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: 2016/07/01-2016/09/30

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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 06/15/2016 to 09/17/2016, time series velocity field analyses for the GAGE reprocessing analyses (1996-2016). Several earthquakes were investigated this quarter but none had >1 mm coseismic displacements although for some we could not make this assessment due to not available post-earthquake data. For this quarter the last finals results were for September 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.*, *in press*, 2016RG000529, is now in press 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 1919 stations were processed compared to 1914 for the previous quarter. New stations are being added and 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: June 15, 2016 and September 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 June 15, 2016 and September 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 1.0 mm for all centers and as low as 0.82-0.79 mm for PBO north and east components. The up RMS scatters are less than or equal 4.5 mm and as low as 3.75 mm for the PBO solutions. These statistics are similar to 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 1919, 1919 and 1919 stations for PBO, NMT and CWU analyzed in the finals analysis between June 15, 2016 and September 17, 2016. Histograms of the RMS scatters are shown in Figure 1-3.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
PBO	0.82	0.79	3.75
NMT	0.83	0.86	3.85
CWU	1.02	0.92	4.41
70%			
PBO	0.98	0.97	4.29
NMT	1.00	1.06	4.52
CWU	1.19	1.13	5.16
95%			
PBO	1.62	1.64	6.20
NMT	1.67	1.81	6.86
CWU	1.90	1.92	7.56

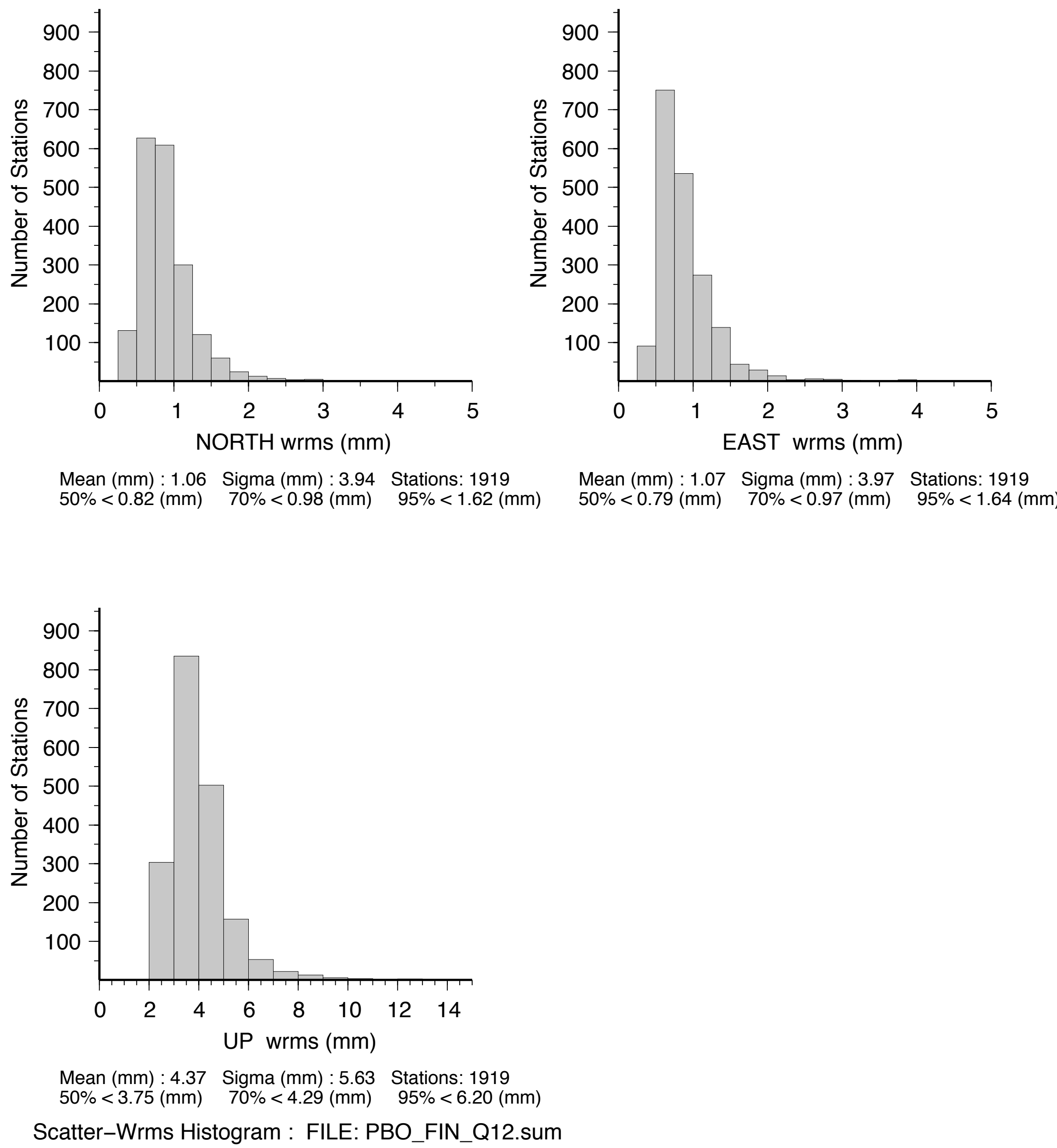


Figure 1: PBO combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1919 stations analyzed between June 15, 2016 and September 17, 2016. Linear trends and annual signals were estimated from the time series.

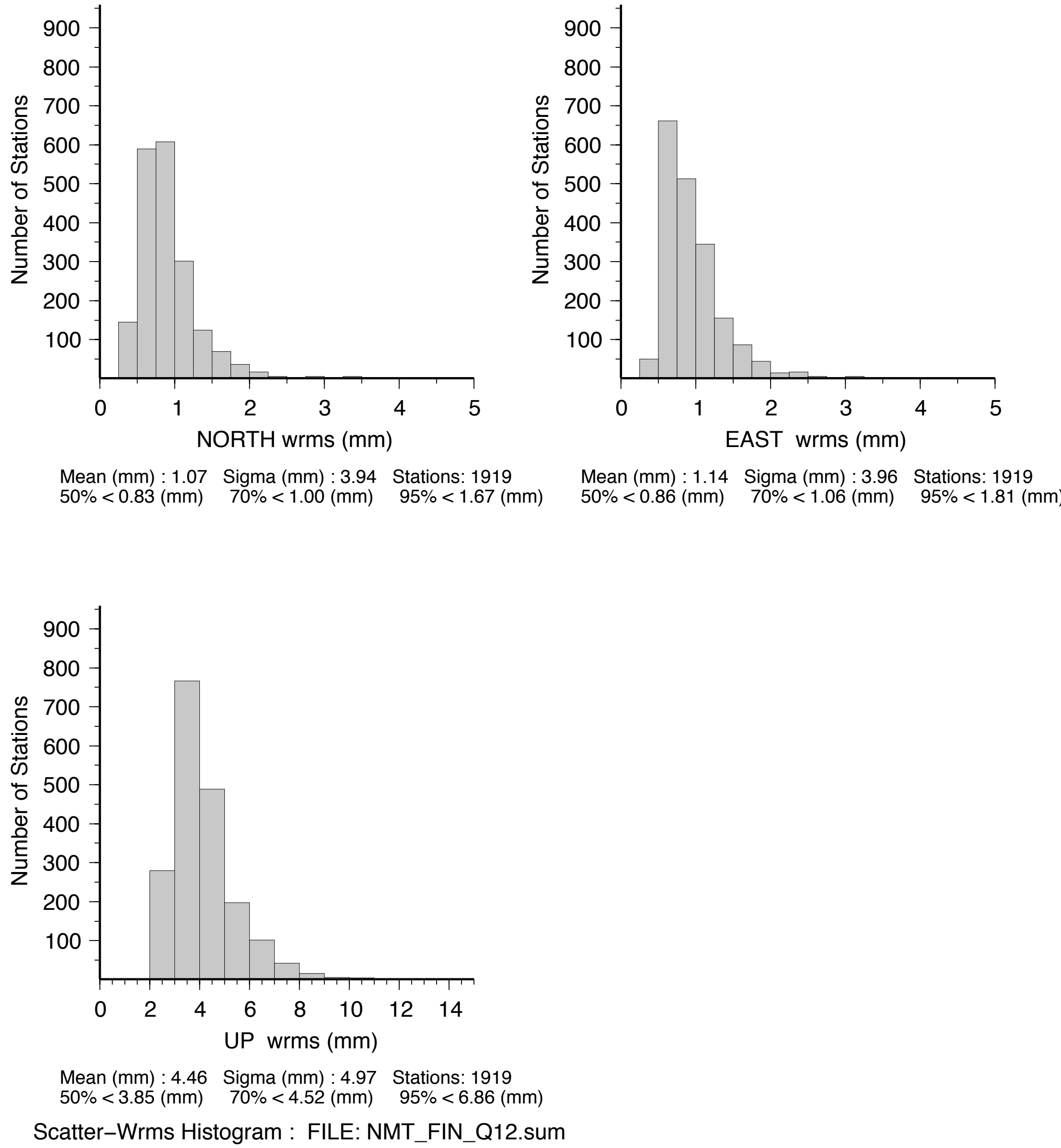


Figure 2: NMT combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1919 stations analyzed between June 15, 2016 and September 17, 2016. Linear trends and annual signals were estimated from the time series.

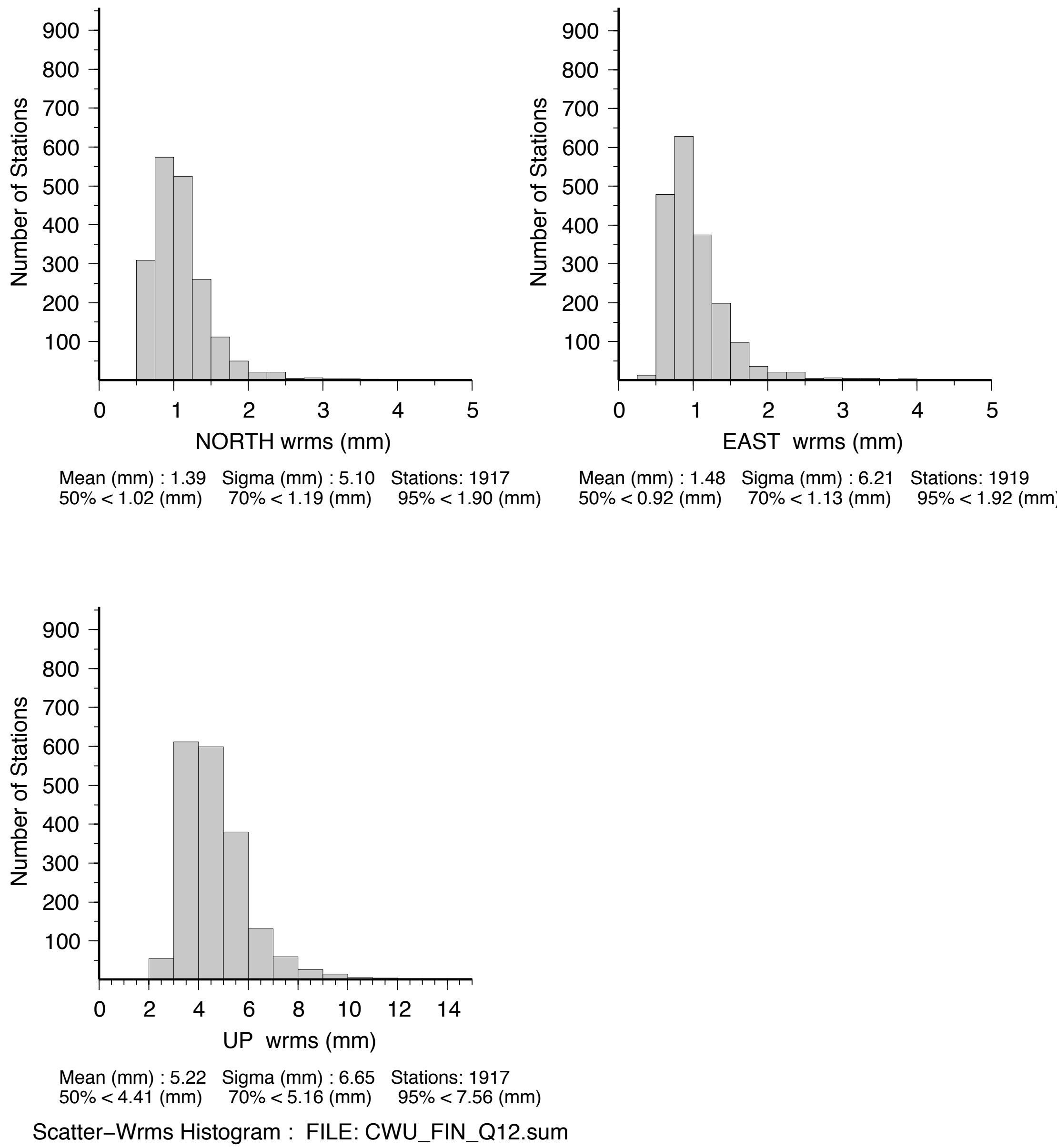


Figure 3: CWU combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1919 stations analyzed between June 15, 2016 and September 17, 2016. Editing removes two stations for North and Up. Linear trends and annual signals were estimated from the time series.

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_Q12.tab. There are 1919 stations in the file. The contents of the files are of this form:

```
Tabular Position RMS scatters created from PBO_FIN_Q12.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    45      1.3   0.60      1.7   0.73     5.6   0.53     13.27
 1NSU    95      1.1   0.59      1.1   0.62     4.8   0.62     12.67
 1ULM    94      1.1   0.62      1.2   0.71     5.5   0.73     13.26
 7ODM    95      0.6   0.35      0.7   0.42     3.8   0.56     15.41
…
 ZBW1    95      1.0   0.47      0.9   0.50     4.4   0.58     13.29
 ZDC1    94      1.0   0.46      1.2   0.69     5.1   0.67     13.29
 ZDV1    95      0.9   0.40      0.8   0.47     4.3   0.60     13.29
 ZKC1    95      1.0   0.48      0.9   0.54     4.1   0.55     13.29
 ZLA1    95      1.1   0.56      0.8   0.47     4.2   0.56     13.29
 ZME1    95      1.1   0.55      1.1   0.58     5.4   0.67     13.52
 ZMP1    95      0.8   0.35      0.8   0.48     3.8   0.53     13.76
 ZNY1    95      1.0   0.49      1.0   0.60     4.7   0.64     13.68
 ZSE1    95      0.7   0.33      0.7   0.41     2.8   0.41     13.68
 ZTL4    95      0.9   0.47      1.0   0.55     5.7   0.70     13.87
```

Table 2: RMS scatter of the position residuals for the PBO combined solution between June 15, 2016 and September 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	0.72	0.69	3.37	841
NUCLEUS	0.66	0.65	3.35	209
USGS SCIGN	0.73	0.74	3.59	129
Expanded	0.95	0.92	4.29	614
GAMA	0.88	0.86	4.89	13
COCO Net	1.33	1.39	5.88	113
70 %				
PBO	0.84	0.82	3.79	
NUCLEUS	0.77	0.77	3.68	
USGS SCIGN	0.93	0.95	4.06	
Expanded	1.06	1.10	4.67	
GAMA	0.92	0.92	4.92	
COCO Net	1.53	1.64	9.23	
95%				
PBO	1.45	1.38	4.91	
NUCLEUS	1.28	1.15	5.20	
USGS SCIGN	1.48	1.51	5.50	
Expanded	1.60	1.59	6.16	
GAMA	1.10	0.94	5.44	
COCO Net	2.89	3.83	12.43	

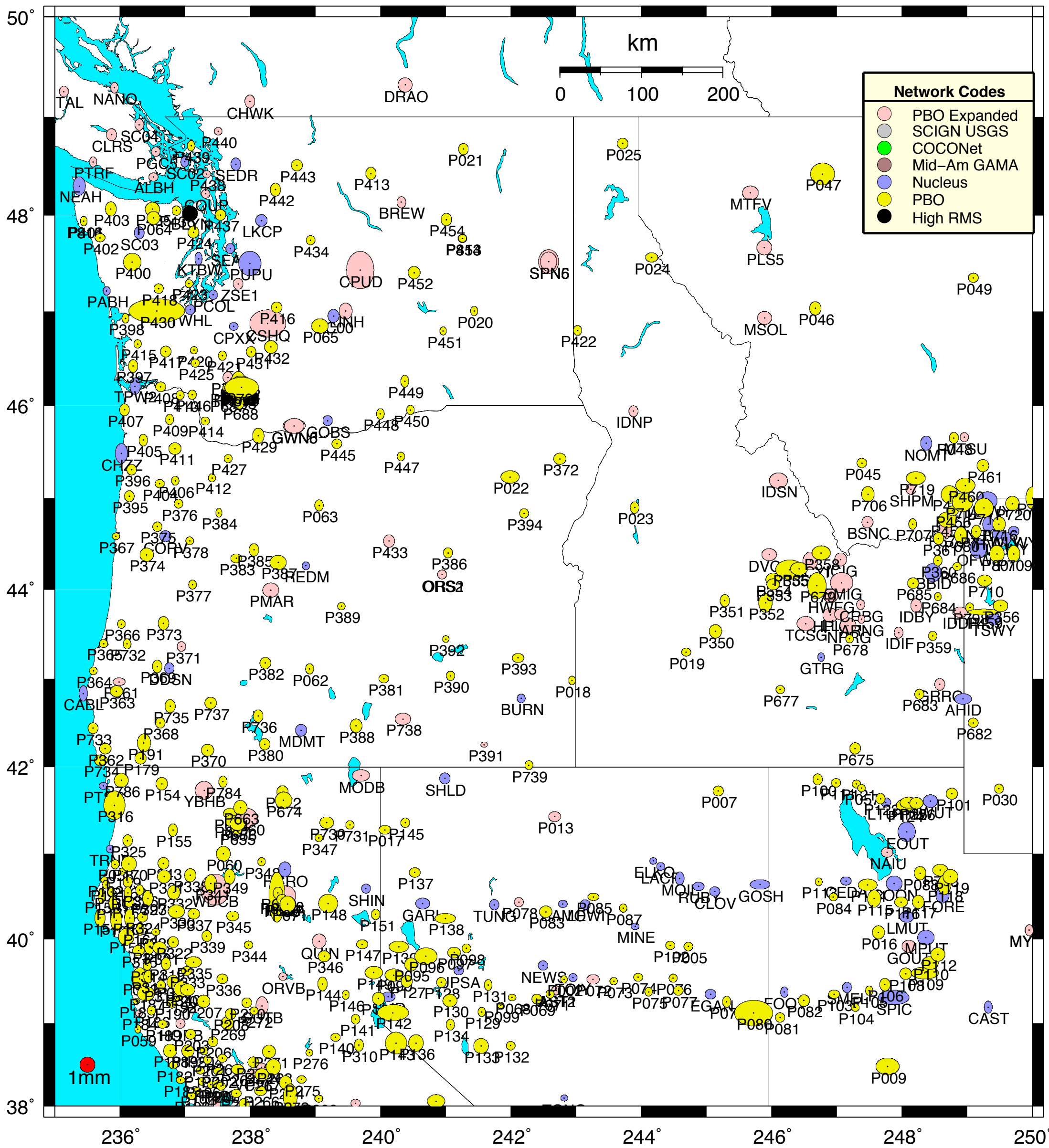


Figure 4: Distribution of the RMS scatters of horizontal position estimates from the PBO combined analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the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

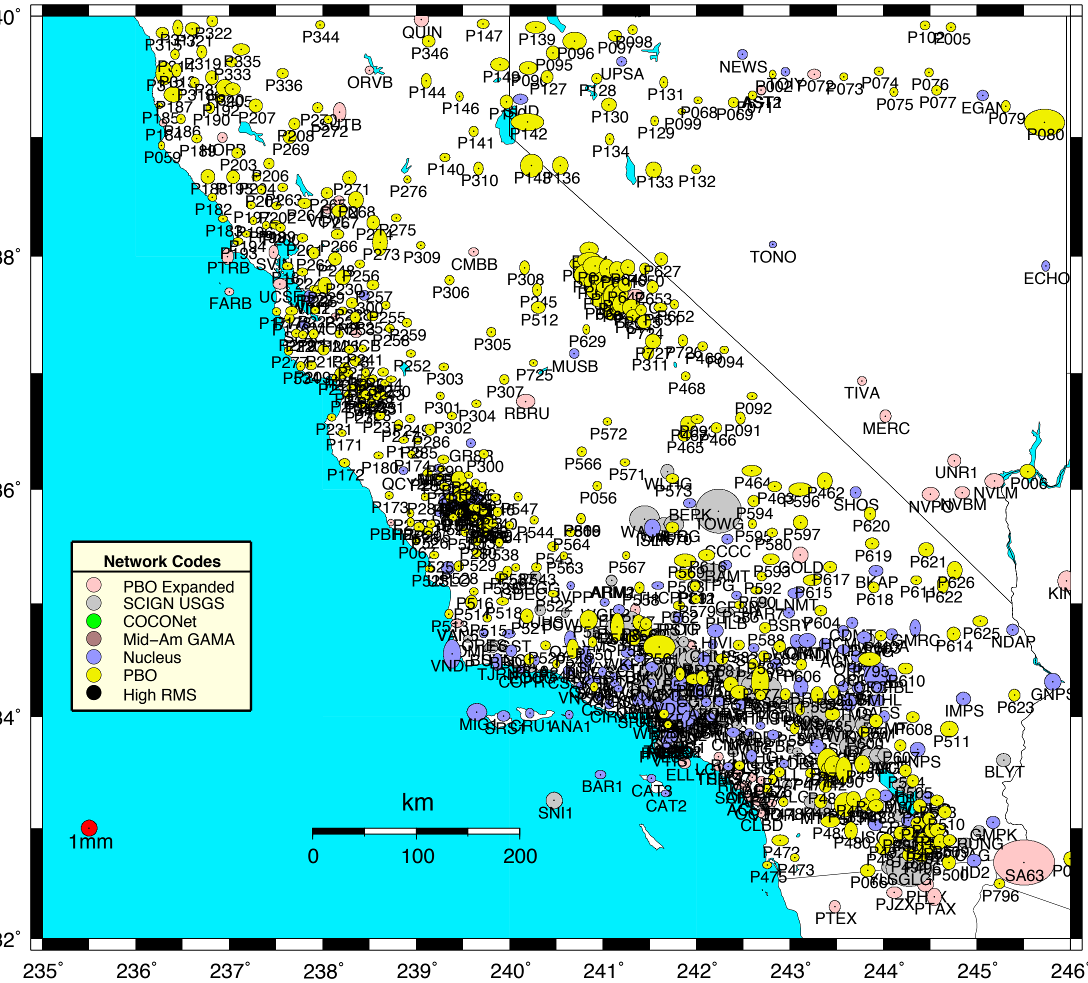


Figure 5: Same as Figure 4 except for the Southern Western United States. Black circles in the Yucca mountain region have no data during this 3-month period.

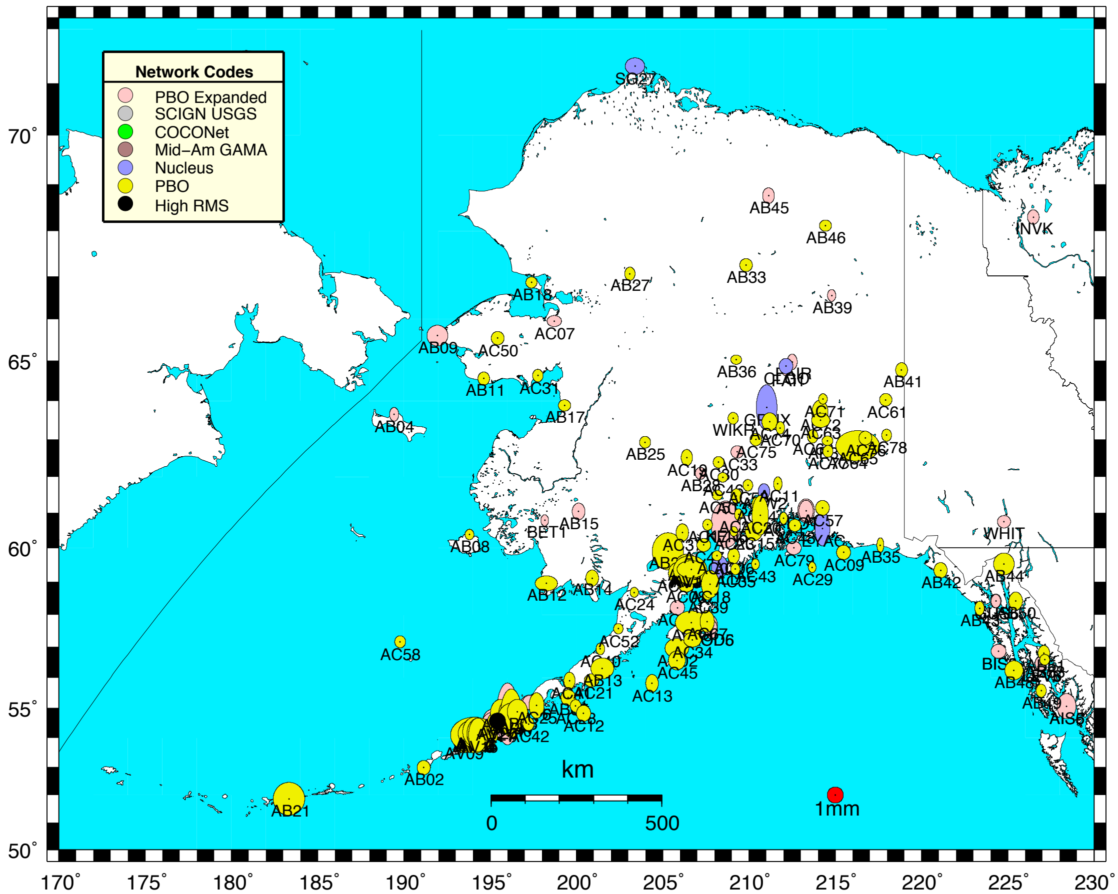


Figure 6: Same as Figure 4 except for the Alaskan region.

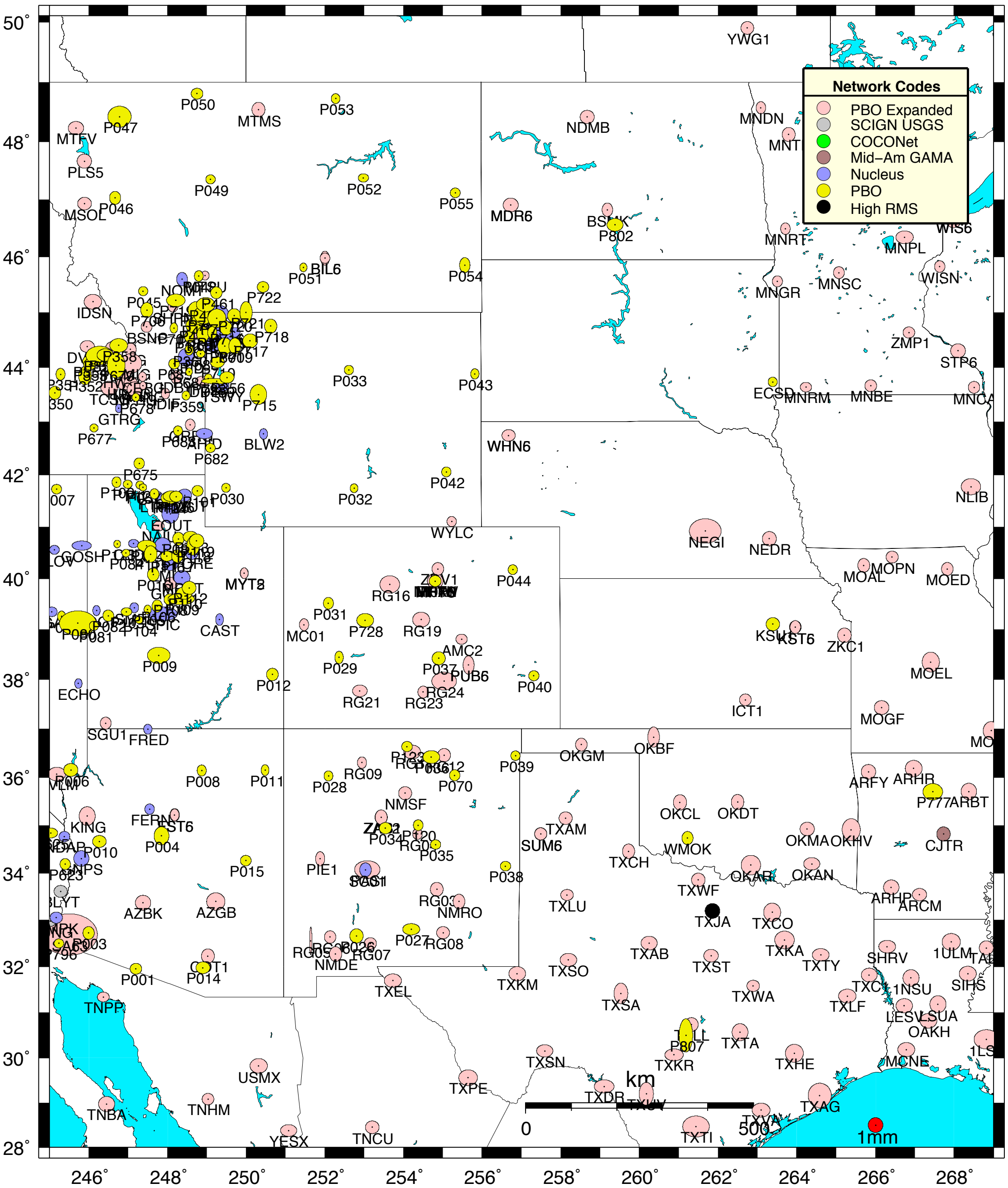


Figure 7: Same as Figure 4 except for the Central United States

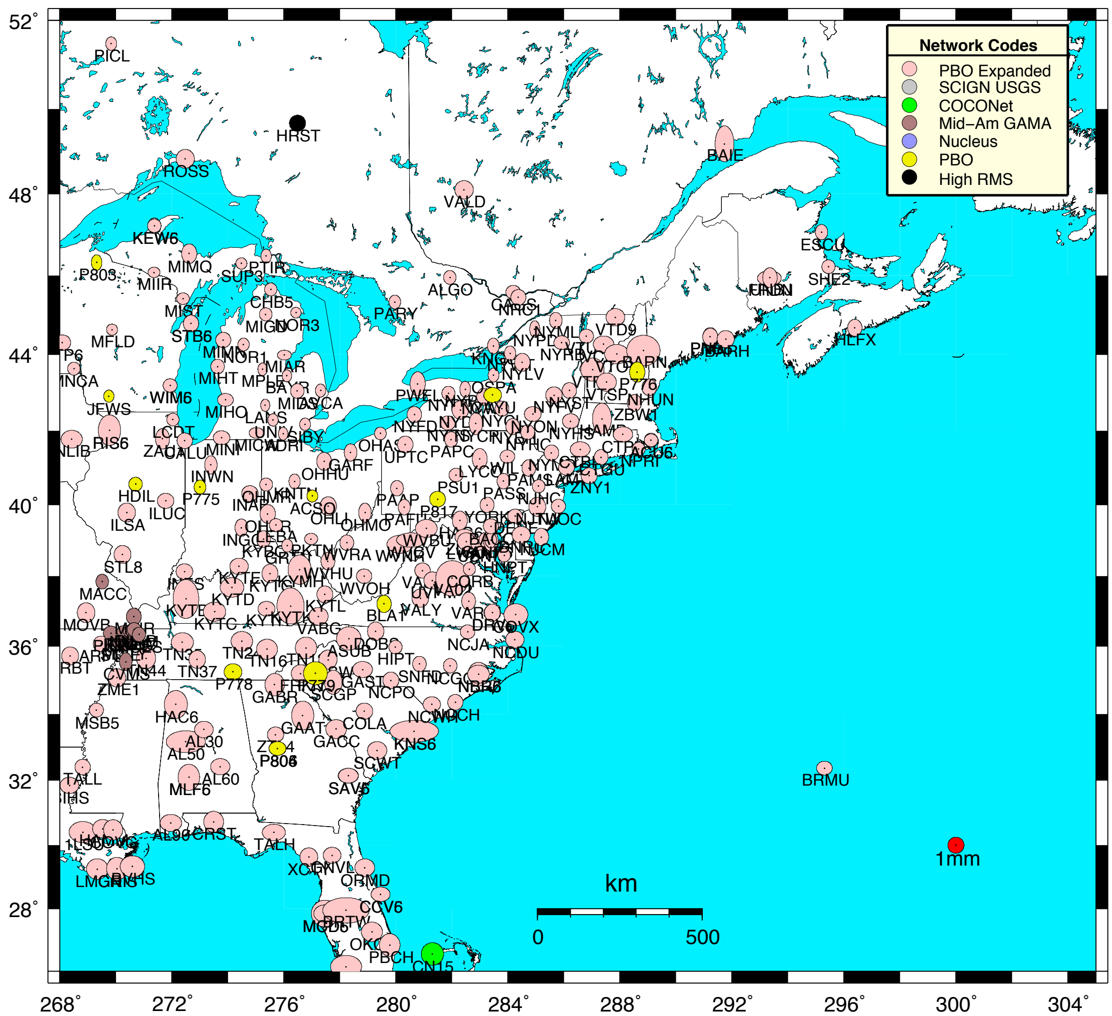


Figure 8: Same as Figure 4 except for the Eastern United States

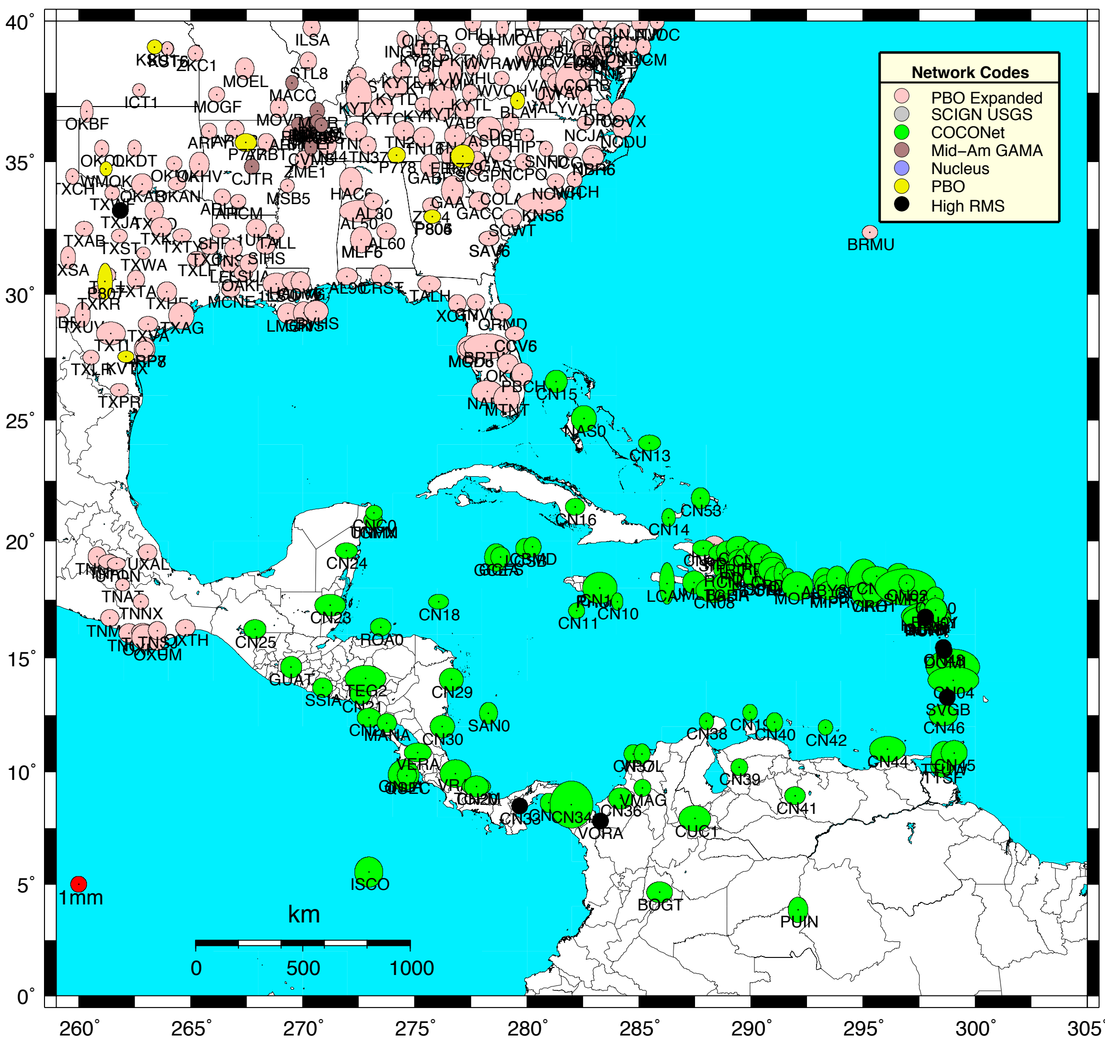


Figure 9: Same as Figure 4 except for the Caribbean region.

Analysis of large RMS stations

We add here a new analysis of high RMS scatter sites. These notes are compiled from the analysis of time series.

Table 3: Comments on time series with high RMS scatters during this quarter.

Added 2016-09-23/2016-10-07 (Q12)

AB51	Large change in slope and coseismic offset after 2013-01-05 M 7.5 EQ 173 km away. Post-seismic: Needs log with ~80-day time constant
AB49	Break 2015-07-15: Looks like trees were cleared new site.
AV26	Long period (multi-year) systematics and outliers that could be skewness (RMS NE 3-4 mm, systematics a few millimeters.

CN36	Strange excursions in mid-2015 and March 2016. Peak ~ 10mm, signs opposite
CN48	Site is noisy with ~3.5 mm NE scatter and 13 mm vertical. RMS worse in summer.
SMM2	Site on Greenland ice sheet. There is break on 2016-08-16 of ~0.5 m in vertical that looks like the antenna height was changed. No log entry for this change.
SVGB	Noisy, especially in summer, with large data gaps at start and early 2016. 2.8-4.1 mm NE scatter, 11 mm vertical
TXJA	Scatter increases after 2016-08-16. Gap in data before increase but no log entry for equipment change. Recent scatter is 3-5 mm NE. 11 mm vertical.
VORA	Station starts April 2016 and after June 2016 is degrading in quality. RMS 3-8 mm NE and 15 mm vertical.

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 2202 stations in the combined PBO solution, which is 18 more stations than last quarter. 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 2186, 2185 and 2179 stations analyzed by PBO, NMT and CWU in the reprocessed analysis for data collected between Jan 1, 1996 and September 17, 2016.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
PBO	1.13	1.17	5.30
NMT	1.13	1.22	5.72
CWU	1.34	1.32	5.98
70%			
PBO	1.45	1.48	5.98
NMT	1.46	1.57	6.47
CWU	1.66	1.63	6.78
95%			
PBO	3.20	3.07	8.93
NMT	3.18	3.12	9.17
CWU	3.40	3.33	10.29

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 with in 0.5 meters of each other (the difference in number of values arises from groups of sites within). The χ^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 χ^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 18-94% optimistic over expectations. The 10-worst stations are MCD5, P801, P282, P713, MCD1, MYT2, SAV1, JNPR, SAV5, and LST1. This is the same list as the previous quarter (the order different because the list is in order of increasing scatter.

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 2186, 2185 and 2179 stations. WRMS is weighted-root-mean-scatter and NRMS is sqrt(χ^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 (mm/yr)	U WRMS (mm/yr)	NE NRMS	U NRMS
All	2202	0.08	0.74	1.19	2.02
Edited -10 worst	2185	0.07	0.73	1.08	1.98
Less than median (0.14 0.44 mm/yr)	1231	0.07	0.73	1.10	2.13
Added minimum sigma NE 0.05 U 0.50 mm/yr					
All	2202	0.12	1.02	0.98	1.13
Edited -10 worst	2185	0.11	0.97	0.87	1.08
Less than median (0.15 0.0.67 mm/yr)	1299	0.08	0.79	0.78	0.98

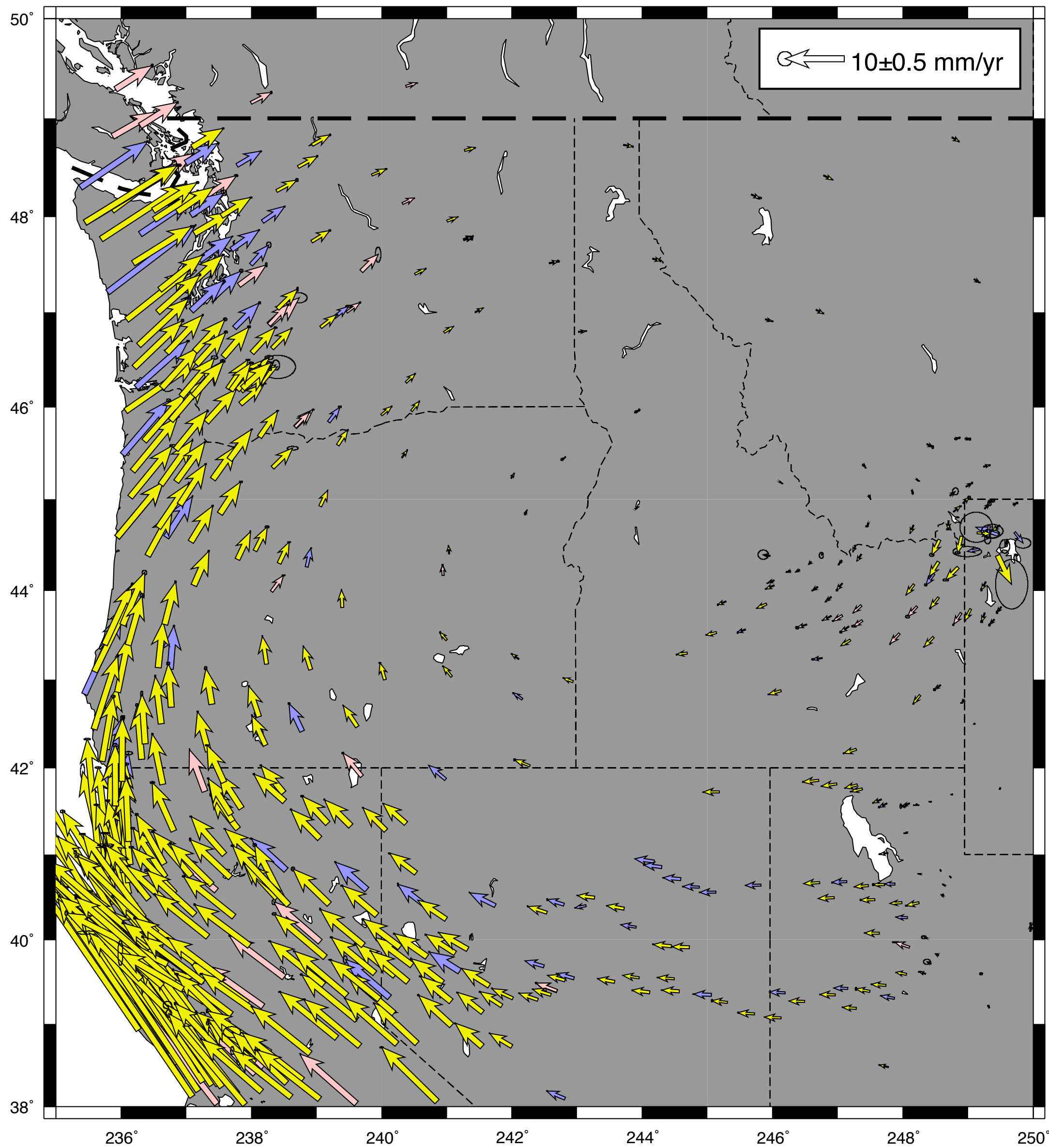


Figure 10: Velocity field estimates from the combined PBO solutions generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal standard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

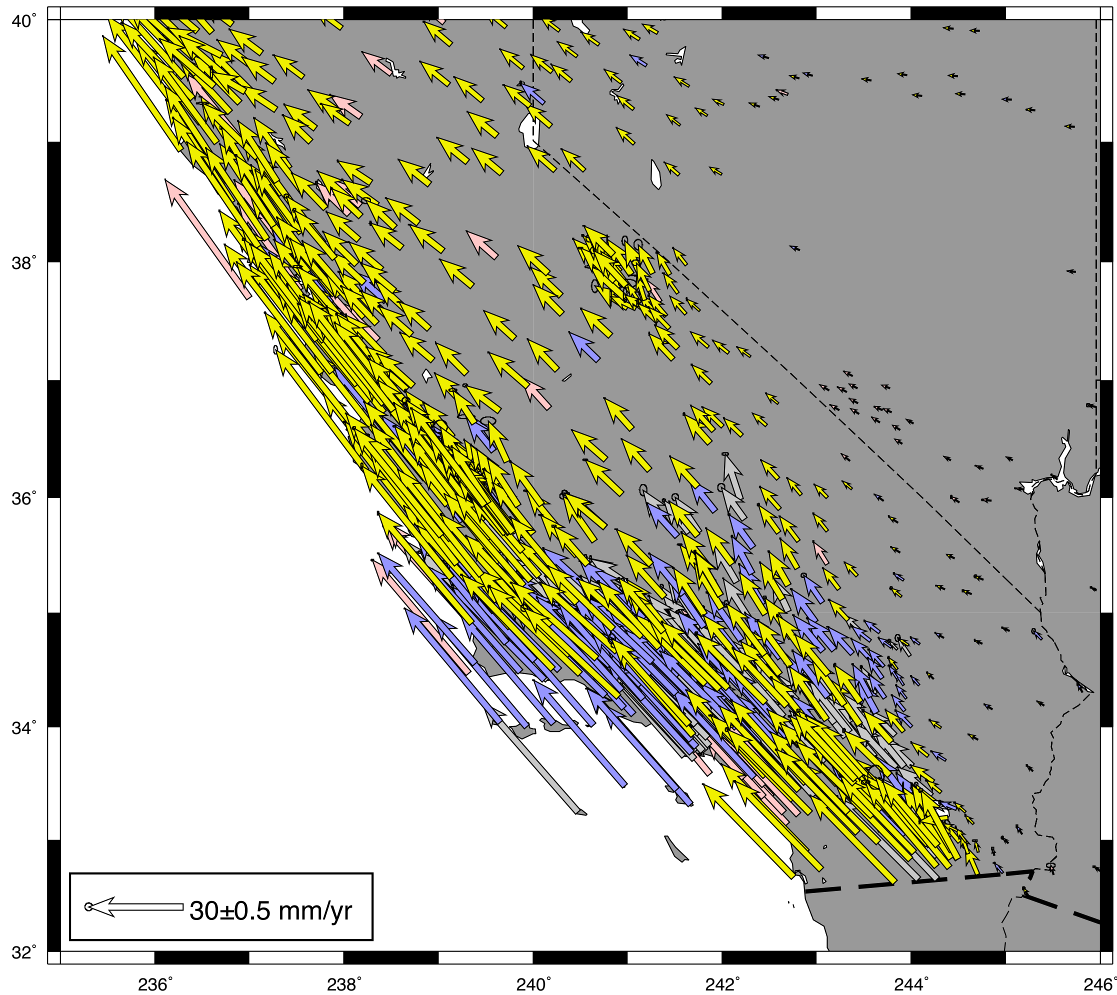


Figure 11: Same as Figure 10 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

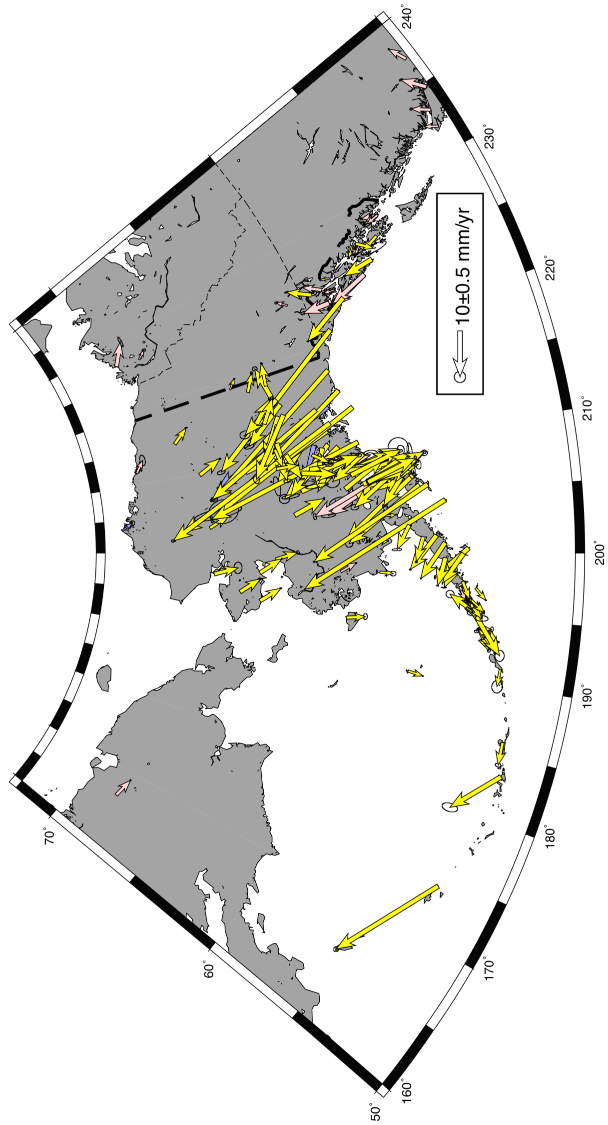


Figure 12: Same as Figure 10 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

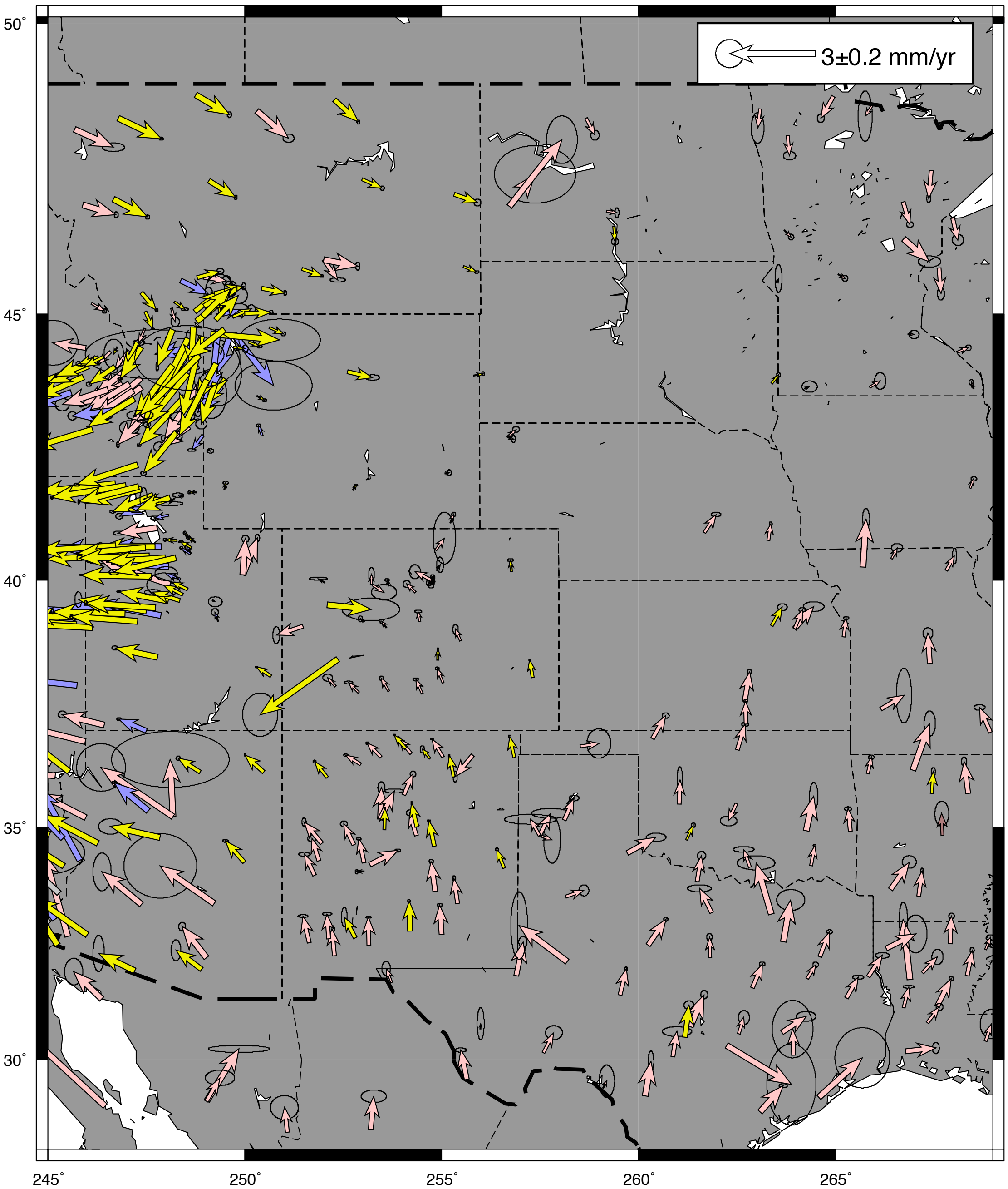
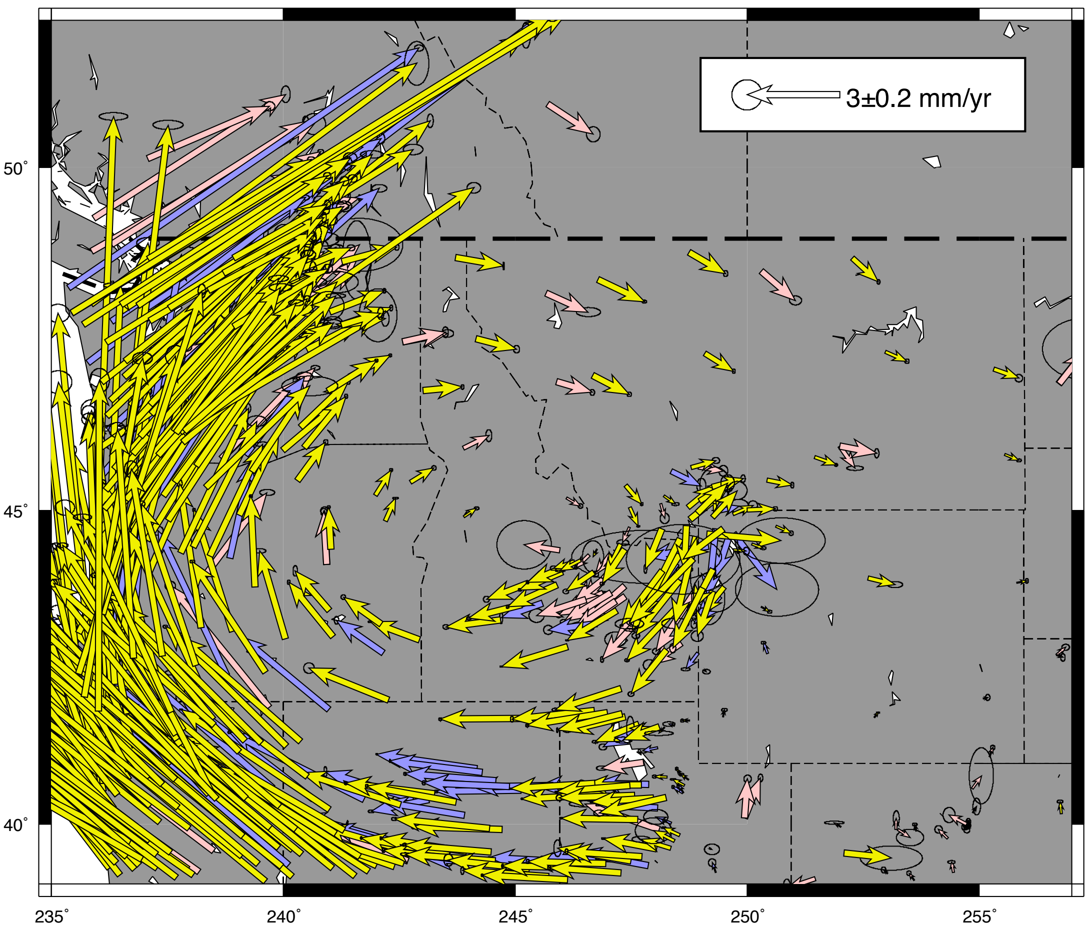


Figure 13: Same as Figure 10 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

Fig



ure 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.

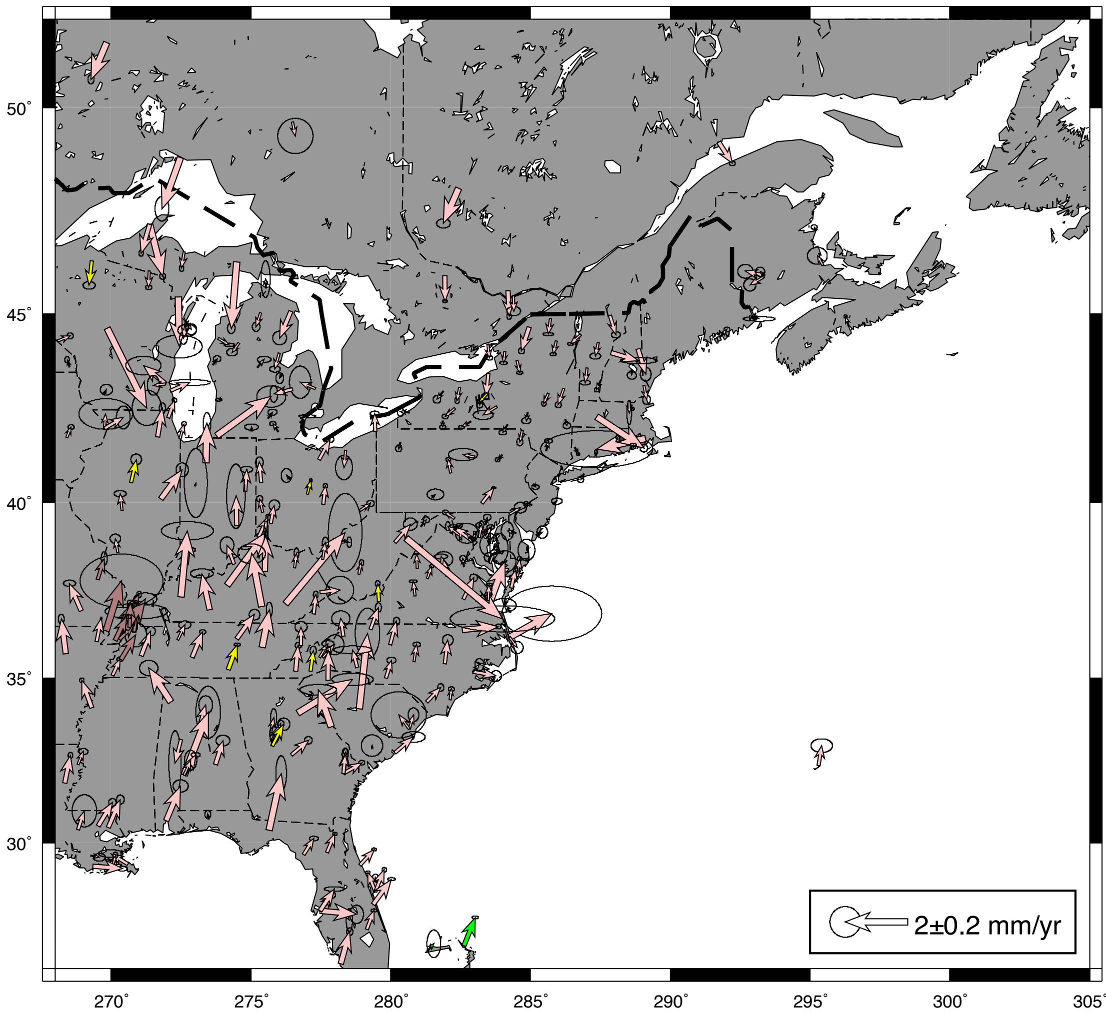


Figure 15: Same as Figure 10 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities. The vertical motions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

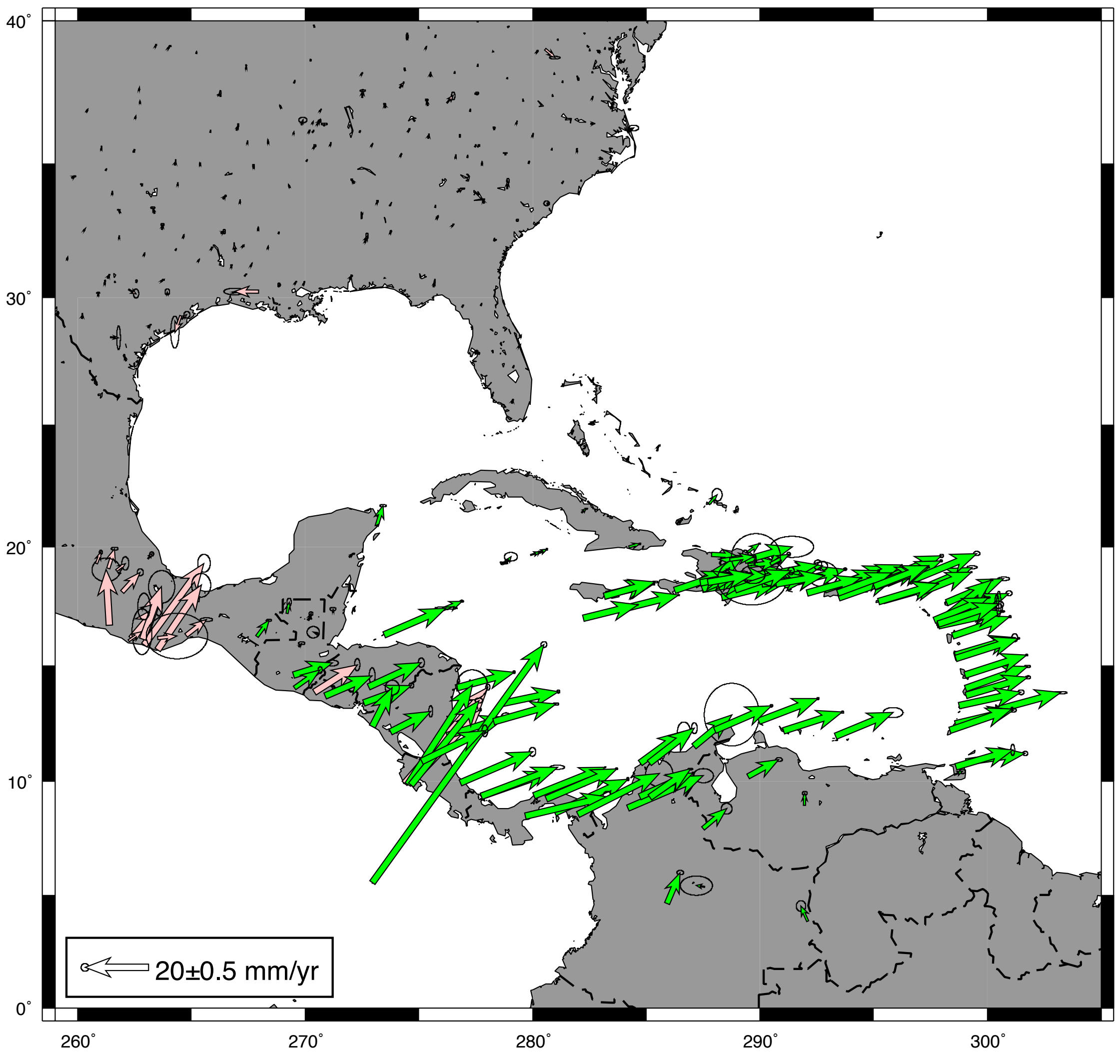


Figure 16: Same as Figure 10 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2016/06/01-2016/08/31.

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 June/July 2016 we investigated the following events.

```
* EQDEFS for 2016 06 14 to 2016 07 15 Generated Fri Jul 15 15:40:15 EDT 2016
* Proximity based on Week_All.Pos file
* ----------------------------------
* SEQ Earthquake # 1
* EQ 14 P707_GPS       6.00       9.50 CoS        1.8 mm
* EQ_DEF M4.0 52km W of West Yellowstone
 eq_def 01   44.7325 -111.7652      9.5 8 2016 06 14 14 36    0.001
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.001      0.001      0.001
* ----------------------------------
* SEQ Earthquake # 2
* EQ 57 CTMS_GPS       5.80       8.70 CoS        0.0 mm
* EQ_DEF M3.5 7km SE of Yucca Valley
 eq_def 02   34.0723 -116.3785      8.7 8 2016 06 16 17 03    0.000
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.000      0.000      0.000
* ----------------------------------
* SEQ Earthquake # 3
* EQ 227 P498_GPS       8.36       9.30 CoS        0.9 mm
* EQ 227 P499_GPS       7.73       9.30 CoS        1.1 mm
* EQ 227 WMDG_GPS       7.30       9.30 CoS        1.2 mm
* EQ_DEF M3.9 4km W of Brawley
 eq_def 03   32.9735 -115.5718      9.3 8 2016 06 21 21 56    0.001
 eq_rename 03
 eq_coseis 03  0.001 0.001 0.001      0.001      0.001      0.001
* ----------------------------------
* SEQ Earthquake # 4
* EQ 614 P498_GPS       3.89       9.10 CoS        0.0 mm
* EQ 614 P499_GPS       8.78       9.10 CoS        0.0 mm
* EQ 614 P744_GPS       9.09       9.10 CoS        0.0 mm
* EQ_DEF M3.8 8km NNE of Imperial
 eq_def 04   32.9090 -115.5313      9.1 8 2016 07 07 12 56    0.000
 eq_rename 04
 eq_coseis 04  0.001 0.001 0.001      0.000      0.000      0.000
```

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

In July/Ausust 2016, the following events were investigated

```
* EQDEFS for 2016 07 14 to 2016 08 15 Generated Tue Aug 16 09:00:06 EDT 2016
* Proximity based on Week_All.Pos file
* ----------------------------------
* SEQ Earthquake # 1
* EQ 133 P237_GPS       8.14       9.20 CoS        1.0 mm
* EQ_DEF M3.8 13km SSE of Ridgemark
 eq_def 01   36.6898 -121.3252      9.2 8 2016 07 18 05 54    0.001
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.001      0.001      0.001
* ----------------------------------
* SEQ Earthquake # 2
* EQ 187 P237_GPS       8.09      10.20 CoS        2.0 mm
* EQ_DEF M4.2 13km SSE of Ridgemark
 eq_def 02   36.6925 -121.3297     10.2 8 2016 07 19 21 39    0.002
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.002      0.002      0.002
* ----------------------------------
* SEQ Earthquake # 3
* EQ 188 P237_GPS       7.88       9.40 CoS        1.0 mm
* EQ_DEF M3.9 13km NE of Chualar
 eq_def 03   36.6970 -121.3413      9.4 8 2016 07 19 21 40    0.001
 eq_rename 03
```

```
 eq_coseis 03  0.001 0.001 0.001      0.001      0.001      0.001
* ----------------------------------
* SEQ Earthquake # 4
* EQ 242 P168_GPS       6.24      13.10 CoS        9.9 mm
* EQ 242 P169_GPS       9.89      13.10 CoS        3.9 mm
* EQ_DEF M4.7 19km SE of Bayside
 eq_def 04   40.7243 -123.8918     13.1 8 2016 07 21 23 10    0.006
 eq_rename 04
 eq_coseis 04  0.001 0.001 0.001      0.006      0.006      0.006
* ----------------------------------
* SEQ Earthquake # 5
* EQ 275 AC24_GPS      25.85      28.50 CoS        5.0 mm
* EQ_DEF M5.6 20km SSE of King Salmon
 eq_def 05   58.4734 -156.4568     28.5 8 2016 07 23 09 60    0.052
 eq_rename 05
 eq_coseis 05  0.001 0.001 0.001      0.052      0.052      0.052
* ----------------------------------
* SEQ Earthquake # 6
* EQ 337 CN51_GPS       7.90      11.00 CoS        2.1 mm
* EQ_DEF M4.4 49km NW of The Valley
 eq_def 06   18.5531  -63.3619     11.0 8 2016 07 25 16 53    0.002
 eq_rename 06
 eq_coseis 06  0.001 0.001 0.001      0.002      0.002      0.002
* ----------------------------------
* SEQ Earthquake # 7
* EQ 381 RDHI_GPS       3.89       8.80 CoS        0.0 mm
* EQ_DEF M3.6 4km W of Salvaleon de Higuey
 eq_def 07   18.6138  -68.7526      8.8 8 2016 07 27 07 01    0.000
 eq_rename 07
 eq_coseis 07  0.001 0.001 0.001      0.000      0.000      0.000
* ----------------------------------
* SEQ Earthquake # 8
* EQ 473 FSHB_GPS       4.09       9.60 CoS        3.8 mm
* EQ 473 P493_GPS       6.16       9.60 CoS        1.7 mm
* EQ 473 P503_GPS       3.78       9.60 CoS        4.5 mm
* EQ_DEF M4.0 16km SW of Westmorland
 eq_def 08   32.9583 -115.7605      9.6 8 2016 07 31 16 22    0.001
 eq_rename 08
 eq_coseis 08  0.001 0.001 0.001      0.001      0.001      0.001
* ----------------------------------
* SEQ Earthquake # 9
* EQ 626 P205_GPS      15.96      17.00 CoS        3.5 mm
* EQ 626 P207_GPS      10.45      17.00 CoS        8.2 mm
* EQ_DEF M5.1 20km NNE of Upper Lake
 eq_def 09   39.3293 -122.8018     17.0 8 2016 08 10 02 58    0.014
 eq_rename 09
 eq_coseis 09  0.001 0.001 0.001      0.014      0.014      0.014
* ----------------------------------
* SEQ Earthquake # 10
* EQ 734 AC66_GPS      24.92      28.50 CoS        5.4 mm
* EQ_DEF M5.6 45km S of Semisopochnoi Island
 eq_def 10   51.5396  179.5501     28.5 8 2016 08 14 16 29    0.052
 eq_rename 10
 eq_coseis 10  0.001 0.001 0.001      0.052      0.052      0.052
```

Event #4 may have produced a small North co-seismic offset at P168 but there are missing data after the earthquake which make the determination not that robust. The KF estimate is 1.4 +- 0.52 mm (the LSQ estimate is smaller).
For Event #7, there are no recent data for RDHI so any offset cannot be determined. Based on the expected magnitude, it is unlikely there is a large offset.
For Event #9, there are no recent data for AC66 so any offset cannot be determined. This site has been displaced by other earthquakes. Most recently 2014/06/23.

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

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

```
* EQDEFS for 2016 08 14 to 2016 09 15 Generated Fri Sep 16 11:10:25 EDT 2016
* Proximity based on Week_All.Pos file
* ---------------------------------
* SEQ Earthquake # 1
* EQ 32 AC66_GPS      23.10      28.50 CoS        6.2 mm
* EQ_DEF M5.6 45km S of Semisopochnoi Island
 eq_def 01   51.5437  179.5022     28.5 8 2016 08 14 16 29    0.052
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.052      0.052      0.052
* ---------------------------------
* SEQ Earthquake # 2
* EQ 59 P237_GPS       8.46       8.80 CoS        0.0 mm
* EQ_DEF M3.6 12km SSE of Ridgemark
 eq_def 02   36.7015 -121.3380      8.8 8 2016 08 15 16 18    0.000
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.000      0.000      0.000
* ---------------------------------
* SEQ Earthquake # 3
* EQ 302 P631_GPS       2.94       8.70 CoS        0.0 mm
* EQ 302 P639_GPS       4.02       8.70 CoS        0.0 mm
* EQ 302 P642_GPS       7.48       8.70 CoS        0.0 mm
* EQ 302 P646_GPS       8.69       8.70 CoS        0.0 mm
* EQ_DEF M3.5 7km ESE of Mammoth Lakes
 eq_def 03   37.6232 -118.8928      8.7 8 2016 08 21 21 48    0.000
 eq_rename 03
 eq_coseis 03  0.001 0.001 0.001      0.000      0.000      0.000
* ---------------------------------
* SEQ Earthquake # 4
* EQ 703 WIKR_GPS       8.66       8.80 CoS        0.0 mm
* EQ_DEF M3.6 92km WNW of Cantwell
 eq_def 04   63.5713 -150.7540      8.8 8 2016 09 05 06 38    0.000
 eq_rename 04
 eq_coseis 04  0.001 0.001 0.001      0.000      0.000      0.000
* ---------------------------------
* SEQ Earthquake # 5
* EQ 859 P224_GPS       6.89       8.70 CoS        0.0 mm
* EQ_DEF M3.5 3km SE of Piedmont
 eq_def 05   37.8047 -122.1975      8.7 8 2016 09 13 07 51    0.000
 eq_rename 05
 eq_coseis 05  0.001 0.001 0.001      0.000      0.000      0.000
```

For event 1: There is no recent data from AC66 so we cannot determine if there was any offset. Based on the expected magnitude there probably was not any.

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

Antenna Change Offsets: 2016/06/01-2016/08/31

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

```
Station       Date           From            To
 AV35  2016  6 20  0 35 TRM59800.00   TRM59800.80
 CABL  2016  6  2  0  0 TRM29659.00   TRM59800.80
```

```
GUAX  2016  6 19  2  7 ASH701945C_M  TRM59800.00
HOLB  2016  6 15  0  0 TRM59800.00   TRM59800.00
P375  2016  6  2  0  0 TRM29659.00   TRM59800.80
P380  2016  6 30  0  0 TRM29659.00   TRM59800.80
P409  2016  6  3  0  0 TRM29659.00   TRM59800.80
P733  2016  6  2  0  0 TRM29659.00   TRM59800.80
P784  2016  6 29  0  0 TRM29659.00   TRM59800.00
AC17  2016  7 13  6  4 TRM29659.00   TRM59800.80
BAIE  2016  7  8 13 18 AOAD/M_T      TPSCR.G3
ESCU  2013 10 23 17 56 ASH701945C_M  RM29659.00
ESCU  2016  7 10 23  7 TRM29659.00   ASH701945E_M
P154  2016  7  1  0  0 TRM29659.00   TRM59800.80
P387  2016  7 19 17 31 TRM29659.00   TRM59800.80
P389  2016  7 19 20 22 TRM29659.00   TRM59800.80
SLID  2016  7 12 17 48 TRM29659.00   TRM59800.80
AC17  2016  7 13  6  4 TRM29659.00   TRM59800.80
BAIE  2016  7  8 13 18 AOAD/M_T      TPSCR.G3
ESCU  2013 10 23 17 56 ASH701945C_M  RM29659.00
ESCU  2016  7 10 23  7 TRM29659.00   ASH701945E_M
P154  2016  7  1  0  0 TRM29659.00   TRM59800.80
P387  2016  7 19 17 31 TRM29659.00   TRM59800.80
P389  2016  7 19 20 22 TRM29659.00   TRM59800.80
SLID  2016  7 12 17 48 TRM29659.00   TRM59800.80
```

Analysis

AV35: WLS dNEU -0.74 +- 9.84, 0.96 +- 6.33, -14.11 +- 19.35 mm,
KF dNEU 1.15 +- 0.65, -0.71 +- 0.46, -10.66 +- 1.67 mm
Large gap in the time series and snow effects make these estimates somewhat unreliable

CABL: WLS dNEU 1.74 +- 3.73, -3.77 +- 2.07, 3.06 +- 12.32 mm,
KF dNEU 3.20 +- 0.28, -2.85 +- 0.22, 4.54 +- 0.89 mm
The NE offsets are very clear in the data.

GUAX: WLS dNEU 2.19 +- 1.49, -10.04 +- 1.29, 13.69 +- 6.63 mm,
KF dNEU 2.49 +- 2.81, -9.10 +- 2.65, 12.93 +- 10.66 mm
Almost a decade gap in the data. Also no rapid results from the station

HOLB: WLS dNEU -0.93 +- 10.57, 3.67 +- 10.60, 0.99 +- 8.70 mm, KF
dNEU 1.72 +- 0.47, 1.00 +- 0.39, -0.38 +- 0.97 mm
Data bad between 2016/05/09 and 2016/06/04 and seem to come good again 11 days before the antenna is changed. Height off by 10 cm +- 10 cm range. Offset computed with data deleted in May-June.

P375: WLS dNEU -3.47 +- 0.77, -0.02 +- 1.25, 3.41 +- 5.10 mm,
KF dNEU -3.39 +- 0.33, 0.32 +- 0.33, 4.36 +- 1.33 mm
North break is clear but estimate may be affected by ETS events (one 4 months before antenna change.

P380: WLS dNEU -4.85 +- 2.46, 2.71 +- 1.84, 1.13 +- 11.11 mm,
KF dNEU -3.99 +- 0.40, 2.32 +- 0.33, 1.62 +- 1.35 mm
North offset is quite clear. Estimate with annual estimated.

P409: WLS dNEU 0.31 +- 1.66, -0.82 +- 0.67, 3.04 +- 2.98 mm,
KF dNEU 0.24 +- 0.39, -0.78 +- 0.27, 3.36 +- 1.09 mm
Offsets appear small and estimates are possibly affected by ETS events (similar to P375)

P733: WLS dNEU 0.38 +- 0.92, 2.42 +- 0.51, -2.31 +- 2.15 mm,
KF dNEU 1.03 +- 0.33, 2.38 +- 0.26, -1.78 +- 1.04 mm
East offset may be affected by systematics in time series.

P784: WLS dNEU -0.48 +- 1.19, 4.70 +- 3.47, 3.18 +- 9.04 mm,
KF dNEU -0.60 +- 0.45, 5.46 +- 0.39, 4.62 +- 1.56 mm
East offset is clear but estimate could be affected by systematics.

AC17: WLS dNEU -1.39 +- 5.08, -2.09 +- 4.16, 0.19 +- 9.27 mm,
KF dNEU -2.58 +- 0.39, -1.75 +- 0.30, 3.65 +- 1.04 mm
Possibly small offset. Site does have snow events and seasonal signals
BAIE: WLS dNEU 0.84 +- 1.60, -1.38 +- 1.87, 4.85 +- 5.40 mm,
KF dNEU 0.62 +- 0.40, -0.95 +- 0.31, 7.30 +- 1.24 mm
Offsets are small with some outliers after change. Snow events at site also.
ESCU:
Break 2013 10 23 0 0 :
WLS dNEU 6.55 +- 0.29, -2.85 +- 0.32, -9.16 +- 1.43 mm,
KF dNEU 6.15 +- 0.25, -3.00 +- 0.23, -9.87 +- 0.72 mm
Break 2016 7 10 23 7:
WLS dNEU -1.71 +- 1.02, 1.44 +- 1.07, -4.09 +- 4.91 mm,
KF dNEU -1.33 +- 0.38, 0.70 +- 0.31, -2.83 +- 1.22 mm
An earlier antenna change in 2013 was found for this site. The earlier break is larger in size.
P154: WLS dNEU -1.07 +- 1.16, 1.74 +- 1.17, 0.84 +- 5.65 mm,
KF dNEU -0.72 +- 0.32, 1.23 +- 0.27, 1.93 +- 1.08 mm
Break is small in this case.
P387: WLS dNEU 3.75 +- 7.83, -6.87 +- 13.95, -0.12 +- 7.55 mm,
KF dNEU 3.00 +- 0.52, -5.04 +- 0.49, -0.45 +- 1.54 mm
Break in this case is very clear in the time series.
P389: WLS dNEU 6.86 +- 4.99, -0.83 +- 0.57, 0.40 +- 6.75 mm,
KF dNEU 5.89 +- 0.40, -0.91 +- 0.30, 0.68 +- 1.21 mm
Break is clear in the data in North. There is large North transient (15 mm) in North at the sites between 2007 10 21 when the site starts and approximated 2008 2 6. It is not clear what happened.
SLID: WLS dNEU -1.74 +- 8.69, 0.84 +- 5.59, 2.59 +- 9.37 mm,
KF dNEU 0.88 +- 0.45, 1.70 +- 0.35, 1.26 +- 1.07 mm
Large gap before the antenna change make this offset estimates less robust.

GRTN WLS dNEU -2.09 +- 1.36, -1.61 +- 1.22, 21.38 +- 5.72 mm,
KF dNEU -2.22 +- 0.48, -1.49 +- 0.45, 22.97 +- 1.55 mm
There is over a year gap before this break sp estimates could be unreliable. When a vertical rate is estimated (-0.7 mm/yr), the vertical offsets is clear. There is an earlier antenna discontinuity at this site (2007/04/04)
OZST WLS dNEU -0.70 +- 0.68, -0.33 +- 1.49, 8.50 +- 10.39 mm,
KF dNEU -0.45 +- 0.30, -1.29 +- 0.28, 5.46 +- 1.14 mm
Small offsets, vertical offset is not so clear.
P010 WLS dNEU 0.39 +- 5.21, 2.68 +- 0.62, -1.70 +- 6.14 mm,
KF dNEU -0.78 +- 0.42, 2.44 +- 0.36, -1.63 +- 1.42 mm
Gap before antenna change (~2 weeks). East offset is pretty clear.
P088 WLS dNEU -3.14 +- 0.46, -2.69 +- 0.83, 1.05 +- 5.28 mm,

KF dNEU   -3.33 +- 0.25, -3.22 +- 0.23,   0.69 +- 0.88 mm
North ands east offset both are clear. Some large sigma values before antenna change.
P306 WLS dNEU   4.55 +- 1.76, -1.15 +- 2.63,   4.64 +- 27.12 mm,
KF dNEU   4.32 +- 0.40, -3.03 +- 0.36,   0.39 +- 1.62 mm
The north and east offsets are clear. There is a ~1 week gap in the data before the antenna change
P538 WLS dNEU   1.63 +- 2.14,   2.55 +- 0.61,   3.61 +- 12.07 mm,
KF dNEU   1.82 +- 0.29,   2.22 +- 0.25,   1.62 +- 1.09 mm
The north and east offsets are clear.
P664 WLS dNEU   -1.74 +- 1.61, -1.72 +- 0.96,   1.99 +- 6.65 mm,
KF dNEU   0.06 +- 0.36, -1.14 +- 0.29, -0.14 +- 1.30 mm
Snow/Ice outlier data removed before estimates. This affects the estimated values.
DOME removal seems to have little impact.
P665 WLS dNEU   0.83 +- 1.06, -0.33 +- 1.48,   5.06 +- 8.00 mm,
KF dNEU   0.61 +- 0.31,   0.22 +- 0.27,   2.69 +- 1.11 mm
Snow/Ice outlier data removed before estimates.

New offsets of unknown origin

One new unknown offset was added in the quarter.
Fri Jun 17 09:51:51 EDT 2016
rename DAM2   DAM2_APS 2016 3 4 24 0 ! 5 mm North break for unknown reason.
TAH on 2016-06-17 09:52:11

Earthquake post-seismic updates.

A large change in slope after 2013-01-05 M 7.5 earthquake at many sites offset by this earthquake necessitates adding a post-seismic parameterization. This is event eq_def 24 and a post-seismic log with ~80-day time constant was added to this earthquake description.

Script updates

No major changes have been to the scripts.

GAMIT/GLOBK Community Support

During this quarter our primary effort has been to test and debug our modifications to GAMIT allowing the processing of two-frequency observations from satellites of any single GNSS. Using GPS and IRNSS data, we found and corrected problems with reading RINEX 3 navigation files, estimating receiver clock offsets, and detecting bad data on RINEX observation files. We also made significant progress on a refined Beidou yaw model. We were not able, as hoped, to complete the coding of cycle-slip repair and ambiguity resolution for Glonass FDMA observations, but will make that a priority for the next quarter.

We continue to spend 5-10 hours per week in email support of users. During the quarter we issued 17 royalty-free licenses to educational and research institutions.