Notes on the 2016 GAGE Velocity field to GPS Week 1925 2016-12-03

These notes add supplemental information to "Notes on the 2015 PBO Velocity field to Week 1870 2015-11-14" https://www.unavco.org/data/gps-gnss/derived-products/docs/GAGE_GPS_Velocity_Release_Notes_20151223.pdf

The 2016 GAGE full velocity solution includes GPS data from GPS week 0834 (Jan-01-1996) to week 1925 (Dec-03-2016).

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 2015 release documents the methods being used to generate these velocity fields.
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. Twelve sites are excluded based on this criterion (AC30 AV05 CAPI CN44 CN49 HVHS P323 P656 SMM1 SMM2 SUMM VORA). 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. 544 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 8112123 station-days. The outlier criteria remove 9129 (0.11%) of NMT and 46934 (0.58%) of CWU station-days of solutions.

The processing divides the 2174 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 100 to 285 individual site names to accommodate the discontinuities). There is no overlap between the sites in the first 28 networks. A 29^{th} network is created to tie all the other 28 networks into a single solution. To form the sites in the 29^{th} 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 ~20Gb 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 1126 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 33 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 (2016-12-03 GPS Week 1925 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 two and half years 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 765 stations in the solution (These stations have velocity standards less than the median standard deviations in north, east and up in all three components. The number of stations is less than half the number of stations because the standard deviation condition must be met in all components). 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 2015 velocity solution) and in height less than 0.8 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 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 6-years old and will soon be replaced by ITRF2014 (IGS14) in early 2016.

Along with this release of the velocity field we also release a folder with ancillary files and results similar to the files released for the Reviews of Geophysics paper. The contents of the DOI_161203 folder are described in Table 5.

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 entries PBO_2015 and PBO_2014 are the earlier 2015 and 2014 PBO full solution generated in November 2015 and 2014. # is the number of common sites in the solutions.

Soln1 - Soln2	#	N mean (mm/yr)	N WRMS (mm/yr)	N NRMS	E mean (mm/yr)	E WRMS (mm/yr)	E NRMS
PBO_GKNA-	CWU_GKNA	2167	-0.02	0.07	0.316	-0.00	0.06	0.304
PBO_GKNA-	NMT_GKNA	2173	0.01	0.06	0.271	0.00	0.07	0.320
CWU_GKNA-	NMT_GKNA	2166	0.03	0.12	0.568	0.00	0.13	0.607
PBO_GKNA-	PBO_TSLS	2174	-0.02	0.13	0.848	-0.02	0.13	0.832
PBO_GKNA-	PBO_TSKF	2173	-0.03	0.15	0.831	-0.01	0.14	0.782
PBO_GKNA-	CWU_TSLS	2167	-0.02	0.15	0.933	-0.02	0.15	0.924
PBO_GKNA-	CWU_TSKF	2165	-0.02	0.16	0.881	-0.01	0.16	0.851
PBO_GKNA-	NMT_TSLS	2173	-0.01	0.16	1.017	-0.02	0.15	0.924
PBO_GKNA-	NMT_TSKF	2170	-0.03	0.18	0.945	-0.02	0.15	0.830
PBO_GKNA-	PBO_GKIG	2174	-0.00	0.09	0.426	0.21	0.24	1.145
PBO_GKNA-	CWU_GKIG	2167	-0.00	0.10	0.468	0.21	0.24	1.156
PBO_GKNA-	NMT_GKIG	2173	0.02	0.10	0.486	0.20	0.23	1.107
PBO_GKNA-	PBO_2015	2137	-0.02	0.18	0.831	-0.03	0.16	0.740

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/yr)	Hz WRMS (mm/yr)	Hz NRMS	U Mean (mm/yr)	U WRMS (mm/yr)	U NRMS
PBO_GKNA-	CWU_GKNA	2167	-0.01	0.06	0.310	0.01	0.21	0.384
PBO_GKNA-	NMT_GKNA	2173	0.01	0.06	0.296	-0.06	0.18	0.344
CWU_GKNA-	NMT_GKNA	2166	0.02	0.12	0.588	-0.07	0.36	0.660
PBO_GKNA-	PBO_TSLS	2174	-0.02	0.13	0.840	0.00	0.35	0.803
PBO_GKNA-	PBO_TSKF	2173	-0.02	0.15	0.807	-0.06	0.38	0.816
PBO_GKNA-	CWU_TSLS	2167	-0.02	0.15	0.928	-0.02	0.41	0.903

PBO_GKNA-	CWU_TSKF	2165	-0.02	0.16	0.866	-0.08	0.42	0.877
PBO_GKNA-	NMT_TSLS	2173	-0.02	0.15	0.972	-0.40	0.70	1.538
PBO_GKNA-	NMT_TSKF	2170	-0.02	0.16	0.889	-0.44	0.73	1.508
PBO_GKNA-	PBO_GKI G	2174	0.11	0.18	0.864	-0.42	0.45	0.849
PBO_GKNA-	CWU_GKI G	2167	0.11	0.19	0.882	-0.18	0.29	0.514
PBO_GKNA-	NMT_GKI G	2173	0.11	0.18	0.855	-0.60	0.66	1.280
PBO_GKNA-	PBO_2015	2137	-0.03	0.17	0.787	0.04	0.41	0.673

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 1087 sites is because both horizontal and vertical sigma conditions must be satisfied.)

Soln 1-	Soln 2	#	N mean (mm/yr)	N WRMS (mm/yr)	N NRMS	E mean (mm/yr)	E WRMS (mm/yr)	E NRMS
PBO_GKNA-	CWU_GKNA	765	-0.02	0.04	0.275	0.01	0.05	0.310
PBO_GKNA-	NMT_GKNA	765	0.01	0.04	0.230	-0.00	0.05	0.320
CWU_GKNA-	NMT_GKNA	765	0.03	0.08	0.488	-0.01	0.10	0.616
PBO_GKNA-	PBO_TSLS	765	-0.02	0.09	0.789	-0.01	0.08	0.685
PBO_GKNA-	PBO_TSKF	765	-0.02	0.10	0.719	-0.01	0.09	0.623
PBO_GKNA-	CWU_TSLS	765	-0.02	0.09	0.802	-0.01	0.09	0.734
PBO_GKNA-	CWU_TSKF	765	-0.02	0.10	0.690	-0.00	0.09	0.617
PBO_GKNA-	NMT_TSLS	765	-0.01	0.11	0.889	-0.02	0.09	0.738
PBO_GKNA-	NMT_TSKF	765	-0.02	0.11	0.765	-0.02	0.09	0.651
PBO_GKNA-	PBO_GKI G	765	0.01	0.08	0.490	0.22	0.24	1.503
PBO_GKNA-	CWU_GKI G	765	0.01	0.08	0.481	0.22	0.24	1.509
PBO_GKNA-	NMT_GKI G	765	0.04	0.09	0.554	0.21	0.23	1.447
PBO_GKNA-	PBO_2015	765	-0.01	0.11	0.664	-0.03	0.09	0.538

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

Soln 1-	Soln 2	#	Hz Mean (mm/yr)	Hz WRMS (mm/yr)	Hz NRMS	U Mean (mm/yr)	U WRMS (mm/yr)	U NRMS
PBO_GKNA-	CWU_GKNA	765	-0.01	0.05	0.293	0.03	0.16	0.378
PBO_GKNA-	NMT_GKNA	765	0.00	0.04	0.279	-0.06	0.13	0.344
CWU_GKNA-	NMT_GKNA	765	0.01	0.09	0.556	-0.08	0.26	0.644
PBO_GKNA-	PBO_TSLS	765	-0.02	0.09	0.739	-0.01	0.25	0.779
PBO_GKNA-	PBO_TSKF	765	-0.01	0.09	0.673	-0.06	0.28	0.809
PBO_GKNA-	CWU_TSLS	765	-0.02	0.09	0.769	-0.04	0.28	0.837
PBO_GKNA-	CWU_TSKF	765	-0.01	0.09	0.654	-0.09	0.30	0.844
PBO_GKNA-	NMT_TSLS	765	-0.01	0.10	0.817	-0.36	0.60	1.763

PBO_GKNA-NMT_TSKF 765 -0.02 0.10 0.710 -0.41 0.62 1.754

PBO_GKNA-PBO_GKIG 765 0.12 0.18 1.118 -0.40 0.42 1.087
PBO_GKNA-CWU_GKIG 765 0.11 0.18 1.120 -0.16 0.23 0.551
PBO_GKNA-NMT_GKIG 765 0.12 0.18 1.096 -0.58 0.62 1.638

PBO_GKNA-PBO_2015 765 -0.02 0.10 0.604 0.04 0.28 0.595

Table 5: Ancillary and velocity fields supplied with this solution (folder DOI_161203/)

File	Description
All_PBO.rw	Random walk parameters by station for use in GLOBK Kalman filter
All_PBO_ants.eq	List of epochs of discontinuities due to antenna and radome changes in GLOBK EQ-format. There are 1454 entries.
All_PBO_edits.eq	List of sites and times of position estimates removed from the final velocity solution combination either because they are outliers (e.g., snow/ice on antenna) or have large standard deviations (60814 entries).
All_PBO_eqs.eq	List of 42 earthquakes included for co-seismic offset discontinuities. 9 of these earthquakes include parameterized logarithmic post-seismic terms.
All_PBO_unkn.eq	List of sites and epochs of discontinuities in position time series that occur for unknown reasons (or unknown times when an antenna partially fails).
All_PBO_netsel.use	List of sub-networks used to create the combined velocity solution.
pbo.final_nam08.20161203.vel	Combined velocity field based on GLOBK SINEX file analysis in the NAM08 reference frame. PBO velocity field file format.
cwu.final_nam08.20161203.vel	CWU velocity field based on GLOBK SINEX file analysis in the NAM08 reference frame. PBO velocity field file format.
nmt.final_nam08.20161203.vel	NMT velocity field based on GLOBK SINEX file analysis in the NAM08 reference frame. PBO velocity field file format.
pbo.snaps_nam08.20161203.vel	Combined velocity field based on time series

	analysis in the NAM08 reference frame. PBO velocity field file format.
cwu.snaps_nam08.20161203.vel	CWU velocity field based on time series analysis in the NAM08 reference frame. PBO velocity field file format.
nmt.snaps_nam08.20161203.vel	NMT velocity field based on time series analysis in the NAM08 reference frame. PBO velocity field file format.
pbo.final_igs08.20161203.vel	Combined velocity field based on GLOBK SINEX file analysis in the IGS08 reference frame. PBO velocity field file format.
pbo.tswls_nam08.20161203.gvl	Combined velocity field based on time series weighted least squares (WLS) analysis in the NAM08 reference frame. GLOBK velocity field file format.
pbo.tskfa_nam08.20161203.gvl	Combined velocity field based on time series Kalman filter (KF) analysis in the NAM08 reference frame. GLOBK velocity field file format.
pbo.kfiga_nab08.20161203.gvl	Combined velocity field based on GLOBK SINEX file analysis in a North America reference frame directly realized from the IGb08 reference frame sites. GLOBK velocity field file format.
cwu.tswls_nam08.20161203.gvl	CWU velocity field based on time series weighted least squares (WLS) analysis in the NAM08 reference frame. GLOBK velocity field file format.
cwu.tskfa_nam08.20161203.gvl	CWU velocity field based on time series Kalman filter (KF) analysis in the NAM08 reference frame. GLOBK velocity field file format.
cwu.kfiga_nab08.20161203.gvl	CWU velocity field based on GLOBK SINEX file analysis in a North America reference frame directly realized from the IGb08 reference frame sites. GLOBK velocity field file format.
nmt.tswls_nam08.20161203.gvl	NMT velocity field based on time series weighted least squares (WLS) analysis in the NAM08 reference frame. GLOBK velocity field file format.
nmt.tskfa_nam08.20161203.gvl	NMT velocity field based on time series Kalman filter (KF) analysis in the NAM08 reference frame. GLOBK velocity field file format.
nmt.kfiga_nab08.20161203.gvl	NMT velocity field based on GLOBK SINEX file analysis in a North America reference frame directly realized from the IGb08 reference frame sites. GLOBK velocity field file format.