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

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Period: 2021/01/01-2021/03/31

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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 NAM08 reference frame. In this report, we show analyses of the data processing for the period 2020/12/15 to 2021/03/31, time series velocity field analyses for the GAGE reprocessing analyses (1996-2021). Several earthquakes were investigated this quarter but none generated coseismic displacements > 1mm.

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 1945 stations were processed which is 5 less than last quarter despite new stations being added to the analyses. We are losing sites each quarter most likely due to failed sites. The loss this quarter is half that of last quarter. In addition up to 51 sites were processed in the ANET solutions, 4 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, 2020– March 20, 2021

For this report, we generated the statistics using the ~3 months of CWU results between December 15, 2020 and March 20, 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 1960 stations for CWU analyzed in the finals analysis between December 15, 2020 and March 20, 2021. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.96	0.88	4.75
70%			
CWU	1.20	1.08	5.57
95%			
CWU	2.63	2.47	10.41

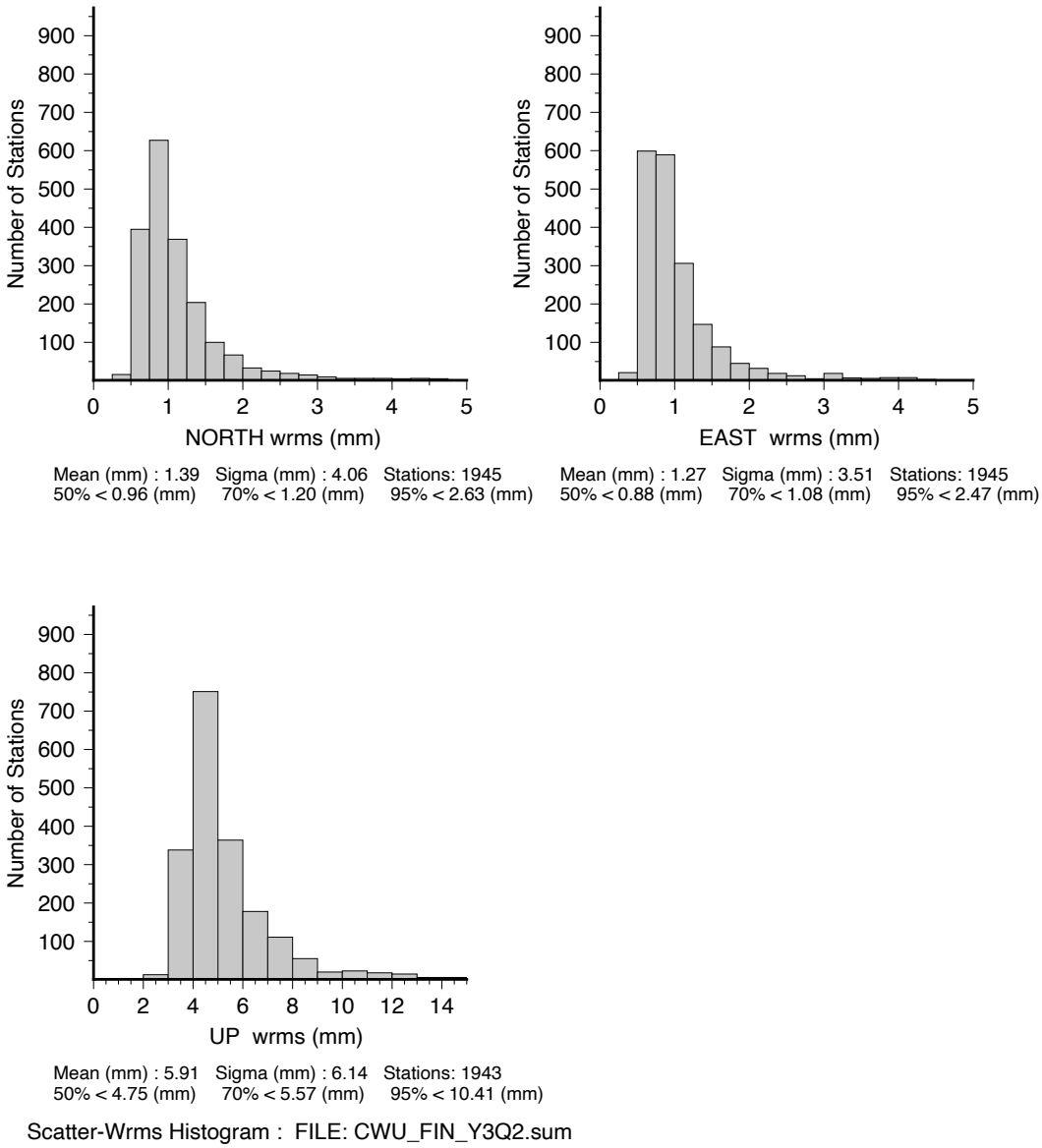

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 1945 stations analyzed between December 15, 2020 and March 20, 2021. Linear trends and annual signals were estimated from the time series.

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_Y3Q2.tab.

There are 1960 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_Y3Q2.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    96       1.2   0.61      1.6   0.78     7.3   0.77     17.91
 1NSU    94       1.0   0.58      1.0   0.62     6.1   0.81     17.16
 1ULM    96       0.8   0.47      0.8   0.53     5.9   0.79     17.77
 7ODM    79       1.5   0.83      0.8   0.54     4.9   0.64     19.87
…
 ZDV1    96       0.8   0.39      1.1   0.71     4.7   0.62     17.80
 ZKC1    96       1.0   0.50      0.8   0.55     5.2   0.68     17.80
 ZLA1    96       1.3   0.72      0.8   0.55     4.4   0.59     17.80
 ZLC1    96       0.9   0.45      0.7   0.49     4.5   0.61     18.02
 ZME1    96       1.0   0.53      0.9   0.57     5.7   0.76     18.02
 ZMP1    96       0.9   0.43      0.6   0.43     6.2   0.84     18.27
 ZNY1    96       0.9   0.45      0.9   0.57     5.6   0.76     18.18
 ZOA1     5       0.9   0.46      0.3   0.17     4.8   0.64     18.46
 ZSE1    96       1.0   0.49      0.9   0.61     5.0   0.69     18.18
 ZTL4    96       0.8   0.44      0.8   0.51     5.5   0.73     18.37
```

Table 2: RMS scatter of the position residuals for the CWU solution between December 15, 2020 and March 20, 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	0.88	0.81	4.42	819
NUCLEUS	0.85	0.75	4.15	196
GAMA	1.43	0.95	5.40	15
COCONet	1.42	1.42	6.32	64
USGS_SCIGN	0.94	0.78	4.24	107
Expanded	1.05	0.96	5.37	744
70%				
PBO	1.08	1.01	4.97	
NUCLEUS	1.00	0.88	4.66	
GAMA	1.71	1.13	5.85	
COCONet	1.50	1.67	7.34	
USGS_SCIGN	1.10	0.90	4.57	
Expanded	1.33	1.18	6.19	
95%				

PBO	2.38	2.35	9.21
NUCLEUS	1.75	1.52	7.41
GAMA	1.89	1.54	6.73
COCONet	2.38	3.41	13.24
USGS_SCIGN	1.78	1.46	7.43
Expanded	2.84	3.06	11.24

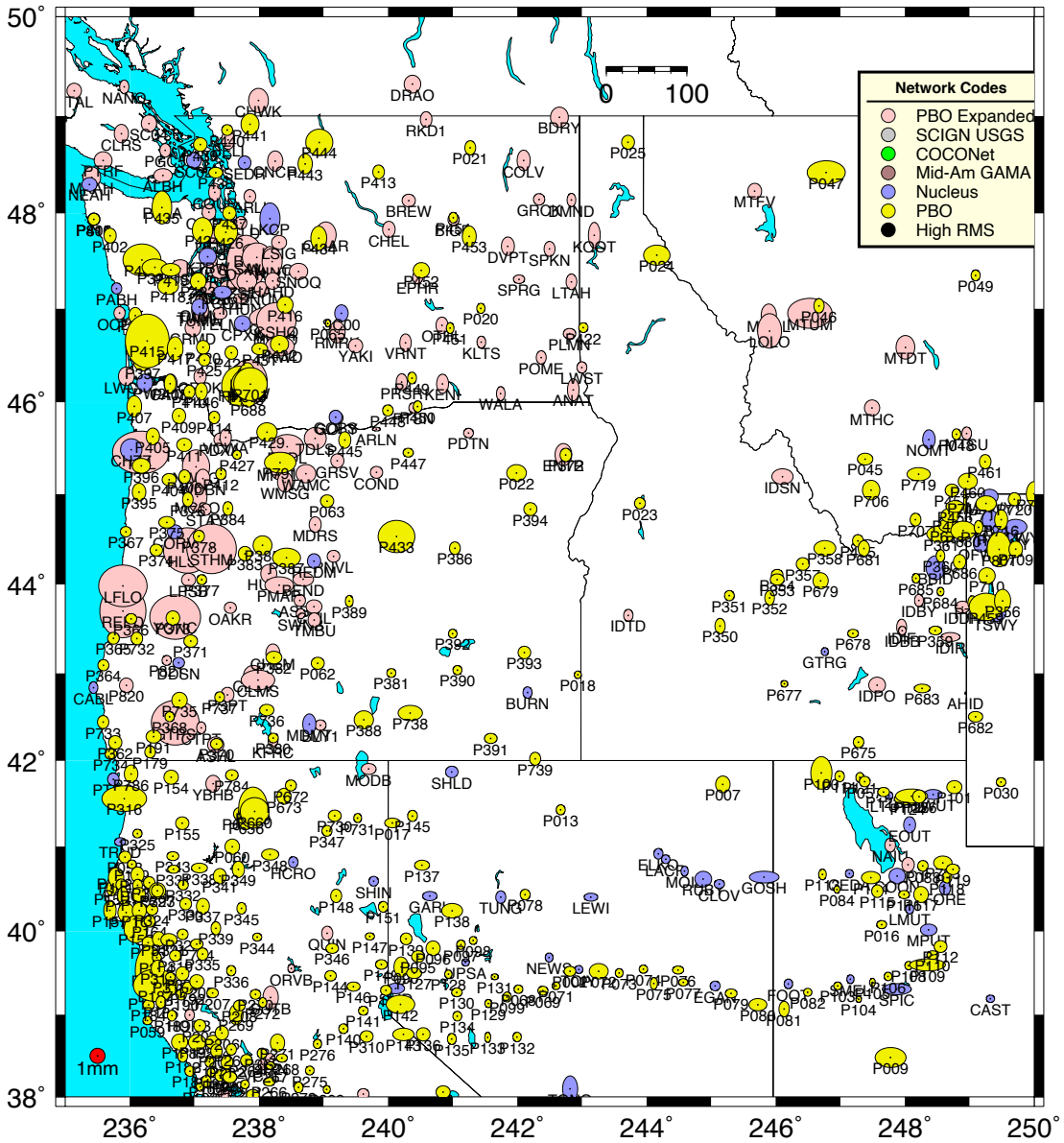

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1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

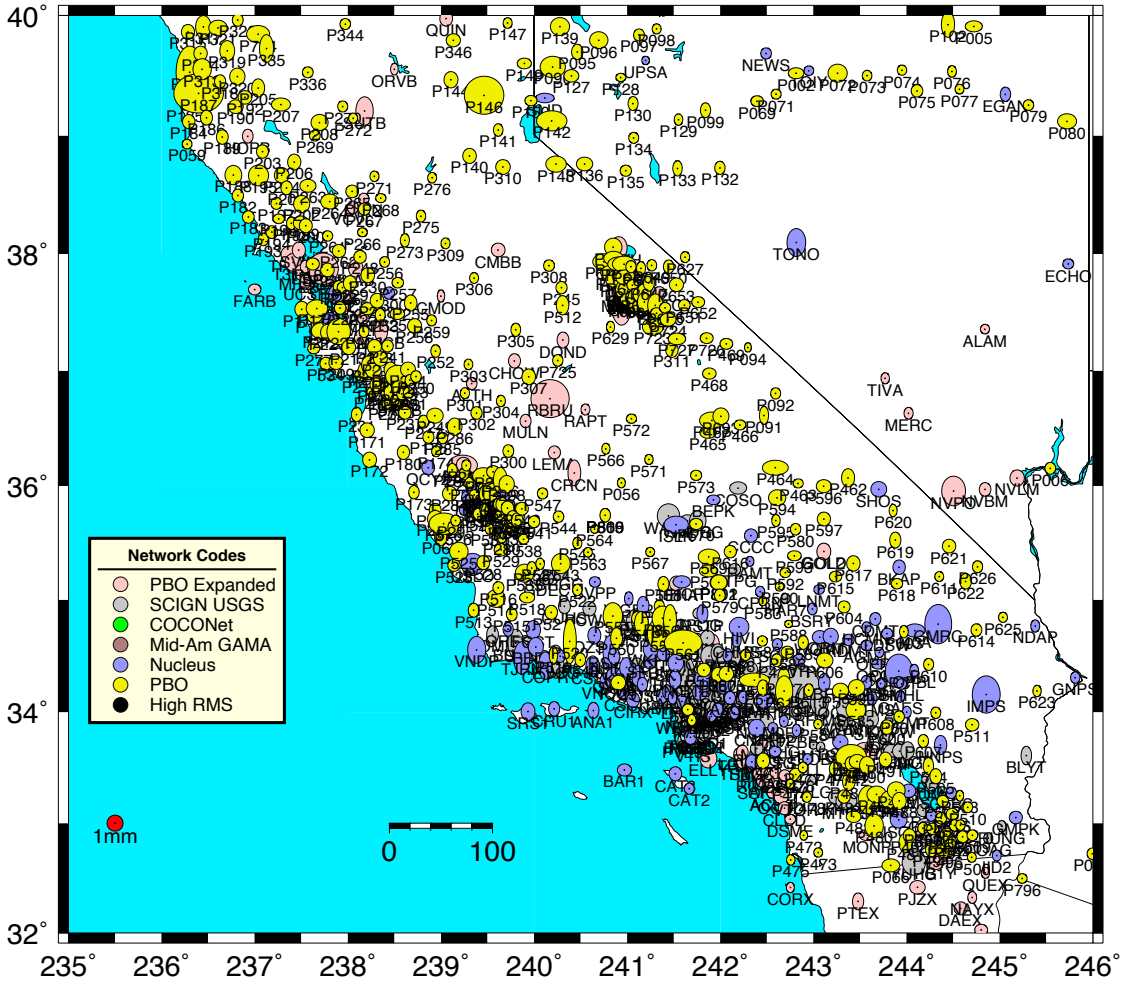

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

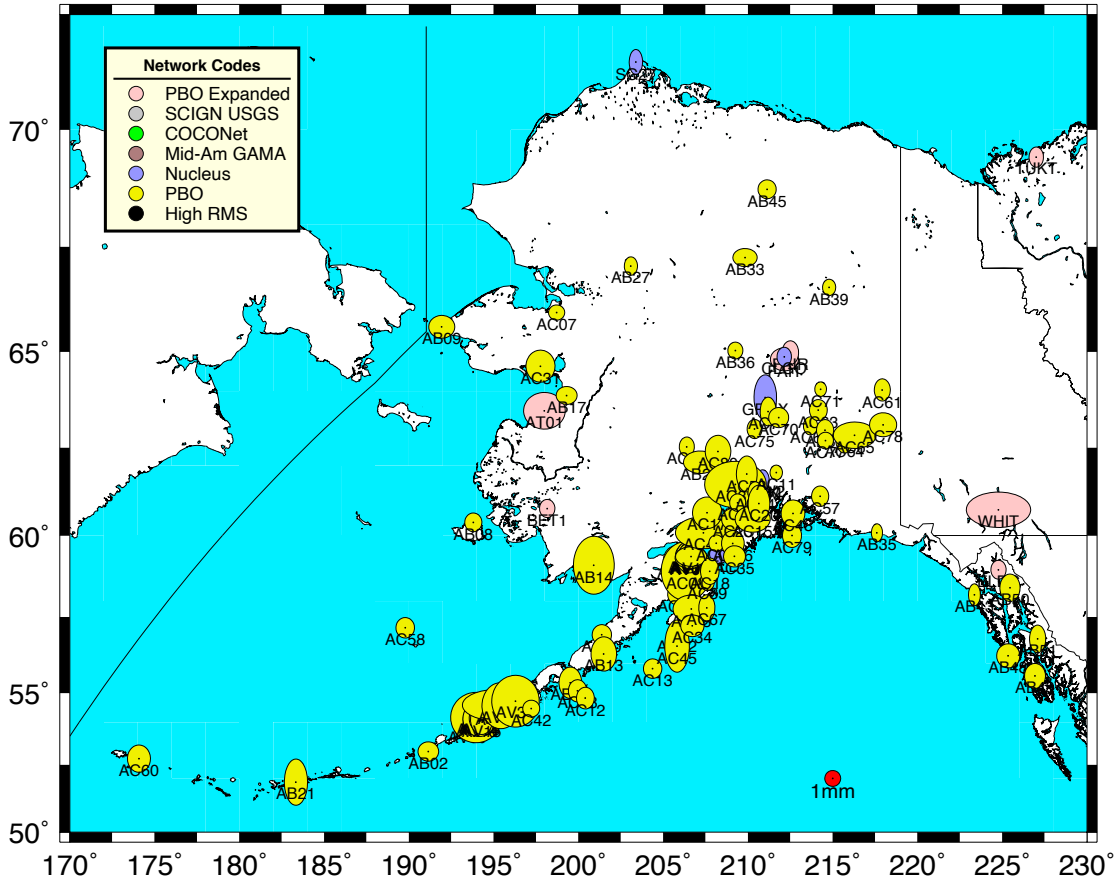

Figure 4: Same as Figure 4 except for the Alaskan region.

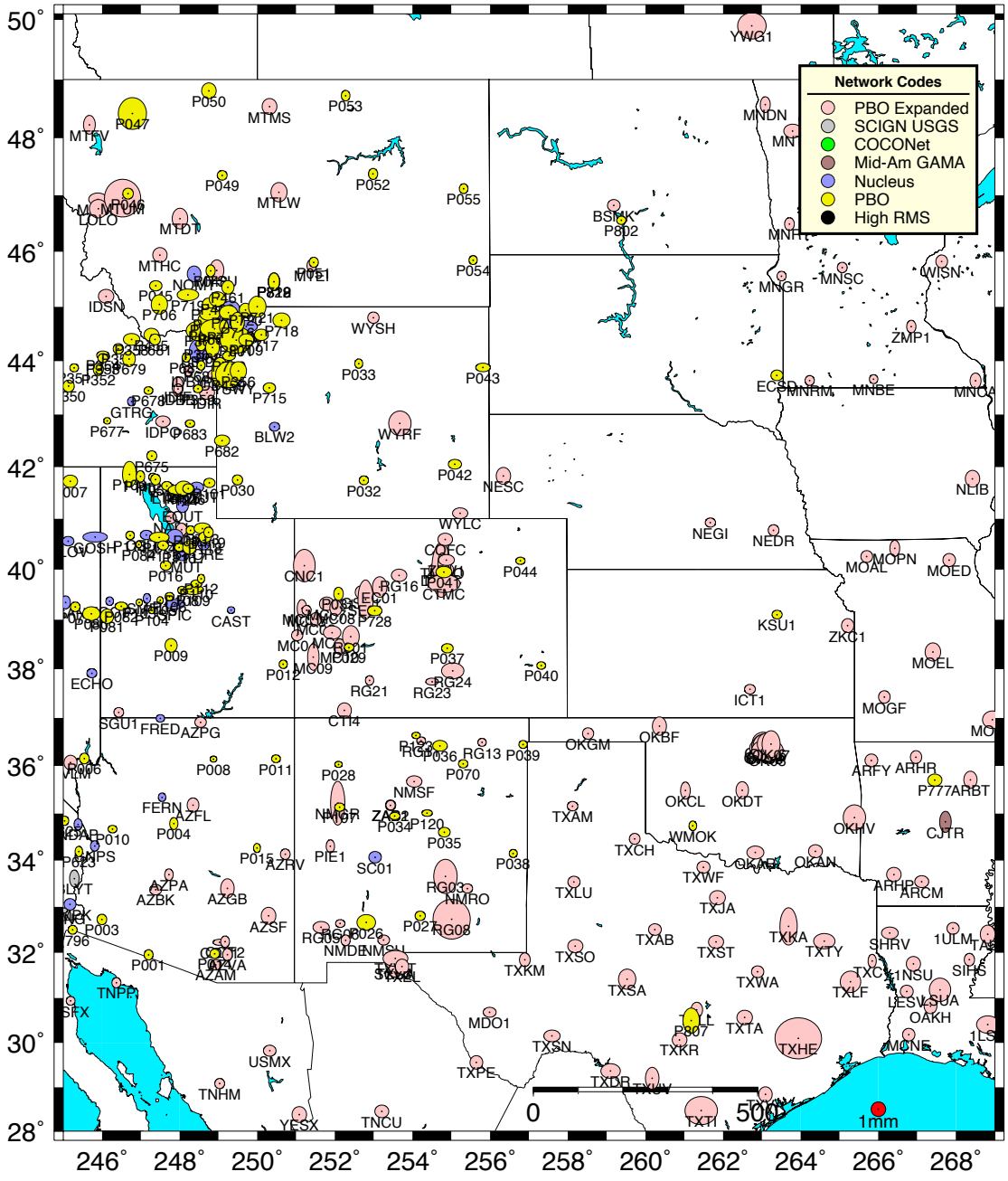

Figure 5: Same as Figure 4 except for the Central United States

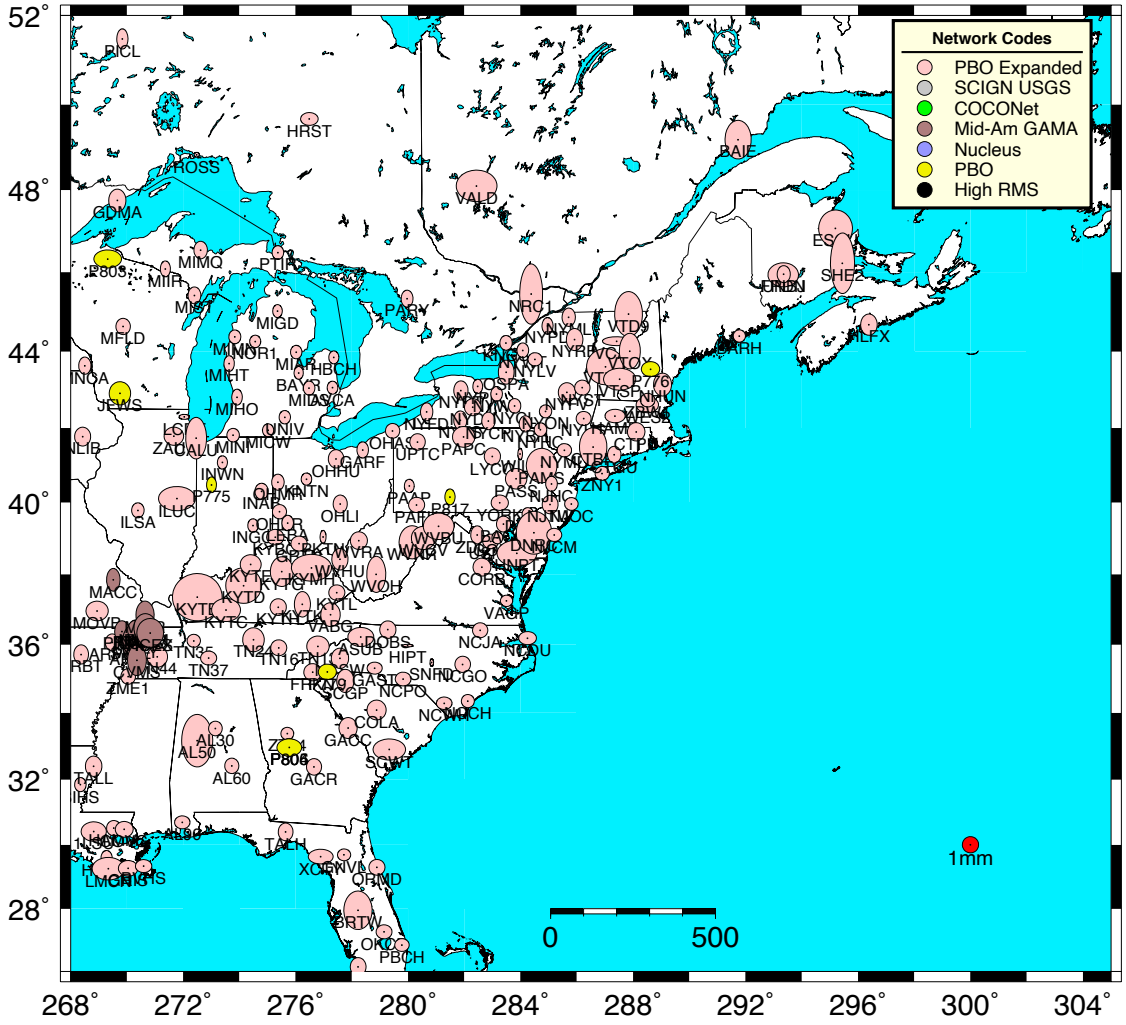

Figure 6: Same as Figure 4 except for the Eastern United States

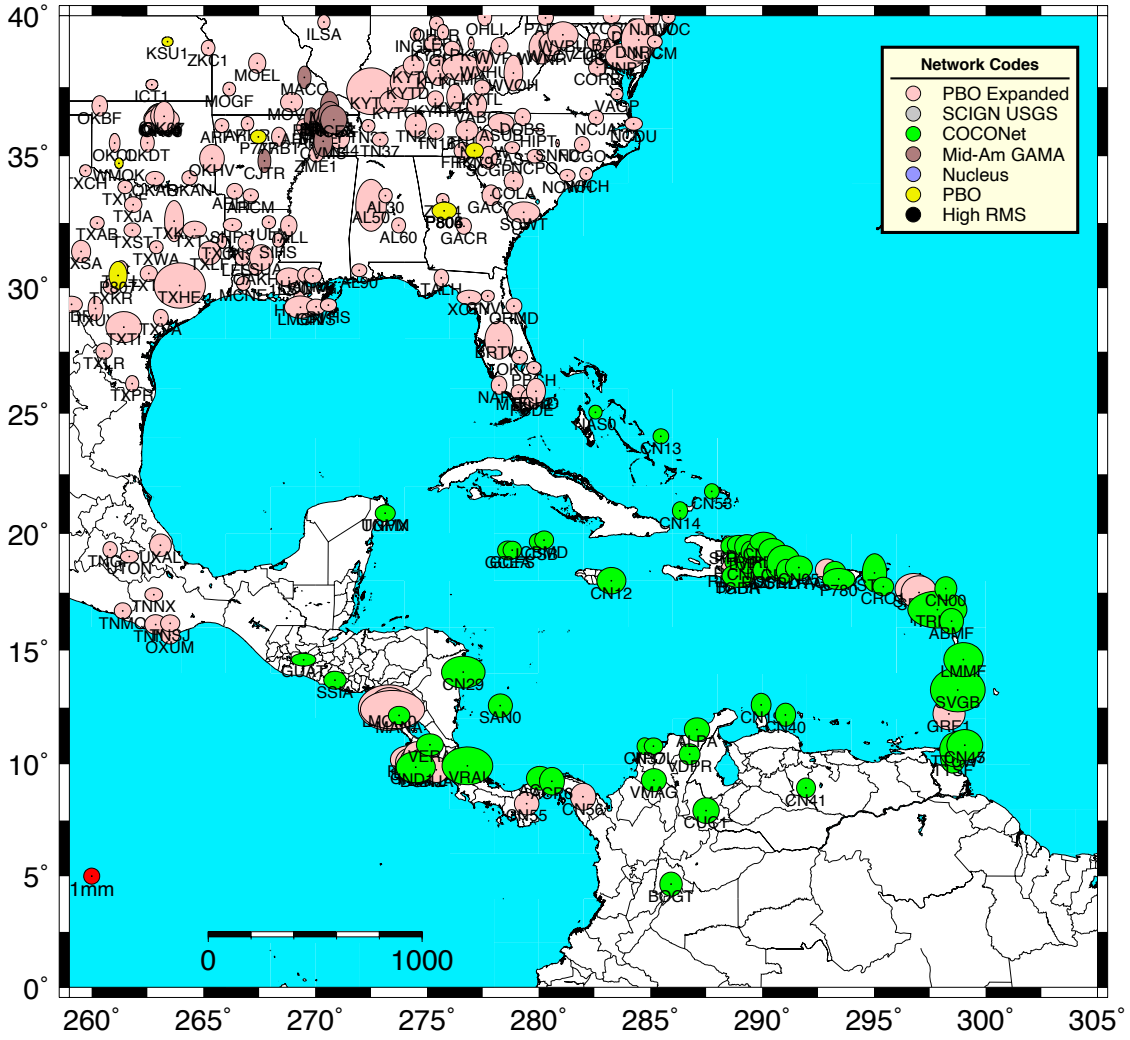

Figure 7: Same as Figure 4 except for the Caribbean region.

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 2652 stations in the CWU solution (22 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_210320.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_210320.snpvel.

Table 3: Statistics of the fits of 2652 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and March 20, 2021.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.40	1.35	6.15
70%			
CWU	1.75	1.70	7.01
95%			
CWU	3.89	3.59	11.67

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.

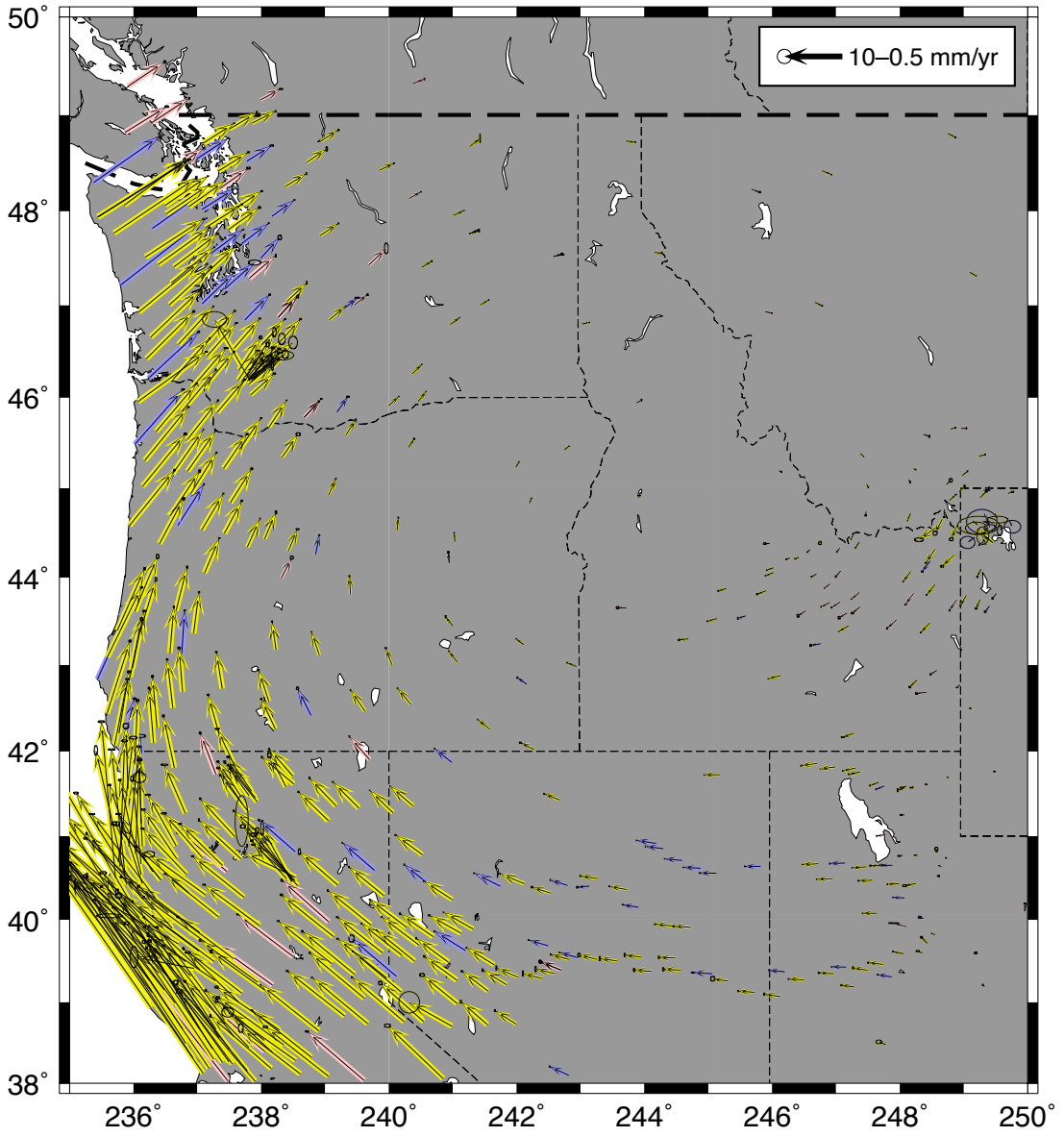

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

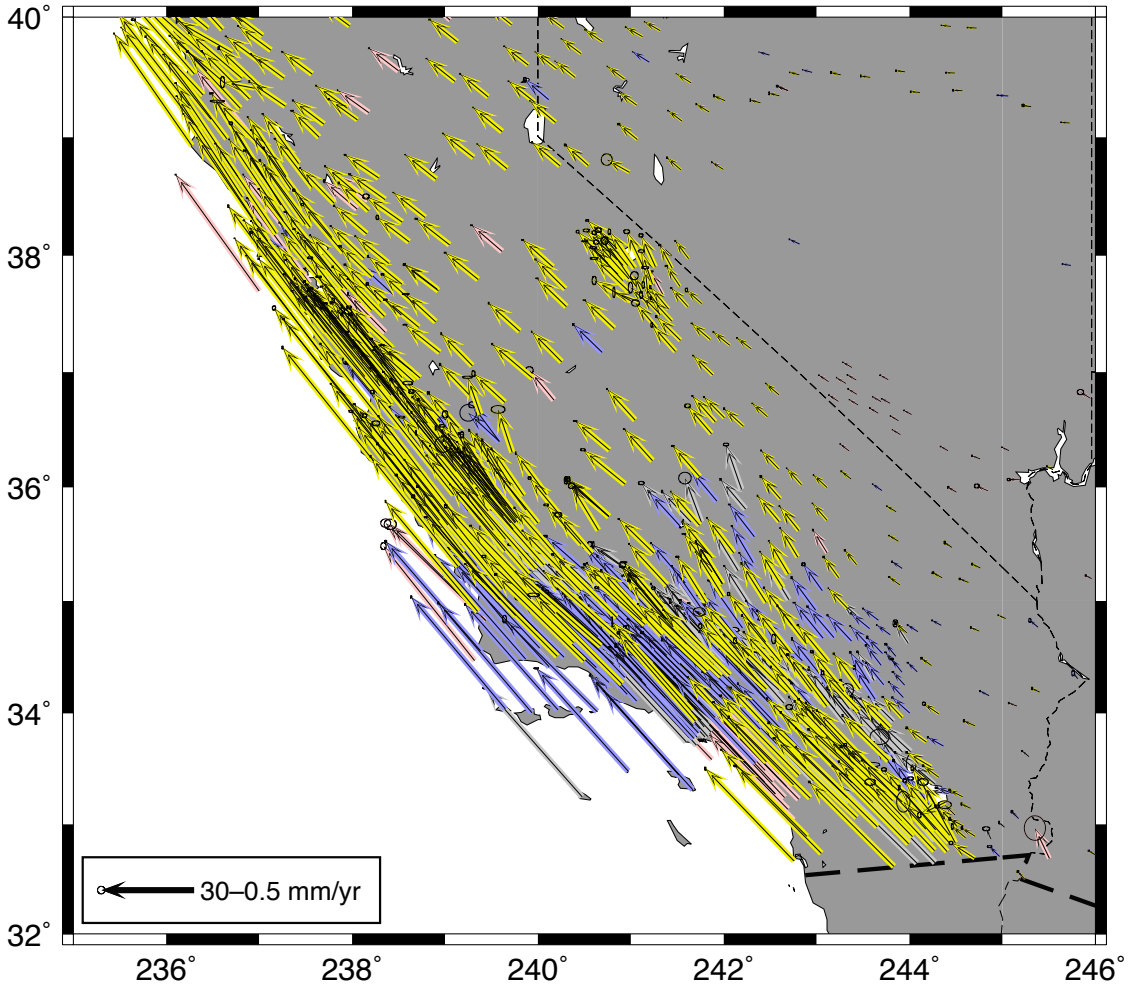

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

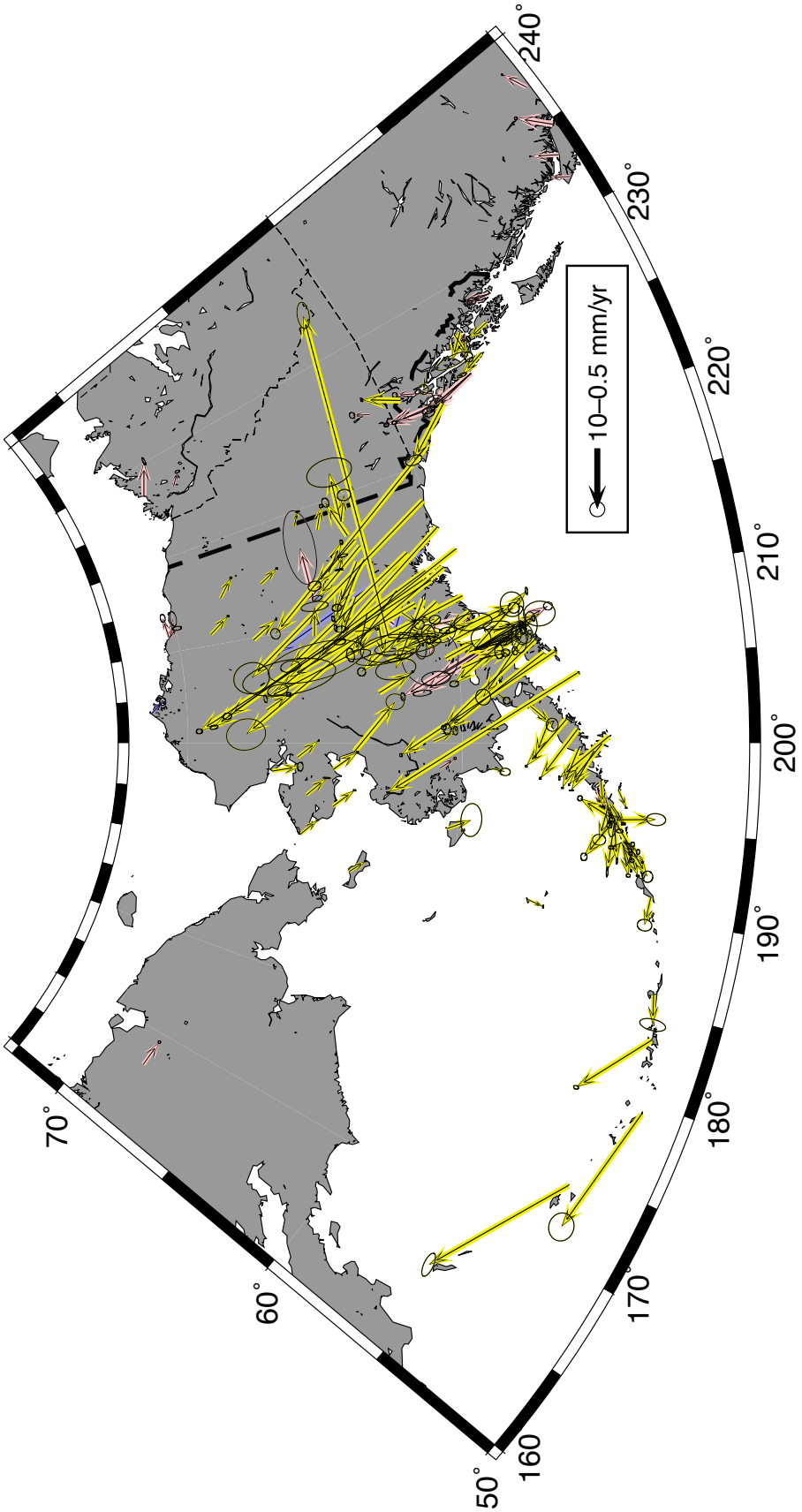

Figure 10:

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

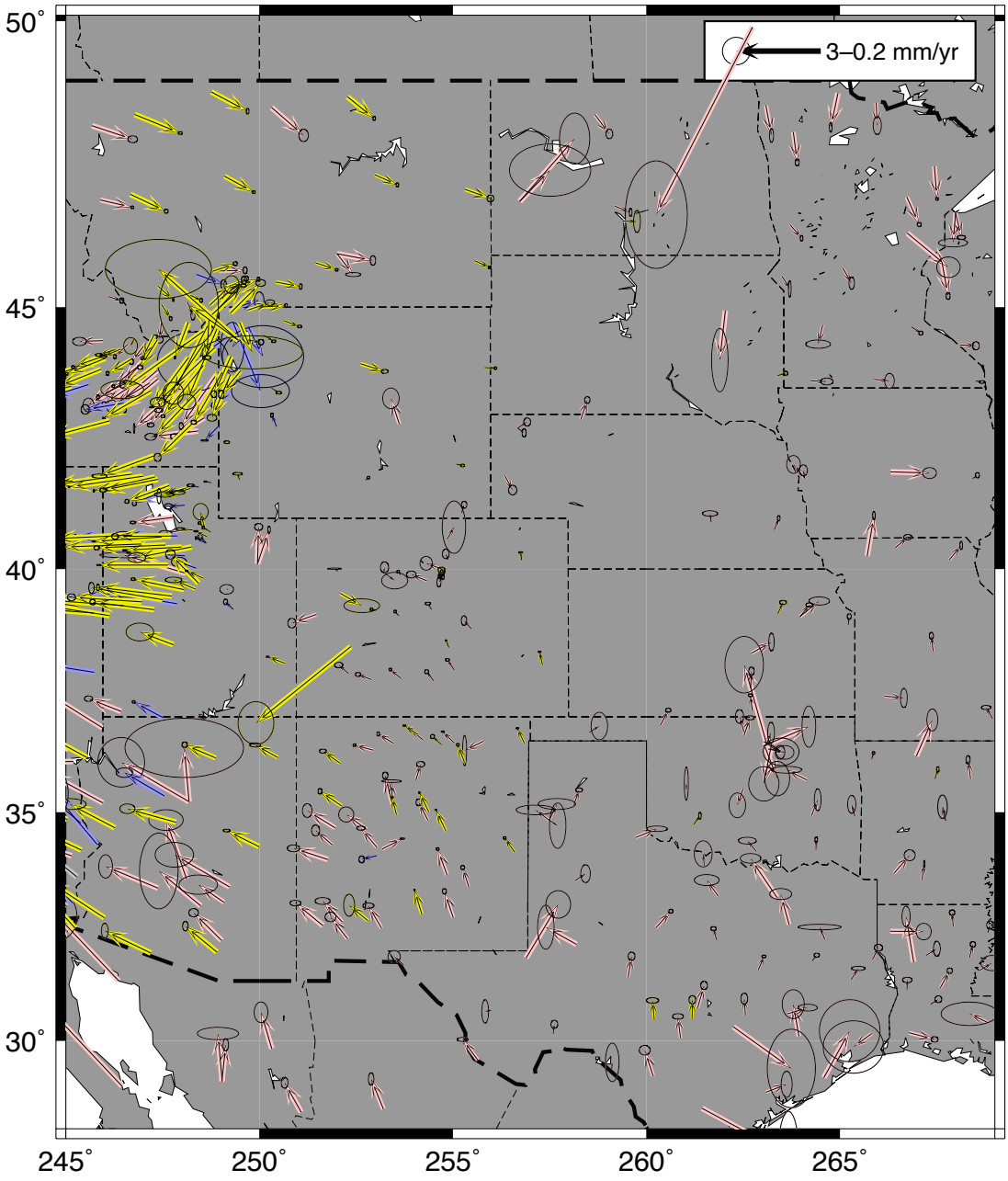

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

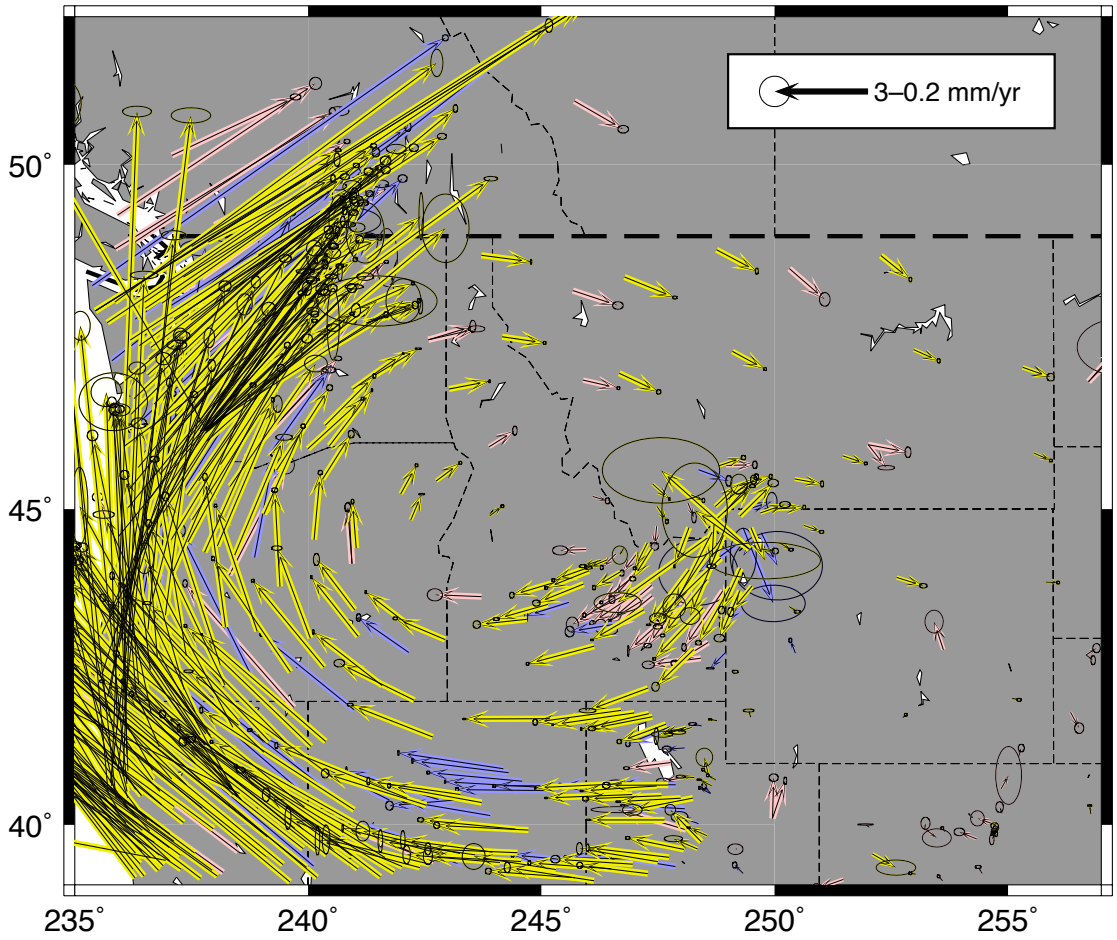

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

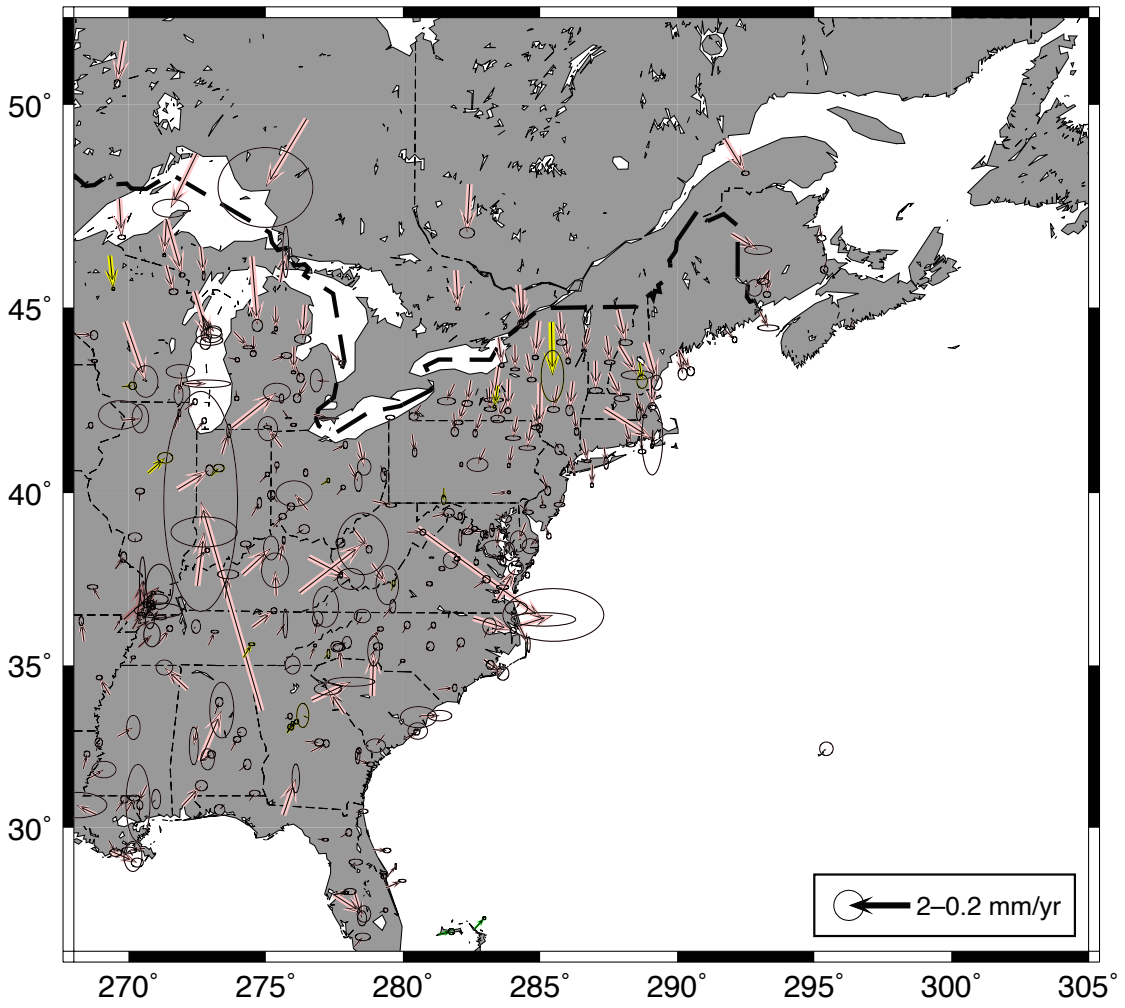

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

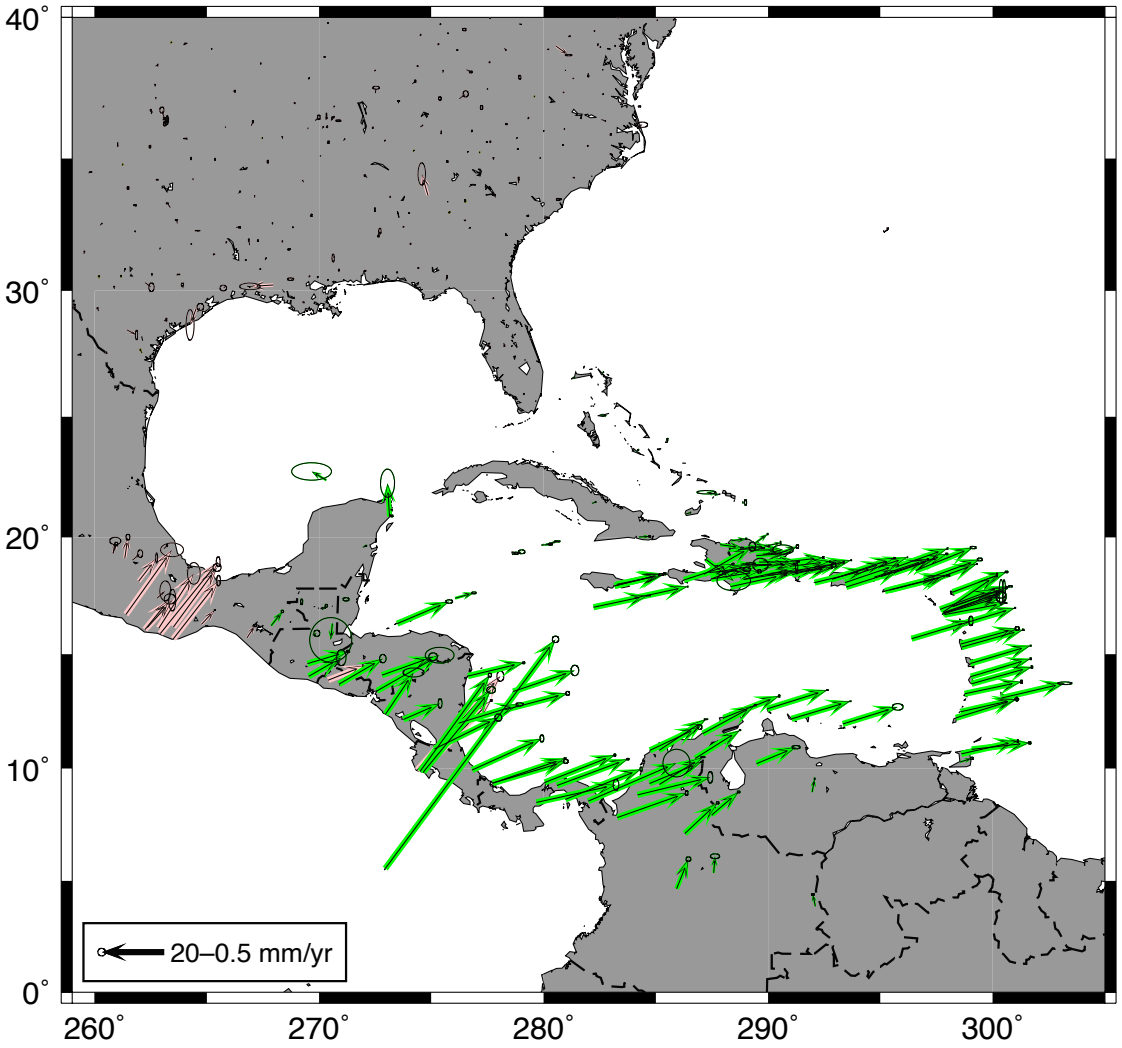

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2020/12/15-2021/03/31

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 31 earthquakes examined during this quarter none generated displacements more than 1 mm.

Antenna and other discontinuity events.

Antenna swaps at 25 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 in all three months of the quarter.

Anomalous sites

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

Site/s	Issues related to site
2021-01-16	
OHPR	Systematic position changes before antenna swap 2020-02-04. ~-6 mm offset in East on 2020-09-08 with return to nominal 2020-02-04. North is more systematic and not so clear. Height shows offset after antenna change of ~30 mm. TRM55971.00 to TRM115000.00 change.
TRDS	2019 11 12 offset of -13 mm in North for unknown reason. Smaller offset in East. Added as APS to unkn.eq. file.
P496	Systematic in east starting in 2017 that stops postseismic from 2010-04-04 GU earthquake from being estimated in latest tsfit runs.
P711	Very systematic along with P708 and P729.
P300	Very systematic for whole time series (see P302 below).
P630	Very systematic for whole time series. Long period plus saw tooth annual.
P203	Systematic in east 25 mm amplitude; similar amplitude in height and opposite sign.
P639	Systematic for whole time series 20 mm amplitude NE.
P716	Systematic for whole time series 30 mm amplitude east; 15 mm north.
P642	Systematic for whole time series 20 mm amplitude NE. Sawtooth annual.
P249	Long period systematic (>10 years)
P631	Systematic over whole period plus skewed in North (near LA).
P302	Systematic In east. On San Andreas fault. Similar pattern but smaller amplitude seen at P300. No height signal. Need detrended near-by sites plots on station home pages.
2021-01-22	
AC53	Long term systematics ±10 mm amplitude since 2007. Large offset from EQ47 (2018-11-30)
BON2	Large postseismic more EQ21 2012 09 05; 2-year saw tooth in east as well. * EQ_ID 21 ANSS(ComCat) usp000jrs EQ_DEF mww7.6 Costa Rica (35 km depth fixed)
MAR6	Jump in rapid North 2021-01-11; might be temporary. Jump 12 mm north between 2021 1 11 and 2021 1 21.
ARLN	Antenna change 2020 197; SEPCHOKE_B3E6 SPKE from LEIAT504GG LEIS. PANGA site log not updated.
2021-01-29	
AIRS	Noisy and systematic with error bars that seem small compared to scatter. Vegetation growth has been a problem in the past.
CTBR	Maybe offset 1/18/2021.
LCSO	Noisy in all components since start of 2020; maybe be offline start of 2021
P349	-8 mm offset in East; +4 mm N, 20mm U on 1/27/2021. Check if earthquake.
2021-02-05	

CLMS	Lots of missing data: Snow issues?
MINS	Large gap 2002-2010; systematic mainly In east.
MWTP	Possible 10 mm offset North 2/2/2021.
RLAP	Possible offset 2/3/2021 after few week gap in data; Antenna change.
WVBU	Annual in east develops mid-2018. Failing antenna or vegetation?
2021-02-19	
BEMT	Slope in North seems to have changed in last 6 months. 2020-04-09. No nearby earthquakes: http://geoweb.mit.edu/~tah/ACC_PBO/BEMT.CWU.jpg
MTUM	Developing annual in height (start 2015); east annual ends about that time. http://geoweb.mit.edu/~tah/ACC_PBO/MTUM.CWU.jpg
P470	Possible post-seismic from El-Major Cucapah earthquake. Little co-seismic. http://geoweb.mit.edu/~tah/ACC_PBO/P470.CWU.jpg
P594	East skewed residuals. On edge of a valley based on photos. http://geoweb.mit.edu/~tah/ACC_PBO/P594.CWU.jpg
P617	Possible post-seismic from El-Major Cucapah earthquake with little co-seismic. 1 mm N log estimate. Accumulates to 5 mm by 2021. http://geoweb.mit.edu/~tah/ACC_PBO/P617.CWU.jpg
R301	Slope change East 2017; annual in North starting 2018. http://geoweb.mit.edu/~tah/ACC_PBO/R301.CWU.jpg
TJRN	Skewed in North http://geoweb.mit.edu/~tah/ACC_PBO/TJRN.CWU.jpg
CN45	Moved > 1 meter; Now CN57. North http://geoweb.mit.edu/~tah/ACC_PBO/CN45.CWU.jpg
2021-02-26	
P801	Long term systematics and some short period (1-2 months) is 2017 and 2020 winters. Yellowstone. http://geoweb.mit.edu/~tah/ACC_PBO/P801.CWU.jpg
2021-03-06	
OBSR	Stange bi-modal distribution in East. Pronounced 2013-2018. http://geoweb.mit.edu/~tah/ACC_PBO/OBSR.CWU.jpg
OXMT	Oscillation in east and height after 2019. http://geoweb.mit.edu/~tah/ACC_PBO/OXMT.CWU.jpg
SEAS	Noisy and jump on height mid-2019. http://geoweb.mit.edu/~tah/ACC_PBO/SEAS.CWU.jpg
SCGB	Noisy after break ends mid-2020. http://geoweb.mit.edu/~tah/ACC_PBO/SVGB.CWU.jpg
2021-03-16	
RG08	Quality starts degrading on and after 3/9/2021 (-10cm height outlier on 3/9/21) http://geoweb.mit.edu/~tah/ACC_PBO/RG08.CWU.jpg
SCH2	Jump in north and east on 3/10 and 3/11/2021 (different days for different components, 10 mm amplitude). http://geoweb.mit.edu/~tah/ACC_PBO/SCH2.CWU.jpg
2021-03-19	
WYRF	40 mm jump in height, few millimeters NE 03/16/2021. http://geoweb.mit.edu/~tah/ACC_PBO/WYRF.CWU.jpg
2021-03-26	
CIT1	Maybe a failed antenna starting back in 2014.

	http://geoweb.mit.edu/~tah/ACC_PBO/CIT1.CWU.jpg
TNMT	Saw-tooth annual in North (mainly) started 2019.8 http://geoweb.mit.edu/~tah/ACC_PBO/TNMT.CWU.jpg
P688	Clear snow signal most years. Strong in 2011 and 2012. 2013 changed sign in North. http://geoweb.mit.edu/~tah/ACC_PBO/TNMT.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 55 stations in the ANET region for CWU analyzed in the final orbit analysis between December 15, 2020 and March 20, 2021.

CWU	North (mm)	East (mm)	Up (mm)
Median ANET	1.14	1.03	5.37
70% ANET	1.30	1.20	5.96
90 % ANET	2.17	3.03	8.88

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

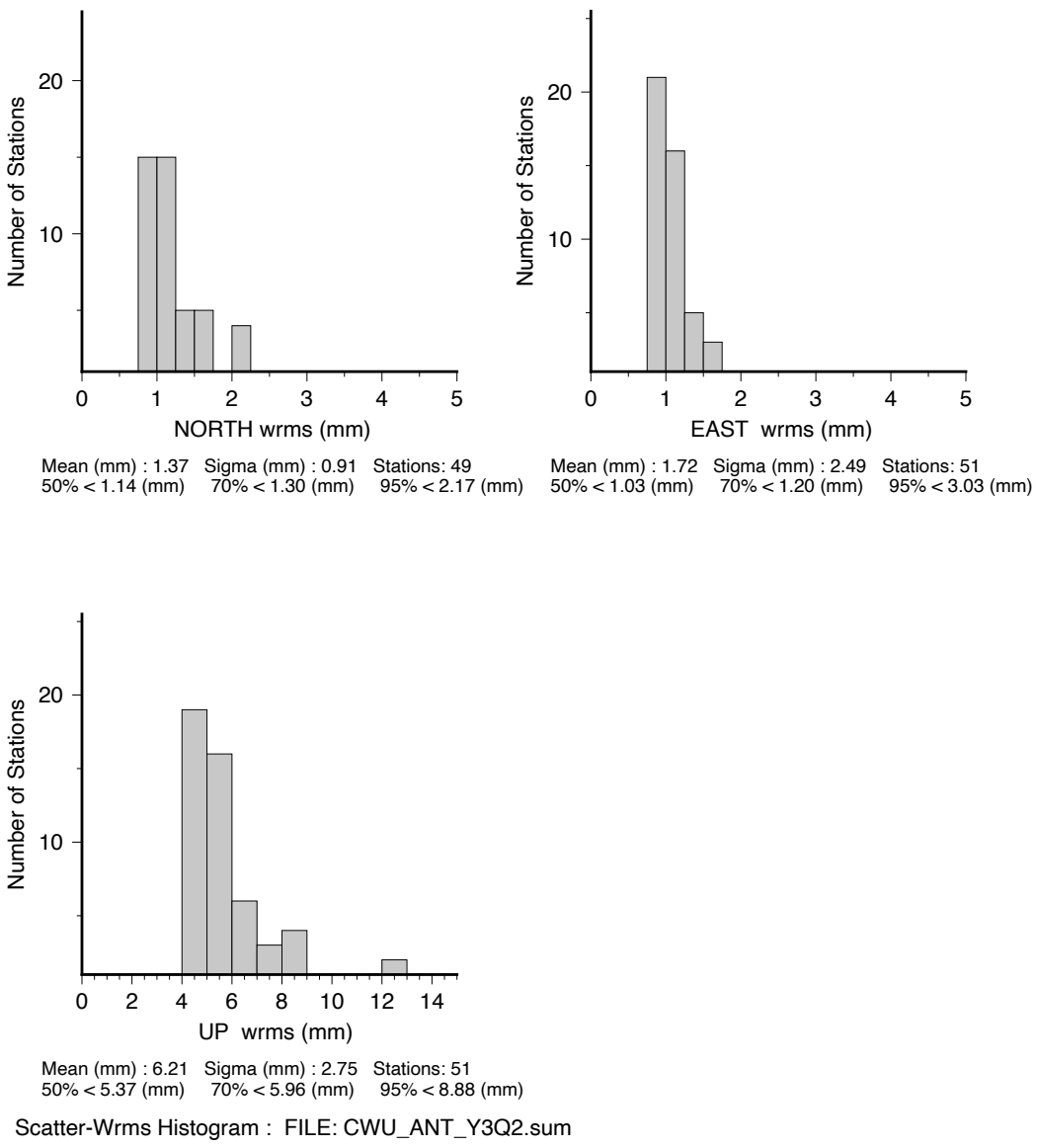

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 51 stations in Antarctica analyzed between December 15, 2020 and March 20, 2021. Linear trends and annual signals were estimated from the time series.

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