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: 2015/07/01-2015/09/30

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Summary

Under the GAGE Facility Data Analysis subcontract, MIT has been combining results from the New Mexico Tech (NMT) and Central Washington University (CWU). In this report, we show analyses of the data processing for the period 06/15/2015 to 09/12/2015, time series velocity field analyses for the GAGE reprocessing analyses (1996-2015), earthquake effects during the interval (only one detected event that effected only one site, M6.9 73km SSW of Nikolski at 2015 07 27 05 50, effected AB02), position offsets from antenna changes, comparison between results from the previous quarter. Because the quarterly reports are due near the start of the month and the data used in the finals processing has an age between 2-3 weeks, early in the month the finals results the last two weeks of the previous month are not available. For this quarter the last finals results were for September 12, 2015. No new "bad" sites were added this quarter. Currently there are 94 sites in the list. We have retained the list and explanation from previous quarters for completeness of this report. 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 1925 sites were processed compared to 1917 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: June 15, 2015 and September 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 June 15, 2015 and September 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 PBO east components. The up RMS scatters are less than or equal 4.6 mm and as low as 4.4 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 June 15, 2015 and September 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	4.4
NMT	0.8	0.9	4.5
CWU	1.1	0.9	4.6
70%			
PBO	1.0	1.0	4.4
NMT	1.0	1.1	4.6
CWU	1.3	1.1	5.2
95%			
PBO	1.7	1.7	6.3
NMT	1.6	1.8	6.6
CWU	2.0	2.0	7.8

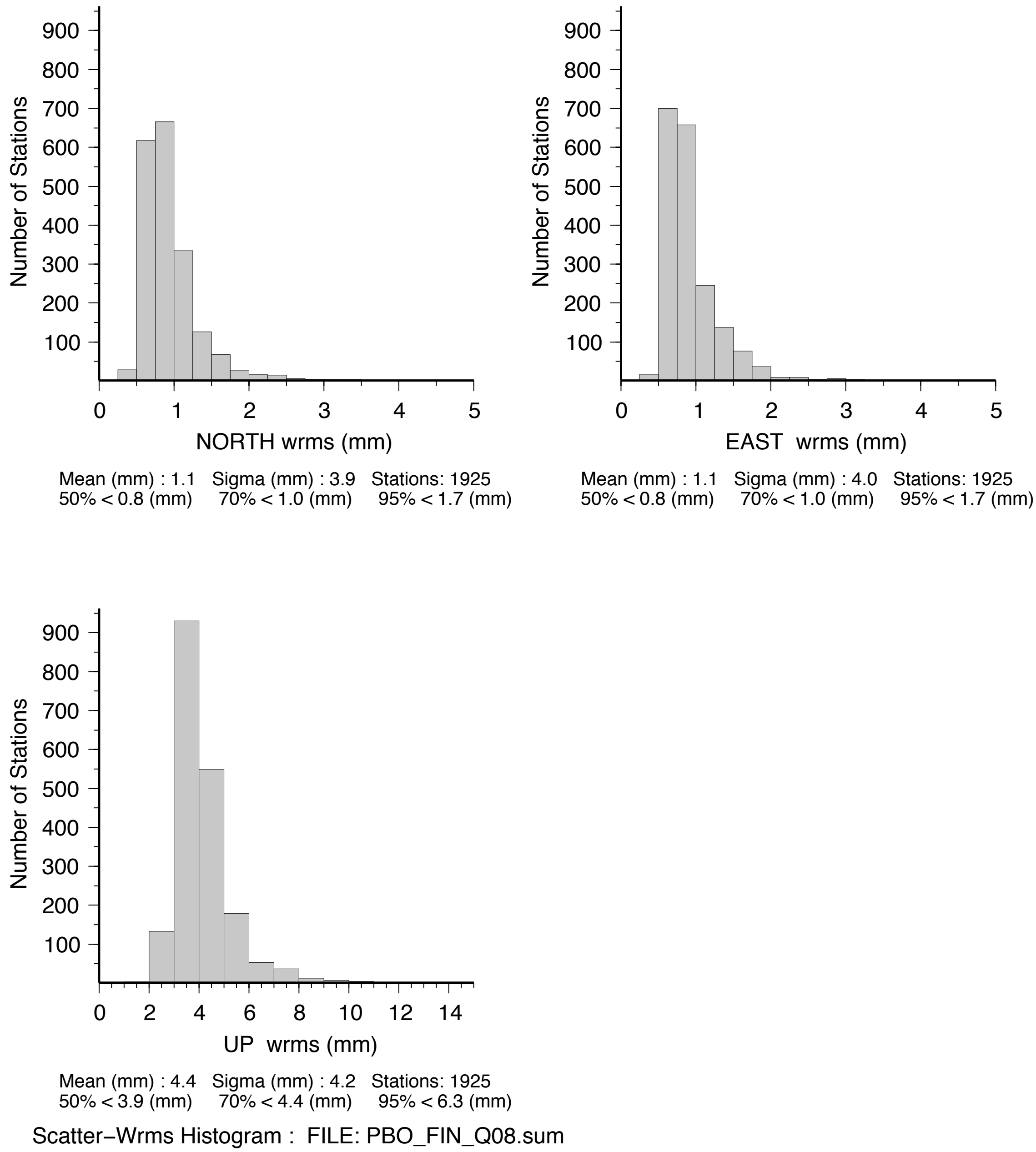

Figure 1: PBO combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1925 sites analyzed between June 15, 2015 and September 12, 2015. Linear trends and annual signals were estimated from the time series.

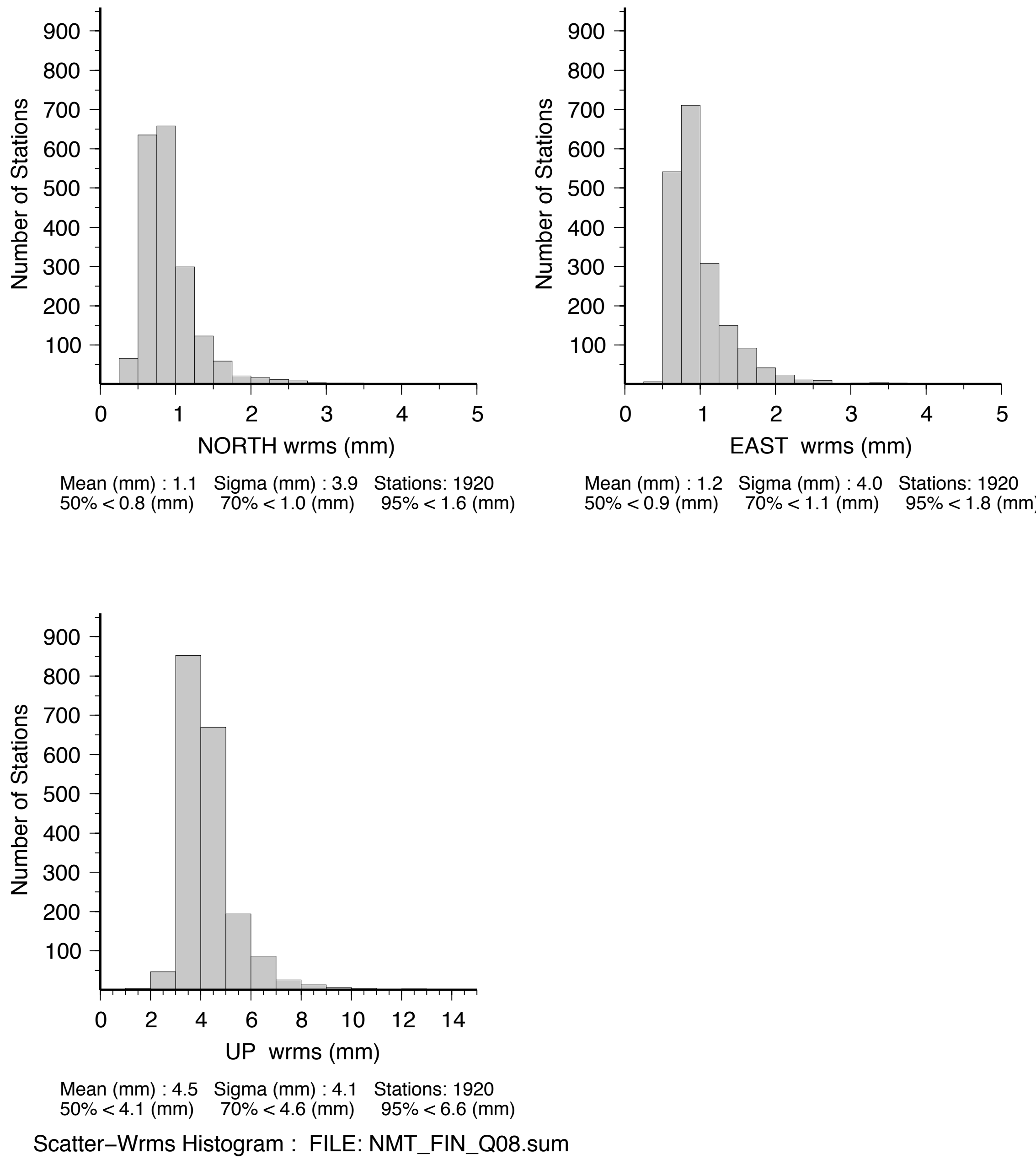

Figure 2: NMT combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1922 sites analyzed between June 15, 2015 and September 12, 2015. Linear trends and annual signals were estimated from the time series.

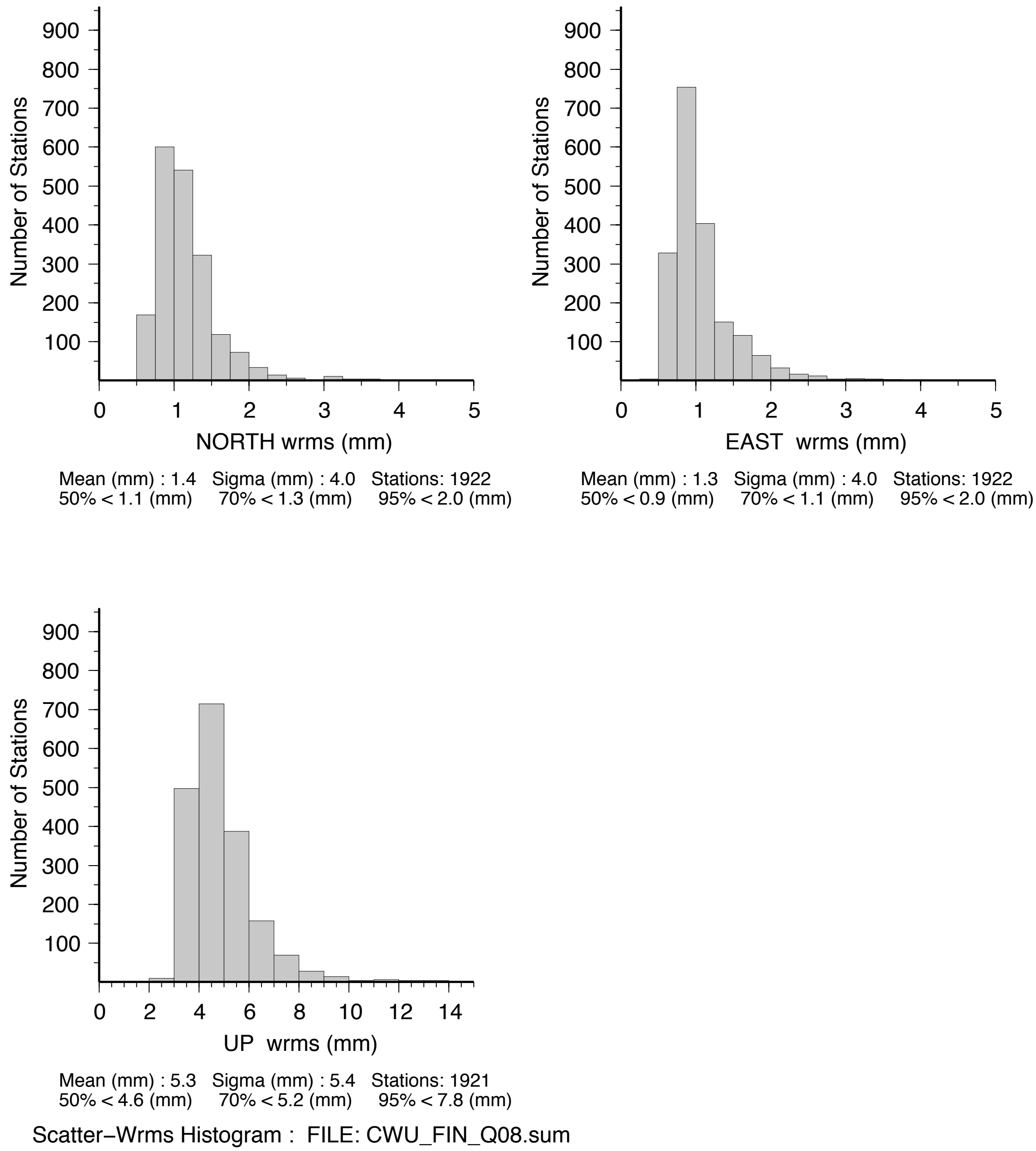

Figure 3: CWU combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1920 sites analyzed between June 15, 2015 and September 12, 2015. Linear trends and annual signals were estimated from the time series.

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_Q08.tab. There are 1925 sites in the file. The contents of the files is of this form:

```
Tabular Position RMS scatters created from PBO_FIN_Q08.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     90      1.0   0.53      1.6   0.86     5.8   0.77     12.39
 1NSU     90      0.9   0.50      1.4   0.74     4.6   0.61     11.66
 1ULM     90      1.1   0.63      0.9   0.54     4.6   0.65     12.25
 7ODM     90      0.9   0.49      0.7   0.43     4.3   0.62     14.40
 …
 ZDC1     90      1.1   0.54      0.8   0.47     5.2   0.70     12.28
 ZDV1     90      0.8   0.39      0.8   0.44     4.2   0.60     12.28
 ZKC1     90      1.0   0.51      0.8   0.45     4.7   0.65     12.28
 ZLA1     90      1.0   0.49      1.0   0.54     4.5   0.58     12.28
 ZME1     90      1.2   0.57      1.2   0.64     5.8   0.72     12.50
 ZMP1     90      0.7   0.36      0.9   0.52     4.4   0.62     12.75
 ZNY1     90      1.0   0.51      0.9   0.53     4.7   0.63     12.66
 ZSE1     90      0.8   0.36      0.6   0.38     4.0   0.54     12.66
 ZTL4     90      1.2   0.62      1.3   0.68     5.5   0.69     12.85
```

Table 2: RMS scatter of the position residuals for the PBO combined solution between June 15, 2015 and September 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	0.8	0.7	3.9	886
NUCLEUS	0.7	0.7	3.6	209
USGS SCIGN	0.8	0.8	4.0	131
Expanded	1.0	0.9	4.3	588
GAMA	0.9	0.9	4.7	13
COCO Net	1.3	1.5	6.0	98
70 %				
PBO	0.9	0.9	4.0	
NUCLEUS	0.8	0.8	3.9	
USGS SCIGN	0.9	1.0	4.4	
Expanded	1.1	1.1	4.7	
GAMA	0.9	0.9	4.8	
COCO Net	1.6	1.8	7.2	
95%				
PBO	1.6	1.5	5.3	
NUCLEUS	1.3	1.2	5.1	
USGS SCIGN	1.4	1.4	5.4	
Expanded	1.6	1.7	6.4	
GAMA	1.0	1.1	5.8	
COCO Net	3.0	4.6	11.3	

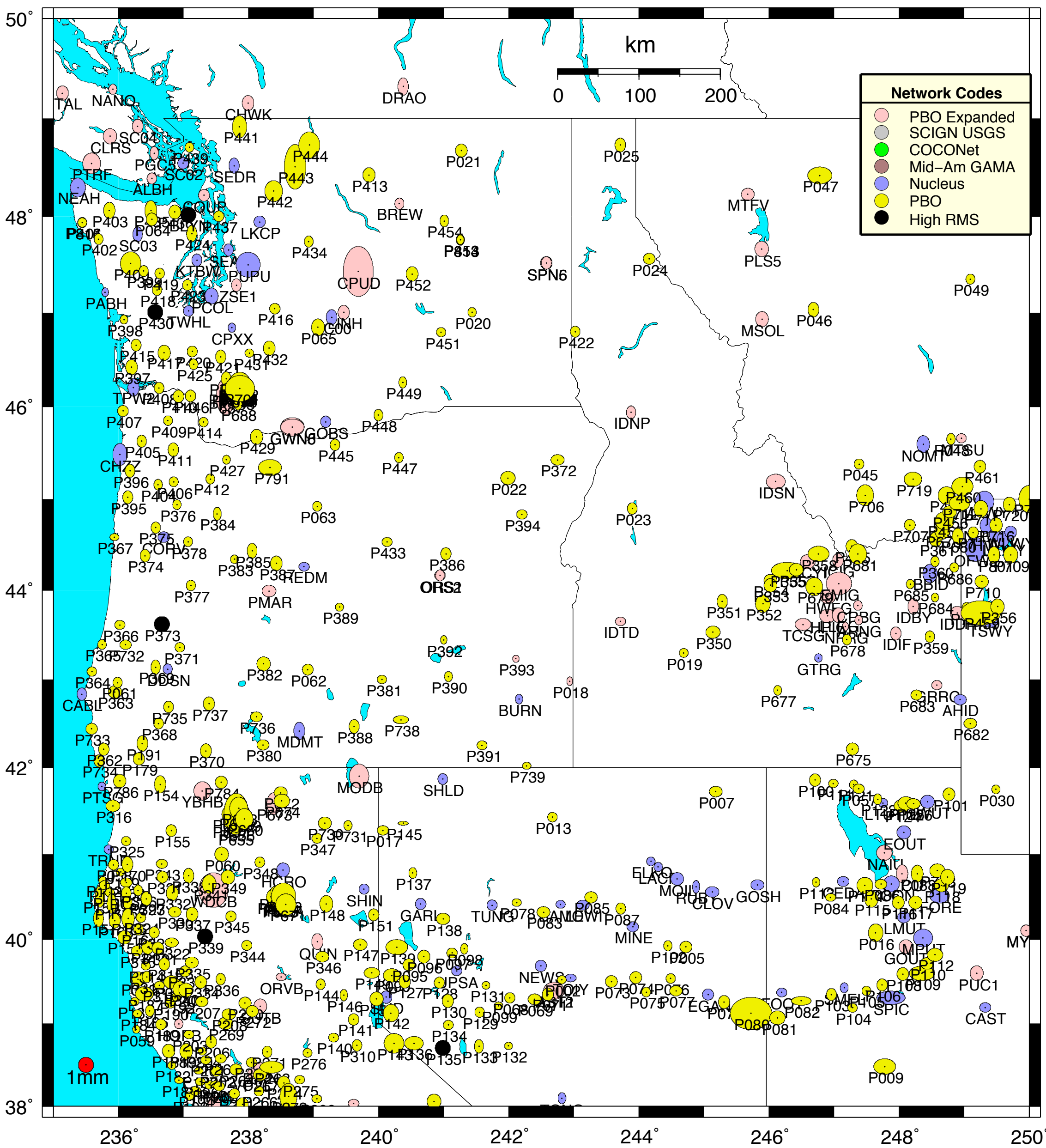

Figure 4: Distribution of the RMS scatters of horizontal position estimates from the PBO combined analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the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

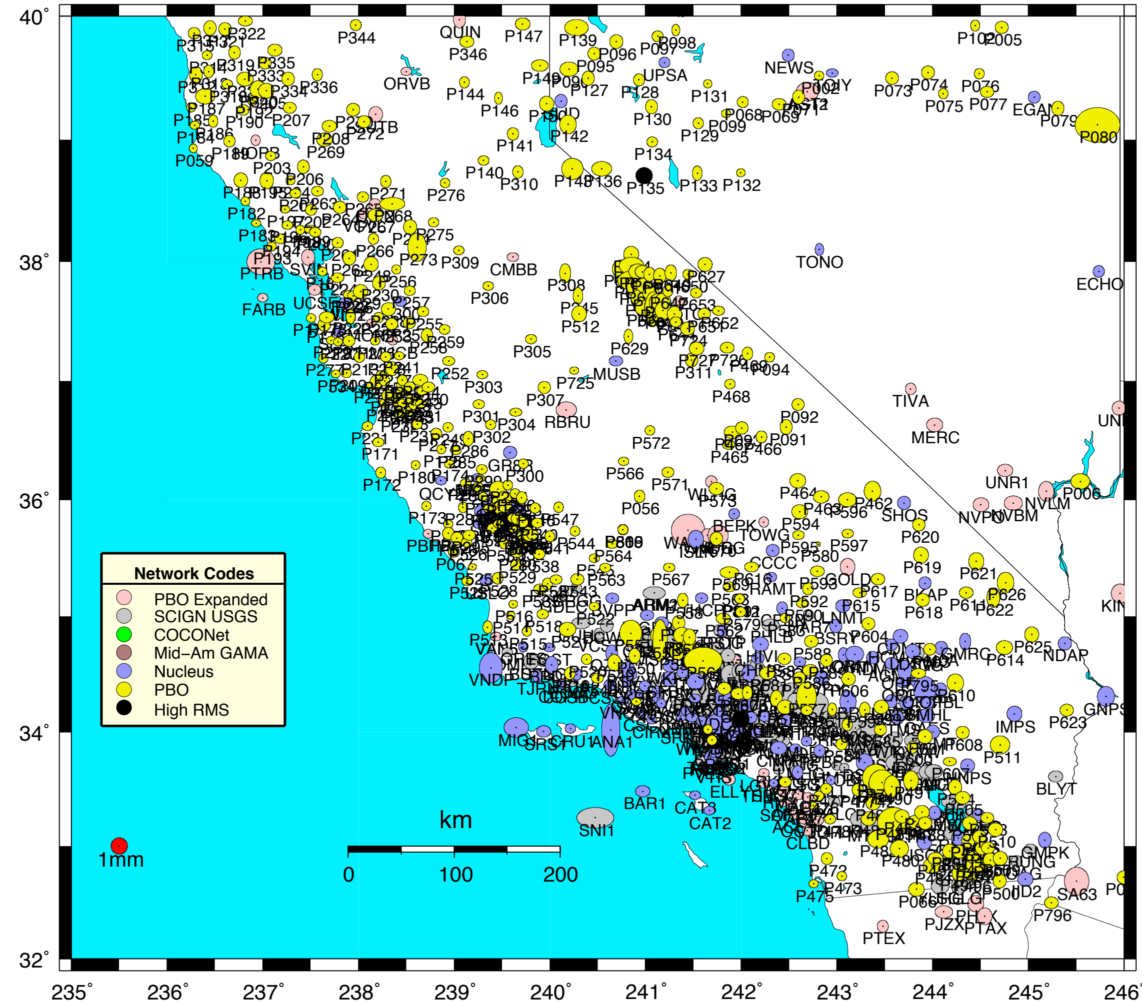

Figure 5: Same as Figure 4 except for the Southern Western United States. Black circles in the Yucca mountain region have no data during this 3-month period.

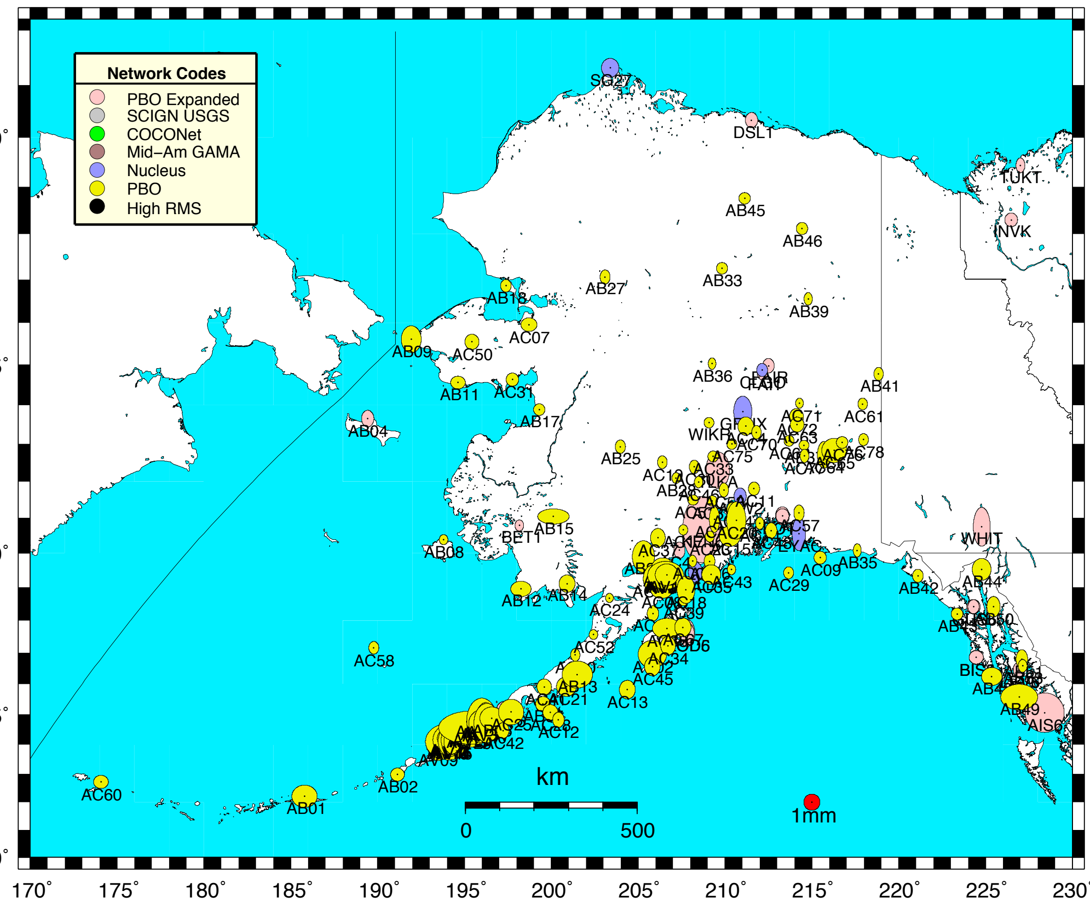

Figure 6: Same as Figure 4 except for the Alaskan region.

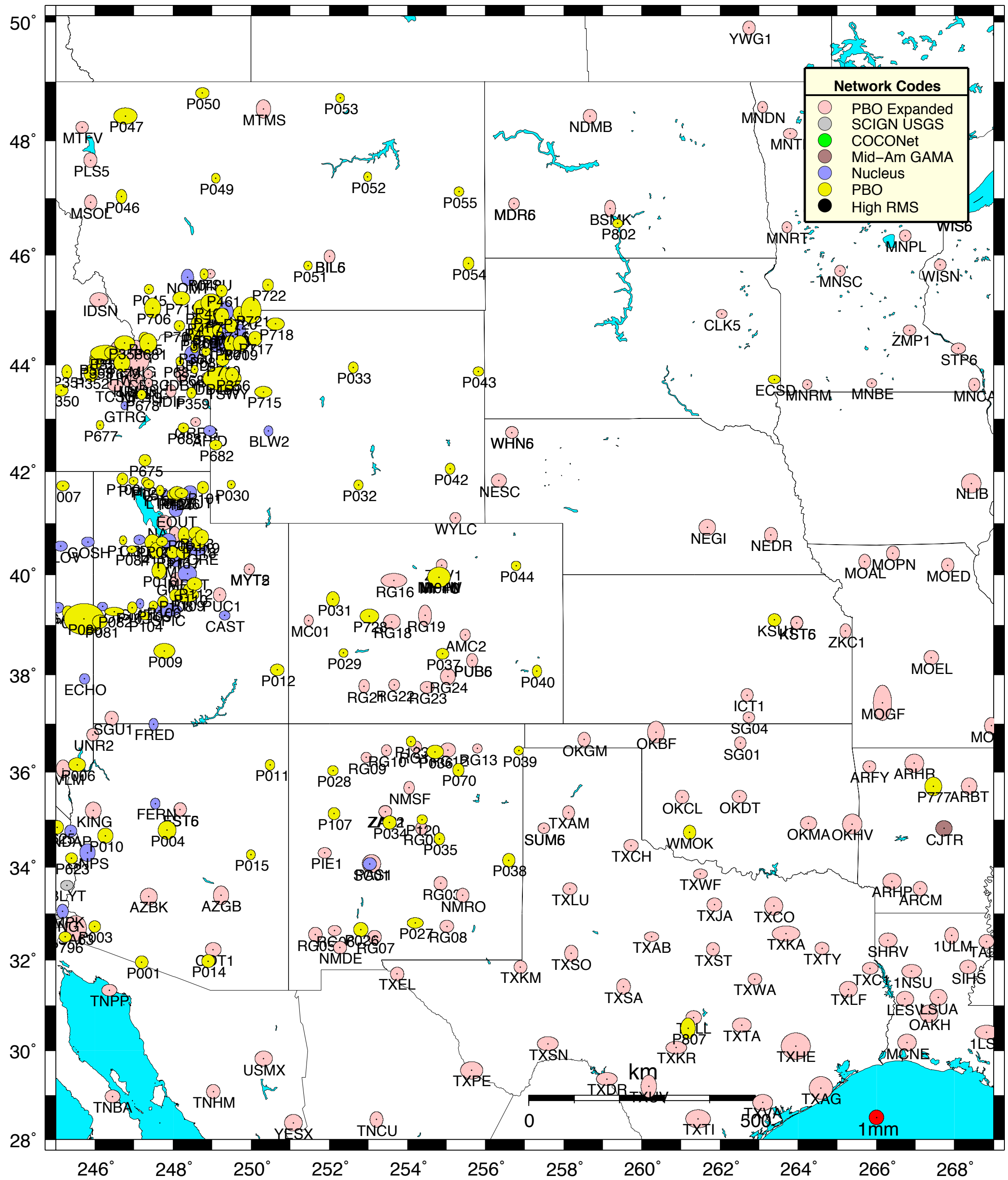

Figure 7: Same as Figure 4 except for the Central United States

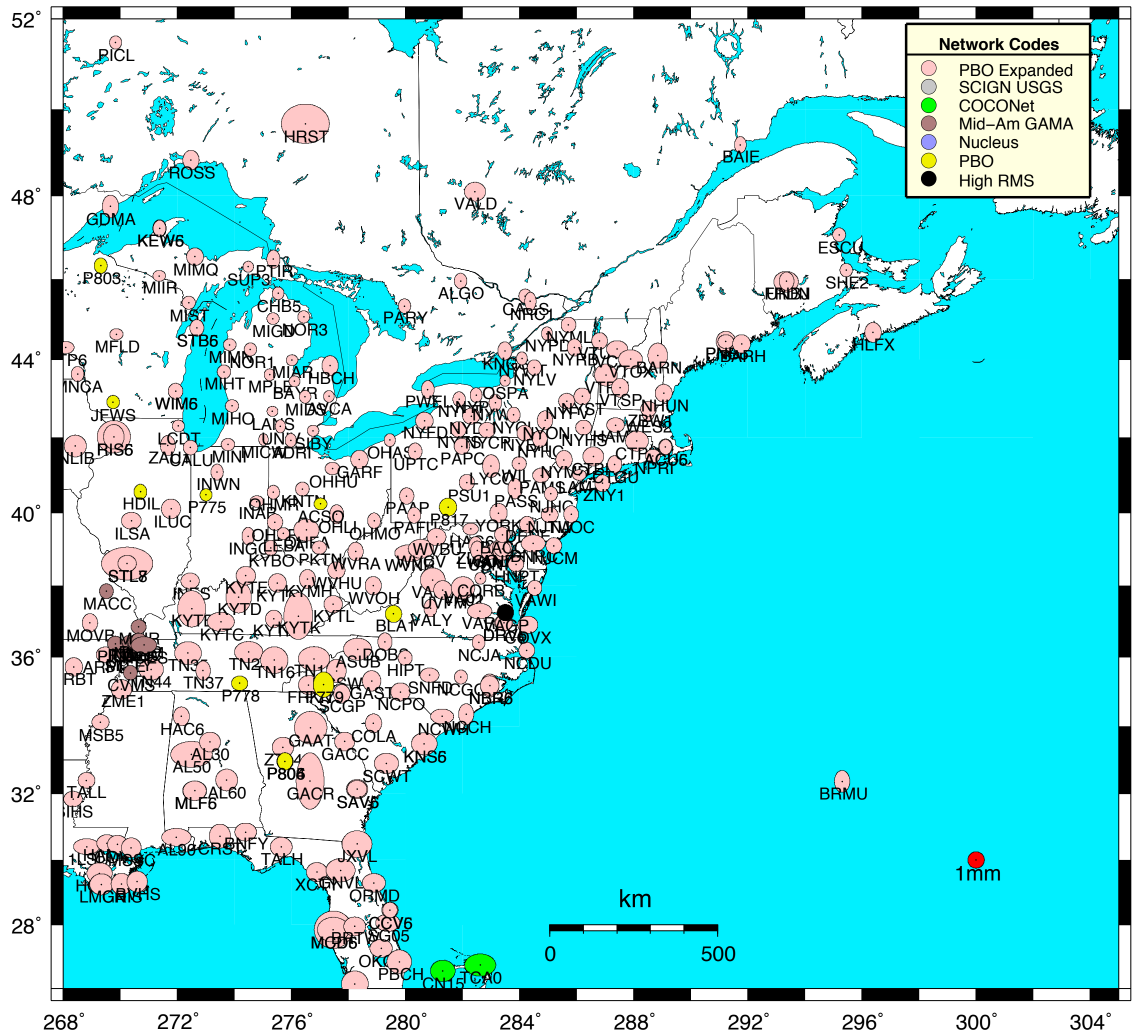

Figure 8: Same as Figure 4 except for the Eastern United States

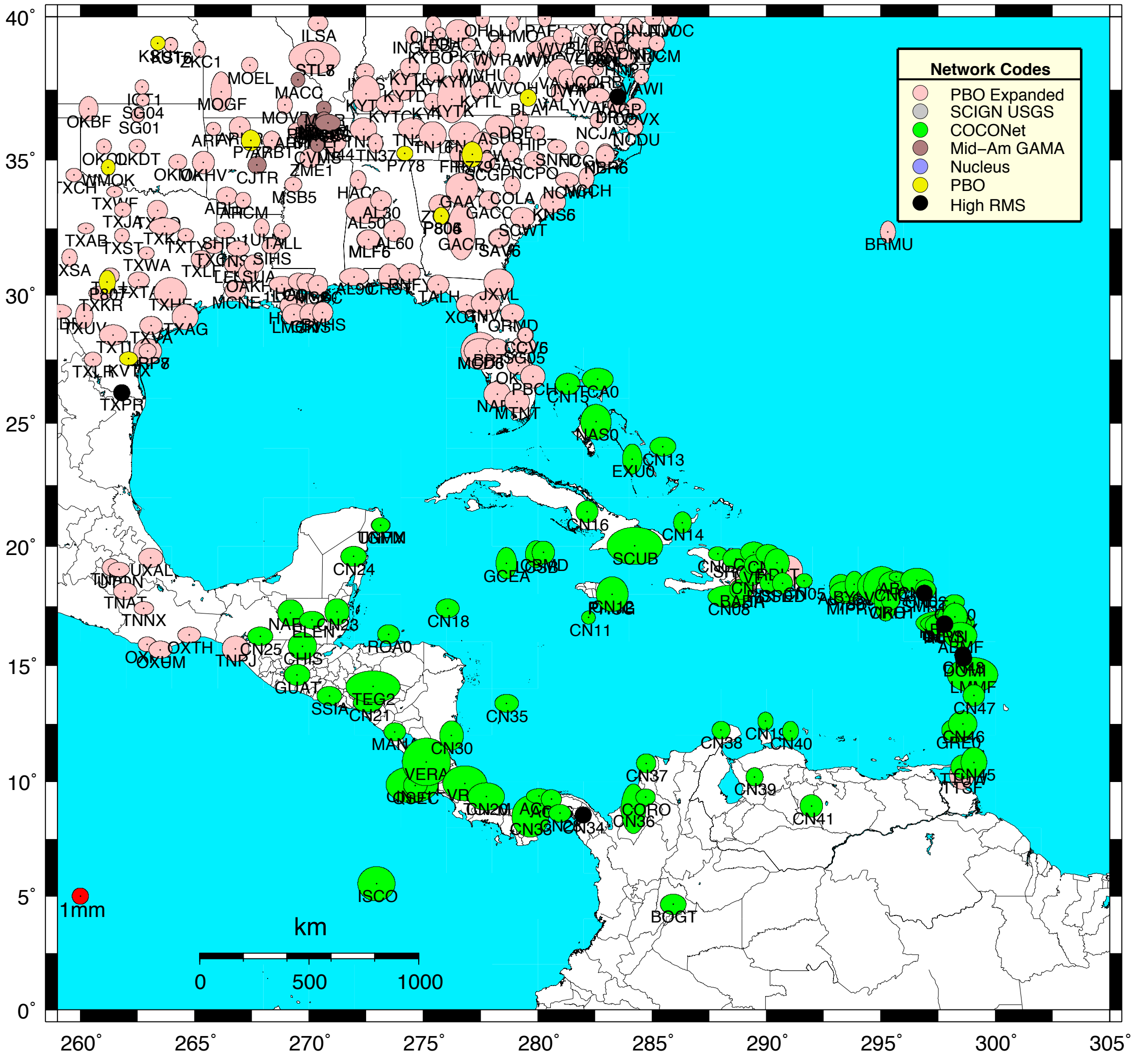

Figure 9: Same as Figure 4 except for the Caribbean region.

Analysis of large RMS sites

In Table 3, reproduced from earlier quarters, gives a summary of the qualitative description of the nature of the times series of all the sites with large RMS scatters (black circles shown in Figures 4-9). Snow is often the reason and falls into types: one class where the snow is systematic for a period of time with normal looking results in between and the other class where it is difficult to see any good data in the time series. For example P665 in in first category and P690 is in the second category. For some sites, it is not clear what is happening at the site. No new sites were added this quarter nor have any been removed (analysis is based on long running time series). There are 94 sites in the table.

Table 3: Description of time series characteristics of sites with high RMS scatter (black symbols on figures above)

Long (deg)	Lat (deg)	Site	Description
198.2537	58.9508	AB12	Snow with some periods of OK data
197.3865	66.8584	AB18	Strange long period systematics with excursions in 2008 and 20012 (10-15 mm in east)
209.2560	65.0304	AB36	Strange annual
227.1328	56.5848	AB53	Snow events and may be systematic between events.
215.4762	59.8685	AC09	Evolving Rate change 2012-2013
212.0004	60.8487	AC14	Snow events; NE look flat in between but height may have curvature
211.9068	60.5182	AC16	Snow events; but OK in between but height may have curvature as for AC14 (probably annual)
210.6475	60.9292	AC20	Long period N systematic
212.2608	59.8558	AC30	Little data 2007.7-2009.1 with large gap and snow systematic
209.3149	62.6712	AC33	Snow with flat in between (systematic snow).
209.2068	59.3758	AC35	Long period N and E systematic
207.3761	60.0815	AC47	Generally systematic; long lived snow.
179.3013	51.3781	AC66	Curvature offset 14/06/23
289.1134	41.7433	ACU6	Offset 06/12/21
297.7861	16.7408	AIRS	Multi-year variations
228.4008	55.0689	AIS6	Bi-modal data separated by ~5-10 mm NE, EQ like log 2012/10/28 N, 13/01/06 E offset
297.6595	82.4943	ALRT	Lots of variations, does not quite look like snow but maybe.
264.5149	29.3015	ANG1	Slow event ~22 mm N, 6 mm E between 2004/05/26-2004/06/14, offset near end
210.8677	61.5978	ATW2	Clear E offset from Denali Earthquake, 2002 11 3 22 12, but much larger decadal systematic
262.2437	30.3117	AUS5	Unknown break 2002 10 12
206.5553	59.3626	AV04	Bad snow but flat in between
206.5773	59.3629	AV05	Little data between 2004.6-2005 and 2005.6-2006.1, run off at end
194.1022	54.1531	AV13	Some snow intervals each year
206.5718	59.3474	AV20	Snow; bad winter 2008 and 2010
195.4195	54.5717	AV26	Heavily skewed in U and E
195.2768	54.4924	AV27	Maybe snow. Bad in 2009 winter, systematic 2014.
195.4139	54.4724	AV29	Lots of snow
195.6131	54.8467	AV35	Snow but more random in nature. Looks noisy between snow times.
196.2191	54.8315	AV38	Very skewed in N and U. Unknown break: 2011 6 15 6-7 mm in East.
196.0015	54.8113	AV39	Also skewed, systematic, gap 2010.8-2011.5,
300.3909	13.0880	BDOS	Multi-year trends; E 2007-2011 15 mm

223.5204	58.7829	BMCP	Snow most likely but noisy in nature
244.2703	33.3646	BOMG	Multiyear systematic; break 2011 8 18 (looks slow; EQ Postseismic?); offset at El Mayor Cucapah (10/04/04).
291.9863	46.8684	CARM	Un-modeled breaks
277.7437	9.3517	CN20	Noisy CWU processing; NMT seems OK.
281.9852	8.5489	CN34	Systematic with maybe a tree growing nearby.
240.3261	34.9426	CUHS	Strong loading signal with change around 2011.0
270.3565	35.5414	CVMS	Bad "antenna" 2013/03/18- 2014/02/26. Firm ware update on 2014/02/26; +8N,-12E offset.
298.6109	15.3062	DOMI	Noisy site. NMT missing at start of data.
250.6167	-27.1482	EISL	Noisy site
297.8057	16.7948	GERD	Slow slip 2006 and 2010.
242.6021	34.2039	GHRP	Some snow but slow slip in 2007-2007.5
249.4640	44.6136	HVWY	Multiyear systematic: Yellowstone.
240.9918	34.3985	KBRC	Even with bad antenna between 2002/12/04-2004/05/25 removed, still multiyear systematic.
208.6498	60.6751	KEN5	Strange multimodal positions in N and E.
208.6498	60.6748	KEN6	Similar behavior to KEN5 suggesting motions are real (on same USCG tower apparently).
267.9549	30.2214	KJUN	Maybe bad antenna between 2004/07/29-2005/01/25 but no log entries. Offset at end of data 2008/08/12,
207.8066	57.6177	KOD1	Strange deviations in 1999.1-1999.9.
207.8066	57.6177	KOD5	No overlap with KOD1 but has similar excursion 2012.1-2012.3 (but KOD6 only partially sees event). USCG site
276.2404	37.1515	KYTK	Systematic with bad antenna: 2013/08/12-2014/01/31; then offset
241.7967	33.7878	LBCH	Bad antenna 2000/01/03-2003/02/03 and replaced. Still multiyear systematic.
278.1928	28.8262	LEES	Un-modeled offset 2011/09/15.
249.5998	44.5651	LKWY	Yellowstone multiyear systematic changes
241.9966	34.1119	LONG	Probably a failing antenna starting Jan 2007. CWU having problems processing data.
285.4171	44.6197	LOZ1	Noisy with N U annual (removed late 2013).
247.7532	41.5921	LTUT	Bad antenna from start 2002/10/23-2008/04/18 large annual in all components
273.7510	12.1489	MANA	Large slow slip events in 2004/10 and 2012/08/27+2012/09/05 (fast EQ)
241.7559	33.9391	MHMS	Most likely bad antenna from 2000/01/12 to 2012/02/15 when it was replaced. ASH701945B_M during bad times.
254.7377	39.9954	NISU	Antenna offsets but no log (ends 2009.5).
243.9323	34.1410	OAES	Failed antenna. 1999/03/05-2007/09/11: Maybe

			some data until 2000/10/13.
249.1688	44.4511	OFW2	Long period systematic (Yellowstone)
297.7723	16.7504	OLVN	Skewed in E&U, slow type event in 2009.5
262.3462	16.1512	OXTU	Systematic; 2009.8; break 2012/04/23 (gap) ends early 2013.
239.2898	36.2568	P299	Strong ground water signal in all components.
239.7230	36.3044	P300	Very large multiyear deviations (creep on San Andreas?)
237.0366	39.8457	P323	Starts 2007.6 and fails 2008.0; ends 2008.1
244.2679	32.7597	P494	Washer on antenna until 2011/09/21 when removed (no log entry). Strange height systematic.
240.9996	37.6130	P630	Strong N seasonal with trend change mid-2011.
241.0841	37.6053	P631	Very skewed, strong seasonal all components, trend change 2011.8 dNv 11 mm/yr, dUv 13 mm/yr
241.1833	37.5914	P642	Similar to P631 but not soo skewed. Same rate changes.
241.1800	37.6770	P646	Large systematic in East and Up (±10 mm deviations from linear)
237.8042	41.3448	P656	Large gaps and big snow in 2010, 2011.
238.4742	40.4561	P665	Snow events most years
238.5326	40.4658	P667	Snow events most years
237.8101	46.1800	P690	Snow events: Different in nature to P665 and P667 (more radon and longer % of year)
237.7977	46.2103	P693	Similar to P690 (these sites will be hard to edit)
237.8358	46.1990	P695	Similar to P690 but with long period rate change.
237.8234	46.1876	P697	Similar to P690 but less extreme; long term east variations.
237.7968	46.1898	P699	Similar to P690. Offset in east in mid 2006 (gap) already in All_PBO_unkn.eq file.
249.0664	43.7864	P708	Snow events most years but could be edited (similar to P665)
249.4885	44.7183	P716	Long-term curvature in NE from 2006-2014. Change in rate after gap.
237.8631	46.2446	P792	Gaps in time series with snow events; skewed in N. Maybe break in 2012-04 but hard to tell due gap in data.
269.8248	36.3703	PIGT	Strange bi-modal in 2000 (start until Apr 2001) and then systematic since then with possible rate change Apr 2009 (1 mm/yr N largest)
270.6546	36.4742	RLAP	Bad antenna 2005/10/06-2009/08/10 (replaced at end)
250.3118	31.3683	SA24	Strange seasonal signal plus broken antenna.
321.5405	72.5796	SMM1	Greenland Summit ice site. Trend change after 29 m antenna move 2013/07/09
270.8834	13.6971	SSIA	Data 2000/09/28-2010/07/18 has variable large

			offset; rate change in 2012 after large gap.
141.8448	43.5286	STK2	Earthquake looking offset 2003/09/25 with "log", unknown offset 2011/03/11 undocumented.
270.2411	38.6113	STL7	Noisy in NE; STL8 looks fine.
209.5797	62.3077	TLKA	Long term systematics and strange seasonal; possible break 2002/11/04 (not documented).
297.8367	16.7643	TRNT	Major slow slip events in 2007, 2010 (same as GERD)
227.0057	69.4382	TUKT	Lots of systematic strange seasonal signals; slow offset E 2013.
261.4357	28.4680	TXTI	Strange multiyear deviations in the North (10mm deviations from linear)
249.7133	44.6395	WLWY	Deviations associated with Yellowstone.

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, 21 more than 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_150912.tab, nmt_nam08_150912.tab and cwu_nam08_150912.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_150912.snpvel, nmt_nam08_150912.snpvel and cwu_nam08_150912.snpvel.

Table 4: Statistics of the fits of 2149, 2148 and 2142 sites analyzed by PBO, NMT and CWU in the reprocessed analysis for data collected between Jan 1, 1996 and September 12, 2015.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
PBO	1.1	1.2	5.3
NMT	1.1	1.2	5.6
CWU	1.4	1.4	6.0
70%			
PBO	1.5	1.5	6.0
NMT	1.4	1.6	6.3
CWU	1.7	1.7	6.8
95%			
PBO	3.2	3.1	8.9
NMT	3.2	3.1	9.0
CWU	3.5	3.3	10.3

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 0.09 mm/yr horizontal and 0.64 mm/yr vertical in direct difference of all sites with in 0.5 meters of each other (2156 comparisons). The χ^2/f of the difference is $(1.22)^2$ for the horizontal and $(1.69)^2$ 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 P713, MTA1, P613, MCD1, P801, P486, SAV1, JNPR, SAV5 and LST1. This list is similar to previous quarters 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 2149, 2148 and 2142 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	2156	0.09	0.64	1.22	1.69
Edited -10 worst	2139	0.08	0.62	1.12	1.64
Less than median (0.14 0.45 mm/yr)	1188	0.07	0.54	1.21	1.70
Added minimum sigma NE 0.06 U 0.40 mm/yr					
All	2156	0.13	0.85	0.98	1.10
Edited -10 worst	2139	0.12	0.80	0.84	1.03
Less than median (0.15 0.0.60 mm/yr)	1188	0.08	0.62	0.75	0.89

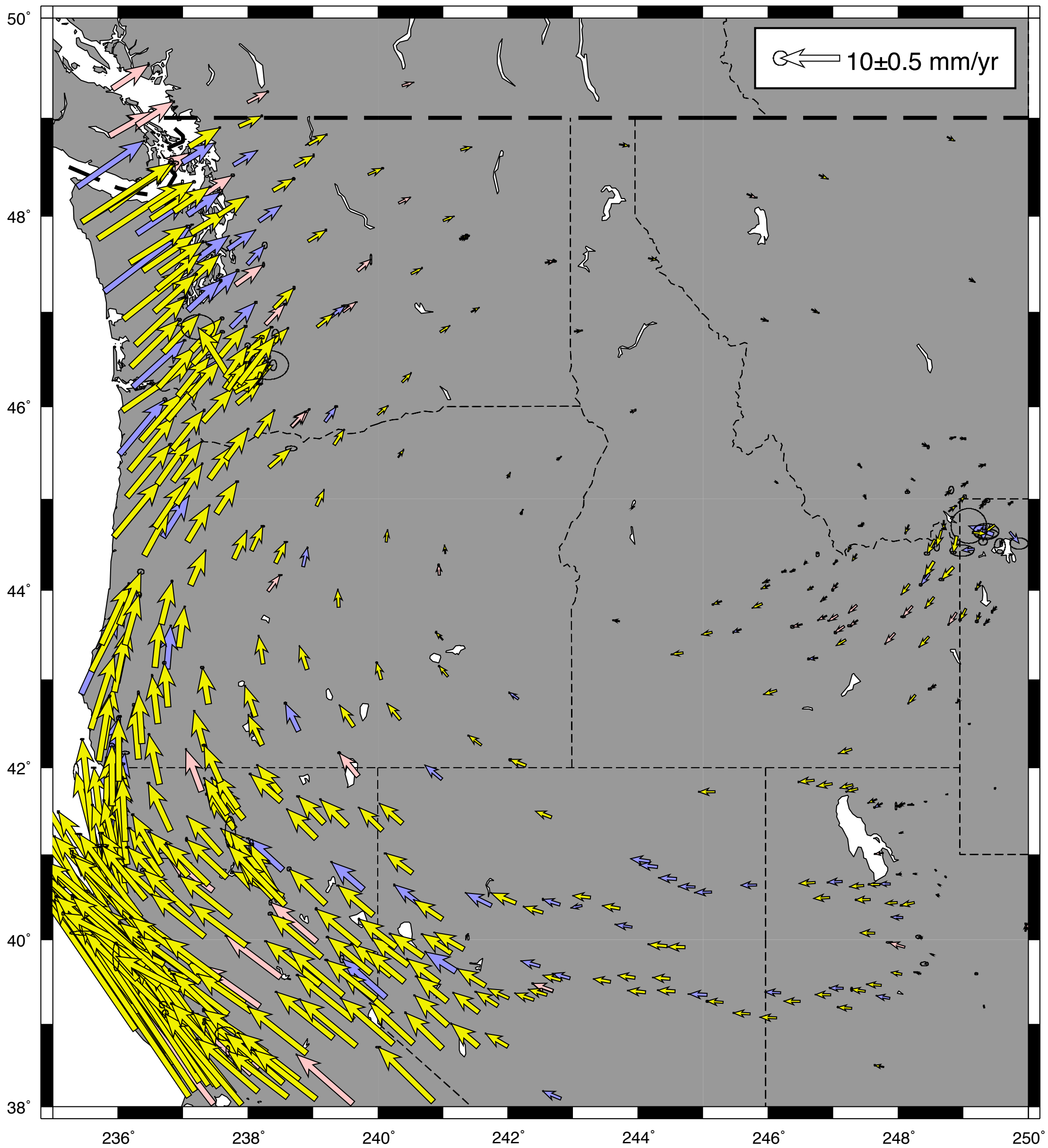

Figure 10: Velocity field estimates from the combined PBO solutions generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal standard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

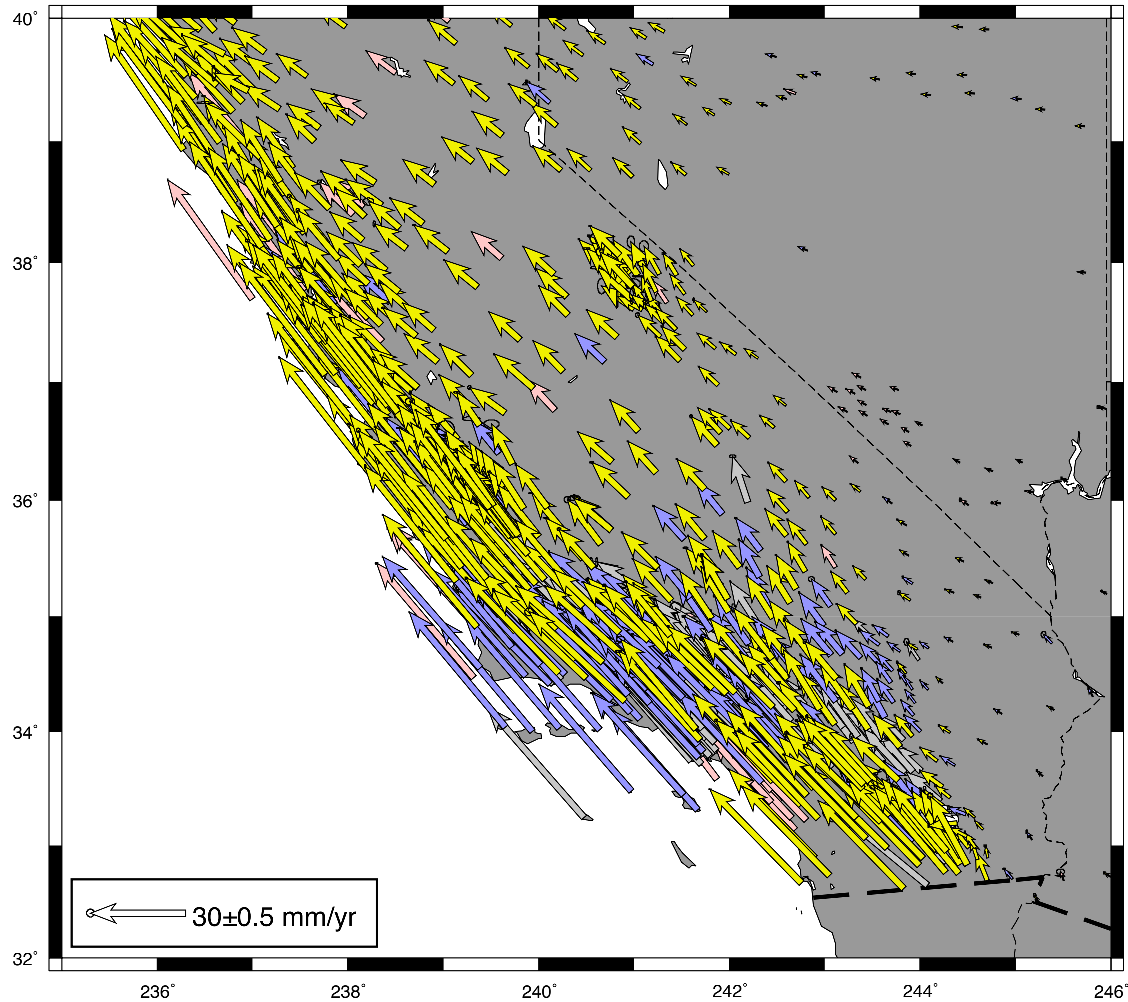

Figure 11: Same as Figure 10 except for South Western United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

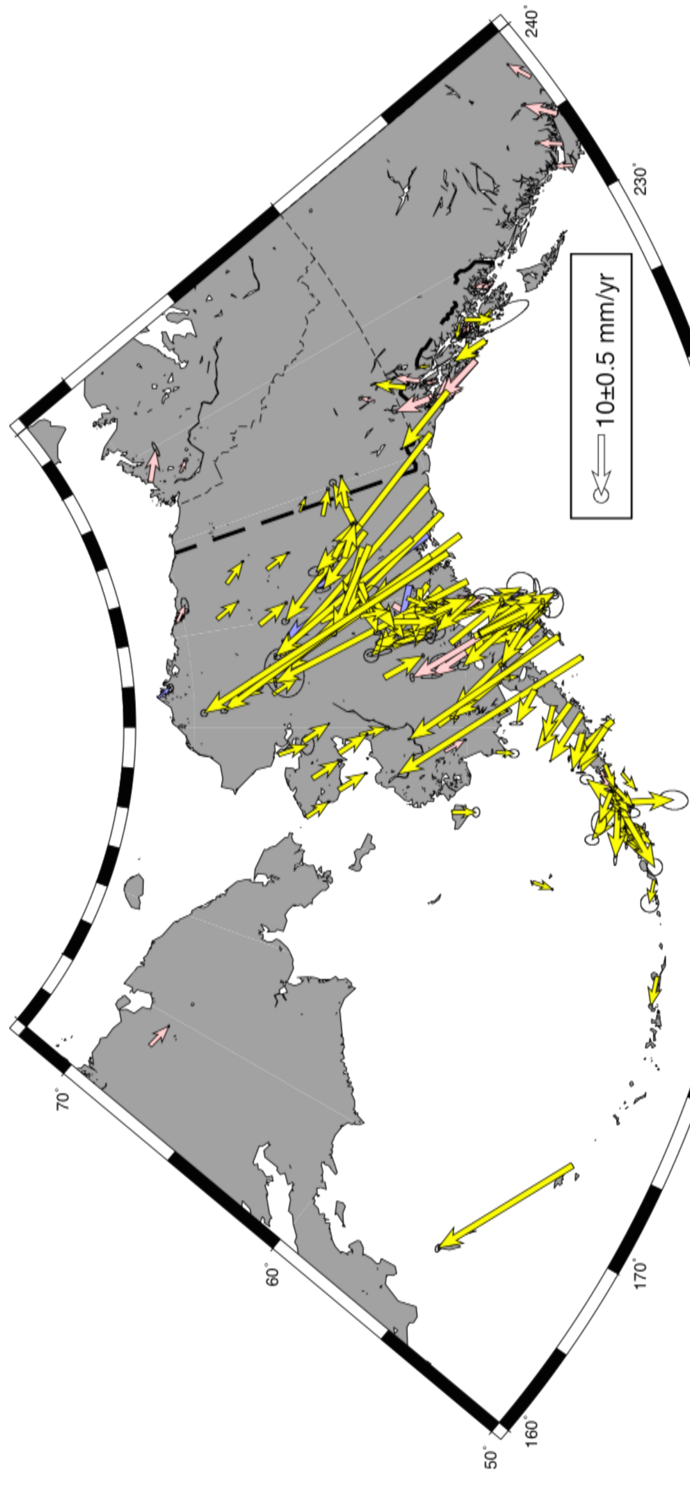

Figure 12: Same as Figure 10 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown

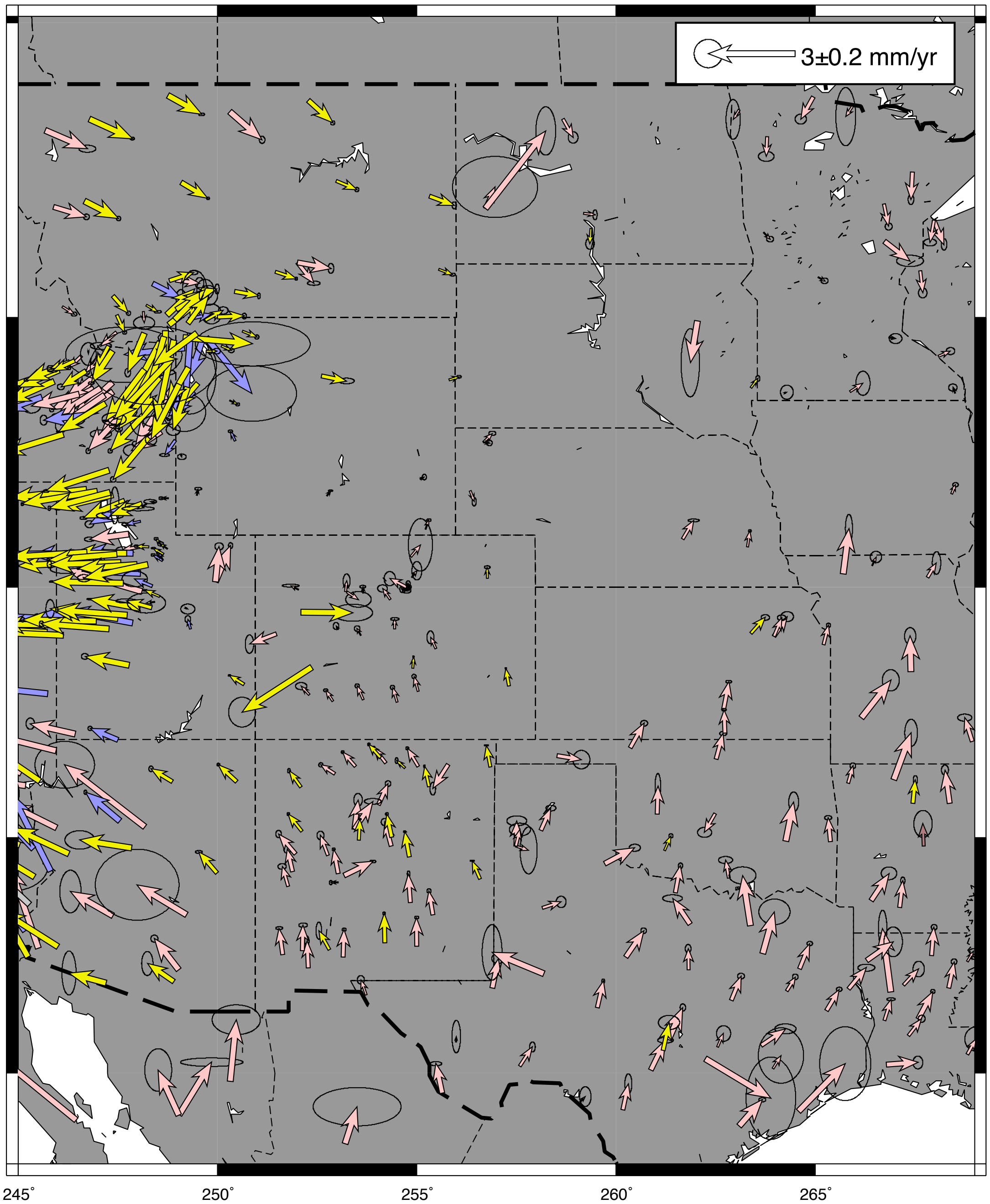

Figure 13: Same as Figure 10 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

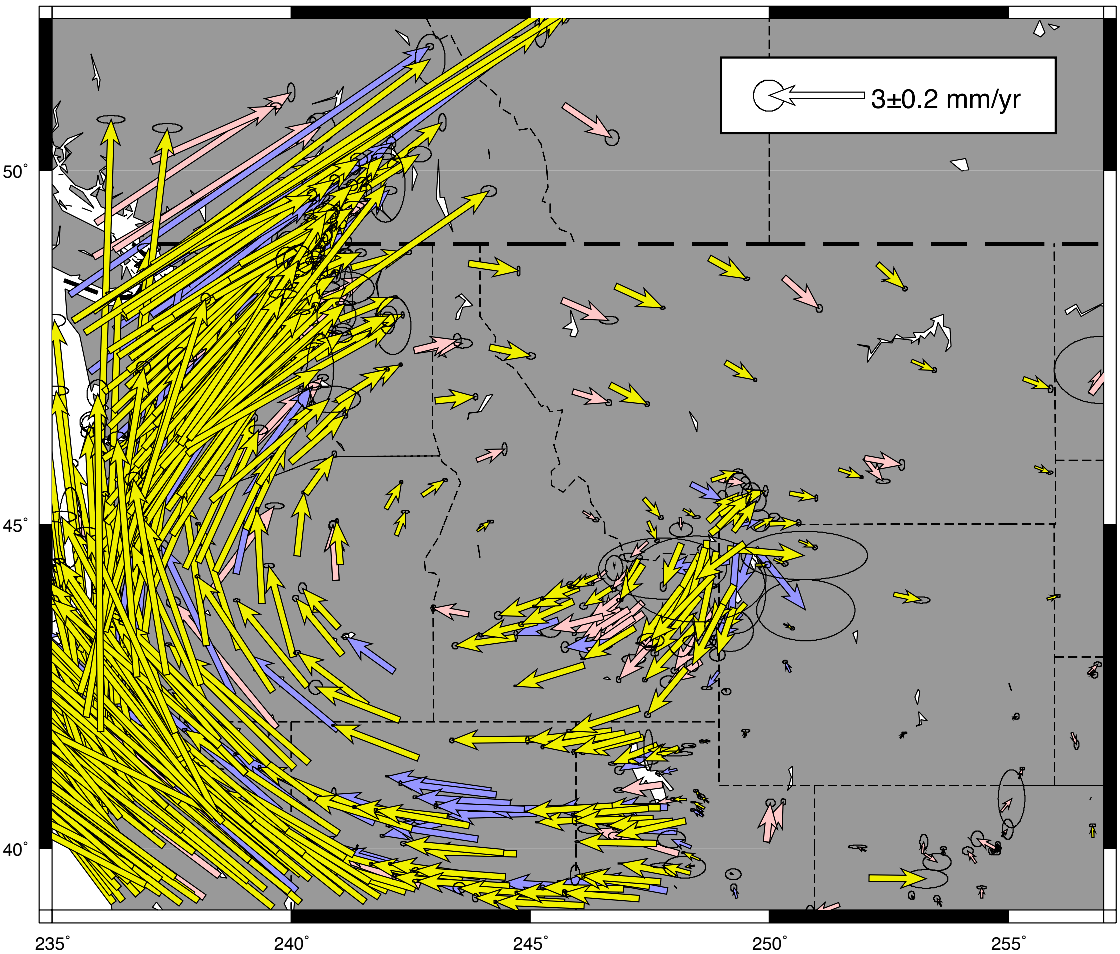

Figure 14: Same as Figure 10 except for Western Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown. Anomalous vectors at longitude 250° are in the Yellowstone National Park and most likely are showing volcanic processes.

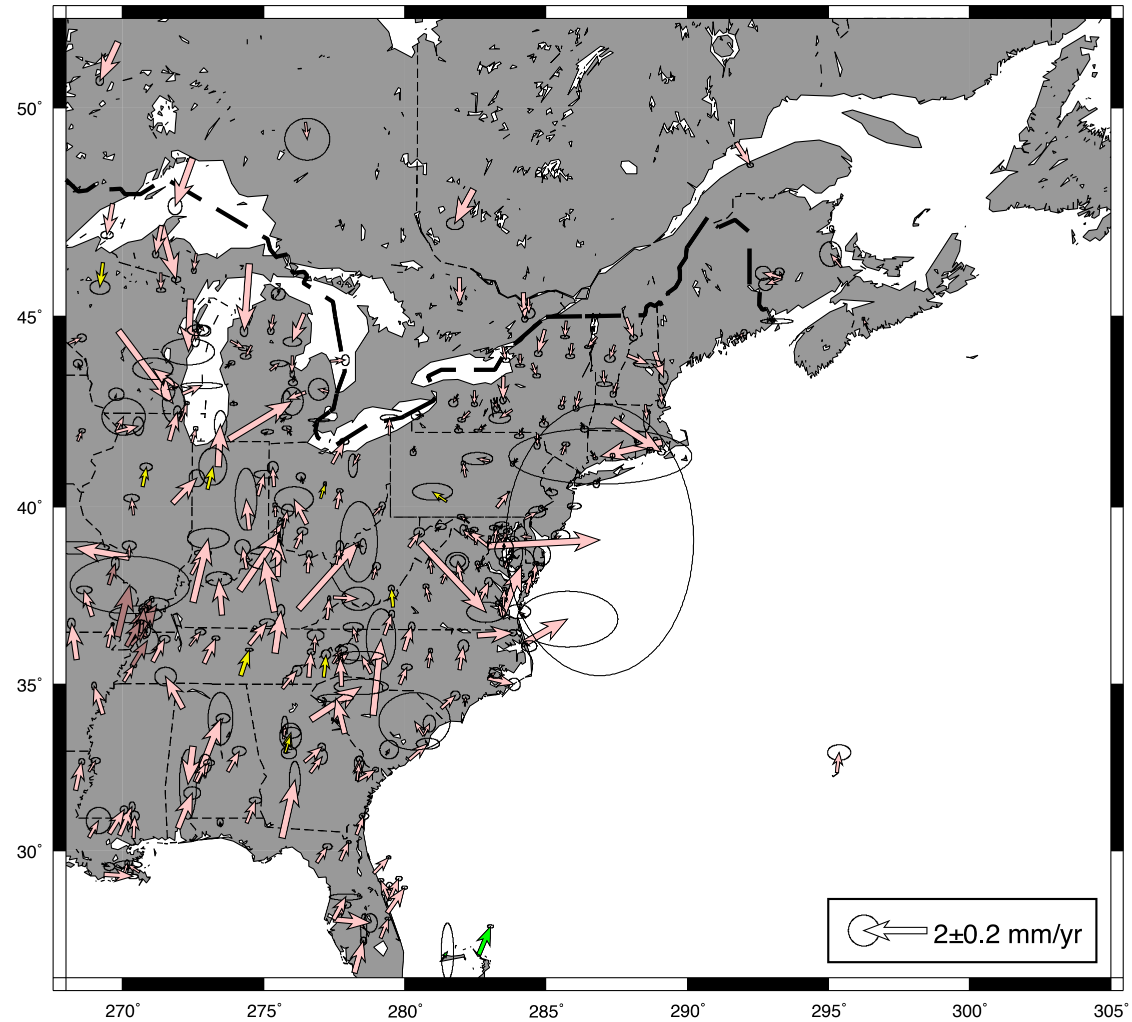

Figure 15: Same as Figure 10 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown. The systematic western velocity of sites in the Northeast is being investigated although profiles from Canada to the Gulf of Mexico indicate that horizontal 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.

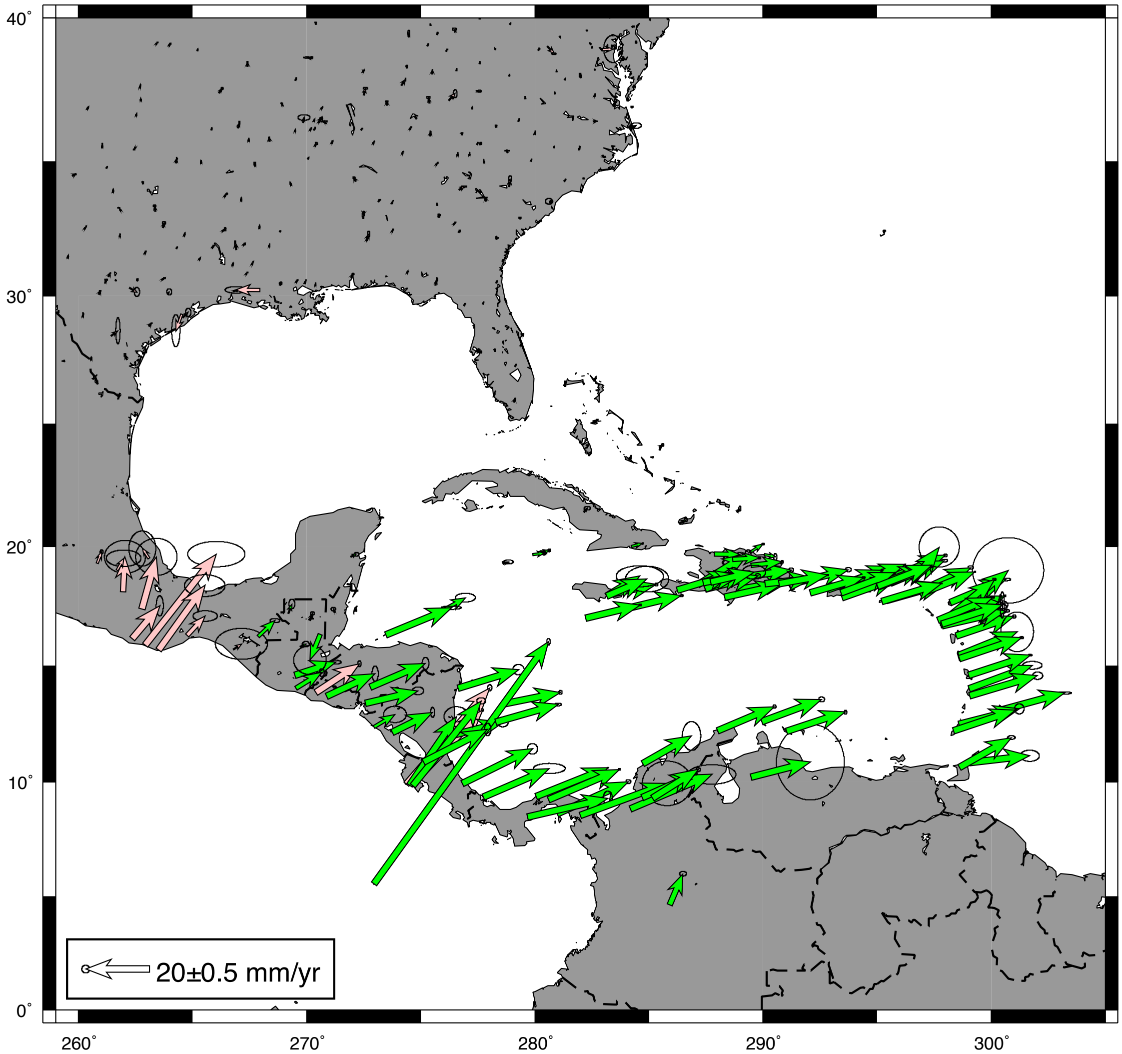

Figure 16: Same as Figure 10 except for the Caribbean region. Only velocities with horizontal standard deviations less than 5 mm/yr are shown.

Earthquake Analyses: 2015/07/01-2015/09/30.

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 June/July 2015 we investigated the following events.

```
* EQDEFS for 2015 06 12 to 2015 07 14 Generated Wed Jul 15 09:57:45 EDT 2015
* Proximity based on Week_All.Pos file
* ------------------------------------
* SEQ Earthquake # 1
* EQ 307 AC51_GPS      19.67      32.10 CoS       11.1 mm
* EQ_DEF M5.7 103km W of Willow
 eq_def 01   61.6644 -151.9620     32.1 8 2015 06 24 22 33    0.067
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.067      0.067      0.067
* ------------------------------------
* SEQ Earthquake # 2
* EQ 452 P495_GPS       8.44       8.80 CoS        0.0 mm
* EQ 452 P499_GPS       8.59       8.80 CoS        0.0 mm
* EQ 452 WMDG_GPS       6.38       8.80 CoS        0.0 mm
* EQ_DEF M3.6 5km W of Brawley
 eq_def 02   32.9810 -115.5813      8.8 8 2015 07 02 19 39    0.000
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.000      0.000      0.000
* ------------------------------------
* SEQ Earthquake # 3
* EQ 491 P377_GPS       5.27      10.20 CoS        2.3 mm
* EQ_DEF M4.2 14km ENE of Springfield
 eq_def 03   44.0817 -122.8370     10.2 8 2015 07 04 15 43    0.001
 eq_rename 03
 eq_coseis 03  0.001 0.001 0.001      0.001      0.001      0.001
```

None of these earthquakes seem to have generated any significant offsets. AC51 shows snow events and other systematics but any offset at the time of the earthquake is small.

In July/August 2015, the following events were investigated

```
* EQDEFS for 2015 07 12 to 2015 08 19 Generated Mon Aug 24 10:43:12 EDT 2015
* Proximity based on Week_All.Pos file
* ------------------------------------
* SEQ Earthquake # 1
* EQ 93 TNMR_GPS       2.71      12.80 CoS       43.6 mm
* EQ_DEF M4.7 58km SE of Coahuayana
 eq_def 01   18.2935 -103.3720     12.8 8 2015 07 14 01 26    0.005
 eq_rename 01
 eq_coseis 01  0.001 0.001 0.001      0.005      0.005      0.005
* ------------------------------------
* SEQ Earthquake # 2
* EQ 479 EWPP_GPS       7.68      10.10 CoS        1.1 mm
* EQ 479 RTHS_GPS       8.33      10.10 CoS        0.9 mm
* EQ_DEF M4.2 1km ESE of Fontana
 eq_def 02   34.0920 -117.4450     10.1 8 2015 07 25 12 55    0.001
 eq_rename 02
 eq_coseis 02  0.001 0.001 0.001      0.001      0.001      0.001
* ------------------------------------
* SEQ Earthquake # 3
* EQ 494 KEN5_GPS       8.80       9.10 CoS        0.8 mm
* EQ 494 KEN6_GPS       8.80       9.10 CoS        0.8 mm
* EQ_DEF M3.8 5km ESE of Nikiski
 eq_def 03   60.6766 -151.1902      9.1 8 2015 07 26 00 48    0.001
 eq_rename 03
 eq_coseis 03  0.001 0.001 0.001      0.001      0.001      0.001
* ------------------------------------
* SEQ Earthquake # 4
* EQ 543 AB02_GPS      77.24     174.30 CoS       15.6 mm
* EQ_DEF M6.9 73km SSW of Nikolski
```

```
 eq_def 04   52.3760 -169.4458    174.3 8 2015 07 27 04 50    1.457
 eq_rename 04
 eq_coseis 04  0.001 0.001 0.001      1.457      1.457      1.457
* ------------------------------------
* SEQ Earthquake # 5
* EQ 646 AC37_GPS      71.25      71.30 CoS        3.9 mm
* EQ 646 AC47_GPS      38.05      71.30 CoS       13.8 mm
* EQ 646 AC59_GPS      42.42      71.30 CoS       11.1 mm
* EQ 646 AUGL_GPS      58.93      71.30 CoS        5.8 mm
* EQ 646 AV01_GPS      61.41      71.30 CoS        5.3 mm
* EQ 646 AV02_GPS      63.77      71.30 CoS        4.9 mm
* EQ 646 AV03_GPS      58.64      71.30 CoS        5.8 mm
* EQ 646 AV04_GPS      60.75      71.30 CoS        5.4 mm
* EQ 646 AV05_GPS      60.44      71.30 CoS        5.5 mm
* EQ 646 AV11_GPS      58.90      71.30 CoS        5.8 mm
* EQ 646 AV16_GPS      59.66      71.30 CoS        5.6 mm
* EQ 646 AV17_GPS      56.38      71.30 CoS        6.3 mm
* EQ 646 AV18_GPS      58.72      71.30 CoS        5.8 mm
* EQ 646 AV19_GPS      61.22      71.30 CoS        5.3 mm
* EQ 646 AV20_GPS      62.20      71.30 CoS        5.2 mm
* EQ 646 AV21_GPS      58.93      71.30 CoS        5.8 mm
* EQ_DEF M6.3 70km SSW of Redoubt Volcano
 eq_def 05   59.8935 -153.1961     71.3 8 2015 07 29 02 36    0.313
 eq_rename 05
 eq_coseis 05  0.001 0.001 0.001      0.313      0.313      0.313
* ------------------------------------
* SEQ Earthquake # 6
* EQ 1022 P224_GPS       3.22       9.60 CoS        6.2 mm
* EQ_DEF M4.0 1km N of Piedmont
 eq_def 06   37.8365 -122.2322      9.6 8 2015 08 17 13 50    0.001
 eq_rename 06
 eq_coseis 06  0.001 0.001 0.001      0.001      0.001      0.001
```

eq_def 01: We are unable to test this earthquake because there have been no results from TNMR since 2015/07/14. The effects of this earthquake will need to be evaluated when data becomes available.
eq_def 04: Displaced AB02 by -5 mm N, -1mm E and 1.2 mm U. This appears to be only site affected by the earthquake. This is EQ Event 36.and the event files have been sent to UNAVCO

None of the other earthquakes generated significant offsets.

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

```
* 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.

Antenna Change Offsets: 2015/07/01-2015/09/30

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

```
 Site      Date           From             To
 AC26  2015  6 18  0  0 TRM29659.00     TRM59800.00
 AL90  2015  6 24 16 40 LEIAX1203+GNSS  LEIAR10
 NYML  2015  6 16 17 58 LEIAT504        LEIAR10
 NYPD  2015  6 17 14 29 LEIAT504        LEIAR10
 P135  2015  6  4  0  0 TRM29659.00     TRM59800.80
 P793  2015  6 10 22 10 TRM29659.00     TRM59800.80

 CJTR  2015  7 16 18 18 ASH700936D_M    ASH701945D_M
 CN23  2015  7 10  0  0 NONE            SCIT Radome
 FLIN  2015  7  7  0  0 NONE            SCIT Radome
 P250  2015  7 14 16 36 TRM29659.00     TRM59800.80
 PTSG  2015  7  1 20 32 TRM29659.00     TRM59800.80
 WMOK  2015  7 25 18 14 TRM29659.00     TRM59800.80

 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


MKEA  2015  4  8  0  0  AOAD/M_T      JAVRINGANT_DM
P014  2015  4 19 19 33  TRM29659.00   TRM59800.80
P041  2015  4  9  0  0  TRM29659.00   TRM59800.80
P312  2015  4 29 19 21  TRM29659.00   TRM59800.80
P444  2015  4 28 17 47  TRM29659.00   TRM59800.80
P729  2015  4 24 16  5  TRM29659.00   TRM59800.00
SC02  2015  4 29 19  5  TRM29659.00   TRM59800.80

IDDR  2015  5  6 15  0  LEIAX1202GG   LEIAR10
KYTH  2015  5  6 13 29  TRM55971.00   TRM57971.00
NYLV  2015  5 20 15 28  LEIAT504      LEIAR10
NYWT  2015  5 21 15 36  LEIAT504      LEIAR10
P182  2015  5  6  0  0  TRM29659.00   TRM59800.80
P183  2015  5  6  0  0  TRM29659.00   TRM59800.80
```

```
P215  2015  5 15  0  0  TRM29659.00   TRM59800.80
P689  2015  5  8  0  0  TRM29659.00   TRM59800.00
P694  2015  5  7 19 48  TRM29659.00   TRM59800.80
P701  2015  5  8  0  0  TRM29659.00   TRM29659.00
P701  2015  5 21  0  0  TRM29659.00   TRM59800.80
```

Analysis

AC26: WLS dNEU -5.63 +- 11.81, 0.34 +- 6.50, 0.30 +- 11.27, mm, KF dNEU -2.94 +- 0.72, -1.03 +- 0.53, -0.94 +- 2.11, mm

This site is quite systematic making the offset determination noisy. Also there are only few measurements after the antenna change.

AL90: WLS dNEU 19.83 +- 6.60, 6.04 +- 12.36, 8.76 +- 26.03, mm, KF dNEU 18.90 +- 1.13, 4.29 +- 1.20, 6.44 +- 4.64, mm

There are only a few days of data after the change where the AC used the correct antenna model for the new antenna and thus the estimates here have lager sigmas. A better estimate could be made once the final results (with the correct models) are submitted.

NYML: WLS dNEU -1.74 +- 0.87, -1.28 +- 2.80, 1.64 +- 5.58, mm, KF dNEU -1.69 +- 0.45, -0.20 +- 0.38, 1.04 +- 1.51, mm

The offsets here as small. The north offset maybe due to systematics.

NYPD: WLS dNEU -2.47 +- 1.42, -1.95 +- 1.65, -2.44 +- 4.96, mm, KF dNEU -2.26 +- 0.46, -1.46 +- 0.37, -2.02 +- 1.54, mm

Offsets are small and estimates maybe affected by systematics.

P135: The replacement antenna seems bad and data stops 2016/06/21. Edit line added to All_PBO_unkn.eq:

rename P135 P135_XPS 2015 6 4 0 0 2015 6 22 0 0 ! Antenna seems bad after replacement. Added by tah on 2015-07-15 11:30:31

P793: WLS dNEU 0.49 +- 0.81, -0.95 +- 6.26, 7.31 +- 10.12, mm, KF dNEU 0.74 +- 0.42, -2.68 +- 0.52, 8.09 +- 1.60, mm

There is a large gap before the antenna change, so the estimates may not be that reliable.

CJTR: WLS dNEU -5.61 +- 6.10, 10.93 +- 4.12, -1.07 +- 9.43, mm, KF dNEU -8.48 +- 0.50, 11.48 +- 0.47, 5.28 +- 1.69, mm .

Offset in east is very clear. As second undocumented break was found at 2009-06-29. No meta data changes or earthquakes could be associated with this event. The offsets for this event are

WLS dNEU 3.29 +- 1.58, -10.80 +- 1.06, -4.64 +- 2.38, mm, KF dNEU 0.49 +- 0.42, -7.82 +- 0.35, -2.54 +- 0.97, mm

CN23: The DOME swap here did not seem to generate any offsets although the rename has been retained.

FLIN: No apparent offset with this radome change. Break has been retained.

P250: WLS dNEU 2.25 +- 1.35, -4.57 +- 2.09, 8.34 +- 17.34, mm, KF dNEU 1.41 +- 0.26, -3.86 +- 0.25, 6.21 +- 1.21, mm .

East and North offsets can be seen in time series. Height offset is less obvious.

PTSG: WLS dNEU -0.36 +- 1.20, -1.28 +- 2.44, -0.28 +- 6.00, mm, KF dNEU -0.36 +- 0.31, -1.01 +- 0.31, 1.88 +- 1.06, mm .

There is a data gap before this change which makes the assessment more difficult.
WMOK: WLS dNEU 2.41 +- 0.95, 1.48 +- 1.26, -1.41 +- 12.93, mm, KF dNEU 2.86 +- 0.37, 0.73 +- 0.36, 1.77 +- 1.48, mm .
Again a gap before the antenna replacements make the assessment more difficult.

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
There is a gap in data before antenna was replaced. Visually, the north rate seems to change after the swap but this is probably due to systematics in the time series.

The only addition to the unkn offset file is to remove the data during the interval when the antenna at P135 was not functioning correctly.

Rename	Date Range	Explanation
P135 P135_XPS	2015 6 4 2015 6 22	Position estimates are bad before the antenna is replaced on June 22.

New GLOBK SINEX file velocity solution

We have now completed the first 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). 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 same program is used for GAMIT sub-networking and velocity solution sub-networking). The process noise models, in the form of random walk time-step variances are given in All_PBO.rw. These values are generated by analysis of the position residuals are fitting the time series for each site. Sites that have process noise values greater than 100.0 mm^2/yr are not included in this velocity solution so that they do not contaminate nearby sites. Twelve sites are excluded based on this criterion. 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 generate 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. Because of the long run time of these SINEX velocity solutions, they are currently run using day3 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 ~2000 sites analyzed into 28 networks where the 28th network is created to ties all the other 27 networks into a single solution. The analyses of the 28 networks can be run in parallel takes a few hours to run. The combination of the 28 networks uses ~9 Gbytes of memory and the NMT and CWU combination, along the equating of velocities 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 the end of the combination. We generate to four realizations: (1) A North America frame aligned to our current NAM08 frame using ~1000 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. 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 ago. Tables 6 and 7 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 6's caption explains the naming scheme used to describe the solutions. There are the three analysis, NMT, CWU and their combination PBO and then 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 (2) 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 (Ib). 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.

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 and in height less than 0.7 mm/yr. The NRMS scatter of the differences is typically close to unity showing that the error bars are of the same size as the differences.

While examining the new GLOBK SINEX velocity solution, we noticed a group of ~50 sites which had larger than expected velocity uncertainties. On examining these sites, we realized one network was not been well aligned to the over all network (the sites used to align to the whole network were almost collinear). The algorithm used to select sites for aligning each network needs to be refined to eliminate this poor geometry case. We are upgrading that algorithm and expect to have new improved solution within a week.

When the new velocity solution is released we use the version 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 6: Comparison of North and East velocities between different velocity field determination methods. The solution codes describe the solution. The codes are of the form AAA_BBCC where AAA is the center or combination CWU, NMT and PBO; BB is the solution type: KF is Kalman filter time series analysis, LS is weighted least squares and GK is GLOBK SINEX velocity solutions; and CC is TS for time series (generated in current realization of the NAM08 reference frames, NA is for the GLOBK SINEX analysis and the same NAM08 frames as used in the time series generation and Ib is a re-alignment to the IGb08 reference frame rotated in the North America frame. The mean offset, especially in east, reveals our current North America reference differs from the new realization by ~0.3 mm/yr in East.

Soln 1 - Soln 2	#	N mean (mm)	N WRMS (mm)	N NRMS	E mean (mm)	E WRMS (mm)	E NRMS
CWU_KFTS-CWU_LSTS	2110	0.00	0.11	0.873	-0.00	0.13	0.992
CWU_KFTS-NMT_KFTS	2105	-0.01	0.11	0.658	0.01	0.15	0.872
CWU_KFTS-NMT_LSTS	2108	0.00	0.14	1.100	0.01	0.17	1.276
CWU_KFTS-PBO_KFTS	2108	-0.00	0.07	0.421	0.01	0.09	0.548
CWU_KFTS-PBO_LSTS	2109	-0.00	0.12	0.946	0.01	0.15	1.096
CWU_KFTS-CWU_GKNA	1972	0.01	0.15	0.749	0.02	0.22	1.059
CWU_KFTS-NMT_GKNA	1971	0.02	0.16	0.819	0.03	0.23	1.160
CWU_KFTS-PBO_GKNA	1972	0.02	0.15	0.894	0.03	0.21	1.251
CWU_LSTS-NMT_KFTS	2109	-0.01	0.14	1.106	0.01	0.15	1.113
CWU_LSTS-NMT_LSTS	2122	0.00	0.07	1.066	0.01	0.09	1.191
CWU_LSTS-PBO_KFTS	2112	-0.00	0.13	0.987	0.01	0.14	1.021
CWU_LSTS-PBO_LSTS	2122	-0.00	0.04	0.630	0.01	0.05	0.606
CWU_LSTS-CWU_GKNA	1985	0.01	0.14	0.797	0.02	0.19	1.067
CWU_LSTS-NMT_GKNA	1984	0.02	0.16	0.931	0.04	0.20	1.174
CWU_LSTS-PBO_GKNA	1985	0.02	0.14	1.046	0.03	0.18	1.336
CWU_KFTS-CWU_GKIb	1972	0.03	0.18	0.809	0.29	0.37	1.727
CWU_KFTS-NMT_GKIb	1971	0.09	0.19	0.924	0.34	0.42	1.976
CWU_KFTS-PBO_GKIb	1972	0.07	0.18	1.023	0.31	0.38	2.181

CWU_LSTS-CWU_GKIb	1985	0.03	0.17	0.861	0.29	0.36	1.890
CWU_LSTS-NMT_GKIb	1984	0.09	0.19	1.037	0.34	0.40	2.183
CWU_LSTS-PBO_GKIb	1985	0.07	0.17	1.193	0.31	0.37	2.593

NMT_KFTS-NMT_LSTS	2121	0.01	0.12	0.922	0.00	0.11	0.872
NMT_KFTS-PBO_KFTS	2117	0.01	0.08	0.492	-0.00	0.09	0.561
NMT_KFTS-PBO_LSTS	2119	0.01	0.13	1.011	-0.00	0.13	1.011
NMT_KFTS-CWU_GKNA	1972	0.02	0.19	0.921	0.02	0.22	1.067
NMT_KFTS-NMT_GKNA	1979	0.03	0.17	0.855	0.03	0.20	0.998
NMT_KFTS-PBO_GKNA	1979	0.03	0.17	1.020	0.03	0.20	1.183
NMT_LSTS-PBO_KFTS	2121	-0.01	0.14	1.065	-0.01	0.15	1.100
NMT_LSTS-PBO_LSTS	2134	-0.00	0.05	0.819	-0.01	0.07	0.926
NMT_LSTS-CWU_GKNA	1984	0.01	0.18	1.008	0.01	0.21	1.172
NMT_LSTS-NMT_GKNA	1991	0.02	0.16	0.964	0.03	0.19	1.111
NMT_LSTS-PBO_GKNA	1991	0.01	0.15	1.193	0.02	0.18	1.366

NMT_KFTS-CWU_GKIb	1972	0.04	0.21	0.966	0.28	0.37	1.732
NMT_KFTS-NMT_GKIb	1979	0.10	0.20	0.972	0.34	0.40	1.895
NMT_KFTS-PBO_GKIb	1979	0.08	0.20	1.148	0.30	0.37	2.153
NMT_LSTS-CWU_GKIb	1984	0.03	0.21	1.060	0.28	0.37	1.939
NMT_LSTS-NMT_GKIb	1991	0.08	0.20	1.078	0.33	0.39	2.149
NMT_LSTS-PBO_GKIb	1991	0.07	0.19	1.333	0.30	0.36	2.613

PBO_KFTS-PBO_LSTS	2123	0.00	0.11	0.903	0.00	0.12	0.940
PBO_KFTS-CWU_GKNA	1975	0.02	0.17	0.831	0.02	0.20	0.970
PBO_KFTS-NMT_GKNA	1981	0.03	0.16	0.811	0.03	0.20	0.998
PBO_KFTS-PBO_GKNA	1982	0.02	0.15	0.929	0.02	0.19	1.115
PBO_LSTS-CWU_GKNA	1986	0.01	0.15	0.846	0.02	0.19	1.041
PBO_LSTS-NMT_GKNA	1993	0.02	0.15	0.869	0.03	0.19	1.073
PBO_LSTS-PBO_GKNA	1994	0.02	0.13	1.030	0.03	0.17	1.248

PBO_KFTS-CWU_GKIb	1975	0.03	0.19	0.884	0.28	0.36	1.680
PBO_KFTS-NMT_GKIb	1981	0.09	0.19	0.926	0.34	0.40	1.896
PBO_KFTS-PBO_GKIb	1982	0.08	0.18	1.062	0.30	0.36	2.121
PBO_LSTS-CWU_GKIb	1986	0.03	0.18	0.909	0.29	0.36	1.873
PBO_LSTS-NMT_GKIb	1993	0.09	0.18	0.996	0.34	0.39	2.131
PBO_LSTS-PBO_GKIb	1994	0.07	0.17	1.195	0.31	0.36	2.558

CWU_GKIb-CWU_GKNA	2111	-0.01	0.07	0.285	-0.27	0.29	1.186
CWU_GKIb-NMT_GKNA	2102	-0.01	0.13	0.535	-0.25	0.31	1.288
CWU_GKIb-PBO_GKNA	2111	-0.01	0.09	0.436	-0.26	0.29	1.378

CWU_GKNA-NMT_GKNA	2102	0.01	0.10	0.454	0.02	0.12	0.524
CWU_GKNA-PBO_GKNA	2111	0.01	0.06	0.289	0.01	0.06	0.317

CWU_GKIb-NMT_GKIb	2102	0.06	0.12	0.491	0.05	0.13	0.537
CWU_GKIb-PBO_GKIb	2111	0.04	0.07	0.339	0.02	0.07	0.313
CWU_GKNA-NMT_GKIb	2102	0.07	0.14	0.569	0.32	0.35	1.486
CWU_GKNA-PBO_GKIb	2111	0.06	0.10	0.477	0.29	0.31	1.512

NMT_GKIb-NMT_GKNA	2118	-0.06	0.08	0.361	-0.31	0.32	1.397
NMT_GKIb-PBO_GKNA	2110	-0.07	0.10	0.474	-0.31	0.33	1.619
NMT_GKNA-PBO_GKNA	2110	-0.00	0.05	0.249	-0.01	0.06	0.299

NMT_GKIb-PBO_GKIb	2110	-0.01	0.05	0.247	-0.03	0.07	0.319

NMT_GKNA-PBO_GKIb	2110	0.05	0.09	0.458	0.27	0.30	1.517
PBO_GKIb-PBO_GKNA	2119	-0.05	0.08	0.463	-0.28	0.30	1.792

Table 7: Similar to Table 6 except here the mean horizontal velocity (Hz Mean, H WRMS, H NRMS) and vertical velocity (U columns) are compared.

Soln 1 - Soln 2	#	Hz Mean	H WRMS (mm)	H NRMS (mm)	U Mean	U WRMS (mm)	U NRMS (mm)
CWU_KFTS-CWU_LSTS	2110	-0.00	0.12	0.934	-0.00	0.34	0.861
CWU_KFTS-NMT_KFTS	2105	-0.00	0.13	0.772	-0.22	0.56	1.273
CWU_KFTS-NMT_LSTS	2108	0.01	0.16	1.191	-0.13	0.59	1.432
CWU_KFTS-PBO_KFTS	2108	0.00	0.08	0.489	0.05	0.24	0.556
CWU_KFTS-PBO_LSTS	2109	0.00	0.14	1.024	0.05	0.39	0.988
CWU_KFTS-CWU_GKNA	1972	0.02	0.19	0.917	0.02	0.55	0.864
CWU_KFTS-NMT_GKNA	1971	0.03	0.20	1.004	-0.07	0.58	0.952
CWU_KFTS-PBO_GKNA	1972	0.02	0.18	1.087	-0.03	0.52	1.038
CWU_LSTS-NMT_KFTS	2109	0.00	0.15	1.110	-0.23	0.67	1.649
CWU_LSTS-NMT_LSTS	2122	0.01	0.08	1.131	-0.14	0.59	1.569
CWU_LSTS-PBO_KFTS	2112	0.00	0.13	1.004	0.06	0.40	1.037
CWU_LSTS-PBO_LSTS	2122	0.00	0.04	0.618	0.05	0.22	0.611
CWU_LSTS-CWU_GKNA	1985	0.02	0.17	0.942	0.01	0.50	0.811
CWU_LSTS-NMT_GKNA	1984	0.03	0.18	1.059	-0.08	0.55	0.950
CWU_LSTS-PBO_GKNA	1985	0.03	0.16	1.200	-0.04	0.48	1.036
CWU_KFTS-CWU_GKIb	1972	0.16	0.29	1.349	-0.17	0.61	0.881
CWU_KFTS-NMT_GKIb	1971	0.21	0.32	1.543	-0.30	0.67	1.065
CWU_KFTS-PBO_GKIb	1972	0.19	0.30	1.703	-0.25	0.60	1.151
CWU_LSTS-CWU_GKIb	1985	0.16	0.28	1.468	-0.19	0.56	0.841
CWU_LSTS-NMT_GKIb	1984	0.21	0.32	1.709	-0.32	0.65	1.075
CWU_LSTS-PBO_GKIb	1985	0.19	0.29	2.018	-0.26	0.57	1.167
NMT_KFTS-NMT_LSTS	2121	0.01	0.12	0.897	0.08	0.33	0.863
NMT_KFTS-PBO_KFTS	2117	0.00	0.09	0.528	0.27	0.51	1.188
NMT_KFTS-PBO_LSTS	2119	0.00	0.13	1.011	0.28	0.65	1.632
NMT_KFTS-CWU_GKNA	1972	0.02	0.20	0.996	0.27	0.76	1.197
NMT_KFTS-NMT_GKNA	1979	0.03	0.18	0.929	0.17	0.61	1.011
NMT_KFTS-PBO_GKNA	1979	0.03	0.18	1.104	0.21	0.63	1.281
NMT_LSTS-PBO_KFTS	2121	-0.01	0.14	1.083	0.18	0.55	1.398
NMT_LSTS-PBO_LSTS	2134	-0.01	0.06	0.874	0.19	0.55	1.514
NMT_LSTS-CWU_GKNA	1984	0.01	0.19	1.093	0.16	0.70	1.146
NMT_LSTS-NMT_GKNA	1991	0.02	0.18	1.040	0.07	0.56	0.967
NMT_LSTS-PBO_GKNA	1991	0.02	0.17	1.282	0.11	0.58	1.251
NMT_KFTS-CWU_GKIb	1972	0.16	0.30	1.402	0.07	0.74	1.088
NMT_KFTS-NMT_GKIb	1979	0.22	0.31	1.506	-0.07	0.61	0.978
NMT_KFTS-PBO_GKIb	1979	0.19	0.30	1.725	-0.00	0.61	1.205
NMT_LSTS-CWU_GKIb	1984	0.16	0.30	1.562	-0.04	0.70	1.066
NMT_LSTS-NMT_GKIb	1991	0.21	0.31	1.700	-0.17	0.59	0.994
NMT_LSTS-PBO_GKIb	1991	0.19	0.29	2.074	-0.10	0.59	1.228
PBO_KFTS-PBO_LSTS	2123	0.00	0.12	0.921	-0.01	0.35	0.921
PBO_KFTS-CWU_GKNA	1975	0.02	0.18	0.903	-0.03	0.55	0.868
PBO_KFTS-NMT_GKNA	1981	0.03	0.18	0.909	-0.12	0.51	0.860
PBO_KFTS-PBO_GKNA	1982	0.02	0.17	1.026	-0.08	0.47	0.973

PBO_LSTS-CWU_GKNA	1986	0.02	0.17	0.949	-0.04	0.50	0.823
PBO_LSTS-NMT_GKNA	1993	0.03	0.17	0.976	-0.13	0.48	0.839
PBO_LSTS-PBO_GKNA	1994	0.02	0.15	1.145	-0.09	0.44	0.954
PBO_KFTS-CWU_GKIb	1975	0.16	0.29	1.342	-0.22	0.61	0.912
PBO_KFTS-NMT_GKIb	1981	0.21	0.31	1.492	-0.36	0.63	1.027
PBO_KFTS-PBO_GKIb	1982	0.19	0.29	1.677	-0.30	0.58	1.144
PBO_LSTS-CWU_GKIb	1986	0.16	0.28	1.472	-0.24	0.57	0.882
PBO_LSTS-NMT_GKIb	1993	0.21	0.30	1.663	-0.36	0.61	1.021
PBO_LSTS-PBO_GKIb	1994	0.19	0.28	1.996	-0.30	0.55	1.148
CWU_GKIb-CWU_GKNA	2111	-0.14	0.21	0.863	0.21	0.24	0.304
CWU_GKIb-NMT_GKNA	2102	-0.13	0.23	0.986	0.13	0.46	0.612
CWU_GKIb-PBO_GKNA	2111	-0.14	0.22	1.022	0.16	0.32	0.467
CWU_GKNA-NMT_GKNA	2102	0.01	0.11	0.490	-0.09	0.44	0.612
CWU_GKNA-PBO_GKNA	2111	0.01	0.06	0.303	-0.05	0.25	0.399
CWU_GKIb-NMT_GKIb	2102	0.06	0.13	0.515	-0.11	0.46	0.595
CWU_GKIb-PBO_GKIb	2111	0.03	0.07	0.326	-0.05	0.26	0.381
CWU_GKNA-NMT_GKIb	2102	0.20	0.27	1.125	-0.33	0.56	0.751
CWU_GKNA-PBO_GKIb	2111	0.17	0.23	1.121	-0.27	0.38	0.589
NMT_GKIb-NMT_GKNA	2118	-0.18	0.24	1.020	0.24	0.25	0.354
NMT_GKIb-PBO_GKNA	2110	-0.19	0.24	1.193	0.28	0.35	0.561
NMT_GKNA-PBO_GKNA	2110	-0.00	0.05	0.275	0.04	0.20	0.330
NMT_GKIb-PBO_GKIb	2110	-0.02	0.06	0.285	0.06	0.21	0.332
NMT_GKNA-PBO_GKIb	2110	0.16	0.22	1.121	-0.18	0.28	0.454
PBO_GKIb-PBO_GKNA	2119	-0.17	0.22	1.309	0.22	0.24	0.456

Script updates

No major changes have been to the scripts.

GAMIT/GLOBK Community Support

During this quarter we conducted a 4-day short course at UNAVCO attended in person by 24 analysts, and virtually by another 22. One of the three MIT instructors monitored the virtual interface throughout, allowing effective communication with participants asking questions during and following the lectures. We continue to spend 5-10 hours per week in email support of users. During the quarter we issued 22 royalty-free licenses to educational and research institutions. The total number of institutions who have requested licenses is over 100 in the US, and over 1000 internationally, but we cannot verify how many of these are being actively used.

As indicated in our earlier reports, we are modifying GAMIT to allow processing of two-frequency observations from satellites of any single GNSS, and GLOBK to combine the daily coordinate estimates from the individual GAMIT solutions. Although not as rigorous as direct combination of phase and pseudo-range observables, or the use of more than two frequencies, the advantages of direct combination over our approach are likely to be marginal for long-session observations. We already resolve > 90% of the phase ambiguities and model well the small 2nd- and 3rd order ionospheric effects. For short-session or kinematic measurements the additional strength of the full GNSS array could be important if inter-channel and inter- system biases can be calibrated, not yet a resolved issue. Although achieving direct-combination capability in GAMIT and TRACK is a long-term goal, the task is a full man-year's effort beyond our current resources.

We completed in July Phase 1 of our GNSS 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). We tested the new code for GPS processing and included the modifications in the GAMIT/GLOBK 10.60 release in July. In September we added the ability to read RINEX 3 files, the now-accepted format for multi-GNSS observations.

Phase 2 is to incorporate the models specific to each of the non-GPS systems. These include satellite yaw, radiation-pressure parameters, SV antenna phase-center offsets and variations, and, for GLONASS, satellite-dependent carrier frequencies. The recent release of an IGS ANTEX file (igs08_1854.atx) with BeiDou, Galileo, QZSS, and IRNSS entries (as well as the GPS and GLONASS entries that have existed for some time) has allowed us to create a nearly complete mapping of GNSS PRNs to SVs for modeling. We have tested successfully fitting our orbit integrations to SP3 files generated by other groups for GLONASS and BeiDou. During the next quarter we will incorporate yaw models for BeiDou MEO, GEO, and IGSO satellites into our existing routine for GPS and GLONASS and add satellite-dependent frequencies for GLONASS.