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

Thomas Herring, Robert King and Mike Floyd

Period: 2013/10/01-2013/12/31

Table of Contents

Summary ... 2
GPS Analysis of Level 2a and 2b products ... 2
  Level 2a products: Rapid products ... 2
  Level 2a products: Final products ... 3
  Level 2a products: 12-week, 26-week supplement products ... 3
  Analysis of Final products: October 1, 2013-December 31, 2013 ... 4
  Snapshot velocity field analysis from the reprocessed PBO analysis ... 14
  Earthquake Analyses: 2013/10/01-2013/12/31. ... 21
  Script updates ... 22
GAMIT/GLOBK Community Support ... 23

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 10/1/2013 to 12/31/2013, time series velocity field analyses for the GAGE reprocessing analyses (1996-2013), earthquake effects during the interval (no detectable events) and updates on the LDM delivery of data from MIT to UNAVCO. Associated with report are 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 generated routinely during this quarter. The rapid products are generated daily and sent to UNAVCO via LDM. These products consistent of the original SINEX files submitted by the analysis centers (AC) and the combined loosely constrained SINEX file (rapid_loose.snx), a merged phase RMS file (rapid_nam08.rms), and ITRF2008 North America fixed frame resolved SINEX files for each AC and combined (rapid_nam08.snx). In addition to these files, copies of the atmospheric delay estimate files (a.met) are sent to UNAVCO. These met files are sent asynchronously. Each product is time tagged with the date that is sent. Starting late in 2013, all products are gzip'd before the LDM transfer. For example, the product list for 2013/12/31 rapid analysis consisted of:

```
CWU17732.20131231.a.met.20140101183501.gz
nmt17732.20131231.a.met.20140104183501.gz
pbo17732.rapid_loose.snx.gz.20140104150126
cwu17732.rapid_loose.snx.gz.20140104150126
nmt17732.rapid_loose.snx.gz.20140104150126
pbo17732.rapid_nam08.rms.gz.20140104150126
cwu17732.rapid_nam08.snx.gz.20140104150126
nmt17732.rapid_nam08.snx.gz.20140104150126
pbo17732.rapid_nam08.snx.gz.20140104150126
```

A summary of the analysis is sent to an email exploder pbo_acs@chandler.mit.edu. This list has the following recipients: murray@ees.nmt.edu, marcelo@geology.cwu.edu, tim@geology.cwu.edu, bbwoods@geology.cwu.edu, walter@geology.cwu.edu, dap@unavco.org, puskas@unavco.org, mattioli@unavco.org, boler@unavco.org, jsmith@unavco.org, dmaggert@unavco.org, rwk@chandler.mit.edu, mfloyd@MIT.EDU, tah@mit.edu. The email summaries reports on numbers of stations in the analyses, the scale of the solution (inferred from the average height adjustments of the frame definition sites, the phase RMS scatters of sites that are unique to an AC solutions, metadata errors, and RMS fits to the reference frame sites for the combined (PBO) and individual AC solutions. Sites with position adjustments to the apriori coordinates that are large compared to their standard deviations are also listed. An example summary email is PBO_RAP_17732.sum. Currently each gzipped day of products is about 630 Mbytes.

Time series files are generated from the frame resolved AC and combined solutions. The time series files contain only those rapid solution dates that have not yet been included in the finals analyses. The fundamental SINEX files are generated in the NAM08 reference frame and this analysis forms the basis of the time series files. The combined (PBO) time series are also generated in the IGS08, IGS05 and SNARF 1.0 frames by aligning the time series to these frames (through rotations and translations of the coordinate estimates). Once the final NAM08 reference frame realization is completed using the 1996-2013 reprocessed results, the older IGS05 and SNARF 1.0 frame realized results will be eliminated. The rapid time series tar files are usually less than 100 Mbytes. The files are nominally transferred daily based on when the AC submit their results.

Level 2a products: Final products

The final products are generated weekly and are based on the final IGS orbits. The product list is the same as the rapid solutions except more stations are included since these solutions usually run 2-3 weeks behind real time which allows more time for data downloads. The size of the SINEX products is typically 650 Mb per day with transfers of about 4.5Gb per week. The same email summary file is generated and sent to pbo_acs@chandler.mit.edu but these generally arrive in 7 day groups. The time series files for the finals contain all position results for data from 2004/1/1 to the date of the finals run. Currently, the tar file for each solution type is ~900 Mb. Since time series files are generated in NAM08 (ACs and PBO) and IGS08, IGS05 and SNARF 1.0 for the PBO series, the weekly tar files are about 6.6 Gb. These are transferred once per week. When the NAM08 reference frame is fully realized using all the reprocessed results, the time series files will extend back to 1996/1/1. Each analysis type will then be about 1.4 Gb but since only NAM08 and IGS08 will be sent the total file transfer per week will remain about the same.

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. For the ACs these runs include only new data that has become available since the finals for that week were processed (i.e, the 6 month supplemental run includes site that we in the 12-week supplemental as well as new sites that have become available). These supplemental runs are merged with original finals products and sent to UNAVCO via LDM. Each of these analyses, generates another ~5 Gb of SINEX files per week. The time series are also updated and sent in there entirety (i.e, 2 ~7 Gb per week). In all with the finals, 12-week and 26-week supplemental runs, of order 40 Gb products are generated and transferred per week.

During the first quarter of GAGE, no 12-week or 26-week supplemental products have been sent to UNAVCO. NMT has submitted these results and they are in the ftp area at MIT. CWU has not submitted these results due to computer resource limitations as they complete the reprocessing analysis. As of January 12, 2013, CWU has only a 13 more weeks of results to submit to complete the reprocessing through to GPS week 1716 (12/1/2012). All

Analysis of Final products: October 1, 2013-December 31, 2013

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 2004 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 Oct 1, 2013 and Dec 21,2013. These results are summarized in table 1 and figures 1-X.

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 1.1 mm for all centers and as low as 0.7 mm for NMT north component. The up RMS scatters are less than 6.7 mm and as low as 5.8 mm. 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 1847 sites analyzed in the finals analysis between Oct 1, 2013 and Dec 21, 2013. PBO is the combined solution. Histograms of the RMS scatters are shown in Figure 1-3.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
PBO	0.8	0.9	5.8
NMT	0.7	0.8	4.8
CWU	1.0	1.1	6.7
70%			
PBO	1.1	1.4	4.7
NMT	0.9	1.0	5.5
CWU	1.3	1.6	5.9
95%			
PBO	2.2	2.3	9.1
NMT	2.0	2.1	8.1
CWU	2.8	2.9	10.6

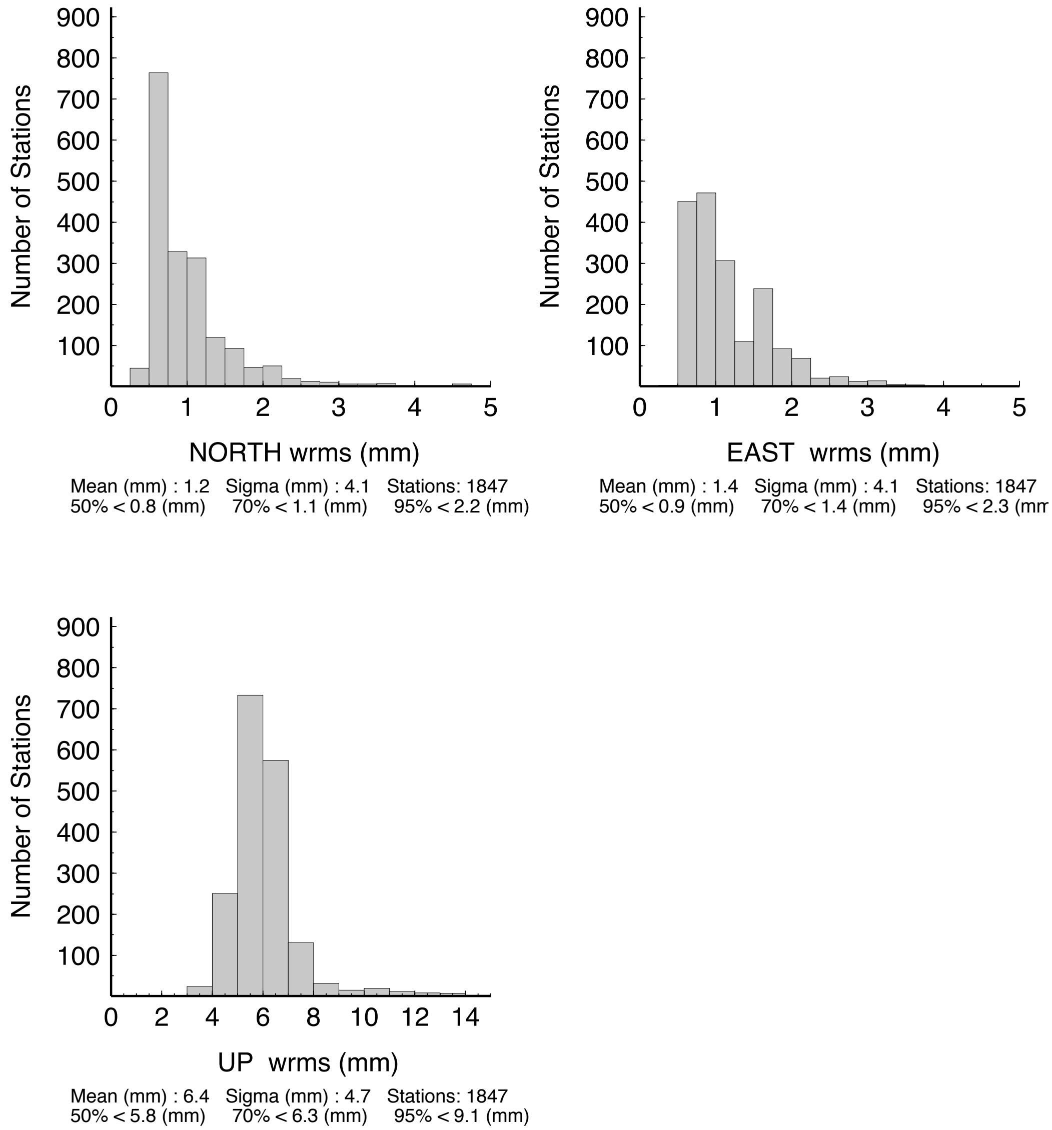


Figure 1: PBO combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1847 sites analyzed between Oct 1, 2013 and Dec 21, 2013. Linear trends and annual signals were estimated from the time series.

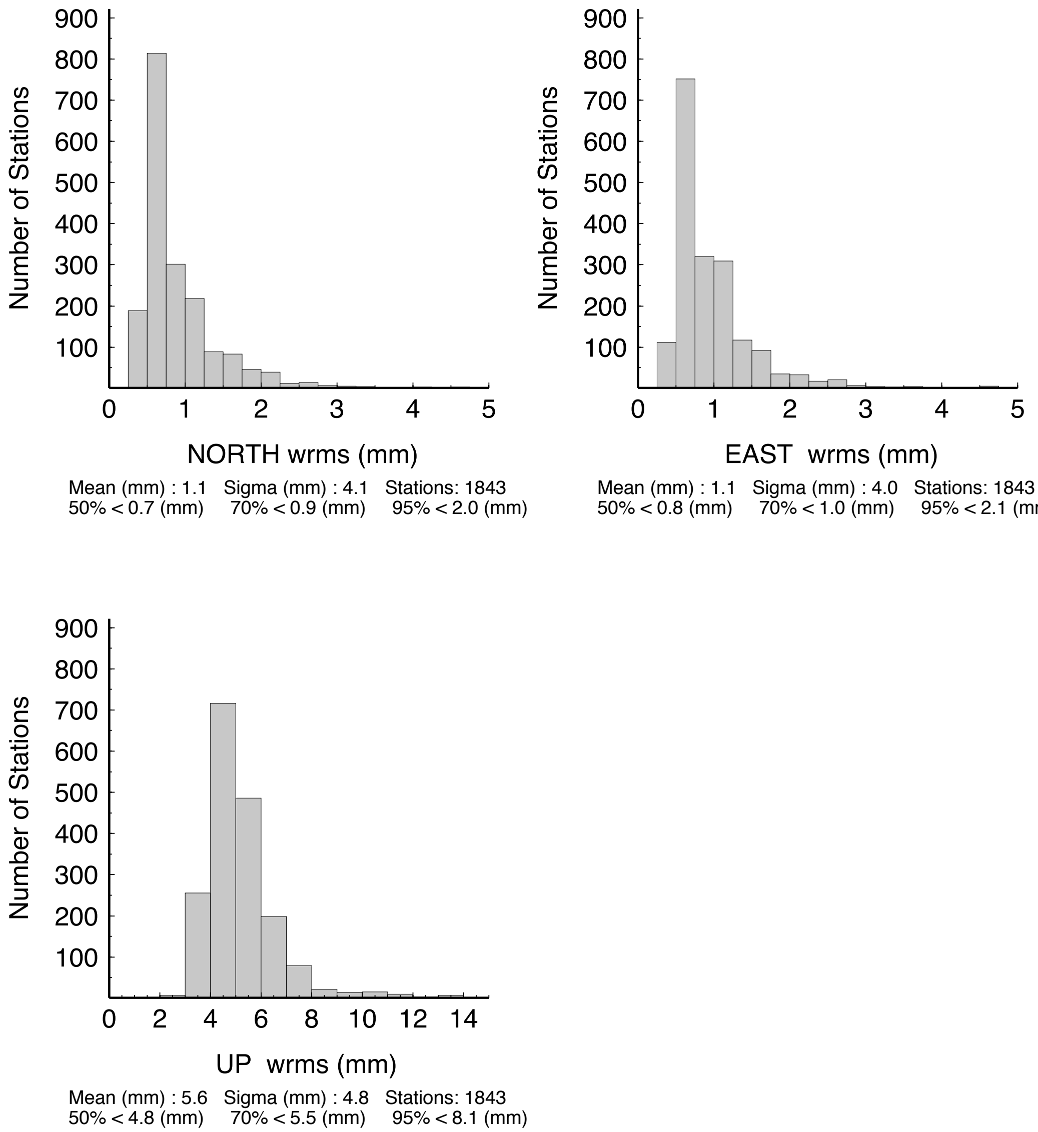


Figure 2: NMT combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1843 sites analyzed between Oct 1, 2013 and Dec 21, 2013. Linear trends and annual signals were estimated from the time series.

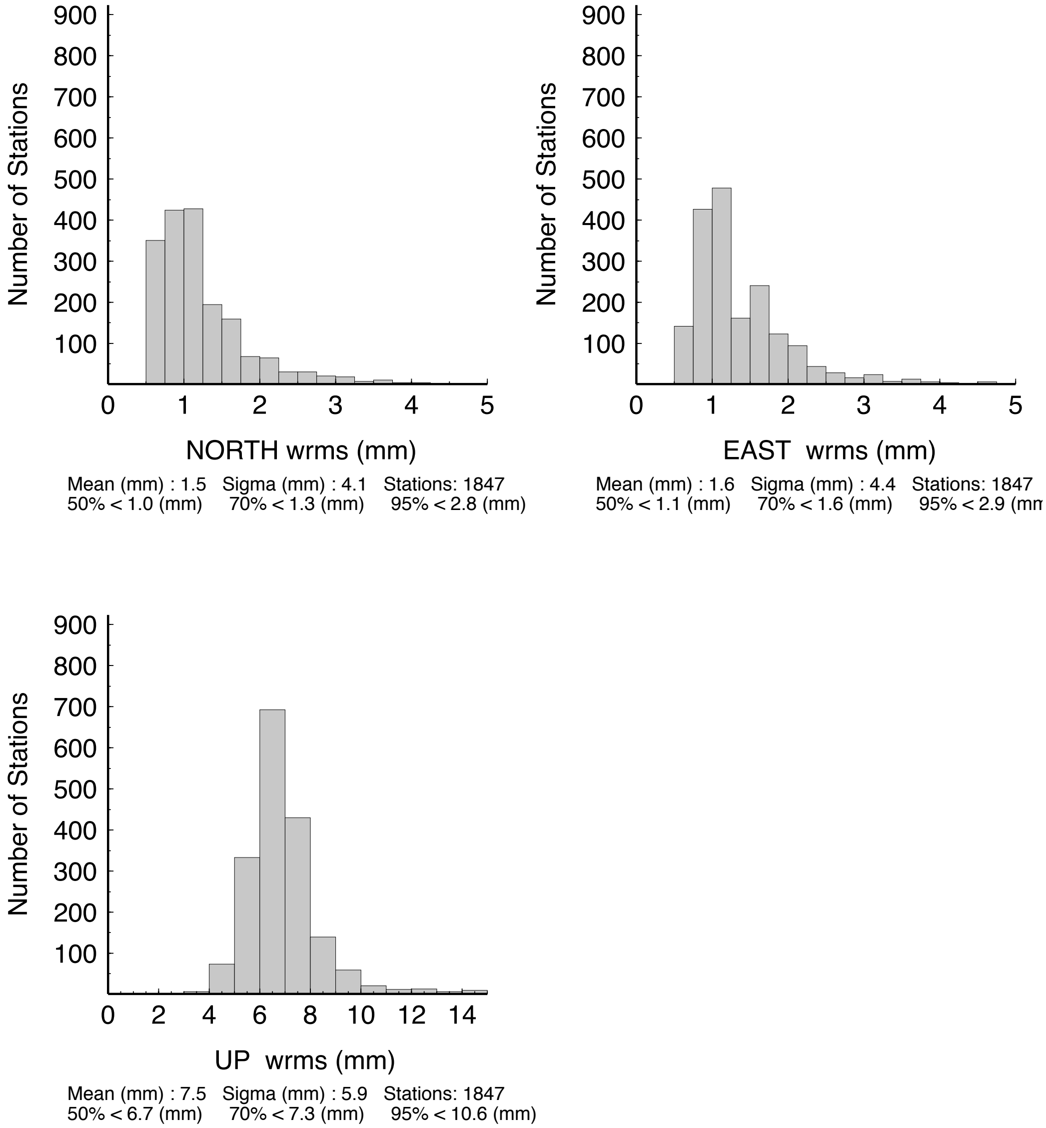


Figure 3: CWU combined solution histograms of the North, East and Up RMS scatters of the position residuals for 1847 sites analyzed between Oct 1, 2013 and Dec 21, 2013. Linear trends and annual signals were estimated from the time series.

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 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_Q01.tab. There are 1849 sites in the file. The contents of the files is of this form:

```
Tabular Position RMS scatters created from PBO_FIN_Q01.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
 1LSU     82       0.8   0.53       1.6   0.97     4.9   0.76
 1NSU     82       1.0   0.64       1.5   0.89     6.0   0.91
 1ULM     82       0.9   0.56       1.5   0.95     5.5   0.91
 7ODM     82       1.1   0.63       1.1   0.70    23.4   3.54
 AB01     81       2.3   1.27       1.4   0.98     5.9   1.01
…
 ZDC1     82       1.1   0.58       1.8   1.02     5.8   0.83
 ZDV1     82       1.0   0.48       1.2   0.64     6.4   0.86
 ZKC1     82       1.1   0.52       1.6   0.85     6.2   0.84
 ZLA1     82       1.1   0.48       1.6   0.83     6.5   0.81
 ZME1     82       1.3   0.64       1.7   0.83     6.4   0.79
 ZNY1     82       1.3   0.61       1.6   0.88     5.1   0.69
 ZSE1     82       1.1   0.43       1.1   0.57     5.3   0.69
 ZTL4     82       1.0   0.50       1.7   0.86     5.0   0.64
```

Table 2: RMS scatter of the position residuals for the PBO combined solution between Oct 1, 2013 and Dec 21, 2013 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	0.8	5.6	903
NUCLEUS	0.6	0.8	5.9	208
USGS SCIGN	0.7	1.0	6.4	98
Expanded	1.1	1.5	6.0	557
GAMA	0.8	1.7	5.9	12
COCO Net	2.0	2.0	7.6	69
70 %				
PBO	0.8	1.0	6.0	
NUCLEUS	0.8	0.9	6.1	
USGS SCIGN	1.0	1.1	7.1	
Expanded	1.2	1.7	6.5	
GAMA	0.9	2.0	6.4	
COCO Net	2.2	2.3	8.4	
95%				
PBO	1.9	1.9	7.1	
NUCLEUS	1.5	1.3	7.2	
USGS SCIGN	2.3	1.9	23.2	
Expanded	2.2	2.4	11.1	
GAMA	1.5	2.7	9.2	
COCO Net	3.4	4.9	13.6	

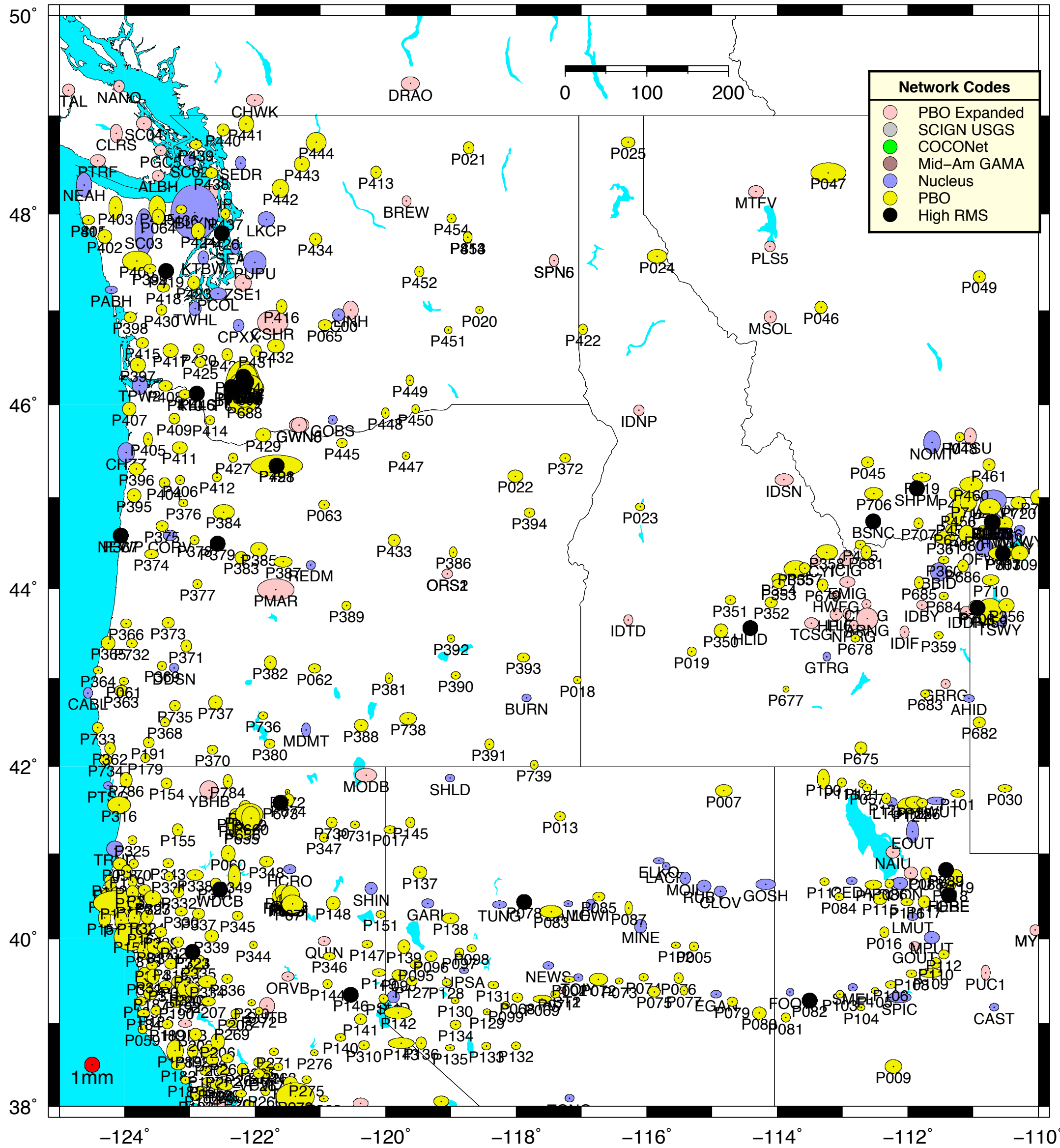


Figure 4: Distribution of the RMS scatters of horizontal position estimates from the PBO combined analysis for the Northern Western United States. The color of the ellipses that give the north and east RMS scatters denotes the network given by the legend in the figure. The small red circle shows the size of 1 mm scatters. Sites shown with black circles have combined RMS scatters in north and east greater than 5 mm.

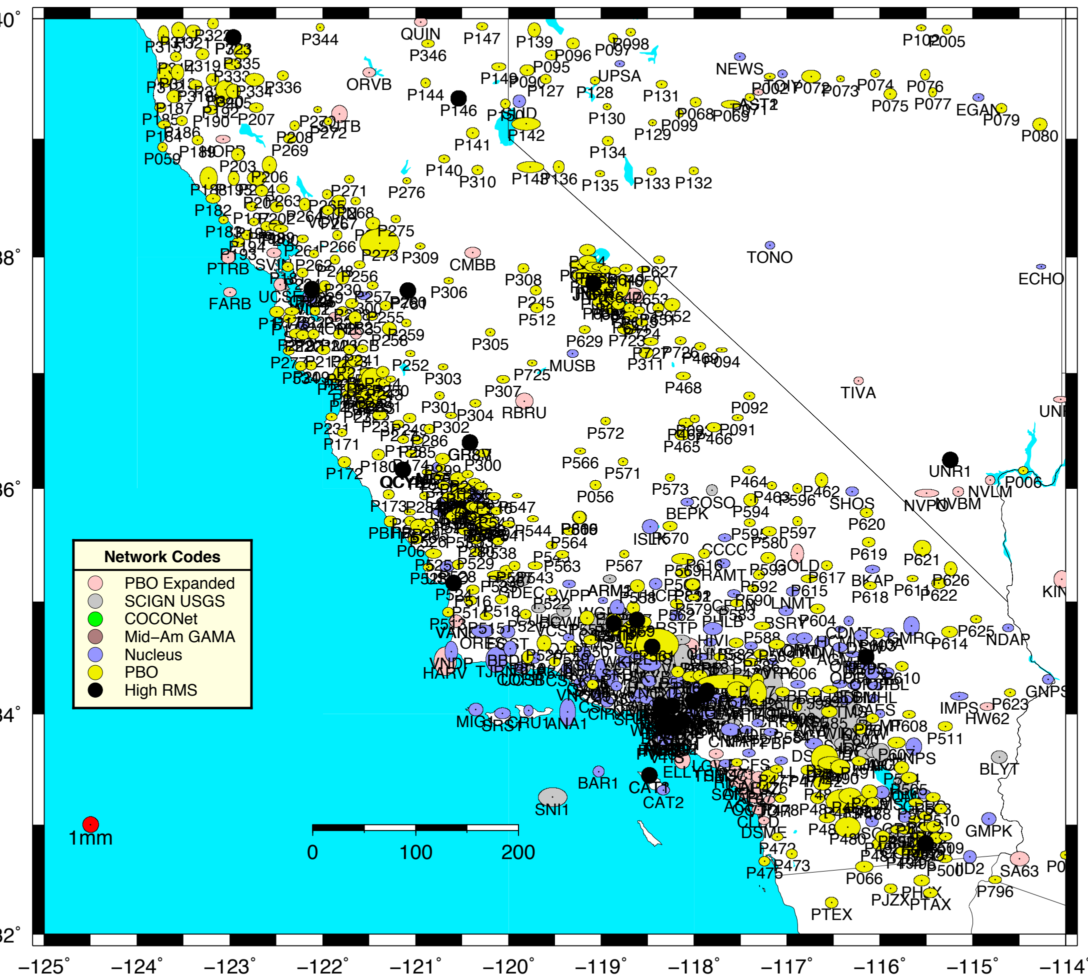
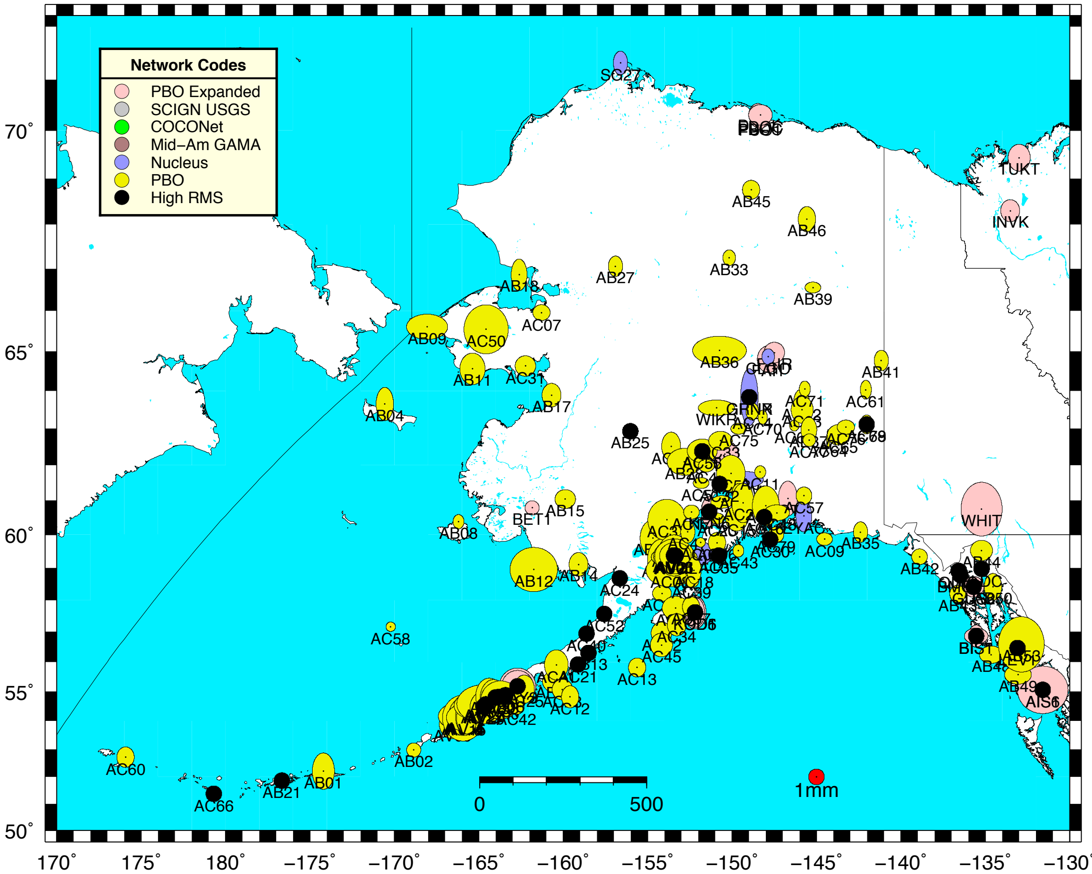


Figure 5: Same as Figure 4 except for the Southern Western United States.


Network Codes
PBO Expanded
SCIGN USGS
COCONet
Mid–Am GAMA
Nucleus
PBO
High RMS
70˚
65˚
60˚
55˚
50˚
170˚
175˚
180˚
−175˚
−170˚
−165˚
−160˚
−155˚
−150˚
−145˚
−140˚
−135˚
−130˚
0
500
1mm
SG27
TUKT
INVK
AB45
AB46
AB33
AB39
AB27
AB18
AC07
AB09
AC50
AB11
AC31
AB17
AB04
AB36
AB41
AC61
AB25
WIKR
AC75
AC70
AC71
AC57
AC11
BET1
AB15
AB08
WHIT
AC09
AB35
AB42
AB44
AB12
AB14
AC24
AC58
AC52
AC45
AC13
AC21
AC12
AC42
BIS1
AB49
AIS6
AB02
AC60
AB21
AB01
AC66

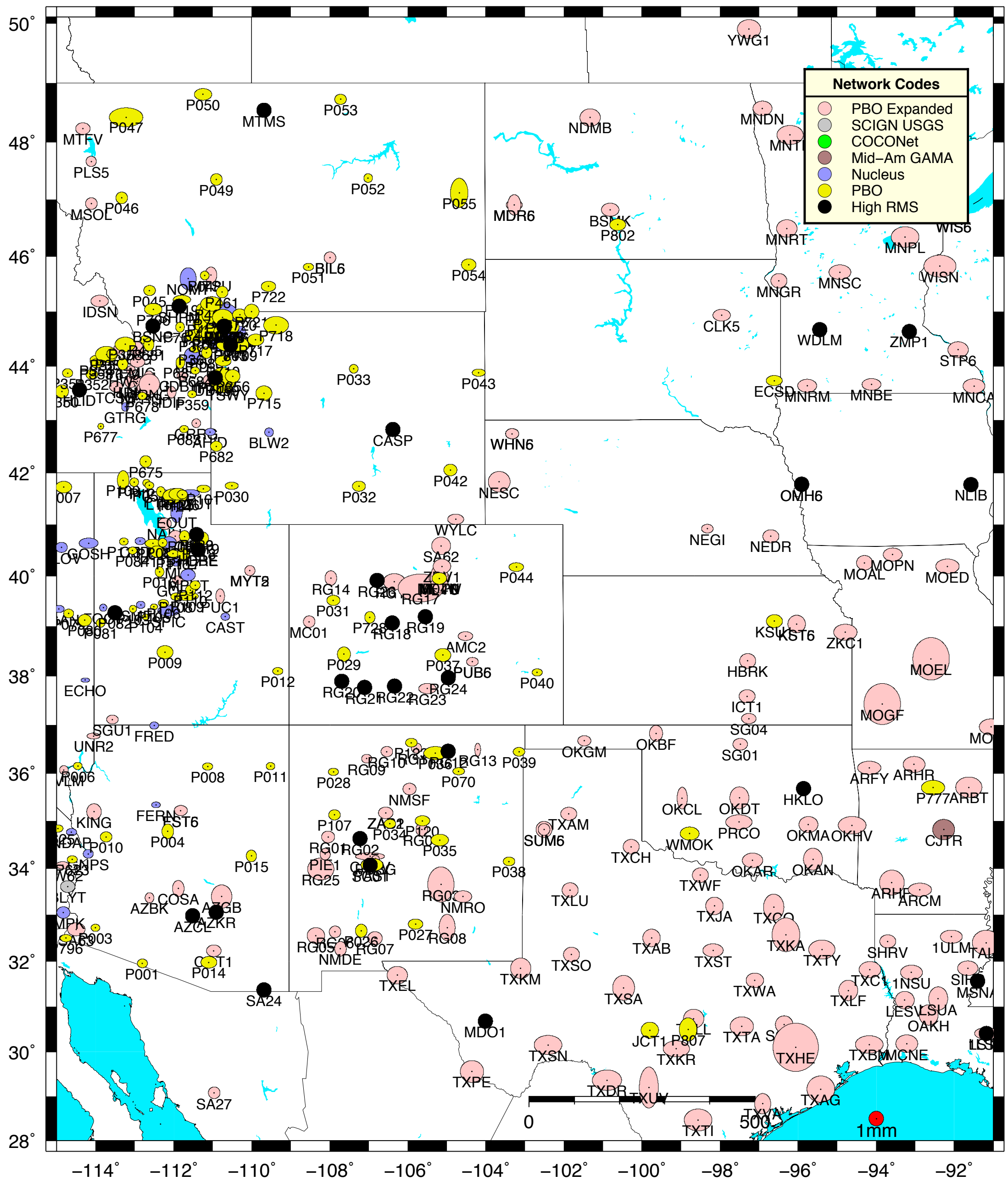


Figure 7: Same as Figure 4 except for the Central United States

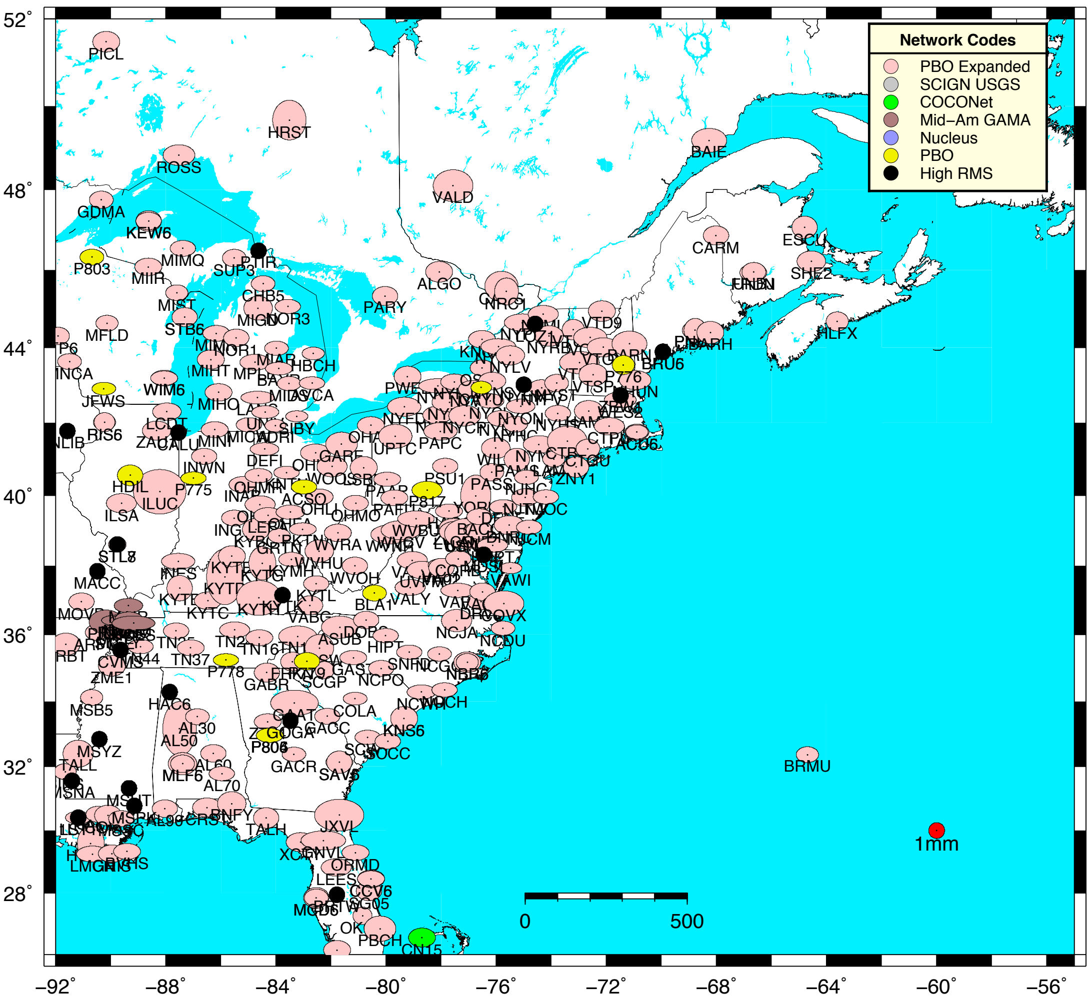


Figure 8: Same as Figure 4 except for the Eastern United States

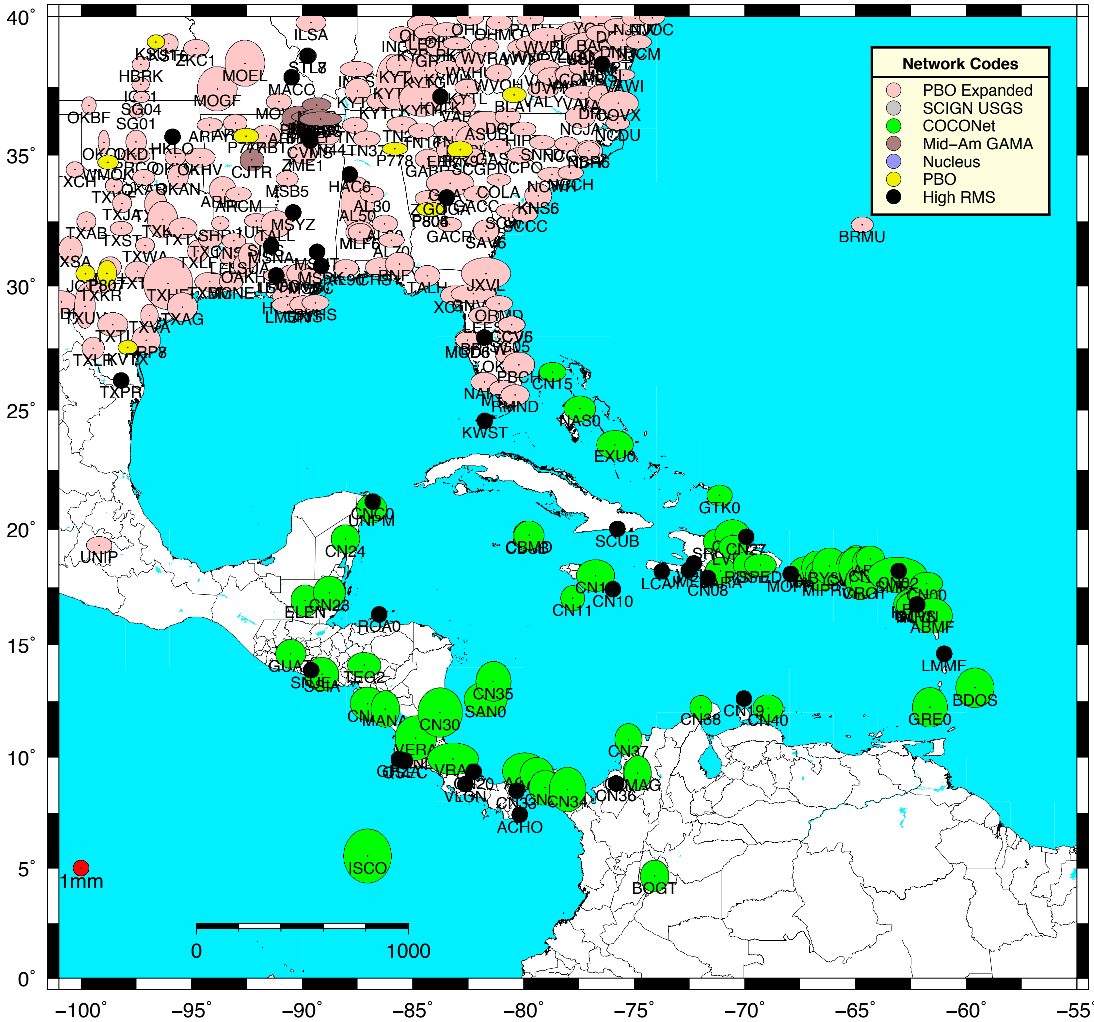


Figure 9: Same as Figure 4 except for the Caribbean region.

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. For this quarterly report, we generate these velocity estimates for the reprocessed results and the current GAGE analyses (starting 2012/09/23) that are in the NAM08 reference frame. There 2044 sites in the analyses and the statistics of the fits to results are shown in Table 3. In this analysis, offsets are estimated for antenna changes and earthquakes. Annual signals are estimated and for some earthquakes, logarithmic post-seismic signals are also estimated. The full tables of RMS fits along with the duration of the data used are given in the following linked files: pbo_nam08_131221.tab, nmt_nam08_131221.tab and cwu_nam08_131221.tab. The velocity estimates are shown by region and network type in Figures 10-15. The color scheme used is the same as Figures 4-9. The snapshot velocity field files are linked as: pbo_nam08_131221.snpvel, nmt_nam08_131221.snpvel and cwu_nam08_131221.snpvel.

Table 3: Statistics of the fits of 2044 sites analyzed in the reprocessed analysis for data collected between Jan 1, 1996 and Dec 21, 2013.

Center	North (mm)	East (mm)	Up (mm)
Median (50%)			
PBO	1.5	1.7	8.1
NMT	1.2	1.3	5.5
CWU	1.8	2.6	9.1
70%			
PBO	2.0	2.6	8.6
NMT	1.6	1.8	6.5
CWU	2.4	3.7	10.0
95%			
PBO	4.1	4.4	11.9
NMT	3.5	3.4	9.4
CWU	4.6	6.1	14.8

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 which 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 0.22 mm/yr horizontal and 0.8 mm/yr vertical in direct difference of all sites in both solutions (2022 sites). The χ/f^2 of the difference is $(1.68)^2$. Since the RMS is weighted, sites with small standard deviations with tend to dominate the WRMS. Establishing a lower bound on the standard deviation of the velocity estimates 0.3 mm/yr (summed squared into the horizontal velocity standard deviations) generates and RMS difference of 0.37 mm/yr with a χ/f^2 of unity. In the next quarter, we will generate a new NAM08 realization using all of the reprocessed GPS results.

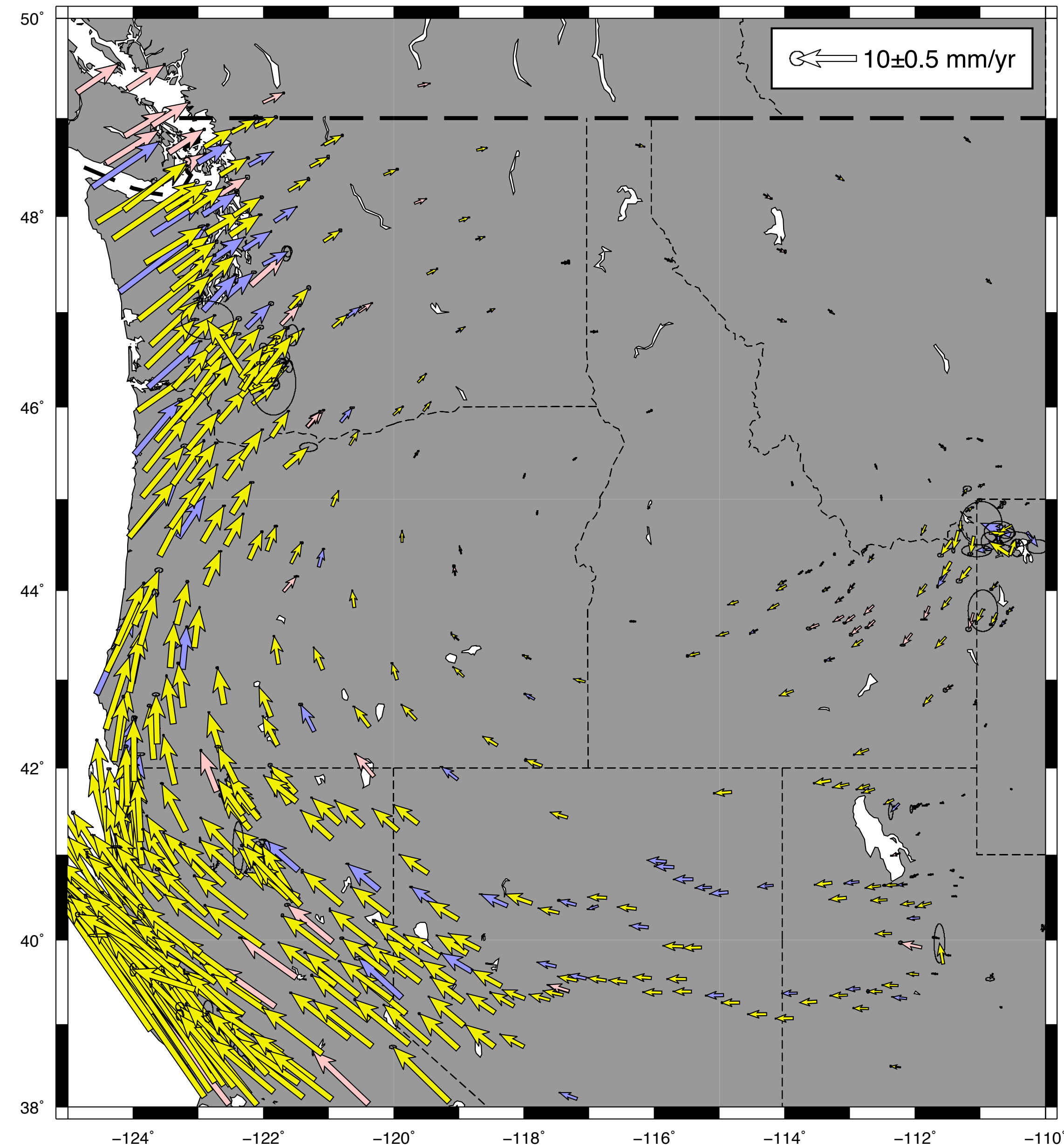


Figure 10: Velocity field estimates from the combined PBO solutions generated using time series analysis and the FOGMEX error model. 95% confidence interval error ellipses are shown. The color scheme of the vectors matches the network type legend in Figure 4. Only velocities with horizontal standard deviations less than 3 mm/yr are shown.

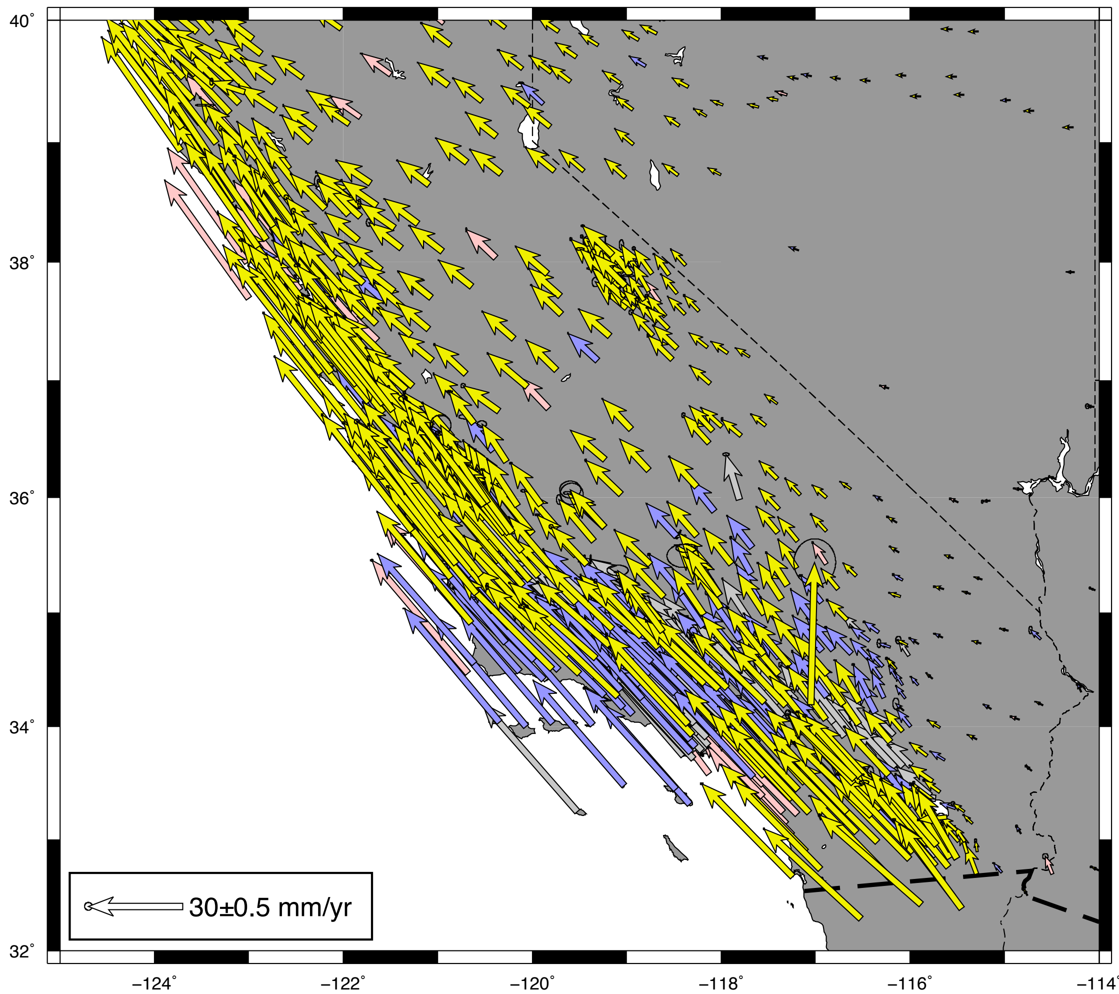


Figure 11: Same as Figure 10 except for South Western United States. Only velocities with horizontal standard deviations less than 5 mm/yr are shown. The anomalous site at latitude 34, longitude -117 is P613 and is effected by the estimation of post-seismic motion after the 2010 Apr 4 El Major Cucupah earthquake.

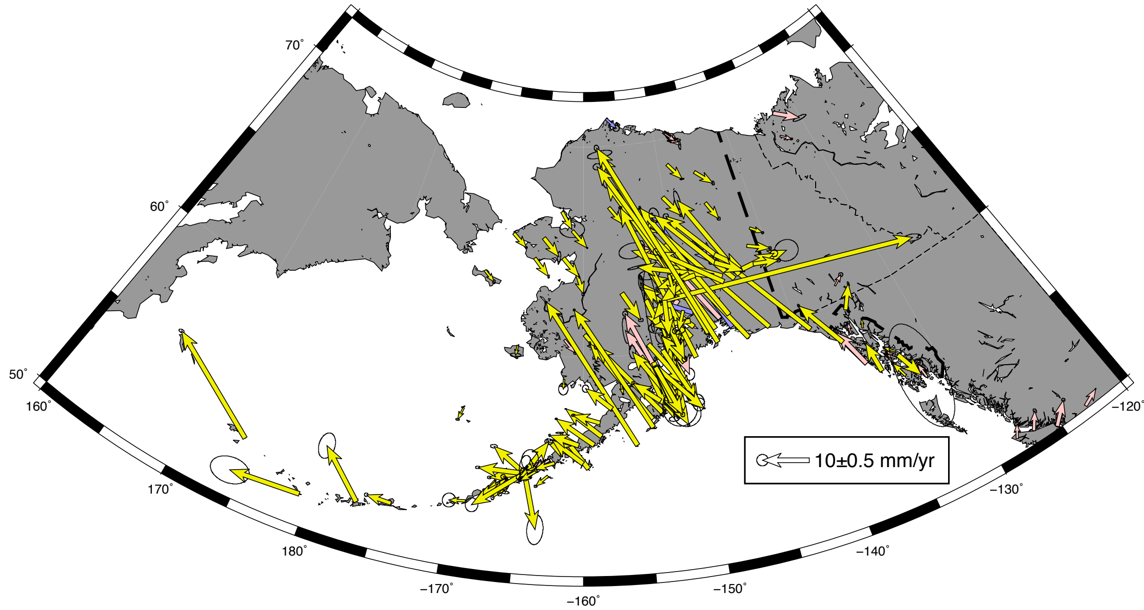


Figure 12: Same as Figure 10 except for Alaska. Only velocities with horizontal standard deviations less than 5 mm/yr are shown. The anomalous vector in Central Alaska is AC55 as the sites does move with anomalous motion. The site was discontinued in mid-2010.

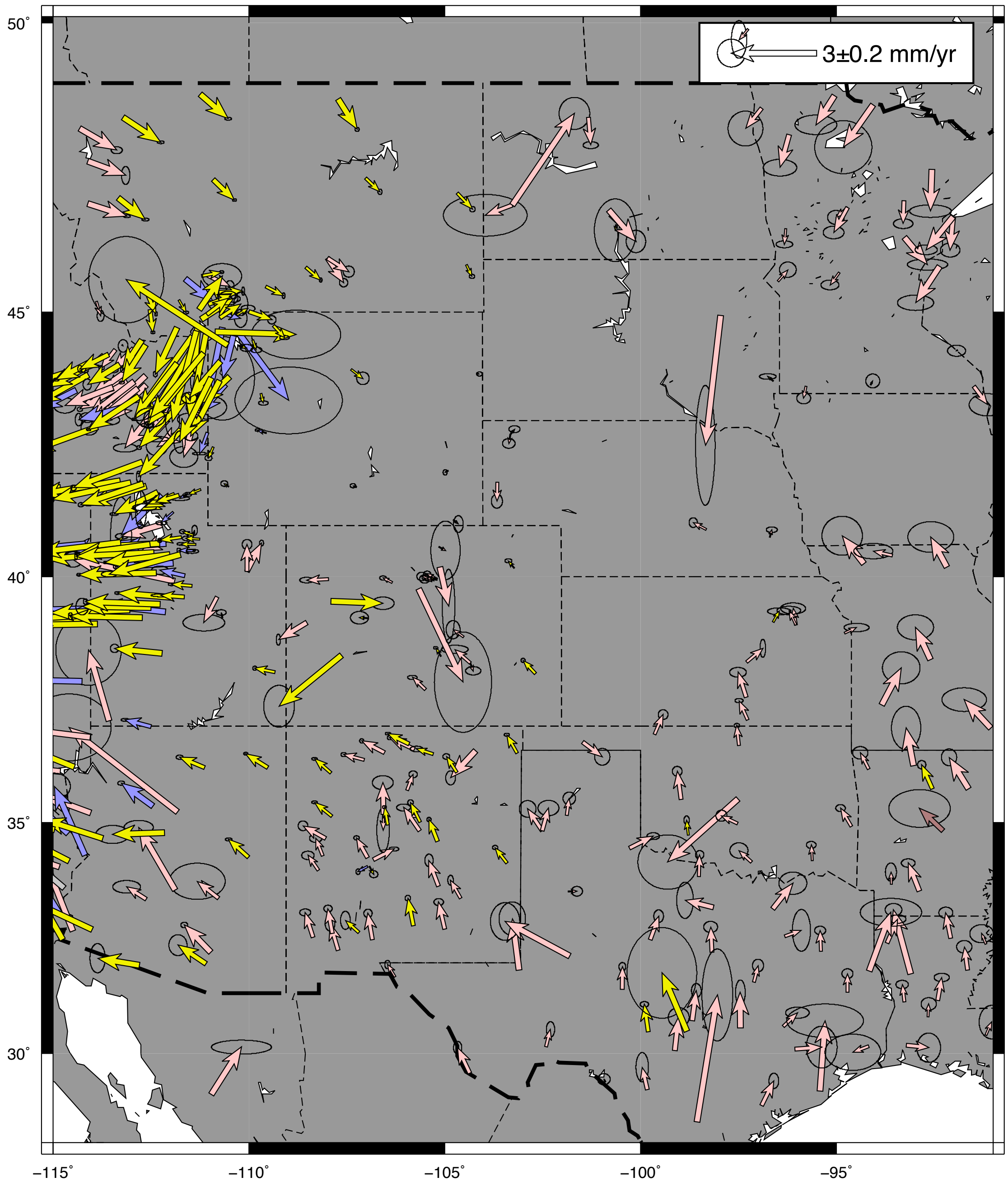


Figure 13: Same as Figure 10 except for Central United States. Only velocities with horizontal standard deviations less than 1 mm/yr are shown.

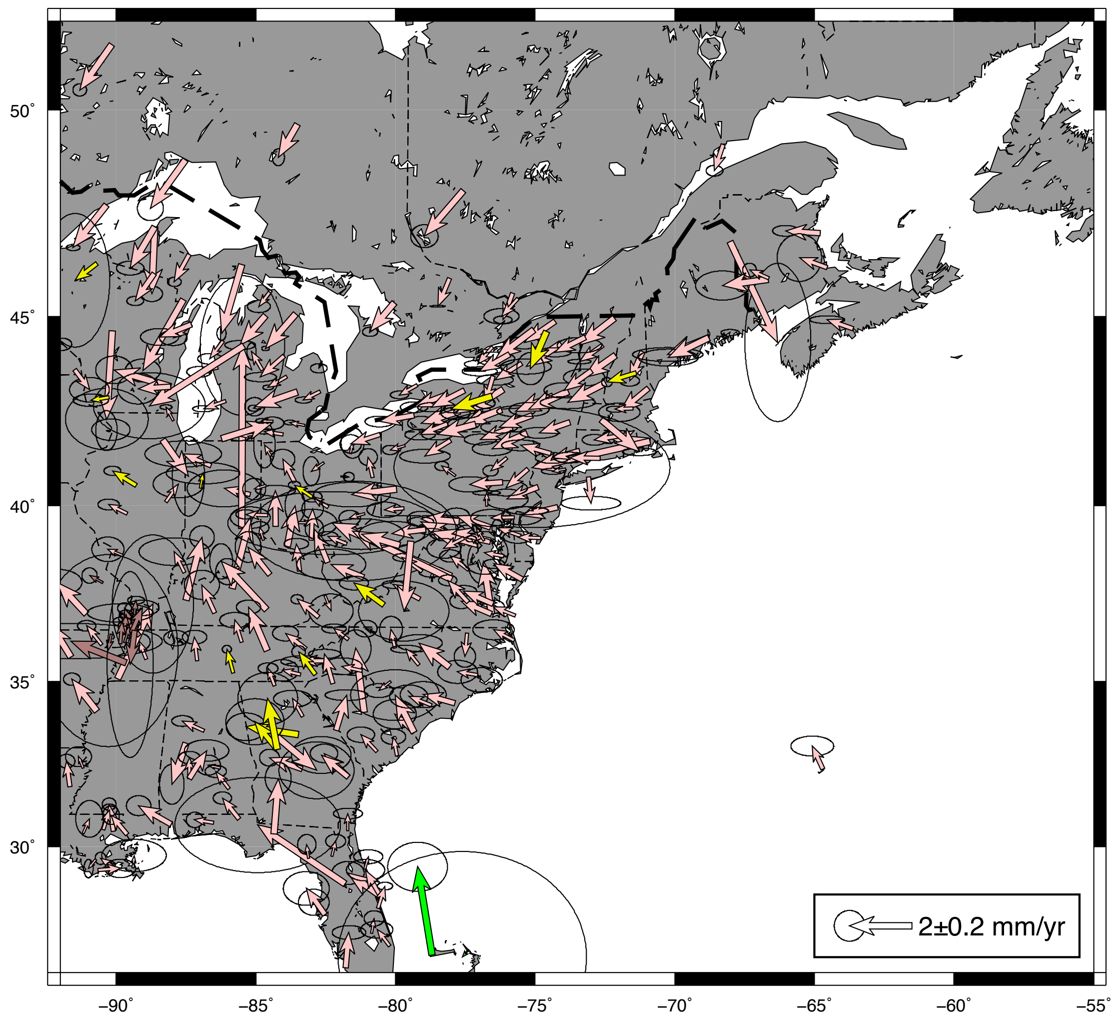


Figure 14: Same as Figure 10 except for the Eastern United States. Only velocities with horizontal standard deviations less than 2 mm/yr are shown.

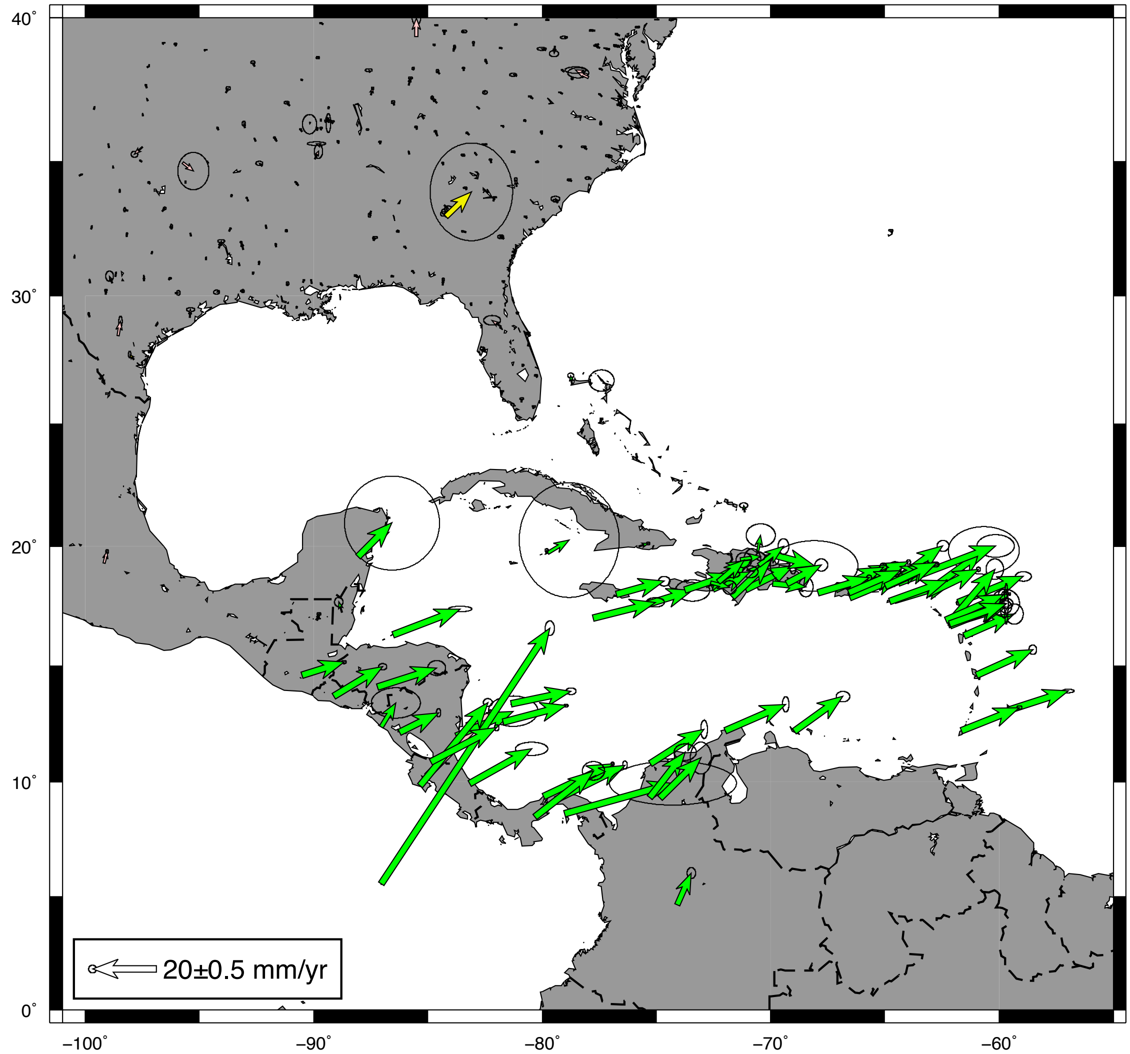


Figure 15: Same as Figure 10 except for the Caribbean region. Only velocities with horizontal standard deviations less than 10 mm/yr are shown.

Earthquake Analyses: 2013/10/01-2013/12/31.

We use the NEIC catalog to search for earthquakes that could cause coseismic offsets at the sites analyzed by the GAGE analysis centers. The search web site is http://earthquake.usgs.gov/earthquakes/search/ which generates a URL used for the search of the form: http://comcat.cr.usgs.gov/fdsnws/event/1/query?starttime=2013-09-01%2000:00:00&maxlatitude=80&minlatitude=0&maxlongitude=-50&minlongitude=-170&minmagnitude=3.5&format=csv&endtime=2014-01-04%2023:59:59&orderby=time. We directly generate the URL and use wget to recover the catalog entries over the desired time interval and geographic region. The output is a comma separated file with columns: time,latitude,longitude,depth,mag,magType,nst,gap,dmin,rms,net,id,updated,place,type.

The earthquakes are then tested to see if they might generate coseismic motions based on an empirical algorithm that uses distance to and magnitude of the event. In the interval between 2013/09/01 and 2014/01/04 only a few events were detected that might have generated coseismic offsets. The largest of these were a pair of events 2 km south west of La Verne in California.

```
2013-09-19T11:43:55.900Z,34.0817,-
117.785,2.9,3.7,Ml,148,14.4,0.01796631,0.2,ci,ci11366538,20
13-12-25T07:58:22.516Z,"2km SW of La Verne,
California",earthquake
2013-09-19T12:06:33.500Z,34.0817,-
117.784,3.6,3.8,Ml,154,14.4,0.01796631,0.23,ci,ci11366562,2
013-12-25T07:46:06.038Z,"2km SW of La Verne,
California",earthquake
```

The predicted possible displacements from the larger of these events were computed to be 10.1 mm at PSDM (2.5 km from the epicenter) and 1.6 and 1.1 mm are LORS and CLAR, 6.3 and 7.5 km from the epicenter. The PBO time series for these sites at the time of the events did not show any offsets at and consequently we have not added this event to our list of significant earthquakes. The other possible significant event was 90km ESE of Old Iliamna, Alaska.

```
2013-12-28T14:42:58.000Z,59.3494,-
153.5151,117.1,4.1,ml,29,151.199987904001,0.03772924,0.57,a
k,ak10907457,2013-12-28T22:45:26.378Z,”90km ESE of Old
Iliamna, Alaska”,earthquake
```

This event may has caused displacements at AV01 6.4 mm, AV02 2.4 mm, AV03 2.1 mm, AV04 3.7 mm, AV05 2.2 mm, AV11 0.7 mm, AV16 3.6 mm, AV17 1.3 mm, AV18 2.1 mm, AV19 2.0 mm, AV20 2.7 mm and AV21 0.7 mm. Not offsets were apparent in the time series for the sites most likely effected by the earthquake but some sites (AV03, AV04, AV05 and AV21) have not had recent data and so we cannot check at these sites yet.

Script updates

With the delivery of large volumes of data through the LDM queuing system we have made extensive changes to the methods used to add results to the LDM queue. One of the recurring problems we have had is the LDM queue being drained to allow more products to be added before all the products were extracted from the queue at UNAVCO. We have implemented script control of our LDM queue additions to avoid loss of data if the queue has not drained completely. Before adding new products to the MIT queue, we compute how much space will be needed to add these products and then we compute how much space is available by comparing the MIT queue entries to the products available in the ftp products area at UNAVCO. If there is sufficient space, we add the new products. If there is not enough space, we sleep the process for 10 minutes and then check the UNAVCO ftp area again to see if more products have been transferred to the ftp area. After every hour of waiting, an email is sent to indicate that product transfers are delayed. This approach was necessary with the large volumes of products being delivered as various parts of the reprocessing results are updated. This new approach is working well especially after we put an additional limitation, requested by UNAVCO, not to queue more than 50 Gb of products per day. Due to this limit, we are still delivering reprocessed results to the UNAVCO archive.

GAMIT/GLOBK Community Support

During this period we carried out routine development of the GAMIT/GLOBK software: minor enhancement for 14 features, table updates of PRN reassignments for two satellites, generation of lunisolar tables for 2014, and support for 6 new receivers and 8 new antennas.

There were no workshops, but we spent 5-10 hours per week in email support for users. During this period, we issued royalty-free licenses to 24 new users from universities and government laboratories, including 4 from US institutions.