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: 2015/10/01-2015/12/31

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Summary

Under the GAGE Facility Data Analysis subcontract, MIT has been combining results from the New Mexico Tech (NMT) and Central Washington University (CWU). In this report, we show analyses of the data processing for the period 09/15/2015 to 12/12/2015, time series velocity field analyses for the GAGE reprocessing analyses (1996-2015). There were no earthquakes that generated measureable coseismic offsets this quarter. For this quarter the last finals results were for December 12, 2015. No new "bad" sites were added this quarter. Currently there are 94 sites in the list. Earlier quarterly reports contain the details of these sites. 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 is slowly increasing since a number of new sites are being added. In this quarter 1918 sites were processed compared to 1925 for the previous quarter.

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

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

Analysis of Final products: September 15, 2015 and December 12, 2015

Each month, we submit reports of the statistics of the PBO combined analyses and estimates of the latest velocity fields in the NAM08 reference frame based on the time series analysis of data between 1996 and month preceding the report (we need to allow 2-3 weeks for the generation of the final products). For this report, we generated the statistics using the ~3 months of results generated between September 15, 2015 and December 12, 2015. 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 site 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 1.1 mm for all centers and as low as 0.8 mm for NMT and PBO north and east components. The up RMS scatters are less than or equal 5.0 mm and as low as 4.3 mm for the PBO combination. 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 1917, 1916 and 1916 sites for PBO, NMT and CWU analyzed in the finals analysis between September 15, 2015 and December 12, 2015. Histograms of the RMS scatters are shown in Figure 1-3.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
PBO	0.8	0.8	4.3
NMT	0.8	0.8	4.5
CWU	1.1	0.9	5.0
70%			
PBO	1.0	1.0	5.0
NMT	1.0	1.1	5.1
CWU	1.2	1.2	5.8
95%			
PBO	2.0	1.9	7.0
NMT	1.9	2.0	7.0
CWU	2.3	2.4	8.5

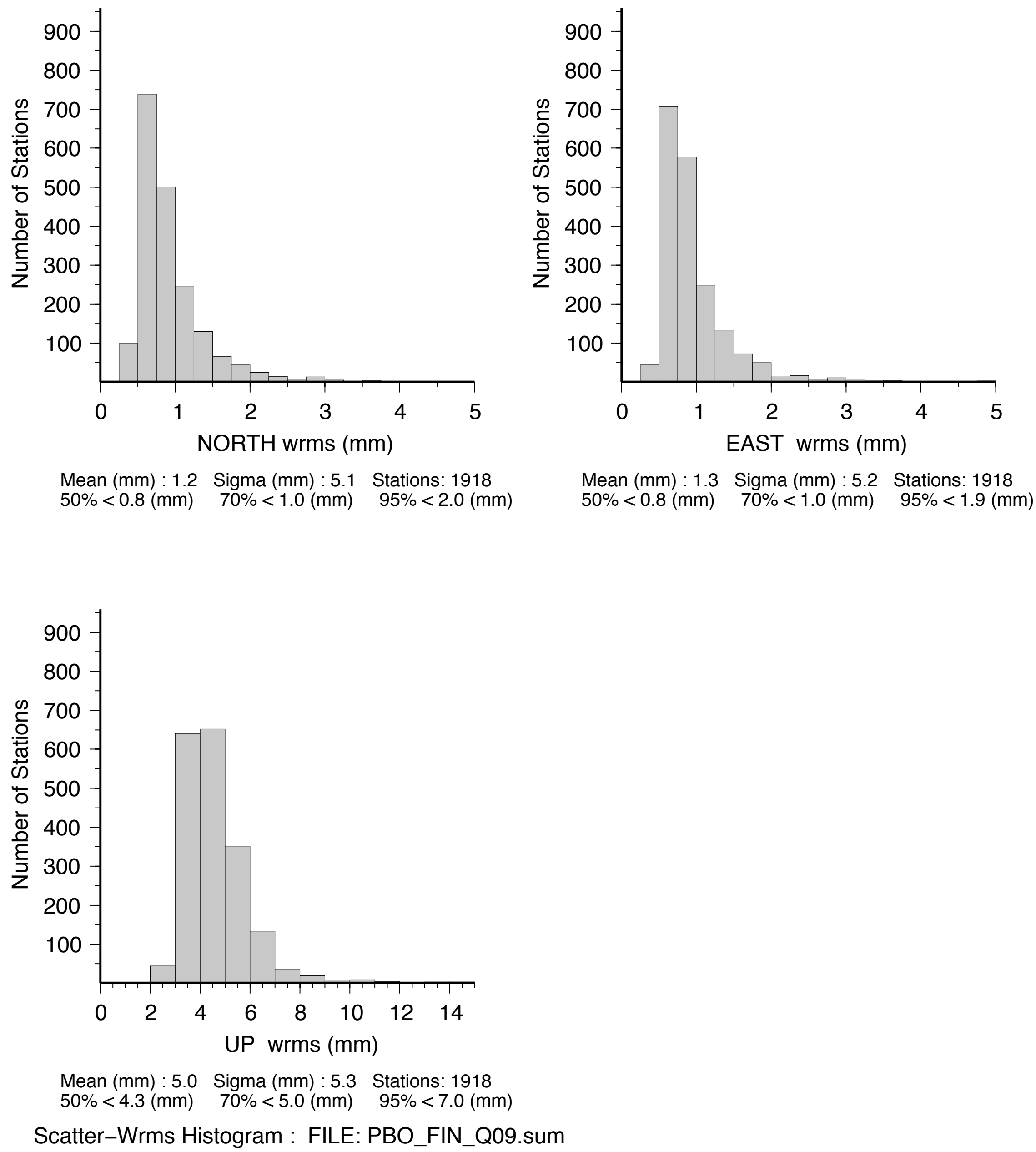

Figure 1: PBO combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1918 sites analyzed between September 15, 2015 and December 12, 2015. Linear trends and annual signals were estimated from the time series.

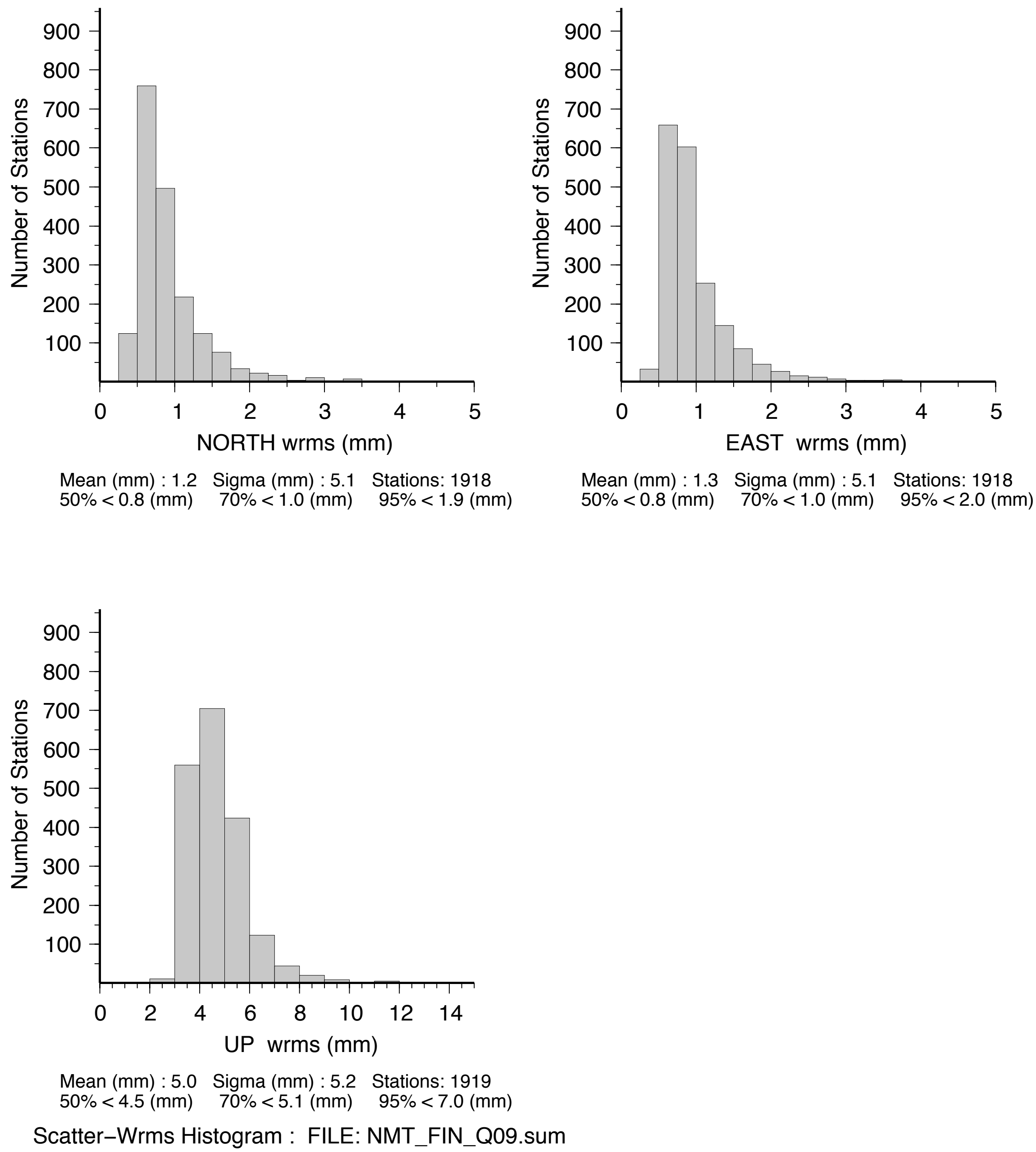

Figure 2: NMT combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1918 sites analyzed between September 15, 2015 and December 12, 2015. Linear trends and annual signals were estimated from the time series.

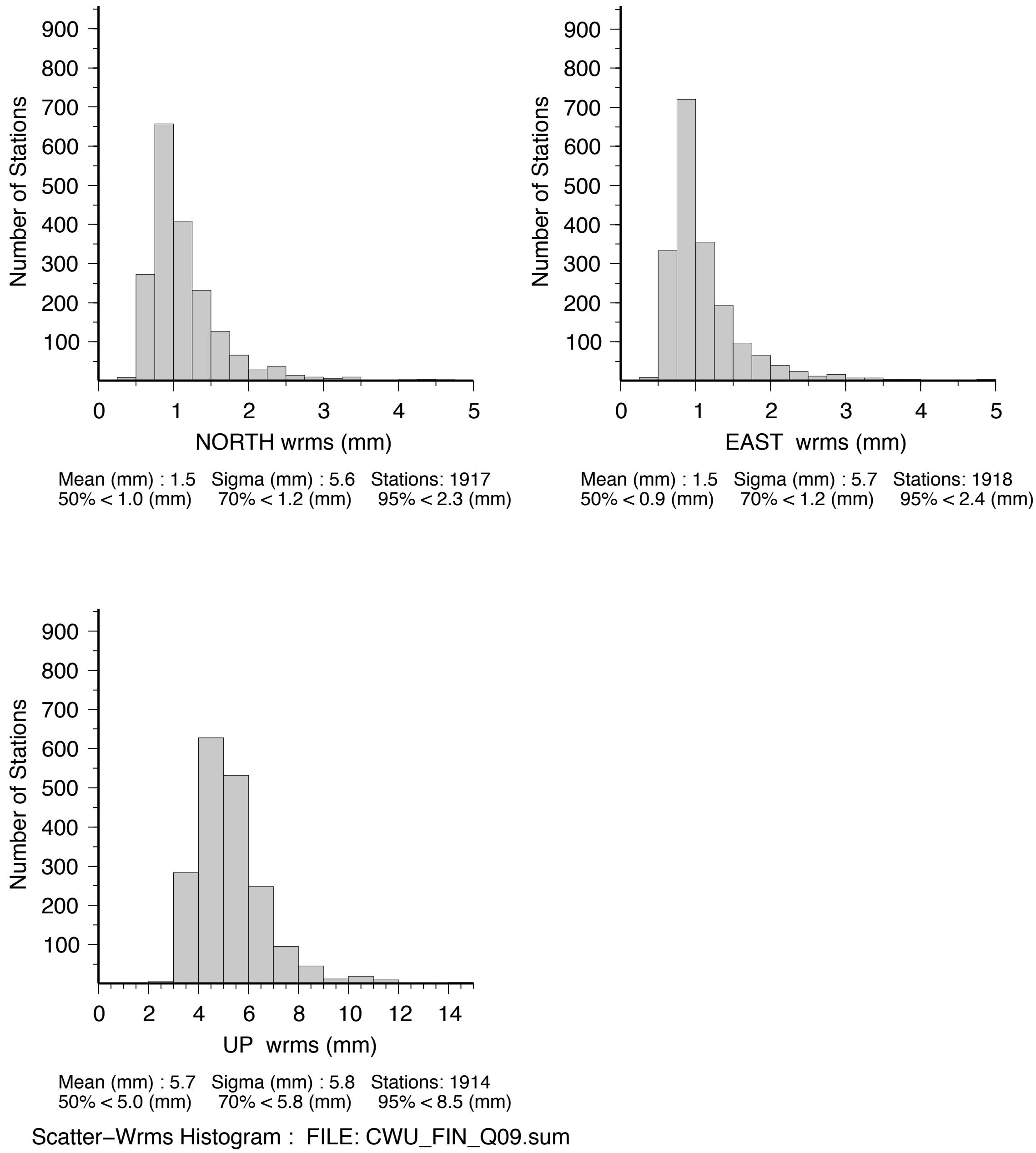

Figure 3: CWU combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1918 sites analyzed between September 15, 2015 and December 12, 2015. Linear trends and annual signals were estimated from the time series.

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_Q09.tab. There are 1920 sites in the file. The contents of the files is of this form:

```
Tabular Position RMS scatters created from PBO_FIN_Q09.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      0.6   0.39      1.0    0.57     4.7   0.65     12.64
 1NSU    89      0.7   0.39      0.9    0.54     4.3   0.63     11.90
 1ULM    89      0.5   0.35      0.7    0.45     4.8   0.80     12.50
 7ODM    89      1.4   0.77      0.8    0.51     5.2   0.75     14.64
…
 ZBW1    89      0.7   0.36      0.8    0.49     4.9   0.71     12.53
 ZDC1    89      0.7   0.38      0.8    0.50     4.8   0.73     12.53
 ZDV1    89      1.0   0.53      0.9    0.51     4.9   0.71     12.53
 ZKC1    89      0.8   0.45      0.8    0.44     5.4   0.78     12.53
 ZLA1    89      0.9   0.46      0.8    0.47     4.2   0.57     12.53
 ZME1    89      0.8   0.42      0.7    0.37     5.0   0.68     12.75
 ZMP1    89      0.8   0.44      0.6    0.36     6.5   0.98     13.00
 ZNY1    89      0.8   0.43      0.7    0.43     4.7   0.69     12.91
 ZSE1    78      0.9   0.40      0.7    0.40     4.6   0.63     12.91
 ZTL4    89      0.7   0.36      0.6    0.36     5.3   0.74     13.10
```

Table 2: RMS scatter of the position residuals for the PBO combined solution between September 15, 2015 and December 12, 2015 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	0.7	0.7	4.0	875
NUCLEUS	0.7	0.7	3.9	207
USGS SCIGN	0.9	0.9	4.1	128
Expanded	0.8	0.8	4.9	592
GAMA	0.5	0.6	5.2	13
COCO Net	1.5	1.5	6.3	103
70 %				
PBO	0.9	0.9	4.4	
NUCLEUS	0.8	0.8	4.3	
USGS SCIGN	1.0	1.1	4.6	
Expanded	1.0	1.0	5.4	
GAMA	0.5	0.7	5.4	
COCO Net	1.7	1.8	7.3	
95%				
PBO	1.8	1.8	6.1	
NUCLEUS	1.4	1.3	6.0	
USGS SCIGN	1.6	1.7	6.1	
Expanded	1.9	1.9	7.1	
GAMA	0.7	0.8	6.0	
COCO Net	2.9	3.3	11.8	

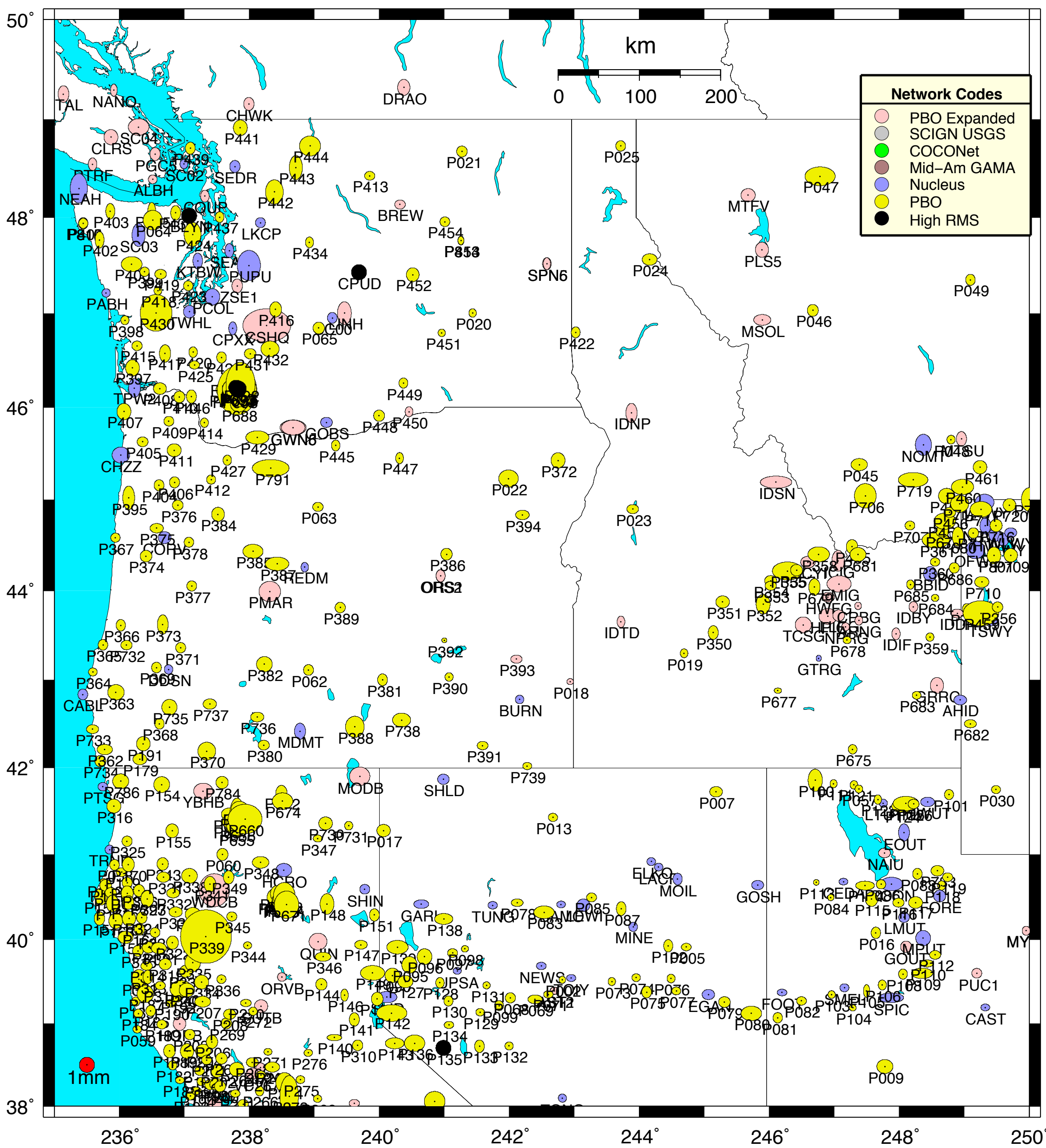

Figure 4: Distribution of the RMS scatters of horizontal position estimates from the PBO combined analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the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

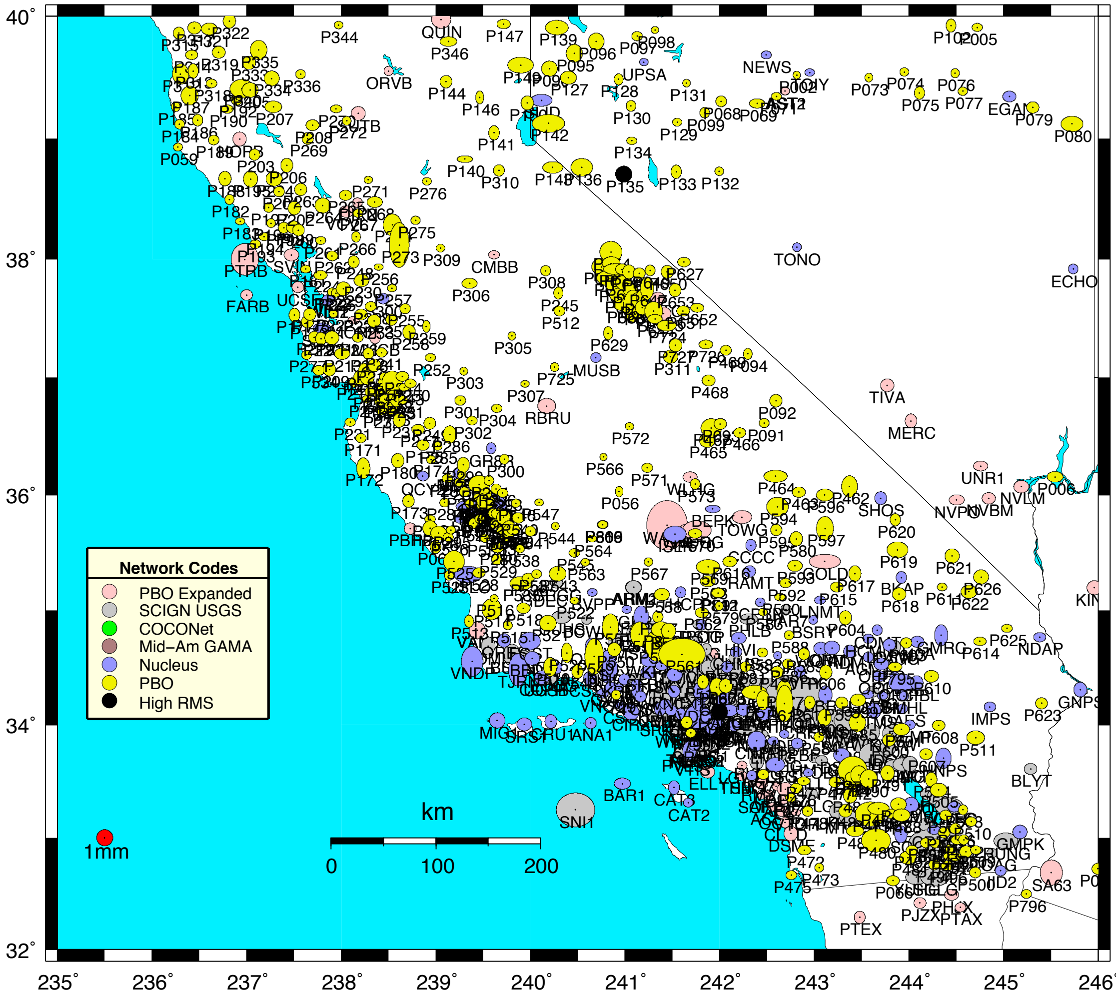

Figure 5: Same as Figure 4 except for the Southern Western United States. Black circles in the Yucca mountain region have no data during this 3-month period.

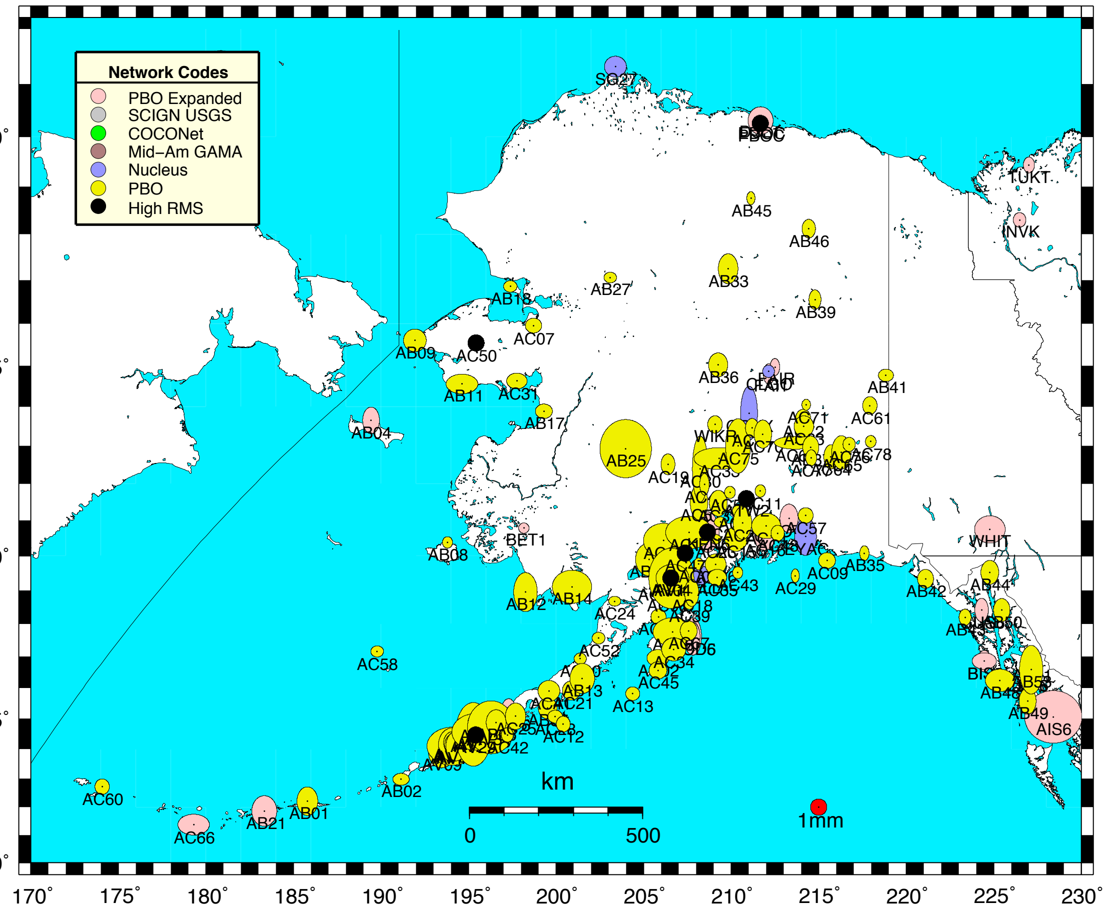

Figure 6: Same as Figure 4 except for the Alaskan region.

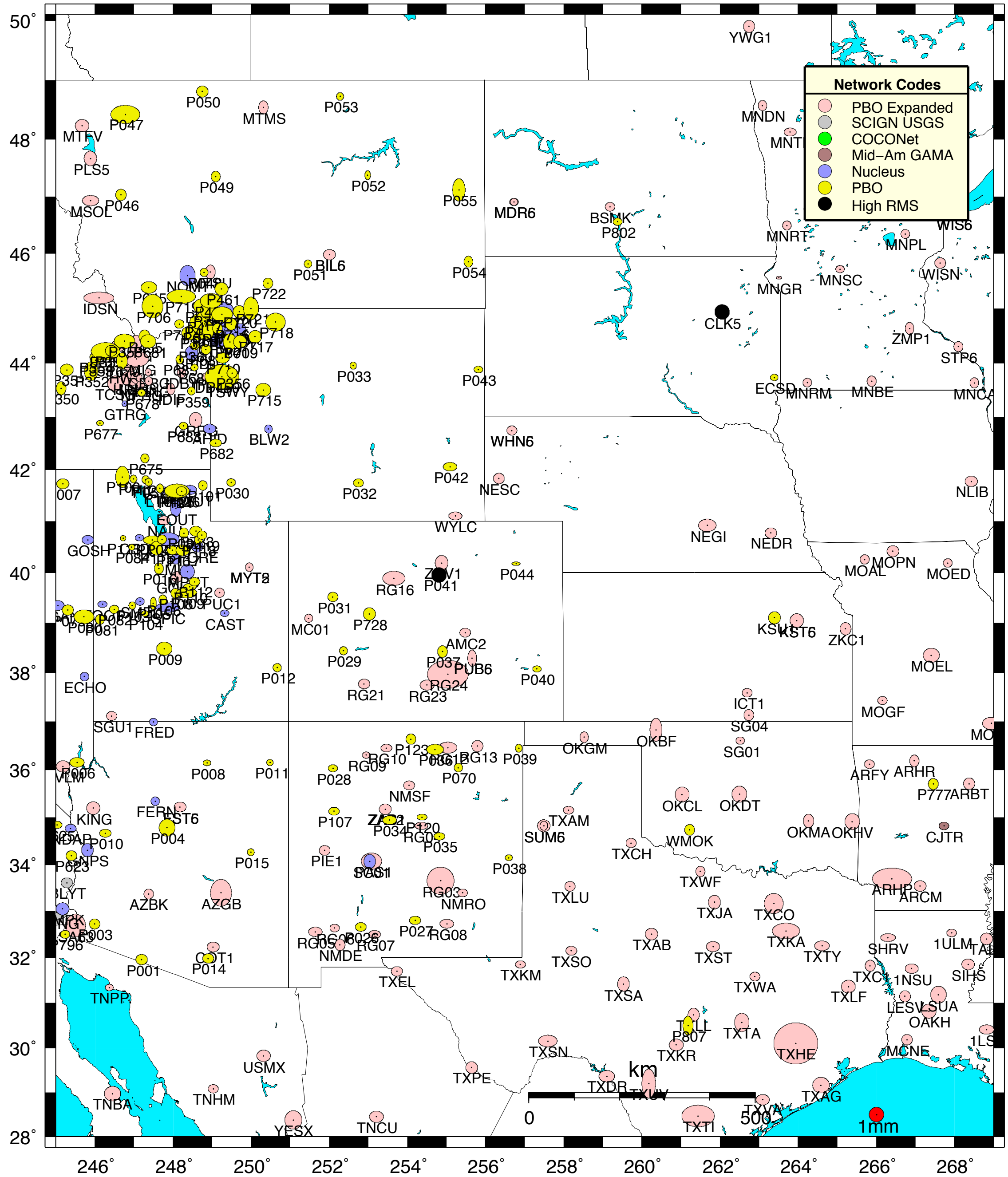

Figure 7: Same as Figure 4 except for the Central United States

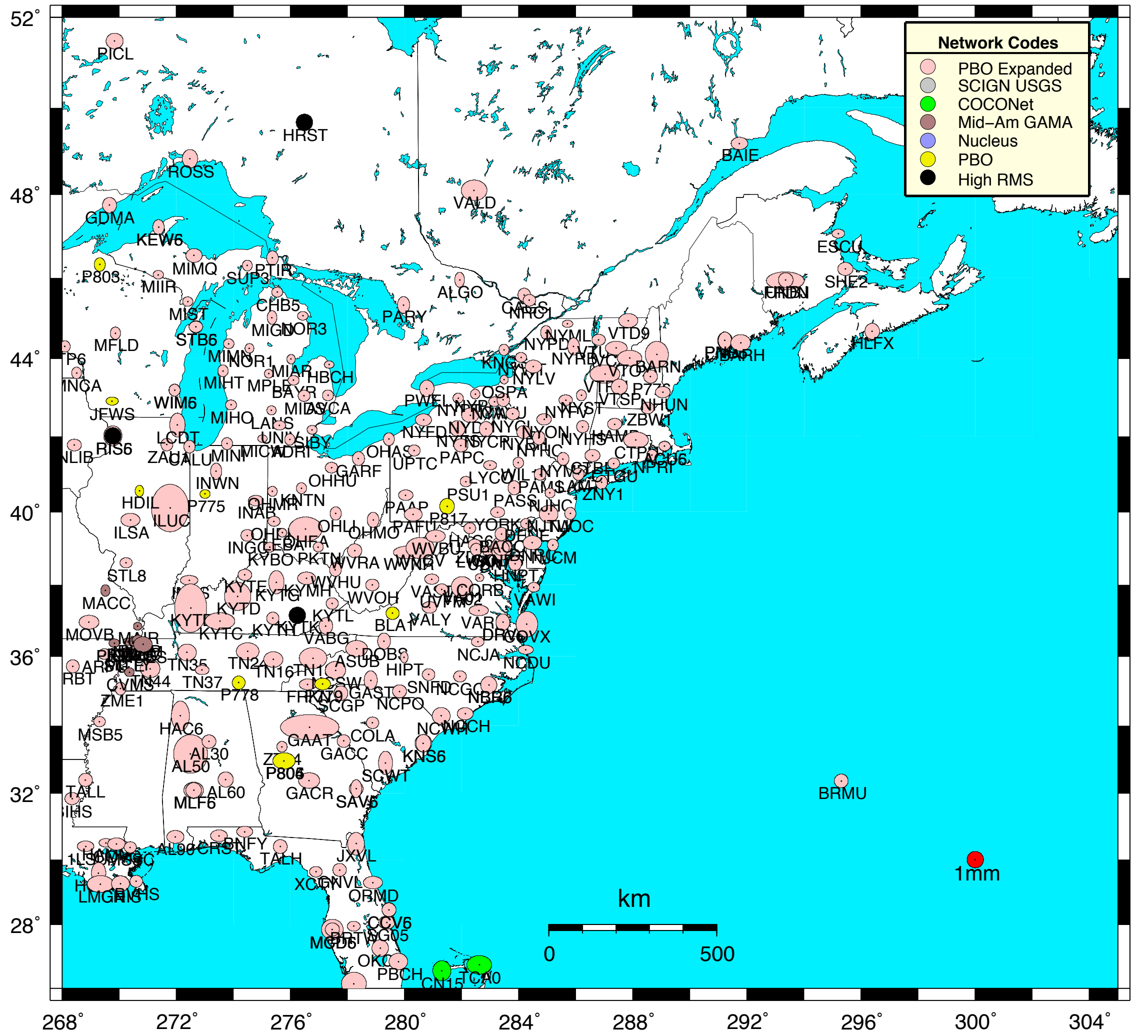

Figure 8: Same as Figure 4 except for the Eastern United States

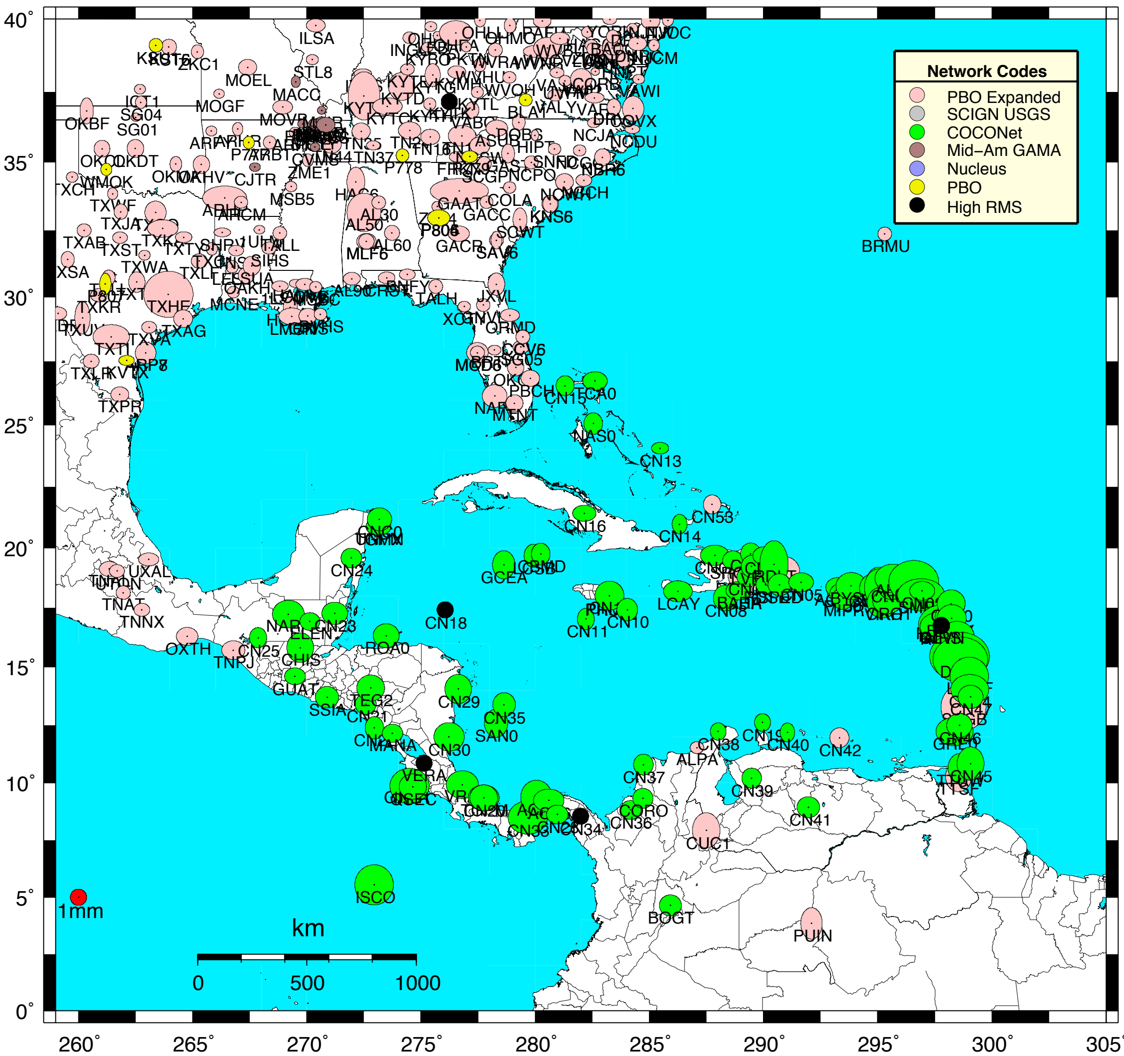

Figure 9: Same as Figure 4 except for the Caribbean region.

Analysis of large RMS sites

The analysis of the large RMS sites 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 sites 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 sites 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_1501212.tab, nmt_nam08_151212.tab and cwu_nam08_151212.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_151212.snpvel, nmt_nam08_151212.snpvel and cwu_nam08_151212.snpvel.

Table 4: Statistics of the fits of 2159, 2160 and 2153 sites analyzed by PBO, NMT and CWU in the reprocessed analysis for data collected between Jan 1, 1996 and December 12, 2015.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
PBO	1.1	1.2	5.7
NMT	1.1	1.1	5.3
CWU	1.3	1.3	6.0
70%			
PBO	1.4	1.6	6.5
NMT	1.4	1.5	6.0
CWU	1.6	1.6	6.8
95%			
PBO	3.2	3.1	9.1
NMT	3.2	3.1	8.9
CWU	3.4	3.2	10.1

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 0.72 mm/yr vertical in direct difference of all sites with in 0.5 meters of each other (2173 comparisons). The χ^2/f of the difference is $(1.18)^2$ for the horizontal and $(1.89)^2$ 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 22-69% optimistic over expectations. The 10-worst sites are AV02, MYT2, P613, MTA1, P801, MCD1, SAV1, JNPR, SAV5, and LST1. This list is similar to previous quarters (Q08 list P713, MTA1, P613, MCD1, P801, P486, 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 sites 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 2156, 2157 and 2147 sites. WRMS is weighted-root-mean-scatter and NRMS is sqrt(χ^2/f) where f is the number of comparisons. Larger numbers of sites appear below because sites 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	2173	0.08	0.72	1.18	1.89
Edited -10 worst	2156	0.07	0.70	1.07	1.83
Less than median (0.14 0.45 mm/yr)	1193	0.06	0.59	1.14	1.83
Added minimum sigma NE 0.05 U 0.50 mm/yr					
All	2173	0.12	1.06	0.97	1.16
Edited -10 worst	2160	0.11	1.01	0.87	1.11
Less than median (0.15 0.0.67 mm/yr)	1268	0.08	0.71	0.76	0.86

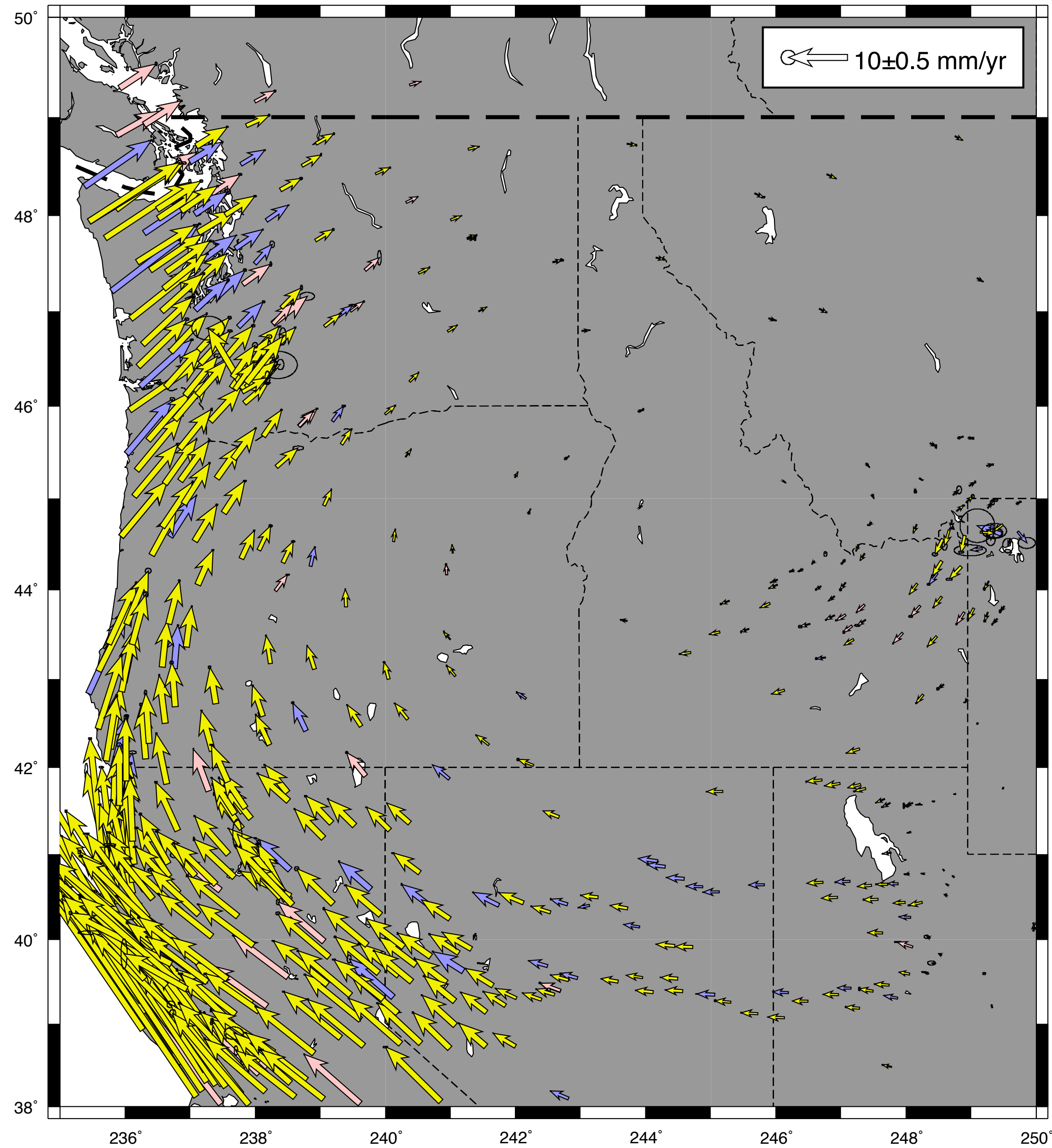

Figure 10: Velocity field estimates from the combined PBO solutions generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal standard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

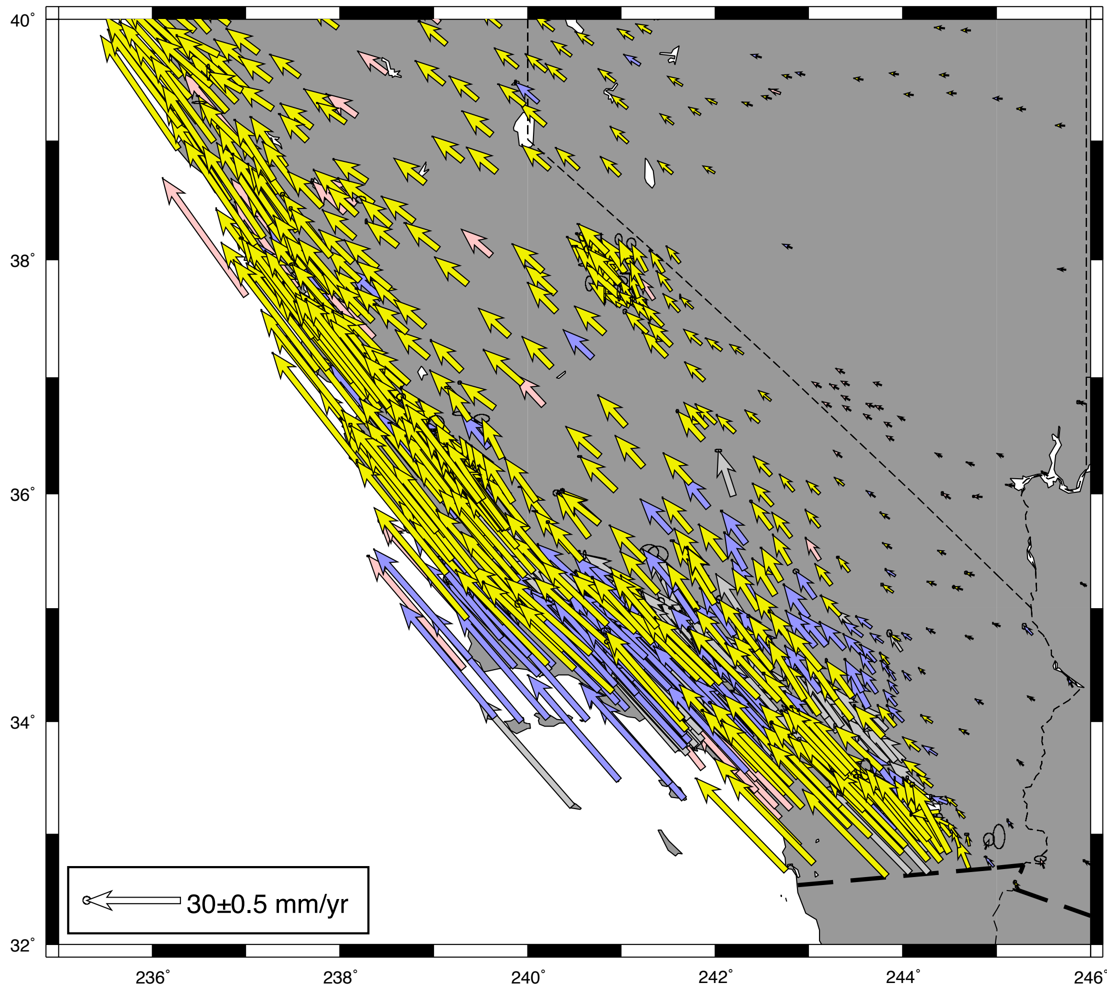

Figure 11: Same as Figure 10 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

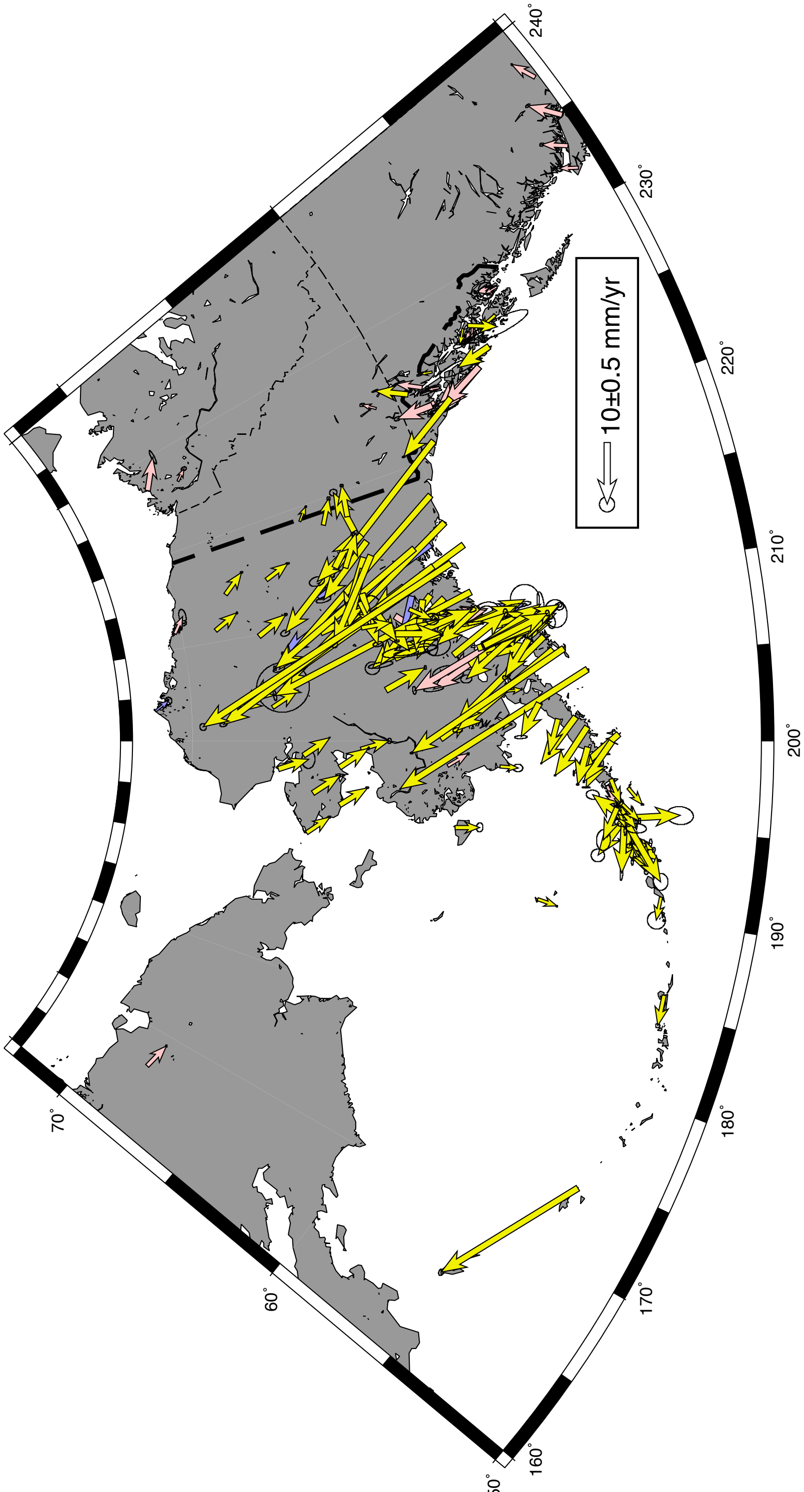

Figure 12: Same as Figure 10 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

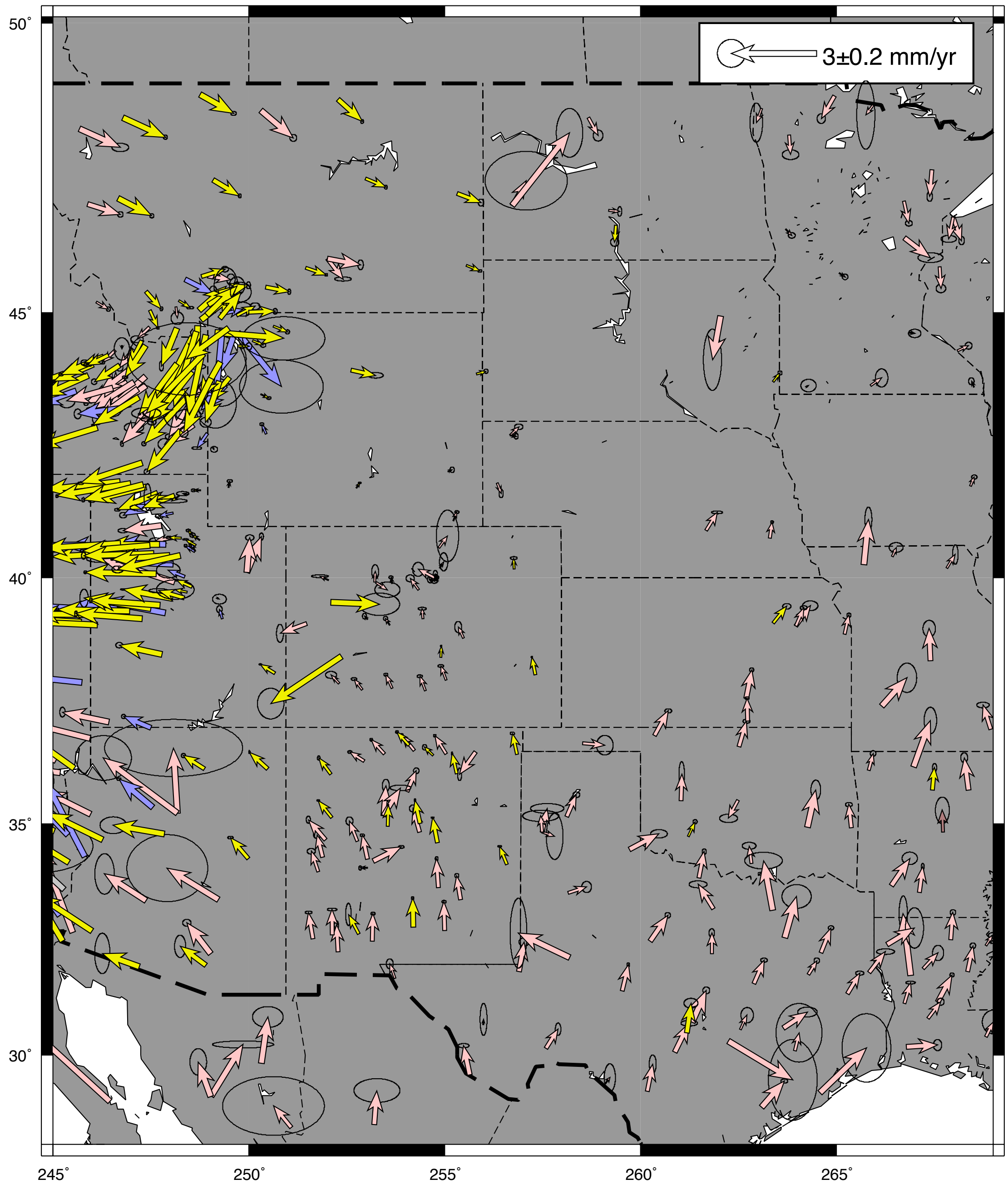

Figure 13: Same as Figure 10 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

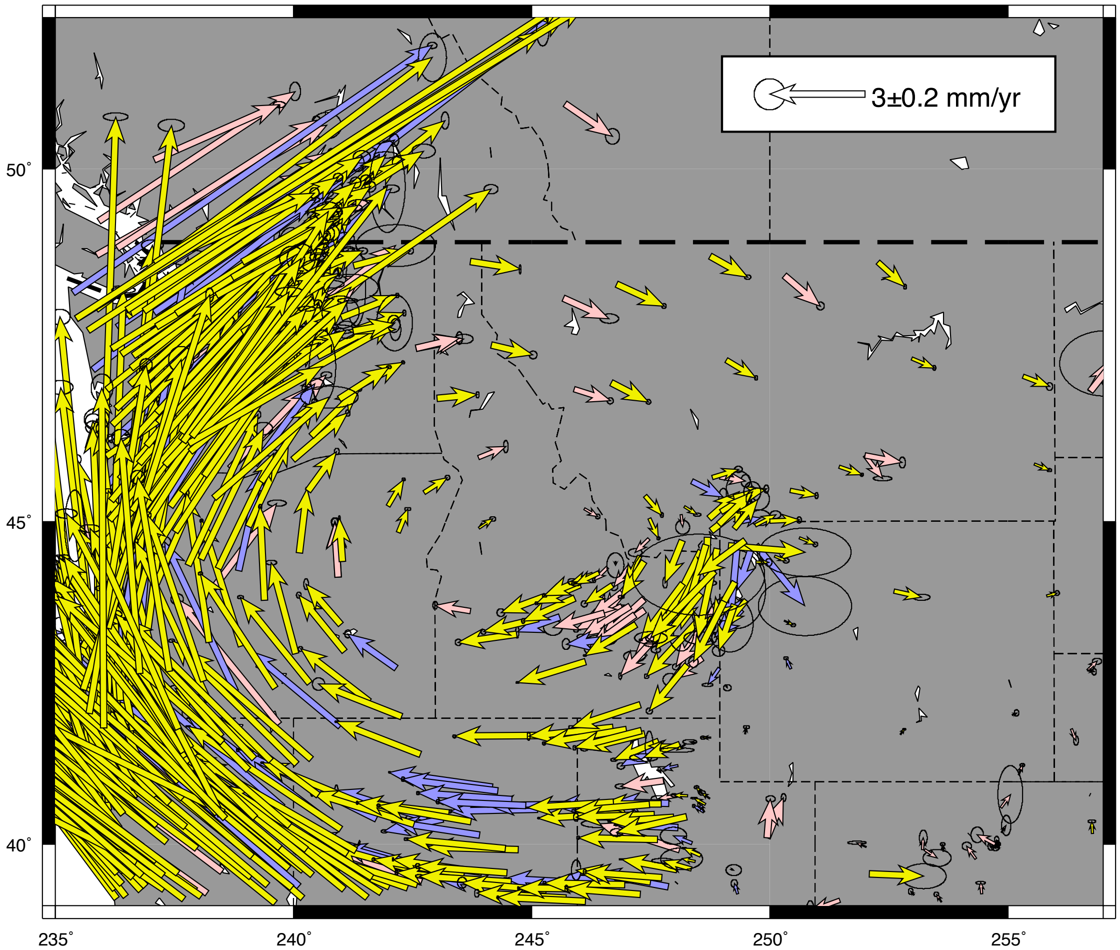

Figure 14: Same as Figure 10 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

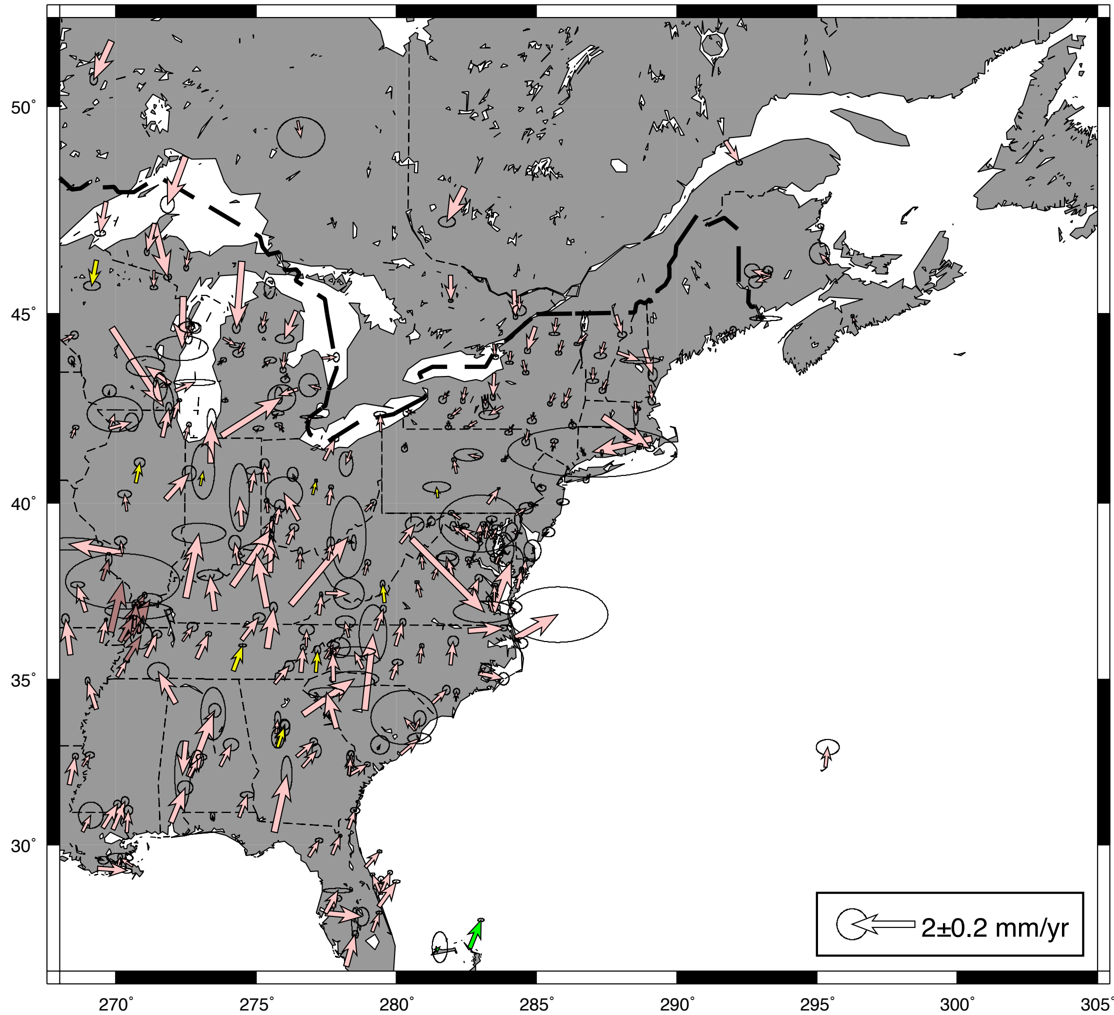

Figure 15: Same as Figure 10 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic western velocity of sites in the Northeast is being investigated although profiles from Canada to the Gulf of Mexico indicate that horizontal glacial isostatic adjustment (GIA) horizontal signals may be seen in the velocity results. If this is the case, the North America Euler pole from ITRF2008 may be affected by these motions.

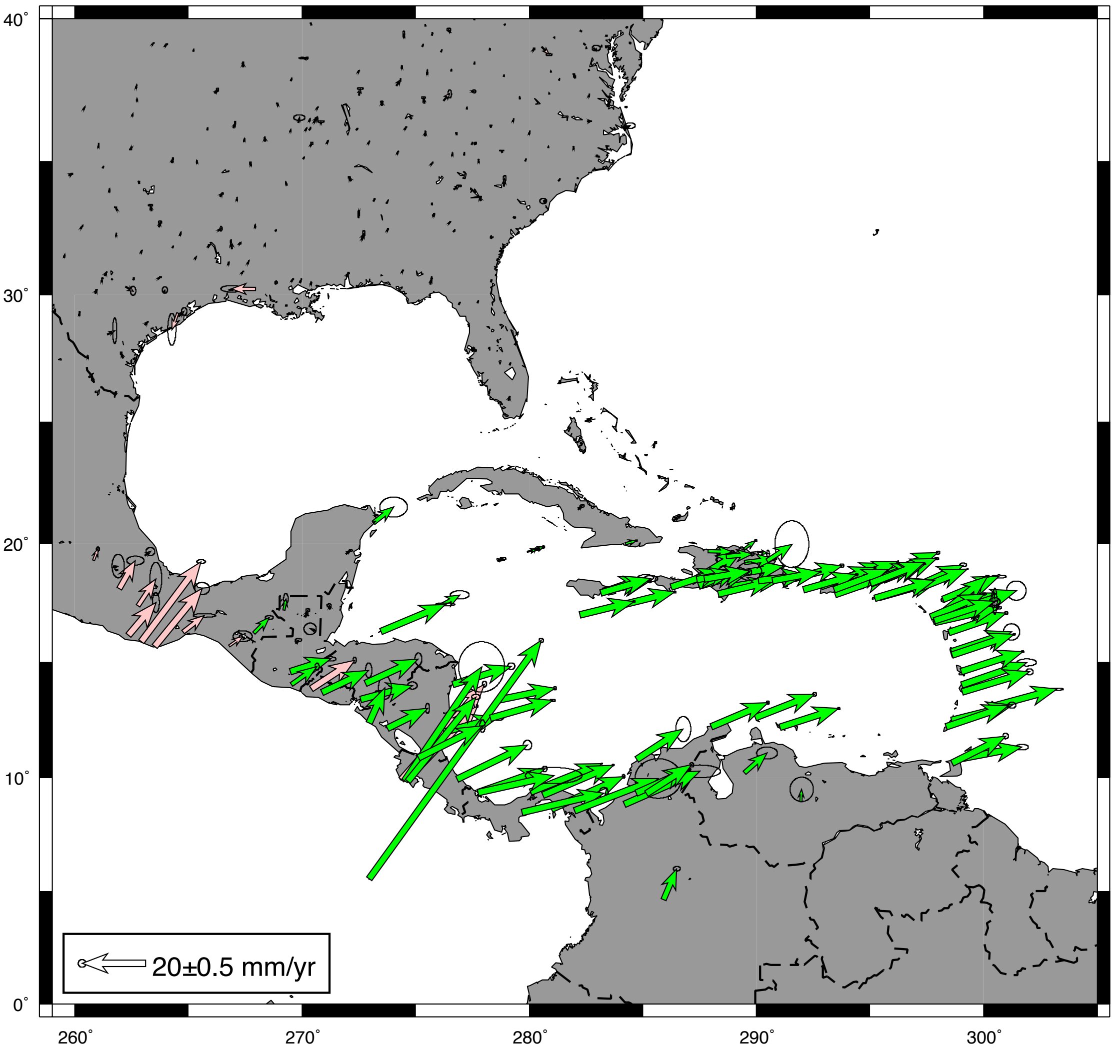

Figure 16: Same as Figure 10 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2015/10/01-2015/12/31.

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 site 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 August/September 2015 we investigated the following events.

```
* EQDEFS for 2015 08 15 to 2015 09 16 Generated Thu Sep 17 16:35:40 EDT 2015
* Proximity based on Week_All.Pos file
* ----------------------------------
* SEQ Earthquake # 1
* EQ 64 P224_GPS       3.22       9.60 CoS        6.2 mm
* EQ_DEF M4.0 1km N of Piedmont
 eq_def 01   37.8365 -122.2322      9.6 8 2015 08 17 13 50    0.001
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.001      0.001      0.001
* ----------------------------------
* SEQ Earthquake # 2
* EQ 179 P642_GPS       2.75       9.00 CoS        0.0 mm
* EQ 179 P643_GPS       8.75       9.00 CoS        0.0 mm
* EQ_DEF M3.7 17km ESE of Mammoth Lakes
 eq_def 02   37.5975 -118.7878      9.0 8 2015 08 22 13 35    0.000
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.000      0.000      0.000
* ----------------------------------
* SEQ Earthquake # 3
* EQ 315 P313_GPS       8.58       8.80 CoS        0.0 mm
* EQ_DEF M3.6 18km ENE of Fort Bragg
 eq_def 03   39.4810 -123.5968      8.8 8 2015 08 29 08 14    0.000
 eq_rename 03
 eq_coseis 03  0.001 0.001 0.001      0.000      0.000      0.000
* ----------------------------------
* SEQ Earthquake # 4
* EQ 638 TNTB_GPS      59.73     110.60 CoS       12.1 mm
* EQ_DEF M6.6 59km SSW of Topolobampo
 eq_def 04   25.1556 -109.3772    110.6 8 2015 09 13 08 15    0.675
 eq_rename 04
 eq_coseis 04  0.001 0.001 0.001      0.675      0.675      0.675
```

None of the other earthquakes generated significant offsets. TNTB is a very new site with only ~2 weeks of data before the earthquake. There does not appear to be any offset at the time of the earthquake.

In September/October 2015, the following events were investigated

```
* EQDEFS for 2015 09 15 to 2015 10 15 Generated Thu Oct 15 10:23:12 EDT 2015
* Proximity based on Week_All.Pos file
* ----------------------------------
* SEQ Earthquake # 1
* EQ 53 FHOG_GPS       8.77       9.60 CoS        0.8 mm
* EQ 53 P609_GPS       8.94       9.60 CoS        0.8 mm
* EQ_DEF M4.0 13km SSE of Big Bear Lake
 eq_def 01   34.1372 -116.8580      9.6 8 2015 09 16 16 11    0.001
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.001      0.001      0.001
* ----------------------------------
* SEQ Earthquake # 2
* EQ 629 P205_GPS       5.40       9.40 CoS        2.2 mm
* EQ 629 P340_GPS       6.74       9.40 CoS        1.4 mm
* EQ_DEF M3.9 27km NE of Redwood Valley
 eq_def 02   39.4435 -122.9865      9.4 8 2015 09 28 21 37    0.001
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.001      0.001      0.001
* ----------------------------------
* SEQ Earthquake # 3
* EQ 876 AC12_GPS      10.26      15.80 CoS        6.7 mm
* EQ_DEF M5.0 13km NNE of Chernabura Island
```

```
 eq_def 03   54.9013 -159.4875     15.8 8 2015 10 12 19 31    0.011
 eq_rename 03
 eq_coseis 03  0.001 0.001 0.001      0.011      0.011      0.011
```

None of the other earthquakes generated significant offsets. There is only 1 rapid value available for AC12 after the 2015 10 12 earthquake. Based on this one value, any offset seems small (< 2mm in all components).

In October/Novmebr 2015, the following events were investigated but none show co-seismic offsets.

```
* EQDEFS for 2015 10 14 to 2015 11 15 Generated Mon Nov 16 09:11:27 EST 2015
* Proximity based on Week_All.Pos file
* ----------------------------------
* SEQ Earthquake # 1
* EQ 143 P229_GPS       4.92       8.80 CoS        0.0 mm
* EQ_DEF M3.6 1km NE of San Ramon
 eq_def 01   37.7918 -121.9635      8.8 8 2015 10 19 23 22    0.000
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.000      0.000      0.000
* ----------------------------------
* SEQ Earthquake # 2
* EQ 475 DOMI_GPS       4.66      13.70 CoS       20.6 mm
* EQ_DEF M4.8 4km E of Roseau
 eq_def 02   15.3042  -61.3471     13.7 8 2015 11 03 17 33    0.007
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.007      0.007      0.007
* ----------------------------------
* SEQ Earthquake # 3
* EQ 540 ABVI_GPS       5.80       9.00 CoS        0.0 mm
* EQ_DEF M3.7 50km NE of Road Town
 eq_def 03   18.7817  -64.3363      9.0 8 2015 11 07 03 08    0.000
 eq_rename 03
 eq_coseis 03  0.001 0.001 0.001      0.000      0.000      0.000
* ----------------------------------
* SEQ Earthquake # 4
* EQ 692 P251_GPS       6.55       8.70 CoS        0.0 mm
* EQ_DEF M3.5 7km ESE of Ridgemark
 eq_def 04   36.7760 -121.2907      8.7 8 2015 11 13 07 37    0.000
 eq_rename 04
 eq_coseis 04  0.001 0.001 0.001      0.000      0.000      0.000
* ----------------------------------
* SEQ Earthquake # 5
* EQ 700 PALX_GPS       7.66      10.50 CoS        2.2 mm
* EQ_DEF M4.3 53km ESE of Maneadero
 eq_def 05   31.6135 -116.0157     10.5 8 2015 11 13 17 18    0.002
 eq_rename 05
 eq_coseis 05  0.001 0.001 0.001      0.002      0.002      0.002
```

None of these earthquakes generated significant offsets. There are no rapid data for ABVI but the computed magnitude of the likely offset suggests that no offset will be detected. DOMI has a relatively large expected offset but non can be seen. This is common with our algorithm for small earthquakes near to sites.

Antenna Change Offsets: 2015/10/01-2015/12/31

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

```
Site      Date           From            To
BOGT  2015  8 19 21  0  ASH701945E_M      JAVRINGANT_DM
GMPK  2015  8 21  0  0  ASH701945B_M      TRM59800.80
LMNL  2015  8 20 17 42  TRM29659.00       TRM59800.00
P309  2015  8 27 14 57  TRM29659.00       TRM59800.80
P566  2015  8  7 16 35  TRM29659.00       TRM59800.80

ALBH  2015  9 19  0  0  AOAD/M_T          TRM59800.00
LL01  2015  9 30 16 33  TPSCR.G3          TRM57971.00
P030  2015  9 13 21 51  TRM29659.00       TRM59800.00
P244  2015  9 29 22  6  !RM29659.00       TRM59800.80
VTD9  2015  9 22 12  0  TRM55971.00       TRM57971.00

CRO1  2015 10 20  0  0  ASH701945G_M       JAVRINGANT_DM
P487  2015 10  8  0  0  TRM29659.00        TRM59800.80
P488  2015 10  8  0  0  TRM29659.00        TRM59800.80
P498  2015 10  6  0  0  TRM41249.00        TRM59800.80
SLMS  2015 10  8 19 50  ASH701945B_M       TRM59800.80
USGC  2015 10  7 17  8  ASH701945C_M       TRM59800.80
```

Analysis

BOGT: WLS dNEU -1.21 +- 90.05, -3.66 +- 45.47, 29.76 +- 357.22 mm,
KF dNEU 0.38 +- 1.48, 0.20 +- 1.90, 8.73 +- 6.64 mm .
There is a gap and only two data points in the rapid since the antenna change. Offset does look small.

GMPK: WLS dNEU 1.93 +- 1.72, -3.77 +- 1.01, 10.56 +- 4.57 mm,
KF dNEU 2.02 +- 0.45, -4.03 +- 0.41, 10.10 +- 1.68 mm .
The East offset is very clear in the data.

LMNL: WLS dNEU 2.68 +- 3.09, -7.09 +- 2.05, 2.39 +- 7.51 mm,
KF dNEU 4.34 +- 0.58, -6.27 +- 0.57, 0.91 +- 1.95 mm .
Large gap before antenna is replaced and there is on-going postseismic deformation from the 2012 9 5 M 7.6 earthquake which was 33 km away.

P309: WLS dNEU 8.00 +- 1.33, -4.62 +- 9.12, 8.25 +- 15.90 mm,
KF dNEU 7.28 +- 0.42, -1.87 +- 0.42, 4.02 +- 1.54 mm
North offset is very clear in the data.

P566: WLS dNEU -3.50 +- 0.81, 3.60 +- 1.06, 3.26 +- 5.32 mm,
KF dNEU -3.87 +- 0.30, 3.19 +- 0.28, 4.07 +- 1.04 mm
Gap in data before antenna was replaced. Visually, the north rate seem to change after the swap but this is probably due to systematics in the time series.

ALBH WLS dNEU 1.17 +- 0.29, -0.58 +- 0.51, 26.88 +- 1.53 mm,
KF dNEU 1.96 +- 0.43, -0.64 +- 0.36, 25.76 +- 1.26 mm
For these estimates we used the NMT rapid analysis because these results were generated with the correct antenna models.

LL01 WLS dNEU 2.82 +- 5.70, 0.88 +- 3.58, 6.29 +- 14.95 mm,
KF dNEU 4.58 +- 0.48, 0.16 +- 0.44, 0.17 +- 1.75 mm
North offset is clear in the data. There are missing days of data at this site.

P030 WLS dNEU 5.49 +- 0.60, -2.58 +- 1.23, 7.68 +- 5.61 mm,
KF dNEU 5.85 +- 0.31, -2.57 +- 0.27, 6.24 +- 1.03 mm
Very clear offset in North.and East.

P244 WLS dNEU 1.92 +- 3.24, -6.10 +- 2.25, 0.49 +- 23.38 mm,

KF dNEU   1.92 +- 0.61, -6.10 +- 0.53,   0.46 +- 2.23 mm
The east break is clear in the data but while looking at this break there was another break on 2015 9 9.
The WLS and KF estimates of offset are
WLS dNEU   0.20 +- 2.05, -4.50 +- 1.40,   3.99 +- 14.69 mm,
KF dNEU   -0.78 +- 0.42, -4.77 +- 0.37, -4.25 +- 1.57 mm
Again the east offset is clear in the data. We have added this break to the All_PBO_unkn.eq file.
VTD9 WLS dNEU   0.87 +- 3.47,   0.42 +- 2.19,   5.15 +- 15.42 mm,
KF dNEU   1.86 +- 0.71, -0.24 +- 0.58,   6.49 +- 2.40 mm
There is a large gap (from 05/05/2015) before data becomes available with the new antenna. There are only 7 rapid values available to estimate the break.

CRO1 WLS dNEU   -6.43 +- 13.71,   4.37 +- 13.88, -3.86 +- 19.81 mm,
KF dNEU   -6.27 +- 0.84,   8.04 +- 0.94, -3.60 +- 3.80 mm
There are results with incorrect meta data used which appear as outliers in the time series. Currently there are only a few rapid values to determine the offset.
P487 WLS dNEU   3.09 +- 0.62, -1.52 +- 0.76,   7.19 +- 3.55 mm,
KF dNEU   3.02 +- 0.29, -1.67 +- 0.30,   5.05 +- 1.18 mm
Offsets appear to be significant especially in the north component.
P488 WLS dNEU   -0.80 +- 0.69,   0.07 +- 0.71,   4.23 +- 3.90 mm,
KF dNEU   -0.77 +- 0.31,   0.02 +- 0.30,   1.19 +- 1.24 mm
In this case, the offset with the antenna change does not appear significant.
P498 WLS dNEU   -2.97 +- 2.34,   1.31 +- 0.83, 22.18 +- 2.90 mm,
KF dNEU   -0.73 +- 0.41,   2.42 +- 0.29, 18.84 +- 1.09 mm
There are systematic post-seismic motions and after-shocks that make the resiudals systematic. The east and up components can be seen in the time series.
SLMS WLS dNEU   -3.51 +- 2.86,   0.15 +- 1.49, 11.17 +- 4.09 mm,
KF dNEU   -2.38 +- 0.33,   0.40 +- 0.29,   8.81 +- 1.06 mm
Within the systematics, these offsets are so clear.
USGC WLS dNEU   4.45 +- 2.65, -2.84 +- 2.10,   6.07 +- 4.98 mm,
KF dNEU   5.54 +- 0.27, -2.61 +- 0.25,   3.43 +- 0.88 mm
North offset is clear in the time series; east and up are not so clear.

The only "unknown" offset added this quarter was due to metadata updates. These are given in the advisory section added by MIT to the GAGE GPS AC product log (see next section)

MIT issued advisories

MIT added advisories to the GAGE GPS AC product log. These are given here in reverse chronological order as they appear in the log (most recent entries first).

12/31/2015	MIT	User Advisory	Site P222 results	On 2015/12/17 (GPS week 1875 day 4) the antenna at site was changed and this results in another small offset which can be associated with the antenna change. See note below

				concerning metadata error at this site.
12/21/2015	MIT	User Advisory	Site ATW2 results	Analysis of the PBO time series for site ATW2 show large scatter after an antenna change on 2015/11/12. The NMT analysis after this data do not show any problem and noise can be traced to poor (40-100 mm) RMS scatter of the CWU analyses.
12/21/2015	MIT	User Advisory	All final and later products (suppl) time series and SINEX files.	Starting Week 1849 (2015/06/14), 2nd order ionospheric delay corrections started being applied to the GAGE analyses to make the processing consistet with the ITRF2014 IGS processing models. The application of this model may have induced a ~0.5 ppb (3 mm) height offset into the PBO products. The exact magnitude of this change and the consistency between the CWU and NMT processing with model applied is being investigated. Preliminary results from the IERS ITRF2014 combinations suggest this change might be expected between ITRF2008 and ITRF2014.
11/28/2015	MIT	User Advisory	All SINEX and position time series products between 2013/01/06 and 2014/03/22 (GPS weeks 1722-1784)	A block of GAGE analysis is being repeated to fix some deficiencies in the original analyses carried in 2013 and early 2014. The reprocessing period is 2013/01/06-2014/03/22 (GPS weeks 1722-1784) for CWU and 2013/04/07-2013/05/04 (GPS weeks 1735-1738) for NMT. The reprocessing will correct noisy results in height estimates during this period. SINEX files and time series will be re-generated and during the few days needed to re-combine all the reprocessed results there could be a blend of old and new processing results in the GAGE time series. The recombined shoudl be completed by 2015/12/01. These solutions are denoted with Soln code rern6 in the time series files.
11/28/2015	MIT	User Advisory	P222 position time series	An antenna metadata error was discovered at site P222 in mid-October 2015. The error in the meta data (wrong antenna type) had been present since 2005/03/10 when the site was installed. The antenna error was corrected by the ACs starting 2015/10/25 (GPS week 1868) which results in an offset in the time series of ~20 mm up even though there was no change in equipment at the time. The offset at this date will go away after the next GAGE reprocessing which is expected sometime in mid-2016.

Note on the 2015 PBO Velocity field to Week 1870 2015-11-14

This note is part of the velocity submission sent to Unavco on Dec 23, 2015 describing the generation of the latest GAGE full SINEX combination velocity field. Table numbers here appear as they did in the original note.

The complete analysis of the full GAGE velocity field generated from SINEX files (i.e., incorporating full variance covariance matrices and allowing re-alignment of the reference frame for the velocity field) is now being released. The number of sites in these solutions has grown so large that the run-time has become excessive and we are now generating these velocity solutions using a network approach similar to the methods used to create networks for GAMIT processing of large networks. The process noise models, in the form of random walk time-step variances or process noise (RWPN) are given in All_PBO.rw. These values are generated by analysis of the position residuals from fitting the time series for each site. Sites that have process noise values greater than 100.0 mm^2/yr are not included in this velocity solution so that they do not contaminate nearby sites. Seven sites are excluded based on this criterion (AC30, AV05, BOMG, P323, P656, SMM1, TNMZ). Most of these sites have a combination of large systematics and/or short durations of valid data. We also impose a minimum RWPN value of 0.05 mm^2/yr. 563 sites have computed RWPN values less than this value.. The process noise statistics are generated from the time series using the GAMIT/GLOBK script sh_gen_stats based on tsfit fits to the time series with the realistic sigma algorithm used to account for correlated noise. The tsfit solution also generates a list of site position estimates not to be used in the velocity solution because they are outliers (either due to bad analyses, antenna failures or snow on antennas). The current list of edited site position estimates is given in All_PBO_edits.eq. These edits can by AC or for both ACs. The total GAGE time series contain 7418670 station-days. The outlier criteria remove 8339 (0.11%) of NMT and 31372 (0.42%) of CWU station-days of solutions. Because of the long run time of these SINEX velocity solutions, they are currently run using day 3 of each week (i.e., one day per week). When the correlated noise models are used including the additional days of the week has little effect on the estimates of the velocities or their standard deviations i.e., comparison of results from different days of the week or using all seven days in the week show differences small compared the standard deviations of the estimates.

The processing divides the ~2137 sites analyzed into 29 networks each with approximately 77 site locations. (The final number of estimated parameters for each network depends on the number of breaks needed at each site. The networks need from 99 to 288 individual site names to accommodate the discontinuities). There is no overlap between the sites in the first 28 networks. A 29th network is created to tie all the other 28 networks into a single solution. To form the sites in the 29th network, three sites for each network are chosen so as to minimize the trace of the covariance matrix of the estimates of rotation and translation using these sites. Weights assigned to each site in accord with the expected variance of the velocity estimate for the site (i.e., combination of the RWPN and duration of data at the site). If equal weights are given to each site, this algorithm is the same as choosing the three sites that cover the largest area. The details of the sites in each network are given in All_PBO_netsel.use. The analyses of the 29 networks can be run in parallel and takes a few hours to run. The combination of the 29 networks uses ~9

Gbytes of memory and the NMT and CWU combination, along the equating of velocities (with a constraint of ±0.01 mm/yr) at sites with discontinuities takes about a day of CPU time. The NMT and CWU velocity solutions are then merged to form the PBO solution combined solution. This combination uses ~18Gb of memory. The velocity combinations use loose constraints and we align the reference frame as we wish at the end of the combination. We generate four reference frame realizations: (1) A North America frame aligned to our current NAM08 frame using ~1072 sites in our hierarchical list of reference frame sites; (2) A North America frame aligned to IGb08 rotated into the North America frame using the 37 sites original used in ITRF2008 to define the North America plate and (3) and (4) are the same as (1) and (2) except the reference velocities are in a NNR reference frame.

The full GLOBK SINEX velocity solution allows us to re-align the reference frames based on the combination of all of the data collected between 1996 and current day (2015-11-14 GPS Week 1870 for this analysis). The time series analyses for velocities is much faster but the daily solutions need to be aligned the reference frame each day based on an earlier realization of the frames. The current NAM08 frame was originally aligned to the reference frame using data through August of 2014 -- about a year and half ago. Tables 1 and 2 compare the WRMS and NRMS scatters of the differences between the velocity estimates obtained by the two GAGE ACs and the combination of the two ACs using different analysis methods. Table 1's caption explains the naming scheme used to describe the solutions. There are the three analysis centers, NMT, CWU and their combination PBO. The velocity estimates are generated with three different methods (1) GLOBK SINEX combinations, GK (2) time series analyses using weighted least squares (LS) and (3) time series analyses using a Kalman filter of the time series (KF). The time series LS analysis is the one that generates the monthly GAGE SNAPSHOT fields. The GK analysis can be aligned to the current NAM08 frame (NA) or be realigned to the IGb08 frame (IG). In all analyses, the same process noise models, discontinuities and post-seismic non-linear models (based on time series analyses) are used. The comparisons do not re-align the velocity fields in any way. The RMS values are based on the simple difference between the estimates. The numbers of stations do not match between the analyses because the GK analyses exclude sites with large process noise values. Tables 3 and 4 show the same type of comparison when we restrict the sites to the best 706 in the solution. The NRMS values are very consistent with those in Tables 1 and 2 suggesting that even the sites with the smallest sigma match in accordance with their sigmas.

Over all the agreement between the different methods of estimating the velocities are very good with the WRMS difference in the NE components typically <0.2 mm/yr (including comparison to the PBO 2014 velocity solution) and in height less than 0.7 mm/yr. The NRMS scatter of the differences is typically less than unity showing that the error bars are of the somewhat larger than the differences. The comparison to 2014 solution does have NRMS values a little larger than unity.

The official PBO velocity solution is aligned to our current NAM08 frame to keep consistency of the results and to avoid discontinuities. The current IGb08 is now about

5-years old and will soon be replaced by ITRF2014 (probably early 2016). When the new ITRF is released, we will then re-evaluate aligning to the new ITRF.

Table 1: Comparison of North and East velocities between different velocity field determination methods. No transformation parameters between the fields have been estimated. The codes for the solutions are: CCC_TTYY where CCC is the center NMT, CWU or the combined PBO analysis; TT is the type of analysis:
GK – GLOBK Kalman filter; TS – time series fit; and YY is combination of method and reference frame: LS – least squares, KF – Kalman filter; NA – NAM08, IG – IGb08 rotated to NA. The final entry PBO_2014 is the current PBO full solution generated in November 2014. # is the number of common sites in the solutions.

Soln1 - Soln2	#	N mean (mm)	N WRMS (mm)	N NRMS	E mean (mm)	E WRMS (mm)	E NRMS
PBO_GKNA-CWU_GKNA	2130	-0.01	0.06	0.259	-0.00	0.06	0.262
PBO_GKNA-NMT_GKNA	2136	0.01	0.05	0.221	-0.00	0.05	0.246
CWU_GKNA-NMT_GKNA	2129	0.01	0.10	0.461	0.00	0.11	0.495
PBO_GKNA-PBO_TSLS	2137	-0.01	0.14	0.821	0.00	0.14	0.817
PBO_GKNA-PBO_TSKF	2130	-0.01	0.15	0.800	0.00	0.14	0.750
PBO_GKNA-CWU_TSLS	2130	-0.00	0.15	0.879	-0.00	0.15	0.891
PBO_GKNA-CWU_TSKF	2123	-0.01	0.16	0.804	-0.00	0.15	0.765
PBO_GKNA-NMT_TSLS	2136	-0.00	0.16	0.955	0.00	0.16	0.957
PBO_GKNA-NMT_TSKF	2128	-0.02	0.17	0.876	-0.00	0.16	0.841
PBO_GKNA-PBO_GKIG	2137	-0.01	0.07	0.333	0.22	0.24	1.096
PBO_GKNA-CWU_GKIG	2130	-0.03	0.10	0.460	0.22	0.25	1.149
PBO_GKNA-NMT_GKIG	2136	-0.01	0.08	0.369	0.20	0.23	1.067
PBO_GKNA-PBO_2014	2066	-0.03	0.19	1.163	-0.00	0.20	1.169

Table 2: Similar to Table 1 except here the mean horizontal velocity (HzMean, HzWRMS, HzNRMS) and vertical velocity (U columns) are compared.

Soln1 - Soln	#	Hz Mean (mm)	HzWRMS (mm)	HzNRMS	U Mean (mm)	U WRMS (mm)	U NRMS
PBO_GKNA-CWU_GKNA	2130	-0.00	0.06	0.261	0.04	0.24	0.349
PBO_GKNA-NMT_GKNA	2136	0.00	0.05	0.234	-0.03	0.18	0.272
CWU_GKNA-NMT_GKNA	2129	0.01	0.10	0.478	-0.07	0.40	0.593
PBO_GKNA-PBO_TSLS	2137	-0.00	0.14	0.819	0.03	0.42	0.769
PBO_GKNA-PBO_TSKF	2130	-0.01	0.15	0.775	0.12	0.49	0.847
PBO_GKNA-CWU_TSLS	2130	-0.00	0.15	0.885	-0.00	0.50	0.892
PBO_GKNA-CWU_TSKF	2123	-0.01	0.15	0.785	0.07	0.51	0.870
PBO_GKNA-NMT_TSLS	2136	-0.00	0.16	0.956	-0.27	0.66	1.177
PBO_GKNA-NMT_TSKF	2128	-0.01	0.17	0.859	-0.34	0.70	1.197
PBO_GKNA-PBO_GKIG	2137	0.10	0.18	0.810	-0.24	0.27	0.398
PBO_GKNA-CWU_GKIG	2130	0.10	0.19	0.875	-0.19	0.32	0.465

PBO_GKNA-NMT_GKIG	2136	0.10	0.17	0.799	-0.30	0.38	0.560
PBO_GKNA-PBO_2014	2066	-0.02	0.19	1.166	-0.05	0.55	1.008

Table 3: Comparison of North and East velocities similar to Table 1 except we limit the sites to those that have horizontal and vertical velocities sigmas both less than the median horizontal and vertical velocity sigmas. (Reason there are less than 1065 sites is because both horizontal and vertical sigma conditions must be satisfied.)

Soln 1- Soln 2	#	N mean (mm)	N WRMS (mm)	N NRMS	E mean (mm)	E WRMS (mm)	E NRMS
PBO_GKNA-CWU_GKNA	706	-0.01	0.04	0.229	-0.00	0.04	0.257
PBO_GKNA-NMT_GKNA	706	0.01	0.03	0.207	-0.00	0.04	0.245
CWU_GKNA-NMT_GKNA	706	0.01	0.07	0.425	0.00	0.08	0.494
PBO_GKNA-PBO_TSLS	706	-0.01	0.10	0.786	0.01	0.09	0.738
PBO_GKNA-PBO_TSKF	706	-0.02	0.10	0.721	0.01	0.09	0.613
PBO_GKNA-CWU_TSLS	706	-0.01	0.10	0.826	0.01	0.10	0.772
PBO_GKNA-CWU_TSKF	706	-0.02	0.10	0.707	0.01	0.09	0.602
PBO_GKNA-NMT_TSLS	706	-0.01	0.10	0.847	0.01	0.10	0.774
PBO_GKNA-NMT_TSKF	706	-0.02	0.11	0.750	0.01	0.09	0.628
PBO_GKNA-PBO_GKIG	706	-0.00	0.07	0.396	0.22	0.24	1.440
PBO_GKNA-CWU_GKIG	706	-0.02	0.08	0.484	0.23	0.25	1.480
PBO_GKNA-NMT_GKIG	706	0.00	0.07	0.420	0.21	0.23	1.403
PBO_GKNA-PBO_2014	706	-0.03	0.11	0.903	0.01	0.12	0.967

Table 4: Same as Table 3 except for the combined horizontal and vertical comparison.

Soln 1- Soln 2	#	Hz Mean (mm)	HzWRMS (mm)	HzNRMS	U Mean (mm)	U WRMS (mm)	U NRMS
PBO_GKNA-CWU_GKNA	706	-0.00	0.04	0.243	0.02	0.16	0.318
PBO_GKNA-NMT_GKNA	706	0.00	0.04	0.227	-0.02	0.13	0.260
CWU_GKNA-NMT_GKNA	706	0.01	0.07	0.461	-0.04	0.28	0.561
PBO_GKNA-PBO_TSLS	706	-0.00	0.09	0.763	-0.02	0.30	0.741
PBO_GKNA-PBO_TSKF	706	-0.00	0.10	0.670	0.07	0.37	0.861
PBO_GKNA-CWU_TSLS	706	-0.00	0.10	0.799	-0.06	0.35	0.828
PBO_GKNA-CWU_TSKF	706	-0.00	0.10	0.657	0.01	0.37	0.842
PBO_GKNA-NMT_TSLS	706	-0.00	0.10	0.811	-0.24	0.55	1.303
PBO_GKNA-NMT_TSKF	706	-0.01	0.10	0.692	-0.29	0.58	1.328
PBO_GKNA-PBO_GKIG	706	0.11	0.18	1.056	-0.23	0.25	0.497
PBO_GKNA-CWU_GKIG	706	0.11	0.19	1.101	-0.19	0.26	0.508
PBO_GKNA-NMT_GKIG	706	0.11	0.17	1.036	-0.28	0.33	0.659
PBO_GKNA-PBO_2014	706	-0.01	0.12	0.936	-0.07	0.36	0.882

Note on Scale

This document was submitted to UNAVCO describing scale issues and the treatment of scale by different analysis groups.

Script updates

No major changes have been to the scripts.

GAMIT/GLOBK Community Support

During this quarter our primary effort has been to continue the modifications to GAMIT to allow processing of two-frequency observations from satellites of any single GNSS. As noted in our October report, we completed by September Phase 1 of the modifications, adding the book-keeping to tables, internal data file formats, and ~60 subroutines to include the variable indicating which GNSS is being processed (G, R, C, E, J, I), and adding the ability to read RINEX 3 observation files. Between October and December, we added the ability to read RINEX 3 navigation files, modified our code to account for unique aspects of Glonass observations, and added a yaw model for Beidou. Testing of these changes is underway.

We continue to spend 5-10 hours per week in email support of users. During the quarter we issued 18 royalty-free licenses to educational and research institutions.