less than last quarter. In addition up to 48 sites were processed in the ANET solutions, 14 more than last quarter. Sites have been accessed for maintenance and brought back on-line this 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: September 15, 2021– December 18, 2021

For this report, we generated the statistics using the ~3 months of CWU results between September 15, 2021 and December 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 1949 stations for CWU analyzed in the finals analysis between September 15, 2021 and December 18, 2021. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.92	0.90	4.93
70%			
CWU	1.18	1.13	5.70
95%			
CWU	2.39	2.37	9.35

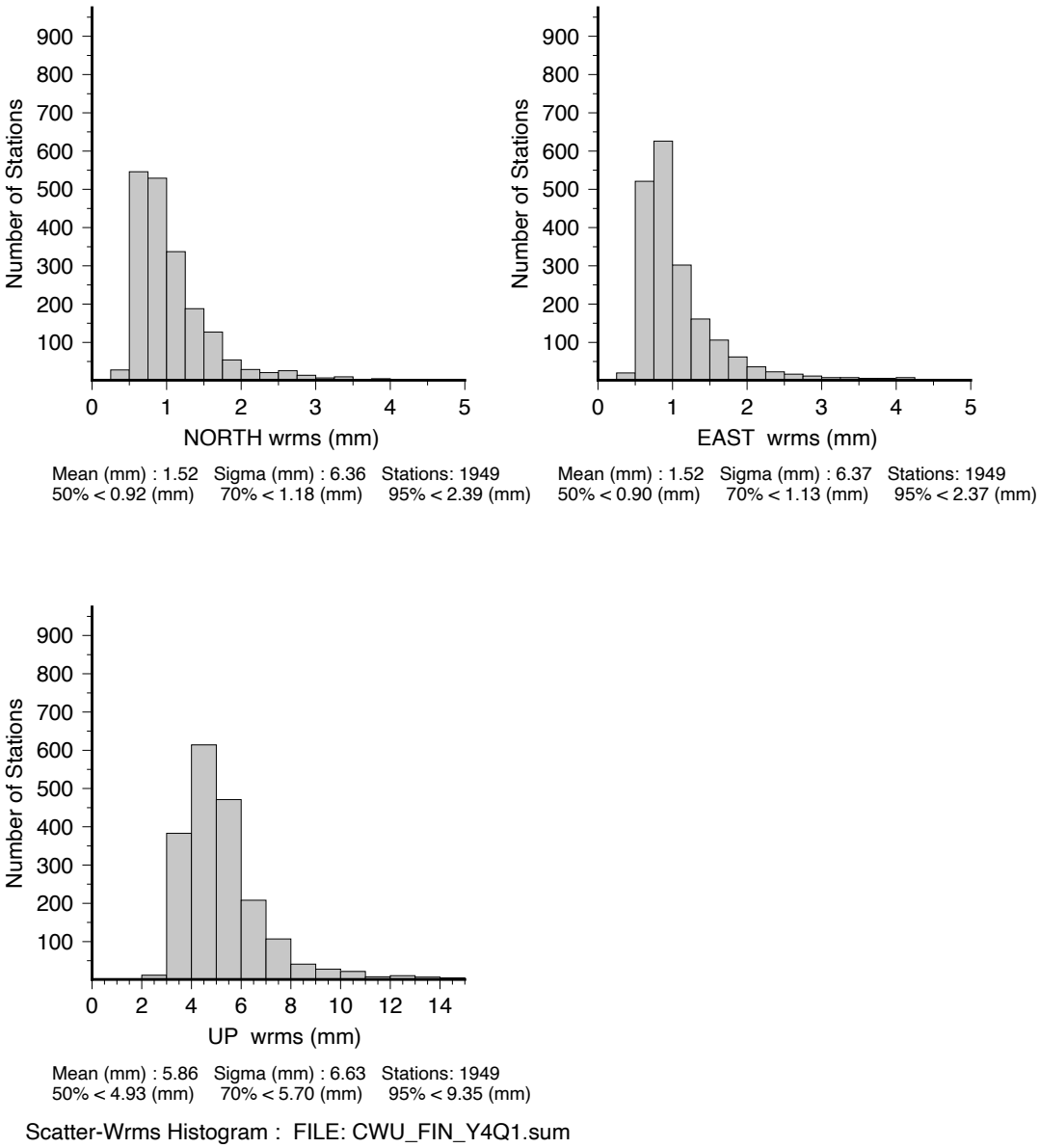

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 1949 stations analyzed between September 15, 2021 and December 18, 2021. Linear trends and annual signals were estimated from the time series.

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_Y4Q1.tab.

There are 1949 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_Y4Q1.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    93       1.3   0.66      1.3   0.62     7.4   0.78     18.66
 1NSU    89       1.0   0.54      0.8   0.48     5.5   0.71     17.91
 1ULM    95       0.8   0.44      0.9   0.55     5.4   0.72     18.51
 AB01    74       1.7   0.68      1.8   0.97     5.3   0.65     14.58
…
 ZDV1    95       0.9   0.46      0.9   0.55     5.0   0.67     18.54
 ZKC1    95       1.0   0.53      0.8   0.47     4.9   0.64     18.54
 ZLA1    95       1.0   0.56      0.8   0.51     4.5   0.60     18.54
 ZLC1    95       0.8   0.40      0.9   0.58     5.2   0.68     18.77
 ZME1    95       0.8   0.47      1.0   0.60     4.9   0.65     18.77
 ZMP1    95       0.9   0.47      0.8   0.55     5.0   0.67     19.01
 ZNY1    95       1.0   0.50      0.9   0.58     5.6   0.73     18.93
 ZOA1    22       0.8   0.44      0.5   0.32     4.2   0.56     19.46
 ZSE1    95       1.0   0.49      1.0   0.66     6.6   0.89     18.93
 ZTL4    95       0.8   0.48      0.9   0.60     6.8   0.90     19.12
```

Table 2: RMS scatter of the position residuals for the CWU solution between September 15, 2021 and December 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	0.82	0.85	4.55	819
NUCLEUS	0.74	0.76	4.10	186
GAMA	0.84	0.86	5.29	14
COCONet	1.54	1.62	7.41	66
USGS_SCIGN	0.81	0.74	4.00	110
Expanded	1.04	1.00	5.39	754
70%				
PBO	1.06	1.05	5.22	
NUCLEUS	0.88	0.89	4.77	
GAMA	0.86	0.92	5.38	
COCONet	1.74	1.91	8.32	

USGS_SCIGN	0.98	0.90	4.42
Expanded	1.28	1.22	6.12
95%			
PBO	2.06	2.14	7.65
NUCLEUS	1.86	1.47	7.23
GAMA	1.03	0.99	5.91
COCONet	3.25	4.24	15.53
USGS_SCIGN	1.51	1.43	6.46
Expanded	2.67	2.92	10.78

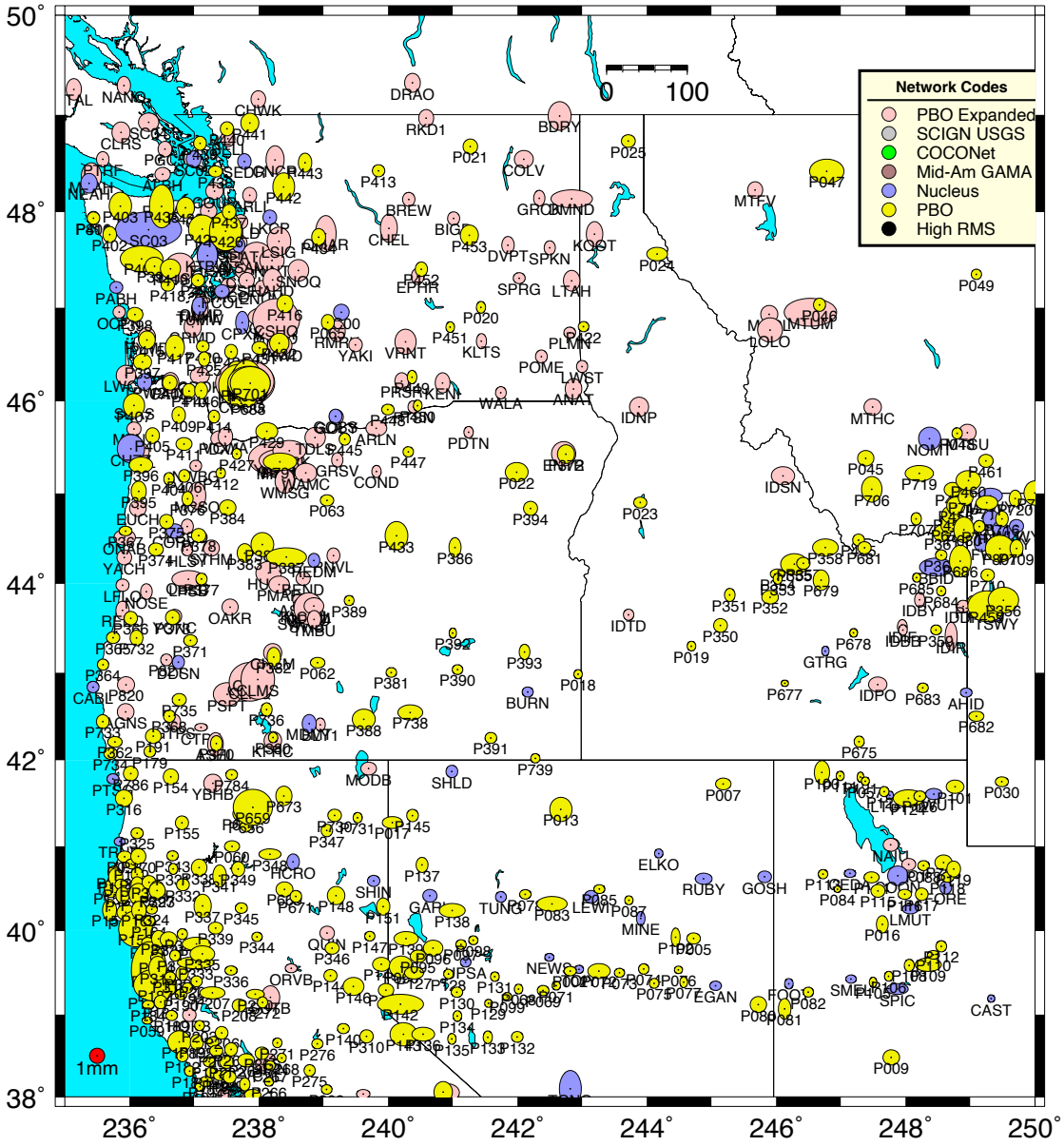

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1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

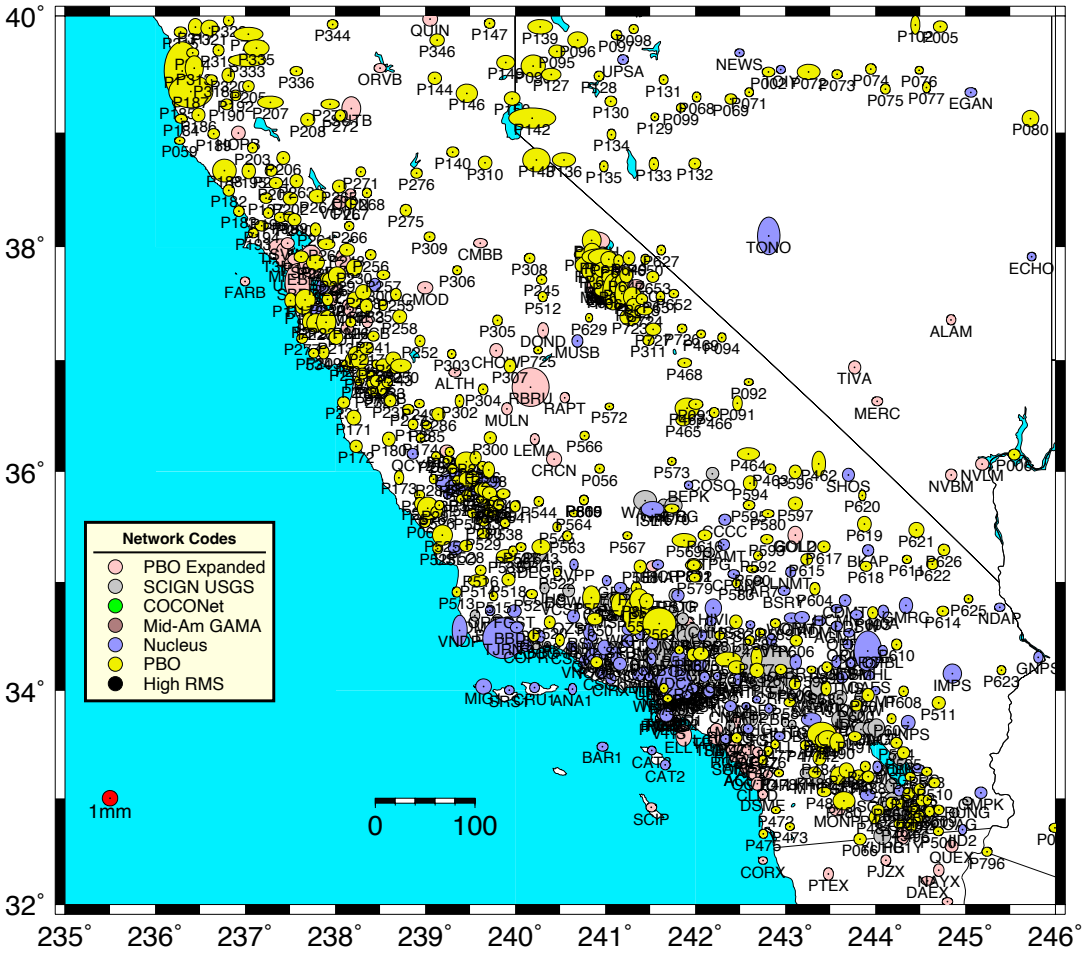

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

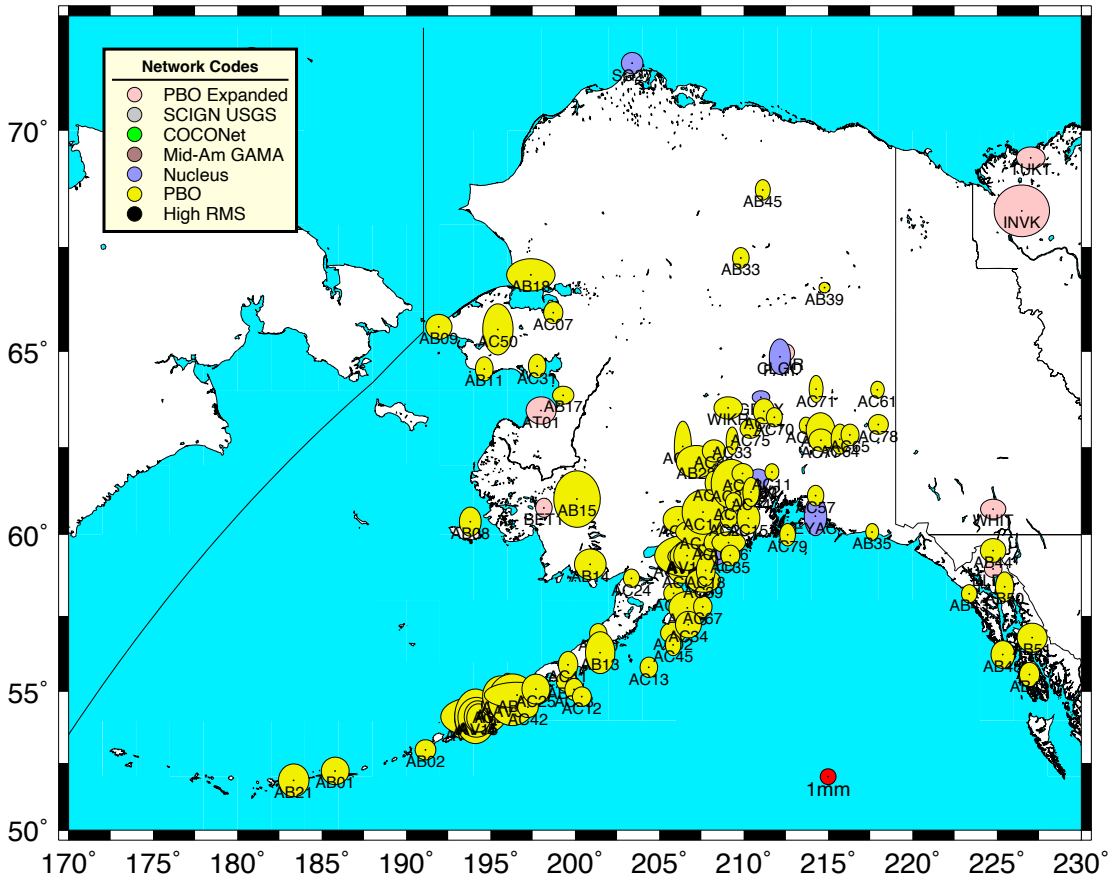

Figure 4: Same as Figure 4 except for the Alaskan region.

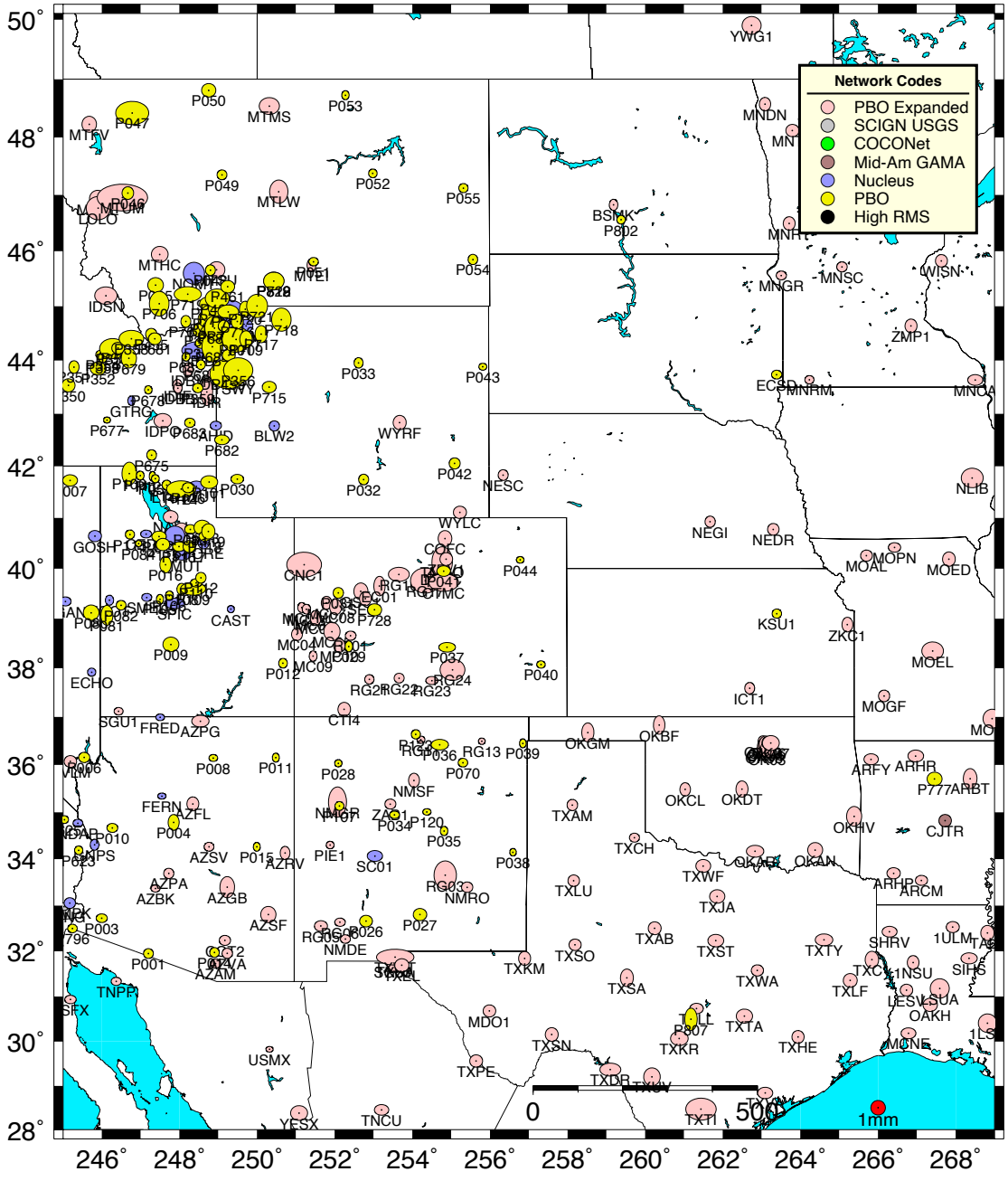

Figure 5: Same as Figure 4 except for the Central United States

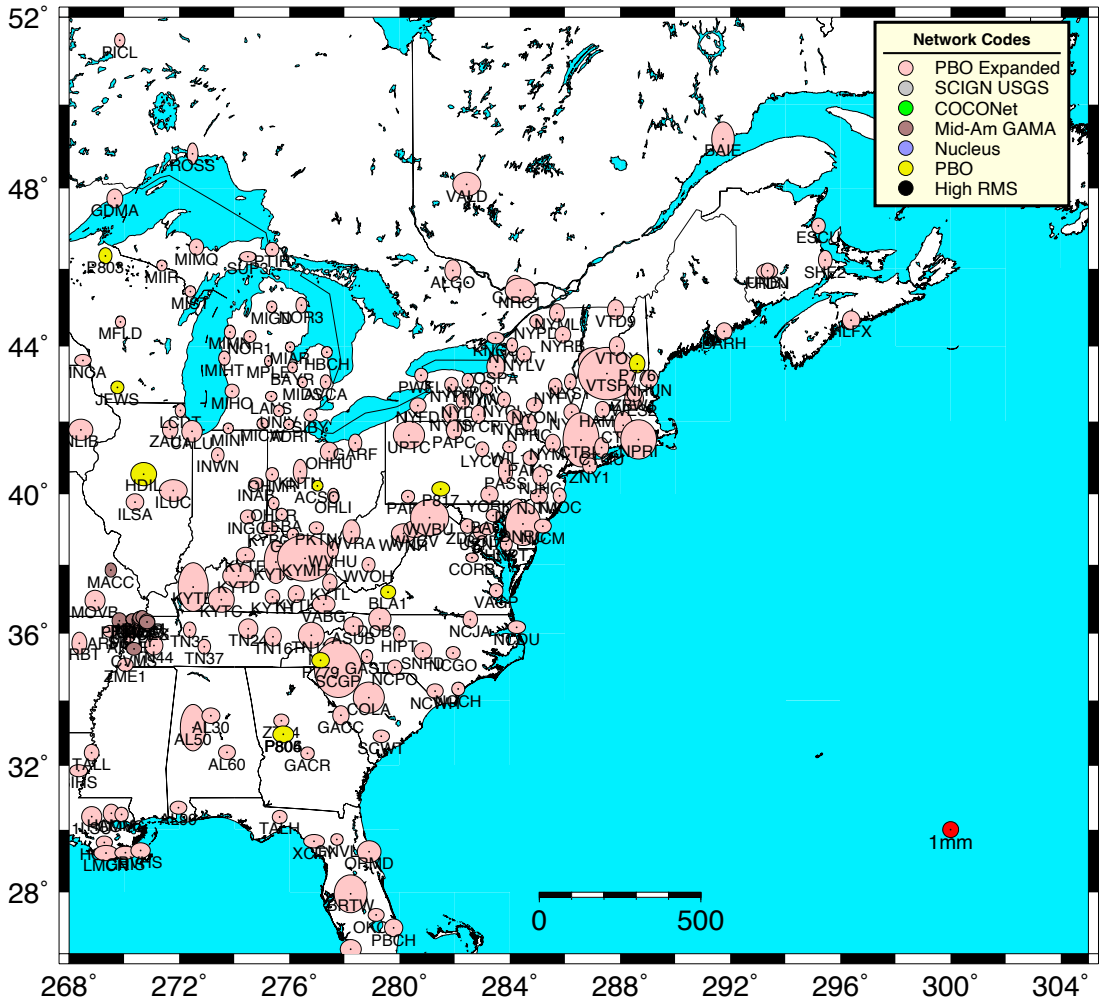

Figure 6: Same as Figure 4 except for the Eastern United States

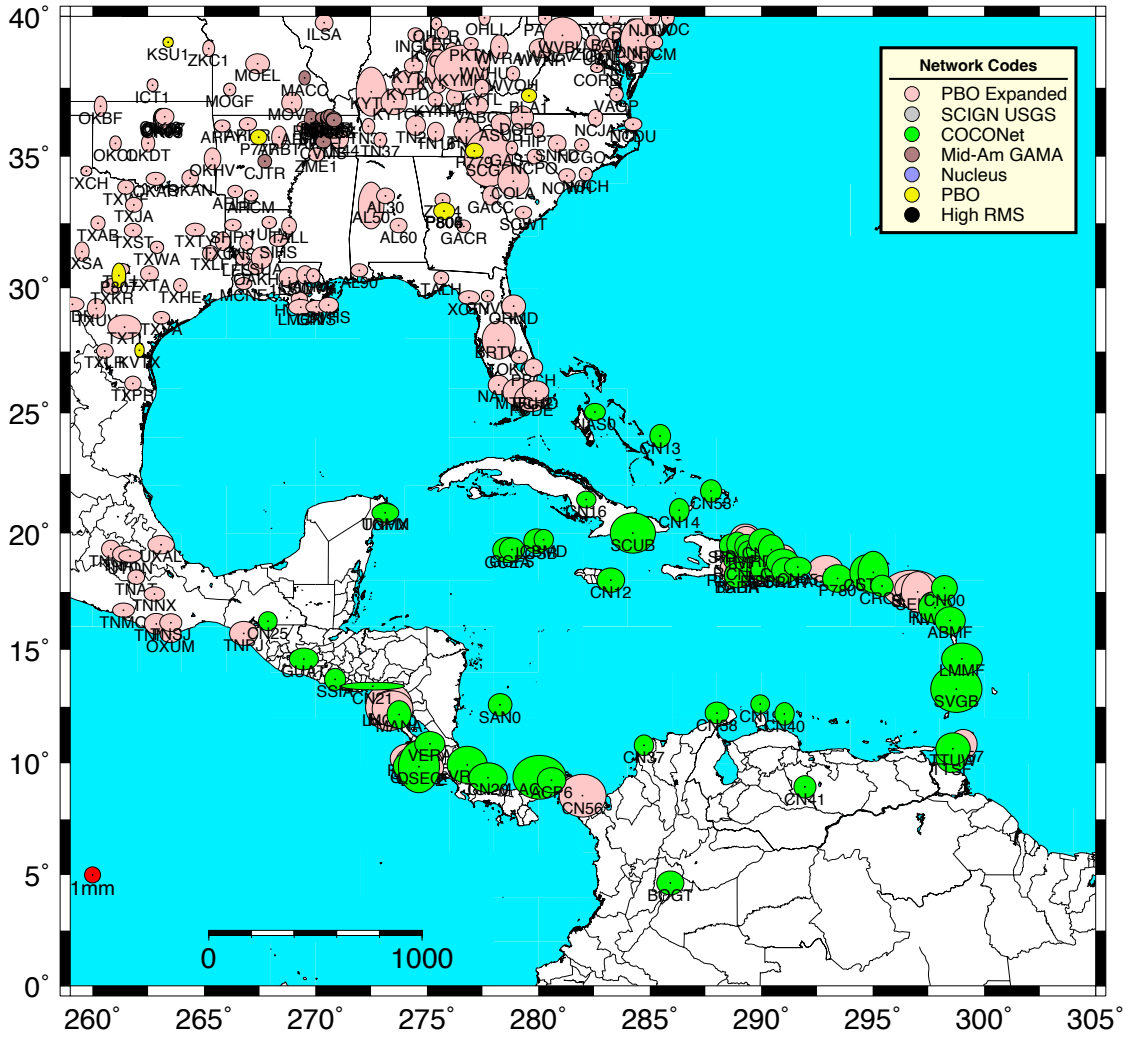

Figure 7: Same as Figure 4 except for the Caribbean region.

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 2666 stations in the CWU solution (6 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 2666 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and December 18, 2021.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.40	1.35	6.16
70%			
CWU	1.76	1.70	7.02
95%			
CWU	3.89	3.61	11.70

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.

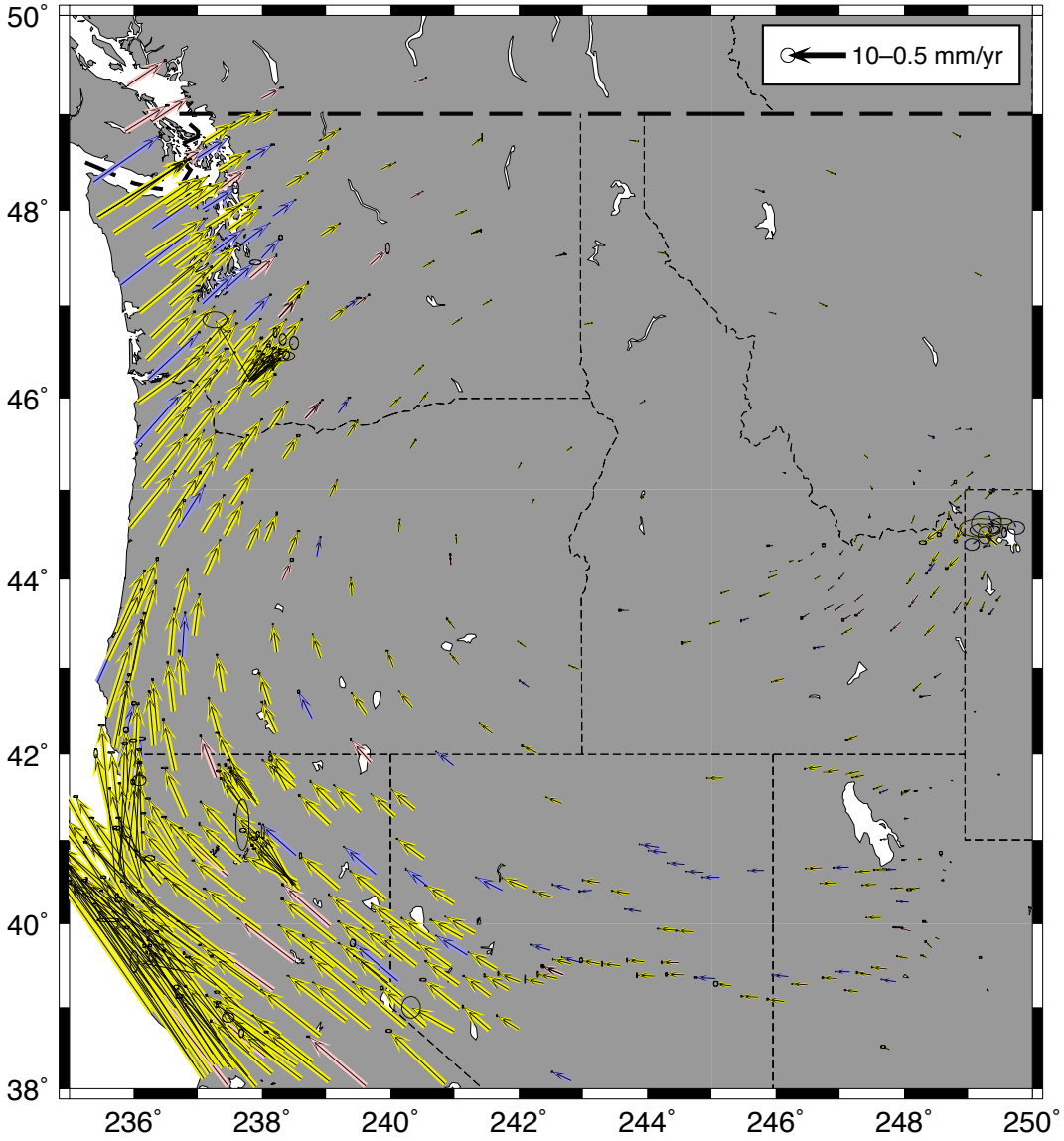

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

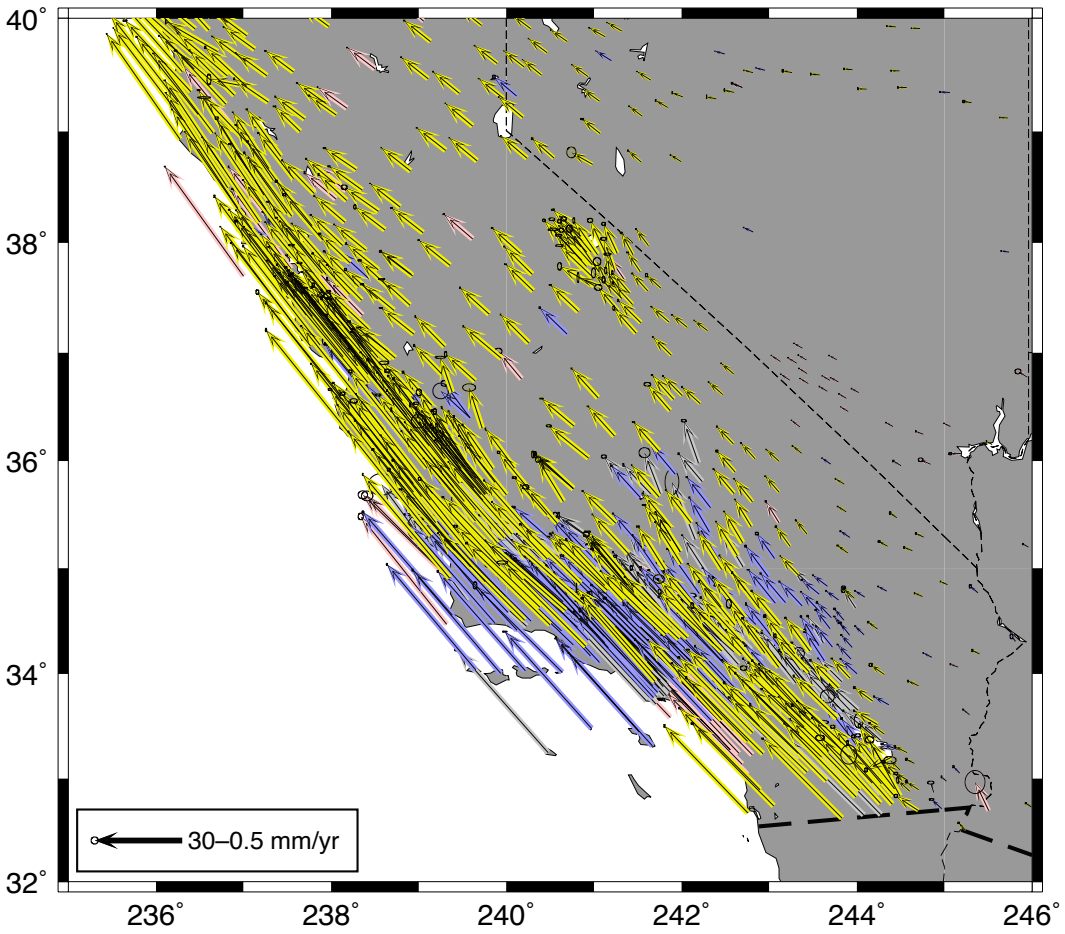

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

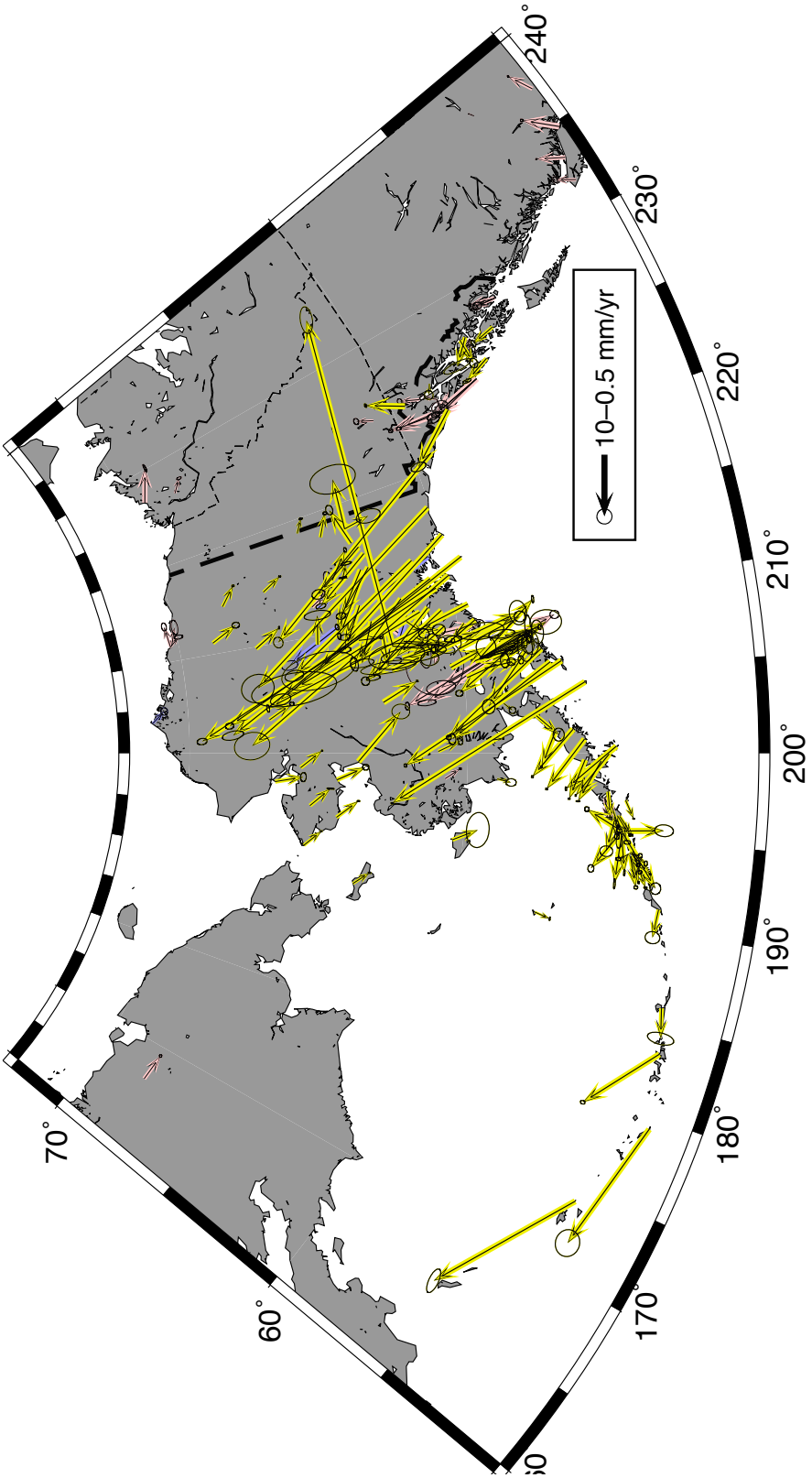

Figure 10: Same as Figure 8 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

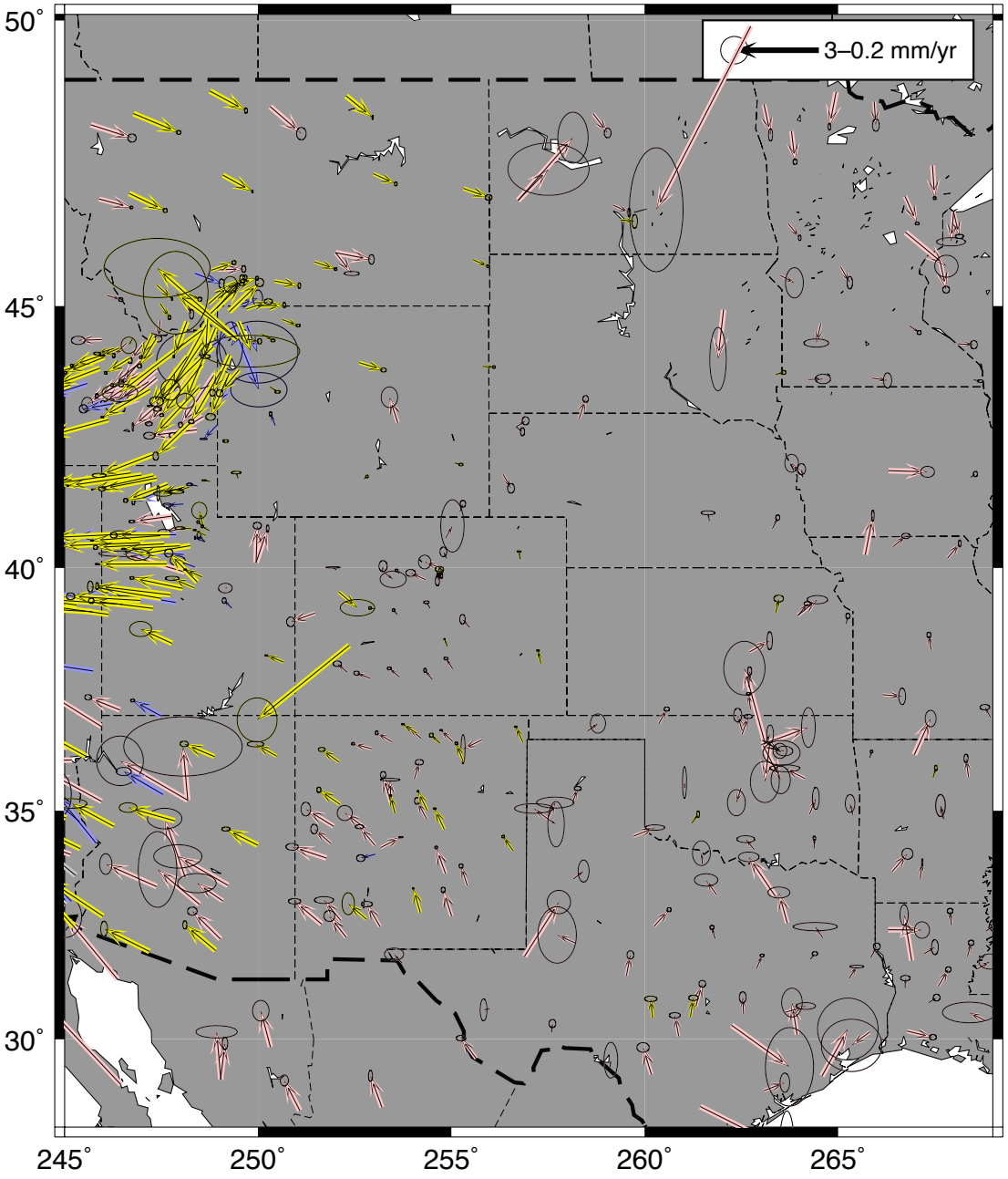

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

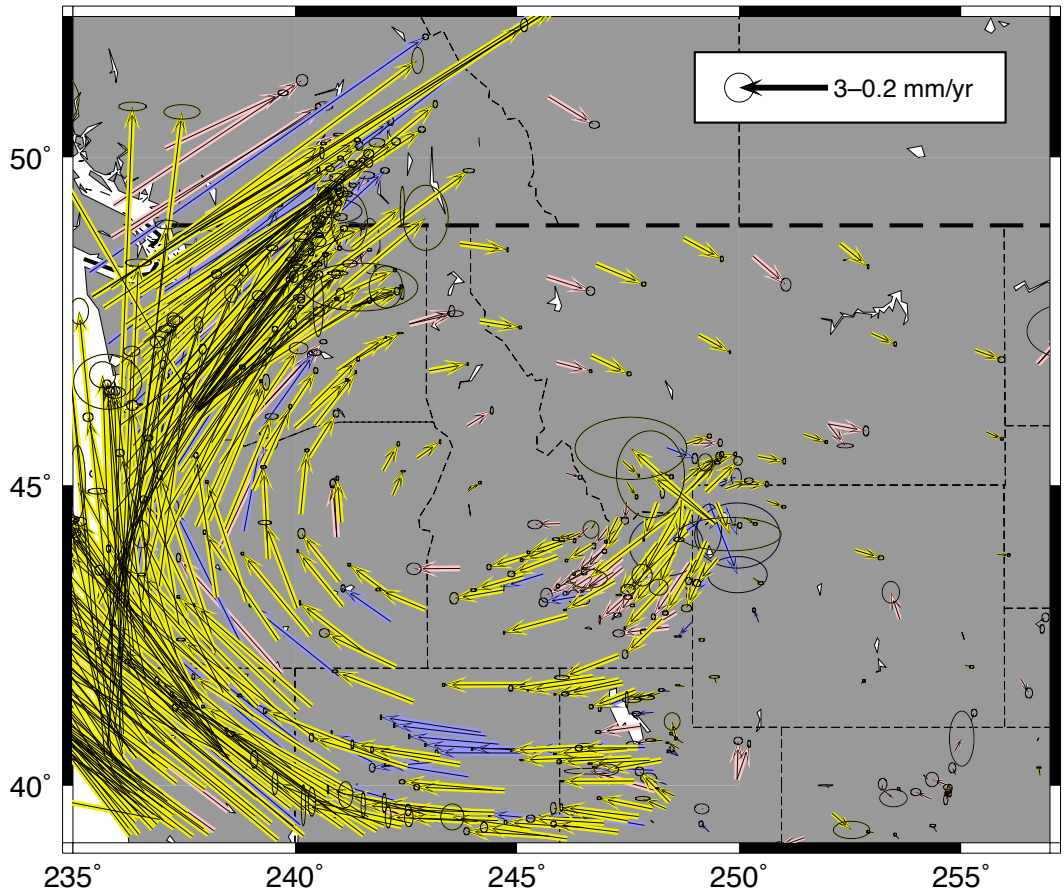

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

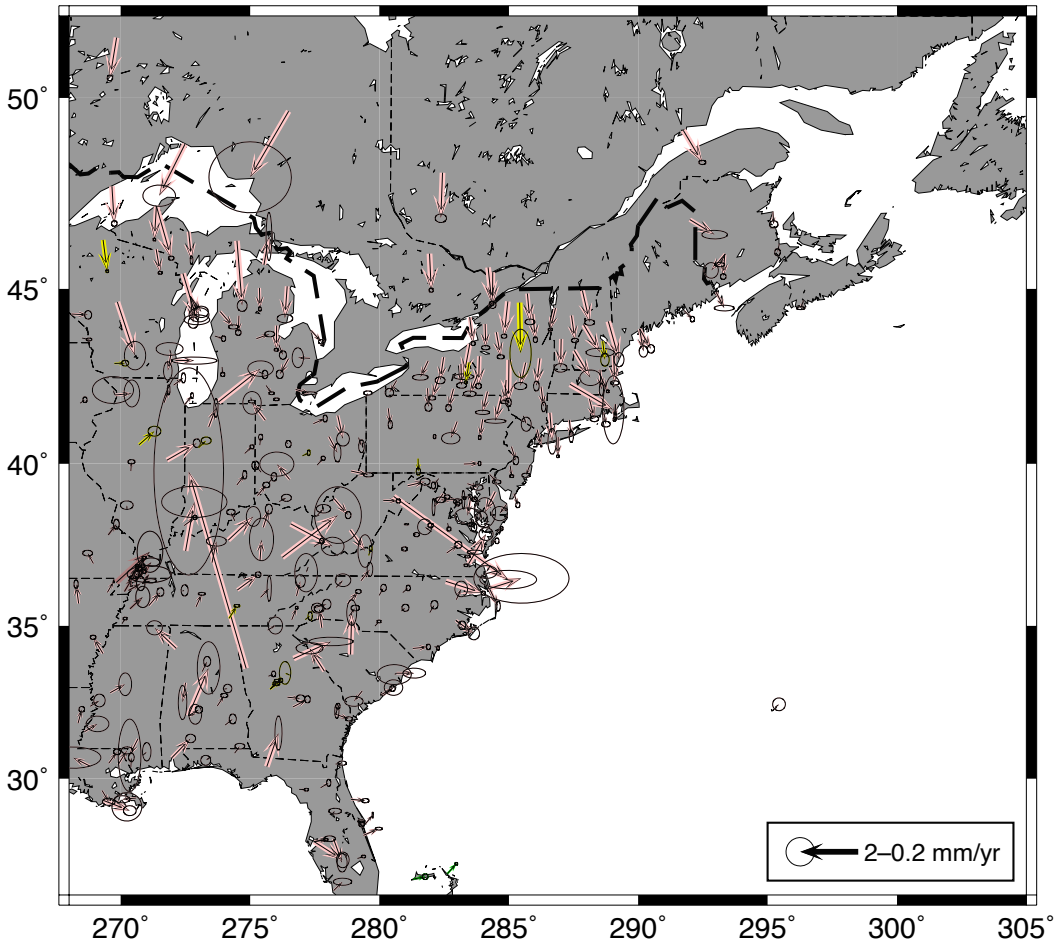

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

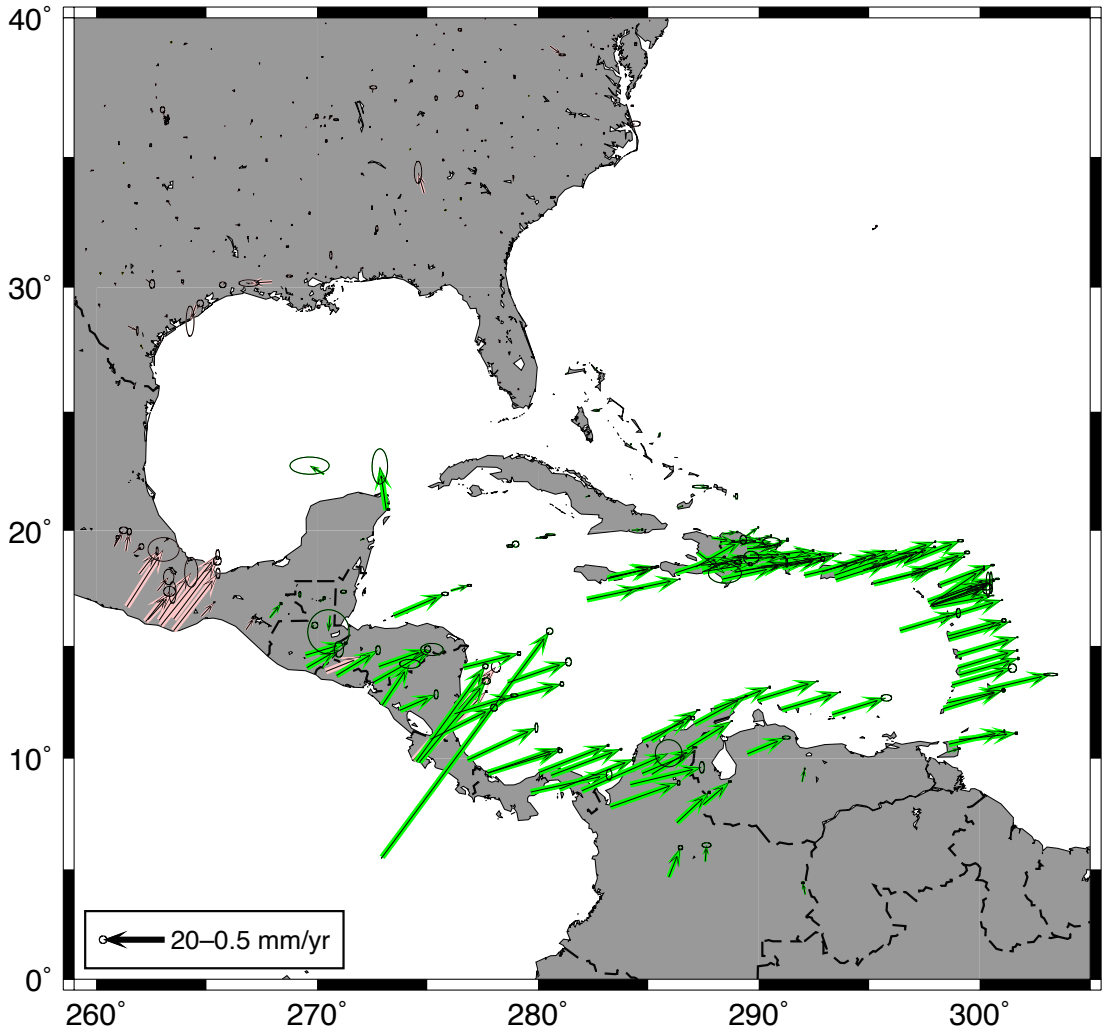

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2021/09/15-2021/12/31

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 29 earthquakes examined during this quarter (same as last quarter) and only one generated displacements more than 1 mm. The eventis EQ64 64 ANSS(ComCat) ak021d1u1nos mww6.9 114 km E of Chignik latitude/longitude 56.2584 -156.5532, Date/Time 2021/10/11 09:11. For this earthquake, there are a number of sites that are likely to have been displaced by the earthquake but for which no recent data were available.

EQ64 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.

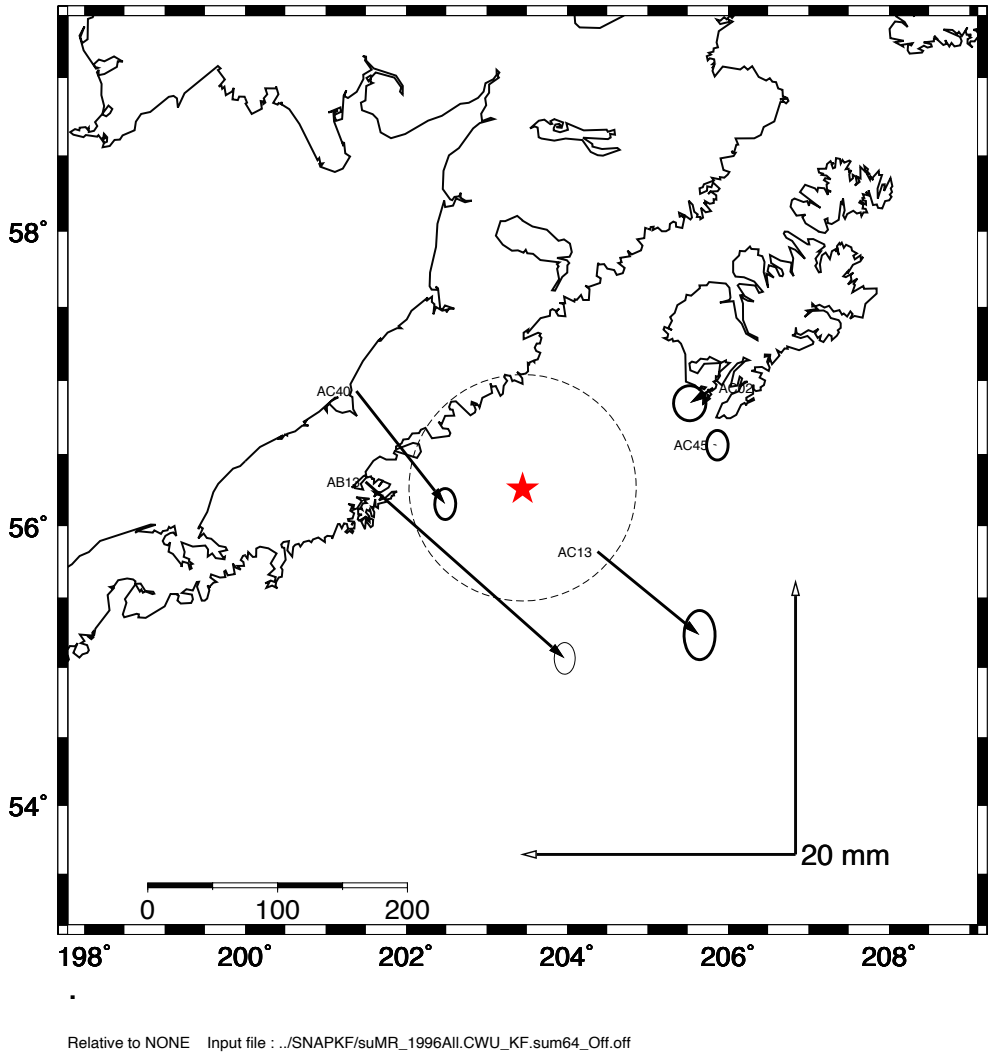

Figure 15: Coseismic offsets from the GAGE event 64 ANSS(ComCat) ak021d1u1nos mww6.9 114 km E of Chignik latitude/longitude 56.2584 -156.5532, Date/Time 2021/10/11 09:11. These results are from the Kalman filter analysis which provides the lowest standard deviation estimates.

Antenna and other discontinuity events.

Antenna swaps at 40 sites have been added to the list of offsets that are estimated when fitting velocities and other parameters to the CWU time series. These offsets were spread throughout the quarter.

Anomalous sites

The following sites have been noted as having anomalous motions during this quarter.

Site/s	Issues related to site
10/15/21	
ALPP	Antenna change to TWIV6150. Large height change when meta data not updated. http://geoweb.mit.edu/~tah/ACC_PBO/ALPP.CWU.jpg
IDNP	Antenna change to TRM115000.10. Large height change when meta data not updated. 50 mm height jump. http://geoweb.mit.edu/~tah/ACC_PBO/IDNP.CWU.jpg
LAFE	Site in Costa Rica one coast west of San Jose. Large postseismic plus slow slip every two years (possibly). http://geoweb.mit.edu/~tah/ACC_PBO/LAFE.CWU.jpg
MTA1	Antenna change to TWIV6150. Large height change when meta data not updated. http://geoweb.mit.edu/~tah/ACC_PBO/MTA1.CWU.jpg
OLVN	Site on Montserrat. Skewed in East plus transient motions. http://geoweb.mit.edu/~tah/ACC_PBO/OLVN.CWU.jpg
SCGP	Antenna change 2021 day 98 but may now be failing. Site in South Carolina. UNR results look OK. http://geoweb.mit.edu/~tah/ACC_PBO/SCGP.CWU.jpg
SKYB	Antenna change to TRM59800.99. Large East offset of 30 mm. Site just north of LA. http://geoweb.mit.edu/~tah/ACC_PBO/SKYB.CWU.jpg
10/22/21	
P221	NE jump of -14 -7 mm on 2021/10/20. Site near San Jose, CA. No apparent earthquakes but P220 may show small offset too. Keep an eye on rapids (only one day offset at moment. May have been a one day outlier. Why? Track solution to see? 21/11/08: Other days afterwards that are outliers but no by so much. http://geoweb.mit.edu/~tah/ACC_PBO/P221.CWU.jpg
10/29/21	
P083	Jump -7 mm East 2021/10/26. No meta data changes in logs yet. (Antenna change back in June. http://geoweb.mit.edu/~tah/ACC_PBO/P083.CWU.jpg
TWRI	Position starts drifting off between 21/10/17 and 21/10/23. Heights seems offset after 21/10/23. http://geoweb.mit.edu/~tah/ACC_PBO/TWRI.CWU.jpg
VCAP	Lots of missing days. Jump in height -25 mm on 21/09/23. http://geoweb.mit.edu/~tah/ACC_PBO/VCAP.CWU.jpg
11/5/21	
AB18	Restarted after a large gap. Interesting east systematics. No major signals in height so strange: http://geoweb.mit.edu/~tah/ACC_PBO/AB18.CWU.jpg
WES2	New antenna TWIV6150. http://geoweb.mit.edu/~tah/ACC_PBO/WES2.CWU.jpg
11/12/21	
HLSY	Looks like tree growing mid-2019 until 21/07/31 when RMS scatter

	drops. Strong annual in N (~3mm). Vertical 5 mm; same quadrant but not in phase. http://geoweb.mit.edu/~tah/ACC_PBO/HLSY.CWU.jpg
LCHS	East excursion in 2021; clear breaks are modeled. http://geoweb.mit.edu/~tah/ACC_PBO/LCHS.CWU.jpg
NVPO	Seems to losing data. Scatter increases after 2020 but outliers have larger error bars. Post seismic from El Major Cucapah 2010 earthquake. http://geoweb.mit.edu/~tah/ACC_PBO/NVPO.CWU.jpg
P142	Skewed in East. Long term vertical signal. On Nevada border east of Sacramento. http://geoweb.mit.edu/~tah/ACC_PBO/P142.CWU.jpg
P168	Breaks modeled. Annual in North Could be failing antenna before change 21/05/07. http://geoweb.mit.edu/~tah/ACC_PBO/P168.CWU.jpg
P435	Skewed in North. Slow slip in east. https://www.unavco.org/instrumentation/networks/status/nota/overview/p435
PIGT	Breaks known. Strange behavior when site first installed in 2001. Site in Arkansas. No photos. http://geoweb.mit.edu/~tah/ACC_PBO/PIGT.CWU.jpg
PTEX	Mexico: Curvature in east ~6.4 mm log from El Major Cucapah. http://geoweb.mit.edu/~tah/ACC_PBO/PTEX.CWU.jpg
PTGX	Break in North 2009/05/01 not in metadata. Site in Missouri. Added to unkn eq list. http://geoweb.mit.edu/~tah/ACC_PBO/PTGX.CWU.jpg
QMAR	Outliers in height. Washington State site. Change in North slope March 2018. http://geoweb.mit.edu/~tah/ACC_PBO/QMAR.CWU.jpg
SMAI	Slow slip in East. http://geoweb.mit.edu/~tah/ACC_PBO/SMAI.CWU.jpg
STHM	Strong annuals in east and north. Looks like failing antenna but change meta data date is before gap in data in 2021. Site In Oregon. UNR height series very strange. HKSV is 30km away and north annual out of phase. Same degrading of signal in 2021. P378 (22km) does not show north annual. http://geoweb.mit.edu/~tah/ACC_PBO/STHM.CWU.jpg
UVFM	Lose of data. Scatter after 2020 consistent with error bars. Site is in Virginia. http://geoweb.mit.edu/~tah/ACC_PBO/UVFM.CWU.jpg
11/19/21	
DUBO	Site near Lake Winnipeg: North excursions may be lake level related? Outliers "evolve" over a few weeks but large east changes for some suggest some-other mechanism? http://geoweb.mit.edu/~tah/ACC_PBO/DUBO.CWU.jpg
11/26/21	
SC03	Outliers in east with offsets of about 10 millimeters. Oscillating between two values 11/20 through 11/24. (On 11/24). http://geoweb.mit.edu/~tah/ACC_PBO/SC03.CWU.jpg
12/3/21	
SELD	Vertical dropping rapidly after 2021-11-01. Total drop about 50 mm with little anomaly in NE components. http://geoweb.mit.edu/~tah/ACC_PBO/SELD.CWU.jpg

TNMQ	Turn around of slow slip event in East. Probably geophysical signal (not noise). Site in Guerrero Mexico. http://geoweb.mit.edu/~tah/ACC_PBO/TNMQ.CWU.jpg
12/10/21	
AV29	Start of 2021 snow season and outlier data. http://geoweb.mit.edu/~tah/ACC_PBO/AV29.CWU.jpg
12/17/21	Not Reported
AB51	10 mm jump East 2021/12/12. No meta change yet. No earthquake http://geoweb.mit.edu/~tah/ACC_PBO/AB51.CWU.jpg
AZPG	Unknown offset 2020/04/12 (maybe artifact from late reported antenna change). http://geoweb.mit.edu/~tah/ACC_PBO/AZPG.CWU.jpg
P399	Drop in height since 2021/12/13. Keep an eye to see if it persists. http://geoweb.mit.edu/~tah/ACC_PBO/P399.CWU.jpg
P613	15 mm east offset 2021/12/13. Site in mountains east of LA. Large systematics in time series as well. http://geoweb.mit.edu/~tah/ACC_PBO/P613.CWU.jpg
12/23/21	
FLINN	Annual signal in height increasing in amplitude since 2018. Could be snow effect. Rapid recent dip. http://geoweb.mit.edu/~tah/ACC_PBO/FLIN.CWU.jpg
PKWD	300 mm jump in height 21/12/21. Errorbar looks OK. Site north of Portland OR. Big break in antenna change. No meta data change Iin PANGA log. http://geoweb.mit.edu/~tah/ACC_PBO/PKWD.CWU.jpg
1/5/22	
AC31	15mm East jump 12/26/2021. Maybe snow, earlier years occasional have this behavior but this year is larger. http://geoweb.mit.edu/~tah/ACC_PBO/AC31.CWU.jpg
BSRY	Offset in north with antenna change from ASH701945B_M to TRM59800.99. http://geoweb.mit.edu/~tah/ACC_PBO/BSRY.CWU.jpg
CNCR	400 mm jump in height; PANGA log shows no update in meta data. http://geoweb.mit.edu/~tah/ACC_PBO/CNCR.CWU.jpg
COLV	30-50 mm jump in EN. PANGA log shows no update in meta data. http://geoweb.mit.edu/~tah/ACC_PBO/COLV.CWU.jpg
COUG	North off -10 mm 12/31-01/03, height jumps 01/03/2022. PANGA log has no update. http://geoweb.mit.edu/~tah/ACC_PBO/COUG.CWU.jpg
KIOS	640 mm height jump 2021/05/14. Added to All_NOTA_unkn.eq file as BPS. http://geoweb.mit.edu/~tah/ACC_PBO/KIOS.CWU.jpg
MTSU	Jump in height 21/06/06 (-30mm) and in North (21/12/27) (-8 mm). CORS site no log update. Added to All_NOTA_unkn.eq. http://geoweb.mit.edu/~tah/ACC_PBO/MTSU.CWU.jpg
NRWY	Very systematic. Site in Yellowstone. http://geoweb.mit.edu/~tah/ACC_PBO/NRWY.CWU.jpg
OLMP	Jumps in height added to All_NOTA_unkn.eq. Site near Olympia. WA. Not

	in UNAVCO station pages. http://geoweb.mit.edu/~tah/ACC_PBO/OLMP.CWU.jpg
P056	Hydrology in Great Valley? http://geoweb.mit.edu/~tah/ACC_PBO/P056.CWU.jpg
P186	North signal in late 2020/early 2021. Looks like break but smooth change over 30 days. Near California coast, mid-way San Francisco and Mendocino triple junction. http://geoweb.mit.edu/~tah/ACC_PBO/P186.CWU.jpg
P333	Probably snow. East of P186. 2000 meters. http://geoweb.mit.edu/~tah/ACC_PBO/P333.CWU.jpg
P384	Maybe snow, east of Salem OR, 1183 meters. http://geoweb.mit.edu/~tah/ACC_PBO/P384.CWU.jpg
P419	West of Seattle. 936 m maybe be failing antenna? http://geoweb.mit.edu/~tah/ACC_PBO/P419.CWU.jpg
RSTP	Postseismic Ridgecrest. North of LA. http://geoweb.mit.edu/~tah/ACC_PBO/RSTP.CWU.jpg
SYNG	Jump in North and East 2017/02/18. Added to All_NOTA_unkn.eq. http://geoweb.mit.edu/~tah/ACC_PBO/SYNG.CWU.jpg
UFDA	Height jump 22/01/02. PANGA no log update. Near Seattle, no UNAVCO station page. http://geodesy.unr.edu/NGLStationPages/stations/UFDA.sta

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 48 stations in the ANET region for CWU analyzed in the final orbit analysis between September 15, 2021 and December 18, 2021.

CWU	North (mm)	East (mm)	Up (mm)
Median ANET	1.10	0.99	5.48
70% ANET	1.37	1.14	6.22
95% ANET	1.97	1.97	8.66

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

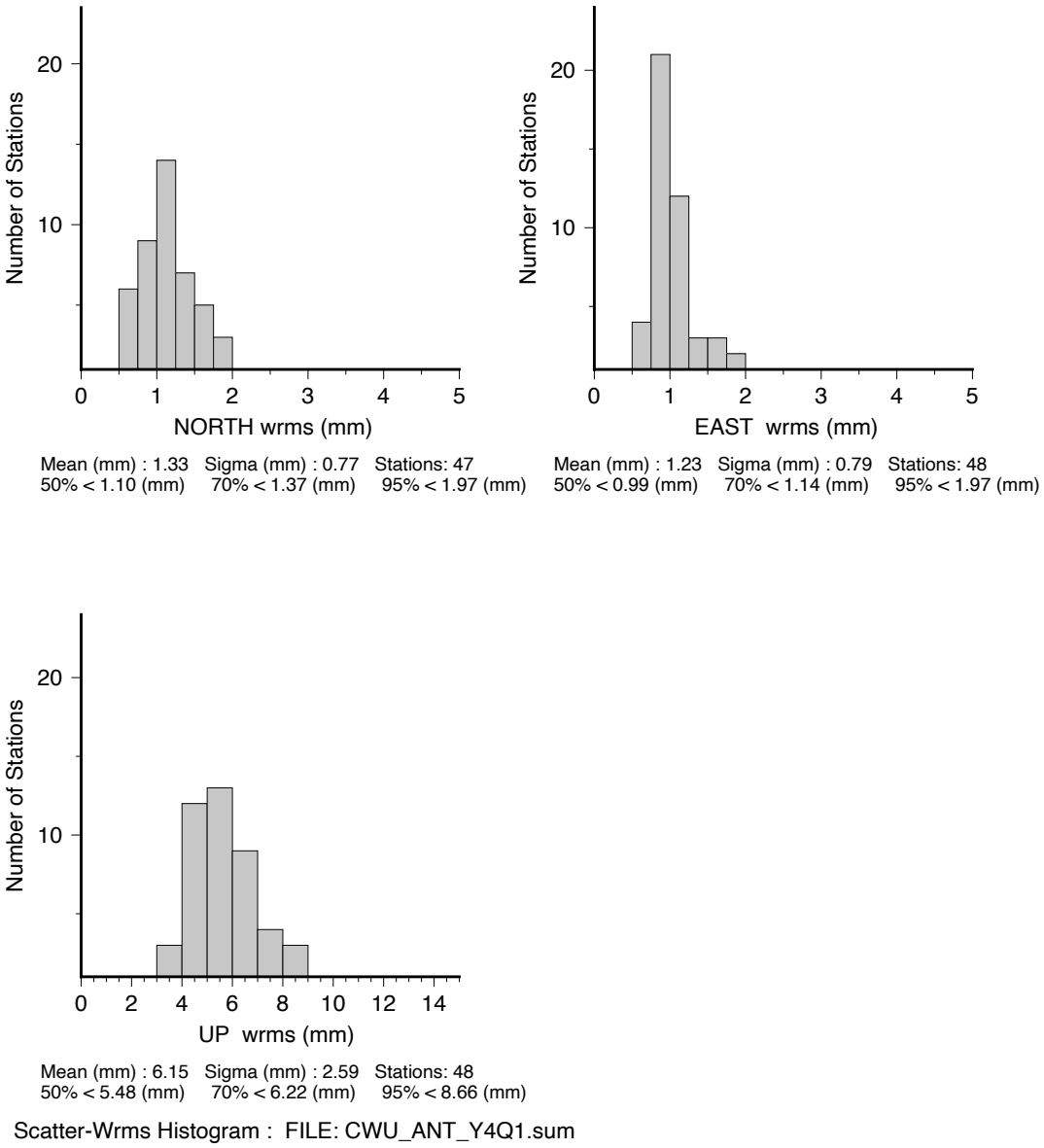

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 48 stations in Antarctica analyzed between September 15, 2021 and December 18, 2021. Linear trends and annual signals were estimated from the time series.

References

Altamimi, Z., P. Rebischung, L. Metivier, and X. Collilieux (2016), ITRF2014: A new release of the International Terrestrial Reference Frame modeling

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