# Quarterly Report
# Massachusetts Institute of Technology
# GAGE Facility GPS Data Analysis Center Coordinator
# And
# GAGE Facility GAMIT/GLOBK Community Support

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**Period: 2018/04/01-2018/06/30**

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## Summary

Under the GAGE Facility Data Analysis subaward, MIT has been combining results from the New Mexico Tech (NMT) and Central Washington University (CWU). In this report, we show analyses of the data processing for the period 2018/03/10 to 2018/06/16, time series velocity field analyses for the GAGE reprocessing analyses (1996-2018). Several earthquakes were investigated this quarter but only one generated coseismic displacements > 1mm. The one significant earthquake was a Mw 6.9, 19km SSW of Leilani Estates (2.06 km depth) in Hawaii. It occurred at 22:33 UTC, 2018/05/04. The event is us1000dyad in ANSS catalog (ComCat). This earthquake is denoted as event 46 in the GAGE event earthquake files.

For this quarter, the last finals results were for June 16, 2018. Associated with the report are the ASCII text files that are sent with this document.

Our monthly reports now contain the estimates of the offsets in the time series due to equipment changes and earthquakes and we generate events files for coseismic offsets and postseismic log terms (when needed) using a Kalman filter time series analysis.

Under the GAGE Facility GAMIT/GLOBK Community Support we report on activities during this quarter.

## GPS Analysis of Level 2a and 2b products

*ITRF2014 transition*

The GAGE analyses are in a transition between the ITRF2008 and ITRF2014 systems. JPL has now generated ITRF2014 orbit and clock files back to 2002 and these are being used by CWU for reprocessing. NMT is using the IGS repro-2 orbits that are available at CDDIS. All operational products in the GAGE analyses are now using ITRF2014 with the transition occurring on 2018 June 10, GPS week 2005 day 0. An advisory has been posted so that users are aware of possible discontinuities in the finals products that could occur associated with this transition. A copy of the notice to users in given in this report as Appendix A.

*Level 2a products: Rapid products*

Final and rapid level 2a products have been in general generated routinely during this quarter. 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 IGS and JPL (CWU) orbits. Until June 10, 2018 , the IGS08 ANTEX phase center model is used by both ACs. After this date the IGS14 ANTEX file is used for finals as well as rapids. The description of these products, the delivery schedule and the delivery list remain unchanged from the previous quarter and will not be reported here. Data volumes being transferred remains about the same. In this quarter 1859 stations were processed which is 4 less than last quarter. The CWU finals and other products are generated with IGb08 consistent orbits and clocks generated by JPL for nearly all of the quarter. NMT results are generated using the IGS14 orbits but still retaining the IGb08 antenna model file to be consistent with the CWU analyses for most of the 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 the ACs. The delivery schedule for these products is also unchanged.

*Analysis of Final products: March 11, 2018 and June 16, 2018*

Each month, we submit reports of the statistics of the PBO combined analyses and estimates of the latest velocity fields in the NAM08 reference frame based on the time series analysis of data between 1996 and month preceding the report (we need to allow 2-3 weeks for the generation of the final products). For this report, we generated the statistics using the ~3 months of results generated between March 11, 2018 and June 16, 2018. These results are summarized in Table 1 and figures 1-3.

For the three months of the final position time series generated by NMT, CWU and combination of the two (PBO), 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. Our first analysis of the distribution of these RMS scatters by analysis center and the combination. Table 1 shows the median (50%), 70% and 95% limits for the RMS scatters for PBO, NMT and CWU. The median horizontal RMS scatters are less than or equal 0.96 mm for all centers and as low as 0.73 mm for NMT North and 0.77 mm for PBO east components. The up-RMS scatters are less than or equal 4.9 mm for all analyses and as low as 4.36 mm for the NMT solution. These statistics are similar to last quarter. Seasonal changes in atmospheric delay properties will introduce small variations in these values quarter to quarter. In the NAM08 frame realization, scale changes are not estimated. If scale changes were estimated, the up scatter would be reduced but the sum of scale change RMS and the lower height scatter would equal the values shown in Table 1. The detailed histograms of the RMS scatters are shown in Figures 1-3 for PBO, NMT and CWU.

**Table 1:** Statistics of the fits of 1859, 1857 and 1858 stations for PBO, NMT and CWU analyzed in the finals analysis between March 11, 2018 and June 16, 2018. Histograms of the RMS scatters are shown in Figure 1-3.

| Center | North (mm) | East (mm) | Up (mm) |
|---|---|---|---|
| Median (50%) | | | |
| PBO | 0.77 | 0.78 | 3.97 |
| NMT | 0.78 | 0.84 | 4.04 |

| | | | |
|---|---|---|---|
| CWU | 0.99 | 0.93 | 4.65 |
| 70% | | | |
| PBO | 0.95 | 0.96 | 4.61 |
| NMT | 0.96 | 1.03 | 4.70 |
| CWU | 1.19 | 1.14 | 5.38 |
| 95% | | | |
| PBO | 1.72 | 1.75 | 6.72 |
| NMT | 1.81 | 1.86 | 7.09 |
| CWU | 2.17 | 2.07 | 7.97 |

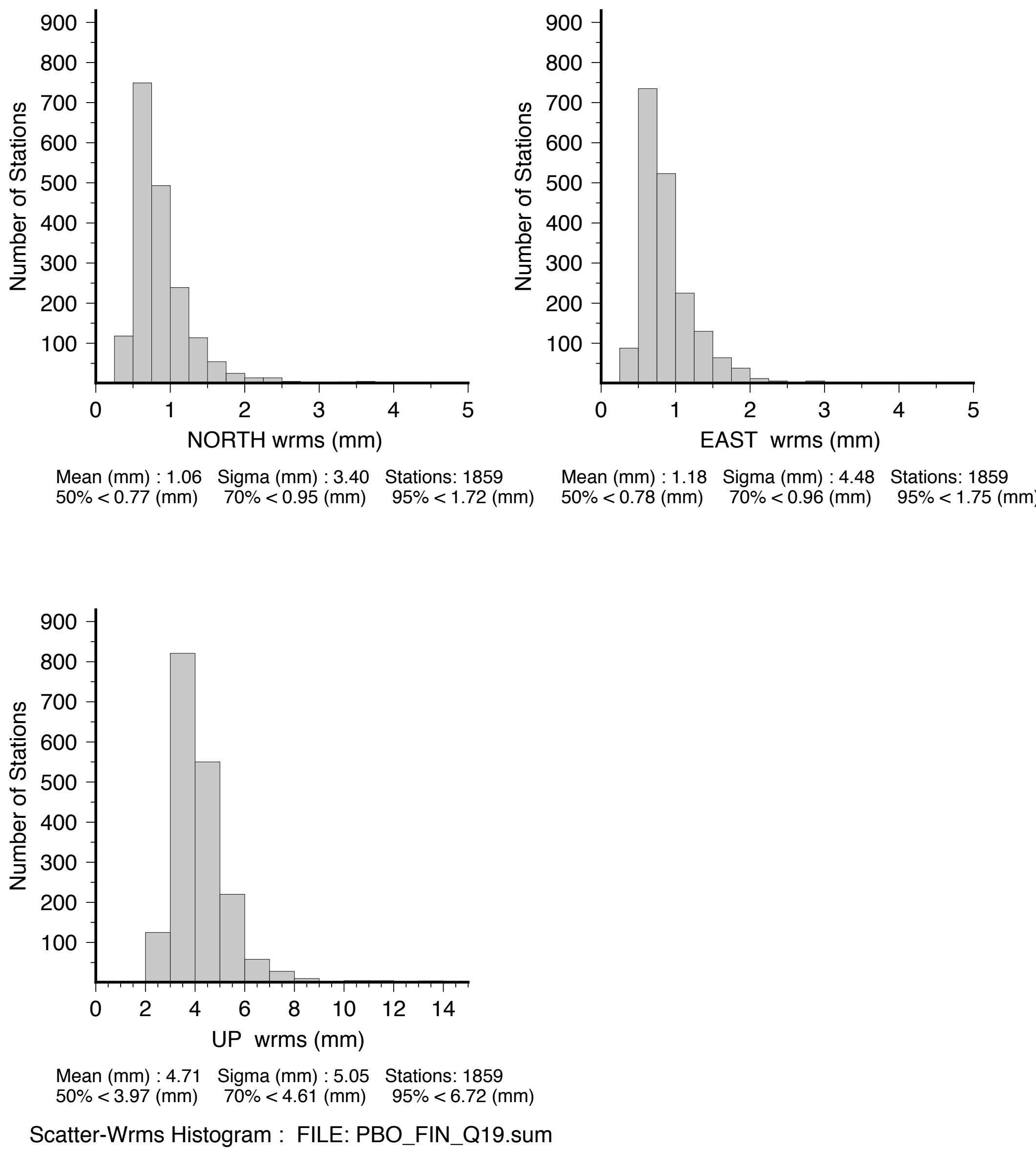


**Figure 1:** PBO combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1859 stations analyzed between March 11, 2018 and June 16, 2018. Linear trends and annual signals were estimated from the time series.

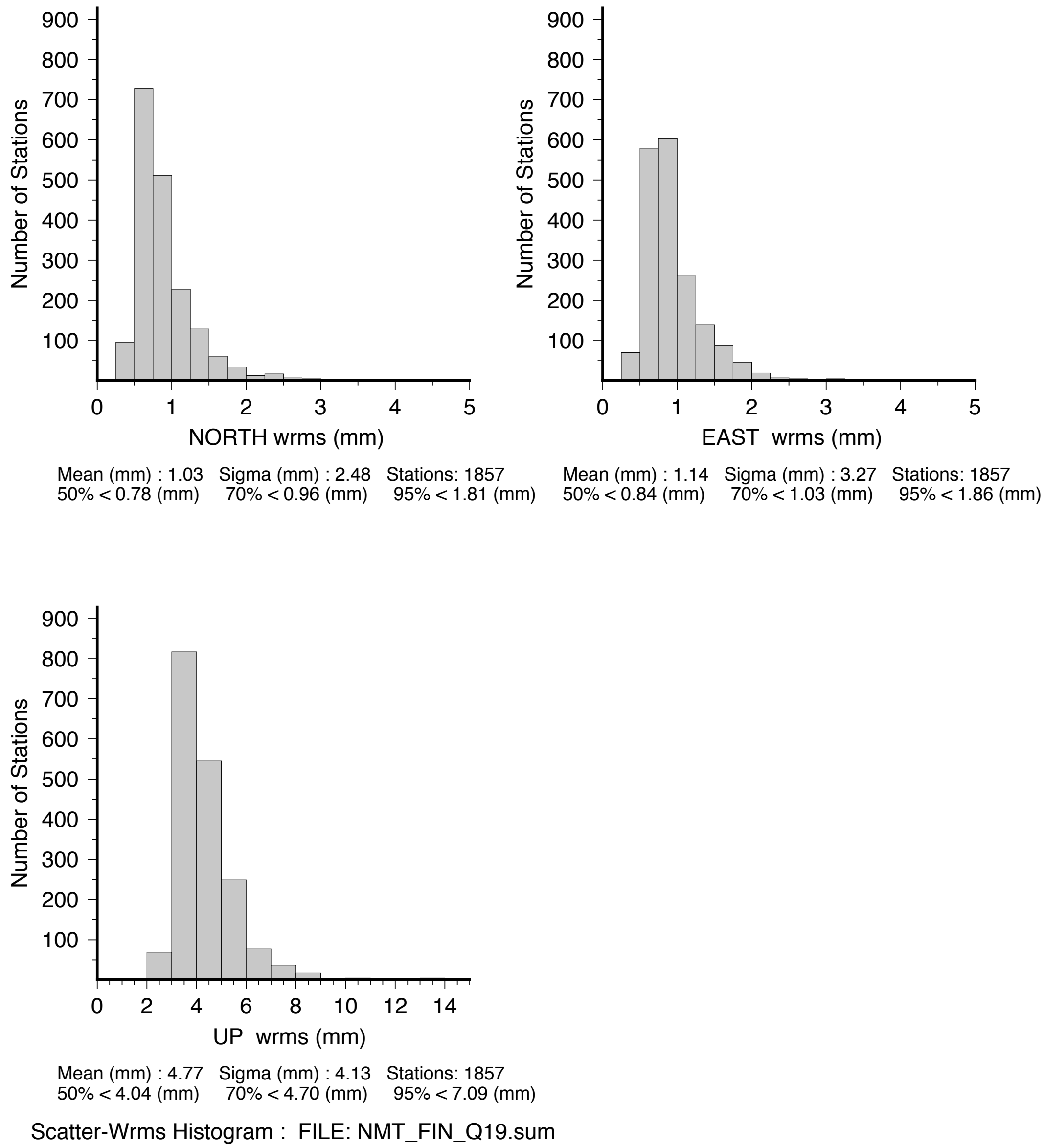


**Figure 2:** NMT combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1857 stations analyzed between March 11, 2018 and June 16, 2018. Linear trends and annual signals were estimated from the time series.

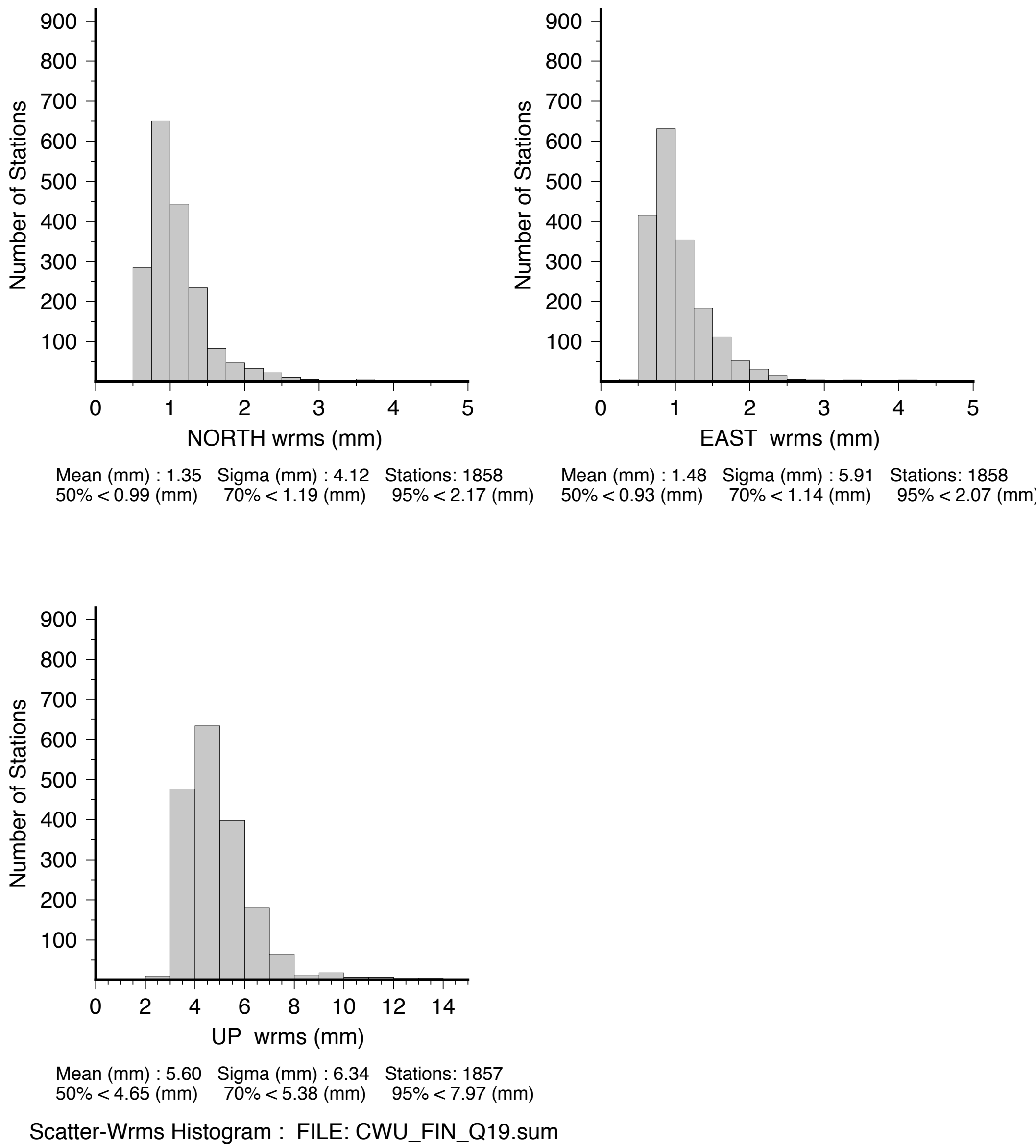


**Figure 3:** CWU combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1858 stations analyzed between March 11, 2018 and June 16, 2018. Editing removes two stations for North and Up. Linear trends and annual signals were estimated from the time series.

For the PBO combined 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 4-9. The values plotted are given in PBO_FIN_Q19.tab. There are 1859 stations in the file for sites that have at least 2 measurements during the month. The contents of the files are of this form:

```
Tabular Position RMS scatters created from PBO_FIN_Q19.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     94       1.1   0.51       1.2   0.53     6.5    0.64      15.15
 1NSU     94       0.8   0.46       0.9   0.52     5.0    0.67      14.41
 1ULM     94       0.8   0.49       1.0   0.61     4.8    0.69      15.01
 7ODM     93       0.7   0.40       0.7   0.44     4.3    0.67      17.16
…
 ZBW1     78       0.9   0.42       0.8   0.49     5.3    0.75      15.04
 ZDC1     55       0.9   0.45       0.7   0.44     5.1    0.71      15.04
 ZDV1     78       0.9   0.42       0.8   0.48     5.1    0.69      15.04
 ZKC1     78       0.9   0.45       0.8   0.49     4.2    0.60      15.04
 ZLA1     60       1.1   0.54       0.9   0.47     3.5    0.44      15.04
 ZME1     77       0.8   0.41       1.0   0.56     5.1    0.63      15.26
 ZMP1     71       0.8   0.36       0.8   0.45     4.5    0.59      15.51
 ZNY1     77       0.8   0.40       0.8   0.44     5.2    0.71      15.42
 ZSE1     73       0.8   0.30       0.9   0.46     4.0    0.50      15.42
 ZTL4     52       0.9   0.37       1.8   0.78     5.5    0.55      15.61
```

**Table 2**: RMS scatter of the position residuals for the PBO combined solution between March 11, 2018 and June 16, 2018 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 | 0.71 | 0.72 | 3.68 | 866 |
| NUCLEUS | 0.67 | 0.71 | 3.48 | 204 |
| GAMA | 0.68 | 0.80 | 4.47 | 14 |
| COCONet | 1.27 | 1.33 | 5.60 | 86 |
| USGS_SCIGN | 0.71 | 0.75 | 3.46 | 128 |
| Expanded | 0.86 | 0.85 | 4.57 | 561 |
| 70% | | | | |
| PBO | 0.85 | 0.88 | 4.13 | |
| NUCLEUS | 0.80 | 0.82 | 3.79 | |
| GAMA | 0.72 | 0.85 | 4.88 | |
| COCONet | 1.49 | 1.52 | 6.52 | |
| USGS_SCIGN | 0.91 | 0.89 | 3.81 | |
| Expanded | 1.01 | 1.04 | 4.96 | |
| 95% | | | | |
| PBO | 1.53 | 1.54 | 5.72 | |
| NUCLEUS | 1.45 | 1.25 | 5.35 | |
| GAMA | 0.88 | 0.98 | 5.43 | |
| COCONet | 3.07 | 4.50 | 12.59 | |
| USGS_SCIGN | 1.75 | 1.80 | 6.35 | |
| Expanded | 1.81 | 1.88 | 7.15 | |

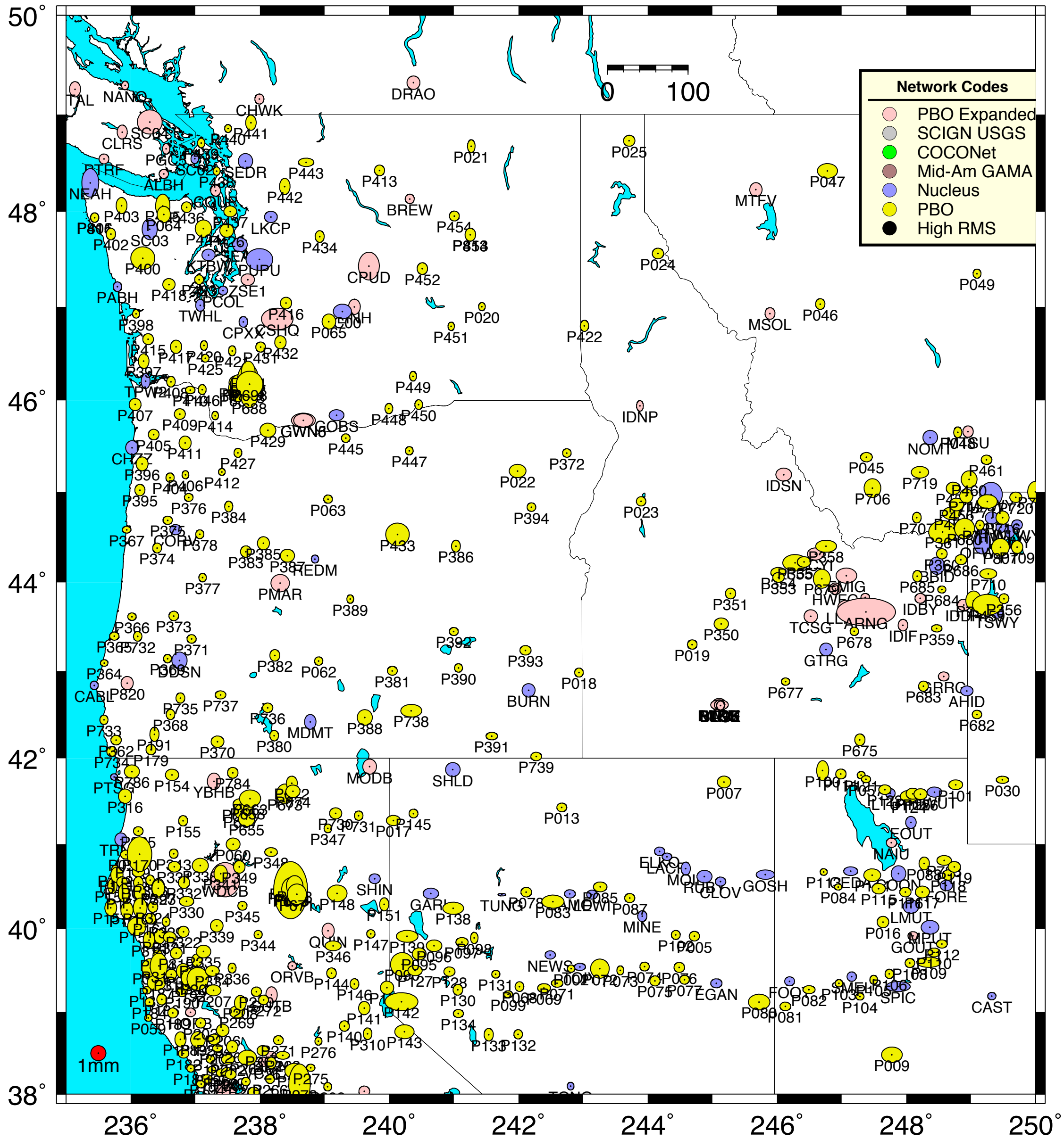


**Figure 4:** Distribution of the RMS scatters of horizontal position estimates from the PBO combined analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows 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.

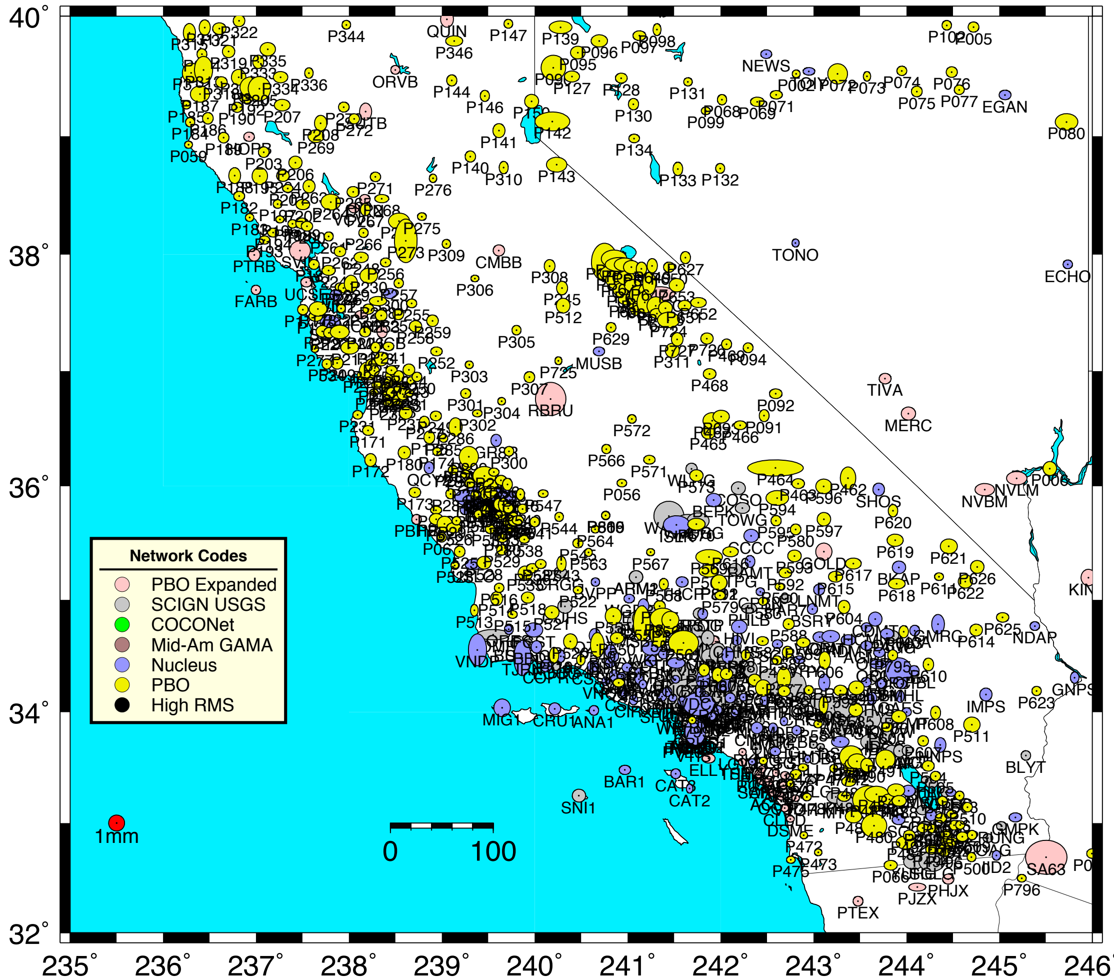


**Figure 5**: Same as Figure 4 except for the Southern Western United States. Black circles show large RMS scatter sites.

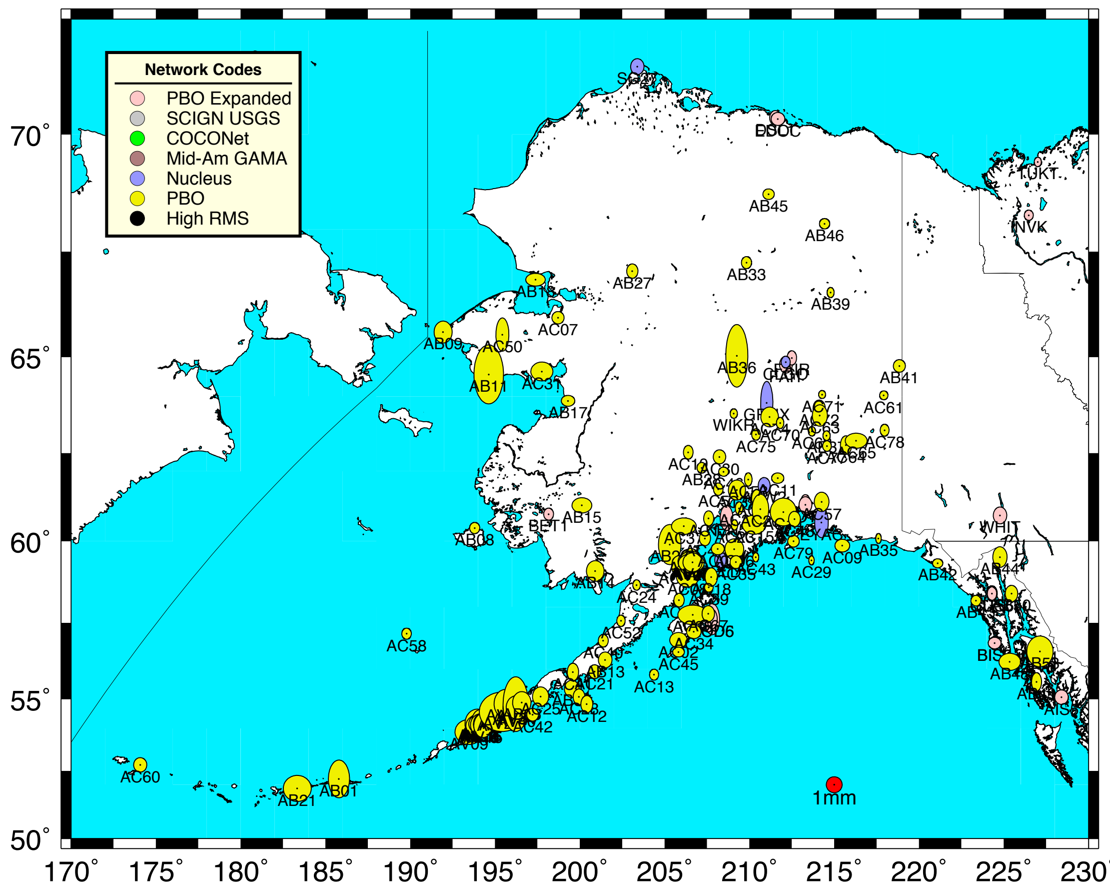


**Figure 6**: Same as Figure 4 except for the Alaskan region.

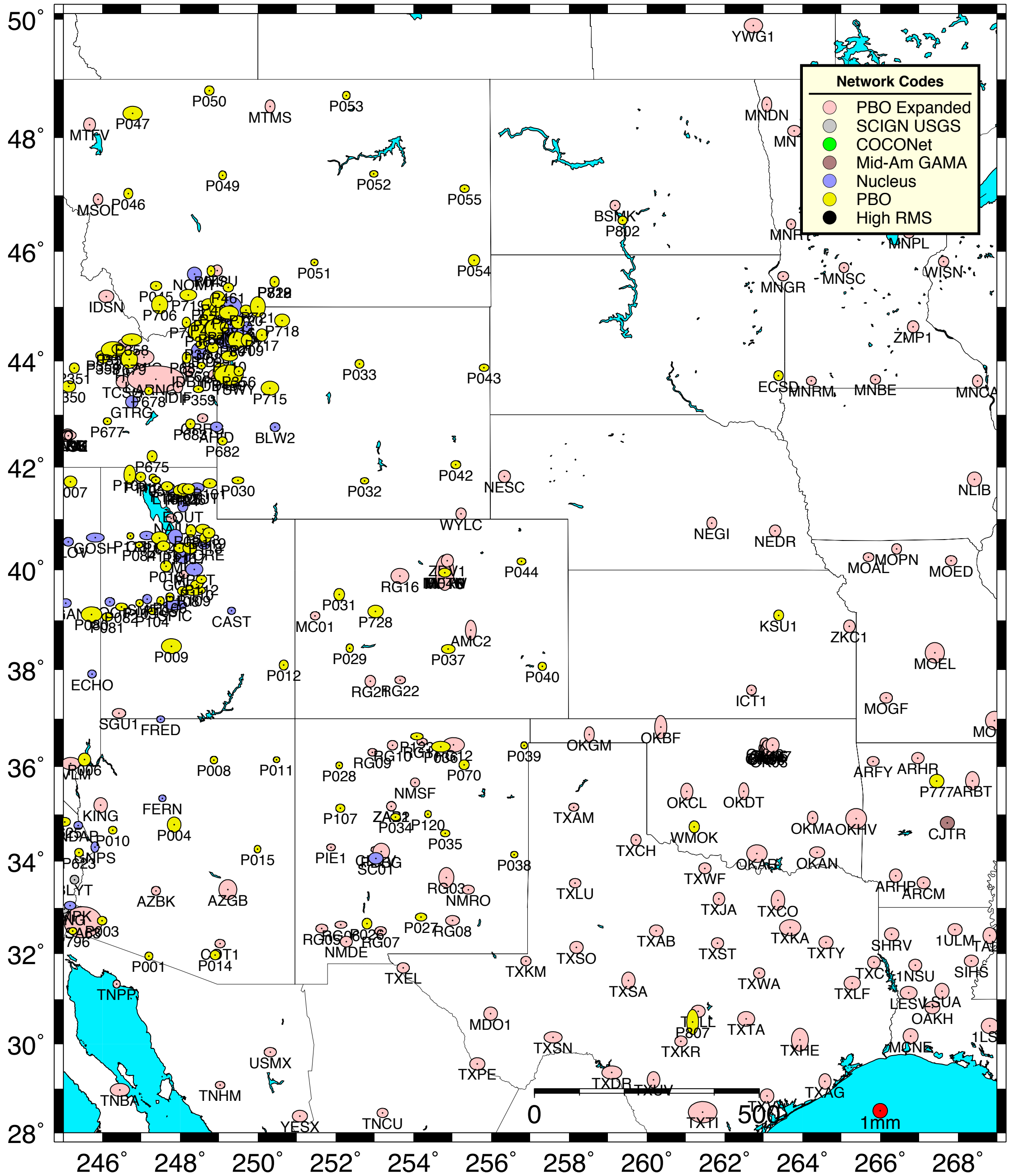


**Figure 7:** Same as Figure 4 except for the Central United States

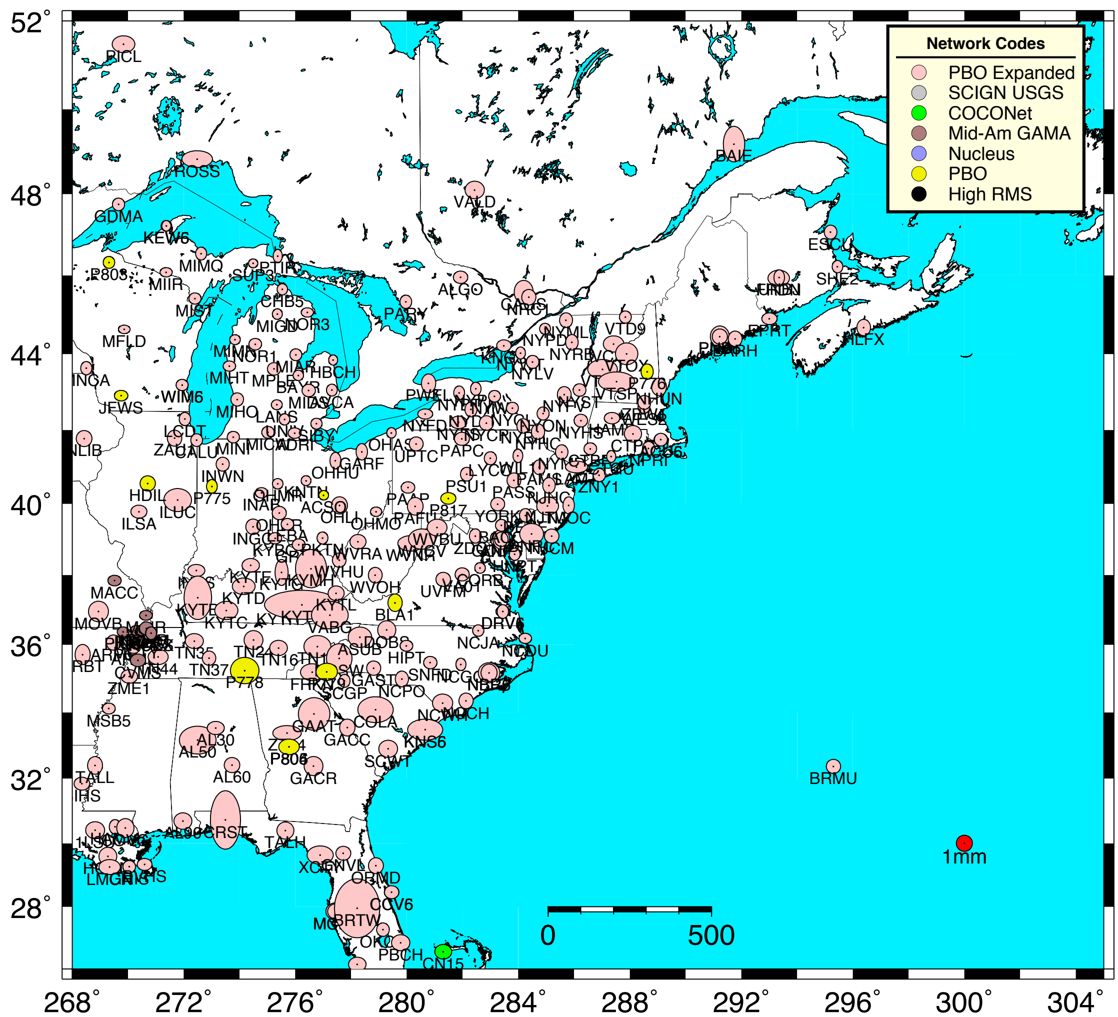


**Figure 8:** Same as Figure 4 except for the Eastern United States

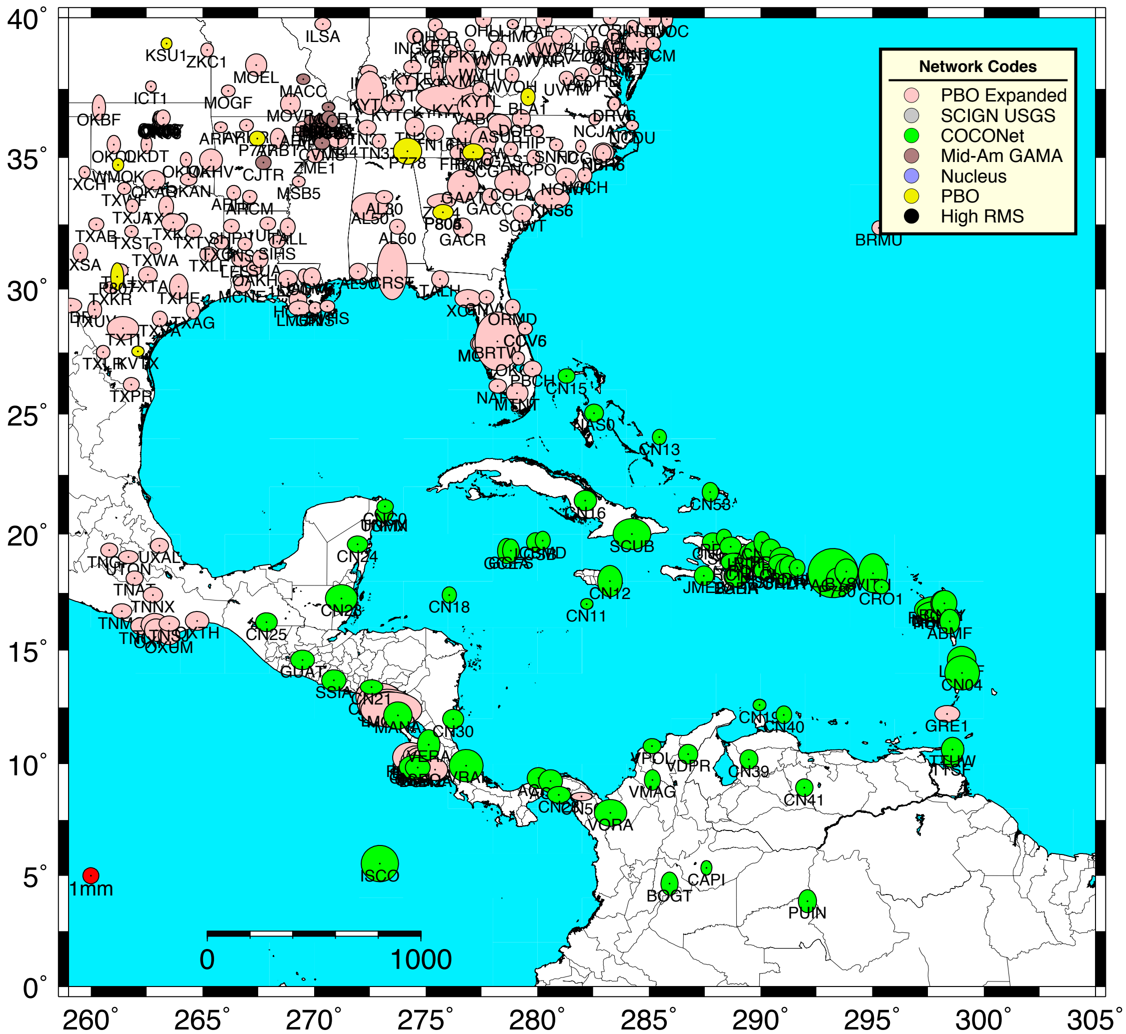


**Figure 9:** Same as Figure 4 except for the Caribbean region.

*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_PBO_eqs.eq All_PBO_ants.eq All_PBO_unkn.eq. The GLOBK apriori coordinate file All_PBO_nam08.apr is the current estimates based on data analysis in this quarterly report. Starting in Q06, we added a GLOBK apriori coordinate file based on the latest SNIPS PBO velocity file that are generated monthly. The SNIPS file updates the coordinates and velocities of stations that have changed in some significant fashion since the generation of the primary apriori coordinate file. The current file is All_PBO_nam08_snips.apr. Both of these apriori files are read with the –PER option in GLOBK (i.e., no periodic terms are applied). In these files, comments have a non-blank character in the first column and text after a ! in lines is treated as a comment. The apriori file contains Cartesian XYZ positions and velocities in meters with the epoch of the position in decimal years (day of year divided by days in the specific year). The comments contain the standard deviations of the estimates and are not specifically used in GLOBK (yet). The GEOD lines give geodetic coordinates and not directly used (information only). The EXTENDED lines give the extended parts of the model parameters. Specifically, OFFSETS are NEU position and velocity offsets at the times of discontinuities. The velocity changes are all zero in the PBO analyses. The Type in the comment at the end of line indicates the type of offset. If a name is given, then this is an antenna or unknown origin offset. For earthquakes, EQ is the type and two characters after is the code for the earthquake. If postseismic motion is model, then LOG or EXP EXTENDED lines will appear. The time constant of the function is given after the date (days) and the amplitudes in meters in NEU frame is given after that. The comment contains the standard deviations in mm. PERIODIC terms give the period (days) after the date and then cosine and sine terms in NEU. The periodic terms are not used in the standard GLOBK analyses. The comment contains the standard deviations. The GLOBK apriori coordinate file contains annual periodic terms but these are not used in the daily reference frame realization.

When interpreting the offsets in the apriori file, it is important to note that these are obtained for a simultaneous analysis of all data from a site. If the residuals to the fit are systematic, the offsets often will not be the same as an offset computed from analysis of shot spans of data on either side of the offset. We are considering adding such an analysis type in the future.

The Kalman filter estimated offsets are now supplied monthly as part of the monthly reports. In this quarter, we added earthquake ID information to be offset file descriptions.

*Snapshot velocity field analysis from the reprocessed PBO analysis.*

In our monthly reports, we generate "snapshot" velocity fields in the NAM08 reference frame based on the time series analysis of all data processed to that time. We have now started to distribute the snapshot fields (SNAPS) and the significant updates to the standard PBO velocity file (SNIPS file) in standard PBO velocity field format. These files are distributed in the monthly reports. For this quarterly report, we generate these velocity estimates for the reprocessed results and the current GAGE analyses that are in the NAM08 reference frame. There are 2252 stations in the combined PBO solution which is one more than last quarter. The statistics of the fits to results are shown in Table 3. 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 the following linked files: pbo_nam08_180616.tab, nmt_nam08_180616.tab and cwu_nam08_180616.tab. The velocity estimates are shown by region and network type in Figures 10-16. The color scheme used is the same as Figures 4-9. The snapshot velocity field files are linked as: pbo_nam08_180616.snpvel, nmt_nam08_180616.snpvel and cwu_nam08_180616.snpvel.

**Table 3:** Statistics of the fits of 2252, 2251 and 2242 stations analyzed by PBO, NMT and CWU in the reprocessed analysis for data collected between Jan 1, 1996 and June 16, 2018.

| Center | North (mm) | East (mm) | Up (mm) |
|---|---|---|---|
| Median (50%) | | | |
| NMT | 1.14 | 1.23 | 5.84 |
| CWU | 1.35 | 1.35 | 6.10 |
| PBO | 1.15 | 1.20 | 5.43 |
| 70% | | | |
| NMT | 1.51 | 1.61 | 6.58 |
| CWU | 1.69 | 1.68 | 6.87 |
| PBO | 1.48 | 1.52 | 6.09 |
| 95% | | | |
| NMT | 3.43 | 3.41 | 9.67 |
| CWU | 3.57 | 3.56 | 10.43 |
| PBO | 3.42 | 3.37 | 9.50 |

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.

A direct comparison of the NMT and CWU solutions shows the weighted root-mean-square (WRMS) difference between the two velocity fields is 0.08 mm/yr horizontal and 0.74 mm/yr vertical from differences of all stations in the two solutions that have velocity sigmas that sum to less than 100 mm/yr. The $\chi^2/f$ of the difference is $(1.15)^2$ for the horizontal and $(1.92)^2$ for the vertical component. These comparisons are summarized in Table 4. As noted in previous reports, adding small minimum sigmas (added in a root-sum-squared sense), computed such that $\chi^2/f$ is near unity changes the statistic slightly (Table 4). With the FOGMEX correlated noise model used to compute the velocity sigmas, the comparison statistics are close but still 15-92% optimistic over expectations. The 10-worst stations, in the order they are removed, are P411, P025, RG03, P599, P508, P509, P483, P588, AC59, MYT2 when the added sigmas are not applied and OLO2, RDMA, FSHB, P599, P483, MYT2, P508, P509, P588, AC59 when the values given in Table 4 are sum-squared into the velocity sigma estimates. This list is similar to the list in the previous quarter.

**Table 4:** Statistics of the differences between the CWU and NMT velocity solutions with no transformation between them. The stations common to the CWU and NMT solutions are used which is a slightly smaller number than in either solution. The PBO, NMT and CWU solutions themselves have 2252, 2251 and 2242 stations whose velocities can be determined to better than 100 mm/yr. WRMS is weighted-root-mean-scatter and NRMS is $\sqrt{(\chi^2/f)}$ where f is the number of comparisons.

| Solution | # | NE WRMS (mm/yr) | U WRMS (mm/yr) | NE NRMS | U NRMS |
|---|---|---|---|---|---|
| All_Normal | 2231 | 0.08 | 0.74 | 1.15 | 1.92 |
| Edited-10_worst | 2221 | 0.07 | 0.74 | 1.08 | 1.90 |
| Less_than_median (0.15 0.51 mm/yr) | 1233 | 0.06 | 0.69 | 1.18 | 2.12 |
| Added minimum sigma NE 0.03 U 0.55 mm/yr | | | | | |
| All_Normal | 2231 | 0.10 | 0.98 | 1.04 | 0.98 |
| Edited-10_worst | 2221 | 0.09 | 0.96 | 0.97 | 0.96 |
| Less_than_median (0.15 0.75 mm/yr) | 1233 | 0.07 | 0.77 | 1.00 | 0.85 |

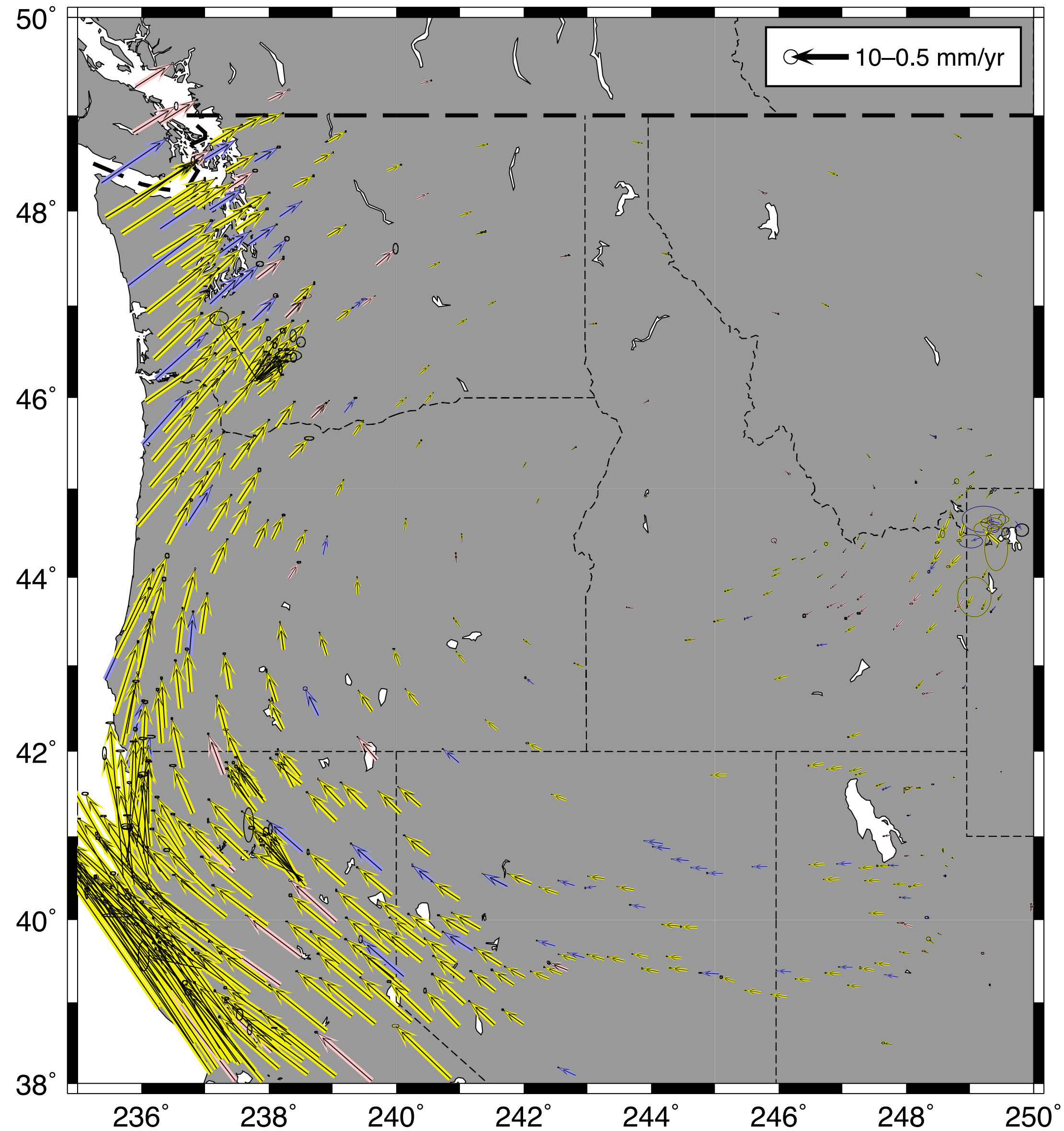


**Figure 10**: Velocity field estimates from the combined PBO solutions generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal standard deviations less than 2 mm/yr are shown (this value is reduced from previous reports due the improved velocity sigmas).

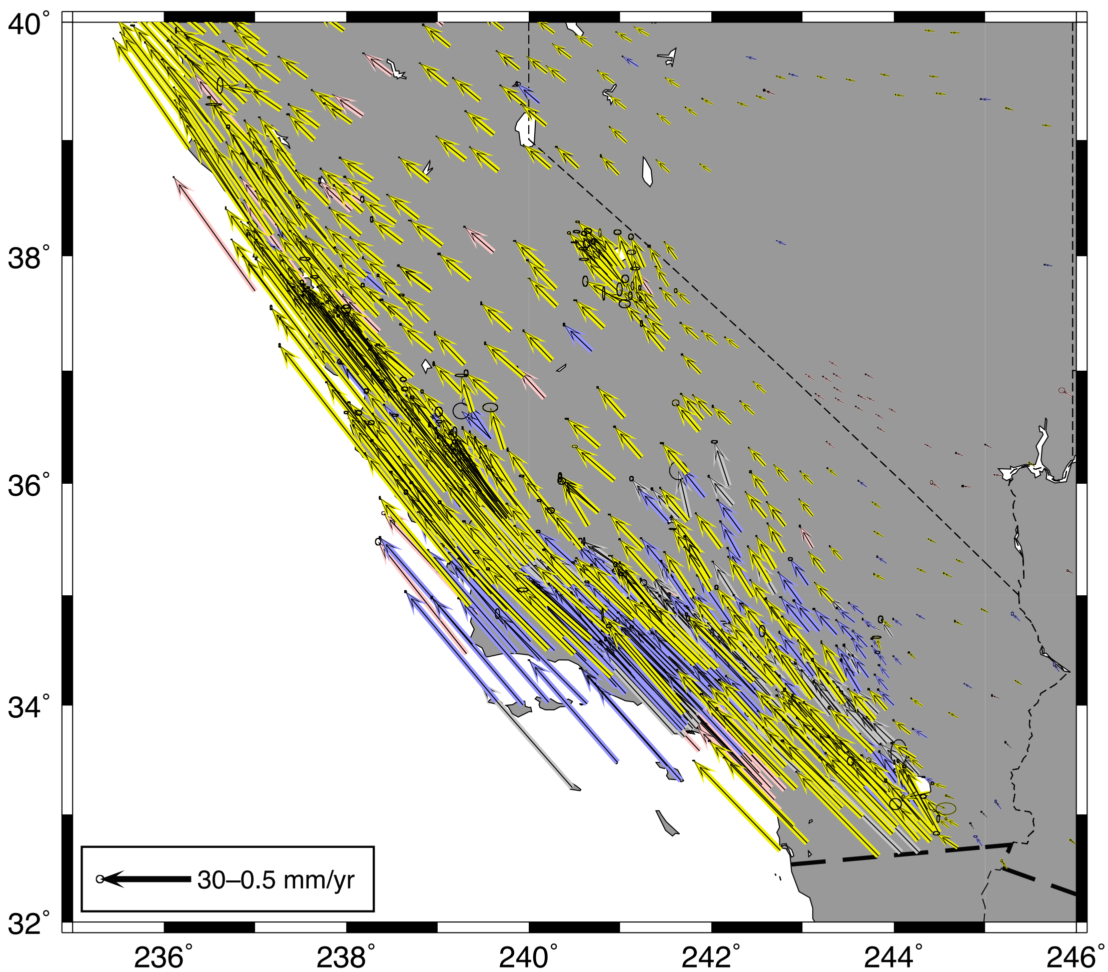


**Figure 11:** Same as Figure 10 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

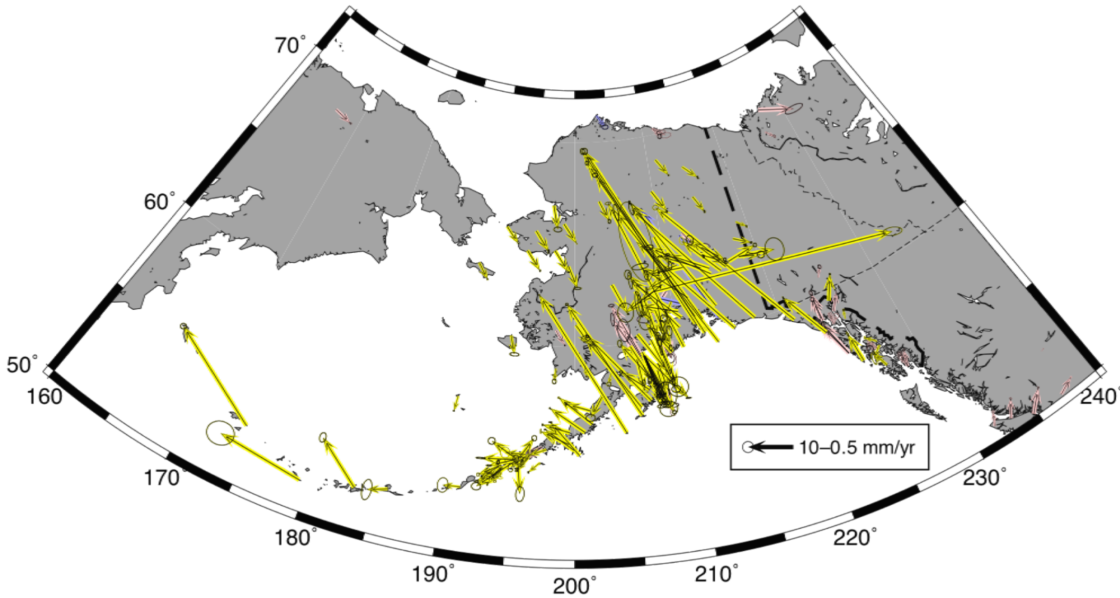


**Figure 12:** Same as Figure 10 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

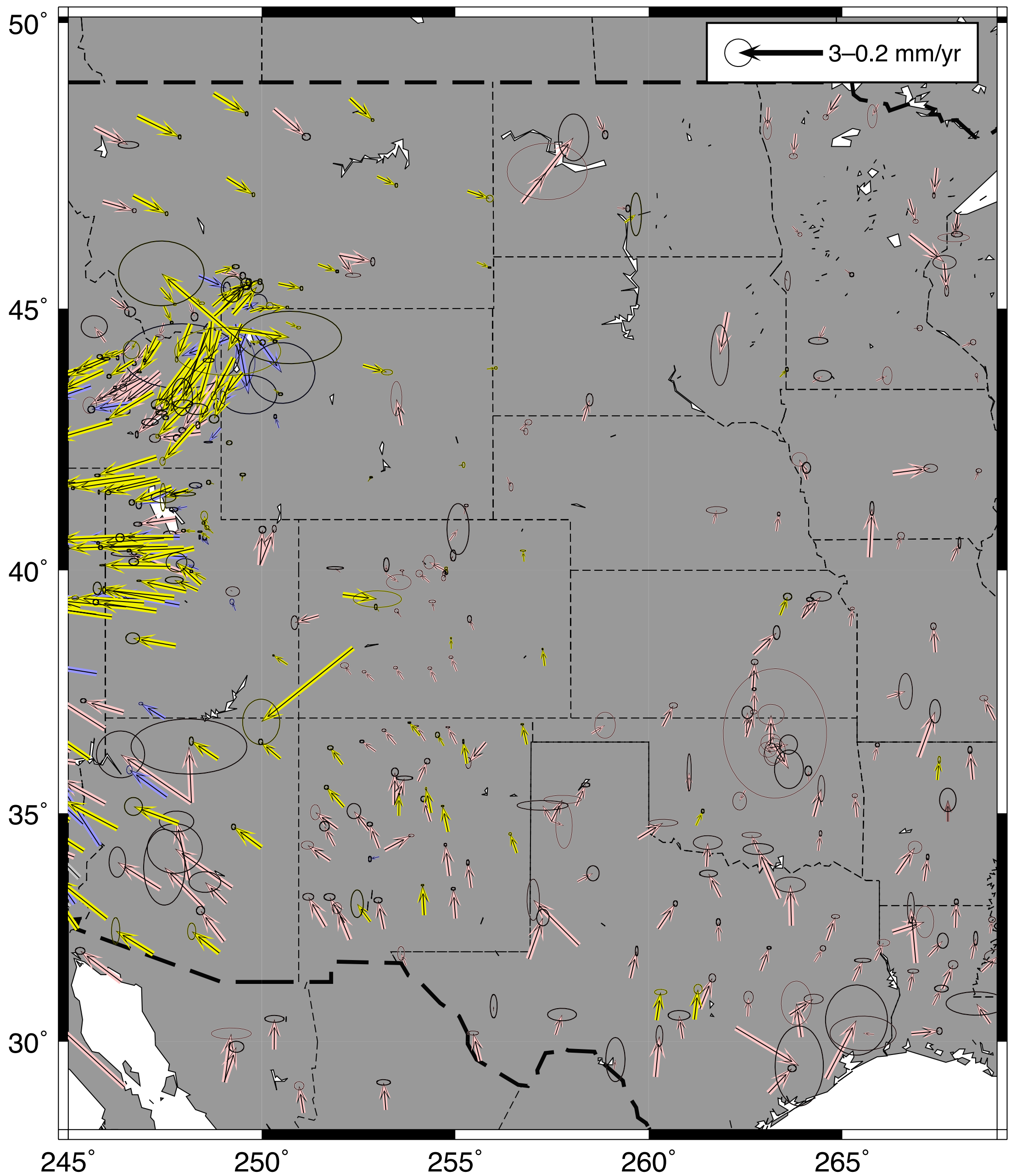


**Figure 13:** Same as Figure 10 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

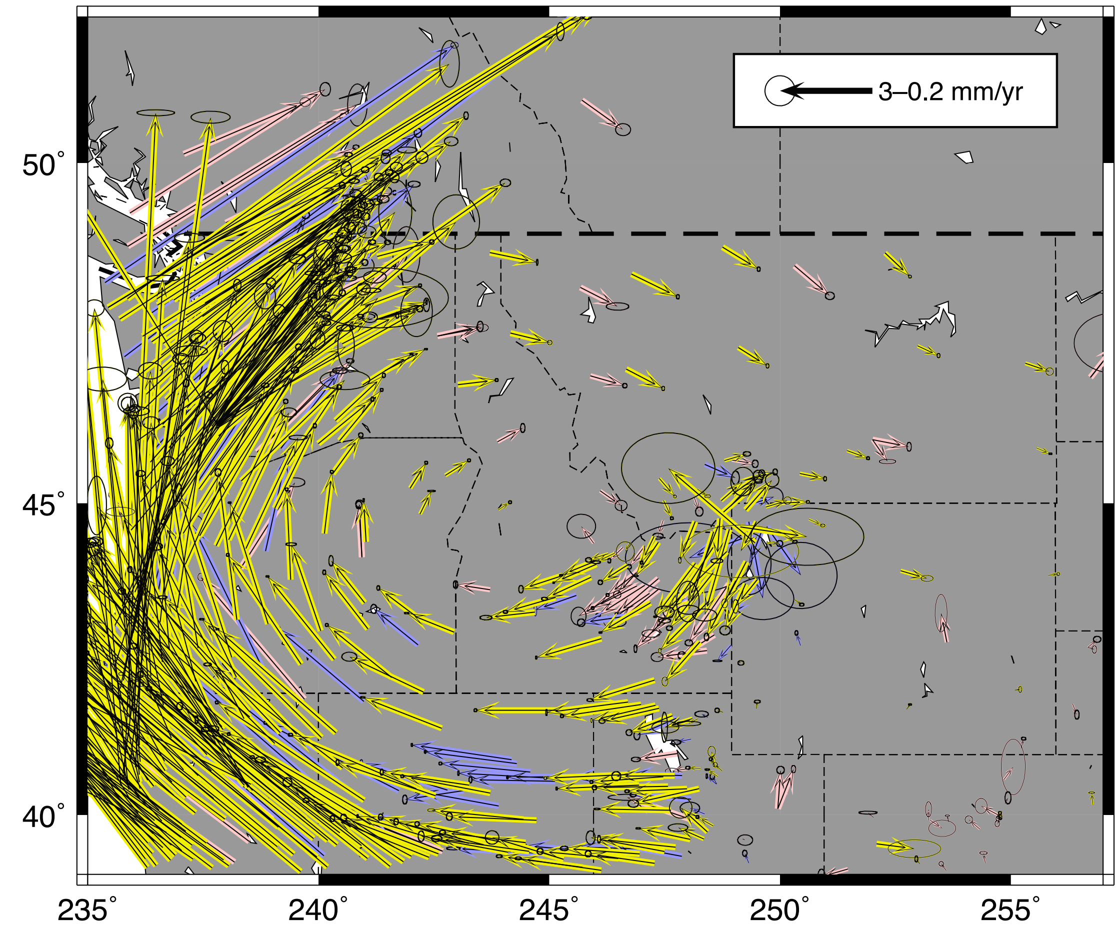


**Figure 14:** Same as Figure 10 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250º are in the Yellowstone National Park and most likely are showing volcanic processes.

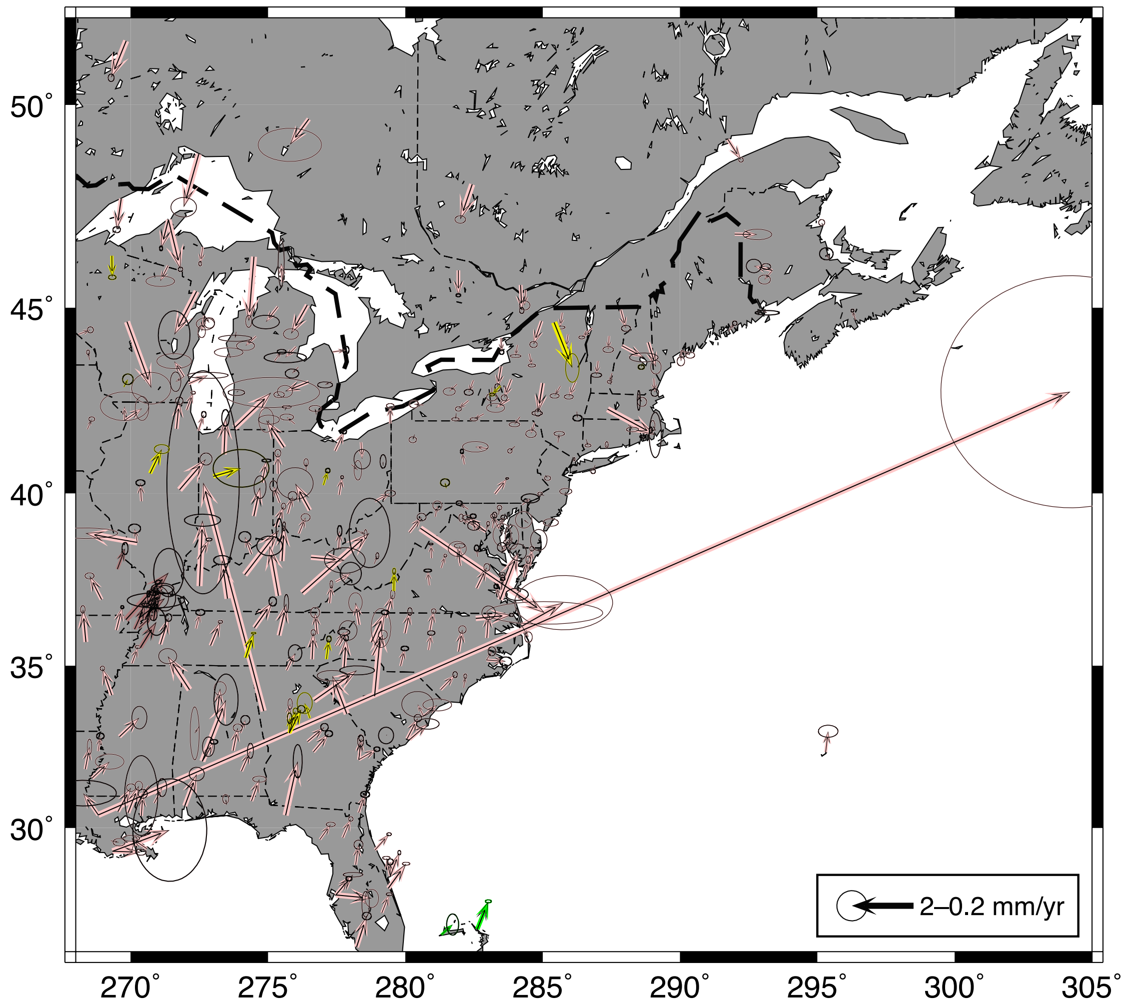


**Figure 15:** Same as Figure 10 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities. The large outlier is LST1 which has only a short amount of data (less than 1 year). The vertical motions match quite well but geodetic vertical motions are already included in the development of the models. Horizontal GIA motions will affect the North America Euler pole from ITRF2008.

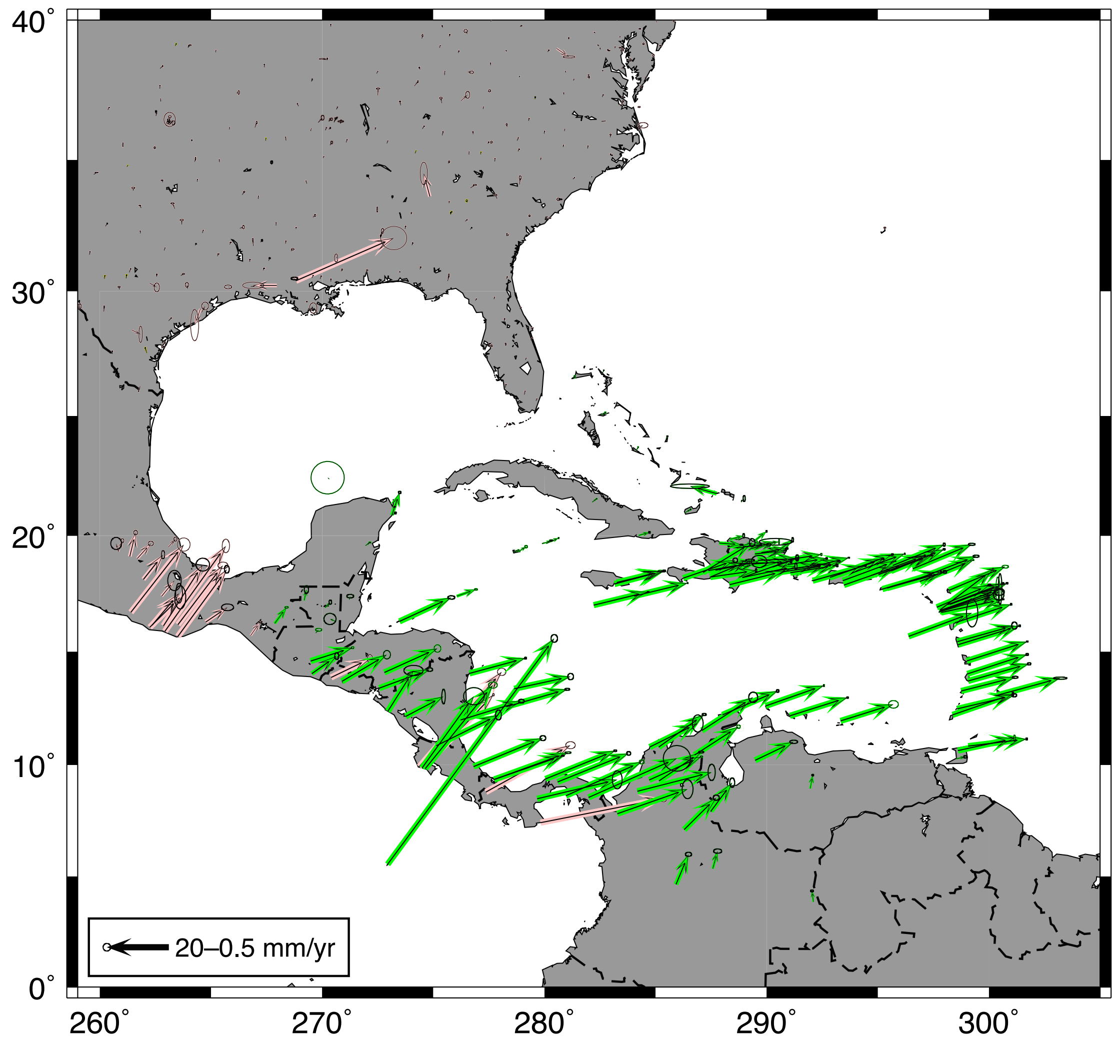


**Figure 16:** Same as Figure 10 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

*Earthquake Analyses: 2018/03/11-2018/06/15.*

We use the NEIC catalog to search for earthquakes that could cause coseismic offsets at the sites analyzed by the GAGE analysis centers. We examined the following earthquakes. In these output, each earthquake that might have generated coseismic displacements is numbered and the "SEQ Earthquake # n" starts the block of information about the earthquake. The EQ MM lines, give station name, distance from hypocenter (km), maximum distance that could cause coseismic offsets > 1 mm, and the "CoS" (coseismic offset) value is the possible offset in the mm. The eq_def lines give the event number, latitude, longitude, radius of influence, and depth of event followed by the date and time of the event. If an event is found to be significant, the event number is modified to reflect the total number of events so far included in the PBO analyses. Large events are often given a two-character code to reflect their location (e.g., PA is Parkfield).

Events investigated in March/April 2018.

```
* EQDEFS for 2018 03 14 to 2018 04 15 Generated Tue Apr 17 09:19:25 EDT 2018
* Proximity based on Week_All.Pos file
* ---------------------------------
* SEQ Earthquake # 1
* EQ 278 CN05_GPS      2.90      8.80 CoS       2.3 mm
* EQ_DEF M3.6 7km ESE of Punta Cana
 eq_def    01   18.5668  -68.3335      8.8  8  2018 03 23 04 35    0.0003
 eq_rename 01
 eq_coseis 01  0.0010 0.0010 0.0010      0.0003     0.0003     0.0003
* ---------------------------------
* SEQ Earthquake # 2
* EQ 650 OK04_GPS      8.78      8.80 CoS       0.2 mm
* EQ 650 OK05_GPS      4.55      8.80 CoS       0.9 mm
* EQ 650 OK06_GPS      1.06      8.80 CoS      17.0 mm
* EQ_DEF M3.6 15km NNW of Pawnee
 eq_def    02   36.4665  -96.8674      8.8  8  2018 04 04 18 18    0.0003
 eq_rename 02
 eq_coseis 02  0.0010 0.0010 0.0010      0.0003     0.0003     0.0003
```

Analysis:
EQ01: No obvious offset at the one site likely to have been displaced by this earthquake.
EQ02: No obvious offsets even at the closest site.

No earthquake event files were generated for this month.

Events investigated in April/May, 2018.

```
* Earthquake definition file created with sh_makeeqdef by Tom Herring on 2018-05-21
* for events from 2018-03-14 to 2018-05-15 (inclusive)
* from http://earthquake.usgs.gov/fdsnws/event/1/.
* Empirical model for radius of influence of earthquake:
* radius = scale*(a*z + b*x^M) + c
* where scale = 1, a = 0, b = 2.5e-3, c = 8, x = 5,
* z is earthquake depth and M is magnitude.
* Proximity based on Week_All.Pos
* -------------------------------------
* Earthquake catalog search result # 323
* Approximate predicted coseismic displacements (epicentral distance):
* CN05_GPS ~     2.5 mm (~ 2.75 km)
* EQ_ID A1 ANSS(ComCat) pr2018082001
* EQ_DEF md3.6 17km SSE of Punta Cana (152 km depth fixed)
```

```
 eq_def A1   18.5668  -68.3335     8.8    8.0  2018 03 23 04 35    0.0003
 eq_rename A1
 eq_coseis A1  0.0010 0.0010 0.0010    0.0003   0.0003   0.0003
* --------------------------------------
* Earthquake catalog search result # 843
* Approximate predicted coseismic displacements (epicentral distance):
* OK04_GPS ~     0.3 mm (~ 8.68 km)
* OK05_GPS ~     1.0 mm (~ 4.46 km)
* OK06_GPS ~    14.5 mm (~ 1.15 km)
* EQ_ID A2 ANSS(ComCat) us1000de9d
* EQ_DEF ml3.6 15km NNW of Pawnee (4.5 km depth)
 eq_def A2   36.4665  -96.8674     8.8    8.0  2018 04 04 18 18    0.0003
 eq_rename A2
 eq_coseis A2  0.0010 0.0010 0.0010    0.0003   0.0003   0.0003
* --------------------------------------
* Earthquake catalog search result # 866
* Approximate predicted coseismic displacements (epicentral distance):
* OK05_GPS ~     0.6 mm (~ 4.50 km)
* OK06_GPS ~     8.9 mm (~ 1.20 km)
* EQ_ID A3 ANSS(ComCat) us2000duvg
* EQ_DEF ml3.5 15km NNW of Pawnee (5.004 km depth)
 eq_def A3   36.4671  -96.8676     8.7    8.0  2018 04 05 08 52    0.0002
 eq_rename A3
 eq_coseis A3  0.0010 0.0010 0.0010    0.0002   0.0002   0.0002
* --------------------------------------
* Earthquake catalog search result # 872
* Approximate predicted coseismic displacements (epicentral distance):
* OXTH_GPS ~     4.9 mm (~ 5.60 km)
* EQ_ID A4 ANSS(ComCat) us2000duza
* EQ_DEF mb4.4 8km N of Salina Cruz (135.34 km depth)
 eq_def A4   16.2426  -95.2144    11.0    8.0  2018 04 05 14 57    0.0024
 eq_rename A4
 eq_coseis A4  0.0010 0.0010 0.0010    0.0024   0.0024   0.0024
* --------------------------------------
* Earthquake catalog search result # 1286
* Approximate predicted coseismic displacements (epicentral distance):
* WGPP_GPS ~     0.8 mm (~ 6.45 km)
* EQ_ID A5 ANSS(ComCat) ci38149752
* EQ_DEF mw3.8 15km NW of Grapevine (7.73 km depth)
 eq_def A5   35.0435 -119.0423     9.1    8.0  2018 04 16 16 37    0.0005
 eq_rename A5
 eq_coseis A5  0.0010 0.0010 0.0010    0.0005   0.0005   0.0005
* --------------------------------------
* Earthquake catalog search result # 1323
* Approximate predicted coseismic displacements (epicentral distance):
* CN01_GPS ~    31.3 mm (~ 3.26 km)
```

```
* EQ_ID A6 ANSS(ComCat) us2000e1rz
* EQ_DEF mb4.7 4km SE of Parham (20.95 km depth)
 eq_def A6   17.0679  -61.7422    12.8    8.0  2018 04 17 20 27    0.0052
 eq_rename A6
 eq_coseis A6  0.0010 0.0010 0.0010    0.0052   0.0052   0.0052
* --------------------------------------
* Earthquake catalog search result # 1477
* Approximate predicted coseismic displacements (epicentral distance):
* P645_GPS ~     0.3 mm (~ 8.18 km)
* P724_GPS ~     1.2 mm (~ 3.97 km)
* EQ_ID A7 ANSS(ComCat) nc73002966
* EQ_DEF mw3.6 8km NNE of Round Valley (13.55 km depth)
 eq_def A7   37.4750 -118.5535     8.8    8.0  2018 04 22 16 05    0.0003
 eq_rename A7
 eq_coseis A7  0.0010 0.0010 0.0010    0.0003   0.0003   0.0003
* --------------------------------------
* Earthquake catalog search result # 1492
* Approximate predicted coseismic displacements (epicentral distance):
* WIDC_GPS ~     0.9 mm (~ 6.66 km)
* EQ_ID A8 ANSS(ComCat) ci37920791
* EQ_DEF mw3.9 13km NNE of Thousand Palms (8.25 km depth)
 eq_def A8   33.9210 -116.3217     9.3    8.0  2018 04 23 00 47    0.0006
 eq_rename A8
 eq_coseis A8  0.0010 0.0010 0.0010    0.0006   0.0006   0.0006
* --------------------------------------
* Earthquake catalog search result # 1841
* Approximate predicted coseismic displacements (epicentral distance):
* MKEA_GPS ~    17.8 mm (~ 72.38 km)
* EQ_ID A9 ANSS(ComCat) us1000dyad
* EQ_DEF mww6.9 19km SSW of Leilani Estates (2.06 km depth)
 eq_def A9   19.3127 -154.9975   174.3    8.0  2018 05 04 22 33    1.4566
 eq_rename A9
 eq_coseis A9  0.0010 0.0010 0.0010    1.4566   1.4566   1.4566
* --------------------------------------
* Earthquake catalog search result # 1958
* Approximate predicted coseismic displacements (epicentral distance):
* SNOG_GPS ~    16.9 mm (~ 3.37 km)
* EQ_ID B1 ANSS(ComCat) ci38167848
* EQ_DEF mw4.5 11km N of Cabazon (12.89 km depth)
 eq_def B1   34.0160 -116.7798    11.4    8.0  2018 05 08 11 50    0.0030
 eq_rename B1
 eq_coseis B1  0.0010 0.0010 0.0010    0.0030   0.0030   0.0030
```

Analysis:

A1:  No offset at CN05

A2:  No horizontal offsets greater than 1 mm.  Vertical offsets < 3mm
A3:  Small aftershock of A2 (both earthquakes combined).
A4:  No apparent offset at OXTH
A5:  No apparent offset at WGPP but site is systematic
A6:   No apparent offset at CN01
A7:  No apparent offsets at either P724 or P645
A8:  No results from WIDC since 2018-04-15 (earthquake is one week later)
A9:  -8 mm N, 10 mm E 1 mm U displacement at MKEA.  This is event 46 in the All_PBO_eqs.eq file.  EQ_ID 46 ANSS(ComCat) us1000dyad  Mw 6.9 19km SSW of Leilani
Estates (2.06 km depth)
B1:  No apparent offsets at SNOG.

Event for EQ 46 (us1000dyad) generated this month.

## Events investigated in May/June, 2018.

```
* Earthquake definition file created with sh_makeeqdef by Tom Herring on 2018-06-18
* for events from 2018-05-14 to 2018-06-15 (inclusive)
* from http://earthquake.usgs.gov/fdsnws/event/1/.
* Empirical model for radius of influence of earthquake:
* radius = scale*(a*z + b*x^M) + c
* where scale = 1, a = 0, b = 2.5e-3, c = 8, x = 5,
* z is earthquake depth and M is magnitude.
* Proximity based on Week_All.Pos
* --------------------------------------
* Earthquake catalog search result # 47
* Approximate predicted coseismic displacements (epicentral distance):
* AB06_GPS ~    11.5 mm (~ 1.67 km)
* EQ_ID A1 ANSS(ComCat) us1000e5j7
* EQ_DEF mb3.8 5km NNW of False Pass (5.04 km depth)
 eq_def A1   54.8987 -163.4358     9.1     8.0  2018 05 15 15 03     0.0005
 eq_rename A1
 eq_coseis A1  0.0010 0.0010 0.0010    0.0005   0.0005   0.0005
* --------------------------------------
* Earthquake catalog search result # 502
* Approximate predicted coseismic displacements (epicentral distance):
* WIDC_GPS ~     0.8 mm (~ 6.52 km)
* EQ_ID A2 ANSS(ComCat) ci37952751
* EQ_DEF mw3.8 13km NNE of Thousand Palms (8.74 km depth)
 eq_def A2   33.9242 -116.3225     9.1     8.0  2018 05 30 19 23     0.0005
 eq_rename A2
 eq_coseis A2  0.0010 0.0010 0.0010    0.0005   0.0005   0.0005
* --------------------------------------
* Earthquake catalog search result # 720
* Approximate predicted coseismic displacements (epicentral distance):
```

* P190_GPS ~ 1.3 mm (~ 4.51 km)
* EQ_ID A3 ANSS(ComCat) nc73027396
* EQ_DEF mw3.7 3km WNW of Redwood Valley (5.45 km depth)
 eq_def A3 39.2758 -123.2333 9.0 8.0 2018 06 08 17 24 0.0004
 eq_rename A3
 eq_coseis A3 0.0010 0.0010 0.0010 0.0004 0.0004 0.0004
Analysis:

A1: No offset can be seen is the time series.
A2: No offset can be seen is the time series.
A3: No offset can be seen is the time series.

No new earthquakes this month.

*Antenna Change Offsets: 2018/04/01-2018/06/30.*

The follow antenna changes were investigated and reported on in the MIT ACC monthly reports.

```
Station  Date            From          To
LMNL  2018  3  5  0  0  Dome SCIT     NONE
P034  2018  3 13 16 59  TRM29659.00   TRM59800.00
P055  2018  3  3  0  0  TRM29659.00   TRM59800.80
SONG  2018  3 22  0  0  TRM59800.00   TRM59800.80
PKTN  2018  4  5 15 55  TRM59900.00   TRM57971.00
EPRT  2018  5 12  0  0  ASH701945E_M  LEIAR20
OKAN  2018  5 22 14  0  ASH700936D_M  LEIAR10
PKTN  2018  5 30 14 52  TRM57971.00   TPSCR.G5

LMNL: WLS dNEU   -1.85 +- 1.67,  -2.56 +- 0.70,  -3.28 +- 3.21 mm,
       KF dNEU   -0.37 +- 1.04,  -2.40 +- 1.00,  -2.28 +- 3.79 mm
Large gap in the data with only 50 data points used to estimate offset.
P034: WLS dNEU   -2.73 +- 0.82,   4.48 +- 0.69,   2.96 +- 4.54 mm,
       KF dNEU   -3.16 +- 0.34,   4.80 +- 0.32,   3.67 +- 1.06 mm
Large gap before antenna replaced.  Offset looks significant despite 5
month gap.
P055: WLS dNEU   -7.94 +- 0.95,  -2.99 +- 0.84,   1.77 +- 5.60 mm,
       KF dNEU   -7.33 +- 0.31,  -2.68 +- 0.26,  -1.45 +- 1.05 mm
Poor data quality before antenna change. Offsets do look significant.
SONG: WLS dNEU   -1.78 +- 1.92,  -4.66 +- 1.67,  -0.71 +- 4.85 mm,
       KF dNEU   -0.53 +- 0.33,  -4.26 +- 0.32,  -0.56 +- 1.16 mm
East offset can be clearly seen in the data

PKTN WLS dNEU   -2.11 +- 5.84,   1.13 +- 4.31,  -1.49 +- 8.80 mm,
      KF dNEU   -0.11 +- 0.34,   0.79 +- 0.29,  -1.09 +- 1.08 mm
Offset does not appear to be significant but is included in the list of
possible offsets.

EPRT: At this site only NMT has updated the metadata for an antenna
change and
consequently the two ACs see two very different results especially for
the height component where CWU see over 10 cm height change because
their analysis is using the wrong antenna.  Some NMT estimated were
```

```
removed because of a lag between the antenna change and when metadata
were updated.
NMT KF dNEU   -4.60 +- 0.64,   3.86 +- 0.73,   8.60 +- 1.82 mm
CWU KF dNEU   -6.72 +- 0.62,  -0.40 +- 0.57, 113.61 +- 1.89 mm

OKAN Same as EPRT above.  CWU has not updated metadata for this site
resulting in
a large height error.  Some NMT data editing (as above)
NMT KF dNEU   -0.63 +- 1.02,   3.88 +- 0.89,   1.25 +- 3.71 mm
CWU KF dNEU   -2.23 +- 0.43,   1.29 +- 0.37, 103.28 +- 1.66 mm
PKTN Same case as about.  The antenna meta data has not been updated by
CWU leading
to a large height offsets. Some NMT data editing (as above)
NMT KF dNEU    1.42 +- 0.78,  -3.47 +- 0.78,   1.66 +- 2.78 mm
CWU KF dNEU    0.56 +- 0.53,  -1.58 +- 0.42, -57.81 +- 1.87 mm
```

*New offsets of unknown origin and data anomalies*

WGPP Large systematic trend with +-4 mm amplitude over the 18 years of data. Possible change in rate around 2014 but after 2017 may be returned to original rate.
BVPP also has systematics but not the same.

**Appendix A: Advisory issued on GAGE transition to IGS14.**

**GAGE Analysis transition to IGS14 system**

Prepared by T. A. Herring, MIT, GAGE GPS Analysis Center Coordinator,
25 June 2018

*Summary*

At GPS week 2005 day 0, 2018 June 10, the GAGE analysis centers will switch fully to the IGS14 reference system. At this time, horizontal offsets in position for most sites will be <0.2 mm and vertical offsets will be 2-3 mm. For some antenna types the changes will be larger with horizontal offsets up to 2 mm and height offsets of 8 mm.

*Analysis*

The GAGE analysis centers will transition to operationally using the IGS14 antenna calibration models starting with final orbit runs for day 0 of GPS week 2005, 2018 June 10. This change is one week after JPL switched to generating final orbit and clock products in the IGS14 system. Since the IGS transition to ITRF2014/IGS14 on January 29, 2017 (GPS week 1934 day 0), the GAGE analysis centers having generating results in mixed systems due to JPL orbits and clocks not being available for the final orbit products in the IGS14 system. Rapid orbit and clock products have been available in the IGS14 systems since January 29, 2017. The GAGE analysis strategy for handling this situation was discussed in the "GAGE/PBO analysis transition to ITRF2014/IGS14" note. (https://www.unavco.org/data/gps-gnss/derived-products/docs/GAGE_IGS14_transition_plan_20170327.pdf). Tables of expected position changes, generated by the IGS, were given in that note. Since JPL is now generating IGS14 products for both rapid and final orbits, both analysis centers will switch to using the IGS14 antenna calibration file. The alignment of the GAGE product reference frame will remain unchanged (NAM08 and IGS08) while reprocessed results in the IGS14 are generated and a new North America reference frame realization is developed. The reprocessing will take several months to complete and analyze. Retention of the same reference frame realizations deduced the impact of switching to the full IGS14 system.

This note discusses the impact on the GAGE times series products with the transition to the IGS14 antenna phase center model. The GAGE analysis have processed selected weeks of data with the IGS14 antenna file and for CWU recently released IGS14 orbits and clocks from JPL. NMT has used the same antenna calibration file and either the IGS operational final orbit files after January 29, 2017 or the IGS orbits from the second reprocessing aligned to the IGS14 system. Here we examine the differences between the new IGS14 processing and the old operational IGS08 processing. For both sets of processing we align through rotation and translation (but no scale change) to the same

NAM08 reference frame realized with typically 500 sites spread over the GAGE network extent.

The overall summary of the results is given in Table 1. Reprocessed results from selected weeks between 2015-2017 were compared with the standard GAGE processing from those same weeks. The time series for each station were differenced and the mean and statistics of the differences were computed for each station. The statistics are the weighted root-mean-square (WRMS) scatter of differences and the normalized RMS scatter (square-root chi-squared per degree of freedom) of the differences. Mean differences for 2057 stations were computed. Table 1 shows the median of the mean, WRMS and NRMS differences for the North, East and Up components by analysis center. The median changes in the horizontal components are small (<0.2 mm) but the median of the height changes are 2.30 to 3.35 mm depending on the AC or the PBO combination. On average, the antenna model change is expected to increase height estimates by ~3 mm. The increase is smaller than the expected changes for the IGS08-IGS14 change (discussed in the earlier note cited above) because we are aligning to the same reference frame in our time series generation. Figures 1-3 show the histogram of the mean differences for the combined PBO analysis and from each of the ACs.

In terms of the visual impact of the changes when time series are viewed, the NRMS value of ~0.3 shows that the "jump" in the heights at week 2005 will be about a "third of a sigma" and so will not be that obvious when time series are viewed. However, the offsets are systematic and users should be cautious of long-term averaging which will more likely show the systematic offset across the week 2005 boundary. When the reprocessing is complete, this offset will no longer be present.

**Table 1:** Characteristics of the changes in time series to be expected with the switch from the IGS08 antenna calibration file to IGS14 antenna calibration.

| Center | | North | | | East | | | Up | |
|---|---|---|---|---|---|---|---|---|---|
| | Median | WRMS | NRMS | Median | WRMS | NRMS | Median | WRMS | NRMS |
| | (mm) | (mm) | | (mm) | (mm) | | (mm) | (mm) | |
| CWU | -0.02 | 0.59 | 0.21 | -0.12 | 0.48 | 0.21 | 2.49 | 2.71 | 0.26 |
| NMT | -0.03 | 0.36 | 0.14 | 0.12 | 0.47 | 0.21 | 3.35 | 2.34 | 0.27 |
| PBO | -0.08 | 0.43 | 0.22 | -0.16 | 0.40 | 0.24 | 2.30 | 2.37 | 0.35 |

The summary in Table 1 shows the overall nature of the change but, as noted by the IGS and in our earlier note on the impact of the change from IGS08 to IGS14, specific antennas can have larger or smaller changes. Table 2 gives the medians of the changes in mean north, east, up position from the PBO combination grouped by antenna type. Some antennas/radomes, such as the TRM29659.00/SCIS had new robot calibrations in IGS14 replacing the converted relative calibration in the IGS08 system. For stations with some antenna types, the change in positions at the week 2005 boundary could be several times larger than the overall median values. Figure 4 and 5 show the histograms for the TRM29659.00 SCIT and the TRM41249.00 SCIT antenna/radome combinations.

Included with report is a folder with postscript plots of the histograms of the mean differences by analysis center and antenna/radome type, and text files with extent .sum which give the mean differences in NEU of each station from the CWU, NMT, and PBO analyses.

**Table 2:** Medians of the mean differences in the position estimates between IGS14 and IGS08 summarized by antenna type and in decreasing of number of stations with specific antenna types.

| Antenna | Radome | Number | ΔN (mm) | ΔE (mm) | ΔU (mm) |
|---|---|---|---|---|---|
| TRM29659.00 | SCIT | 656 | -0.07 | -0.20 | 2.16 |
| TRM59800.80 | SCIT | 244 | -0.09 | -0.19 | 2.29 |
| TRM59800.00 | SCIT | 199 | -0.01 | -0.20 | 2.24 |
| TRM57971.00 | NONE | 178 | -0.04 | -0.48 | 7.36 |
| ASH701945B_M | SCIT | 109 | -0.54 | 0.01 | 2.22 |
| TRM41249.00 | NONE | 84 | 0.03 | -0.13 | 2.40 |
| TPSCR.G3 | SCIT | 79 | -0.27 | -0.15 | 2.01 |
| TRM29659.00 | SCIS | 42 | 0.59 | 0.78 | 1.13 |
| TRM55971.00 | NONE | 38 | 0.11 | 0.05 | 2.24 |
| TRM41249.00 | SCIT | 36 | 1.31 | 1.88 | 6.15 |
| LEIAR10 | NONE | 31 | -0.54 | -1.50 | 2.67 |
| TRM57971.00 | SCIT | 29 | 1.44 | -0.15 | 5.34 |
| LEIAT504 | LEIS | 21 | -0.15 | 1.04 | 0.91 |
| MPL_WAAS_2225NW | NONE | 20 | -0.40 | 0.21 | 2.27 |
| TRM59800.00 | SCIS | 17 | -0.59 | 1.23 | -2.22 |

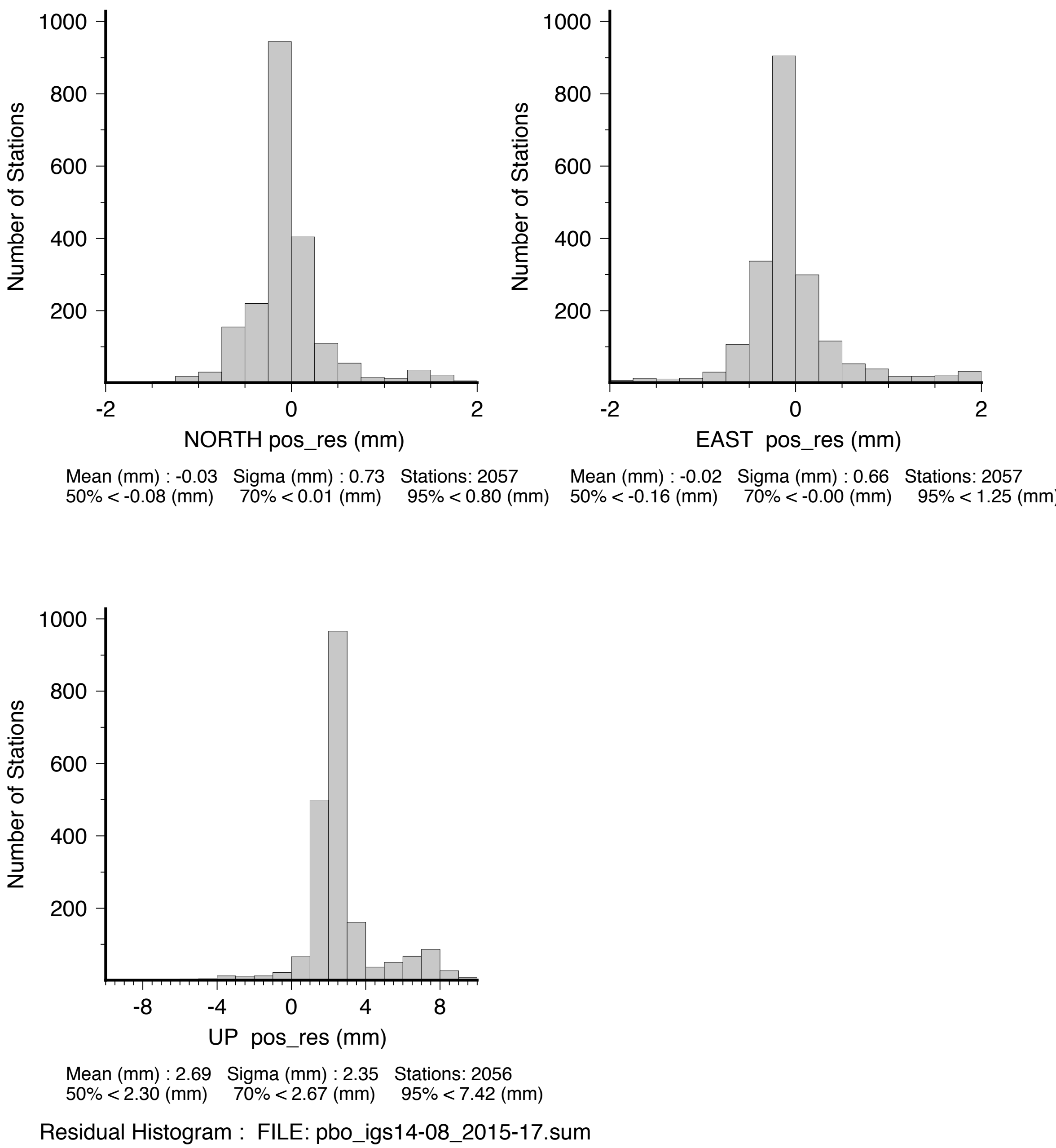


**Figure 1**:  Histogram of the differences in the North, East and Up coordinates for the 2057 stations for selected weeks in 2015-2017 between the IGS14 reprocessing and the IGS08 operational processing.  Both analyses are aligned to the same NAM08 reference frame using ~500 stations each day.

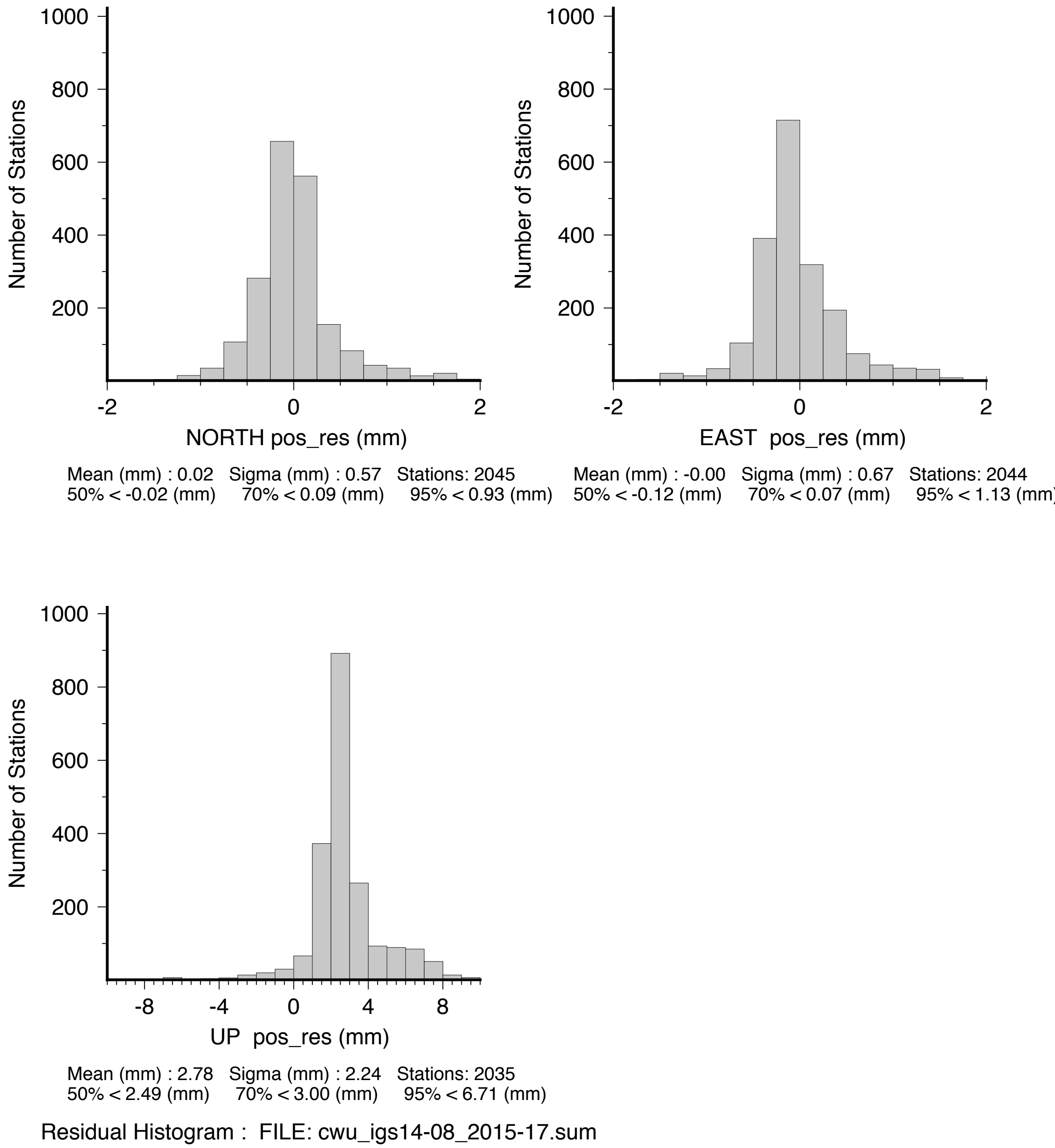


**Figure 2**: Similar to Figure 1 except for the CWU analysis.

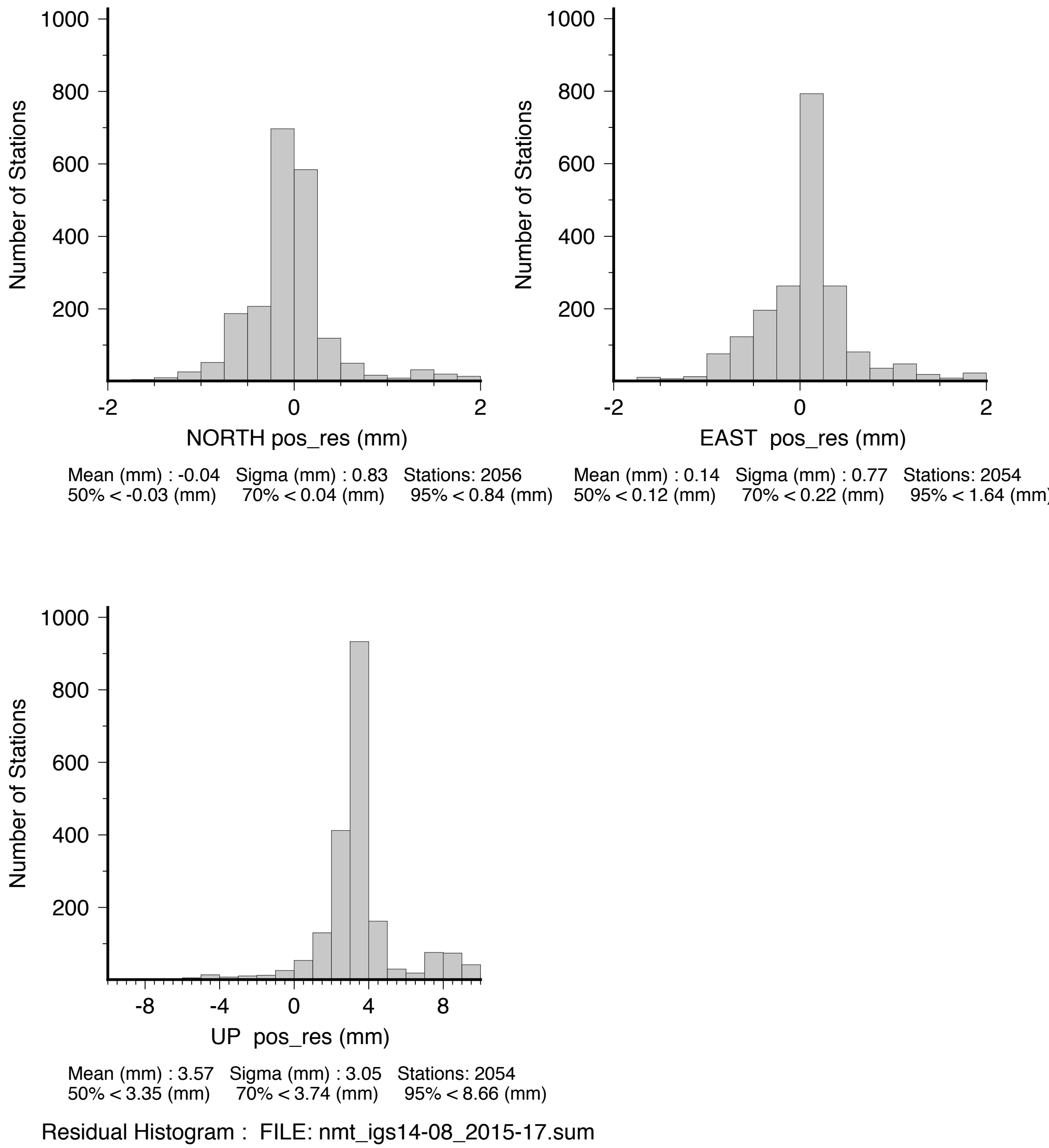


**Figure 3**: Similar to Figure 1 except for the NMT analysis.

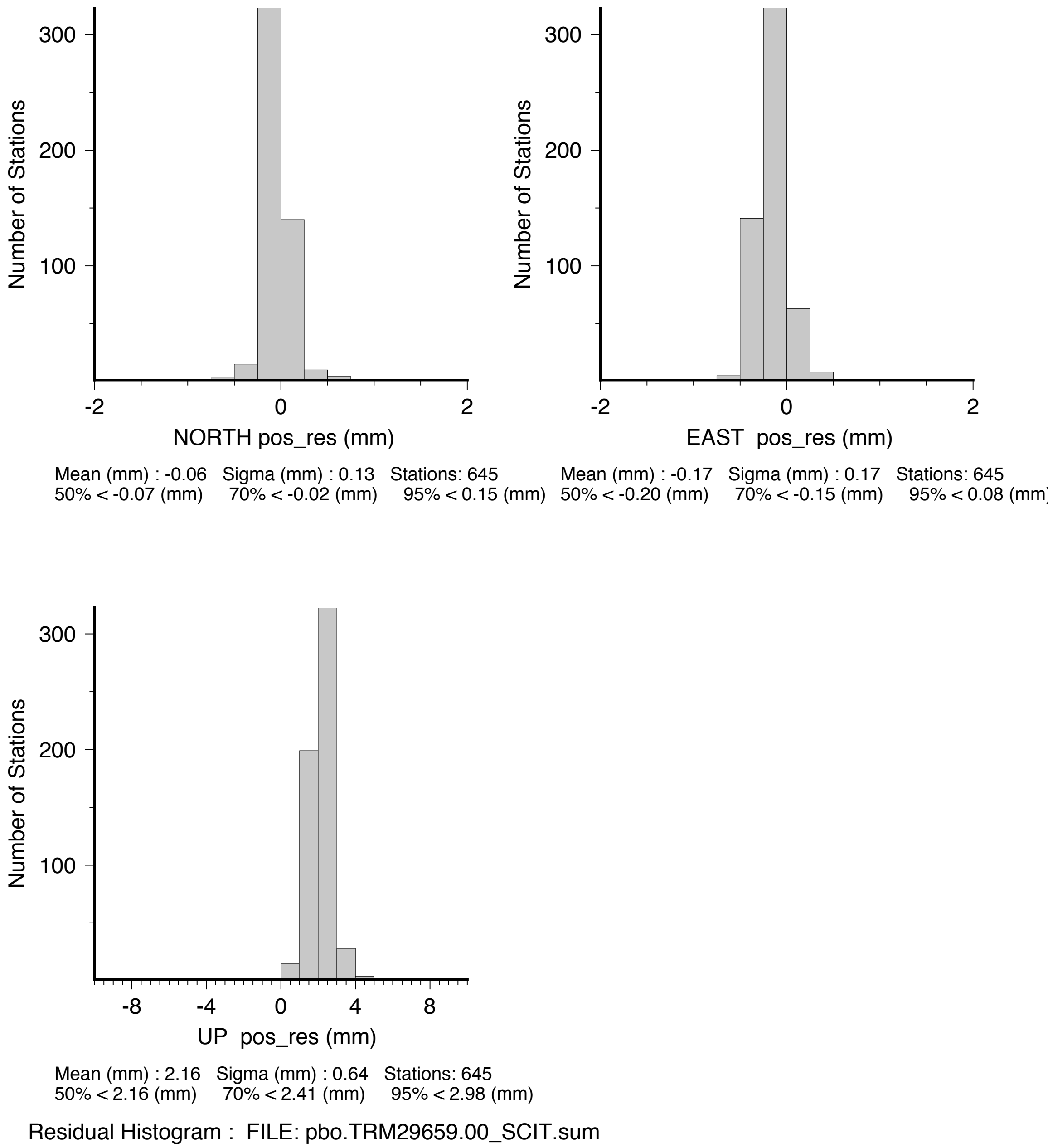


**Figure 4**: Similar to Figure 1 except from the combined PBO analysis for sites with the TRM29659.00 SCIT antenna/radome.

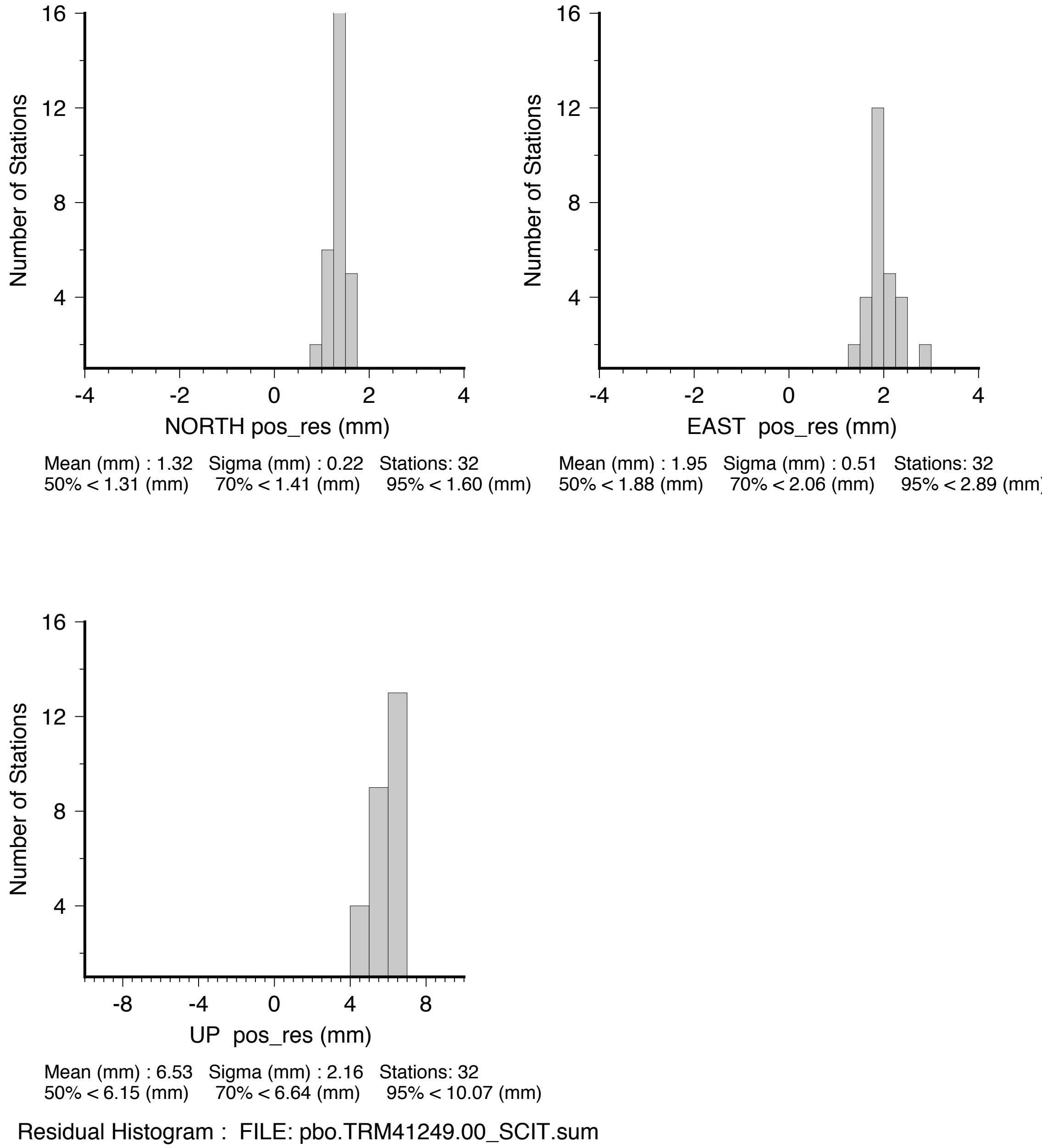


**Figure 5**: Similar to Figure 1 except from the combined PBO analysis for sites with the TRM41249.00 SCIT antenna/radome.

**GAMIT/GLOBK Community Support**

We have updated tables to support added new receivers and antennas and continued to provide regular updates for differential code biases (DCBs), mapping functions (VMF1), and atmospheric loading required by GAMIT users.

We continue to spend 5-10 hours per week in email support of users. During the quarter, April-June, 2018, we issued 21 additional royalty-free licenses to educational and research institutions. The list licensees and their institutions is given in Table C1.

**Table C1**: Licensees and their institutions issued with GAMIT/GLOBK licenses between April and June 2018.

| Date | Contact | Institution | Country |
|---|---|---|---|
| 180403 | Dr. V.C. Ozebo | Department of Physics, University of Lagos | Nigeria. |
| 180408 | Dr. GONG Wenfei | School of Electronic and Information Engineering, Beijing Jiaotong University, Beijing | China |
| 180409 | A. Lakshmanan | National Centre for Earth Science Studies (NCESS), Kerala | India |
| 180411 | Andrey Vilayey | National Center of Space Research and Technology, Almaty | Kazakhstan |
| 180417 | Huseyin Duman | Cumhuiyet University, Geomatics Engineering, Sivas | Turkey |
| 180417 | Smt. A K Anitha, Anjarakandy | Higher Secondary School, Kerala | India |
| 180418 | Prof HUANG Ji-Feng | Ocean University of Chian (OUC), Qingdao | China |
| 180426 | Josefa Varela Guerra | Doutoranda em Oceanografia, Universidade do Estado do Rio de Janeiro (UERJ), Rio de Janeiro | Brasil |
| 180503 | Dr. Feiqin Xie | CMSS/Meteorology Texas A & M University, Corpus Christi | USA |
| 180510 | Prof. BAO Yan | Beijing University of Technology, Beijing | China |
| 180513 | Prof. Mariusz Figurski | Department of Geodesy, Civil and Environmental Engineering, Gdansk University of Technology, Gdansk | Poland |
| 180521 | Dr. LIN Yen-Pin | Coastal Ocean Monitoring Center (COMC),Tainan City | Taiwan |
| 180521 | Farabi Yermekov | Scientific and Educational Center of GIS Technology, Saken Seifullin Kazakh AgroTechnical University, Astana | Kazakhstan |
| 180528 | Dr. Deasy Arisa | Research Center for Geotechnology, | Indonesia |

| | | | |
|---|---|---|---|
| | | Indonesian Institute of Sciences, Jakarta | |
| 180530 | Prof HU Junjie | CPECC East ChinaEnvironmental & Geotechnical Branch, Wuhan | China |
| 180605 | Patrice Boissier | Ingnieur d'Etudes - Dveloppement d'applications,Observatoire Volcanologique, Institut de Physique du Globe de Paris | Reunion |
| 180622 | Manuel Anton | Departmento de Física,Universidad de Extremaduram, Badajoz | Spain |
| 180626 | QIU ZhiJin | Institute of Oceanographic Instrumentation, Shangdong Academy of Sciences (SDIOI), Shangdong | China |
| 180628 | Arian LASKU | State Authority for Geospatial Information (ASIG), Tirana | Albania |
| 180628 | DENG Lian Sheng | Hubei Polytechnic University, Hubei | China |
| 180629 | Dr. Manuel Kleinknecht | Department of Economics, Nurtingen-Geislingen University, Nurtingen | Germany |

*GAMIT/GLOBK Short courses*

Next quarter between July 2-7, 2018, Thomas Herring, Mike Floyd (MIT) and Mason Perry (University of Montana) will teach an advanced GAMIT/GLOBK course in Bishkek, Kyrgyzstan. The class notes for this course are available at http://geoweb.mit.edu/~floyd/courses/gg/201807_Bishkek/.
This course is part of the Central Asia GPS summer school and was sponsored by the German Volkswagen Foundation. The summer school was organized by the Central Asian Institute for Applied Sciences (CAIAS), Helmholtz Center, German Research Center for Geosciences and the Department of Geosciences, and Montana University. Students from Central Asian countries Afghanistan, Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan as well as India will attend the course and have already completed the first part of the course held March 12-17, 2018 in Bishkek.