Notes on the 2017 GAGE Velocity field to GPS Week 1977 2017-12-02

These notes add supplemental information to "Notes on the 2016 PBO Velocity field to Week 1925 2016-12-03" https://www.unavco.org/data/gps-gnss/derived-products/docs/GAGE_GPS_Velocity_Release_Notes_20161203.pdf and "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 2017 GAGE full velocity solution includes GPS data from GPS week 0834 (Jan-01-1996) to week 1977 (Dec-02-2017). Time tag on LMD queue is 20171227092717.

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. These methods remain unchanged and here we update the tables derived from those methods.
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. Twenty sites are excluded based on this criterion (AC09, AC30, AV05, BLKM, BUEG, CN44, EOCG, FCTF, HVHS, NTOE, OLO1, OLO4, OLO5, OLO7, P056, P323, P656, RHCG, SMMx and WLHG). 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. 481 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 8781560 station-days. The outlier criteria remove 12885 (0.15%) of NMT and 62548 (0.71%) of CWU station-days of solutions.

The processing divides the 2230 sites analyzed into 29 networks each with approximately 79 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 103 to 286 individual site names to accommodate the discontinuities). There is no overlap between the sites in the first 28 networks. A 29th network is created to tie all the other 28 networks into a single solution. To form the sites in the 29th network, three sites for each network are chosen so as to minimize the trace of the covariance matrix of the estimates of rotation and translation using these sites. Weights assigned to each site in accord with the expected variance of the velocity estimate for the site (i.e., combination of the RWPN and duration of data at the site). If equal weights are given to each site, this algorithm is the same as

choosing the three sites that cover the largest area. The details of the sites in each network are given in All_PBO_netsel.use. The analyses of the 29 networks can be run in parallel and takes a few hours to run. The combination of the 29 networks uses ~8 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 two days of CPU time. The NMT and CWU velocity solutions are then merged to form the PBO solution combined solution. This combination uses ~28 Gb of memory and also takes about 34 hrs to complete. 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 1241 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 36 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 (2017-12-02 GPS Week 1977 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 three 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 761 stations in the solution. (These stations have velocity standards less than the median standard deviations in north, east and up in all three components, 0.16, 0.15 and 0.46 mm/yr, respectively). 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 2016 and PBO 2015 velocity solutions) 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. There are correlations between these solutions so the NRMS scatter being less than unity should be expected.

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 7-years old and was replaced by ITRF2014 (IGS14) for official products on January 29, 2017 (http://www.igs.org/article/igs14-reference-frame-transition). Current GAGE final-orbit products are still generated in the IGb08 system while we wait for JPL to generate orbit and clock products in the IGS14 system.

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_171202 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_2016 and PBO_2015 are the earlier 2016 and 2015 PBO full solution generated in December 2016 and November 2015. # 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	2202	-0.02	0.07	0.361	-0.00	0.07	0.347
PBO_GKNA- NMT_GKNA	2207	0.01	0.05	0.259	0.00	0.06	0.305
CWU_GKNA- NMT_GKNA	2201	0.03	0.12	0.597	0.00	0.13	0.633
PBO_GKNA- PBO_TSLS	2208	-0.02	0.14	0.893	-0.01	0.14	0.857
PBO_GKNA- PBO_TSKF	2208	-0.03	0.16	0.876	-0.01	0.15	0.815
PBO_GKNA- CWU_TSLS	2200	-0.02	0.15	0.969	-0.01	0.15	0.939
PBO_GKNA- CWU_TSKF	2191	-0.03	0.17	0.916	-0.01	0.16	0.869
PBO_GKNA- NMT_TSLS	2207	-0.02	0.18	1.126	-0.02	0.17	1.041
PBO_GKNA- NMT_TSKF	2207	-0.04	0.19	1.004	-0.02	0.17	0.906
PBO_GKNA- PBO_GKIG	2208	-0.02	0.12	0.566	0.21	0.24	1.143
PBO_GKNA- CWU_GKIG	2202	0.03	0.11	0.502	0.24	0.27	1.263
PBO_GKNA- NMT_GKIG	2207	-0.02	0.14	0.648	0.18	0.22	1.083
PBO_GKNA- PBO_2016	2167	-0.02	0.20	0.981	-0.00	0.18	0.865
PBO_GKNA- PBO_2015	2130	-0.04	0.25	1.181	-0.04	0.22	1.036

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

Soln1 - Soln *	#	HzMean (mm/yr)	HzWRMS (mm/yr)	HzNRMS	U Mean (mm/yr)	U WRMS (mm/yr)	U NRMS
PBO_GKNA- CWU_GKNA	2202	-0.01	0.07	0.354	-0.03	0.29	0.490
PBO_GKNA- NMT_GKNA	2207	0.01	0.06	0.283	-0.03	0.16	0.308
CWU_GKNA- NMT_GKNA	2201	0.01	0.12	0.615	0.00	0.41	0.714
PBO_GKNA- PBO_TSLS	2208	-0.02	0.14	0.875	-0.02	0.42	0.909
PBO_GKNA- PBO_TSKF	2208	-0.02	0.16	0.846	-0.10	0.47	0.976
PBO_GKNA- CWU_TSLS	2200	-0.01	0.15	0.954	-0.05	0.46	0.979
PBO_GKNA- CWU_TSKF	2191	-0.02	0.17	0.893	-0.12	0.51	1.025
PBO_GKNA- NMT_TSLS	2207	-0.02	0.17	1.084	-0.46	0.78	1.616
PBO_GKNA- NMT_TSKF	2207	-0.03	0.18	0.956	-0.45	0.76	1.478
PBO_GKNA- PBO_GKIG	2208	0.10	0.19	0.902	-0.44	0.51	0.960
PBO_GKNA- CWU_GKIG	2202	0.14	0.21	0.961	-0.22	0.37	0.626
PBO_GKNA- NMT_GKIG	2207	0.08	0.19	0.892	-0.58	0.68	1.321
PBO_GKNA- PBO_2016	2167	-0.01	0.19	0.925	0.11	0.45	0.840
PBO_GKNA- PBO_2015	2130	-0.04	0.24	1.111	0.16	0.62	0.980

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 1115 sites is because both horizontal and vertical sigma conditions must be satisfied.) To be included in this table the north and east velocity sigmas must be less than 0.16 and 0.15 mm/yr and the height velocity sigma less than 0.46 mm/yr.

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	761	-0.01	0.06	0.357	0.01	0.06	0.363
PBO_GKNA- NMT_GKNA	761	0.01	0.04	0.239	-0.00	0.04	0.296
CWU_GKNA- NMT_GKNA	761	0.02	0.09	0.572	-0.01	0.10	0.637
PBO_GKNA- PBO_TSLS	761	-0.03	0.10	0.871	-0.01	0.09	0.754
PBO_GKNA- PBO_TSKF	761	-0.03	0.11	0.774	-0.00	0.09	0.679
PBO_GKNA- CWU_TSLS	761	-0.03	0.10	0.867	-0.01	0.09	0.796
PBO_GKNA- CWU_TSKF	761	-0.02	0.10	0.751	0.00	0.10	0.703
PBO_GKNA- NMT_TSLS	761	-0.02	0.11	0.977	-0.01	0.10	0.872
PBO_GKNA- NMT_TSKF	761	-0.03	0.11	0.806	-0.01	0.10	0.703
PBO_GKNA- PBO_GKIG	761	0.01	0.11	0.680	0.21	0.24	1.498
PBO_GKNA- CWU_GKIG	761	0.05	0.10	0.565	0.25	0.27	1.670
PBO_GKNA- NMT_GKIG	761	0.01	0.12	0.783	0.19	0.22	1.407
PBO_GKNA- PBO_2016	761	-0.02	0.09	0.589	0.00	0.09	0.572
PBO_GKNA- PBO_2015	761	-0.02	0.13	0.787	-0.02	0.12	0.714

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

Soln1 - Soln2	#	HzMean (mm/yr)	HzWRMS (mm/yr)	HzNRMS	U Mean (mm/yr)	U WRMS (mm/yr)	U NRMS
PBO_GKNA- CWU_GKNA	761	-0.00	0.06	0.360	0.01	0.21	0.486
PBO_GKNA- NMT_GKNA	761	0.00	0.04	0.269	-0.03	0.12	0.318
CWU_GKNA- NMT_GKNA	761	0.01	0.09	0.606	-0.03	0.29	0.708
PBO_GKNA- PBO_TSLS	761	-0.02	0.09	0.815	0.00	0.26	0.795
PBO_GKNA- PBO_TSKF	761	-0.02	0.10	0.728	-0.09	0.33	0.965
PBO_GKNA- CWU_TSLS	761	-0.02	0.10	0.832	-0.03	0.29	0.866
PBO_GKNA- CWU_TSKF	761	-0.01	0.10	0.728	-0.12	0.37	1.024
PBO_GKNA- NMT_TSLS	761	-0.02	0.11	0.926	-0.42	0.65	1.860
PBO_GKNA- NMT_TSKF	761	-0.02	0.10	0.756	-0.43	0.64	1.733
PBO_GKNA- PBO_GKIG	761	0.11	0.19	1.163	-0.41	0.46	1.193
PBO_GKNA- CWU_GKIG	761	0.15	0.21	1.246	-0.18	0.29	0.659
PBO_GKNA- NMT_GKIG	761	0.10	0.18	1.139	-0.56	0.62	1.677
PBO_GKNA- PBO_2016	761	-0.01	0.09	0.581	0.11	0.28	0.695
PBO_GKNA- PBO_2015	761	-0.02	0.12	0.751	0.17	0.40	0.860

Table 5: Ancillary and velocity fields supplied with this solution (folder DOI_171202/)

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 1531 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 (75433 entries).
All_PBO_eqs.eq	List of 42 earthquakes included for co-seismic offset discontinuities. 11 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.
All_PBO.stab	Hierarchical list of reference frame sites used to define the NAM08 reference frame
All_PBO_nam08.apr	GLOBK apriori position, velocity and extended entry format file defined in NAM08 frame
All_PBO_igs08.apr	GLOBK apriori position, velocity and extended entry format file defined in IGS08 frame
pbo.final_nam08.20171202.vel	Combined velocity field based on GLOBK SINEX file analysis in the NAM08 reference frame. PBO velocity field file format.
cwu.final_nam08.20171202.vel	CWU velocity field based on GLOBK SINEX file analysis in the NAM08 reference frame. PBO velocity field file format.
nmt.final_nam08.20171202.vel	NMT velocity field based on GLOBK SINEX file analysis in the NAM08 reference frame. PBO velocity field file format.
pbo.snaps_nam08.20171202.vel	Combined velocity field based on time series analysis in the NAM08 reference frame. PBO velocity field file format.
cwu.snaps_nam08.20171202.vel	CWU velocity field based on time series analysis in the NAM08 reference frame. PBO velocity field file format.
nmt.snaps_nam08.20171202.vel	NMT velocity field based on time series analysis in the NAM08 reference frame. PBO velocity field file format.
pbo.final_igs08.20171202.vel	Combined velocity field based on GLOBK SINEX file analysis in the IGS08 reference frame. PBO velocity field file format.
pbo.tswls_nam08.20171202.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_nam08.20171202.gvl	Combined velocity field based on time series Kalman filter (KF) analysis in the NAM08 reference frame. GLOBK velocity field file format.
pbo.kfiga_nab08.20171202.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_nam08.20171202.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_nam08.20171202.gvl	CWU velocity field based on time series Kalman filter (KF) analysis in the NAM08 reference frame. GLOBK velocity field file format.
cwu.kfiga_nab08.20171202.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_nam08.20171202.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_nam08.20171202.gvl	NMT velocity field based on time series Kalman filter (KF) analysis in the NAM08 reference frame. GLOBK velocity field file format.
nmt.kfiga_nab08.20171202.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.