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

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Period: 2020/10/01-2020/12/31

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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 NAM08 reference frame. In this report, we show analyses of the data processing for the period 2020/09/15 to 2020/12/31, time series velocity field analyses for the GAGE reprocessing analyses (1996-2020). Several earthquakes were investigated this quarter and one generated coseismic displacements > 1mm. Event file was prepared for event 58. Estimates of the offsets are available in the Kalman filter offset files generated monthly.

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 1960 stations were processed which is 30 less than last quarter. 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 55 sites were processed in the ANET solutions, 1 more 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: September 15, 2020– January 2, 2021

For this report, we generated the statistics using the ~3 months of CWU results between September 15, 2020 and January 2, 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 September 15, 2020 and January 2, 2021. Histograms of the RMS scatters are shown in Figure 1.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	0.87	0.81	4.77
70%			
CWU	1.09	1.04	5.53
95%			
CWU	2.31	2.22	8.85

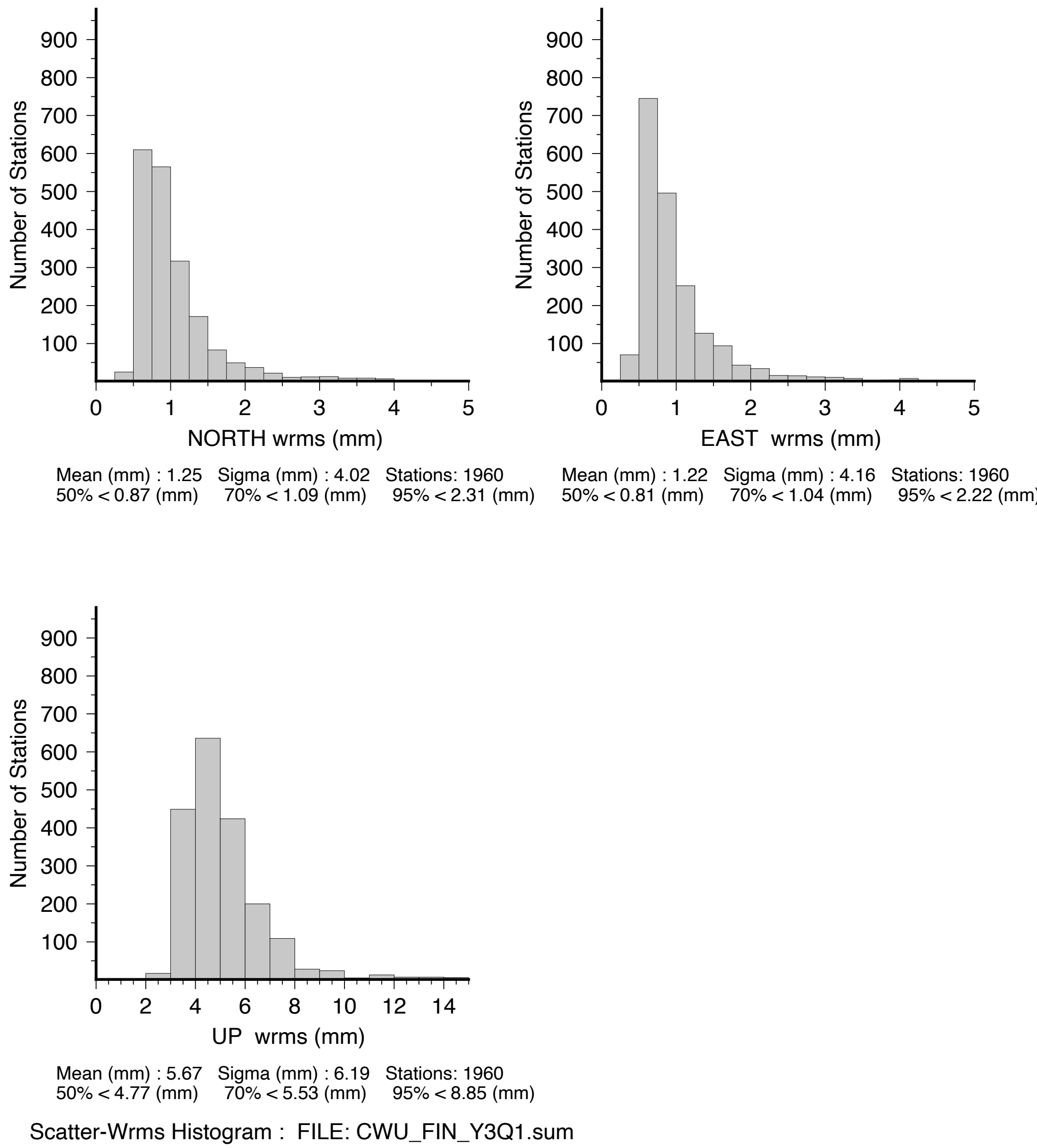

Figure 1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 1960 stations analyzed between September 15, 2020 and January 2, 2021. Linear trends and annual signals were estimated from the time series.

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_Y3Q1.tab.

There are 1960 stations in the file for sites that have at least 2 measurements during the month.

```
Tabular Position RMS scatters created from CWU_FIN_Y3Q1.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   104      1.2   0.63      1.2   0.66     6.0   0.67      17.70
 1NSU   107      0.8   0.47      0.9   0.61     5.0   0.71      16.95
 1ULM   107      0.8   0.48      1.0   0.65     4.6   0.65      17.56
 7ODM   107      0.8   0.47      0.6   0.44     3.9   0.54      19.70
…
 ZDV1   103      1.2   0.58      1.2   0.71     5.8   0.71      17.59
 ZKC1   103      1.0   0.48      0.7   0.44     4.8   0.59      17.59
 ZLA1   103      2.1   1.09      1.2   0.72     6.3   0.77      17.59
 ZLC1   104      1.0   0.46      0.8   0.51     5.7   0.71      17.81
 ZME1   103      1.1   0.57      0.9   0.53     5.6   0.71      17.81
 ZMP1   104      1.0   0.45      0.8   0.53     5.5   0.69      18.06
 ZNY1   103      1.1   0.55      1.2   0.72     6.5   0.80      17.97
 ZOA1    93      1.0   0.50      0.8   0.48     5.7   0.71      18.46
 ZSE1   103      1.3   0.55      1.3   0.80     6.3   0.80      17.97
 ZTL4   103      0.9   0.50      0.9   0.53     6.8   0.84      18.16
```

Table 2: RMS scatter of the position residuals for the CWU solution between September 15, 2020 and January 2, 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	0.78	0.74	4.42	834
NUCLEUS	0.74	0.67	4.17	200
GAMA	0.86	0.73	5.06	13
COCONet	1.41	1.52	6.51	69
USGS_SCIGN	0.76	0.67	3.98	110
Expanded	1.02	0.92	5.38	734
70%				
PBO	0.97	0.93	5.03	
NUCLEUS	0.89	0.85	4.70	
GAMA	0.97	0.80	5.44	
COCONet	1.57	1.69	7.11	
USGS_SCIGN	0.87	0.79	4.24	
Expanded	1.23	1.13	5.99	
95%				

PBO	2.11	1.91	7.54
NUCLEUS	1.80	1.42	7.70
GAMA	1.11	0.90	6.23
COCONet	3.29	4.15	13.55
USGS_SCIGN	1.62	1.49	7.46
Expanded	2.86	2.81	11.29

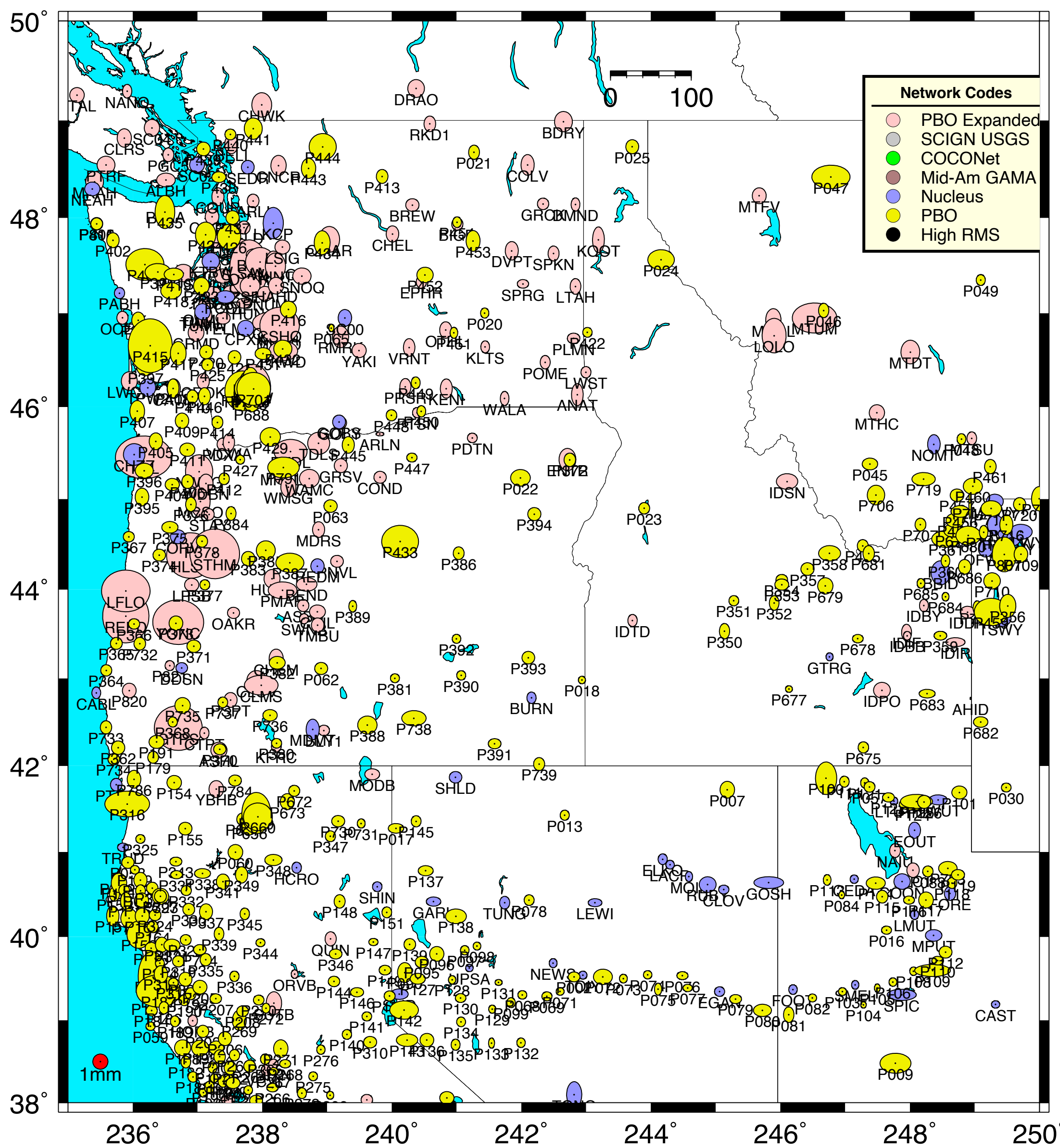

Figure 2: Distribution of the RMS scatters of horizontal position estimates from the CWU analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1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

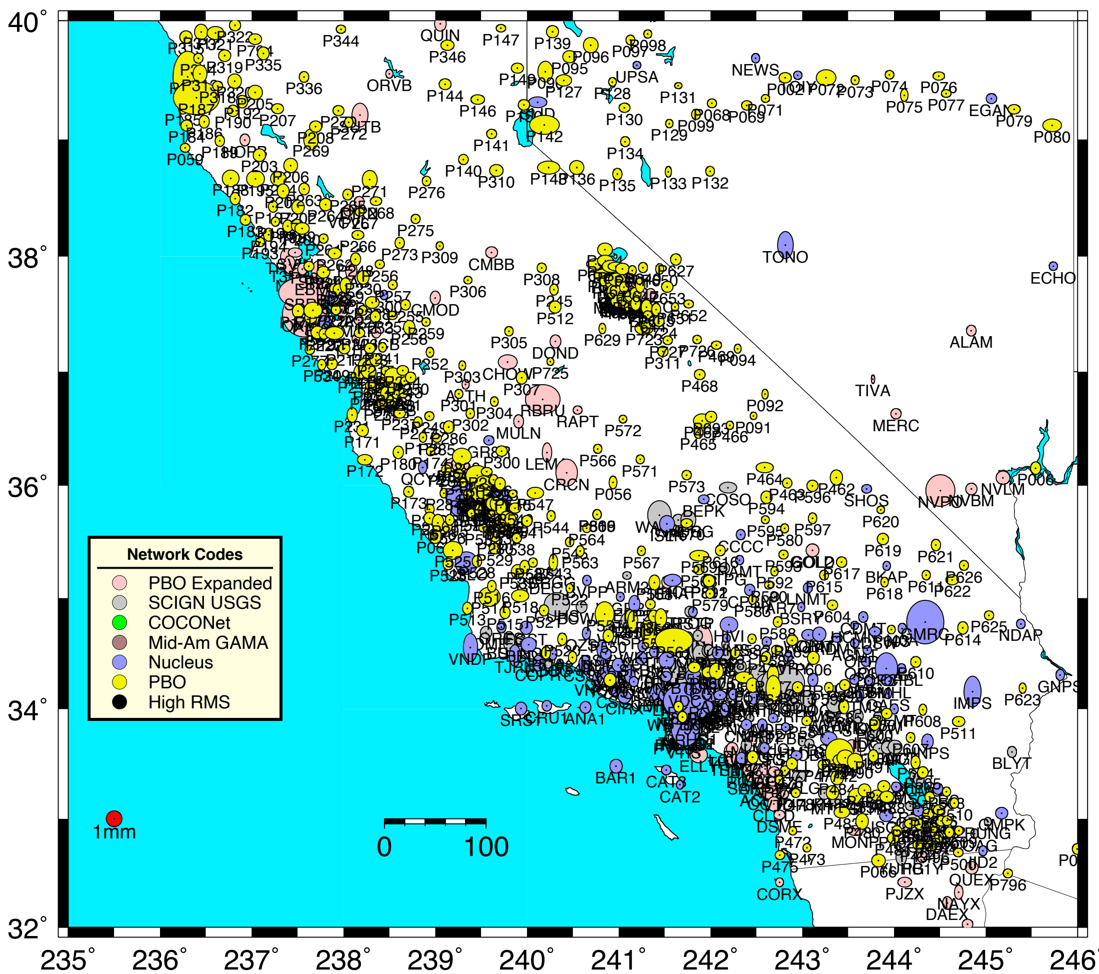

Figure 3: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

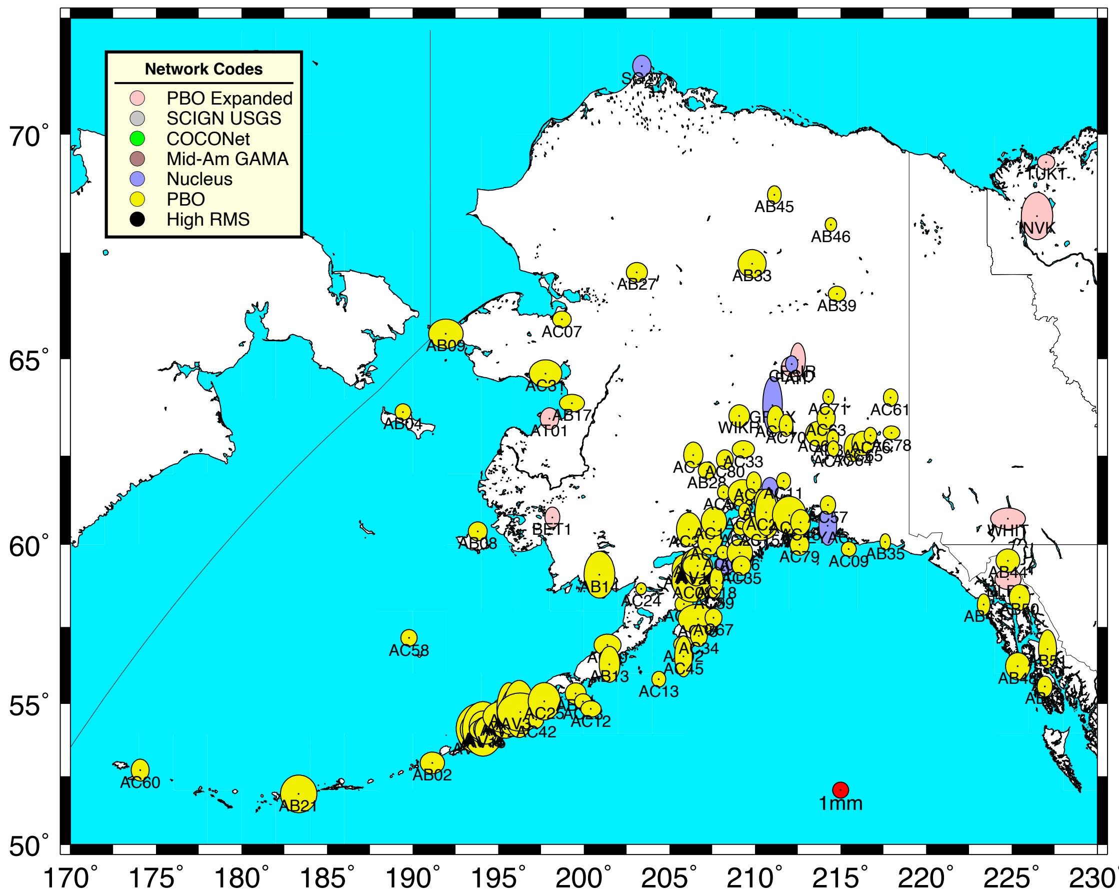

Figure 4: Same as Figure 4 except for the Alaskan region.

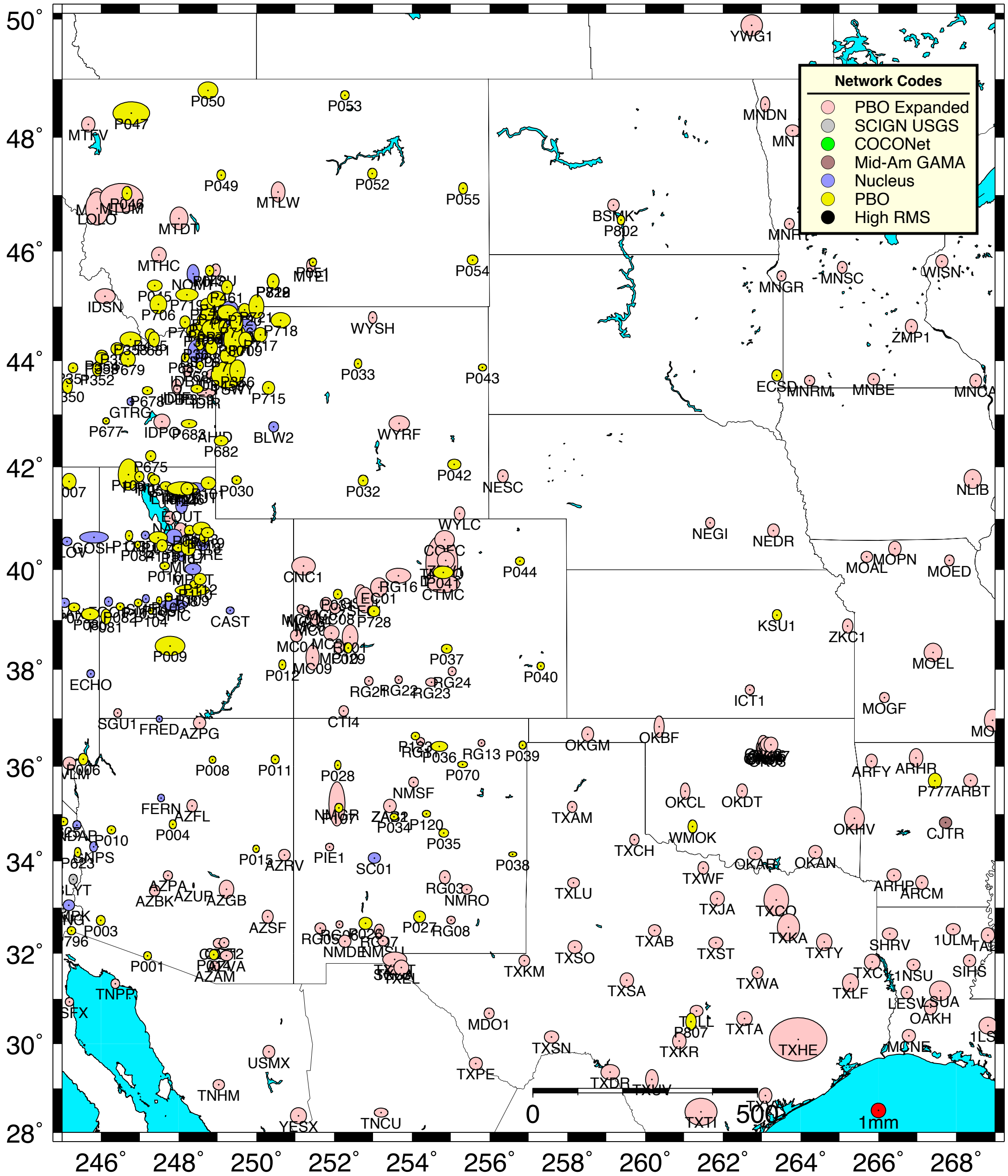

Figure 5: Same as Figure 4 except for the Central United States

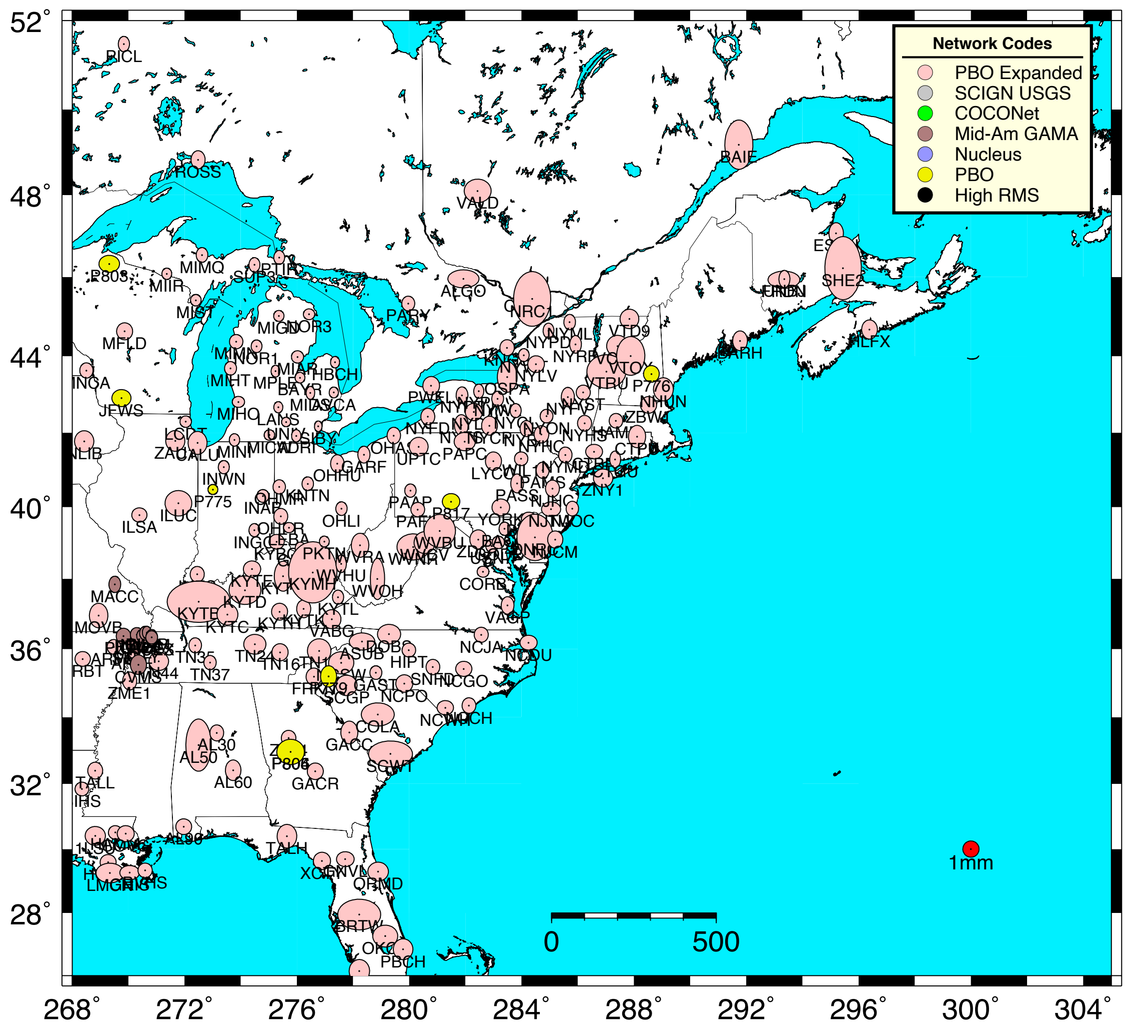

Figure 6: Same as Figure 4 except for the Eastern United States

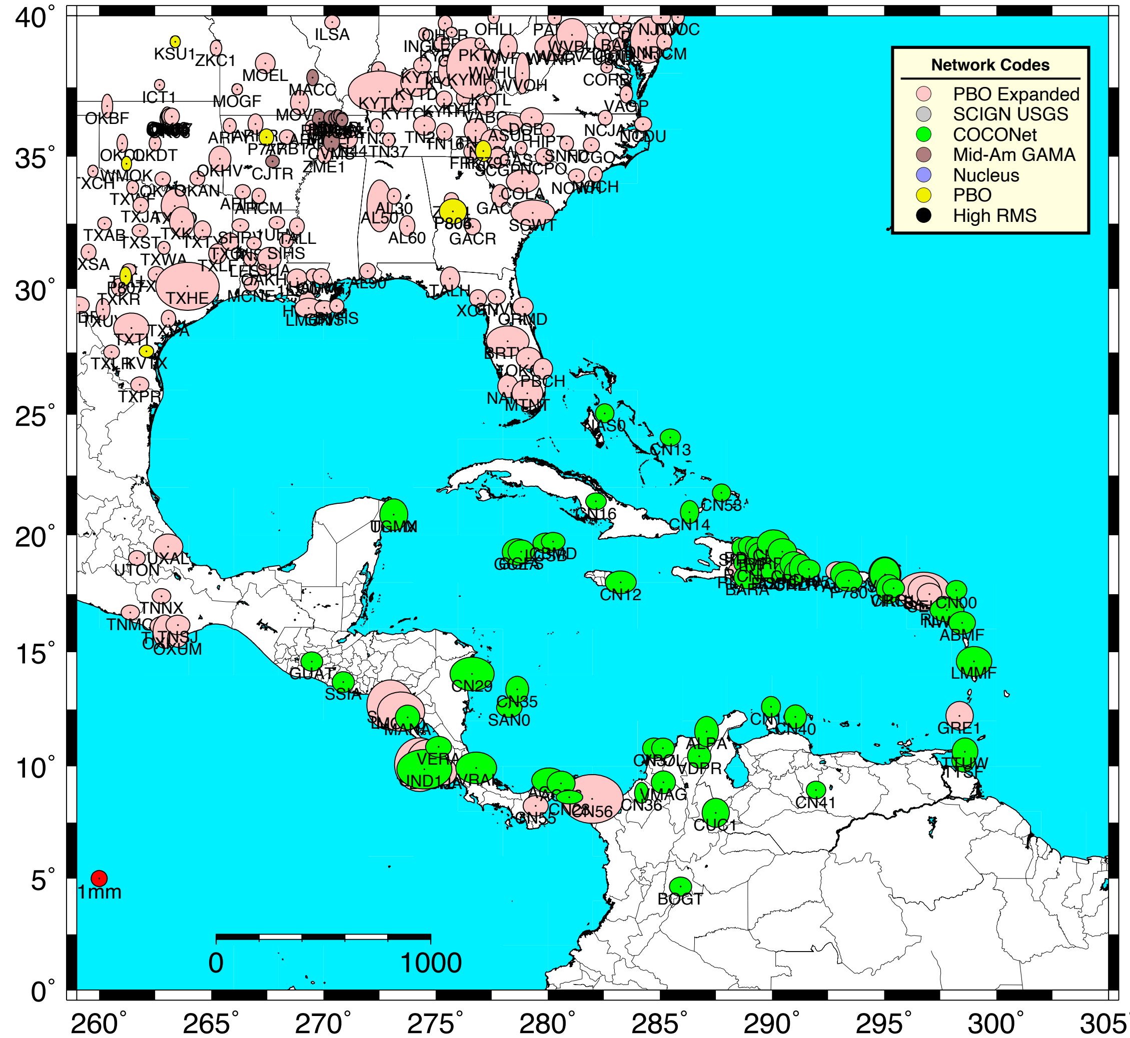

Figure 7: Same as Figure 4 except for the Caribbean region.

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.e]q [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 2630 stations in the CWU solution (same as last 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_210102.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_210102.snpvel.

Table 3: Statistics of the fits of 2630 stations analyzed CWU in the reprocessed analysis for data collected between Jan 1, 1996 and January 2, 2021.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
CWU	1.40	1.35	6.15
70%			
CWU	1.76	1.70	7.00
95%			
CWU	3.83	3.57	11.50

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.

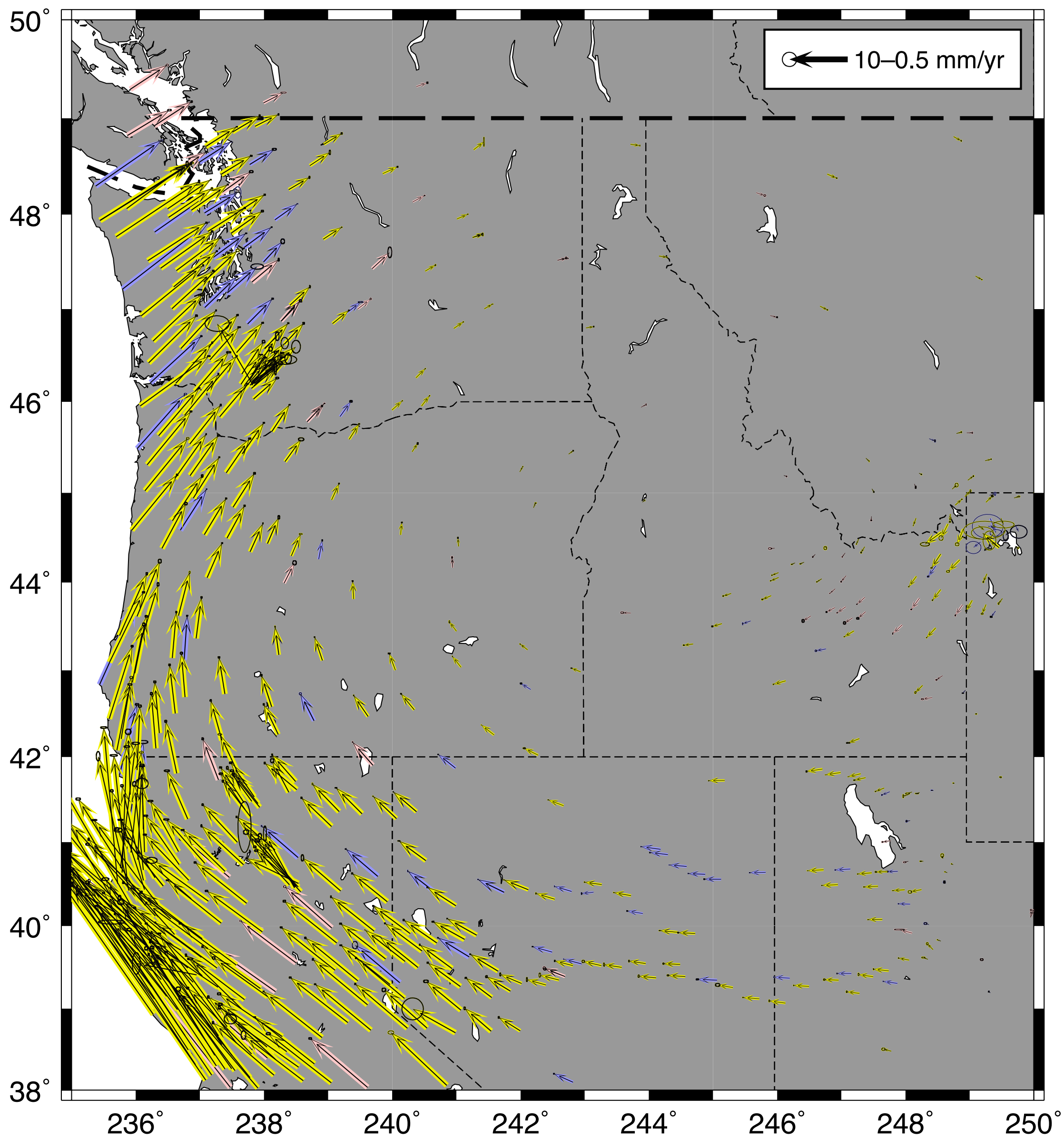

Figure 8: Velocity field estimates for the Pacific north-west from the CWU solution generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal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

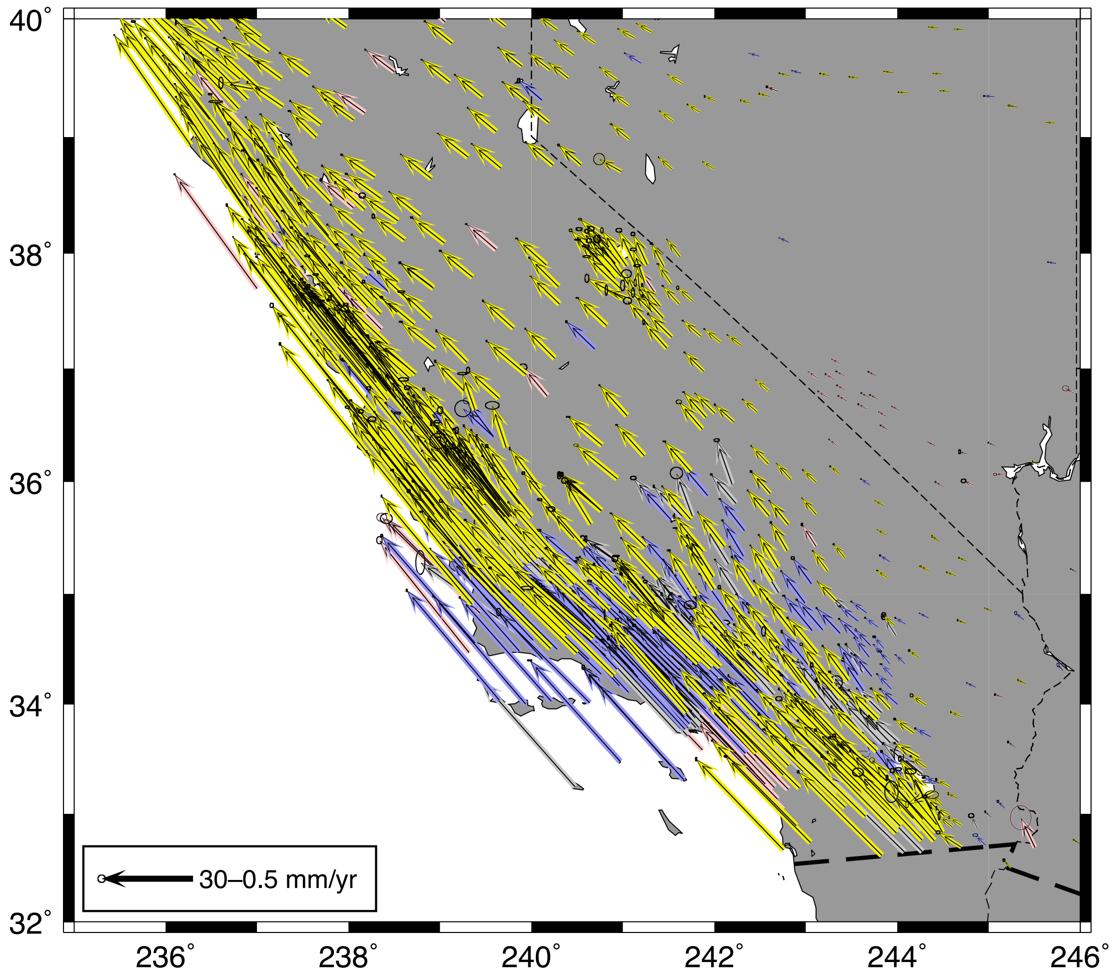

Figure 9: Same as Figure 8 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

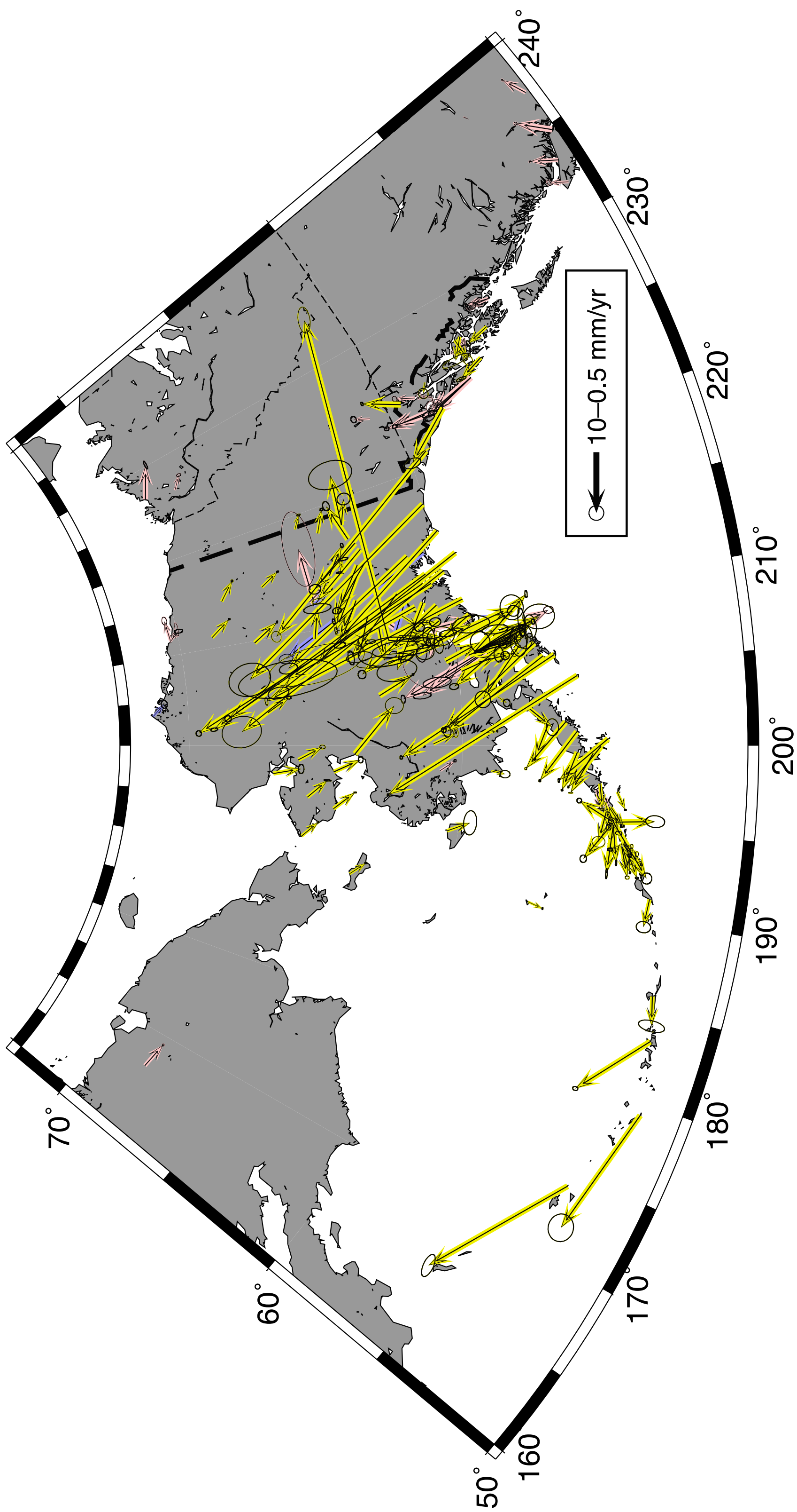

Figure 10: Same as Figure 8 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

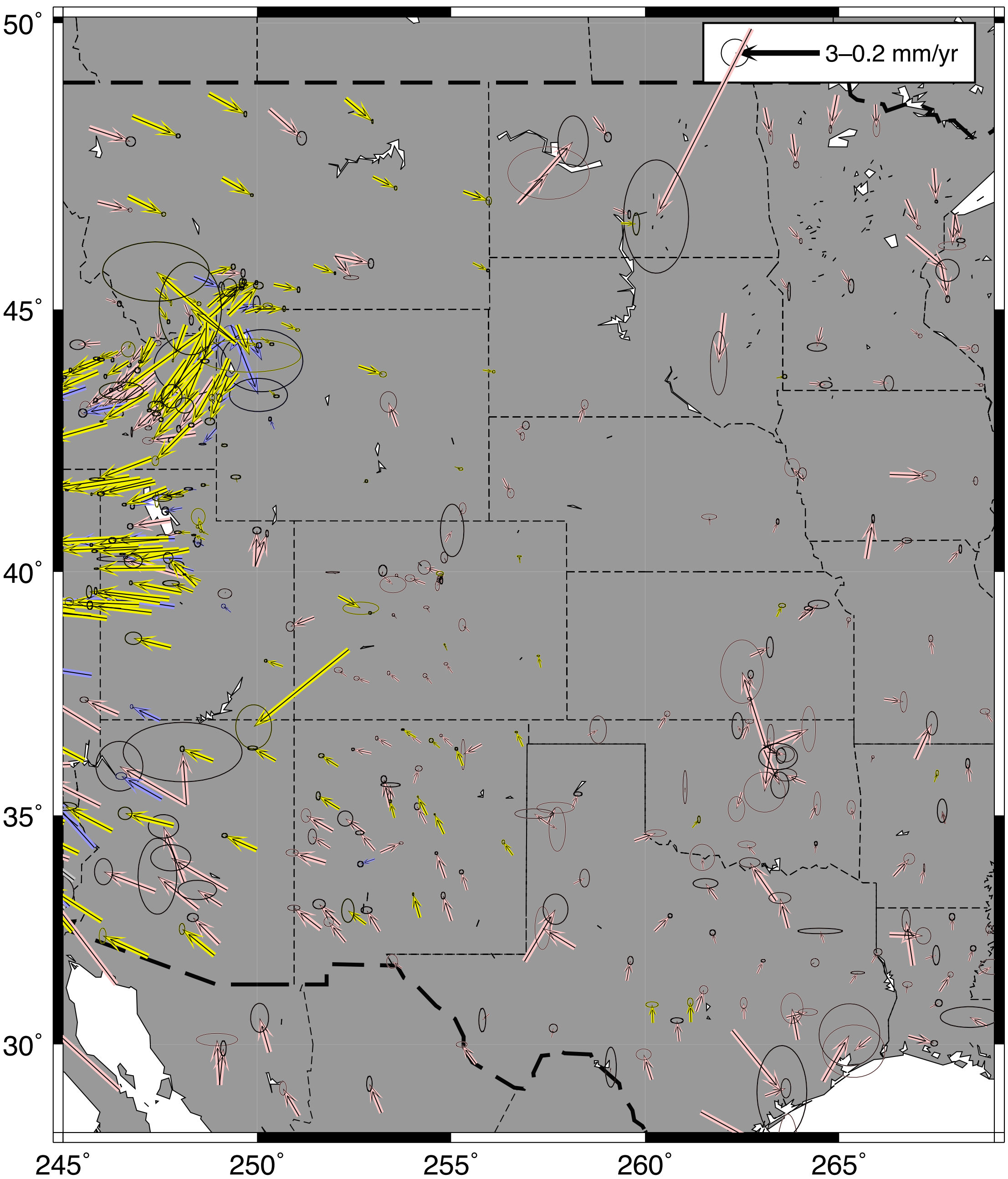

Figure 11: Same as Figure 8 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

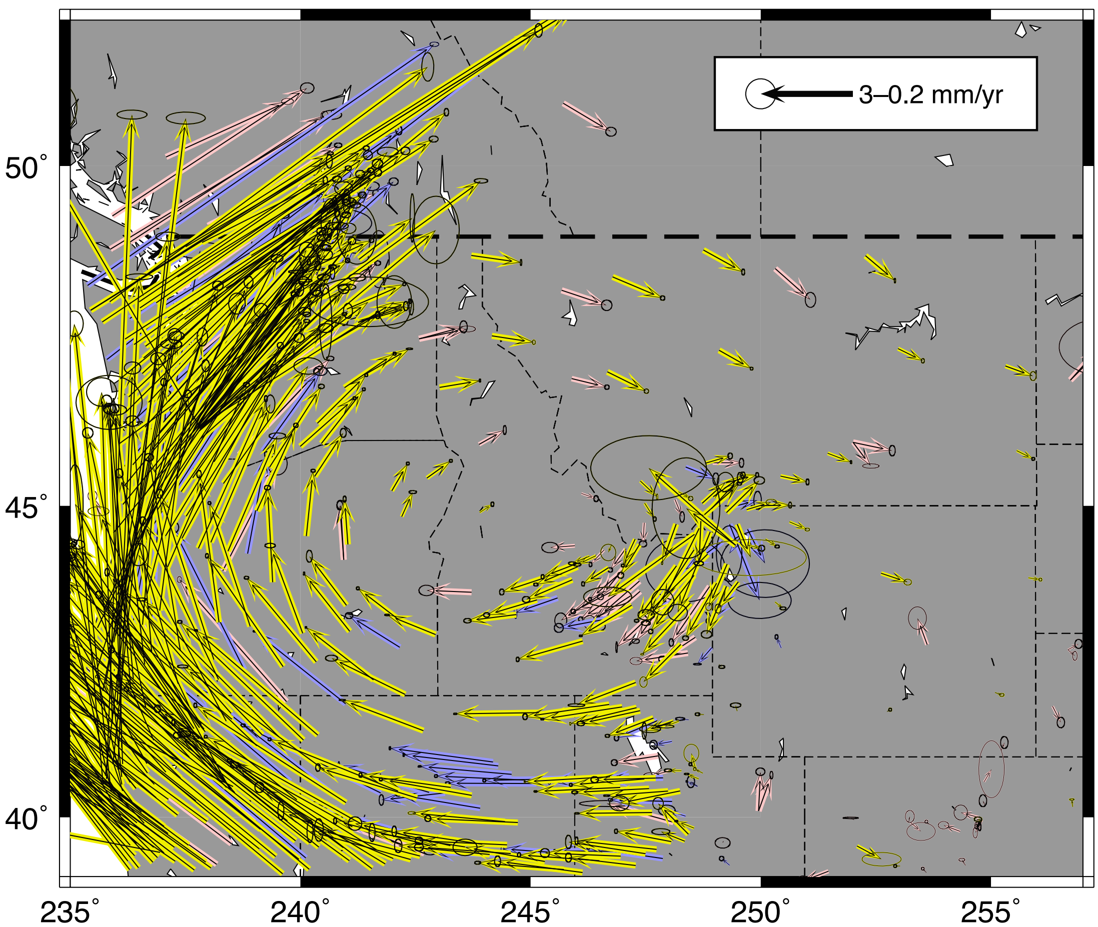

Figure 12: Same as Figure 8 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

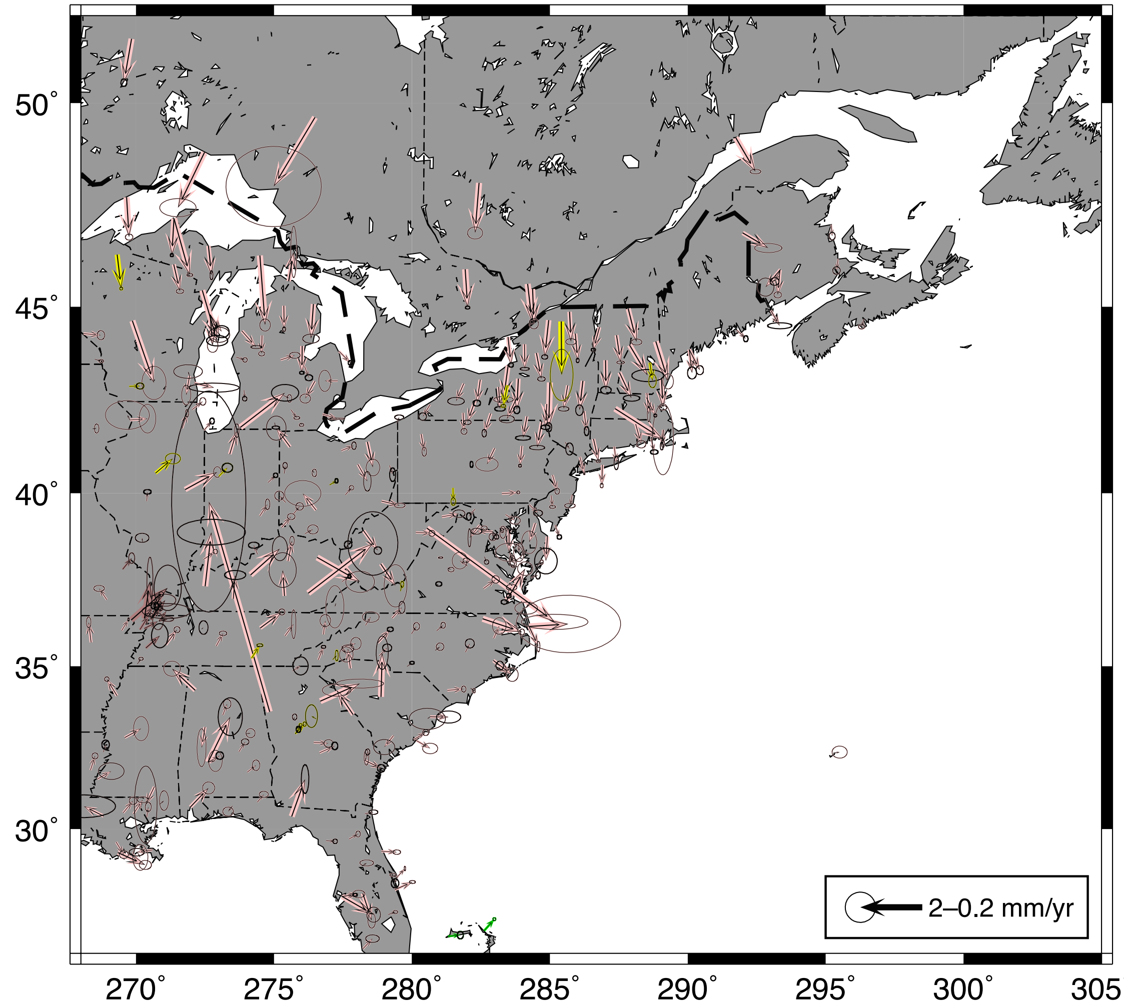

Figure 13: Same as Figure 8 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities.

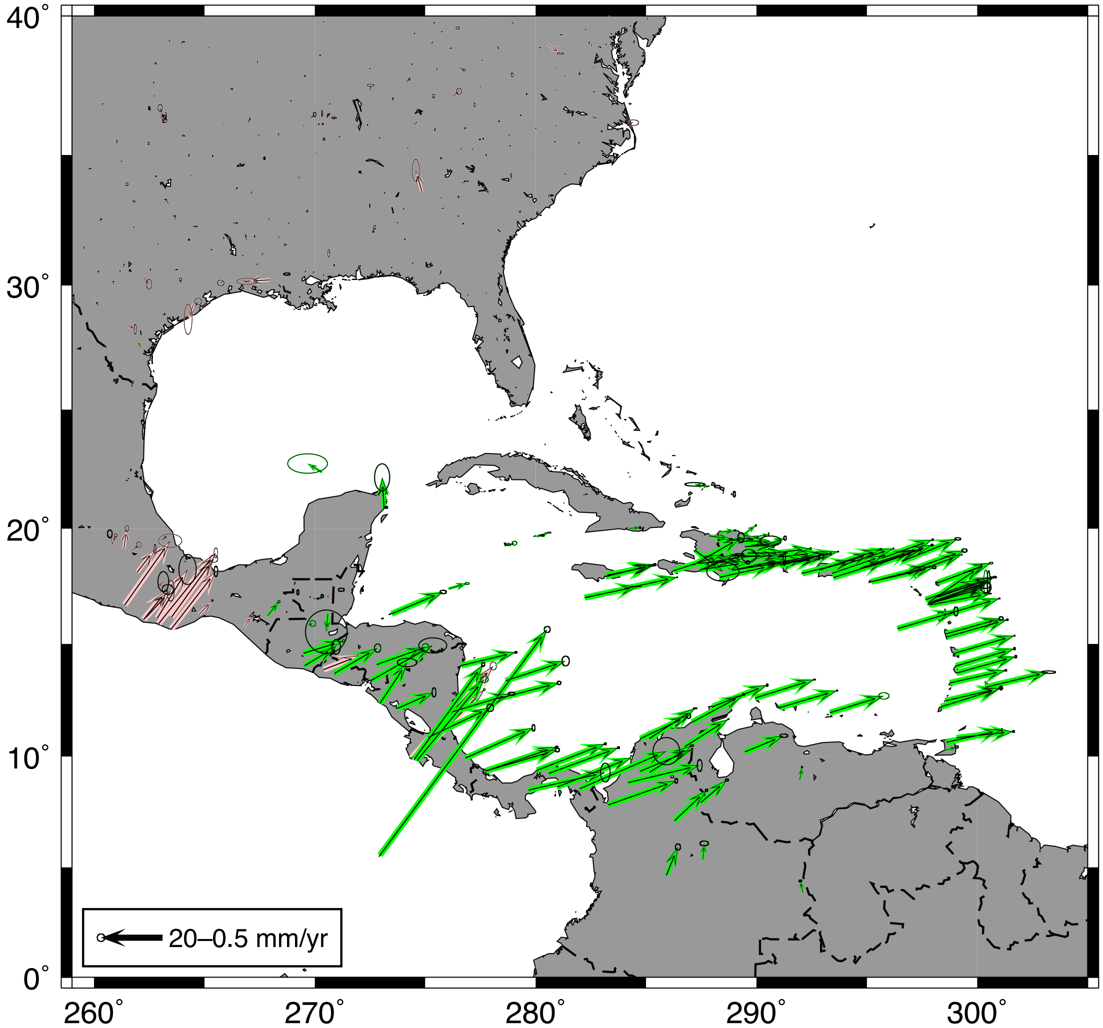

Figure 14: Same as Figure 8 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2020/09/15-2020/12/31

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 38 earthquakes examined during this quarter, only one earthquake generated displacements more than 1 mm. This event has been designated as 58. The coseismic offsets from this event is shown in Figures 15.

The event co-seismic offsets are shown in Figures 15.

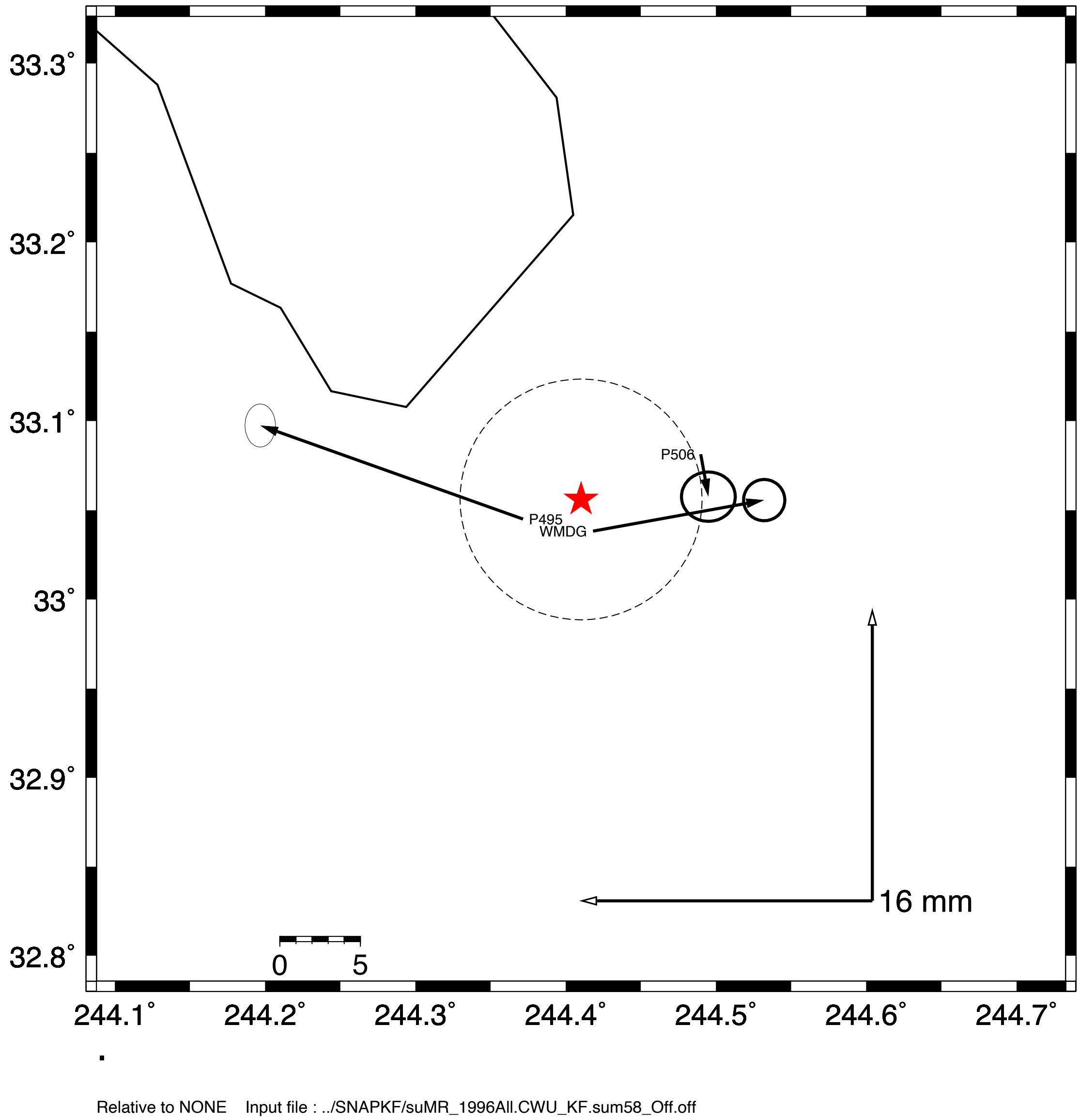

Figure 15: Coseismic offsets from the GAGE event 58: ANSS(ComCat) ci39641528 mw4.9 4km NE of Westmorland (11.54 km depth) ϕ 33.0560 λ -115. 5898 date 2020 10 time 01 00:32 UTC. A rapid event file prepared and sent.

Antenna and other discontinuity events.

Antenna swaps at 35 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.

Analysis of July 6, 2019 Ridgecrest earthquake lead to an increase of its radius of influence from 250 to 330 km.

Anomalous sites

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

Site/s	Issues related to site
2020-09-14	
BIJA LEFA	Added log for EQ42 mww6.5 18km W of Parrita (19.36 km depth) us2000bmhe 9.5264 -84.5054 2017 11 13 02 29 based on BIJA, LEFA but may be part of SSE in region. LEFA has similar look in North 1-yr after
LEPA	Costa Rica earthquakes but LEPA spectrum has 0.8 mm North 176.132 day period term with smaller harmonics as well. Other sites like PUMO, LEFA (less obvious because of large 730 day term) have similar draconic signal
ZLC1	Break during gap 2017 09 25
2010-10-13	
KYHM	Probable failed antenna starting 2016.
P170	Growing tree? Starting 2018.
TDRS	Jump late 2019, mostly north
2020-11-16	
AZSF	Antenna change 2019 262 (data on 19/10/96; day 279) but meta data not updated until 2020 103 (20/04/12).
2020-11-27	
P067	2019 07 04 Effect from Ridgecrest. Rate change -1.72 mm/yr.
P295	Maybe related to Ridgecrest. Also Parkfield (2004/09/28) looks like rapid postseismic and then curved for next decade (north and east). More distinct in North.
P415	Showed strong ETS signal in east but has degraded since July 2020. Failed antenna?
P528	Related to Ridgecrest again in east? Maybe increase in annual as well (in east). Maybe offset on ~2020/06/25. No antenna change.
TGMX	Change in North rate at start of 2020. Maybe offset in North at ~2020/11/01.
2020-12-04	
HRST	Degraded, bad antenna? Since 2014.
LNGB	Un-logged antenna change 2017 12 16. Last PANGA log entry 2007 309. Maybe another change 2020 8 30 when data start up again.
PRDY	Gap and un-logged new antenna staring 2020 11 30. Last PANGA log entry 2007.
2020-12-11	
AV07	Maybe failing more scattered in recent weeks
AV08	Maybe similar to a AV07
CRST	Height has been bad since mid 2017. Residuals of several 100 millimeters.
KIOS	Possible discontinuity near the end of 2020. No log change in the UNAVCO database.
TDLS	Large gap since mid 2019. 200 millimeter height offset when data restarted. Presumably an antenna change during the gap. No update to PANGA logs.

THUN	Height of discontinuity of 10 centimeters on 2017 12 28 presumably due to an antenna change . No update to the PANGA log.
2020-12-18	
GMRC	Lots of outliers starting 11/2020 seems to be small data sets. Postseismic from EQGU in North (offset -2.9 mm, log -1.1 mm) and EQ49 (7/6/2019 Ridgecrest) in East (Offset 2.8 mm, Log 0.68 mm).
GRIS	Offset in East at about 20/07/16 of about 4 mm; maybe change in north velocity at start of 2020.
SAMM	May go bad 20/12/16. Data gap then outlier and large error bar in rapid. Check later to see if problems persist.
MASW	East Ridgecrest -2.13 mm Log -0.81 mm. Vertical decade signal is interesting (all earthquake from San Simeon very clear).

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 September 15, 2020 and January 2, 2021.

CWU	North (mm)	East (mm)	Up (mm)
Median ANET	1.21	1.08	5.72
70% ANET	1.37	1.16	6.00
90 % ANET	1.87	1.81	8.30

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

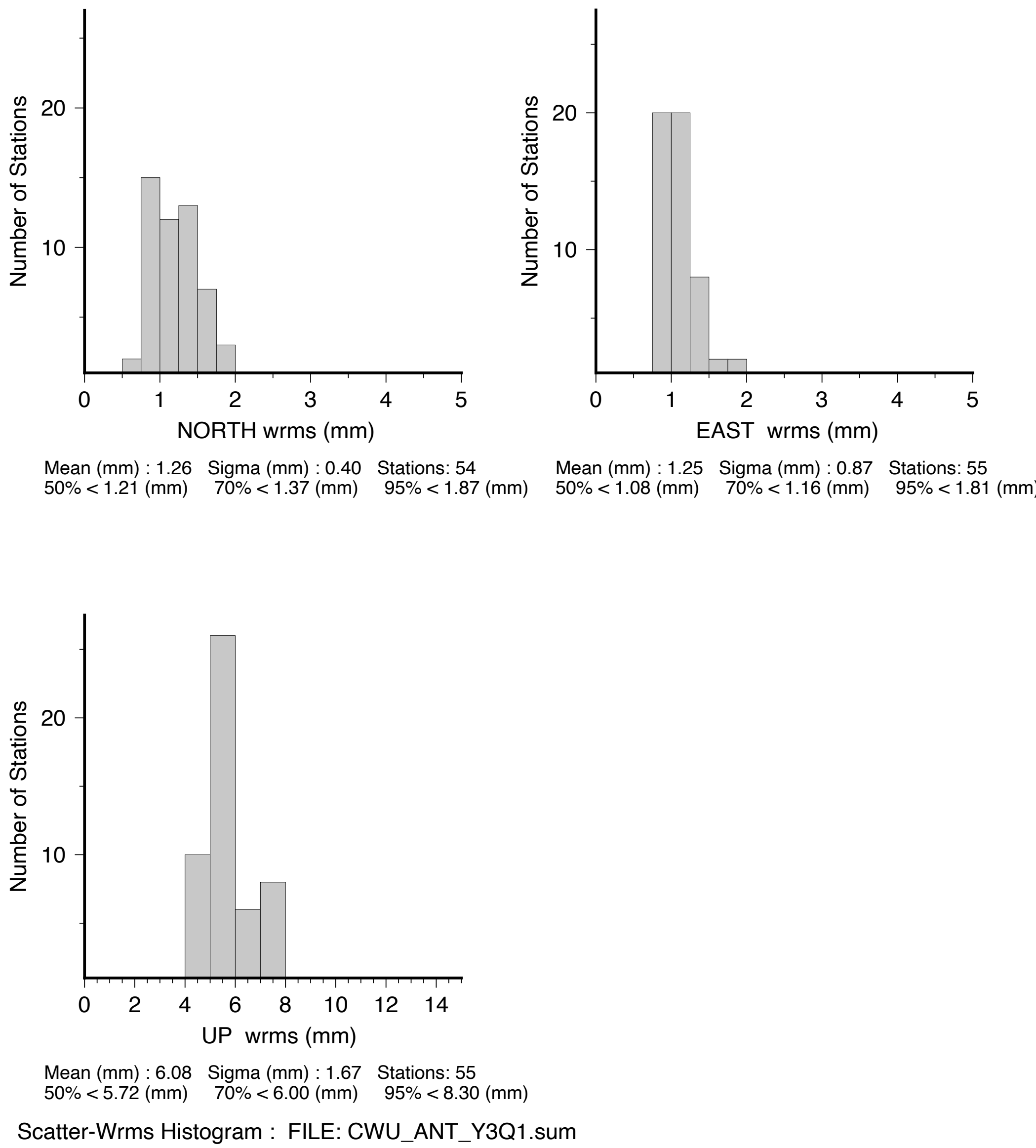

Figure A.1: CWU solution histograms of the North, East and Up RMS scatters of the position residuals for 60 stations in Antarctica analyzed between September 15, 2020 and January 2, 2021. Linear trends and annual signals were estimated from the time series.

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