# 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: 2016/10/01-2016/12/31**

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## Summary

Under the GAGE Facility Data Analysis subcontract, 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 2016/09/15 to 2016/12/17, time series velocity field analyses for the GAGE reprocessing analyses (1996-2016). Several earthquakes were investigated this quarter but only one generated coseismic displacements > 1mm and then only for one station. There were some earthquakes that could be assessed due to no available post-earthquake data although the expected magnitudes for an coseismic displacements were small. For this quarter the last finals results were for December 17, 2016. We added a new bad station table for sites with recently seen high position RMS values. Associated with the report are the ASCII text files that are linked into this document.

The paper describing the GAGE analysis methods and results, Herring, T.A., T. I. Melbourne, M. H. Murray, M. A. Floyd, W. M. Szeliga, R. W. King, D. A. Phillips, C. M. Puskas, M. Santillan, and L. Wang, Plate Boundary Observatory and Related Networks: GPS Data Analysis Methods and Geodetic Products, (2016) *Rev. Geophys*., 54, doi:10.1002/2016RG000529. is now published as an open access article.

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

## 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. 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 orbits. 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 1869 stations were processed compared to 1919 for the previous quarter. The reduction in number of stations could be due to remote site downloads and stations going off-lines

*Level 2a products: 12-week, 26-week supplement products*

Each week we also process the Supplemental (12-week latency) and six month supplemental (26-week latency) analyses from the ACs. The delivery schedule for these products is also unchanged.

*Analysis of Final products: September 15, 2016 and December 17, 2016*

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 September 15, 2016 and December 17, 2016. 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 1.03 mm for all centers and as low as 0.81-0.82 mm for NM north and PBO east components. The up RMS scatters are less than or equal 5.8 mm and as low as 4.56 mm for the PBO solutions. These statistics are somewhat larger than last quarter. Seasonal changes in atmospheric delay properties will introduce small variations in these values quarter to quarter with this quarter being slightly worse than last 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 1869, 1869 and 1867 stations for PBO, NMT and CWU analyzed in the finals analysis between September 15, 2016 and December 17, 2016. Histograms of the RMS scatters are shown in Figure 1-3.

| Center | North (mm) | East (mm) | Up (mm) |
|---|---|---|---|
| *Median (50%)* | | | |
| PBO | 0.83 | 0.82 | 4.56 |
| NMT | 0.81 | 0.86 | 4.57 |
| CWU | 1.03 | 0.95 | 5.75 |
| *70%* | | | |
| PBO | 1.05 | 1.04 | 5.15 |
| NMT | 1.04 | 1.08 | 5.18 |
| CWU | 1.27 | 1.18 | 5.85 |
| *95%* | | | |
| PBO | 1.98 | 2.05 | 7.25 |
| NMT | 2.01 | 2.11 | 7.52 |
| CWU | 2.28 | 2.30 | 8.37 |

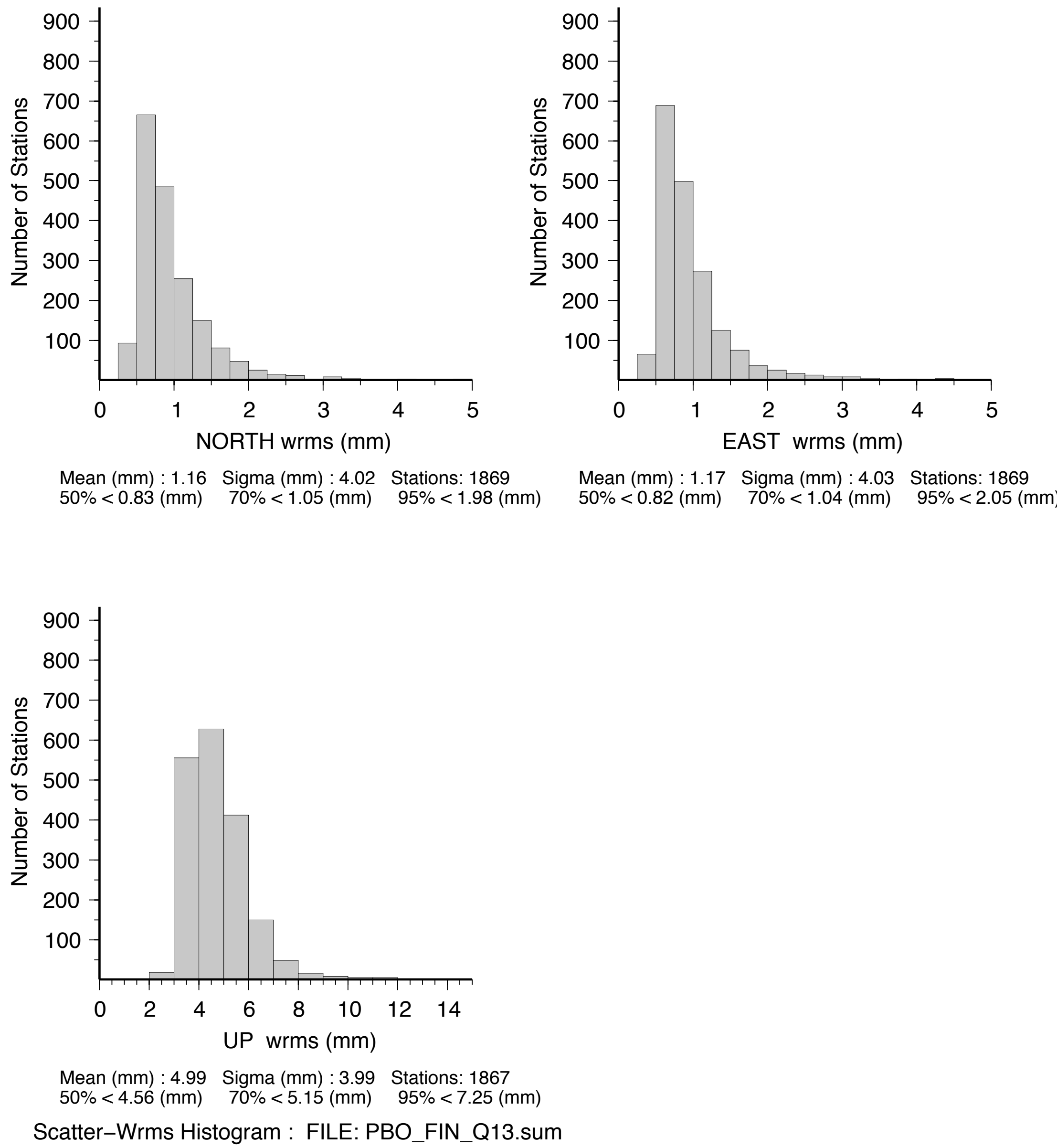


**Figure 1:** PBO combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1869 stations analyzed between September 15, 2016 and December 17, 2016. Linear trends and annual signals were estimated from the time series.

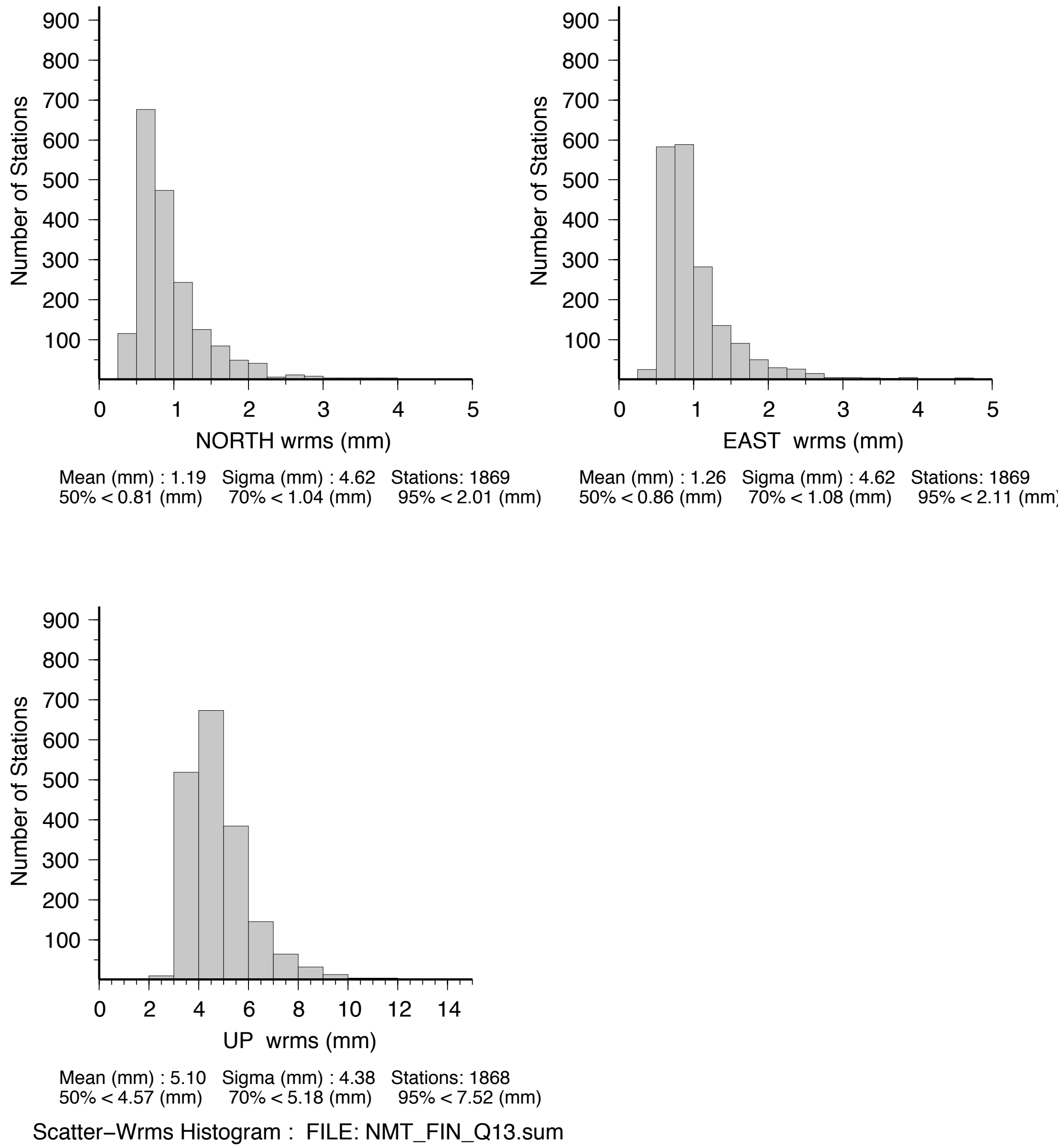


**Figure 2:** NMT combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1869 stations analyzed between September 15, 2016 and December 17, 2016. Linear trends and annual signals were estimated from the time series.

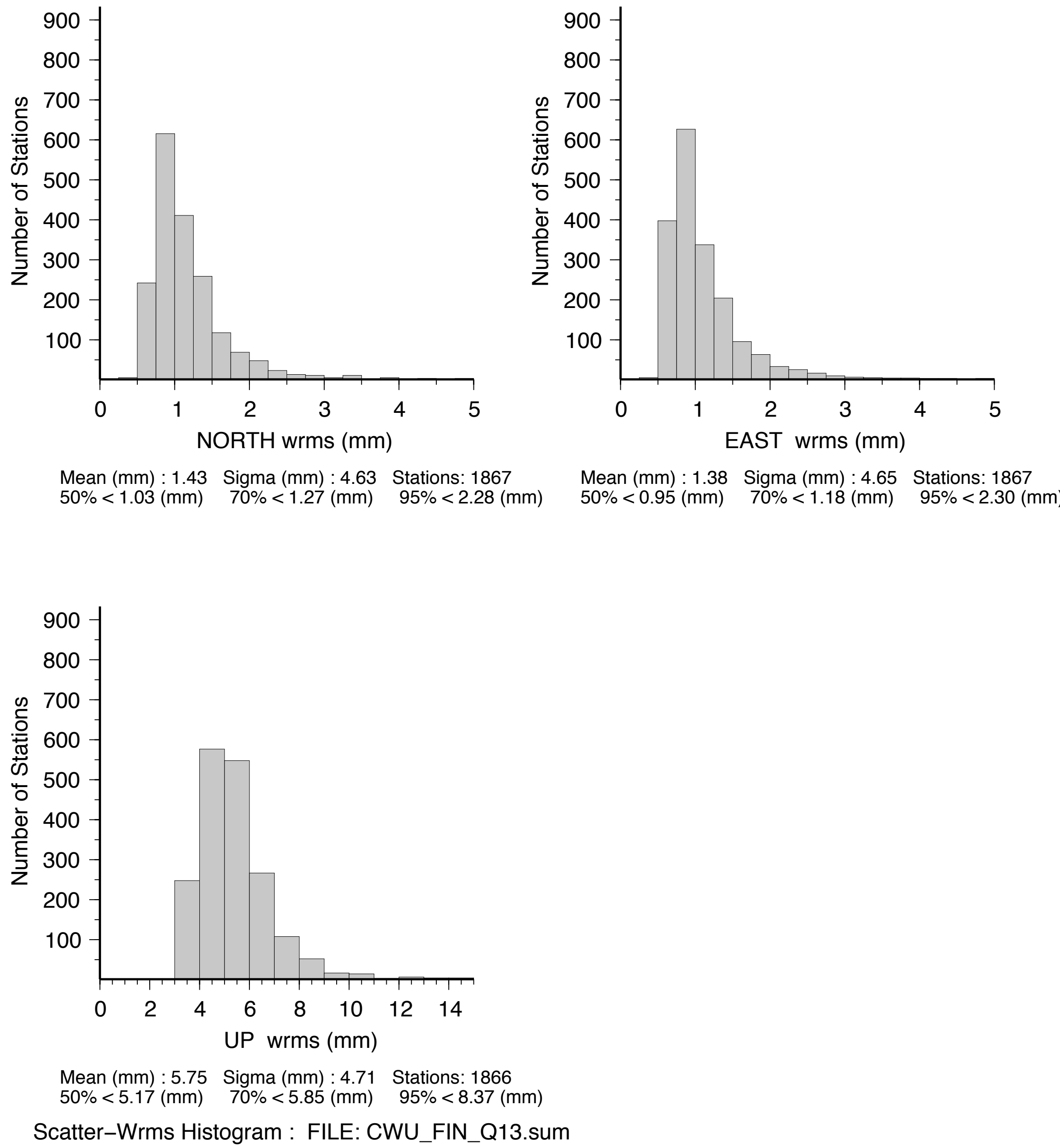


**Figure 3:** CWU combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1867 stations analyzed between September 15, 2016 and December 17, 2016. Editing removes two stations for North and Up. Linear trends and annual signals were estimated from the time series.

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_Q13.tab. There are 1870 stations in the file. The contents of the files are of this form:

```
Tabular Position RMS scatters created from PBO_FIN_Q13.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
 1NSU    94      0.8   0.50      0.8   0.50     4.3   0.64     12.92
 1ULM    65      0.6   0.40      0.7   0.46     3.5   0.56     13.43
 7ODM    91      0.7   0.47      0.6   0.39     3.8   0.66     15.66
 AB02    94      0.7   0.46      0.7   0.62     3.2   0.64      9.57
…
 ZBW1    94      0.8   0.38      0.8   0.46     6.3   0.90     13.54
 ZDC1    94      0.9   0.47      1.1   0.66     5.7   0.89     13.54
 ZDV1    94      0.7   0.35      1.1   0.64     4.5   0.59     13.54
 ZKC1    94      0.7   0.39      0.6   0.42     5.2   0.73     13.77
 ZLA1    94      1.0   0.47      0.8   0.46     5.9   0.90     14.01
 ZME1    94      0.8   0.41      0.6   0.38     4.7   0.69     13.92
 ZMP1    94      0.7   0.33      0.6   0.37     4.6   0.66     13.92
 ZNY1    94      0.7   0.36      0.8   0.49     4.8   0.66     14.12
 ZSE1    94      0.8   0.37      0.7   0.40     0.0   0.00      0.00
 ZTL4    94      0.7   0.40      0.7   0.39     0.0   0.00      0.00
```

**Table 2**: RMS scatter of the position residuals for the PBO combined solution between September 15, 2016 and December 17, 2016 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, Expanded_PBO, COCONet and Expanded_PBO

| Network | North (mm) | East (mm) | Up (mm) | #Sites |
|---|---|---|---|---|
| *Median (50%)* | | | | |
| PBO | 0.79 | 0.80 | 4.32 | 837 |
| NUCLEUS | 0.72 | 0.73 | 3.95 | 207 |
| USGS SCIGN | 0.77 | 0.79 | 4.20 | 128 |
| Expanded | 0.84 | 0.82 | 4.88 | 571 |
| GAMA | 0.54 | 0.55 | 4.86 | 13 |
| COCO Net | 1.40 | 1.38 | 5.81 | 113 |
| *70 %* | | | | |
| PBO | 1.01 | 0.98 | 4.79 | |
| NUCLEUS | 0.85 | 0.87 | 4.56 | |
| USGS SCIGN | 1.01 | 1.00 | 4.15 | |
| Expanded | 1.00 | 1.03 | 5.31 | |
| GAMA | 0.58 | 0.57 | 4.96 | |
| COCO Net | 1.57 | 1.59 | 4.00 | |
| *95%* | | | | |
| PBO | 1.94 | 1.94 | 6.66 | |
| NUCLEUS | 1.57 | 1.39 | 6.39 | |
| USGS SCIGN | 1.88 | 2.50 | 6.68 | |
| Expanded | 2.14 | 2.24 | 7.55 | |
| GAMA | 0.72 | 0.60 | 5.23 | |
| COCO Net | 2.67 | 3.00 | 9.47 | |

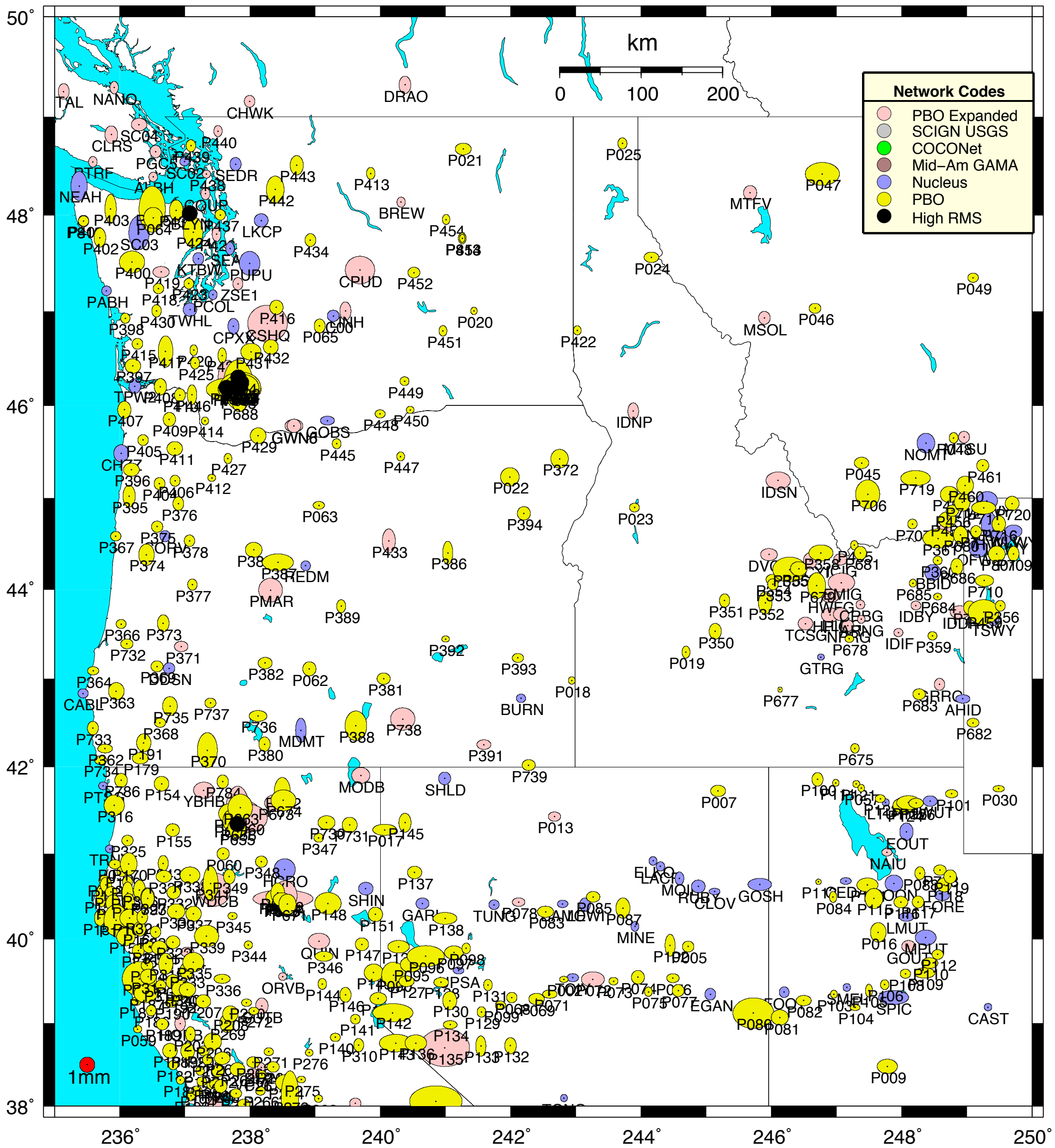


**Figure 4:** Distribution of the RMS scatters of horizontal position estimates from the PBO combined analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows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

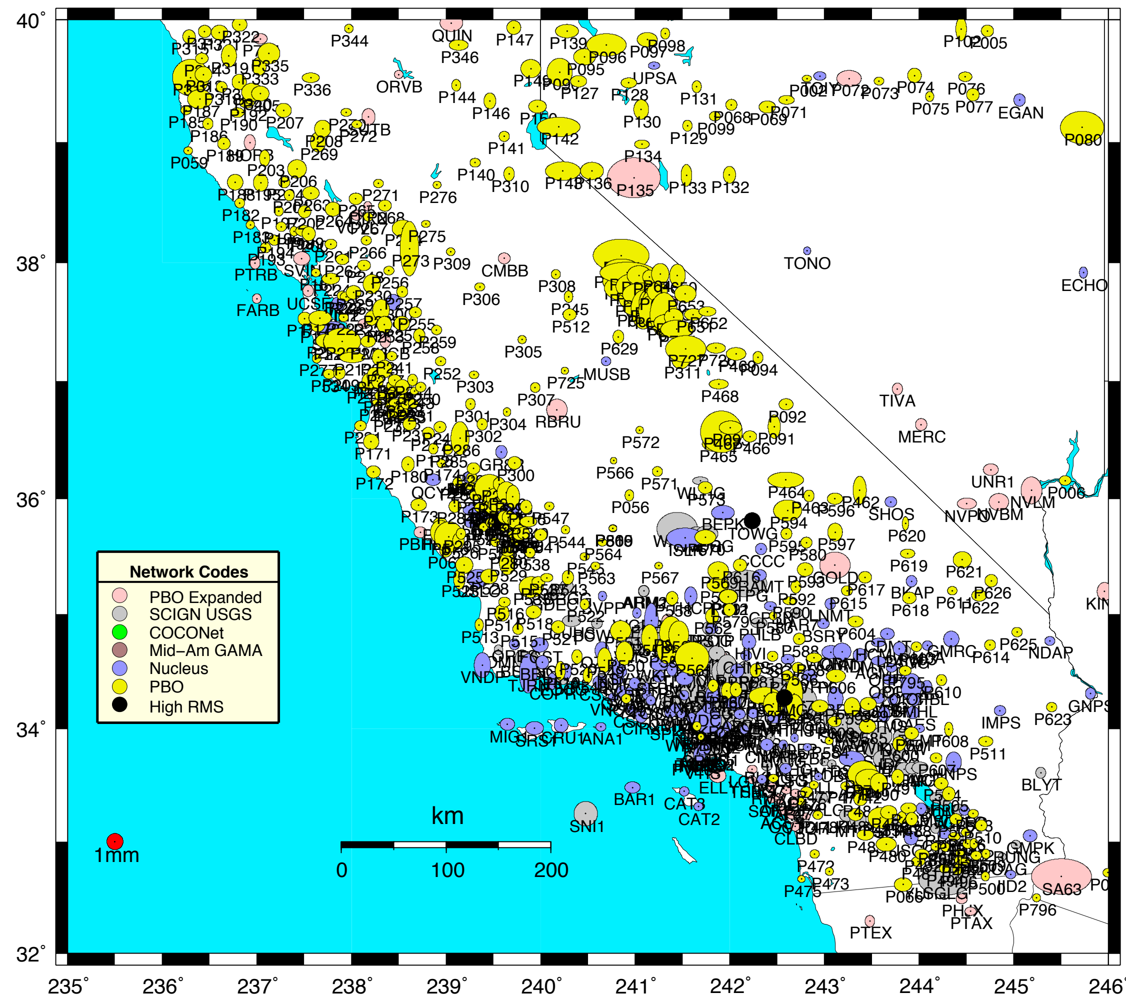


**Figure 5**: Same as Figure 4 except for the Southern Western United States. Black circles in the Yucca mountain region have no data during this 3-month period.

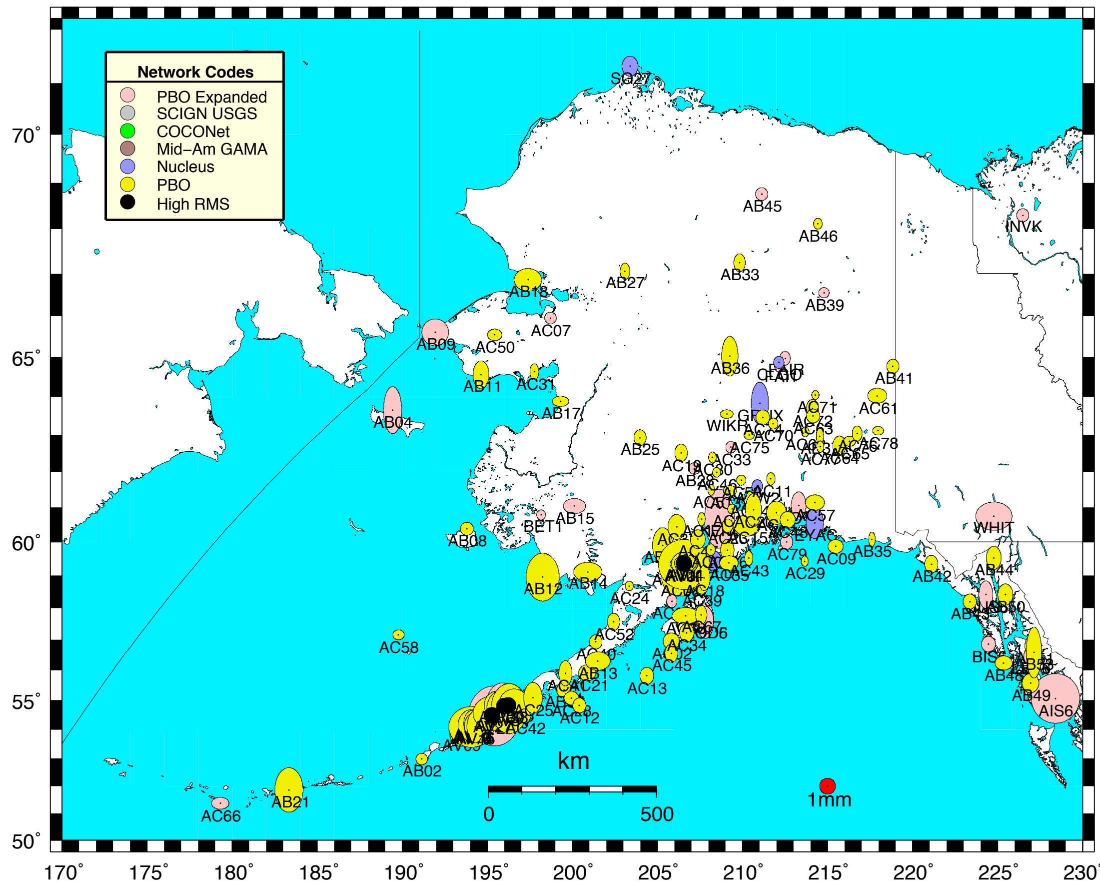


**Figure 6**: Same as Figure 4 except for the Alaskan region.

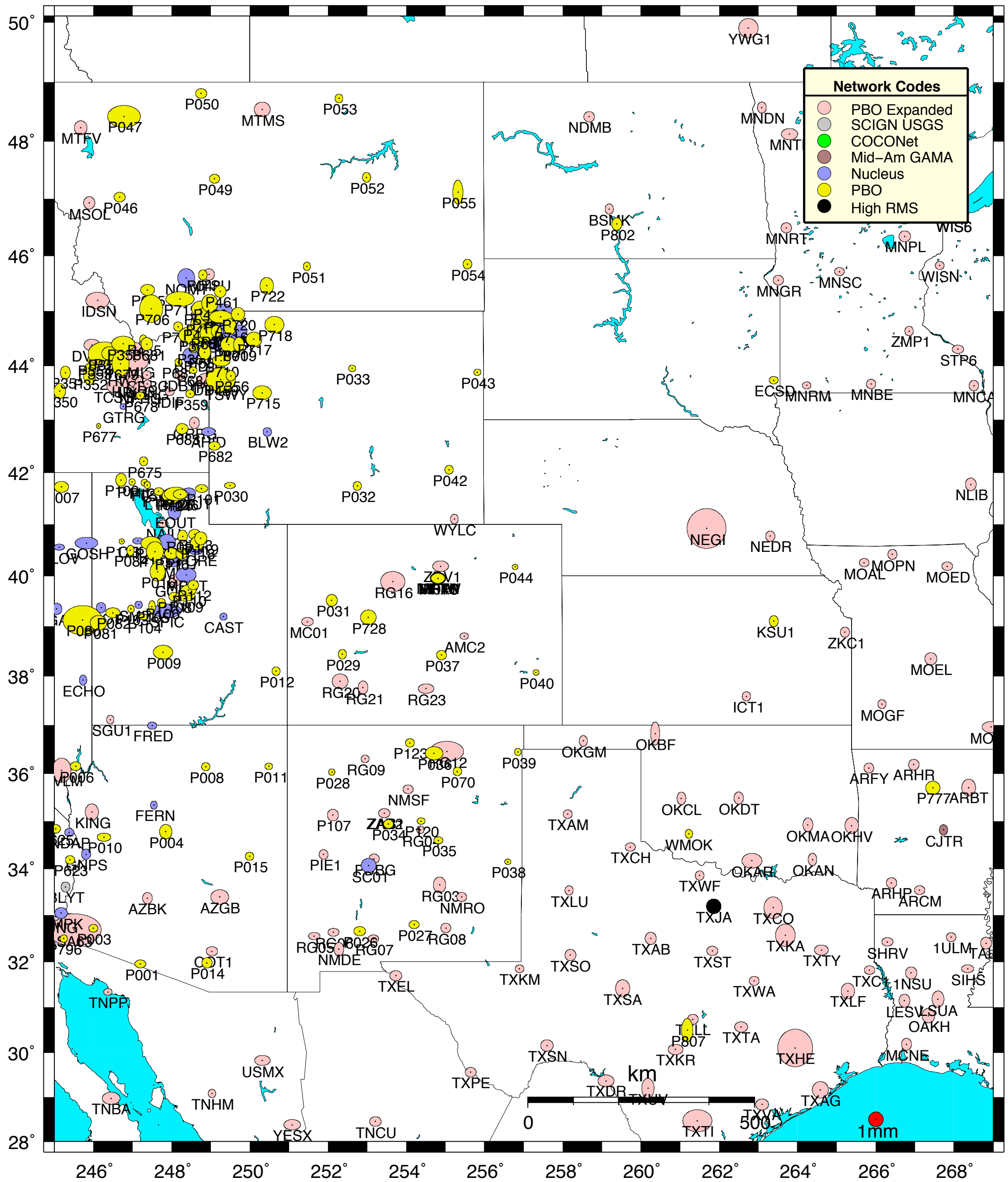


**Figure 7:** Same as Figure 4 except for the Central United States

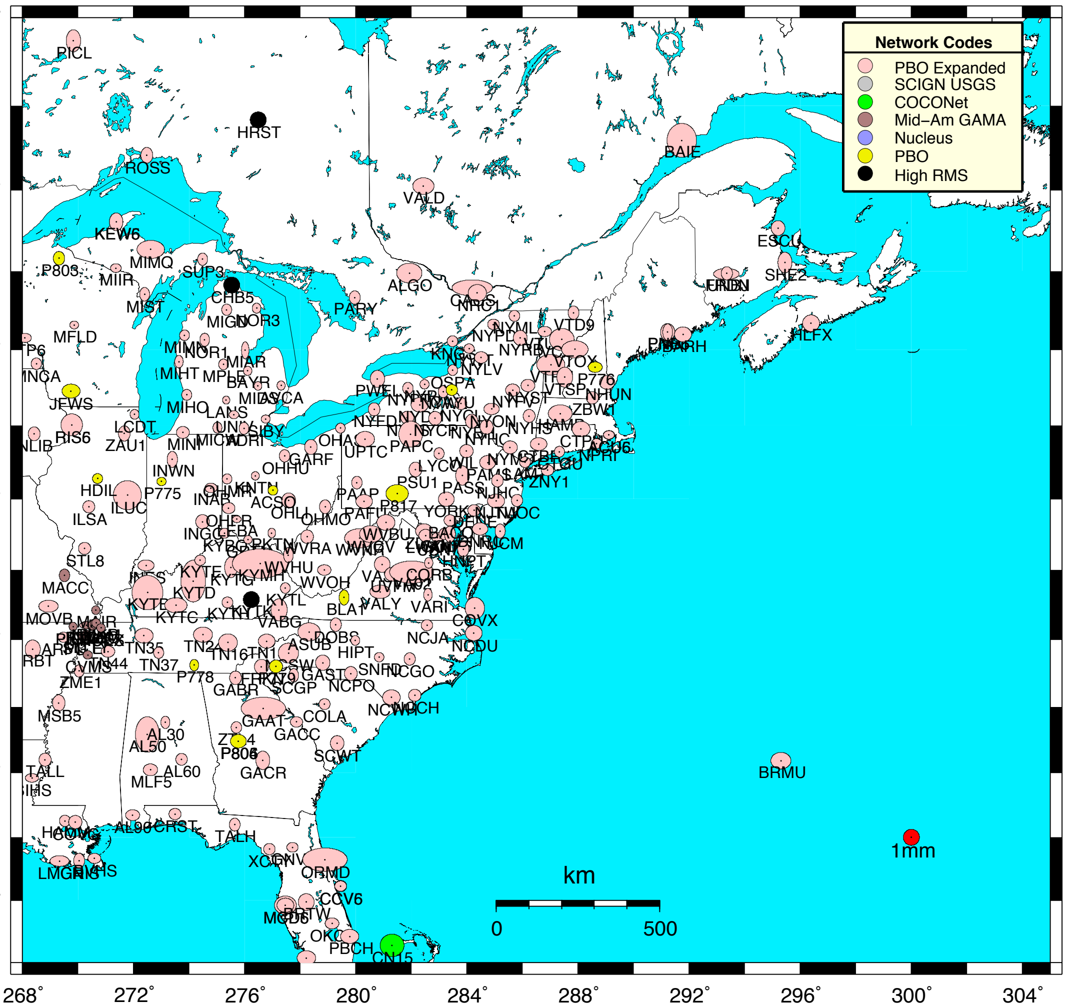


**Figure 8:** Same as Figure 4 except for the Eastern United States

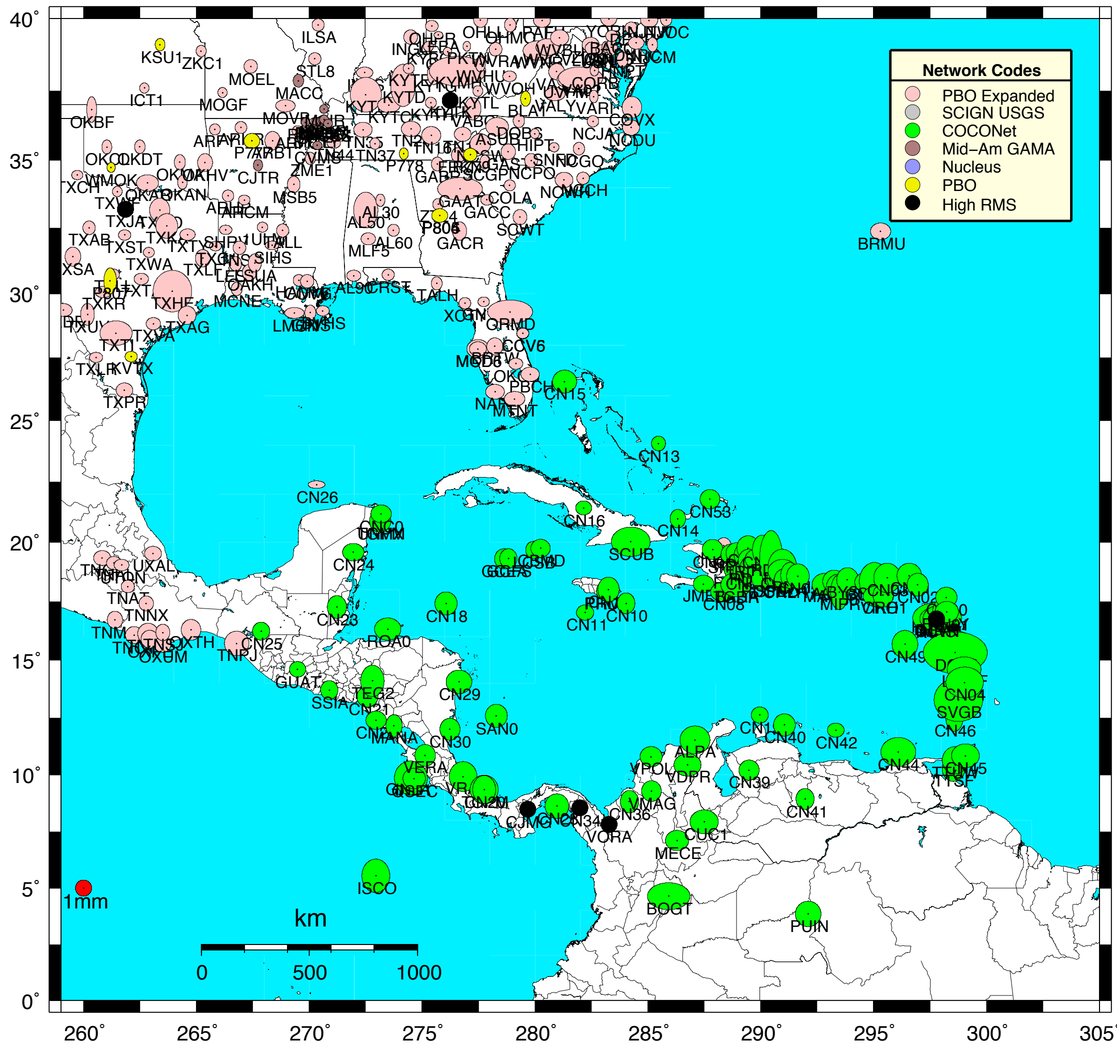


**Figure 9:** Same as Figure 4 except for the Caribbean region.

*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. These links point to the current earthquake and discontinuity files used in the GAGE ACC analyses: 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.

*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 2191 stations in the combined PBO solution which less than the count from last quarter due to a difference in counting methods. In previous quarters this value was the site pairs compared which included comparison between closely spaced stations (see caption to Table 5). The value from the previous quarter computed in the same manner is 2183. The statistics of the fits to results are shown in Table 4. 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 fits along with the duration of the data used are given in the following linked files: pbo_nam08_160917.tab, nmt_nam08_160917.tab and cwu_nam08_1603917.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_160917.snpvel, nmt_nam08_160917snpvel and cwu_nam08_160917.snpvel.

**Table 4:** Statistics of the fits of 2191, 2190 and 2184 stations analyzed by PBO, NMT and CWU in the reprocessed analysis for data collected between Jan 1, 1996 and December 17, 2016.

| Center | North (mm) | East (mm) | Up (mm) |
|---|---|---|---|
| *Median (50%)* | | | |
| PBO | 1.13 | 1.17 | 5.31 |
| NMT | 1.13 | 1.22 | 5.73 |
| CWU | 1.35 | 1.32 | 5.99 |
| *70%* | | | |
| PBO | 1.46 | 1.49 | 5.99 |
| NMT | 1.47 | 1.58 | 6.46 |
| CWU | 1.66 | 1.63 | 6.78 |
| *95%* | | | |
| PBO | 3.18 | 3.10 | 9.01 |
| NMT | 3.19 | 3.13 | 9.18 |
| CWU | 3.41 | 3.33 | 10.37 |

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 0.73 mm/yr vertical from differences of all stations with in 0.5 meters of each other (the difference in number of values arises from groups of sites within). The $\chi^2/f$ of the difference is $(1.19)^2$ for the horizontal and $(2.02)^2$ vertical components. These comparisons are summarized in Table 5. As noted in previous reports, adding small minimum sigmas, computed such that $\chi^2/f$ is near unity changes the statistic slightly (Table 5). With the FOGMEX correlated noise model used to compute the velocity sigmas, the comparison statistics are close but still 19-102% optimistic over expectations. The 10-worst stations are PBHR, RHCG, MCD5, P282, MCD1, AC59, MYT2, SAV1, SAV5, and LST1. This is similar to the list in the previous quarter but some stations have added and removed.

**Table 5:** Statistics of the differences between the CWU and NMT velocity solutions with no transformation between them. In these comparisons stations with the same names and within 0.5 meters of each other are included and the total number of comparisons is larger than the number of stations. The PBO, NMT and CWU solutions themselves have 2191, 2190 and 2184 stations. WRMS is weighted-root-mean-scatter and NRMS is sqrt($\chi^2$/f) where f is the number of comparisons. Larger numbers of stations appear below because stations with 500 meters of each other are included in the counts.

| Solution | # | NE WRMS | U WRMS | NE NRMS | U NRMS |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| | | (mm/yr) | (mm/yr) | | |
| All | 2209 | 0.08 | 0.73 | 1.19 | 2.02 |
| Edited -10 worst | 2195 | 0.07 | 0.72 | 1.07 | 1.99 |
| Less than median (0.14 0.44 mm/yr) | 1245 | 0.06 | 0.66 | 1.12 | 2.18 |
| Added minimum sigma NE 0.03 U 0.25 mm/yr | | | | | |
| All | 2209 | 0.10 | 0.94 | 1.06 | 1.14 |
| Edited -10 worst | 2193 | 0.10 | 0.94 | 0.95 | 1.10 |
| Less than median (0.15 0.0.67 mm/yr) | 1245 | 0.07 | 0.76 | 0.90 | 1.02 |

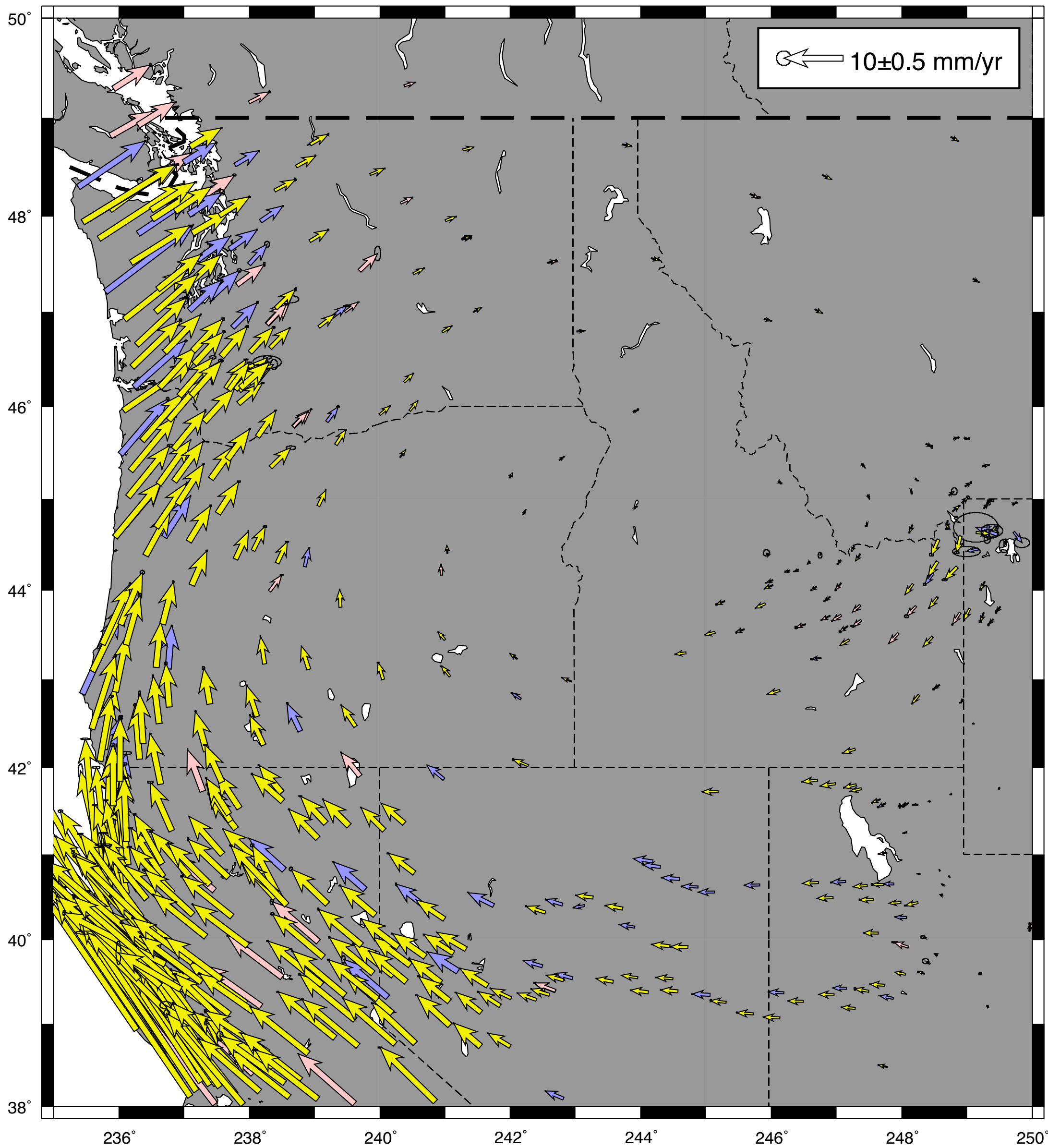


**Figure 10**: Velocity field estimates from the combined PBO solutions generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal standard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

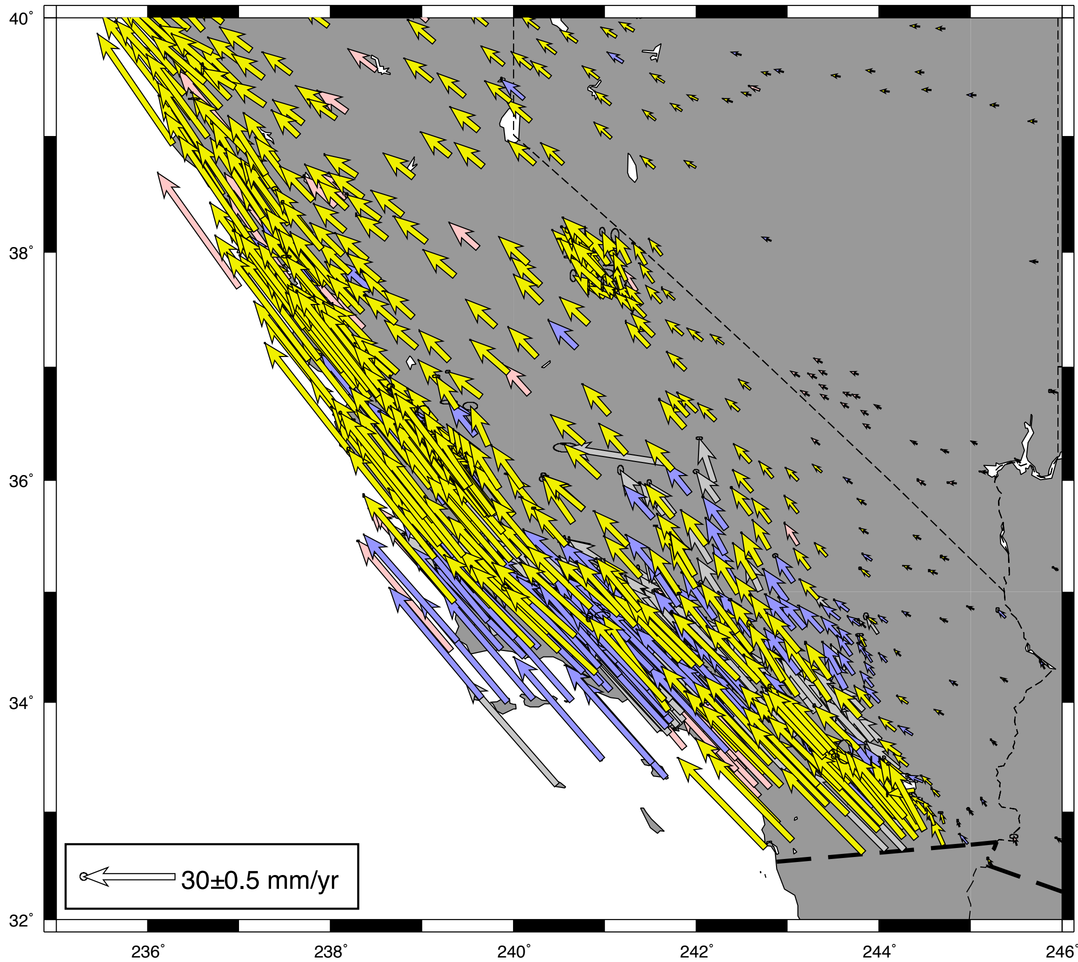


**Figure 11:** Same as Figure 10 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

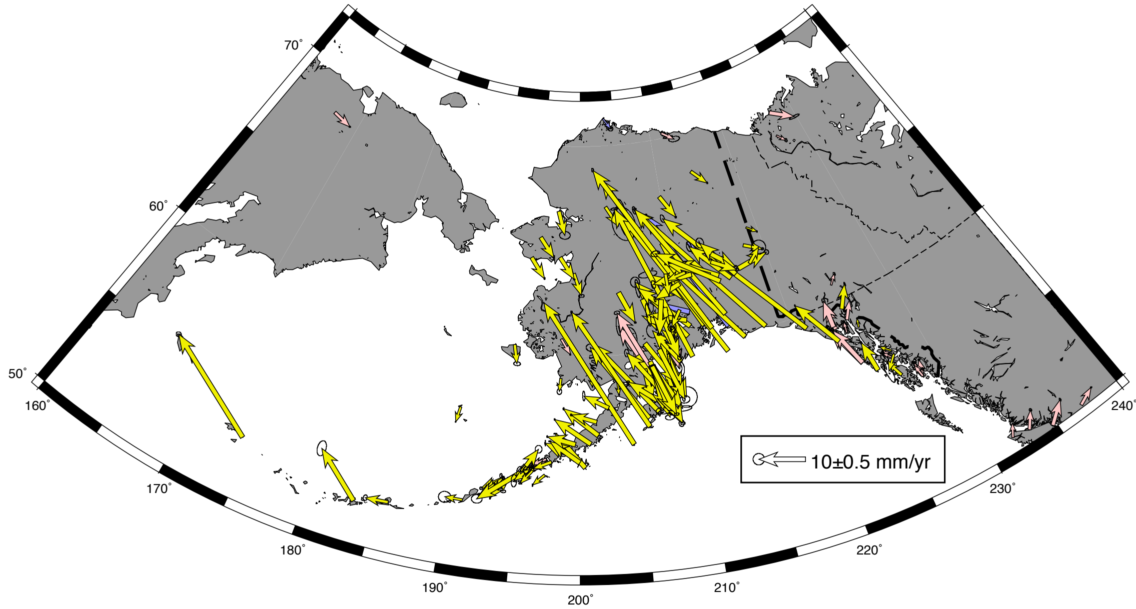


**Figure 12:** Same as Figure 10 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

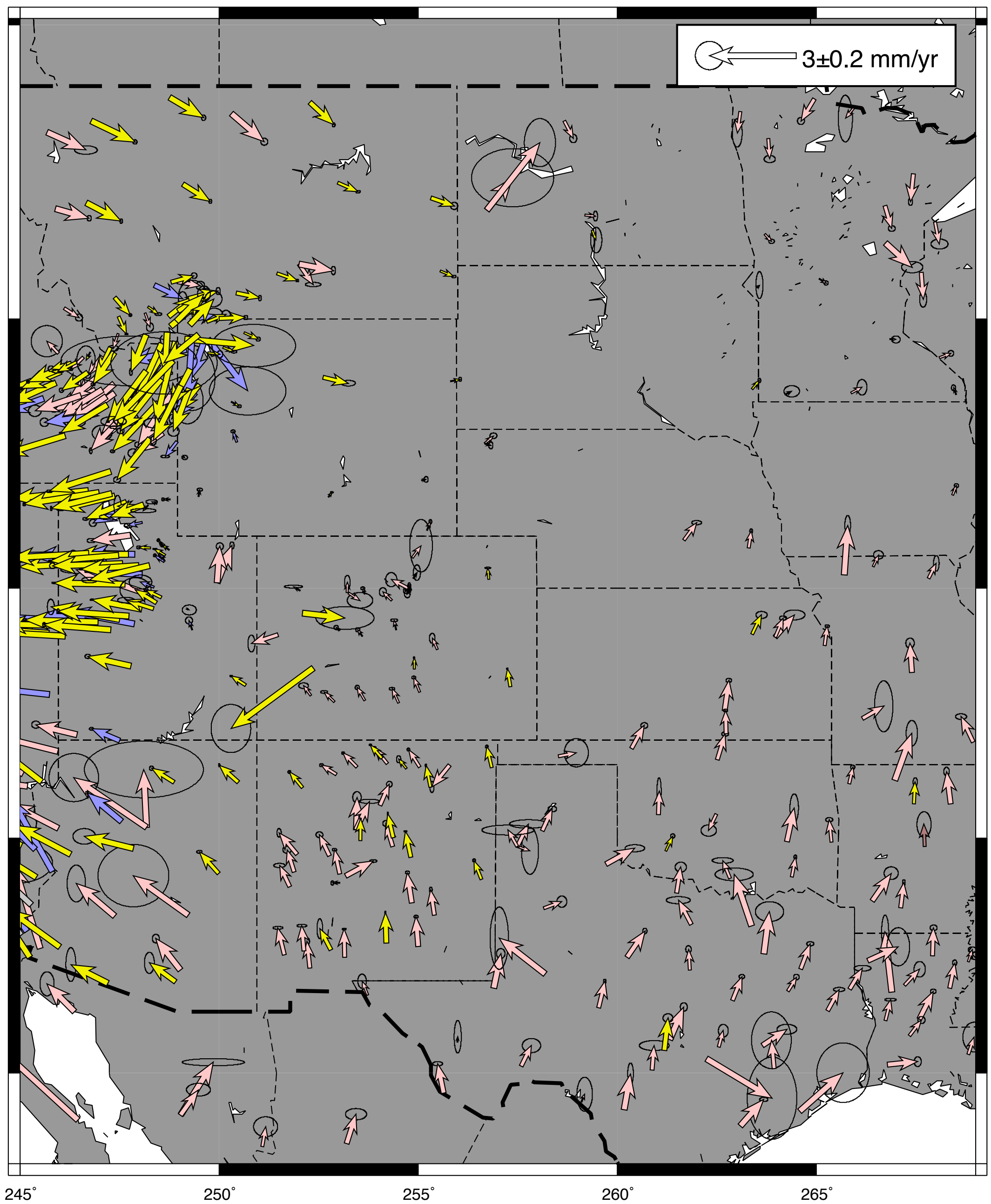


**Figure 13:** Same as Figure 10 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

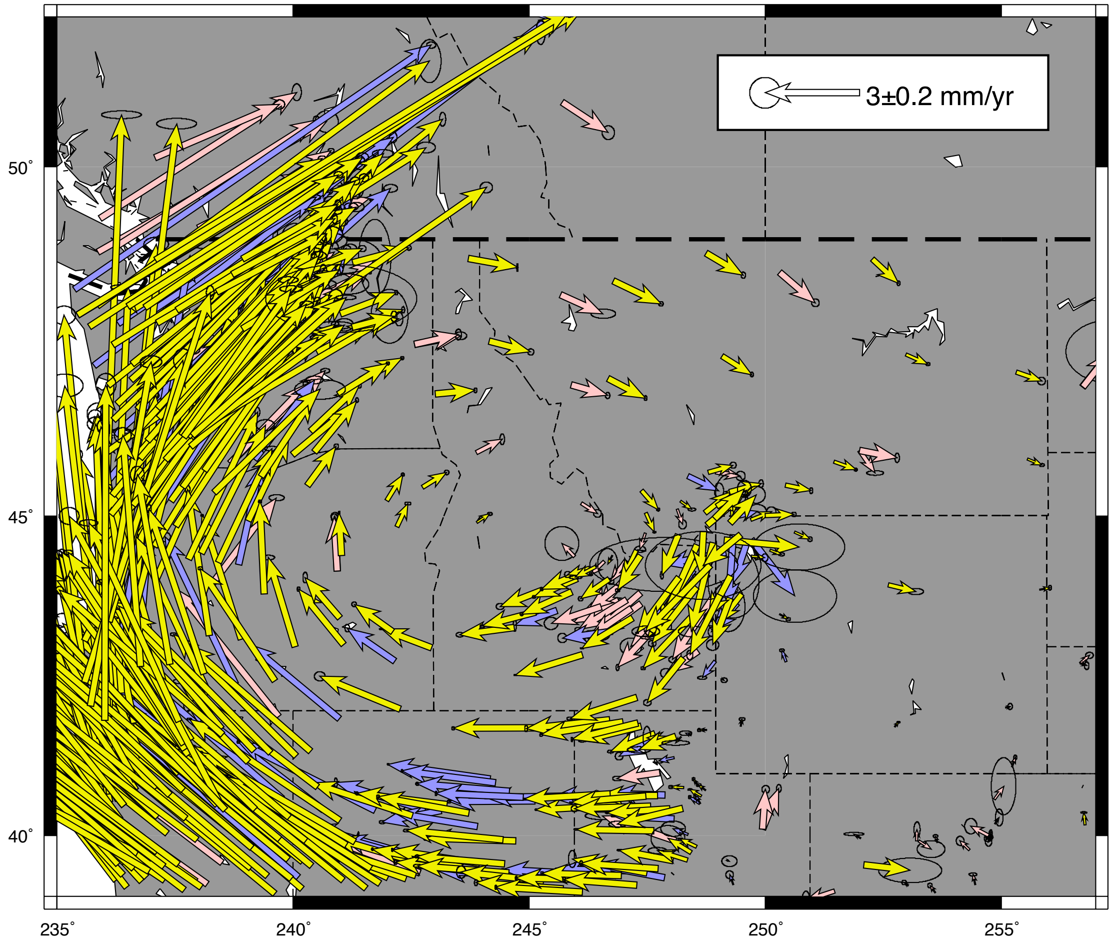


**Figure 14:** Same as Figure 10 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250$^{o}$ are in the Yellowstone National Park and most likely are showing volcanic processes.

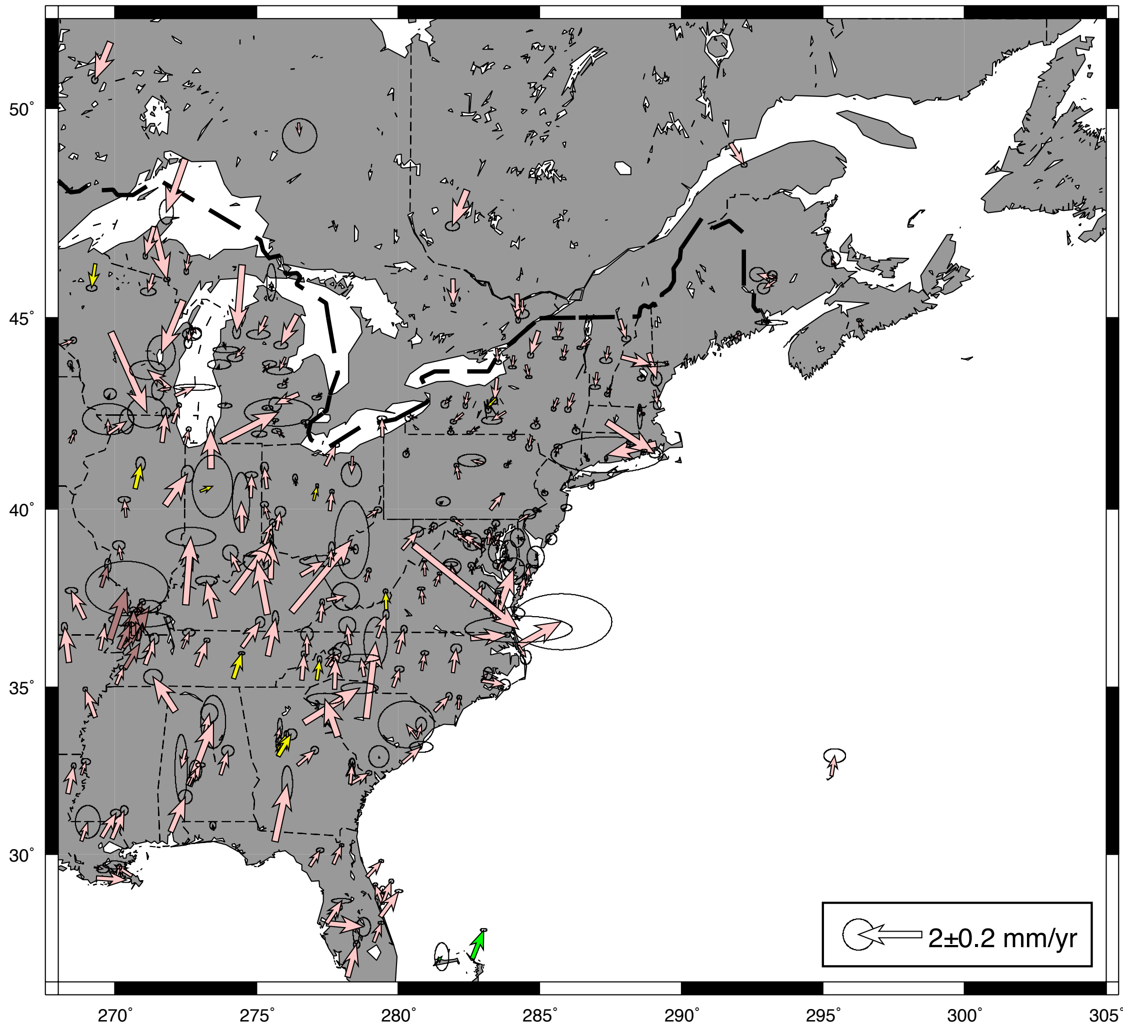


**Figure 15:** Same as Figure 10 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities. The vertical motions 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.

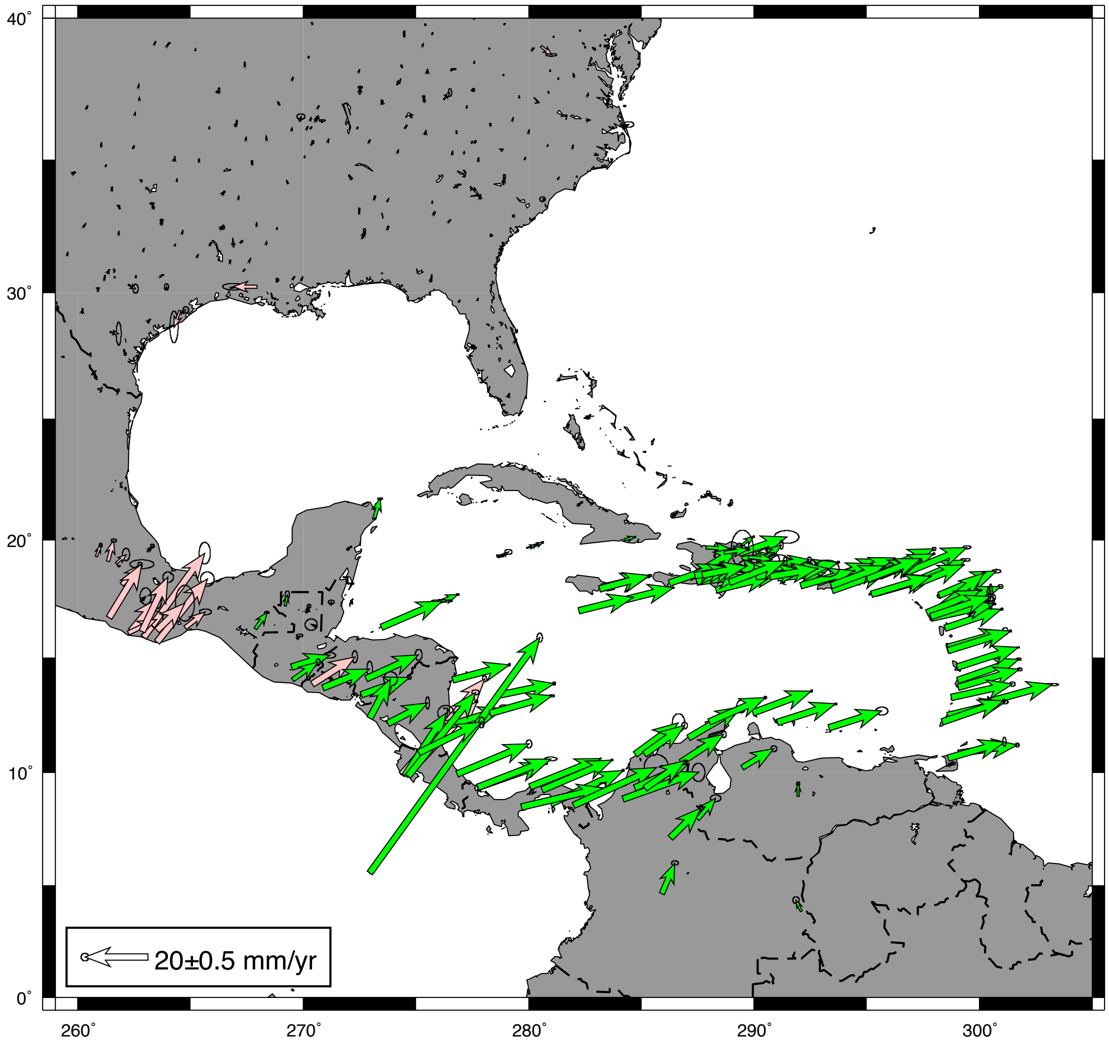


**Figure 16:** Same as Figure 10 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

*Earthquake Analyses: 2016/09/14-2016/12/15.*

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).

In September/October   2016 we investigated the following events.

```
* EQDEFS for 2016 09 14 to 2016 10 15 Generated Mon Oct 17 09:22:57 EDT 2016
* Proximity based on Week_All.Pos file
* ---------------------------------
* SEQ Earthquake # 1
* EQ 290 AB36_GPS       4.57       8.80 CoS        0.0 mm
* EQ_DEF M3.6 7km W of Manley Hot Springs
 eq_def 01   64.9957 -150.7974      8.8 8 2016 09 23 13 27    0.000
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.000      0.000      0.000
* ---------------------------------
* SEQ Earthquake # 2
* EQ 385 BOMG_GPS       7.62      10.50 CoS        2.2 mm
* EQ_DEF M4.3 6km SSE of Bombay Beach
 eq_def 02   33.2977 -115.7137     10.5 8 2016 09 26 14 32    0.002
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.002      0.002      0.002
* ---------------------------------
* SEQ Earthquake # 3
* EQ 397 BOMG_GPS       7.43      10.70 CoS        2.3 mm
* EQ_DEF M4.3 6km SSE of Bombay Beach
 eq_def 03   33.2998 -115.7123     10.7 8 2016 09 27 03 24    0.002
 eq_rename 03
 eq_coseis 03  0.001 0.001 0.001      0.002      0.002      0.002
* ---------------------------------
* SEQ Earthquake # 4
* EQ 398 BOMG_GPS       7.12       9.90 CoS        1.3 mm
* EQ_DEF M4.1 6km SSE of Bombay Beach
 eq_def 04   33.3058 -115.7010      9.9 8 2016 09 27 03 37    0.001
 eq_rename 04
 eq_coseis 04  0.001 0.001 0.001      0.001      0.001      0.001
* ---------------------------------
* SEQ Earthquake # 5
* EQ 427 BOMG_GPS       7.56       8.90 CoS        0.0 mm
* EQ_DEF M3.6 6km SSE of Bombay Beach
 eq_def 05   33.2987 -115.7118      8.9 8 2016 09 28 01 06    0.000
 eq_rename 05
 eq_coseis 05  0.001 0.001 0.001      0.000      0.000      0.000
* ---------------------------------
* SEQ Earthquake # 6
* EQ 696 AC03_GPS       8.01       9.30 CoS        1.0 mm
* EQ_DEF M3.9 3km ESE of Anchor Point
 eq_def 06   59.8312 -151.7888      9.3 8 2016 10 14 12 60    0.001
 eq_rename 06
 eq_coseis 06  0.001 0.001 0.001      0.001      0.001      0.001
```

Event 1 shows strange bi-modal annual position change in North but no co-seismic offset
Event 2-5 shows no offset at BOMG during this swam but this is very systematic site.
Event 6: No offset but possible rate change after eq_def 37 (2016 01 24 M 7.1). Change also looks similar to slow event starting early 2010.  Only a couple of rapid data after event will explore again next monthly report.

None of these earthquakes generated measurable co-seismic offsets at any site.

In October/November 2016 the following events were investigated

```
* EQDEFS for 2016 10 14 to 2016 11 15 Generated Tue Nov 15 09:10:53 EST 2016
* Proximity based on Week_All.Pos file
* ---------------------------------
```

```
* SEQ Earthquake # 1
* EQ 15 AC03_GPS       6.13       9.60 CoS        1.7 mm
* EQ_DEF M4.0 3km ESE of Anchor Point
 eq_def 01   59.8029 -151.7772      9.6 8 2016 10 14 12 60    0.001
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.001      0.001      0.001
* ------------------------------------
* SEQ Earthquake # 2
* EQ 152 CN48_GPS      25.66      28.50 CoS        5.1 mm
* EQ 152 DOMI_GPS      14.63      28.50 CoS       15.6 mm
* EQ_DEF M5.6 12km WSW of Pointe Michel
 eq_def 02   15.2179  -61.4913     28.5 8 2016 10 18 22 09    0.052
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.052      0.052      0.052
* ------------------------------------
* SEQ Earthquake # 3
* EQ 191 AV26_GPS       8.03       8.70 CoS        0.0 mm
* EQ_DEF M3.5 73km WSW of False Pass
 eq_def 03   54.6151 -164.4825      8.7 8 2016 10 20 22 03    0.000
 eq_rename 03
 eq_coseis 03  0.001 0.001 0.001      0.000      0.000      0.000
* ------------------------------------
* SEQ Earthquake # 4
* EQ 313 ABMF_GPS       6.71      12.10 CoS        5.7 mm
* EQ_DEF M4.6 3km NE of Le Gosier
 eq_def 04   16.2340  -61.4735     12.1 8 2016 10 25 18 46    0.004
 eq_rename 04
 eq_coseis 04  0.001 0.001 0.001      0.004      0.004      0.004
* ------------------------------------
* SEQ Earthquake # 5
* EQ 488 P314_GPS       4.87       9.20 CoS        2.7 mm
* EQ_DEF M3.8 13km WSW of Laytonville
 eq_def 05   39.6622 -123.6312      9.2 8 2016 11 03 12 58    0.001
 eq_rename 05
 eq_coseis 05  0.001 0.001 0.001      0.001      0.001      0.001
* ------------------------------------
* SEQ Earthquake # 6
* EQ 530 P314_GPS       5.45       9.70 CoS        2.2 mm
* EQ_DEF M4.1 13km WSW of Laytonville
 eq_def 06   39.6598 -123.6373      9.7 8 2016 11 06 13 01    0.001
 eq_rename 06
 eq_coseis 06  0.001 0.001 0.001      0.001      0.001      0.001
* ------------------------------------
* SEQ Earthquake # 7
* EQ 572 P285_GPS       5.56       8.80 CoS        0.0 mm
* EQ_DEF M3.6 26km NE of Greenfield
 eq_def 07   36.4632 -121.0070      8.8 8 2016 11 09 00 56    0.000
 eq_rename 07
 eq_coseis 07  0.001 0.001 0.001      0.000      0.000      0.000
```

SEQ Earthquake # 4 (EQ 313): No data from ABMF since May 25, 2016. Data went bad (large error bars a fews before stopping) so we can't tell if there is an offset. (Antenna change at P285 might be confused with the last earthquake)

None of the earthquakes generated any measurable co-seismic offsets.

In November/December 2016, the following events were investigated but none show co-seismic offsets.

```
* EQDEFS for 2016 11 14 to 2016 12 15 Generated Mon Dec 19 11:21:53 EST 2016
* Proximity based on Week_All.Pos file
* ------------------------------------
```

```
* SEQ Earthquake # 1
* EQ 170 GRNR_GPS       3.08       9.10 CoS        3.4 mm
* EQ 170 GRNX_GPS       3.08       9.10 CoS        3.4 mm
* EQ_DEF M3.8 2km ESE of Healy
 eq_def 01   63.8481 -148.9236      9.1  8  2016 11 17 07 27    0.0005
 eq_rename 01
 eq_coseis 01  0.0010 0.0010 0.0010      0.0005     0.0005     0.0005
* ---------------------------------
* SEQ Earthquake # 2
* EQ 218 AC33_GPS       6.06       8.70 CoS        0.3 mm
* EQ_DEF M3.5 47km NW of Talkeetna
 eq_def 02   62.6313 -150.7670      8.7  8  2016 11 18 19 20    0.0002
 eq_rename 02
 eq_coseis 02  0.0010 0.0010 0.0010      0.0002     0.0002     0.0002
* ---------------------------------
* SEQ Earthquake # 3
* EQ 314 AC47_GPS       9.21       9.60 CoS        0.7 mm
* EQ_DEF M4.0 51km S of Redoubt Volcano
 eq_def 03   60.0224 -152.7413      9.6  8  2016 11 20 23 25    0.0009
 eq_rename 03
 eq_coseis 03  0.0010 0.0010 0.0010      0.0009     0.0009     0.0009
* ---------------------------------
* SEQ Earthquake # 4
* EQ 461 CN22_GPS     200.37     203.30 CoS        3.0 mm
* EQ 461 SSIA_GPS     195.82     203.30 CoS        3.1 mm
* EQ_DEF M7.0 149km SSW of Puerto El Triunfo
 eq_def 04   11.9597  -88.8355    203.3  8  2016 11 24 18 44    1.8825
 eq_rename 04
 eq_coseis 04  0.0010 0.0010 0.0010      1.8825     1.8825     1.8825
* ---------------------------------
* SEQ Earthquake # 5
* EQ 620 AC47_GPS       9.32      10.50 CoS        1.3 mm
* EQ_DEF M4.3 53km WNW of Anchor Point
 eq_def 05   60.0012 -152.6732     10.5  8  2016 11 30 18 58    0.0018
 eq_rename 05
 eq_coseis 05  0.0010 0.0010 0.0010      0.0018     0.0018     0.0018
* ---------------------------------
* SEQ Earthquake # 6
* EQ 728 P157_GPS       7.36      10.70 CoS        2.5 mm
* EQ_DEF M4.3 33km SW of Rio Dell
 eq_def 06   40.2785 -124.3860     10.7  8  2016 12 05 18 34    0.0021
 eq_rename 06
 eq_coseis 06  0.0010 0.0010 0.0010      0.0021     0.0021     0.0021
* ---------------------------------
* SEQ Earthquake # 7
* EQ 751 CN45_GPS      26.13      41.30 CoS       10.5 mm
* EQ_DEF M5.9 22km SW of Scarborough
 eq_def 07   11.0693  -60.9048     41.3  8  2016 12 06 21 43    0.1120
 eq_rename 07
 eq_coseis 07  0.0010 0.0010 0.0010      0.1120     0.1120     0.1120
* ---------------------------------
* SEQ Earthquake # 8
* EQ 820 CRLR_GPS       6.07       9.60 CoS        1.6 mm
* EQ_DEF M4.0 9km ESE of La Romana
 eq_def 08   18.3810  -68.8949      9.6  8  2016 12 09 06 01    0.0009
 eq_rename 08
 eq_coseis 08  0.0010 0.0010 0.0010      0.0009     0.0009     0.0009
* ---------------------------------
* SEQ Earthquake # 9
* EQ 942 P630_GPS       7.31       9.50 CoS        1.0 mm
* EQ 942 P631_GPS       3.72       9.50 CoS        3.7 mm
* EQ 942 P639_GPS       5.19       9.50 CoS        1.9 mm
* EQ_DEF M4.0 4km ESE of Mammoth Lakes
 eq_def 09   37.6382 -118.9252      9.5  8  2016 12 14 07 45    0.0008
 eq_rename 09
```

```
 eq_coseis 09  0.0010 0.0010 0.0010      0.0008     0.0008     0.0008
* -----------------------------------
* SEQ Earthquake # 10
* EQ 949 P203_GPS       8.28      15.80 CoS       10.4 mm
* EQ_DEF M5.0 8km NW of The Geysers
 eq_def 10   38.8222 -122.8413     15.8  8  2016 12 14 16 42    0.0111
 eq_rename 10
 eq_coseis 10  0.0010 0.0010 0.0010      0.0111     0.0111     0.0111
```

Eq 01 did not generate coseismic offsets but the North and Up coordinates of GRNR and GRNX are very skewed.
Eq 10: M5.0 8km NW of The Geysers 38.8222 -122.8413 2016 12 14 16 42 did effect P203 with coseismic displacements of N 4.61 +- 0.73 mm, E -5.88 +- 0.79 mm, U 0.23 +- 2.53 mm from the Kalman filter processing. WLS estimates are similar. Added as Event 38.

None of the other earthquakes generated any measurable co-seismic offsets.

*Antenna Change Offsets: 2016/09/01-2016/11/30*

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

```
Station      Date           From           To
 LPCG  2016  9  1 19 46 TRM57971.00    TRM41249.00
 P311  2016  9 22 21 50 TRM29659.00    TRM59800.80
 P534  2016  9  9 17 40 TRM29659.00    TRM59800.80
 CN49  2016 10 13 20 45 TRM59800.00    TRM59800.00
 OKAR  2016 10 19  4 47 TRM22020.00+GP LEIAT502
 P096  2016 10 27  0  0 TRM29659.00    TRM59800.80
 P285  2016 10 12 17  8 TRM29659.00    TRM59800.80
 P386  2016 10 13  0  0 TRM29659.00    TRM59800.80
 P447  2016 10 14  0  0 TRM29659.00    TRM59800.80
 P664  2016 10  7  0  0 NONE           SCIT
 P665  2016 10  7  0  0 NONE           SCIT
 P278  2016 11 15 22 51 TRM29659.00    TRM59800.80
```

*Analysis*

LPCG WLS dNEU 4.45 +- 1.46, 5.06 +- 1.63, -2.69 +- 9.63 mm,
KF dNEU 3.57 +- 0.34, 4.40 +- 0.32, -0.62 +- 1.38 mm
Gap in time series before antenna change, but offset look significant.
P311 WLS dNEU 2.07 +- 4.49, 0.21 +- 1.57, 0.59 +- 8.42 mm,
KF dNEU -0.78 +- 0.36, -0.57 +- 0.27, 3.43 +- 1.06 mm
Gap in time series before antenna change. Systematics make assessment of break difficult. No very significant in Kalman filer estimate.
P534 WLS dNEU 0.68 +- 0.79, -0.64 +- 1.28, -1.97 +- 6.36 mm,
KF dNEU 0.59 +- 0.25, -1.49 +- 0.23, -1.88 +- 0.89 mm
East break can be seen in data. Northh and Up are less clear.

CN49 : WLS dNEU -1.73 +- 0.66, -4.50 +- 0.91, -17.16 +- 5.89 mm,
KF dNEU -1.66 +- 1.13, -4.51 +- 1.28, -14.94 +- 5.02 mm

Very new station with data gaps.  It
OKAR : WLS dNEU  -11.82 +- 4.02, -18.77 +- 8.20, -25.01 +- 19.49 mm,
KF dNEU  -11.17 +- 0.63, -13.34 +- 0.58, -20.87 +- 2.49 mm
Offsets are clear in the time series.
P096 : WLS dNEU   -1.46 +- 1.55,   4.91 +- 1.52,  -2.42 +- 6.94 mm,
KF dNEU   -1.29 +- 0.47,   4.56 +- 0.41,  -2.56 +- 1.61 mm
Gap in data (some days before swap are available).  East offset looks real.
P285 : WLS dNEU    3.32 +- 1.41,   0.55 +- 2.03,   4.06 +- 7.59 mm,
KF dNEU    3.00 +- 0.27,   1.07 +- 0.26,   2.84 +- 0.99 mm
North offset can be seen in the time series.
P386 : WLS dNEU    3.15 +- 0.71,  -0.53 +- 0.49,   3.98 +- 6.83 mm,
KF dNEU    3.17 +- 0.31,  -0.51 +- 0.26,   3.34 +- 1.03 mm
North position estimates seem to have more noise after the antenna swap.
P447 : WLS dNEU    1.49 +- 0.82,  -0.17 +- 0.76,  -5.73 +- 3.91 mm,
KF dNEU    1.36 +- 0.31,  -0.27 +- 0.26,  -5.33 +- 0.95 mm
Offsets do not look very significant.
P664 : WLS dNEU   -1.79 +- 1.85,  -1.39 +- 0.98,  -4.15 +- 6.93 mm,
KF dNEU   -0.10 +- 0.36,  -0.56 +- 0.29,  -6.45 +- 1.28 mm
Snow/Ice effected data and removing these values in earlier years effects
the WLS estimate in north.  KF estimate not effecte as much.
P665 : WLS dNEU   -0.10 +- 1.04,  -0.46 +- 1.47,   0.05 +- 8.10 mm,
KF dNEU   -0.49 +- 0.30,  -0.43 +- 0.27,  -3.89 +- 1.08 mm
Again Snow/Ice effected data and removing these values in earlier years effects
the WLS estimates

P278: WLS dNEU   -1.09 +- 1.11,   1.95 +- 2.51,   0.36 +- 4.22 mm,
KF dNEU   -0.50 +- 0.30,   0.85 +- 0.46,  -1.90 +- 1.04 mm
There is a gap before the antenna change that makes the estimates less reliable.

*New offsets of unknown origin*

No new unknown offsets were added in the quarter.

*New Velocity field to GPS Week 1925 2016-12-03*

This report is from a separate document entitled GAGE_Velocity_Field_20161203.
Tables numbers have an A pre-pended to them here.

**Notes on the 2016 GAGE Velocity field to GPS Week 1925 2016-12-03**

These notes add supplemental information to "Notes on the 2015 PBO Velocity field to Week 1870 2015-11-14" https://www.unavco.org/data/gps-gnss/derived-products/docs/GAGE_GPS_Velocity_Release_Notes_20151223.pdf

The 2016 GAGE full velocity solution includes GPS data from GPS week 0834 (Jan-01-1996) to week 1925 (Dec-03-2016).

The complete analysis of the full GAGE velocity field generated from SINEX files (i.e., incorporating full variance covariance matrices and allowing re-alignment of the reference frame for the velocity field) is now being released. The 2015 release documents the methods being used to generate these velocity fields.
The process noise models, in the form of random walk time-step variances or process noise (RWPN) are given in All_PBO.rw. These values are generated by analysis of the position residuals from fitting the time series for each site. Sites that have process noise values greater than 100.0 $mm^2/yr$ are not included in this velocity solution so that they do not contaminate nearby sites. Twelve sites are excluded based on this criterion (AC30 AV05 CAPI CN44 CN49 HVHS P323 P656 SMM1 SMM2 SUMM VORA). Most of these sites have a combination of large systematics and/or short durations of valid data. We also impose a minimum RWPN value of 0.05 $mm^2/yr$. 544 sites have computed RWPN values less than this value. The process noise statistics are generated from the time series using the GAMIT/GLOBK script sh_gen_stats based on tsfit fits to the time series with the realistic sigma algorithm used to account for correlated noise. The tsfit solution also generates a list of site position estimates not to be used in the velocity solution because they are outliers (either due to bad analyses, antenna failures or snow on antennas). The current list of edited site position estimates is given in All_PBO_edits.eq. These edits can by AC or for both ACs. The total GAGE time series contain 8112123 station-days. The outlier criteria remove 9129 (0.11%) of NMT and 46934 (0.58%) of CWU station-days of solutions.

The processing divides the 2174 sites analyzed into 29 networks each with approximately 77 site locations. (The final number of estimated parameters for each network depends on the number of breaks needed at each site. The networks need from 100 to 285 individual site names to accommodate the discontinuities). There is no overlap between the sites in the first 28 networks. A 29th network is created to tie all the other 28 networks into a single solution. To form the sites in the 29th network, three sites for each network are chosen so as to minimize the trace of the covariance matrix of the estimates of rotation and translation using these sites. Weights assigned to each site in accord with the expected variance of the velocity estimate for the site (i.e., combination of the RWPN and duration of data at the site). If equal weights are given to each site, this algorithm is the same as choosing the three sites that cover the largest area. The details of the sites in each network are given in All_PBO_netsel.use. The analyses of the 29 networks can be run in parallel and takes a few hours to run. The combination of the 29 networks uses ~9 Gbytes of memory and the NMT and CWU combination, along the equating of velocities (with a constraint of ±0.01 mm/yr) at sites with discontinuities takes about a day of CPU time. The NMT and CWU velocity solutions are then merged to form the PBO solution combined solution. This combination uses ~20Gb of memory. The velocity combinations use loose constraints and we align the reference frame as we wish at the end of the combination. We generate four reference frame realizations: (1) A North America frame aligned to our current NAM08 frame using 1126 sites in our hierarchical list of reference frame sites; (2) A North America frame aligned to IGb08 rotated into the North America frame using the 33 sites original used in ITRF2008 to define the North

America plate and (3) and (4) are the same as (1) and (2) except the reference velocities are in a NNR reference frame.

The full GLOBK SINEX velocity solution allows us to re-align the reference frames based on the combination of all of the data collected between 1996 and current day (2016-12-03 GPS Week 1925 for this analysis). The time series analyses for velocities is much faster but the daily solutions need to be aligned the reference frame each day based on an earlier realization of the frames. The current NAM08 frame was originally aligned to the reference frame using data through August of 2014 -- about two and half years ago. Tables A1 and A2 compare the WRMS and NRMS scatters of the differences between the velocity estimates obtained by the two GAGE ACs and the combination of the two ACs using different analysis methods. Table A1's caption explains the naming scheme used to describe the solutions. There are the three analysis centers, NMT, CWU and their combination PBO. The velocity estimates are generated with three different methods (1) GLOBK SINEX combinations, GK (2) time series analyses using weighted least squares (LS) and (3) time series analyses using a Kalman filter of the time series (KF). The time series LS analysis is the one that generates the monthly GAGE SNAPSHOT fields. The GK analysis can be aligned to the current NAM08 frame (NA) or be realigned to the IGb08 frame (IG). In all analyses, the same process noise models, discontinuities and post-seismic non-linear models (based on time series analyses) are used. The comparisons do not re-align the velocity fields in any way. The RMS values are based on the simple difference between the estimates. The numbers of stations do not match between the analyses because the GK analyses exclude sites with large process noise values. Tables A3 and A4 show the same type of comparison when we restrict the sites to the best 765 stations in the solution (These stations have velocity standards less than the median standard deviations in north, east and up in all three components. The number of stations is less than half the number of stations because the standard deviation condition must be met in all components). The NRMS values are very consistent with those in Tables A1 and A2 suggesting that even the sites with the smallest sigma match in accordance with their sigmas.

Over all the agreement between the different methods of estimating the velocities are very good with the WRMS difference in the NE components typically <0.2 mm/yr (including comparison to the PBO 2015 velocity solution) and in height less than 0.8 mm/yr. The NRMS scatter of the differences is typically less than unity showing that the error bars are of the somewhat larger than the differences.

The official PBO velocity solution is aligned to our current NAM08 frame to keep consistency of the results and to avoid discontinuities. The current IGb08 is now about 6-years old and will soon be replaced by ITRF2014 (IGS14) in early 2016.

Along with this release of the velocity field we also release a folder with ancillary files and results similar to the files released for the Reviews of Geophysics paper. The contents of the DOI_161203 folder are described in Table A5.

**Table A1:** Comparison of North and East velocities between different velocity field determination methods. No transformation parameters between the fields have been estimated. The codes for the solutions are: CCC_TTYY where CCC is the center NMT, CWU or the combined PBO analysis; TT is the type of analysis:
GK – GLOBK Kalman filter; TS – time series fit; and YY is combination of method and reference frame: LS – least squares, KF – Kalman filter; NA – NAM08, IG – IGb08 rotated to NA. The final entries PBO_2015 and PBO_2014 are the earlier 2015 and 2014 PBO full solution generated in November 2015 and 2014. # is the number of common sites in the solutions.

| Soln1 - Soln2 | # | N mean (mm/yr) | N WRMS (mm/yr) | N NRMS | E mean (mm/yr) | E WRMS (mm/yr) | E NRMS |
|---|---|---|---|---|---|---|---|
| PBO_GKNA-CWU_GKNA | 2167 | -0.02 | 0.07 | 0.316 | -0.00 | 0.06 | 0.304 |
| PBO_GKNA-NMT_GKNA | 2173 | 0.01 | 0.06 | 0.271 | 0.00 | 0.07 | 0.320 |
| CWU_GKNA-NMT_GKNA | 2166 | 0.03 | 0.12 | 0.568 | 0.00 | 0.13 | 0.607 |
| PBO_GKNA-PBO_TSLS | 2174 | -0.02 | 0.13 | 0.848 | -0.02 | 0.13 | 0.832 |
| PBO_GKNA-PBO_TSKF | 2173 | -0.03 | 0.15 | 0.831 | -0.01 | 0.14 | 0.782 |
| PBO_GKNA-CWU_TSLS | 2167 | -0.02 | 0.15 | 0.933 | -0.02 | 0.15 | 0.924 |
| PBO_GKNA-CWU_TSKF | 2165 | -0.02 | 0.16 | 0.881 | -0.01 | 0.16 | 0.851 |
| PBO_GKNA-NMT_TSLS | 2173 | -0.01 | 0.16 | 1.017 | -0.02 | 0.15 | 0.924 |
| PBO_GKNA-NMT_TSKF | 2170 | -0.03 | 0.18 | 0.945 | -0.02 | 0.15 | 0.830 |
| PBO_GKNA-PBO_GKIG | 2174 | -0.00 | 0.09 | 0.426 | 0.21 | 0.24 | 1.145 |
| PBO_GKNA-CWU_GKIG | 2167 | -0.00 | 0.10 | 0.468 | 0.21 | 0.24 | 1.156 |
| PBO_GKNA-NMT_GKIG | 2173 | 0.02 | 0.10 | 0.486 | 0.20 | 0.23 | 1.107 |
| PBO_GKNA-PBO_2015 | 2137 | -0.02 | 0.18 | 0.831 | -0.03 | 0.16 | 0.740 |

**Table A2:** Similar to Table 1 except here the mean horizontal velocity (HzMean, HzWRMS, HzNRMS) and vertical velocity (U columns) are compared.

| Soln1 - Soln | # | HzMean (mm/yr) | HzWRMS (mm/yr) | HzNRMS | U Mean (mm/yr) | U WRMS (mm/yr) | U NRMS |
|---|---|---|---|---|---|---|---|
| PBO_GKNA-CWU_GKNA | 2167 | -0.01 | 0.06 | 0.310 | 0.01 | 0.21 | 0.384 |
| PBO_GKNA-NMT_GKNA | 2173 | 0.01 | 0.06 | 0.296 | -0.06 | 0.18 | 0.344 |
| CWU_GKNA-NMT_GKNA | 2166 | 0.02 | 0.12 | 0.588 | -0.07 | 0.36 | 0.660 |
| PBO_GKNA-PBO_TSLS | 2174 | -0.02 | 0.13 | 0.840 | 0.00 | 0.35 | 0.803 |
| PBO_GKNA-PBO_TSKF | 2173 | -0.02 | 0.15 | 0.807 | -0.06 | 0.38 | 0.816 |
| PBO_GKNA-CWU_TSLS | 2167 | -0.02 | 0.15 | 0.928 | -0.02 | 0.41 | 0.903 |
| PBO_GKNA-CWU_TSKF | 2165 | -0.02 | 0.16 | 0.866 | -0.08 | 0.42 | 0.877 |
| PBO_GKNA-NMT_TSLS | 2173 | -0.02 | 0.15 | 0.972 | -0.40 | 0.70 | 1.538 |
| PBO_GKNA-NMT_TSKF | 2170 | -0.02 | 0.16 | 0.889 | -0.44 | 0.73 | 1.508 |
| PBO_GKNA-PBO_GKIG | 2174 | 0.11 | 0.18 | 0.864 | -0.42 | 0.45 | 0.849 |
| PBO_GKNA-CWU_GKIG | 2167 | 0.11 | 0.19 | 0.882 | -0.18 | 0.29 | 0.514 |
| PBO_GKNA-NMT_GKIG | 2173 | 0.11 | 0.18 | 0.855 | -0.60 | 0.66 | 1.280 |
| PBO_GKNA-PBO_2015 | 2137 | -0.03 | 0.17 | 0.787 | 0.04 | 0.41 | 0.673 |

**Table A3:** Comparison of North and East velocities similar to Table 1 except we limit the sites to those that have horizontal and vertical velocities sigmas both less than the median horizontal and vertical velocity sigmas. (Reason there are less than 1087 sites is because both horizontal and vertical sigma conditions must be satisfied.)

| Soln 1- Soln 2 | # | N mean (mm/yr) | N WRMS (mm/yr) | N NRMS | E mean (mm/yr) | E WRMS (mm/yr) | E NRMS |
|---|---|---|---|---|---|---|---|
| PBO_GKNA-CWU_GKNA | 765 | -0.02 | 0.04 | 0.275 | 0.01 | 0.05 | 0.310 |
| PBO_GKNA-NMT_GKNA | 765 | 0.01 | 0.04 | 0.230 | -0.00 | 0.05 | 0.320 |
| CWU_GKNA-NMT_GKNA | 765 | 0.03 | 0.08 | 0.488 | -0.01 | 0.10 | 0.616 |
| PBO_GKNA-PBO_TSLS | 765 | -0.02 | 0.09 | 0.789 | -0.01 | 0.08 | 0.685 |
| PBO_GKNA-PBO_TSKF | 765 | -0.02 | 0.10 | 0.719 | -0.01 | 0.09 | 0.623 |
| PBO_GKNA-CWU_TSLS | 765 | -0.02 | 0.09 | 0.802 | -0.01 | 0.09 | 0.734 |
| PBO_GKNA-CWU_TSKF | 765 | -0.02 | 0.10 | 0.690 | -0.00 | 0.09 | 0.617 |
| PBO_GKNA-NMT_TSLS | 765 | -0.01 | 0.11 | 0.889 | -0.02 | 0.09 | 0.738 |
| PBO_GKNA-NMT_TSKF | 765 | -0.02 | 0.11 | 0.765 | -0.02 | 0.09 | 0.651 |
| PBO_GKNA-PBO_GKIG | 765 | 0.01 | 0.08 | 0.490 | 0.22 | 0.24 | 1.503 |
| PBO_GKNA-CWU_GKIG | 765 | 0.01 | 0.08 | 0.481 | 0.22 | 0.24 | 1.509 |
| PBO_GKNA-NMT_GKIG | 765 | 0.04 | 0.09 | 0.554 | 0.21 | 0.23 | 1.447 |
| PBO_GKNA-PBO_2015 | 765 | -0.01 | 0.11 | 0.664 | -0.03 | 0.09 | 0.538 |

**Table A4:** Same as Table 3 except for the combined horizontal and vertical comparison.

| Soln 1- Soln 2 | # | HzMean (mm/yr) | HzWRMS (mm/yr) | HzNRMS | U Mean (mm/yr) | U WRMS (mm/yr) | U NRMS |
|---|---|---|---|---|---|---|---|
| PBO_GKNA-CWU_GKNA | 765 | -0.01 | 0.05 | 0.293 | 0.03 | 0.16 | 0.378 |
| PBO_GKNA-NMT_GKNA | 765 | 0.00 | 0.04 | 0.279 | -0.06 | 0.13 | 0.344 |
| CWU_GKNA-NMT_GKNA | 765 | 0.01 | 0.09 | 0.556 | -0.08 | 0.26 | 0.644 |
| PBO_GKNA-PBO_TSLS | 765 | -0.02 | 0.09 | 0.739 | -0.01 | 0.25 | 0.779 |
| PBO_GKNA-PBO_TSKF | 765 | -0.01 | 0.09 | 0.673 | -0.06 | 0.28 | 0.809 |
| PBO_GKNA-CWU_TSLS | 765 | -0.02 | 0.09 | 0.769 | -0.04 | 0.28 | 0.837 |
| PBO_GKNA-CWU_TSKF | 765 | -0.01 | 0.09 | 0.654 | -0.09 | 0.30 | 0.844 |
| PBO_GKNA-NMT_TSLS | 765 | -0.01 | 0.10 | 0.817 | -0.36 | 0.60 | 1.763 |
| PBO_GKNA-NMT_TSKF | 765 | -0.02 | 0.10 | 0.710 | -0.41 | 0.62 | 1.754 |
| PBO_GKNA-PBO_GKIG | 765 | 0.12 | 0.18 | 1.118 | -0.40 | 0.42 | 1.087 |
| PBO_GKNA-CWU_GKIG | 765 | 0.11 | 0.18 | 1.120 | -0.16 | 0.23 | 0.551 |
| PBO_GKNA-NMT_GKIG | 765 | 0.12 | 0.18 | 1.096 | -0.58 | 0.62 | 1.638 |
| PBO_GKNA-PBO_2015 | 765 | -0.02 | 0.10 | 0.604 | 0.04 | 0.28 | 0.595 |

**Table A5:** Ancillary and velocity fields supplied with this solution (folder DOI_161203/)

| File | Description |
|---|---|
| All_PBO.rw | Random walk parameters by station for use in GLOBK Kalman filter |

| | |
|---|---|
| All_PBO_ants.eq | List of epochs of discontinuities due to antenna and radome changes in GLOBK EQ-format. There are 1454 entries. |
| All_PBO_edits.eq | List of sites and times of position estimates removed from the final velocity solution combination either because they are outliers (e.g., snow/ice on antenna) or have large standard deviations (60814 entries). |
| All_PBO_eqs.eq | List of 42 earthquakes included for co-seismic offset discontinuities. 9 of these earthquakes include parameterized logarithmic post-seismic terms. |
| All_PBO_unkn.eq | List of sites and epochs of discontinuities in position time series that occur for unknown reasons (or unknown times when an antenna partially fails). |
| | |
| All_PBO_netsel.use | List of sub-networks used to create the combined velocity solution. |
| | |
| | |
| pbo.final_nam08.20161203.vel | Combined velocity field based on GLOBK SINEX file analysis in the NAM08 reference frame. PBO velocity field file format. |
| cwu.final_nam08.20161203.vel | CWU velocity field based on GLOBK SINEX file analysis in the NAM08 reference frame. PBO velocity field file format. |
| nmt.final_nam08.20161203.vel | NMT velocity field based on GLOBK SINEX file analysis in the NAM08 reference frame. PBO velocity field file format. |
| pbo.snaps_nam08.20161203.vel | Combined velocity field based on time series analysis in the NAM08 reference frame. PBO velocity field file format. |
| cwu.snaps_nam08.20161203.vel | CWU velocity field based on time series analysis in the NAM08 reference frame. PBO velocity field file format. |
| nmt.snaps_nam08.20161203.vel | NMT velocity field based on time series analysis in the NAM08 reference frame. PBO velocity field file format. |
| pbo.final_igs08.20161203.vel | Combined velocity field based on GLOBK SINEX file analysis in the IGS08 reference frame. PBO velocity field file format. |
| | |
| pbo.tswls_nam08.20161203.gvl | Combined velocity field based on time series weighted least squares (WLS) analysis in the NAM08 reference frame. GLOBK velocity field file format. |
| pbo.tskfa_nam08.20161203.gvl | Combined velocity field based on time series Kalman filter (KF) analysis in the NAM08 reference |

| | |
|---|---|
| | frame. GLOBK velocity field file format. |
| pbo.kfiga_nab08.20161203.gvl | Combined velocity field based on GLOBK SINEX file analysis in a North America reference frame directly realized from the IGb08 reference frame sites. GLOBK velocity field file format. |
| | |
| cwu.tswls_nam08.20161203.gvl | CWU velocity field based on time series weighted least squares (WLS) analysis in the NAM08 reference frame. GLOBK velocity field file format. |
| cwu.tskfa_nam08.20161203.gvl | CWU velocity field based on time series Kalman filter (KF) analysis in the NAM08 reference frame. GLOBK velocity field file format. |
| cwu.kfiga_nab08.20161203.gvl | CWU velocity field based on GLOBK SINEX file analysis in a North America reference frame directly realized from the IGb08 reference frame sites. GLOBK velocity field file format. |
| | |
| nmt.tswls_nam08.20161203.gvl | NMT velocity field based on time series weighted least squares (WLS) analysis in the NAM08 reference frame. GLOBK velocity field file format. |
| nmt.tskfa_nam08.20161203.gvl | NMT velocity field based on time series Kalman filter (KF) analysis in the NAM08 reference frame. GLOBK velocity field file format. |
| nmt.kfiga_nab08.20161203.gvl | NMT velocity field based on GLOBK SINEX file analysis in a North America reference frame directly realized from the IGb08 reference frame sites. GLOBK velocity field file format. |

**GAMIT/GLOBK Community Support**

There was no additional work this quarter on GAMIT modifications for GNSS. We updated the software to support seven additional ground antennas and continued regular updates to the tables for ground and SV antennas (ANTEX), 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 we issued 13 royalty-free licenses to educational and research institutions.