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

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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 2016/12/15 to 2017/03/11, time series velocity field analyses for the GAGE reprocessing analyses (1996-2016). Several earthquakes were investigated this quarter but none generated coseismic displacements > 1mm. There were some earthquakes that could not 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 March 11. 2017. 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.

This quarter we introduced a new product which contains the estimates of the offsets in the time series due to equipment changes and earthquakes. The header records in this new product describe the product, its format and notes that it is not a quality tested product.

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 1839 stations were processed compared to 1869 for the previous quarter. The reduction in number of stations could be due to remote site downloads and stations going off-lines. Reductions in the numbers of stations being included in the finals analyses have been noted by the ACs. Based on Table 2 changes since last quarter, most of the loss seems to be in the expanded network although we did revise the site allocation algorithm between PBO and expanded and this may explain some of the difference i.e., in earlier quarters, some PBO stations were assigned to the expanded network category.

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: December 15, 2016 and March 11. 2017

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 December 15, 2016 and March 11. 2017. 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 1.06 mm for all centers and as low as 0.85-0.90 mm for NM north and PBO east components. The up RMS scatters are less than or equal 5.98 mm and as low as 5.54 mm for the PBO solution. These statistics are a little 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 1839, 1835 and 1833 stations for PBO, NMT and CWU analyzed in the finals analysis between December 15, 2016 and March 11. 2017. Histograms of the RMS scatters are shown in Figure 1-3.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
PBO	0.88	0.90	5.54
NMT	0.85	0.91	5.58
CWU	1.06	1.03	5.98
70%			
PBO	1.10	1.15	6.12
NMT	1.08	1.15	6.10
CWU	1.32	1.31	6.65
95%			
PBO	2.56	2.60	9.51
NMT	2.51	2.58	9.88
CWU	2.79	2.89	10.63

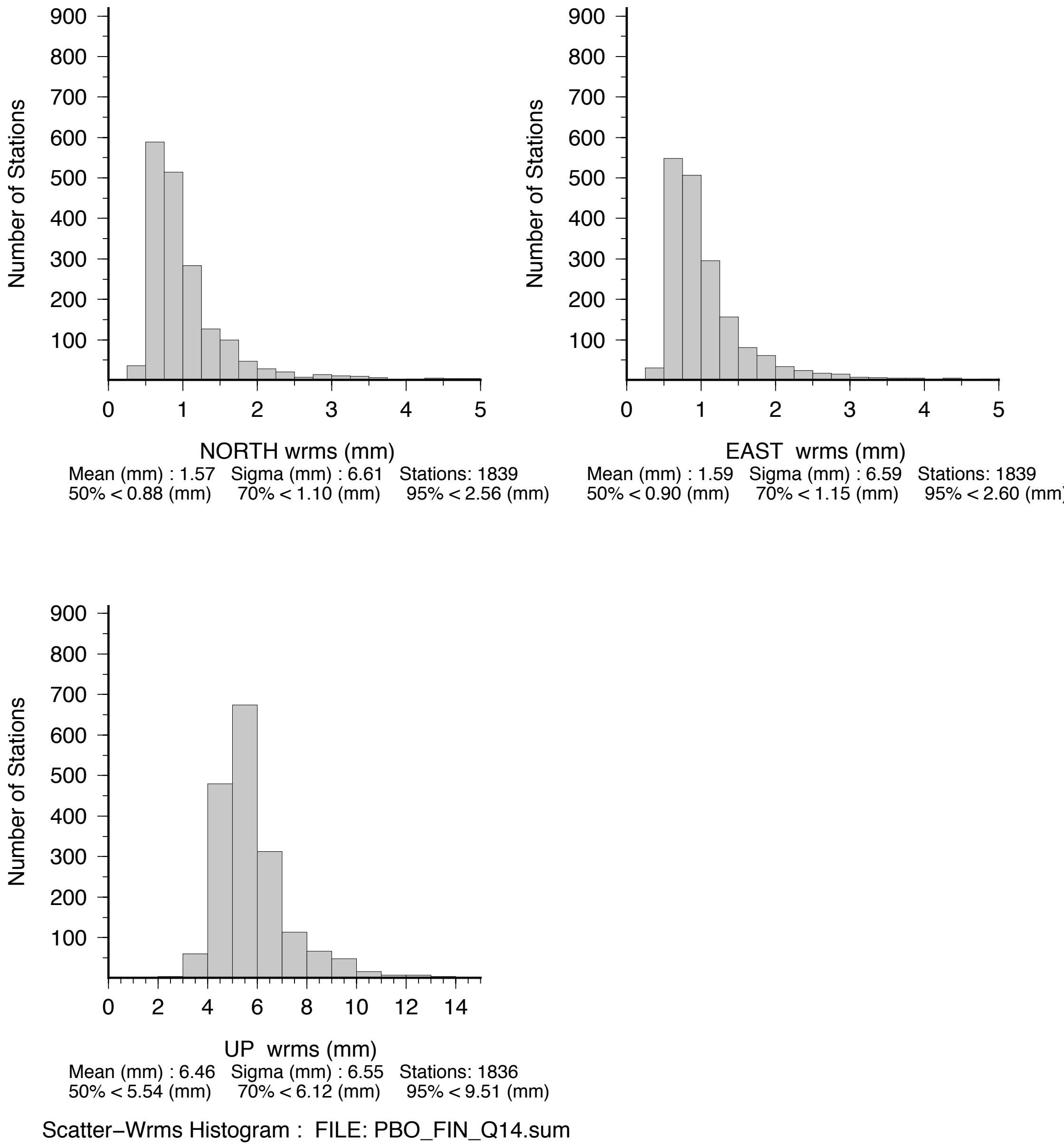

Figure 1: PBO combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1839 stations analyzed between December 15, 2016 and March 11. 2017. Linear trends and annual signals were estimated from the time series.

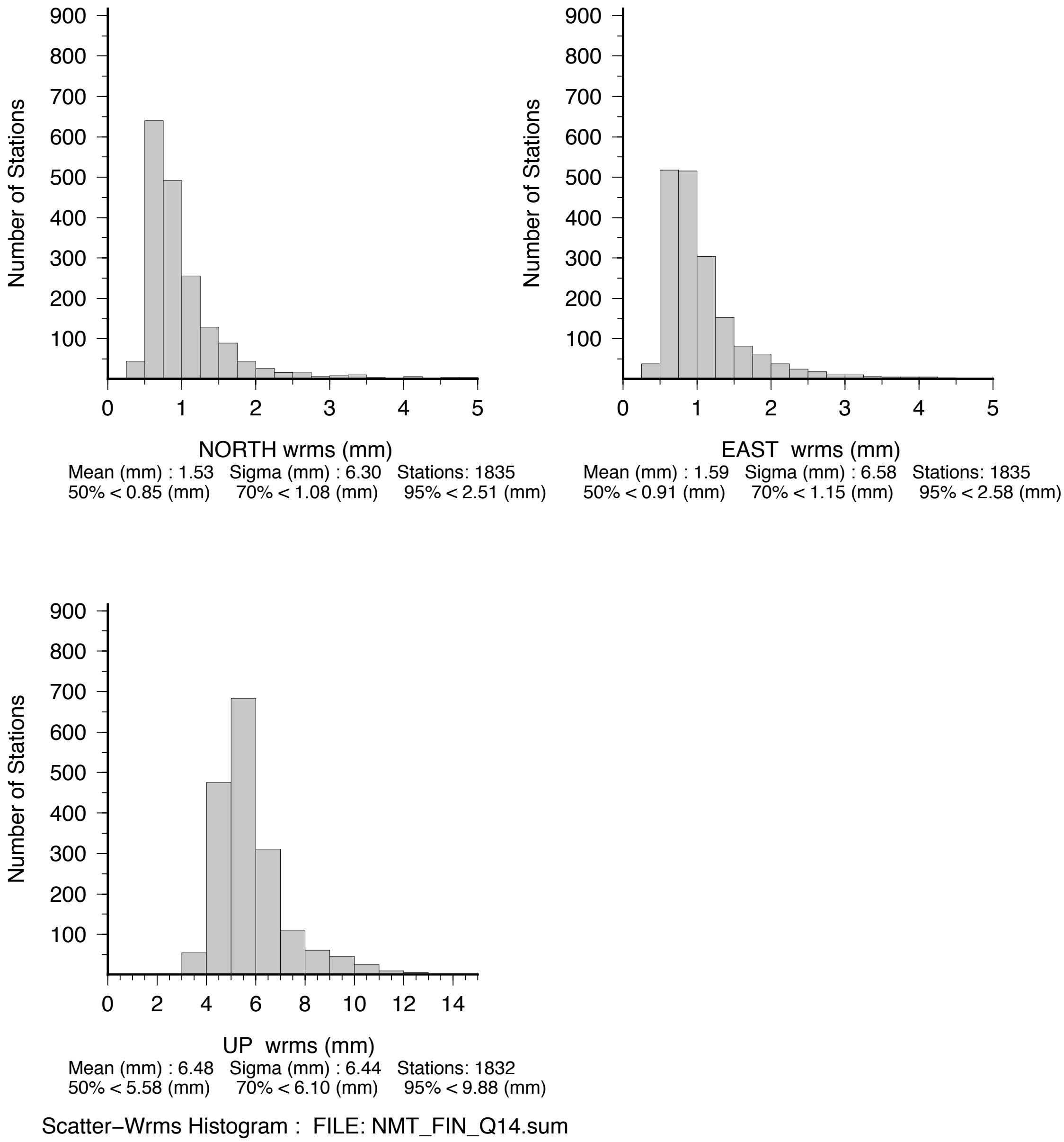

Figure 2: NMT combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1835 stations analyzed between December 15, 2016 and March 11. 2017. Linear trends and annual signals were estimated from the time series.

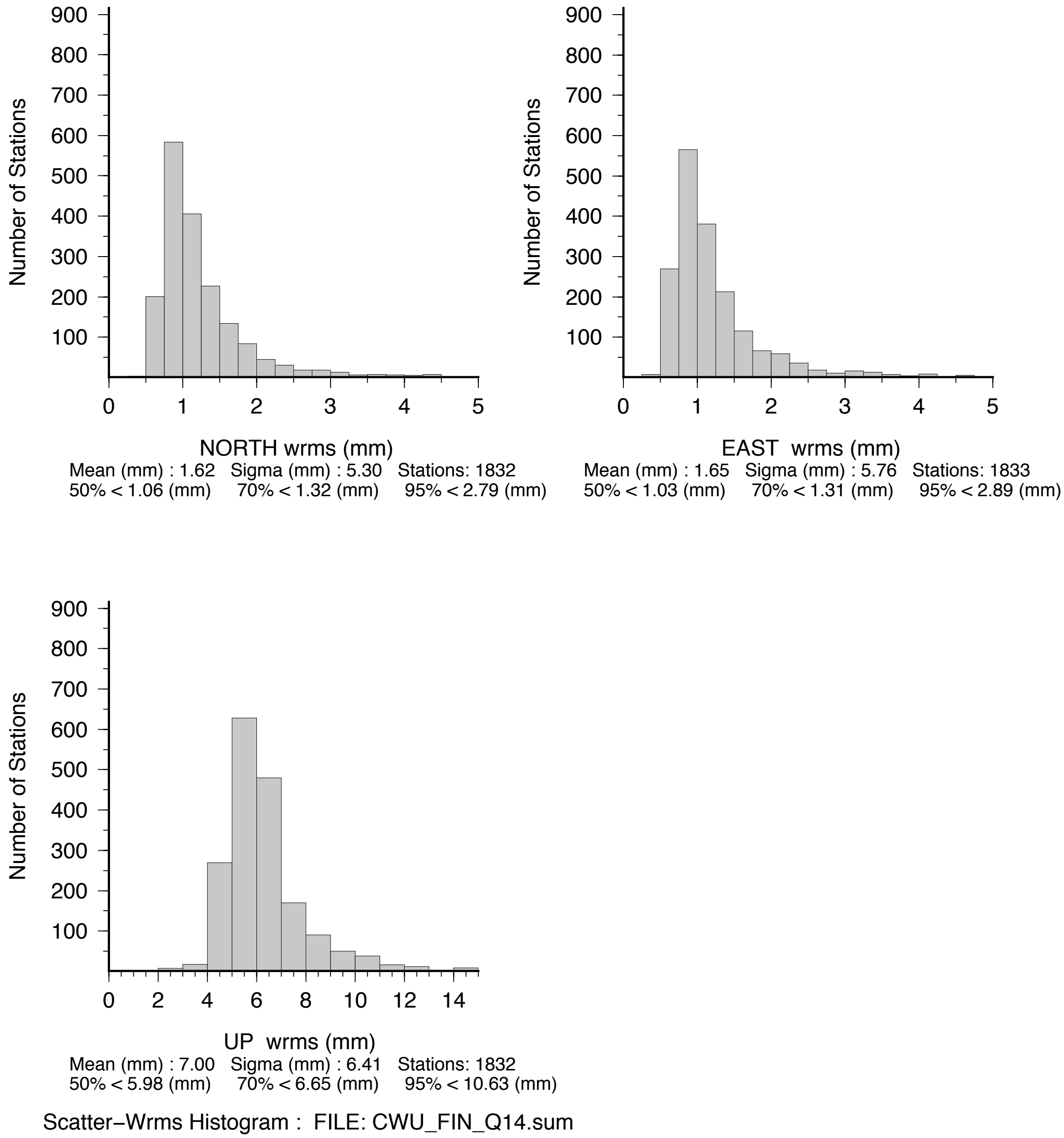

Figure 3: CWU combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1832 stations analyzed between December 15, 2016 and March 11. 2017. Editing removes two stations for North and Up. Linear trends and annual signals were estimated from the time series.

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_Q14.tab. There are 1831 stations in the file for sites that have at least 2 measurements during the month. The contents of the files are of this form:

```
Tabular Position RMS scatters created from PBO_FIN_Q14.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    87      0.8   0.46      1.0   0.63     5.5   0.82     13.15
 1ULM    78      0.7   0.46      0.8   0.55     5.5   0.92     13.73
 7ODM    85      0.7   0.47      0.7   0.56     5.2   0.98     15.89
 AB02    87      0.8   0.56      0.9   0.78     4.3   0.93      9.80
…
 ZBW1    87      0.7   0.36      0.8   0.50     5.6   0.81     13.77
 ZDC1    87      0.8   0.45      0.8   0.55     5.1   0.77     13.77
 ZDV1    86      0.8   0.41      1.1   0.68     6.7   0.95     13.77
 ZKC1    87      0.8   0.43      0.6   0.40     6.0   0.87     13.77
 ZLA1    87      1.6   0.76      1.3   0.70     7.5   0.97     13.77
 ZME1    87      0.9   0.47      0.6   0.38     6.6   0.93     14.00
 ZMP1    87      0.7   0.37      0.7   0.49     6.5   1.01     14.24
 ZNY1    87      0.8   0.41      0.8   0.53     4.8   0.73     14.15
 ZSE1    87      0.9   0.41      1.1   0.67     6.4   0.93     14.15
 ZTL4    87      0.7   0.40      0.7   0.45     5.3   0.74     14.35
```

Table 2: RMS scatter of the position residuals for the PBO combined solution between December 15, 2016 and March 11. 2017 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	0.88	0.89	5.69	870
NUCLEUS	0.80	0.79	5.20	203
GAMA	0.50	0.62	5.83	14
COCO Net	1.22	1.29	5.37	111
USGS SCIGN	0.89	0.89	4.93	131
Expanded	0.84	0.88	5.51	510
70%				
PBO	1.11	1.16	6.27	
NUCLEUS	0.97	0.99	5.97	
GAMA	0.59	0.64	5.95	
COCO Net	1.46	1.58	6.57	
USGS SCIGN	1.21	1.25	5.48	
Expanded	1.02	1.10	5.98	
95%				
PBO	2.94	2.58	9.97	
NUCLEUS	1.63	1.61	8.05	
GAMA	0.71	0.66	6.74	
COCO Net	2.88	4.42	10.82	

USGS SCIGN	2.52	2.91	9.31
Expanded	2.43	2.44	8.88

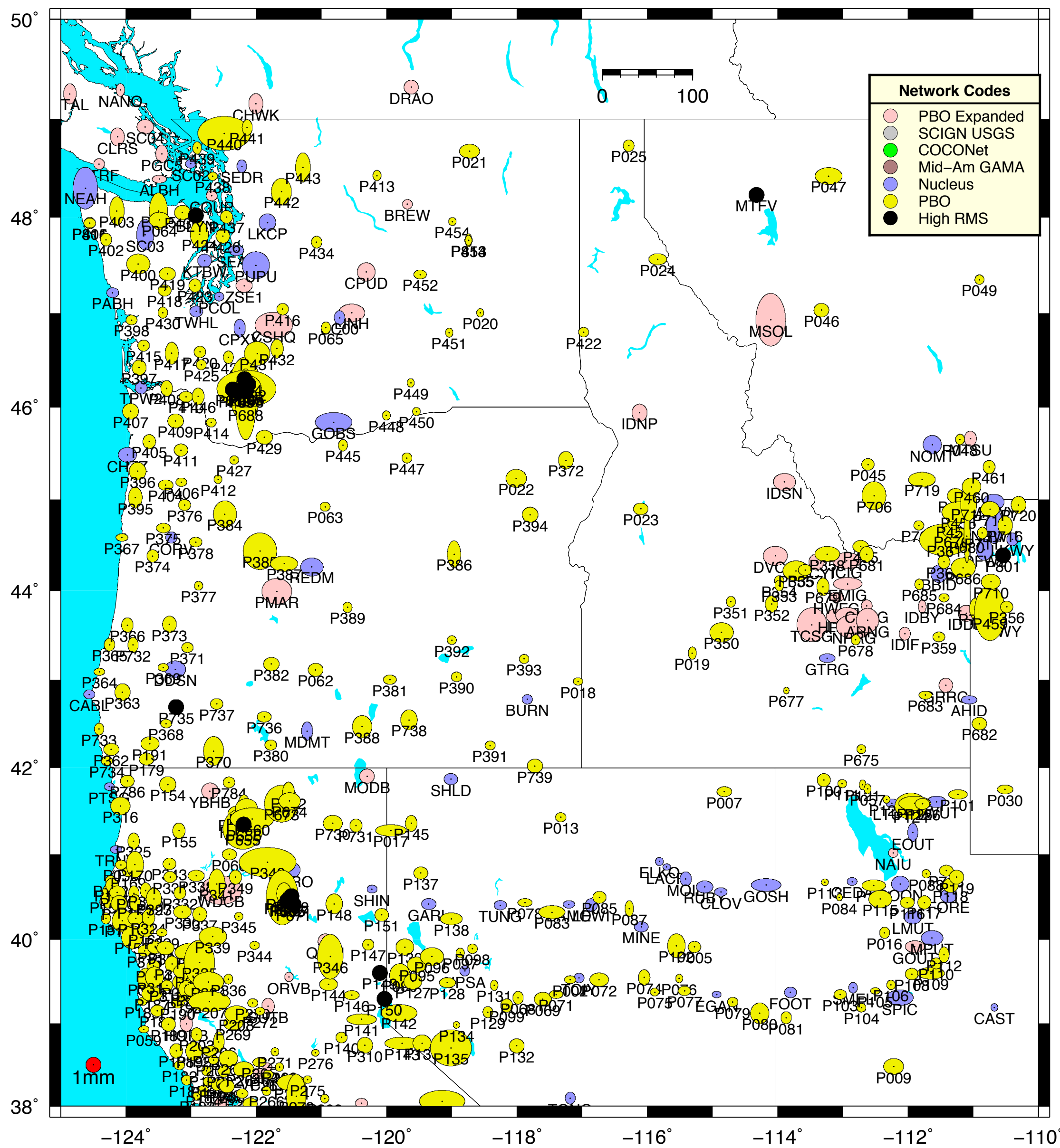

Figure 4: Distribution of the RMS scatters of horizontal position estimates from the PBO combined analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the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

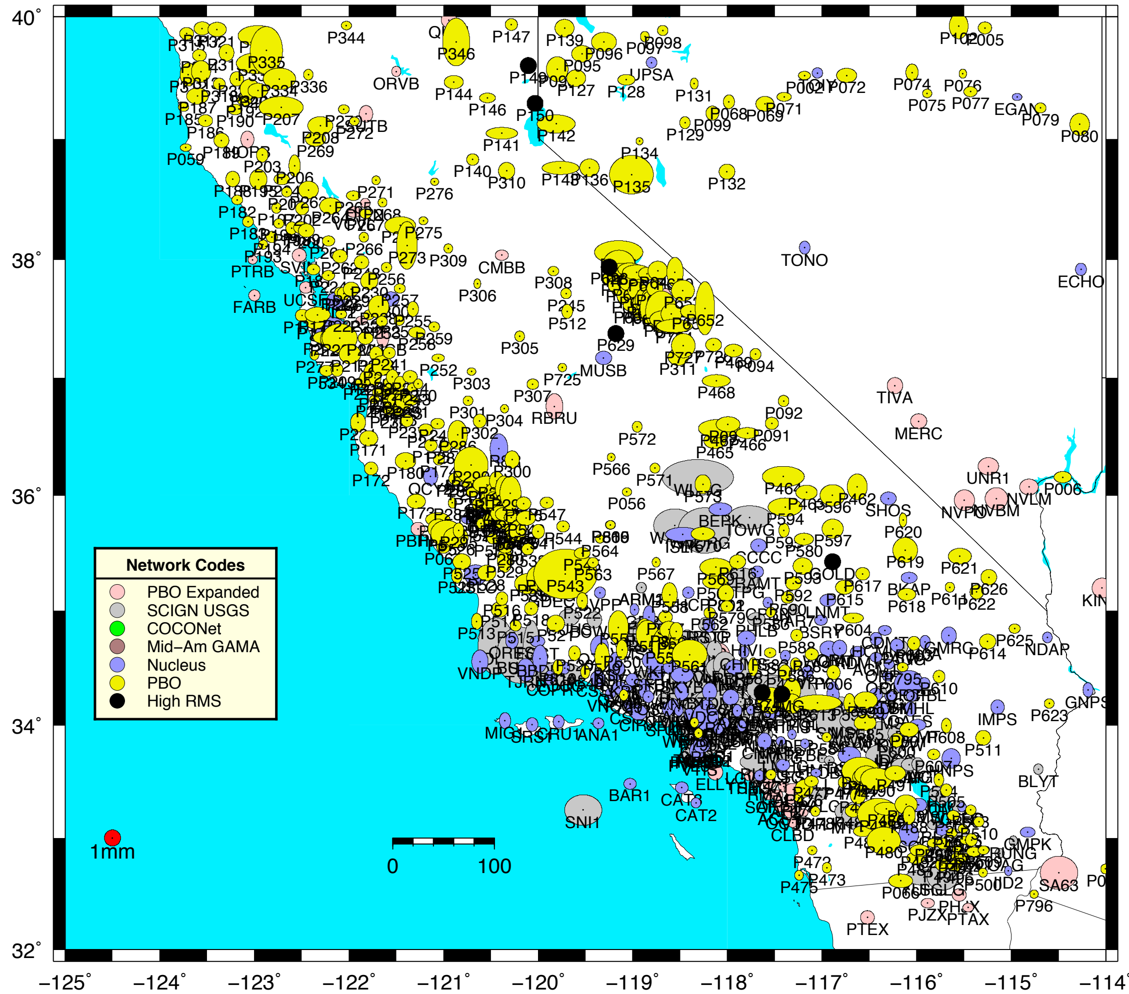

Figure 5: Same as Figure 4 except for the Southern Western United States. Black circles in the Yucca mountain region have no data during this 3-month period.

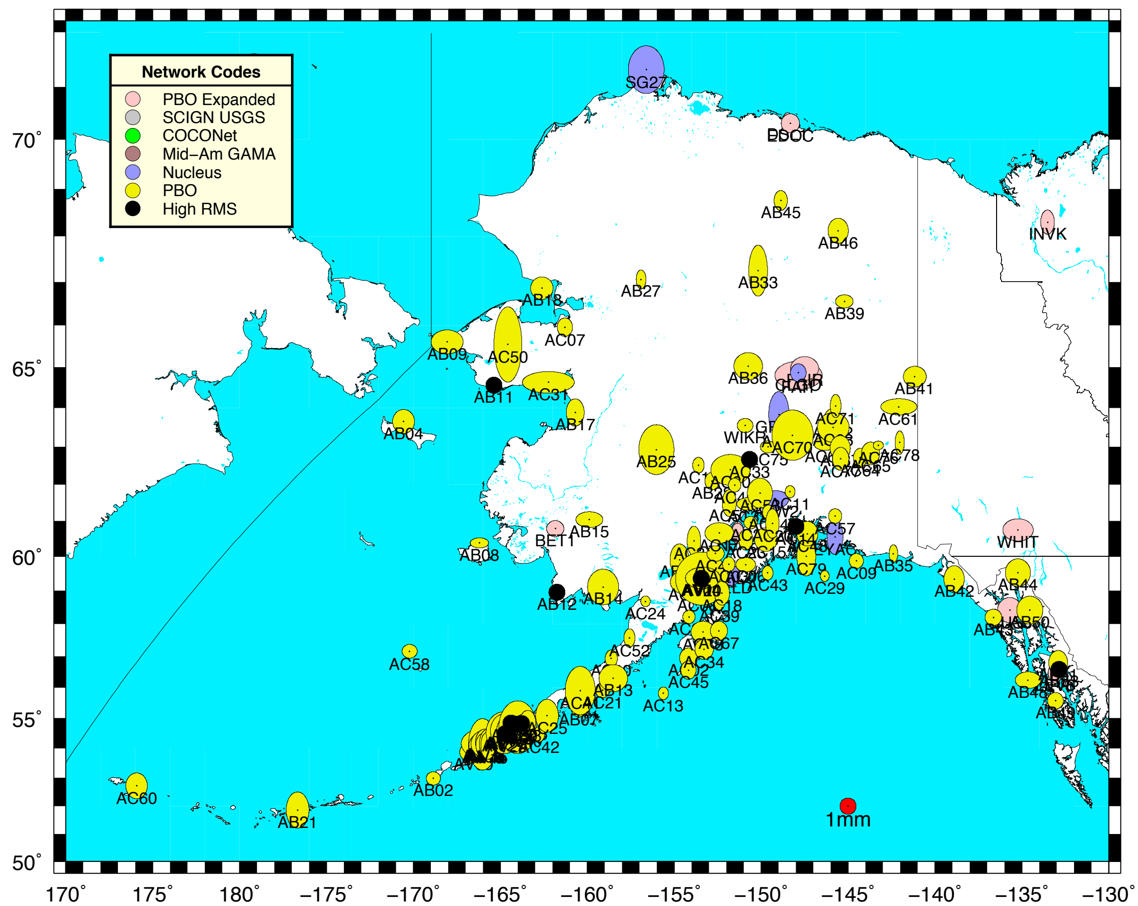

Figure 6: Same as Figure 4 except for the Alaskan region.

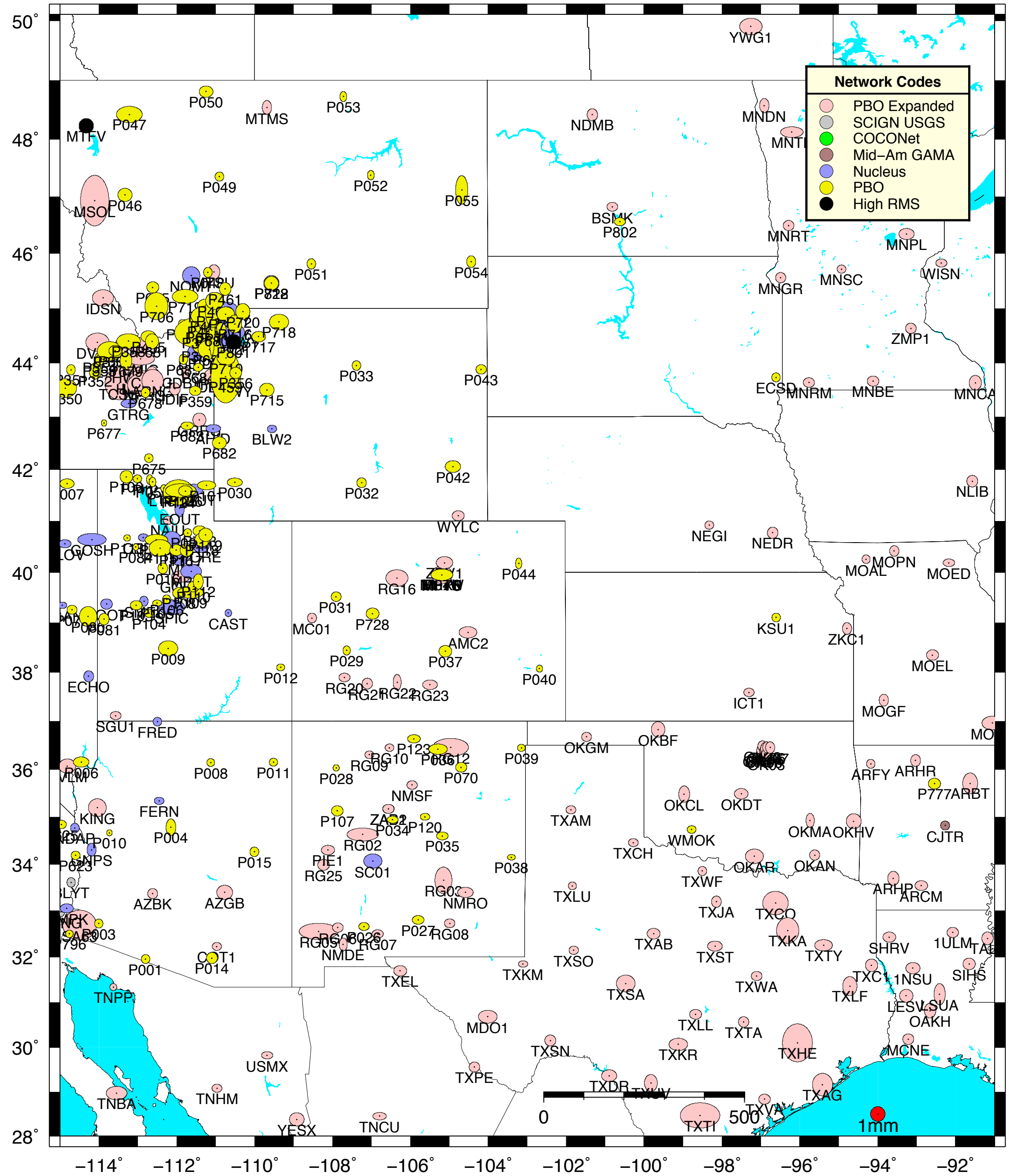

Figure 7: Same as Figure 4 except for the Central United States

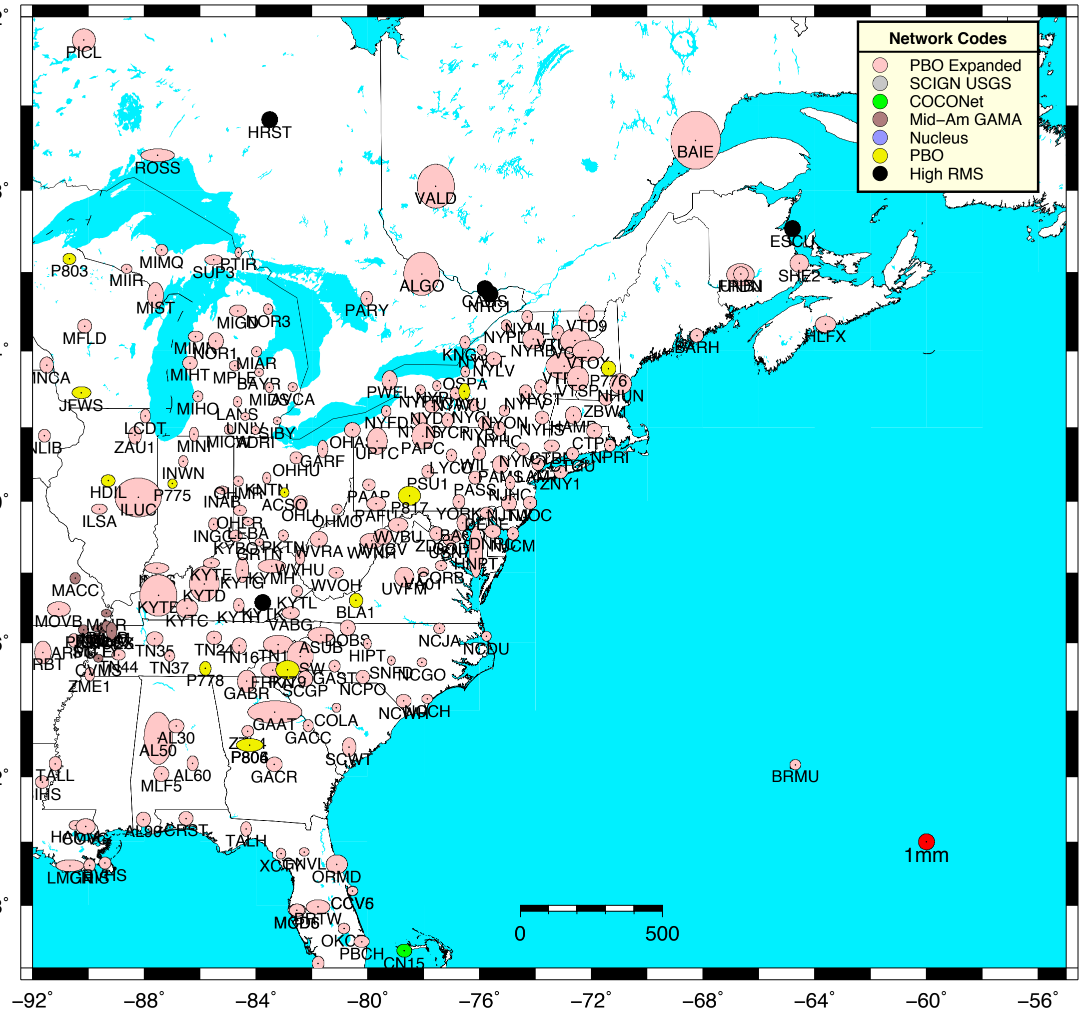

Figure 8: Same as Figure 4 except for the Eastern United States

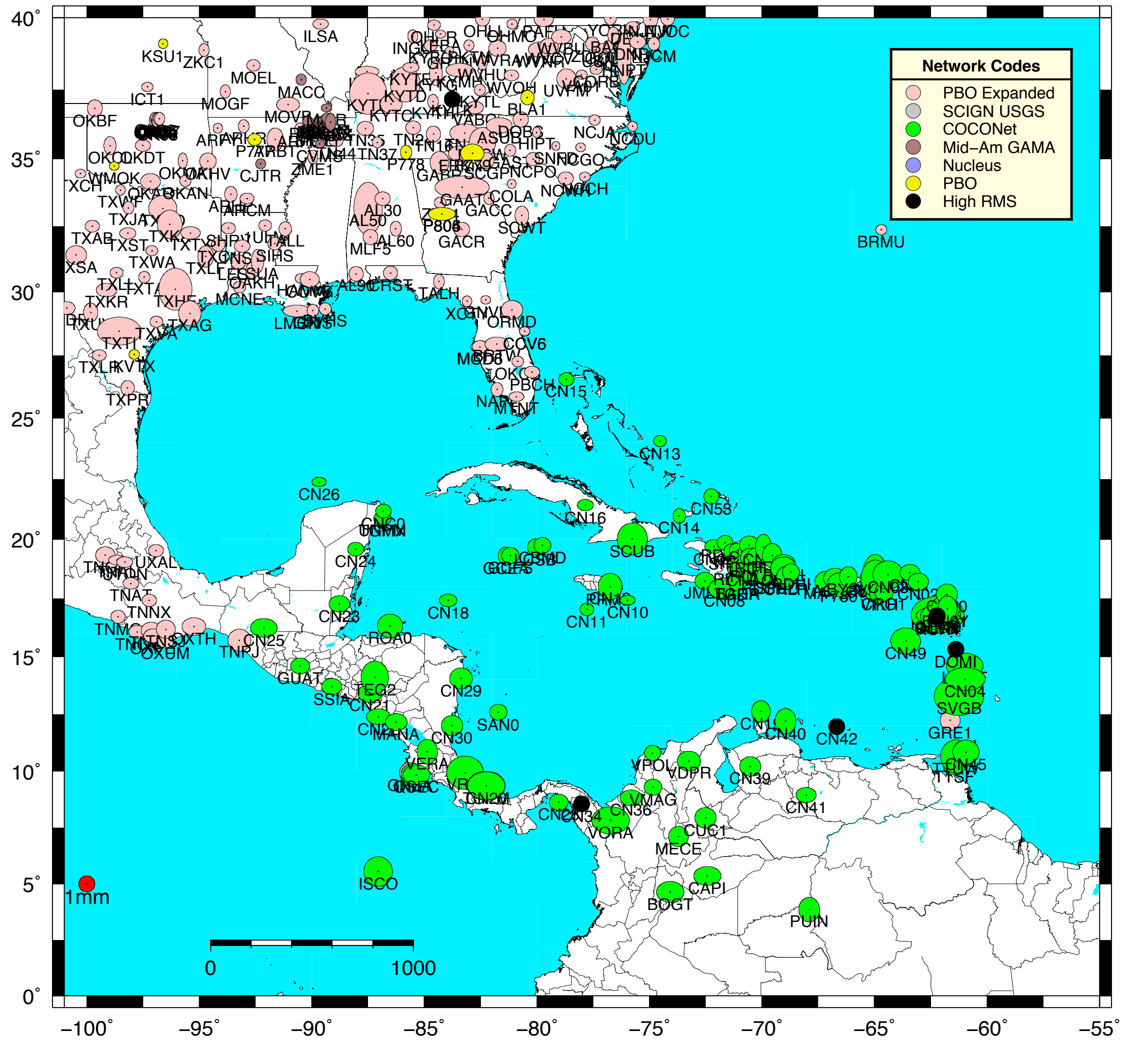

Figure 9: Same as Figure 4 except for the Caribbean region.

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.
We have introduced a new product KFOffsets_20170403.dat, where the date is the date the file was generated, which gives the estimates of the offsets obtained from Kalman filter analysis of the time series. The products is discussed later in the report.

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 2207 stations in the combined PBO solution which is slightly larger than the 2191 stations reported in the last quarter. The statistics of the fits to results are shown in Table 3. In this analysis, offsets are estimated for antenna changes and earthquakes. Annual signals are estimated and for some earthquakes, logarithmic post-seismic signals are also estimated. The full tables of RMS fits along with the duration of the data used are given in the following linked files: pbo_nam08_170311.tab, nmt_nam08_170311.tab and cwu_nam08_170311.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_170311.snpvel, nmt_nam08_170311.snpvel and cwu_nam08_170311.snpvel.

Table 3: Statistics of the fits of 2207, 2205 and 2198 stations analyzed by PBO, NMT and CWU in the reprocessed analysis for data collected between Jan 1, 1996 and March 11. 2017.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
NMT	1.14	1.23	5.78
CWU	1.35	1.33	6.02
PBO	1.14	1.18	5.35
70%			
NMT	1.48	1.58	6.50
CWU	1.67	1.64	6.82
PBO	1.46	1.50	6.04
95%			
NMT	3.28	3.23	9.37
CWU	3.46	3.41	10.39
PBO	3.27	3.21	9.31

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 0.07 mm/yr horizontal and 0.70 mm/yr vertical from differences of all stations in the two solutions that have velocity sigmas that sum to less than 100 mm/yr. This is a small change from previous reports and now only common stations are now compared and nearby stations have been removed. The χ^2/f of the difference is $(1.03)^2$ for the horizontal and $(1.96)^2$ for the vertical component. These comparisons are summarized in Table 4. As noted in previous reports, adding small minimum sigmas (added in a root-sum-squared sense), computed such that χ^2/f is near unity changes the statistic slightly (Table 4). With the FOGMEX correlated noise model used to compute the velocity sigmas, the comparison statistics are close but still 3-96% optimistic over expectations. The 10-worst stations, in the order they are removed, are GOUT, BSNC, P482, AC78, PBHR, MTA1, P025, P483, P282, MYT2 when the added sigmas are not applied and PTGX, FSHB, CN40, P482, MTA1, AC78, PBHR, P483, P282, MYT2 when the values given in Table 4 are sum-squared into the velocity sigma estimates. This list is similar to the list in the previous quarter although this time we have split the list into two parts. Some stations have been added and others removed.

Table 4: Statistics of the differences between the CWU and NMT velocity solutions with no transformation between them. The stations common to the CWU and NMT solutions are used which is a slightly smaller number than in either solution. The PBO, NMT and CWU solutions themselves have 2197, 2197 and 2187 stations whose velocities can be determined to better than 100 mm/yr. WRMS is weighted-root-mean-scatter and NRMS is sqrt(χ^2/f) where f is the number of comparisons.

Solution	#	NE WRMS (mm/yr)	U WRMS (mm/yr)	NE NRMS	U NRMS
All	2185	0.07	0.70	1.02	1.96
Edited-10 worst	2175	0.06	0.69	0.97	1.94
Less than median (0.14 0.43 mm/yr)	1242	0.05	0.65	1.03	2.17
Added minimum sigma NE 0.01 U 0.50 mm/yr					
All	2185	0.07	0.89	1.00	0.99
Edited-10 worst	2175	0.07	0.87	0.94	0.97
Less than median (0.14 0.66 mm/yr)	1242	0.05	0.74	0.98	0.92

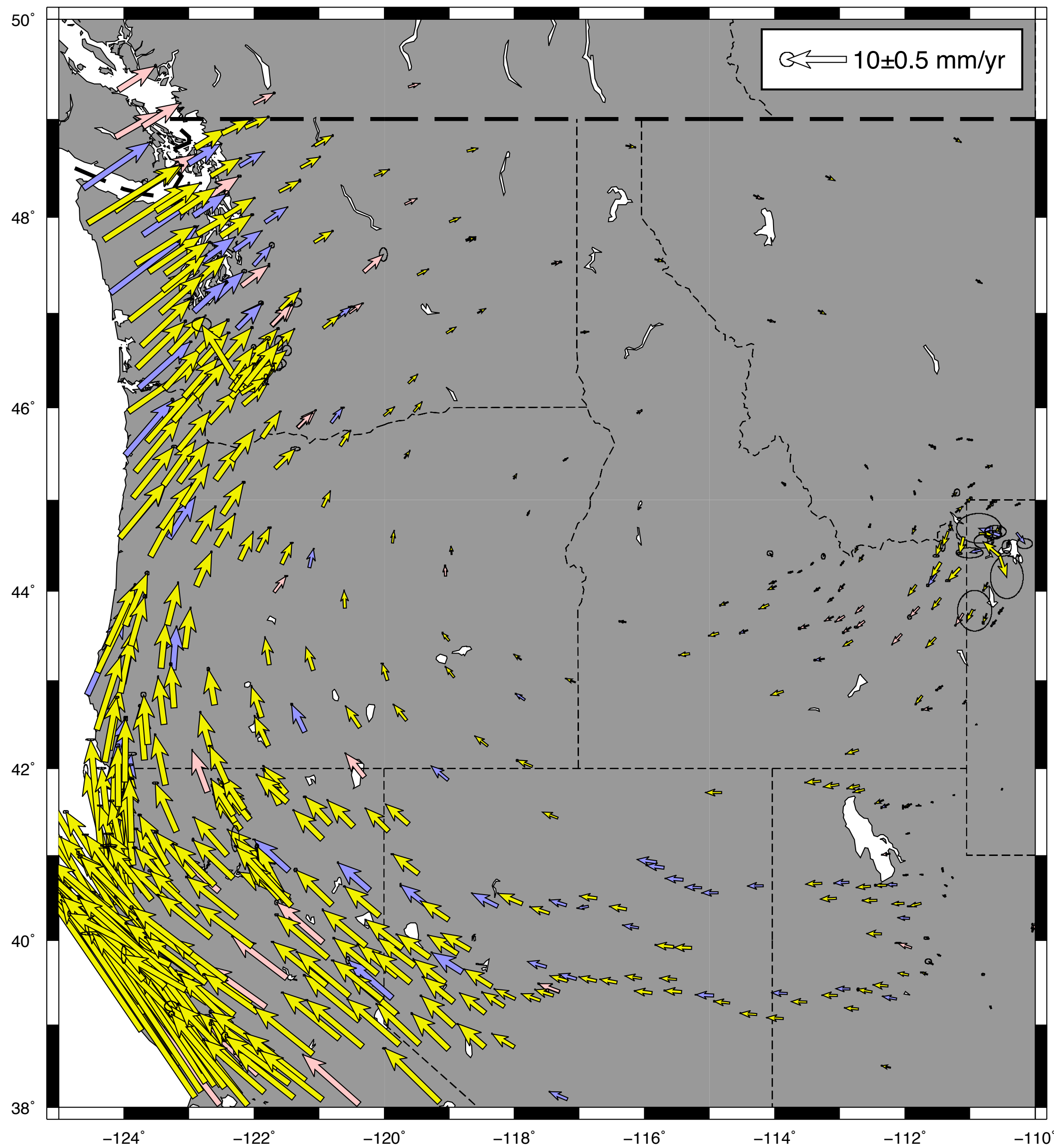

Figure 10: Velocity field estimates from the combined PBO solutions generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal standard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

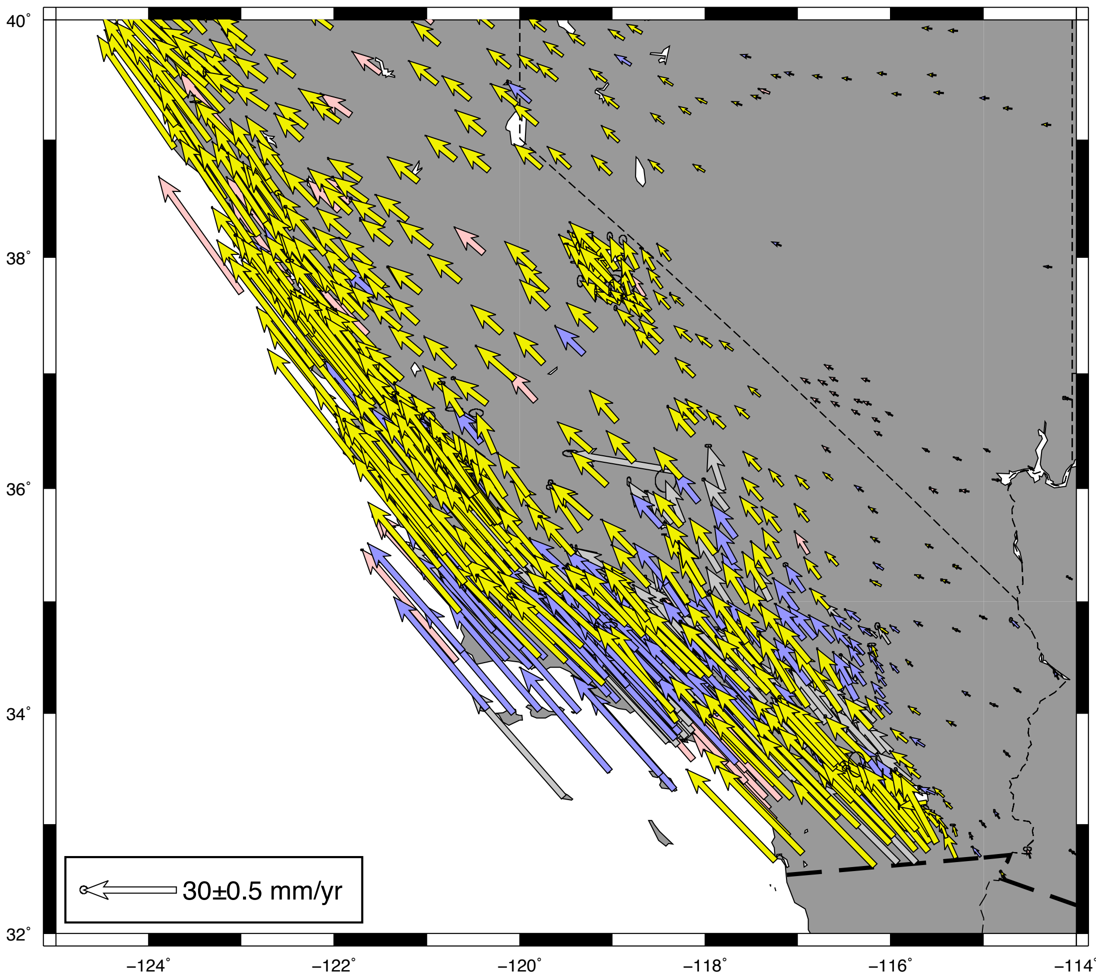

Figure 11: Same as Figure 10 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

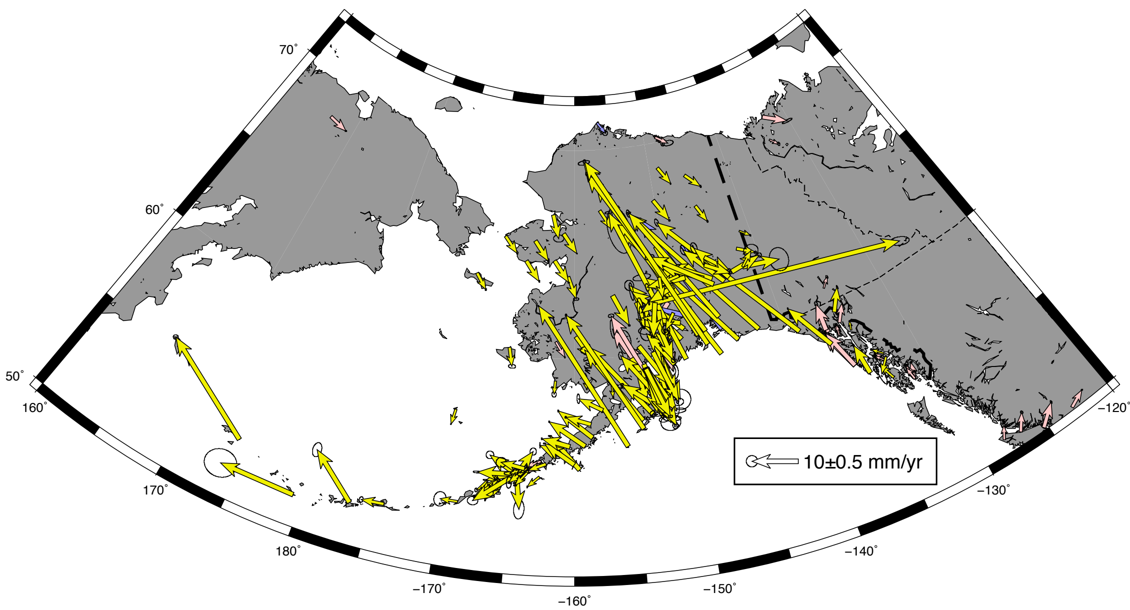

Figure 12: Same as Figure 10 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

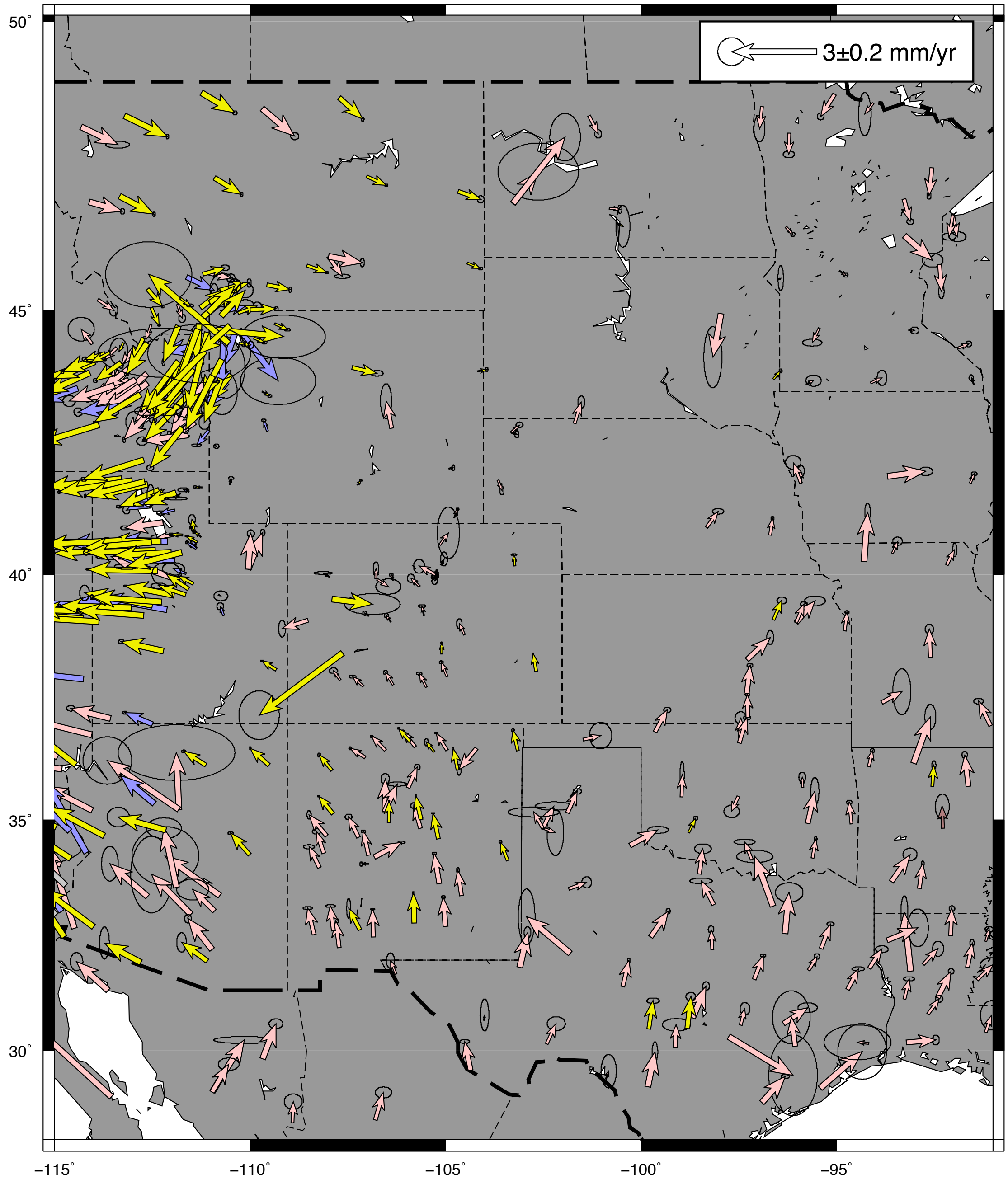

Figure 13: Same as Figure 10 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

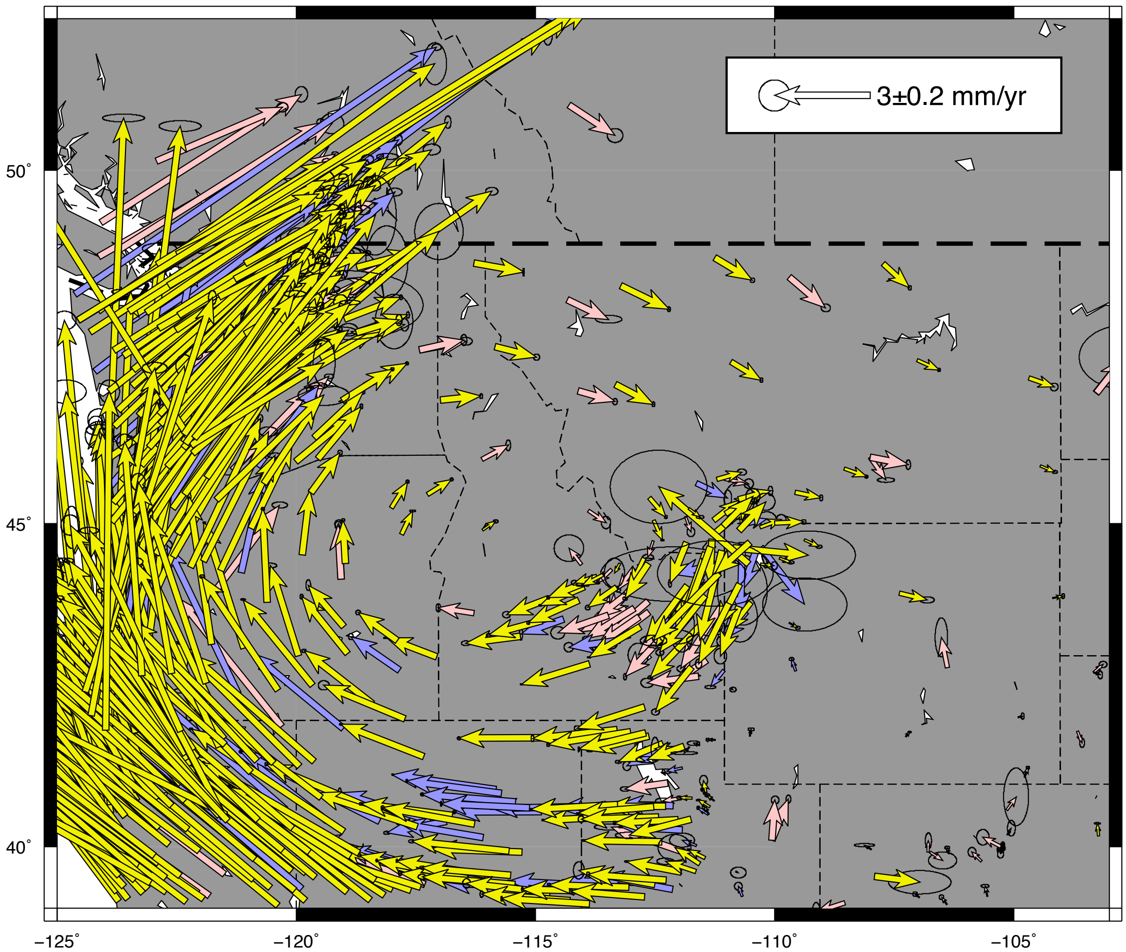

Figure 14: Same as Figure 10 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250^o are in the Yellowstone National Park and most likely are showing volcanic processes.

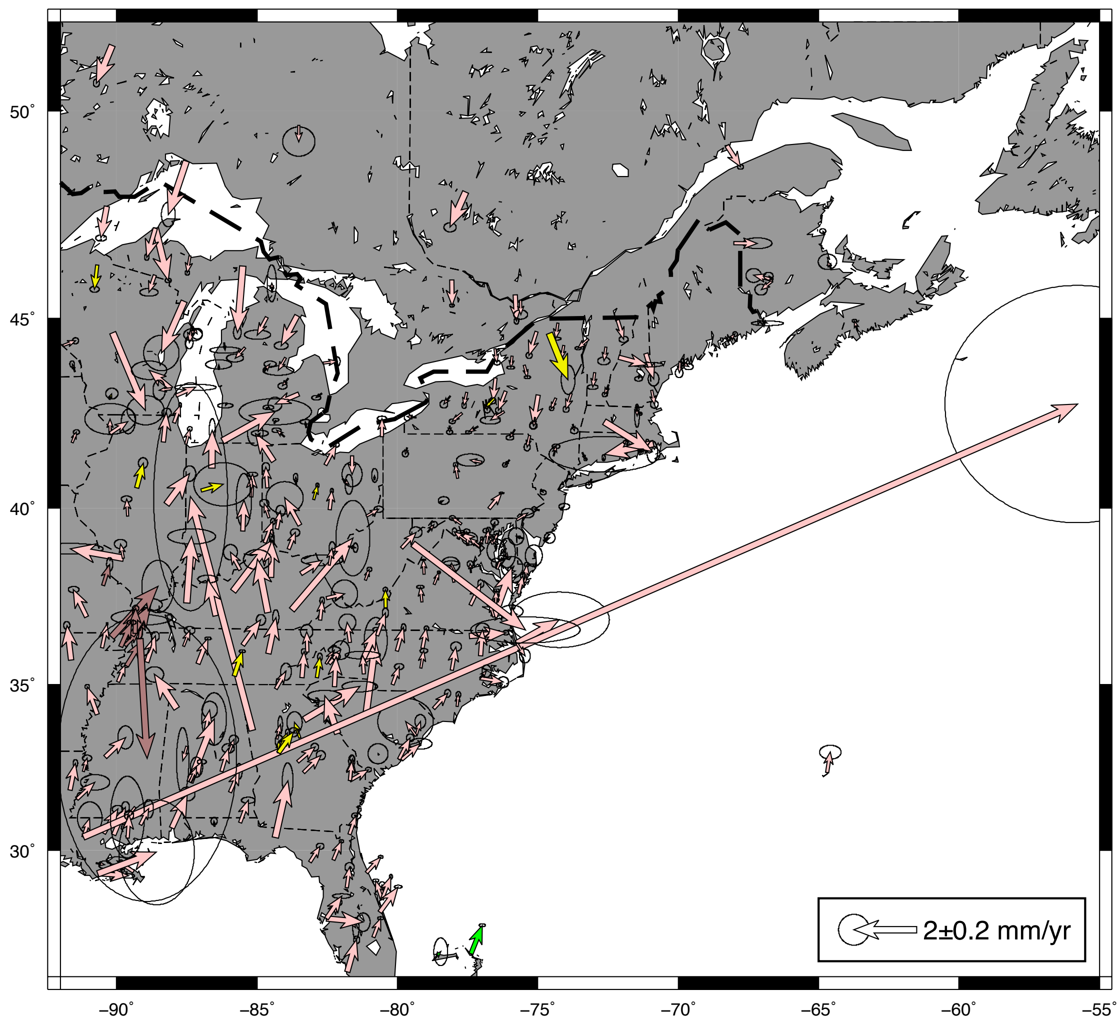

Figure 15: Same as Figure 10 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities. The large outlier is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

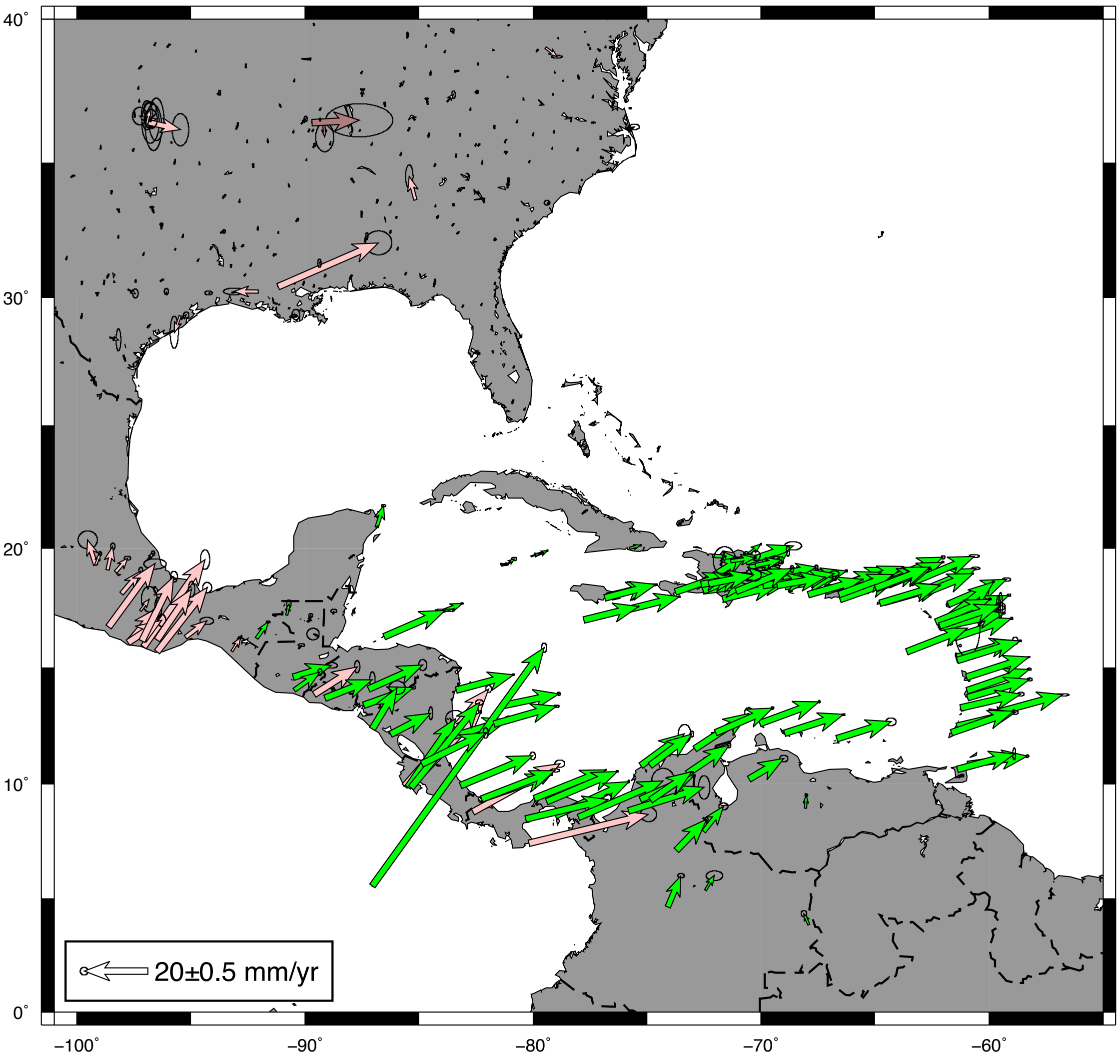

Figure 16: Same as Figure 10 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2016/12/15-2017/03/15.

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 December, 2016-January 2017 we investigated the following events.

```
* EQDEFS for 2016 12 14 to 2017 01 15 Generated Wed Jan 18 09:16:32 EST 2017
* Proximity based on Week_All.Pos file
* ----------------------------------
* SEQ Earthquake # 1
* EQ 13 P630_GPS       7.31       9.50 CoS        1.0 mm
* EQ 13 P631_GPS       3.72       9.50 CoS        3.7 mm
* EQ 13 P639_GPS       5.19       9.50 CoS        1.9 mm
* EQ_DEF M4.0 4km ESE of Mammoth Lakes
 eq_def 01   37.6382 -118.9252      9.5  8  2016 12 14 07 45    0.0008
 eq_rename 01
 eq_coseis 01  0.0010 0.0010 0.0010      0.0008     0.0008     0.0008
* ----------------------------------
* SEQ Earthquake # 2
* EQ 32 P203_GPS       8.28      15.80 CoS       10.4 mm
* EQ_DEF M5.0 8km NW of The Geysers
 eq_def 02   38.8222 -122.8413     15.8  8  2016 12 14 16 42    0.0111
 eq_rename 02
 eq_coseis 02  0.0010 0.0010 0.0010      0.0111     0.0111     0.0111
* ----------------------------------
* SEQ Earthquake # 3
* EQ 572 P598_GPS       4.60       9.40 CoS        2.1 mm
* EQ_DEF M3.9 16km NW of Morongo Valley
 eq_def 03   34.1513 -116.7072      9.4  8  2016 12 28 17 57    0.0007
 eq_rename 03
 eq_coseis 03  0.0010 0.0010 0.0010      0.0007     0.0007     0.0007
* ----------------------------------
* SEQ Earthquake # 4
* EQ 610 P498_GPS       8.73       9.00 CoS        0.3 mm
* EQ 610 P499_GPS       5.54       9.00 CoS        0.8 mm
* EQ 610 WMDG_GPS       7.82       9.00 CoS        0.4 mm
* EQ_DEF M3.7 2km WSW of Brawley
 eq_def 04   32.9745 -115.5483      9.0  8  2016 12 31 22 42    0.0004
 eq_rename 04
 eq_coseis 04  0.0010 0.0010 0.0010      0.0004     0.0004     0.0004
* ----------------------------------
* SEQ Earthquake # 5
* EQ 611 P498_GPS       8.84       9.30 CoS        0.5 mm
* EQ 611 P499_GPS       5.30       9.30 CoS        1.4 mm
* EQ 611 WMDG_GPS       7.87       9.30 CoS        0.6 mm
* EQ_DEF M3.9 2km WSW of Brawley
 eq_def 05   32.9750 -115.5458      9.3  8  2016 12 31 23 07    0.0006
 eq_rename 05
 eq_coseis 05  0.0010 0.0010 0.0010      0.0006     0.0006     0.0006
* ----------------------------------
* SEQ Earthquake # 6
* EQ 612 P499_GPS       4.65       8.90 CoS        0.9 mm
* EQ 612 WMDG_GPS       8.20       8.90 CoS        0.3 mm
* EQ_DEF M3.6 1km WSW of Brawley
 eq_def 06   32.9748 -115.5388      8.9  8  2016 12 31 23 26    0.0003
 eq_rename 06
 eq_coseis 06  0.0010 0.0010 0.0010      0.0003     0.0003     0.0003
* ----------------------------------
* SEQ Earthquake # 7
* EQ 632 P133_GPS       3.12       9.10 CoS        3.3 mm
* EQ_DEF M3.8 23km NNE of Hawthorne
 eq_def 07   38.7016 -118.4821      9.1  8  2017 01 02 02 12    0.0005
 eq_rename 07
 eq_coseis 07  0.0010 0.0010 0.0010      0.0005     0.0005     0.0005
* ----------------------------------
* SEQ Earthquake # 8
* EQ 706 CRLR_GPS       4.55       9.10 CoS        1.5 mm
* EQ_DEF M3.8 7km SE of La Romana
```

```
 eq_def 08   18.3810  -68.9172      9.1  8  2017 01 05 03 52    0.0005
 eq_rename 08
 eq_coseis 08  0.0010 0.0010 0.0010      0.0005     0.0005     0.0005
```

Events 4-6 appear to be part of a swarm in the Brawley seismic zone but strange position changes were seen in the data.
Event 7 is likely to only effect P133 but no results have been seen from this station since 2016 10 28.

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

In January/February 2017 the following events were investigated

```
* EQDEFS for 2017 01 14 to 2017 02 15 Generated Thu Feb 16 11:34:35 EST 2017
* Proximity based on Week_All.Pos file
* ----------------------------------
* SEQ Earthquake # 1
* EQ 256 P247_GPS       5.17       8.70 CoS        0.5 mm
* EQ 256 P249_GPS       7.51       8.70 CoS        0.2 mm
* EQ_DEF M3.5 24km NE of Soledad
 eq_def 01   36.5887 -121.1448      8.7  8  2017 01 23 03 16    0.0002
 eq_rename 01
 eq_coseis 01  0.0010 0.0010 0.0010      0.0002     0.0002     0.0002
* ----------------------------------
* SEQ Earthquake # 2
* EQ 500 P324_GPS       2.22       8.90 CoS        5.2 mm
* EQ_DEF M3.7 20km NE of Redway
 eq_def 02   40.2385 -123.6468      8.9  8  2017 02 03 16 14    0.0004
 eq_rename 02
 eq_coseis 02  0.0010 0.0010 0.0010      0.0004     0.0004     0.0004
```

No offset can be seen for earthquake #1. There is however curvature at P249 but not P247. P251, P233 and P238 all see curvature (over a decade). P238 see ground water as well.
There are gaps in the P324 time series around the time of earthquake #2 but not cosesimic offset is apparent.

No measurable co-seismic offsets seen.

In February/March 2017, the following events were investigated but none show co-seismic offsets.

```
* EQDEFS for 2017 02 14 to 2017 03 15 Generated Mon Mar 20 09:26:29 EDT 2017
* Proximity based on Week_All.Pos file
* ----------------------------------
* SEQ Earthquake # 1
* EQ 72 GUAT_GPS      12.81      13.70 CoS        2.6 mm
* EQ_DEF M4.8 2km SSW of Petapa
 eq_def 01   14.4810  -90.5585     13.7  8  2017 02 16 13 34    0.0067
 eq_rename 01
 eq_coseis 01  0.0010 0.0010 0.0010      0.0067     0.0067     0.0067
* ----------------------------------
* SEQ Earthquake # 2
* EQ 107 AV15_GPS       5.61       9.10 CoS        1.0 mm
* EQ_DEF M3.8 11km SE of Akutan
 eq_def 02   54.0725 -165.6397      9.1  8  2017 02 17 16 11    0.0005
 eq_rename 02
 eq_coseis 02  0.0010 0.0010 0.0010      0.0005     0.0005     0.0005
* ----------------------------------
```

```
* SEQ Earthquake # 3
* EQ 362 P236_GPS       6.42       8.80 CoS        0.5 mm
* EQ 362 P239_GPS       2.39       8.80 CoS        3.4 mm
* EQ 362 P240_GPS       6.14       8.80 CoS        0.5 mm
* EQ_DEF M3.6 5km S of Gilroy
 eq_def 03   36.9590 -121.5757      8.8  8  2017 02 26 14 59    0.0003
 eq_rename 03
 eq_coseis 03  0.0010 0.0010 0.0010      0.0003     0.0003     0.0003
* ------------------------------------
* SEQ Earthquake # 4
* EQ 472 ERRG_GPS       4.06       8.80 CoS        1.2 mm
* EQ_DEF M3.6 20km SSE of Salton City
 eq_def 04   33.1342 -115.8622      8.8  8  2017 03 01 20 19    0.0003
 eq_rename 04
 eq_coseis 04  0.0010 0.0010 0.0010      0.0003     0.0003     0.0003
* ------------------------------------
* SEQ Earthquake # 5
* EQ 499 P157_GPS       8.71       9.20 CoS        0.5 mm
* EQ_DEF M3.9 39km SSW of Ferndale
 eq_def 05   40.2905 -124.3952      9.2  8  2017 03 02 20 24    0.0006
 eq_rename 05
 eq_coseis 05  0.0010 0.0010 0.0010      0.0006     0.0006     0.0006
* ------------------------------------
* SEQ Earthquake # 6
* EQ 669 ABVI_GPS       7.25       8.70 CoS        0.2 mm
* EQ_DEF M3.5 54km NE of Road Town
 eq_def 06   18.7833  -64.2949      8.7  8  2017 03 11 00 53    0.0002
 eq_rename 06
 eq_coseis 06  0.0010 0.0010 0.0010      0.0002     0.0002     0.0002
* ------------------------------------
* SEQ Earthquake # 7
* EQ 733 P488_GPS       4.91       8.80 CoS        0.8 mm
* EQ 733 P489_GPS       8.44       8.80 CoS        0.3 mm
* EQ_DEF M3.6 11km SW of Salton City
 eq_def 07   33.2390 -116.0535      8.8  8  2017 03 14 17 15    0.0003
 eq_rename 07
 eq_coseis 07  0.0010 0.0010 0.0010      0.0003     0.0003     0.0003
* ------------------------------------
* SEQ Earthquake # 8
* EQ 749 CRLR_GPS       3.36       8.80 CoS        1.7 mm
* EQ_DEF M3.6 5km ENE of La Romana
 eq_def 08   18.4454  -68.9284      8.8  8  2017 03 15 15 24    0.0003
 eq_rename 08
 eq_coseis 08  0.0010 0.0010 0.0010      0.0003     0.0003     0.0003
* ------------------------------------
* SEQ Earthquake # 9
* EQ 755 AC66_GPS      24.40      28.50 CoS        5.6 mm
* EQ_DEF M5.6 89km SSE of Little Sitkin Island
 eq_def 09   51.2211  179.0567     28.5  8  2017 03 15 22 20    0.0519
 eq_rename 09
 eq_coseis 09  0.0010 0.0010 0.0010      0.0519     0.0519     0.0519
```

For Eq_def 06 There is no recent data at ABVI (end of data late 2015).
Estimated offset is small so unlikely to have large impact.
For Eq_def 07 There is no data since Jan 25, 2017 at P488.
Expected offset is small so probably not an issue.
For Eq_def 09 There is not date since Sep 30, 2016 at AC66.
Expected offset is small so probably not an issue. Data from this site is also very systematic. There was an offset at 2014 06 23 due to a M 7.9 earthquake 24km SE of Little Sitkin Island (Eq_def 32).

No other offsets can be seen for the other earthquakes in the list.

Antenna Change Offsets: 2016/12/01-2017/02/28

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

```
Station      Date            From            To
P464  2016 12  8 19 35 TRM29659.00    TRM59800.80
P653  2016 12  3  0  0 TRM29659.00    TRM59800.80
TXJA  2016 12  8 16 30 TRM55971.00    TRM57971.00
CAT3  2017  1 31 18 26 TRM29659.00    TRM59800.80
HBCO  2017  1 27 23 52 ASH701945B_M   TPSCR.G3
P493  2017  1 12 21 16 TRM29659.00    TRM59800.00
P722  2017  2 18  0  0 TRM29659.00    TRM59800.80
```

Analysis

P464 WLS dNEU   -0.93 +- 3.48,   1.02 +- 0.60, -5.65 +- 4.40 mm,
KF dNEU -1.75 +- 0.31,   0.86 +- 0.25, -5.77 +- 0.95 mm
Reasonably noisy data. North offset may be significant.
P653 WLS dNEU   1.36 +- 1.12, -1.18 +- 2.47, -1.62 +- 5.90 mm,
KF dNEU   0.71 +- 0.30, -2.60 +- 0.30, -1.66 +- 1.06 mm
East looks significant. Some noisy values after the change.
TXJA WLS dNEU   -2.61 +- 4.16,   1.92 +- 3.19, -7.44 +- 22.16 mm,
KF dNEU -2.87 +- 0.52,   0.25 +- 0.46,   1.80 +- 2.32 mm
There is a large gap with the data between 2016 08 01 until 2016 12 08 being bad.
CAT3 WLS dNEU   1.01 +- 0.71, -3.02 +- 2.71, -1.16 +- 4.00 mm,
KF dNEU   1.19 +- 0.39, -3.86 +- 0.40, -0.29 +- 1.41 mm
There is a gap in the data prior to the new antenna being installed. There was also unknown jump back in 2010 about 80-days before a firmware update.
HBCO WLS dNEU   -0.86 +- 3.47, -0.56 +- 24.31, -2.75 +- 11.74 mm,
KF dNEU -0.73 +- 0.50,   1.43 +- 0.72, -5.95 +- 1.79 mm
Large error bar estimates before antenna change. East systematics noted in data

P493 WLS dNEU   0.09 +- 0.62, -1.67 +- 0.46, -6.81 +- 3.17 mm,
KF dNEU   0.36 +- 0.25, -1.76 +- 0.23, -5.05 +- 0.98 mm
Break looks quite small but a larger unknown break was seen in August 2012.
P272 WLS dNEU   0.38 +- 1.33,   1.23 +- 0.73, -2.37 +- 4.75 mm,
KF dNEU   0.30 +- 0.33,   1.30 +- 0.26, -1.88 +- 1.00 mm
Offsets here are small. There is a gap in the data between 2017/12/17 and 2017/01/28.

New offsets of unknown origin and data anomalies

We did remove two unknown offsets for P158 which turned out to be due to earthquakes that had not been recognized that the time the offsets were added. This site has an offset due to tree removal and when looking at that offset, the earlier offsets in the time series were thought to arise from earlier tree-cutting events.

We did add an exclude of data for TXJA between 2016 8 1 and 2016 12 08 due to poor quality dat

Added four new breaks.

RBRU   RBRU_APS 2016 4 20 0 0 ! tsview break : Jump for unknown reason.

ORES   ORES_APS 2015 5 26 0 0 ! tsview break : Jump for unknown reason.

CAT3   CAT3_APS 2010 4 5 0 0 ! tsview break : Added by tah on 2017-02-16 12:10:03 KF dNEU   1.19 +- 0.39, -3.86 +- 0.40, -0.29 +- 1.41 mm

P493   P493_APS 2012 8 28 0 0 ! tsview break : Added by tah on 2017-02-16 13:44:53 KF dNEU   -0.20 +- 0.21, -3.44 +- 0.19, -1.36 +- 0.83 mm

We did note the following data anomalies in the monthly reports for this quarter.

P598	Recent one day outliers in north seen both by NMT and CWU. (e.g. 2017 1 8, 2016 12 16 ,and 2016 11 20).
CRLR	Data error bars in July 2016 and when station first started in late 2015.
P464	Skewed in East
P801	Sudden vertical drop starting 2016 12 3 (~50 mm) in 1.5 months
AV38	Heavily skewed in N and U.
AC09	Large slow event centered in 2016 04 27. 40 mm in North
AC53	Long term systematics along with other sites in the region
AB33	Rapid drop height Jan 2, 2017
P735	Large offset stating Jan 21,2017. Both in east and height. Smaller but present in North.
RKMG	Strange smooth change in east motion starting early 2017. 10 mm of offset in 1 month
TXTI	Curvature in North 20 mm peak-to-peak in 9 years.
WVCV	Change in east trend starting mid-2014. 15 mm accumulated offset to 2017. Less pronounced in North
P249+	Series of sites P233, P238 and P251 all show quadratic curvature over a decade. Maybe only on the east side of the San Andreas
P286	Skewness in positions. Mostly North.
HBCO	Large systematics in East mostly (amplitude -6 to 6 mm) over decadal period.
CJMG	Quality failing since late 2016
COVG	Strong NE annual (2 mm amplitude); Height is ~4 mm
FHOG	Maybe occasional snow on antenna (small number of days in Jan 2017).
GRIS	CWU height estimates 10-15 mm below NMT

New product: Time series offset estimates from a Kalman Filter analysis

We introduce a new product with estimated offsets at the times of antenna changes, equipment failures and earthquake. The header to the file describes format and caveats associated with these estimates.

Example KFOffsets_20170403.dat

```
* Kalman Filter Offset Estimates up to date 20170403
* Extracted using sh_extOffsets Date Mon Apr  3 14:20:23 EDT 2017
*
* This file is created from Kalman Filter fits to the GAGE time-series.  The process
* noise values used in the Kalman filters are computed for each site as described in
* Herring et al., 2016.  Offsets can be of Break type due to antenna change or due
* to unknown reasons or of type OffEq due an earthquake at the time.  If the standard
* deviation of the offset estimates (sN, sE, sU) are large, the offset can not be
* accurately determined.  In some cases this is due to there being no usable data
* prior to the offset or, in some cases, multiple offsets with no usable data between
* the offsets.
* This product is not quality checked to see if the estimated offsets remove the
* apparent discontinuities in the time series.  For sites with very systematic
* residuals, the estimates might not remove the discontinuities.
* The columns are
* Site              : GAGE 4-character site ID
* YYYY MM DD  HR MN : Year, month, day, hour, minute of the time of the offset
* dN (mm)  sN (mm)  : Change in North,  1-sigma standard deviation (mm)
* dE (mm)  sE (mm)  : Change in East,   1-sigma standard deviation (mm)
* dU (mm)  sU (mm)  : Change in Height, 1-sigma standard deviation (mm)
* TYPE              : Either Break (equipment( or OffEq (earthquake)
*
* 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 (2016),
*    Plate Boundary Observatory and related networks: GPS data analysis methods
*    and geodetic products, Rev. Geophys., 54, 759-808, doi:10.1002/2016RG000529.
*
*Site  YYYY MM DD  HR MN      dN (mm)  sN (mm)     dE (mm)  sE (mm)    dU (mm)  sU (mm)  TYPE
 1LSU  2008 06 20  18 00         2.81     0.44        4.15     0.39      -9.41     1.10  Break
 1LSU  2010 04 14  16 00         0.21     0.39       -4.03     0.37      -2.46     1.05  Break
 1LSU  2014 01 14  18 31        -0.82     0.36        0.67     0.33       3.75     0.96  Break
 1NSU  2010 07 30  00 00         1.84     0.43        1.41     0.24      -1.32     1.14  Break
 1ULM  2010 07 30  00 00        -1.43     0.22        1.97     0.23      -0.28     0.85  Break
 7ODM  2011 08 24  01 06        44.83     0.36       36.34     0.54     -18.19     1.05  Break
 7ODM  2012 05 04  00 00        -0.75     0.35        0.97     0.49      -1.17     0.98  Break
 7ODM  2013 11 07  22 23         1.67     0.33        0.76     0.47     -11.30     0.96  Break
 7ODM  2015 07 05  00 00         3.99     0.34        0.36     0.49      13.81     0.96  Break
 7ODM  1999 10 16  09 46        -0.00     0.00       -0.00     0.00       0.00     0.00  OffEq
 7ODM  2010 04 04  22 40        -4.08     0.39       -0.01     0.56      -8.52     1.13  OffEq
 AB01  2013 08 30  16 25        -7.49     0.41       -0.63     0.31       3.50     0.65  OffEq

...
 ZNY1  2003 05 16  00 00        -0.69     0.29       -8.65     0.26       4.49     0.94  Break
 ZNY1  2007 05 11  00 00        -4.56     0.25        5.53     0.23      10.71     0.76  Break
 ZSE1  2003 04 19  00 00        -5.05     0.45      -14.14     0.31      14.55     1.23  Break
 ZSE1  2007 05 17  00 00        15.15     0.39       10.87     0.26      10.64     0.93  Break
 ZSE1  2001 02 28  18 55         0.65   707.11        5.90   707.11     -11.15   707.11  OffEq
 ZTL4  2003 05 02  00 00         0.70     0.35       -6.21     0.27      26.18     1.02  Break
 ZTL4  2006 12 05  00 00        -8.90     0.31       14.75     0.23       4.53     0.85  Break
```

GAMIT/GLOBK Community Support

During this quarter, our primary effort has been to test operationally and prepare for distribution the next release of the software (10.61), the first to offer users the opportunity exercise our new code to handle Beidou, Galileo, and IRNSS observations. There is still work to be done to refine the yaw models for these satellites, but we hope to have that done by the time the IGS determination of their orbits reaches a level for which the yaw model will matter.

We continue to spend 5-10 hours per week in email support of users. During the quarter, we issued 24 royalty-free licenses to educational and research institutions.