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: 2016/01/01-2016/03/31

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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 12/15/2015 to 03/12/2016, time series velocity field analyses for the GAGE reprocessing analyses (1996-2016). Only one earthquake, event 37, generated measurable coseismic offsets in this quarter. Rapid and final event files were generated for this earthquake which as a magnitude 7.1 83km east of Old Iliamna in Alaska. The epicenter was at 59.6585N -153.4521E deg and the origin time was 2016/01/24 10:31. For this quarter the last finals results were for March 12, 2016. No new "bad" stations were added this quarter. Currently there are 94 stations in the list. Earlier quarterly reports contain the details of these stations. Associated with the report are the ASCII text files that are linked into this document.

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 1913 stations were processed compared to 1918 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: December 15, 2015 and March 12, 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 December 15, 2015 and March 12, 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 0.8 mm for NMT and PBO north and east components (rounded to 0.1 mm from table value). The up RMS scatters are less than or equal 5.5 mm and as low as 4.7 mm for the NMT solution. These statistics are similar to last quarter. Seasonal changes in atmospheric delay properties will introduce small variations in these values quarter to quarter 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 1913, 1912 and 1913 stations for PBO, NMT and CWU analyzed in the finals analysis between December 15, 2015 and March 12, 2016. Histograms of the RMS scatters are shown in Figure 1-3.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
PBO	0.79	0.82	4.87
NMT	0.77	0.82	4.67
CWU	1.00	0.95	5.46
70%			
PBO	1.03	1.02	5.39
NMT	1.00	1.07	5.21
CWU	1.24	1.19	6.01
95%			
PBO	2.17	2.14	7.31
NMT	2.12	2.21	7.22
CWU	2.45	2.43	8.54

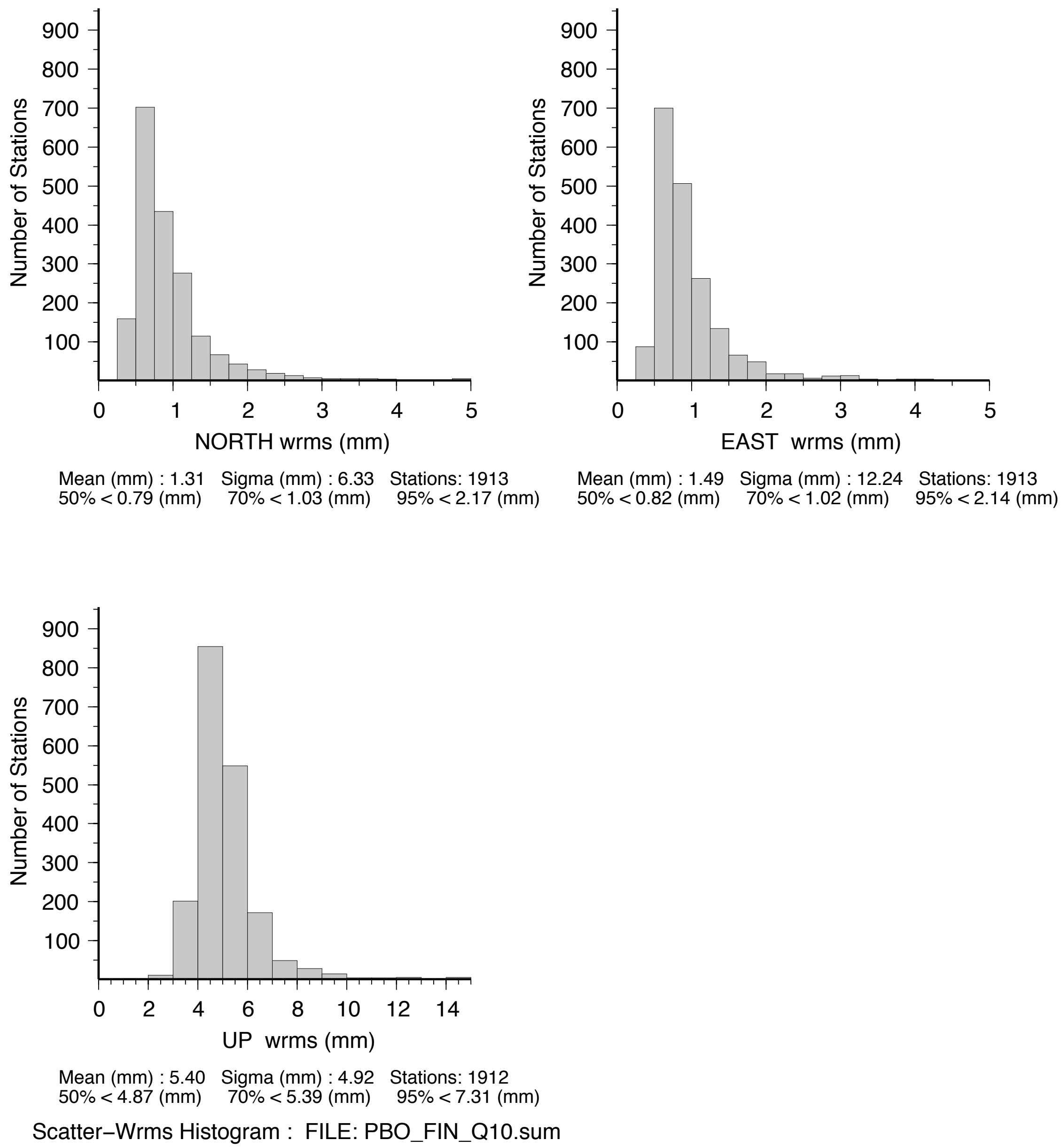

Figure 1: PBO combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1913 stations analyzed between December 15, 2015 and March 12, 2016. Linear trends and annual signals were estimated from the time series.

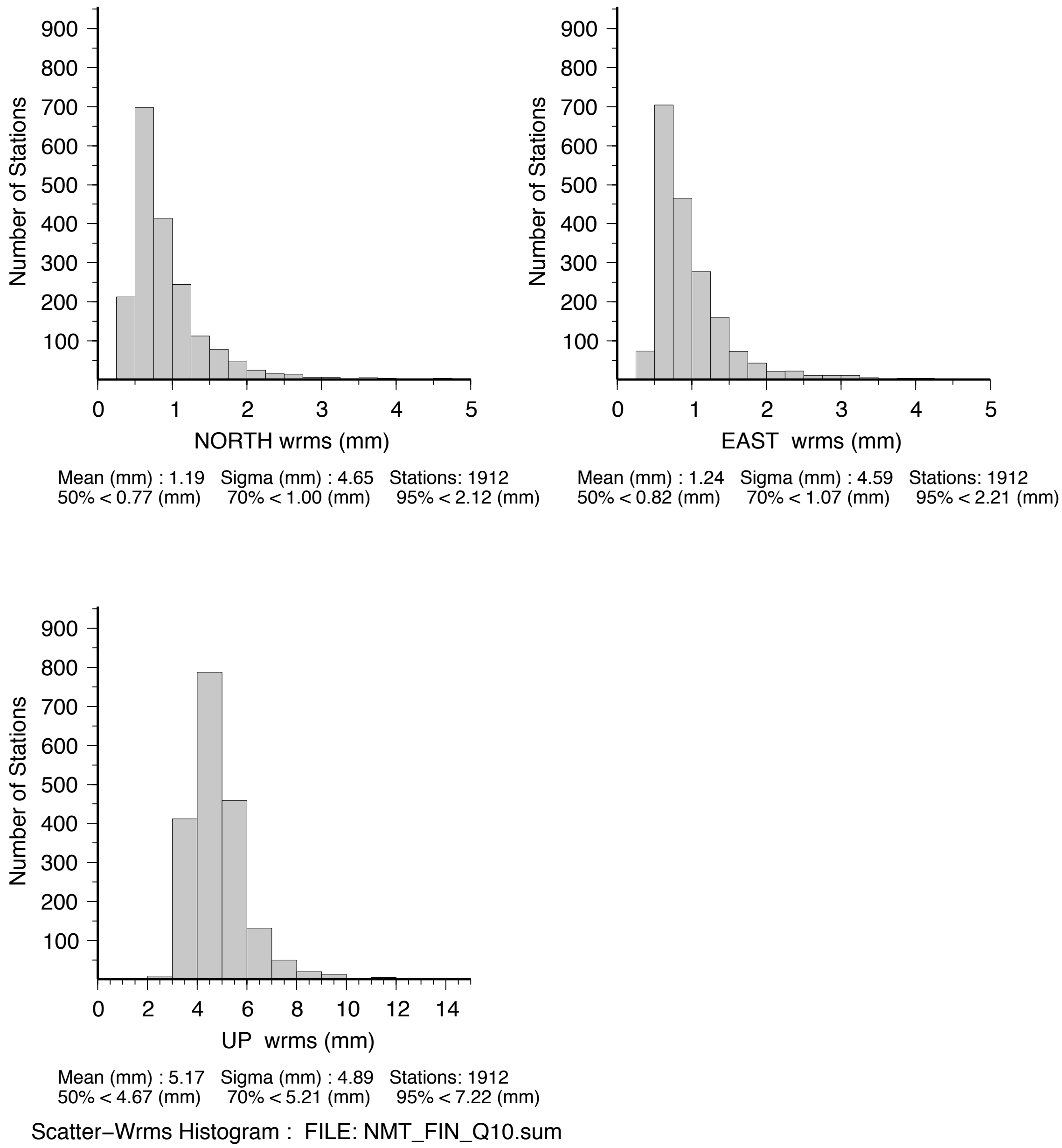

Figure 2: NMT combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1912 stations analyzed between December 15, 2015 and March 12, 2016. Linear trends and annual signals were estimated from the time series.

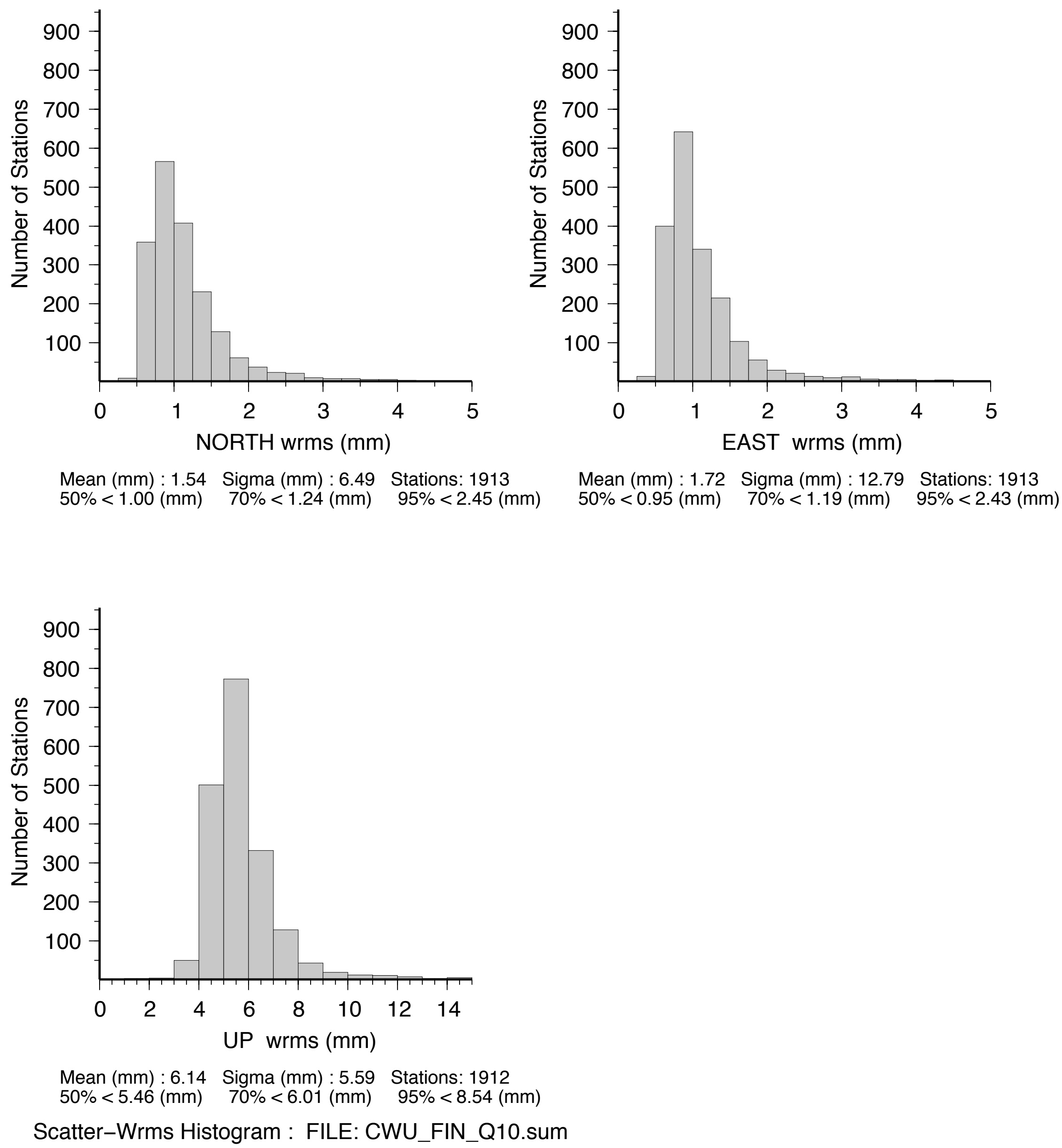

Figure 3: CWU combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1913 stations analyzed between December 15, 2015 and March 12, 2016. Linear trends and annual signals were estimated from the time series.

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_Q10.tab. There are 1913 stations in the file. The contents of the files is of this form:

```
Tabular Position RMS scatters created from PBO_FIN_Q10.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    89      1.2   0.63      1.5   0.73     5.2   0.58     12.89
 1NSU    89      0.6   0.38      0.8   0.52     4.6   0.71     12.15
 1ULM    89      0.5   0.35      0.6   0.43     5.5   0.94     12.75
 7ODM    88      0.8   0.46      0.7   0.45     4.9   0.73     14.89
…
 ZBW1    85      0.7   0.34      0.9   0.53     4.9   0.69     12.77
 ZDC1    85      0.7   0.38      0.8   0.52     5.2   0.78     12.77
 ZDV1    84      0.7   0.37      0.9   0.54     7.1   1.04     12.77
 ZKC1    85      1.0   0.53      0.6   0.37     5.5   0.82     12.77
 ZLA1    85      1.1   0.52      0.9   0.52     5.5   0.73     12.77
 ZME1    85      0.8   0.47      0.7   0.41     4.9   0.70     13.00
 ZMP1    85      0.6   0.32      0.7   0.41     5.8   0.88     13.25
 ZNY1    85      0.7   0.38      0.7   0.45     4.8   0.70     13.16
 ZSE1    85      0.8   0.36      0.8   0.48     5.5   0.76     13.16
 ZTL4    85      0.7   0.36      0.7   0.43     5.0   0.68     13.35
```

Table 2: RMS scatter of the position residuals for the PBO combined solution between December 15, 2015 and March 12, 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	0.76	0.80	4.90	860
NUCLEUS	0.68	0.71	4.63	206
USGS SCIGN	0.75	0.72	4.31	125
Expanded	0.82	0.84	4.99	614
GAMA	0.57	0.66	6.01	13
COCO Net	1.19	1.17	5.15	95
70 %				
PBO	0.98	1.02	5.40	
NUCLEUS	0.90	0.85	5.05	
USGS SCIGN	0.97	0.94	4.59	
Expanded	1.03	1.03	5.47	
GAMA	0.74	0.80	6.31	
COCO Net	1.40	1.47	6.37	
95%				
PBO	2.13	2.21	7.05	
NUCLEUS	1.66	1.51	6.65	
USGS SCIGN	1.74	1.82	5.36	
Expanded	2.45	2.14	7.35	
GAMA	0.90	0.91	7.09	
COCO Net	2.80	3.08	11.25	

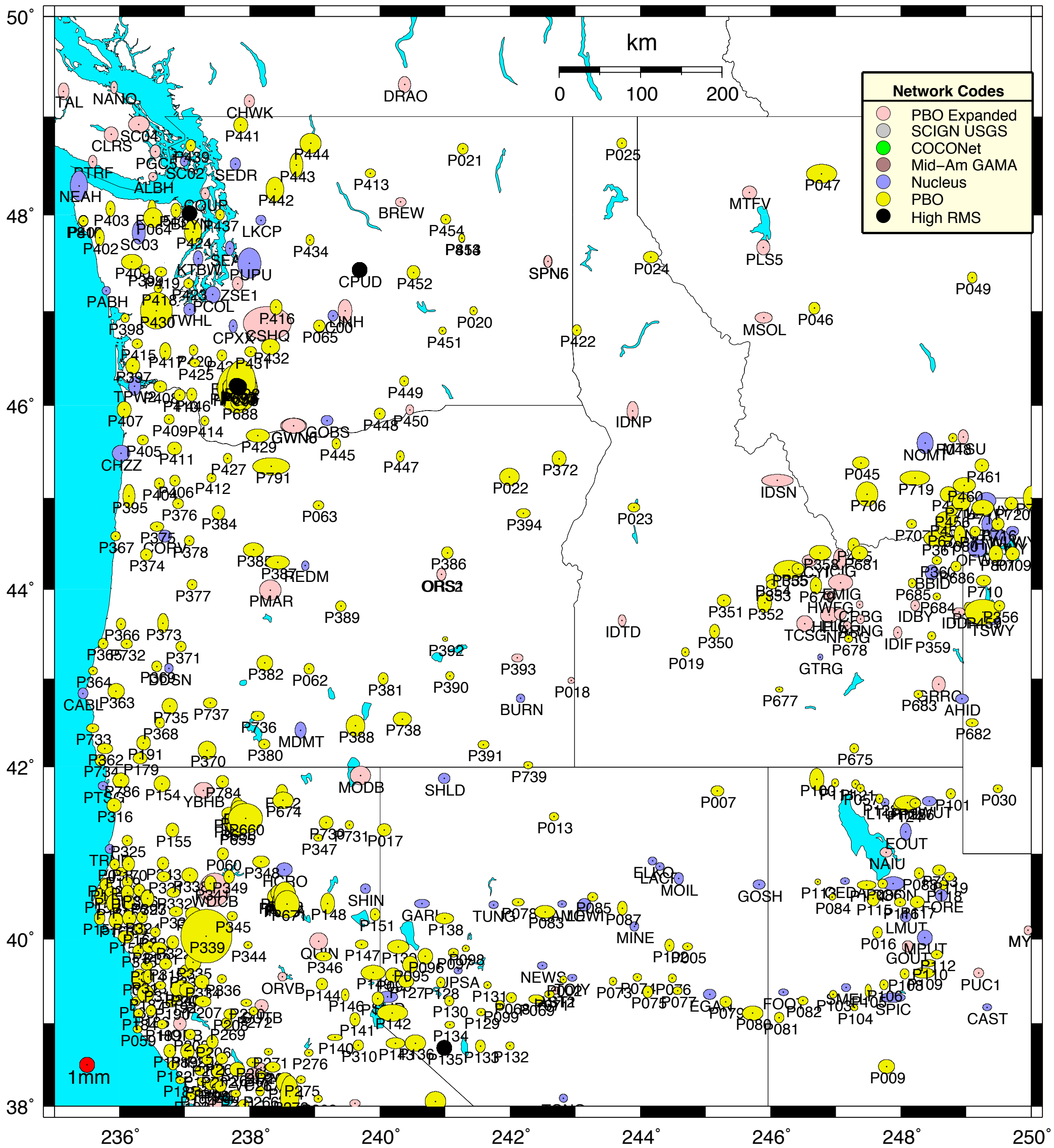

Figure 4: Distribution of the RMS scatters of horizontal position estimates from the PBO combined analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the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

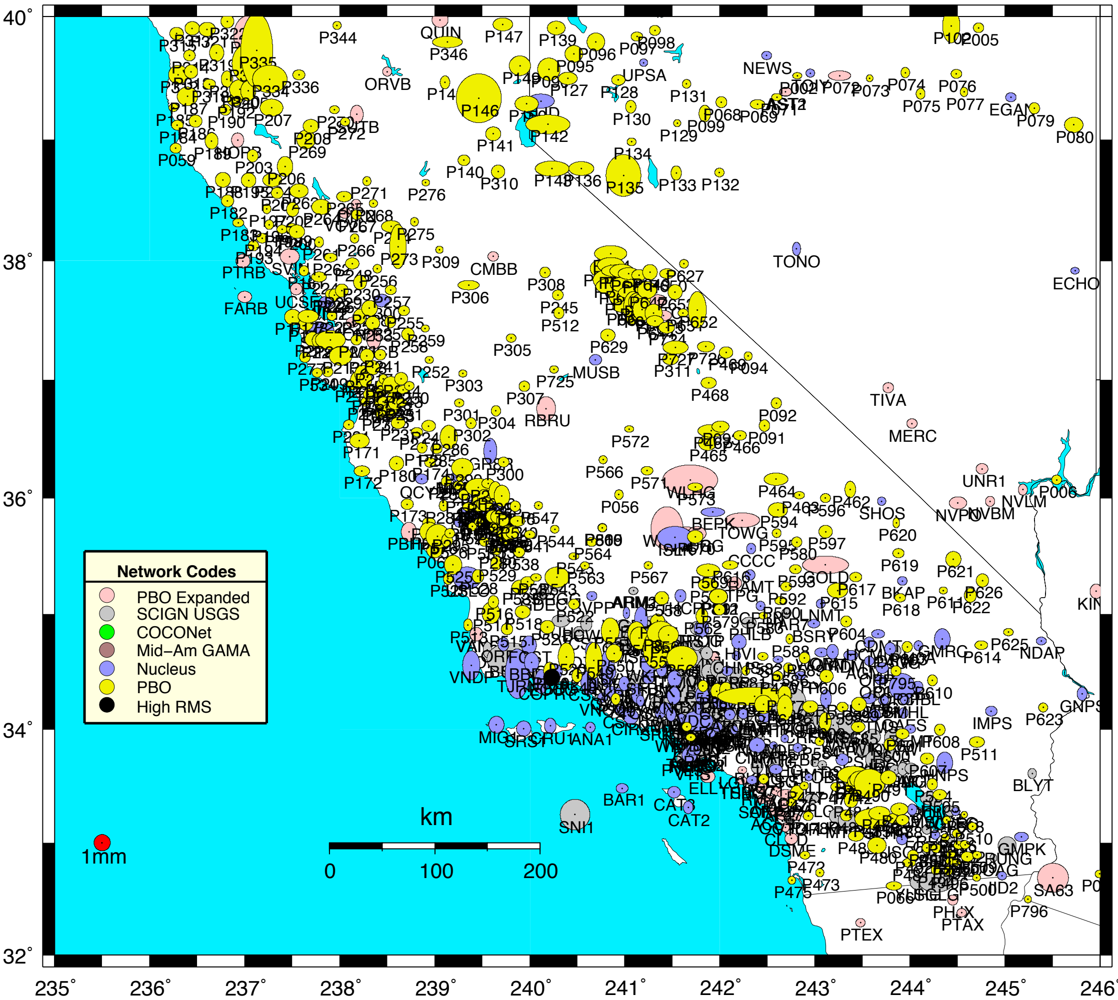

Figure 5: Same as Figure 4 except for the Southern Western United States. Black circles in the Yucca mountain region have no data during this 3-month period.

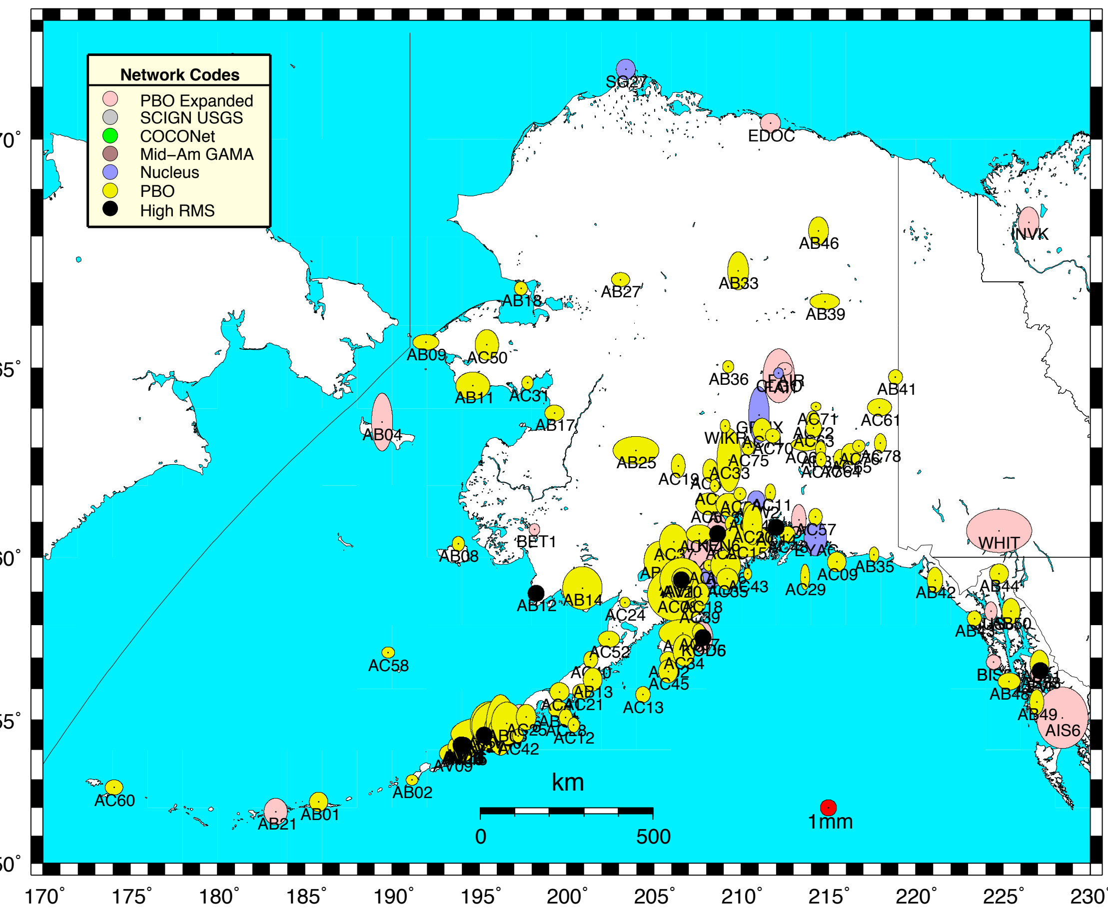

Figure 6: Same as Figure 4 except for the Alaskan region.

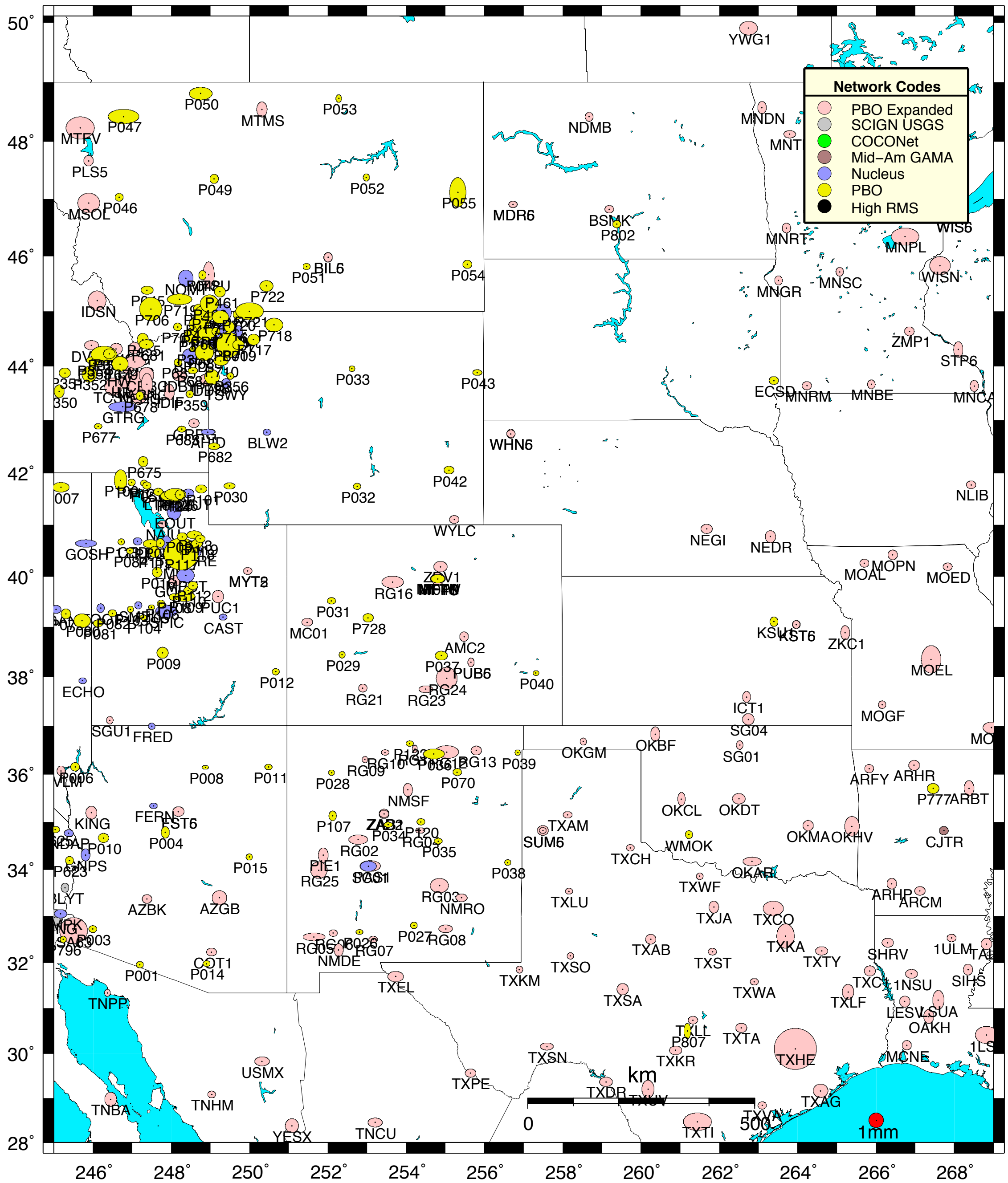

Figure 7: Same as Figure 4 except for the Central United States

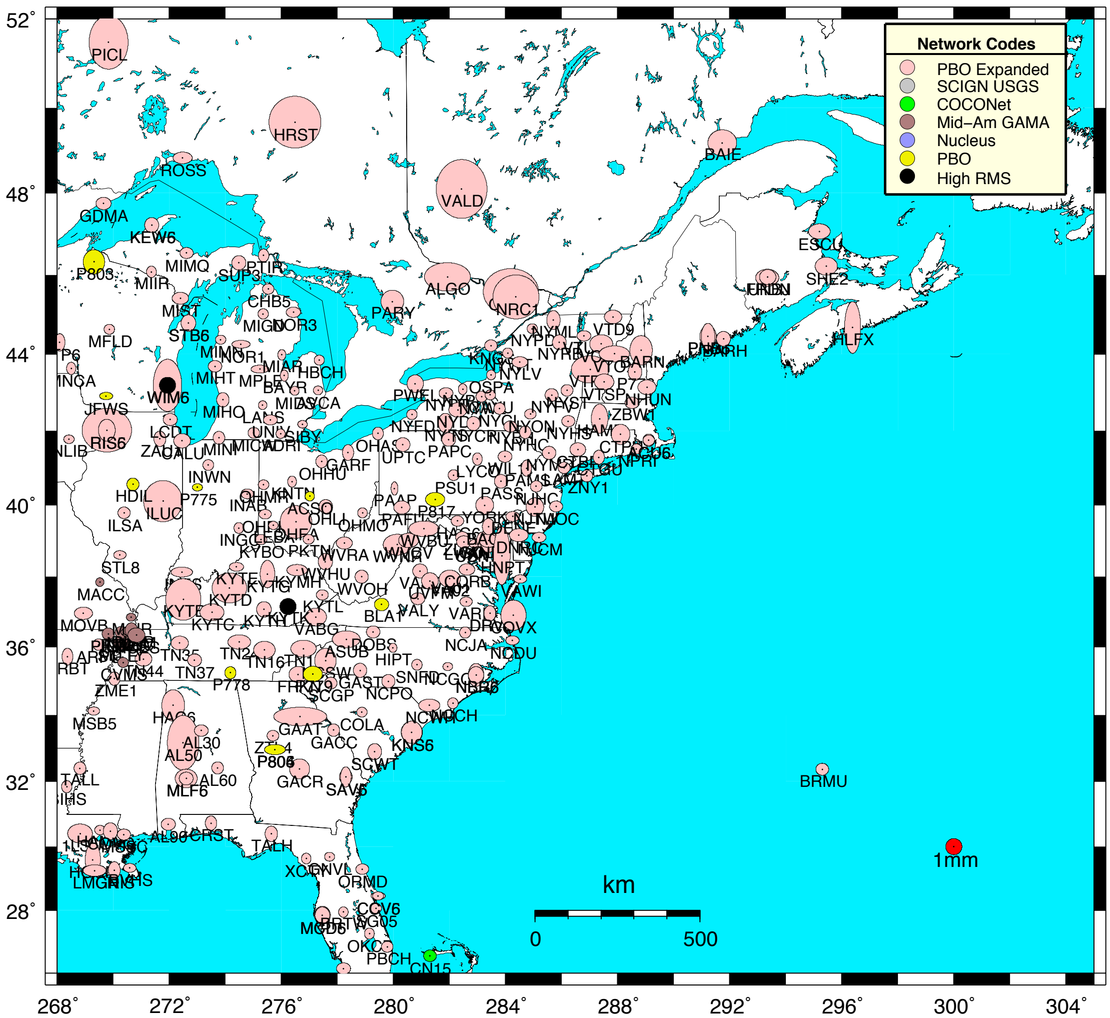

Figure 8: Same as Figure 4 except for the Eastern United States

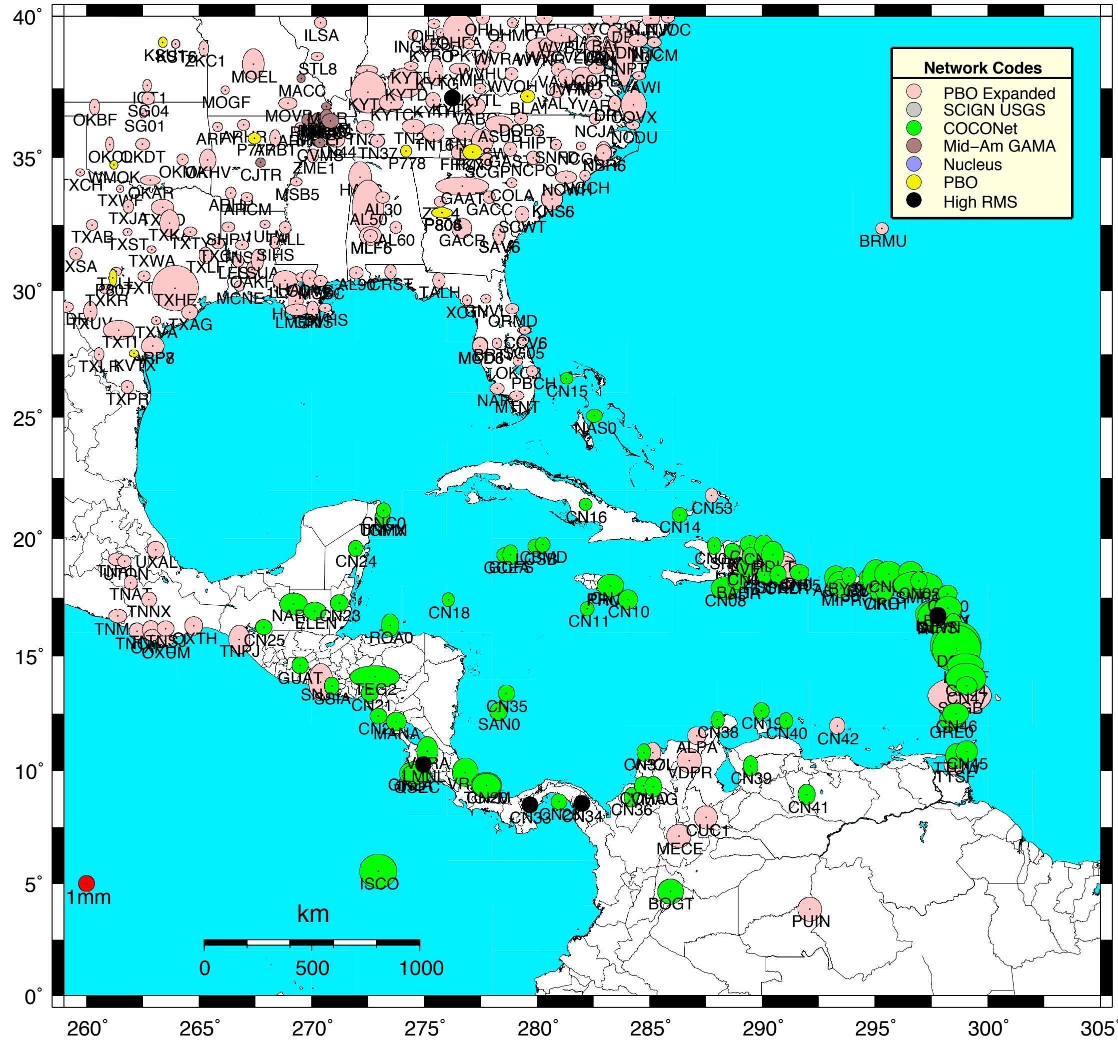

Figure 9: Same as Figure 4 except for the Caribbean region.

Analysis of large RMS stations

The analysis of the large RMS stations has remained unchanged and can be seen in Table 3 of earlier quarterly reports.

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 2156 stations in the combined PBO solution which is the same as last quarter, in the analyses and 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_160312.tab, nmt_nam08_160312.tab and cwu_nam08_160312.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_160312.snpvel, nmt_nam08_160312.snpvel and cwu_nam08_160312.snpvel.

Table 4: Statistics of the fits of 2178, 2177 and 2170 stations analyzed by PBO, NMT and CWU in the reprocessed analysis for data collected between Jan 1, 1996 and March 12, 2016.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
PBO	1.13	1.16	5.30
NMT	1.13	1.21	5.74
CWU	1.34	1.30	5.98
70%			
PBO	1.45	1.48	5.98
NMT	1.45	1.56	6.46
CWU	1.66	1.63	6.79
95%			
PBO	3.20	3.07	8.90
NMT	3.19	3.13	9.03
CWU	3.44	3.26	10.05

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 χ^2/f of the difference is $(1.18)^2$ for the horizontal and $(1.94)^2$ 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 JNPR, LST1, MCD1, MCD5, MYT2, P282, P713, P801, SAV1 and SAV5. This list is similar to previous quarters (Q09 list AV02, MYT2, P613, MTA1, P801, MCD1, SAV1, JNPR, SAV5, and LST1) and the same explanations hold for the differences.

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 2178, 2177 and 2170 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	2187	0.08	0.73	1.18	1.94
Edited -10 worst	2170	0.07	0.71	1.07	1.89
Less than median (0.14 0.45 mm/yr)	1212	0.06	0.62	1.14	1.97
Added minimum sigma NE 0.05 U 0.50 mm/yr					
All	2187	0.12	1.03	0.96	1.14
Edited -10 worst	2170	0.11	0.99	0.86	1.09
Less than median (0.15 0.0.67 mm/yr)	1262	0.08	0.75	0.74	0.91

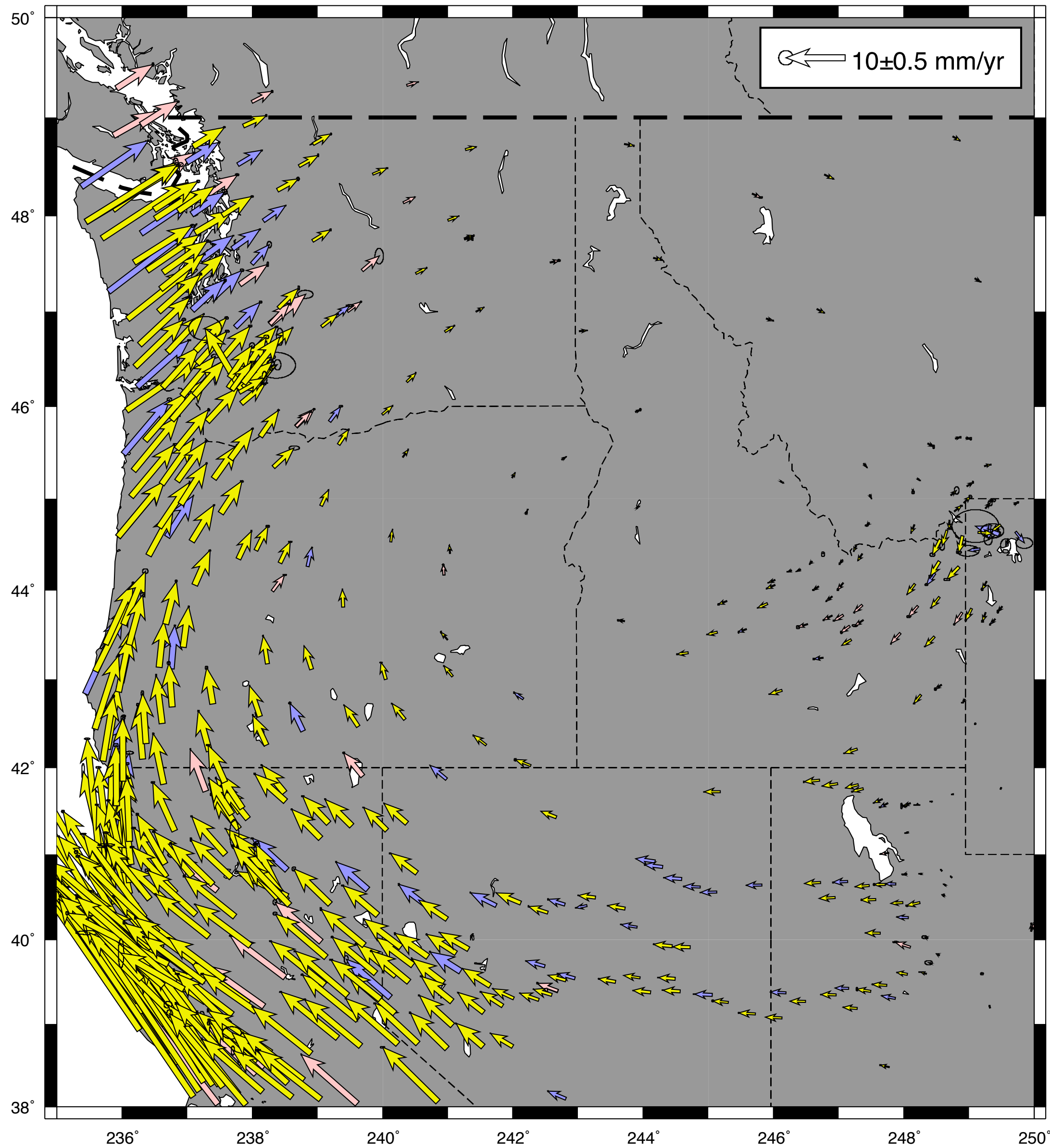

Figure 10: Velocity field estimates from the combined PBO solutions generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal standard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

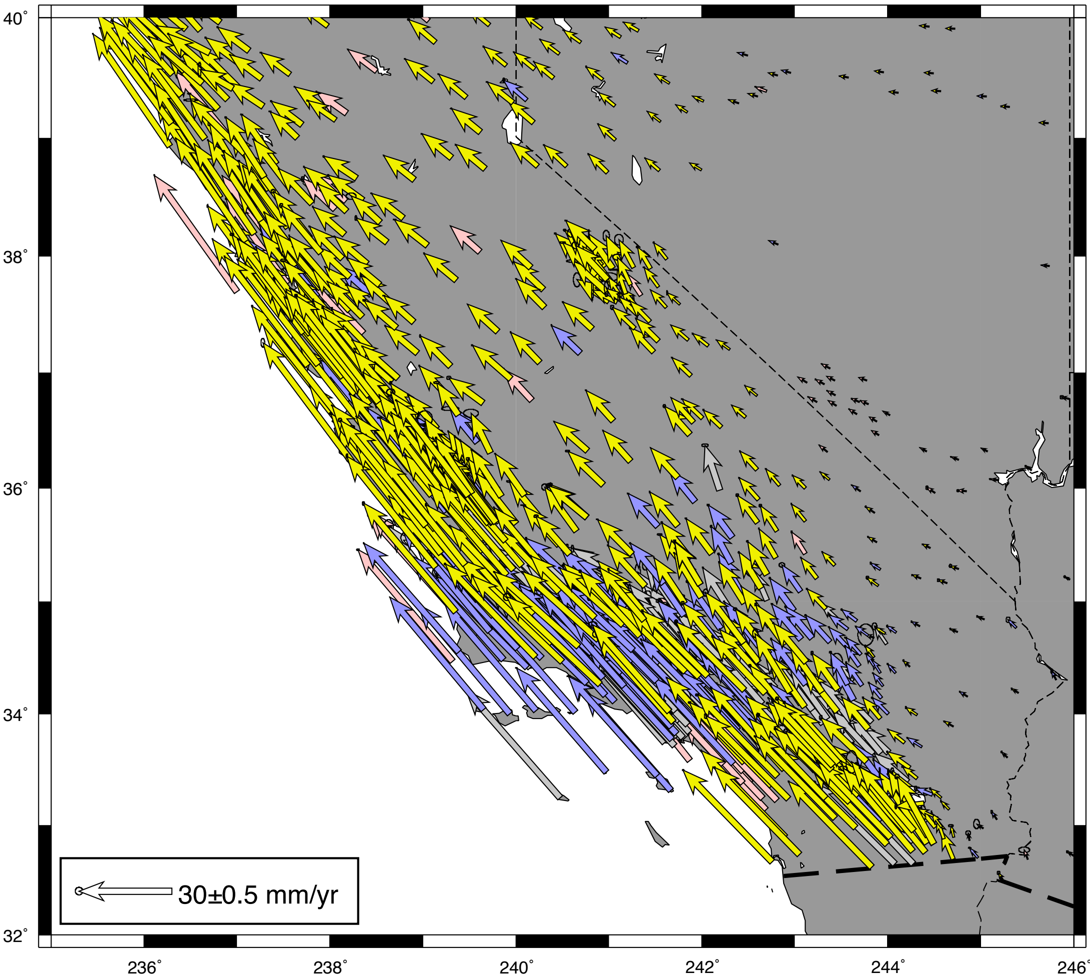

Figure 11: Same as Figure 10 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

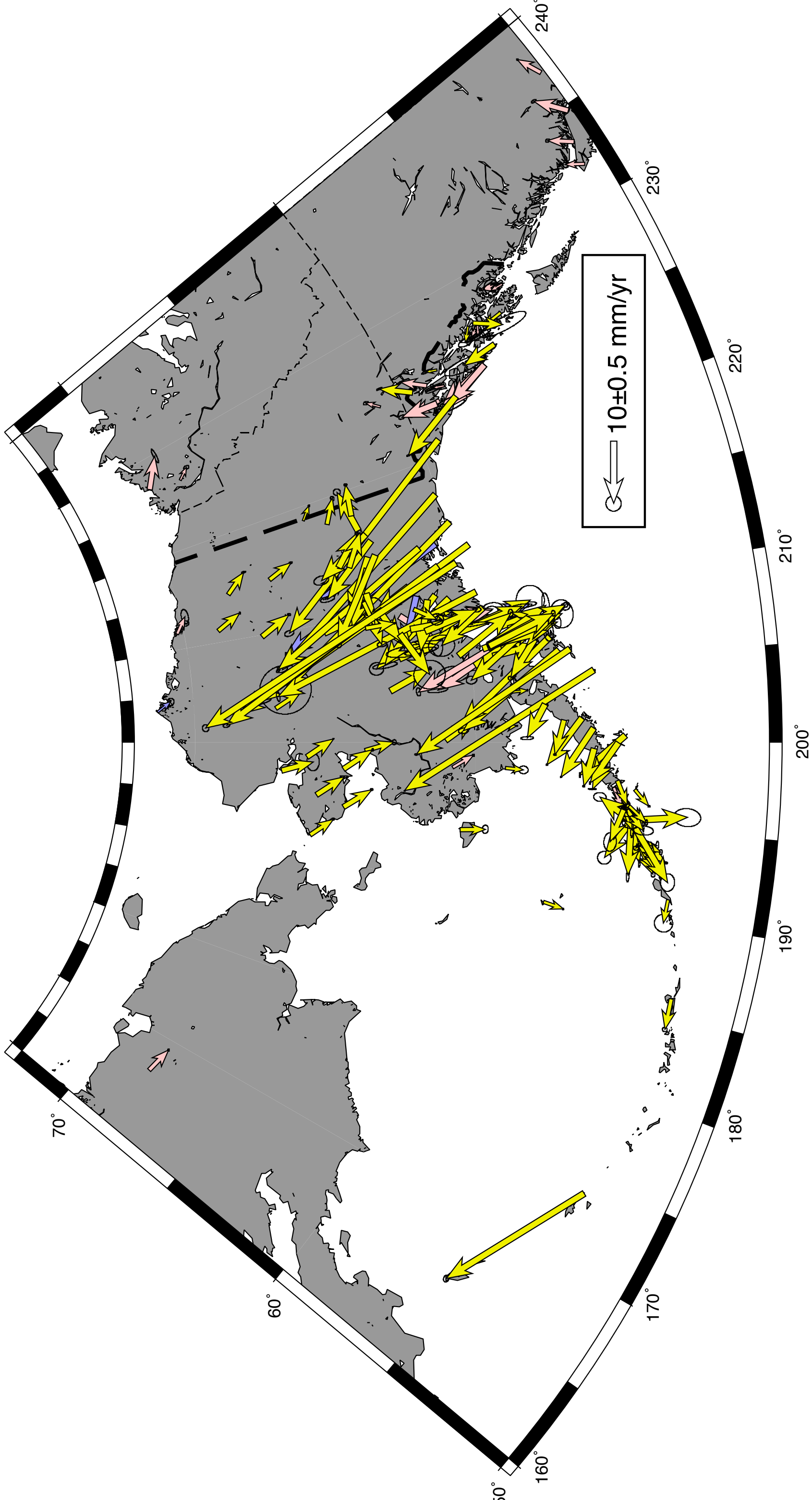

Figure 12: Same as Figure 10 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

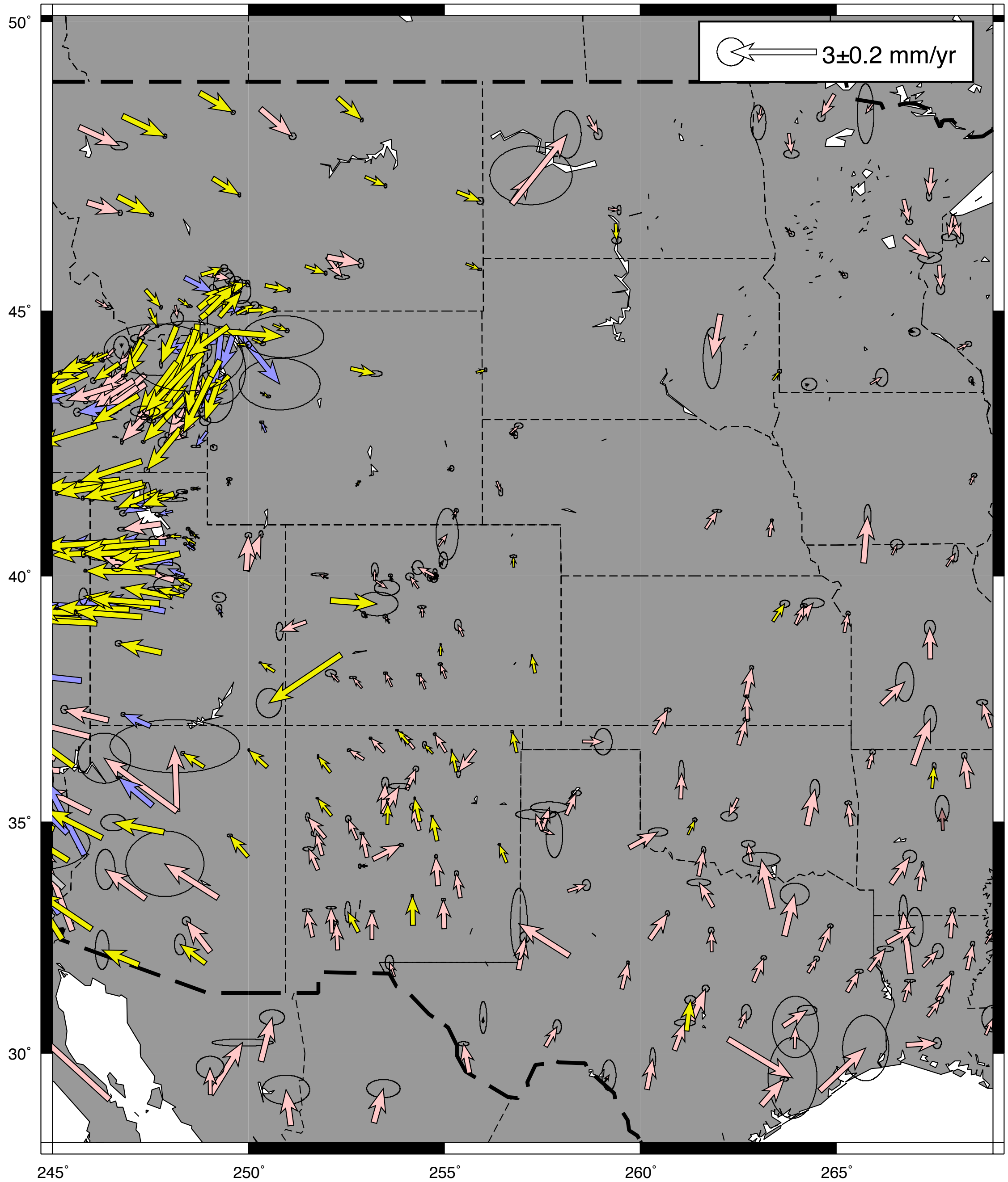

Figure 13: Same as Figure 10 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

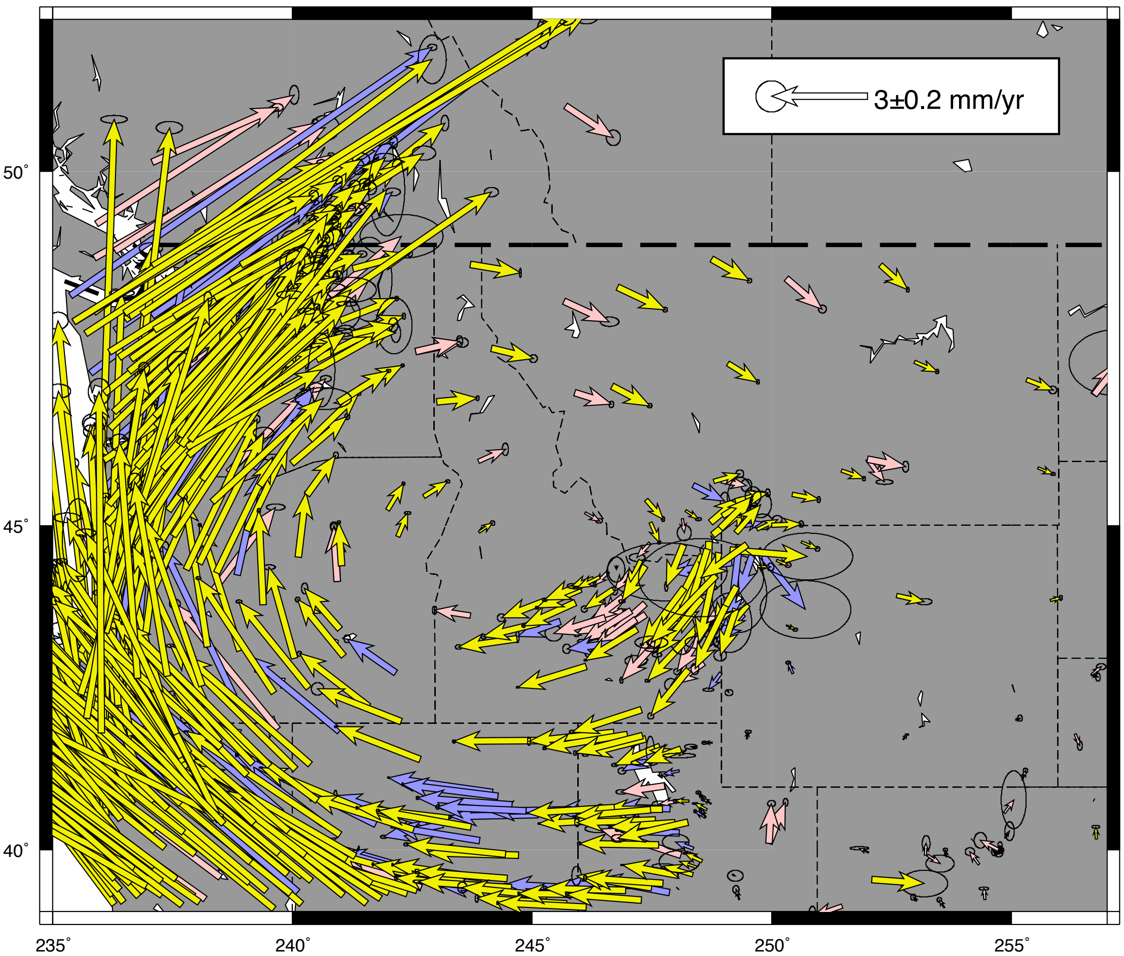

Figure 14: Same as Figure 10 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

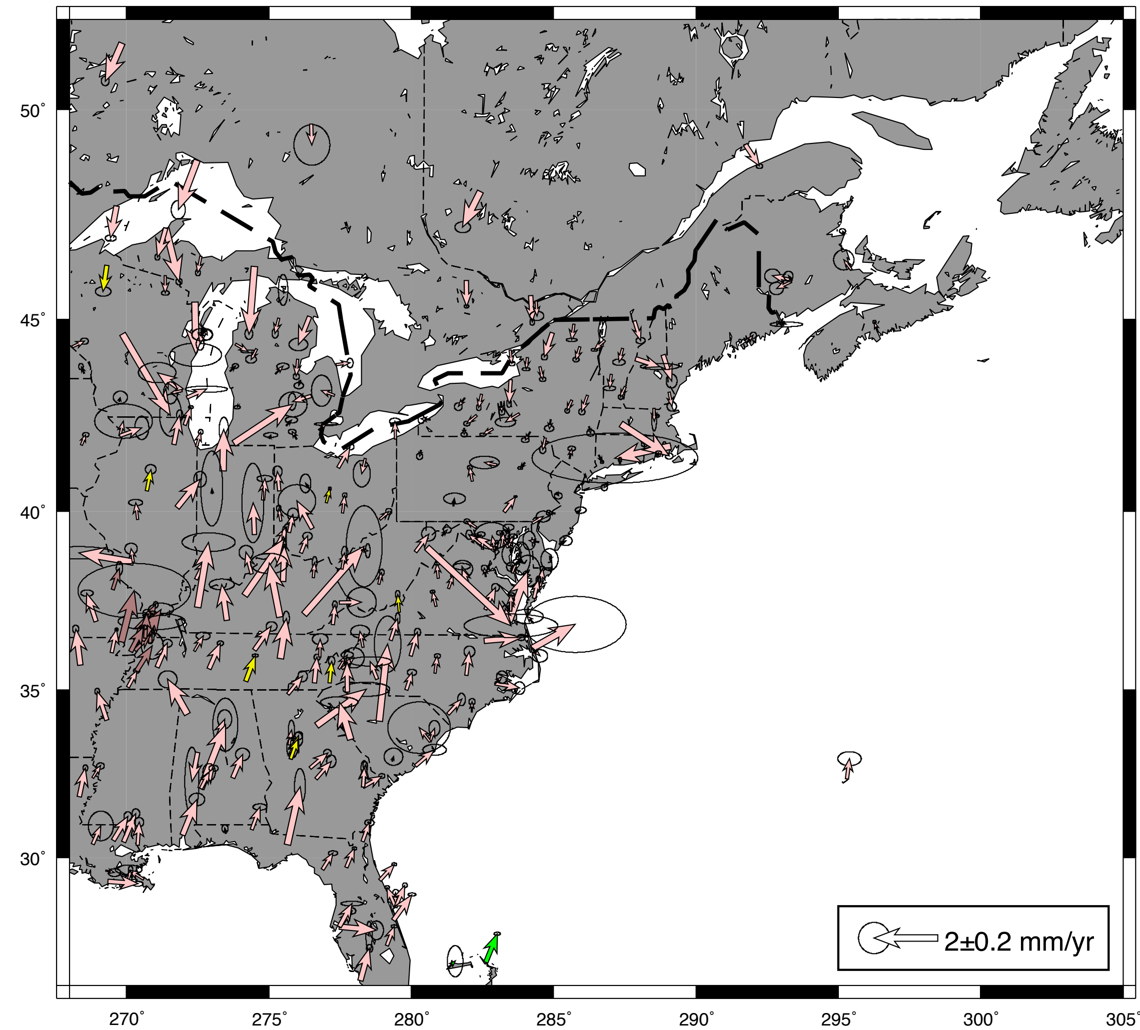

Figure 15: Same as Figure 10 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic velocity of sites in the Northeast and central US show deviations for current GIA models in the horizontal velocities. The vertical motions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

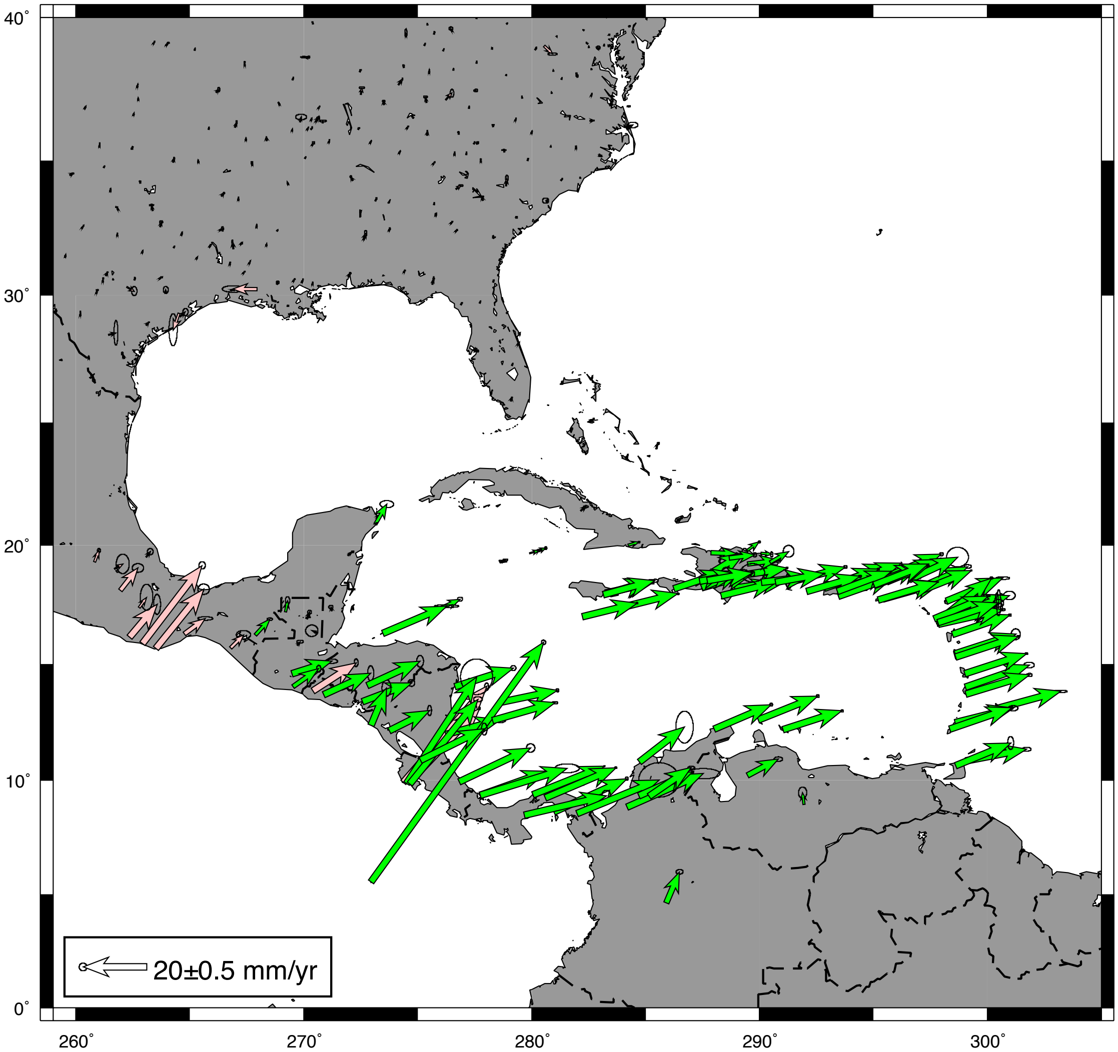

Figure 16: Same as Figure 10 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2015/12/15-2016/03/15.

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 2015/January 2016 we investigated the following events.

```
* EQDEFS for 2015 12 15 to 2016 01 14 Generated Fri Jan 15 09:22:12 EST 2016
* Proximity based on Week_All.Pos file
* ------------------------------------
* SEQ Earthquake # 1
* EQ 47 TNPJ_GPS      31.69     110.60 CoS       43.0 mm
* EQ_DEF M6.6 9km ENE of Tres Picos
 eq_def 01   15.8883  -93.4463    110.6 8 2015 12 17 19 50    0.675
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.675      0.675      0.675
* ------------------------------------
* SEQ Earthquake # 2
* EQ 202 P724_GPS       5.45       9.00 CoS        0.0 mm
* EQ_DEF M3.7 7km NW of West Bishop
 eq_def 02   37.4110 -118.5123      9.0 8 2015 12 24 19 15    0.000
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.000      0.000      0.000
* ------------------------------------
* SEQ Earthquake # 3
* EQ 246 P592_GPS       3.65       9.00 CoS        0.0 mm
* EQ_DEF M3.7 37km ESE of Johannesburg
 eq_def 03   35.2122 -117.2808      9.0 8 2015 12 26 08 05    0.000
 eq_rename 03
 eq_coseis 03  0.001 0.001 0.001      0.000      0.000      0.000
* ------------------------------------
* SEQ Earthquake # 4
* EQ 249 P592_GPS       3.75       9.10 CoS        0.0 mm
* EQ_DEF M3.8 37km ESE of Johannesburg
 eq_def 04   35.2115 -117.2800      9.1 8 2015 12 26 11 56    0.000
 eq_rename 04
 eq_coseis 04  0.001 0.001 0.001      0.000      0.000      0.000
* ------------------------------------
* SEQ Earthquake # 5
* EQ 273 P592_GPS       3.42      10.30 CoS       10.9 mm
* EQ_DEF M4.2 37km ESE of Johannesburg
 eq_def 05   35.2143 -117.2815     10.3 8 2015 12 27 18 32    0.002
 eq_rename 05
 eq_coseis 05  0.001 0.001 0.001      0.002      0.002      0.002
* ------------------------------------
* SEQ Earthquake # 6
* EQ 322 CJMG_GPS       9.00      11.00 CoS        1.6 mm
* EQ 322 GHRP_GPS       1.92      11.00 CoS       34.6 mm
* EQ 322 P612_GPS       8.88      11.00 CoS        1.6 mm
* EQ_DEF M4.4 4km SSW of Devore
 eq_def 06   34.1910 -117.4132     11.0 8 2015 12 30 01 49    0.002
 eq_rename 06
 eq_coseis 06  0.001 0.001 0.001      0.002      0.002      0.002
* ------------------------------------
* SEQ Earthquake # 7
* EQ 323 GHRP_GPS       1.97       9.10 CoS        0.0 mm
* EQ 323 P612_GPS       8.39       9.10 CoS        0.0 mm
* EQ_DEF M3.8 4km S of Devore
 eq_def 07   34.1877 -117.4080      9.1 8 2015 12 30 01 54    0.000
 eq_rename 07
 eq_coseis 07  0.001 0.001 0.001      0.000      0.000      0.000
* ------------------------------------
* SEQ Earthquake # 8
* EQ 327 PGC5_GPS      13.16      13.60 CoS        2.2 mm
* EQ_DEF M4.8 19km NNE of Victoria
 eq_def 08   48.5865 -123.3003     13.6 8 2015 12 30 07 40    0.006
```

```
 eq_rename 08
 eq_coseis 08  0.001 0.001 0.001      0.006      0.006      0.006
* ------------------------------------
* SEQ Earthquake # 9
* EQ 471 BMRY_GPS       9.04      10.90 CoS        1.6 mm
* EQ 471 P584_GPS       9.46      10.90 CoS        1.4 mm
* EQ_DEF M4.4 4km NNW of Banning
 eq_def 09   33.9585 -116.8883     10.9 8 2016 01 06 14 43    0.002
 eq_rename 09
 eq_coseis 09  0.001 0.001 0.001      0.002      0.002      0.002
* ------------------------------------
* SEQ Earthquake # 10
* EQ 482 P157_GPS       3.83      10.60 CoS        8.7 mm
* EQ_DEF M4.3 31km SW of Rio Dell
 eq_def 10   40.2732 -124.3395     10.6 8 2016 01 07 05 50    0.002
 eq_rename 10
 eq_coseis 10  0.001 0.001 0.001      0.002      0.002      0.002
* ------------------------------------
* SEQ Earthquake # 11
* EQ 487 P157_GPS       3.61       8.90 CoS        0.0 mm
* EQ_DEF M3.7 30km SW of Rio Dell
 eq_def 11   40.2780 -124.3240      8.9 8 2016 01 07 08 30    0.000
 eq_rename 11
 eq_coseis 11  0.001 0.001 0.001      0.000      0.000      0.000
```

None of these earthquakes generared co-seismic offsets, including GHRP (2015 12 30 which was very close to the epicenter).

In January/February 2016, the following events were investigated

```
* EQDEFS for 2016 01 13 to 2016 02 15 Generated Thu Feb 18 11:44:50 EST 2016
* Proximity based on Week_All.Pos file
* ------------------------------------
* SEQ Earthquake # 1
* EQ 58 P616_GPS       7.99       8.80 CoS        0.0 mm
* EQ_DEF M3.6 16km WNW of Johannesburg
 eq_def 01   35.4057 -117.8098      8.8 8 2016 01 14 04 24    0.000
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.000      0.000      0.000
* ------------------------------------
* SEQ Earthquake # 2
* EQ 242 LDSW_GPS       2.54       8.90 CoS        0.0 mm
* EQ 242 RAGG_GPS       7.75       8.90 CoS        0.0 mm
* EQ_DEF M3.6 8km WSW of Ludlow
 eq_def 02   34.6920 -116.2368      8.9 8 2016 01 19 10 22    0.000
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.000      0.000      0.000
* ------------------------------------
* SEQ Earthquake # 3
* EQ 356 AB22_GPS      82.35     237.40 CoS       23.0 mm
* EQ 356 AC03_GPS      84.43     237.40 CoS       21.8 mm
* EQ 356 AC06_GPS     138.39     237.40 CoS        8.1 mm
* EQ 356 AC08_GPS      78.94     237.40 CoS       25.0 mm
* EQ 356 AC15_GPS     222.49     237.40 CoS        3.1 mm
* EQ 356 AC17_GPS     127.17     237.40 CoS        9.6 mm
* EQ 356 AC18_GPS      99.03     237.40 CoS       15.9 mm
* EQ 356 AC23_GPS     166.55     237.40 CoS        5.6 mm
* EQ 356 AC24_GPS     216.13     237.40 CoS        3.3 mm
* EQ 356 AC26_GPS     163.31     237.40 CoS        5.8 mm
* EQ 356 AC27_GPS      62.12     237.40 CoS       40.4 mm
* EQ 356 AC35_GPS     146.32     237.40 CoS        7.3 mm
* EQ 356 AC36_GPS     211.54     237.40 CoS        3.5 mm
* EQ 356 AC37_GPS      95.80     237.40 CoS       17.0 mm
* EQ 356 AC38_GPS     207.80     237.40 CoS        3.6 mm
```

```
* EQ 356 AC39_GPS     124.76     237.40 CoS       10.0 mm
* EQ 356 AC43_GPS     209.38     237.40 CoS        3.6 mm
* EQ 356 AC47_GPS      65.02     237.40 CoS       36.8 mm
* EQ 356 AC51_GPS     224.59     237.40 CoS        3.1 mm
* EQ 356 AC59_GPS      15.14     237.40 CoS      678.9 mm
* EQ 356 AC67_GPS     210.40     237.40 CoS        3.5 mm
* EQ 356 AUGL_GPS      27.86     237.40 CoS      200.7 mm
* EQ 356 AV01_GPS      29.97     237.40 CoS      173.4 mm
* EQ 356 AV02_GPS      32.40     237.40 CoS      148.3 mm
* EQ 356 AV03_GPS      27.21     237.40 CoS      210.3 mm
* EQ 356 AV04_GPS      29.33     237.40 CoS      181.0 mm
* EQ 356 AV05_GPS      29.06     237.40 CoS      184.4 mm
* EQ 356 AV11_GPS      27.82     237.40 CoS      201.2 mm
* EQ 356 AV16_GPS      28.38     237.40 CoS      193.3 mm
* EQ 356 AV17_GPS      24.94     237.40 CoS      250.4 mm
* EQ 356 AV18_GPS      27.29     237.40 CoS      209.0 mm
* EQ 356 AV19_GPS      29.87     237.40 CoS      174.5 mm
* EQ 356 AV20_GPS      30.82     237.40 CoS      163.9 mm
* EQ 356 AV21_GPS      27.86     237.40 CoS      200.7 mm
* EQ 356 KEN5_GPS     160.97     237.40 CoS        6.0 mm
* EQ 356 KEN6_GPS     160.94     237.40 CoS        6.0 mm
* EQ 356 KOD1_GPS     232.59     237.40 CoS        2.9 mm
* EQ 356 KOD5_GPS     232.59     237.40 CoS        2.9 mm
* EQ 356 KOD6_GPS     232.59     237.40 CoS        2.9 mm
* EQ 356 SELD_GPS      94.10     237.40 CoS       17.6 mm
* EQ_DEF M7.1 86km W of Anchor Point
 eq_def 03   59.6204 -153.3392    237.4 8 2016 01 24 10 31    2.433
 eq_rename 03
 eq_coseis 03  0.001 0.001 0.001      2.433      2.433      2.433
* ----------------------------------
* SEQ Earthquake # 4
* EQ 376 LDSW_GPS       2.64       9.90 CoS        9.2 mm
* EQ 376 RAGG_GPS       8.06       9.90 CoS        1.0 mm
* EQ_DEF M4.1 8km WSW of Ludlow
 eq_def 04   34.6972 -116.2392      9.9 8 2016 01 24 15 33    0.001
 eq_rename 04
 eq_coseis 04  0.001 0.001 0.001      0.001      0.001      0.001
* ----------------------------------
* SEQ Earthquake # 5
* EQ 525 PETS_GPS     109.92     277.50 CoS       16.7 mm
* EQ_DEF M7.2 91km N of Yelizovo
 eq_def 05   54.0070  158.5064    277.5 8 2016 01 30 03 26    3.144
 eq_rename 05
 eq_coseis 05  0.001 0.001 0.001      3.144      3.144      3.144
```

The M7.1 86km W of Anchor Point earthquake on Jan 24 2016 did produce significant coseismic offsets and this event has been label Event EQ37. Rapid and final solution event files were submitted. The rapid event file is:

```
pbo_160124_1031_EQ37_coseis_rapid.evt.20160201154837
PBO Coseismic Offsets for EQ code 37, Date 2016 01 24 (ymd) Time 10 31 (hr min)
Format Version         : 1.00
EQ Location (lat/long) :  59.6585 -153.4521 deg
Release Date           : 20160201154837
Data
Analyzed           : ../COM/com18805.a.glb ../COM/com18806.a.glb ../COM/com18811
.a.glb ../COM/com18812.a.glb
Analysis Center        : PBO
Analysis Type          : rapid
Event Type             : Coseismic
Event Code             : EQ37
Event Date             : 201601241031
GLOBK Solution file    : ../COM/pbo160124_EQ37.a.org
.  Long        Lat      dE      dN    E +-  N +-      dH      H +-  Site
.   deg        deg      mm      mm     mm    mm       mm       mm     --
```

205.30174	59.89932	-4.99	-0.60	2.13	2.70	2.81	8.00	AB22_G37
208.13547	59.77064	9.69	-0.46	1.06	1.44	9.43	4.33	AC03_G37
209.10944	59.76364	8.81	-2.56	1.23	1.70	0.82	4.37	AC06_G37
206.35530	58.92878	14.56	-0.99	1.41	1.98	-22.30	5.91	AC08_337
210.27599	60.48133	7.50	-0.34	1.43	1.89	-1.17	2.93	AC15_G37
207.59615	60.66390	-2.38	-0.45	0.93	1.27	3.11	3.64	AC17_G37
207.75047	58.92596	3.46	-0.59	0.96	1.30	6.92	3.77	AC18_G37
209.12205	60.47509	3.20	1.37	1.01	1.36	1.77	3.39	AC23_G37
203.34725	58.68157	0.34	0.23	0.94	1.23	0.66	2.69	AC24_G37
205.83712	59.25251	-0.77	5.45	1.07	1.46	9.48	4.49	AC27_337
209.20675	59.37581	8.36	-2.62	1.17	1.61	0.65	4.02	AC35_237
209.39165	60.95532	0.33	-0.36	1.17	1.55	-0.22	2.96	AC36_G37
206.13462	60.43969	-0.47	-5.19	1.20	1.66	3.87	4.97	AC37_G37
206.65813	57.75369	-0.77	3.23	1.25	1.63	1.49	3.07	AC38_G37
207.60593	58.60972	0.72	-0.65	1.12	1.52	0.21	4.16	AC39_G37
210.37126	59.52128	4.13	-0.35	0.90	1.18	0.44	2.58	AC43_G37
207.37606	60.08145	2.58	2.19	1.22	1.64	11.35	4.98	AC47_237
208.16465	61.49808	0.07	-2.20	0.87	1.12	-0.24	2.45	AC51_237
206.41480	59.56720	0.10	-0.51	0.97	1.33	6.84	4.06	AC59_G37
207.57457	57.79072	0.48	1.61	1.26	1.67	0.19	2.98	AC67_G37
206.53920	59.35853	-2.98	-0.29	1.49	1.94	3.29	6.44	AV01_G37
206.57161	59.33297	-0.25	-1.00	1.19	1.66	3.72	5.05	AV02_337
206.64531	59.37063	3.19	-1.11	4.01	5.53	6.10	14.64	AV11_G37
206.46496	59.38591	2.88	-3.64	1.11	1.53	-3.34	4.66	AV16_G37
206.54856	59.40395	-1.16	-2.59	1.09	1.49	2.71	4.57	AV17_G37
206.56317	59.38043	-3.15	2.28	1.31	1.90	-0.54	5.89	AV18_G37
206.58567	59.35491	-8.59	11.29	1.52	1.97	14.76	6.28	AV19_G37
206.57179	59.34738	-1.68	-0.87	1.29	1.93	6.06	5.79	AV20_G37
208.64982	60.67508	5.88	7.63	1.48	2.00	1.13	4.43	KEN5_G37
208.64984	60.67480	5.33	6.37	1.38	1.84	0.37	4.25	KEN6_G37
208.29333	59.44571	11.62	-5.39	1.37	1.85	4.40	5.47	SELD_237

The other earthquakes listed above did not seem to generate significant co-seismic offsets.

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

```
* EQDEFS for 2016 02 14 to 2016 03 15 Generated Wed Mar 16 15:03:25 EDT 2016
* Proximity based on Week_All.Pos file
* ---------------------------------
* SEQ Earthquake # 1
* EQ 52 P631_GPS       6.51       9.00 CoS        0.0 mm
* EQ 52 P642_GPS       4.12       9.00 CoS        0.0 mm
* EQ_DEF M3.7 13km SE of Mammoth Lakes
 eq_def 01   37.5713 -118.8573      9.0 8 2016 02 15 15 43    0.000
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.000      0.000      0.000
* ---------------------------------
* SEQ Earthquake # 2
* EQ 70 BBRY_GPS       4.74       9.20 CoS        2.8 mm
* EQ_DEF M3.9 5km NNW of Big Bear City
 eq_def 02   34.3027 -116.8633      9.2 8 2016 02 16 09 25    0.001
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.001      0.001      0.001
* ---------------------------------
* SEQ Earthquake # 3
* EQ 98 P311_GPS      10.79      13.70 CoS        3.8 mm
* EQ 98 P727_GPS       9.79      13.70 CoS        4.7 mm
* EQ_DEF M4.8 10km WNW of Big Pine
 eq_def 03   37.2023 -118.4035     13.7 8 2016 02 16 23 05    0.007
 eq_rename 03
 eq_coseis 03  0.001 0.001 0.001      0.007      0.007      0.007
* ---------------------------------
* SEQ Earthquake # 4
```

```
* EQ 101 P727_GPS       9.98      10.60 CoS        1.3 mm
* EQ_DEF M4.3 10km WNW of Big Pine
 eq_def 04   37.2023 -118.3998     10.6 8 2016 02 16 23 28    0.002
 eq_rename 04
 eq_coseis 04  0.001 0.001 0.001      0.002      0.002      0.002
* ----------------------------------
* SEQ Earthquake # 5
* EQ 203 RDMT_GPS       3.81      10.60 CoS        8.8 mm
* EQ_DEF M4.3 36km ENE of Lucerne Valley
 eq_def 05   34.6098 -116.6288     10.6 8 2016 02 20 06 14    0.002
 eq_rename 05
 eq_coseis 05  0.001 0.001 0.001      0.002      0.002      0.002
* ----------------------------------
* SEQ Earthquake # 6
* EQ 302 LDSW_GPS       3.01       9.80 CoS        7.1 mm
* EQ 302 RAGG_GPS       8.33       9.80 CoS        0.9 mm
* EQ_DEF M4.1 8km WSW of Ludlow
 eq_def 06   34.6943 -116.2428      9.8 8 2016 02 23 03 20    0.001
 eq_rename 06
 eq_coseis 06  0.001 0.001 0.001      0.001      0.001      0.001
* ----------------------------------
* SEQ Earthquake # 7
* EQ 315 P564_GPS       9.19      14.30 CoS        6.1 mm
* EQ_DEF M4.9 6km SSW of Wasco
 eq_def 07   35.5423 -119.3728     14.3 8 2016 02 24 00 03    0.008
 eq_rename 07
 eq_coseis 07  0.001 0.001 0.001      0.008      0.008      0.008
* ----------------------------------
* SEQ Earthquake # 8
* EQ 666 NHRG_GPS       6.73       9.90 CoS        1.4 mm
* EQ_DEF M4.1 17km ENE of Ojai
 eq_def 08   34.5217 -119.0748      9.9 8 2016 03 12 08 43    0.001
 eq_rename 08
 eq_coseis 08  0.001 0.001 0.001      0.001      0.001      0.001
Analysis:

None of  earthquakes listed above generated significant co-seismic offsets.
```

Antenna Change Offsets: 2015/12/01-2016/02/29

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

```
 station      Date           From            To
 ARHP  2015 12  1 17  0  LEIAX1202         TRM57971.00
 P222  2015 12 17  0  8  TRM29659.00       TRM59800.80

 ATW2  2016  1  6  0  0  TRM59800.80       TRM29659.00
 P190  2016  1 27 18 20  TRM29659.00       TRM59800.80
 P298  2016  1 29 17 45  TRM29659.00       TRM59800.80
 P452  2016  1 21 21 19  TRM29659.00       TRM59800.80

 P172  2016  2 24 20 12  TRM29659.00       TRM59800.80
 PENA  2016  2 17  0  0  Radome NONE       SCIS
```

Analysis
ARHP: WLS dNEU   -1.27 +- 3.60, -7.23 +- 2.54, -17.13 +- 7.13 mm,
KF dNEU   -3.05 +- 0.37, -9.14 +- 0.34, -15.90 +- 1.26 mm
East and height offsets clearly seen.

P222: WLS dNEU 4.81 +- 0.80, 2.93 +- 3.68, -4.05 +- 4.64 mm,
KF dNEU 4.80 +- 0.33, 2.92 +- 0.30, -4.05 +- 1.18 mm
Break 2015 12 17 associated with antenna change. The break below has been added to unknown class and associated with correction of metadata at this site. (2015 10 25. Advisory note added to the GAGE Analysis log)
WLS dNEU 0.59 +- 0.49, 0.83 +- 2.31, 44.82 +- 2.86 mm,
KF dNEU 0.47 +- 0.24, -0.11 +- 0.25, 43.67 +- 0.80 mm

ATW2: WLS dNEU 1.15 +- 1.77, -0.05 +- 0.88, -9.42 +- 6.26 mm,
KF dNEU 0.76 +- 0.60, -0.21 +- 0.38, -11.03 +- 1.94 mm
Time series is quite systematic and these estimates are based on data after 2014 only with editing of outliers before the antenna change.
P190: WLS dNEU -2.39 +- 4.80, 3.34 +- 3.89, -7.14 +- 8.62 mm,
KF dNEU -2.21 +- 0.38, 3.09 +- 0.32, -10.26 +- 1.23 mm
Breaks are not so apparent in time series.
P298: WLS dNEU -5.06 +- 4.04, 1.24 +- 2.84, -2.40 +- 12.79 mm,
KF dNEU -5.85 +- 0.37, 1.87 +- 0.32, -7.58 +- 1.31 mm
North offset is very clear in time series. Height offset is reduced to -3.7 mm (KF) annual signal is also estimated.
P452: WLS dNEU 11.84 +- 1.76, -2.01 +- 1.10, -1.76 +- 8.66 mm,
KF dNEU 12.79 +- 0.51, -1.64 +- 0.40, -6.32 +- 1.63 mm
North offset is very clear. Height offset is reduced to -1.7 mm (KF) if an annual signal is estimated also.

P172: WLS dNEU -0.97 +- 4.66, 1.32 +- 1.13, -0.75 +- 8.19 mm,
KF dNEU -2.39 +- 0.52, 1.28 +- 0.43, -2.62 +- 1.72 mm
Data has gaps and poor quality before change so it is not clear if the break is significant.
PENA: WLS dNEU -1.09 +- 8.68, -1.00 +- 3.23, -2.64 +- 13.06 mm,
KF dNEU -1.15 +- 0.59, -1.03 +- 0.66, -2.73 +- 2.45 mm
This break does not look significant. There is break on 2015 10 25 (eported earlier that is significant: KF dNEU 4.92 +- 0.56, 1.90 +- 0.45, 10.86 +- 1.58 mm

MIT issued advisories

No new advisories were issued this quarter.

Script updates

No major changes have been to the scripts.

GAMIT/GLOBK Community Support

During this quarter we have continued our modifications to GAMIT to allow processing of two-frequency observations from satellites of any single GNSS. The development version of the software can now handle smoothly GPS, Beidou, and Galileo observations and orbits in RINEX 2 or RINEX 3 formats. Still to be completed are the modifications for Glonass, a particular complication for our double-difference algorithms because each satellite transmits on a different frequency. There is work to be done also in testing the yaw models for systems other than GPS.

We continue to spend 5-10 hours per week in email support of users. During the quarter we issued 29 royalty-free licenses to educational and research institutions.