UNAVCO GAGE GNSS Data Product Notice to Users:
Notes on 2025 GAGE CWU NAM14 and ANT14 velocity fields
End GPS week 2346, 2024-12-28
2025-01-24

Prepared by:
Dr. Thomas A. Herring, GAGE GNSS Analysis Center Coordinator, MIT

These notes describe the development of the GAGE velocity fields using Central Washington University (CWU) analysis center results. These notes add supplemental information to: "Notes on 2024 GAGE CWU NAM14 and ANT14 velocity fields, End GPS week 2346, 2023-12-30" https://www.unavco.org/data/gps-gnss/derived-products/docs/GAGE_Velocity_Field_Release_Notes_20231230.pdf and earlier velocity field release notes found at https://www.unavco.org/data/gps-gnss/derived-products/derived-products.html

Associated with this PDF is a folder rel_241228 that contains the comparison velocity fields and other ancillary files used in generating the velocity fields. The contents of the folder are similar to those associated with the Herring et al. (2016) paper.

Two velocity fields are described here. One field in the North America (NA) region is expressed in a North America fixed frame, and the other field is in the Antarctica (ANT) region and is given in an Antarctica fixed frame. The 2025 NA GAGE full velocity solution includes GPS data from GPS week 0834 (Jan-01-1996) to week 2346 (Dec-28-2024) and contains all reprocessed and operational data from the Central Washington University (CWU) analysis center in the ITRF2014 system realization of the North America fixed reference frame. The 2025 ANT solution uses CWU solutions from GPS week 1304 (Feb-12-2005) to week 2346 (Dec-28-2024).

The two sets of velocity fields in the GAGE velocity file format have been sent to EarthScope as cwu.final_igs14.vel. 20250122220535, cwu.final_nam14.vel. 20250122220535 (NA) and cwu.fanet_ant14.vel. 20250122220535, cwu.fanet_igs14.vel. 20250122220535 (ANT)

The reference frames for this release are NAM14 and ANT14 based on the ITRF2014 system [*Altamimi et al.,* 2016] and the North America plate Euler pole in the ITRF2014 system [*Altamimi, et al.,* 2017].

The complete analysis of the full GAGE velocity field generated from CWU SINEX files (i.e., incorporating full variance-covariance matrices and allowing re-aligning of the reference frame for the velocity field) is now released. The 2015 release documents the methods being used to generate these velocity fields using combinations of sub-networks. These methods remain unchanged, except now they are based solely on CWU SINEX files. The ANT region has a small enough number of stations to allow a simple direct generation of the velocity field.

The process noise models, in the form of random walk time-step variances or process noise (RWPN) are given in All_PBO.rw for the NA region and All_ANT.rw for the ANT region. These values are generated by analysis of the position residuals from fitting the time series for each station. Stations with process noise values greater than 2.0 mm^2/yr are not included in this velocity solution so that they do not contaminate nearby stations and the aim of the annual full analysis solution is to create a reference frame solution. For the final full combination for the NAM14 reference frame, we also excluded sites with less than 3 years of data and process noise values greater than 1.8 mm^2/yr. These limits were placed to keep the total number of elements in the Kalman filter state vector less than 40,000. The final number of NAM14 stations in the GLOBK reference frame solution was 2175. In the time series analysis solution (where all data are processed independent of their quality), there are 2733 stations. For the ANT analysis, we restrict the full analysis stations to those RW process noise less than 10 mm^2/yr. The following stations are included in the times series analyses only: KHLR NLSN PECE TOMO and WWAY. We also impose a minimum random walk process noise (RWPN) of 0.05 mm^2/yr. 422 stations in the NA and 18 stations in the ANT analysis 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 FOGMEX algorithm used to account for correlated noise. [*Herring et al*., 2016; *Floyd and Herring*, 2019]. The tsfit solution also generates a list of station 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 station position estimates is given in All_PBO_edits.eq. The outlier criteria remove 68951 of CWU station-days of solutions. In addition, 3083 offsets from antenna/radome changes, 379 offsets for unknown reasons, and offsets from 83 earthquakes were included in the analysis. Postseismic deformation models were needed for 22 of the 83 earthquakes included.

NA processing.

The NA processing divides the 2237 (of a total of 2733) stations analyzed into 30 networks, each with 78 station locations except network 29, which has 53 stations. Network 30, with 87 locations, links all the networks together. The 2175 sites are included in the final combination with breaks included; there are 6615 site names needed to represent the breaks in the time series. (The final number of estimated parameters for each network depends on the number of breaks needed at each station). The networks need from 103 to 370 individual station names to accommodate the discontinuities, with a median number of stations of 207. There is an average of 2.4 breaks per station in the 28 years. There is no overlap between the stations in the first 29 networks. A 30^{th} network is created to tie all the other 29 networks into a single solution. To form the stations in the 30^{th} network, three stations for each network are chosen to minimize the trace of the covariance matrix of the estimates of rotation and translation using these stations. Weights are assigned to each station following the expected variance of the velocity estimate for the station (i.e., a combination of the RWPN and duration of data at the station). If equal weights are given to each station, this algorithm is the same as choosing the three stations that cover the largest area. The details of the stations in each network are given in All_PBO_netsel.use. The analysis of the 30 networks can be run in parallel and takes a few

hours to run. The combination of the 30 networks uses ~11 Gbytes of memory for the CWU combination, along the equating of velocities (with a constraint of ±0.01 mm/yr) at stations with discontinuities takes about two days of CPU time. 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 NAM14 frame using 1765 stations (with multiple names of 698 unique site locations) in our hierarchical list of reference frame stations; (2) A North America frame aligned to IGS14 rotated into the North America frame using the 86 site names (36 locations) original used in ITRF2014 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 for the NA analysis and the current day (2023-12-30 GPS Week 2346 for this analysis). The time series analyses for velocities are much faster, but the daily solutions need to be aligned with the reference frame each day based on an earlier realization of the frames. Tables 1 and 2 compare the WRMS and NRMS scatters of the differences between the velocity estimates obtained using different analysis methods and from the previous PBO combined NAM14 velocity solution released earlier. Table 1's caption explains the naming scheme used to describe the solutions. 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 quarterly GAGE SNAPSHOT fields. The GK analysis can be aligned to the current NAM14 frame (NA) or be realigned to the IGS14 frame (IG). In all analyses, the same process noise models, discontinuities, and post-seismic non-linear models (based on time series analyses) are used. Two sets of comparisons are shown. The first set does not re-align the velocity fields in any way. The RMS values are based on the simple differences between the estimates. The second part of the tables shows results with rotation and translation rates between the reference frames estimated. The numbers of stations do not match between the analyses because the GK analyses exclude stations with large process noise values. Tables 3 and 4 show the same type of comparison when we restrict the stations to the best 748 stations in the solution. (These stations have velocity standards less than the median standard deviations in north, east, and up in all three components, 0.13, 0.13, 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 and, in many cases, smaller, suggesting that even the stations with the smallest sigma match consistent with their sigmas.

Table 1: Comparison of North and East velocities between different velocity field determination methods for the NA analysis. No transformation parameters between the fields have been estimated. The codes for the solutions are: CCC_TTYY where CCC is the center 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 – NAM14, IG – IGS14 rotated to NA. The final entries CWU_2023-19, PBO_2018 are the earlier solutions (2023 is highlighted in yellow). The PBO fields before 2019 are in the NAM08 reference frame, # is the number of common stations 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
CWU_GKNA- CWU_TSLS	2175	0.00	0.10	0.816	0.00	0.10	0.840
CWU_GKNA- CWU_TSKF	2175	0.00	0.11	0.769	-0.00	0.11	0.774
CWU_GKNA- CWU_GKIG	2175	-0.02	0.06	0.342	-0.04	0.08	0.518
CWU_TSLS- CWU_TSKF	2731	0.00	0.13	1.105	-0.00	0.13	1.110
CWU_TSLS- CWU_GKIG	2175	-0.02	0.11	0.855	-0.04	0.13	1.021
CWU_TSKF- CWU_GKIG	2175	-0.03	0.13	0.833	-0.04	0.14	0.939
CWU_GKNA- CWU_2023	2141	-0.01	0.10	0.624	-0.00	0.09	0.560
CWU_GKNA- CWU_2022	2130	-0.01	0.11	0.698	0.00	0.11	0.647
CWU_GKNA- CWU_2021	2117	-0.00	0.13	0.781	-0.01	0.12	0.737
CWU_GKNA- CWU_2020	2117	-0.03	0.15	0.863	0.00	0.14	0.845
CWU_GKNA- CWU_2019	2134	-0.06	0.19	1.057	0.03	0.18	1.004
CWU_GKNA- PBO_2018	2130	-0.06	0.23	1.276	0.03	0.23	1.283
Comparison with rotation and translation alignment							
CWU_GKNA- CWU_TSLS	2175	0.00	0.10	0.819	-0.00	0.10	0.836
CWU_GKNA- CWU_TSKF	2175	-0.00	0.11	0.773	-0.00	0.11	0.768
CWU_GKNA- CWU_GKIG	2175	0.00	0.00	0.025	0.00	0.00	0.025
CWU_TSLS- CWU_TSKF	2731	-0.00	0.13	1.105	-0.00	0.13	1.110
CWU_TSLS- CWU_GKIG	2175	-0.00	0.10	0.788	0.00	0.10	0.804
CWU_TSKF- CWU_GKIG	2175	0.00	0.11	0.753	0.00	0.11	0.749
CWU_GKNA- CWU_2023	2141	0.00	0.10	0.620	-0.00	0.09	0.557
CWU_GKNA- CWU_2022	2130	0.00	0.11	0.696	-0.00	0.11	0.645
CWU_GKNA- CWU_2021	2117	0.00	0.13	0.780	0.00	0.12	0.735
CWU_GKNA- CWU_2020	2117	0.01	0.15	0.843	-0.00	0.14	0.847
CWU_GKNA- CWU_2019	2134	0.01	0.18	0.988	0.00	0.17	0.986
CWU_GKNA- PBO_2018	2130	0.00	0.22	1.241	0.00	0.23	1.254

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

Soln1 - Soln2	#	HzMean (mm/yr)	HzWRMS (mm/yr)	HzNRMS	U Mean (mm/yr)	U WRMS (mm/yr)	U NRMS
CWU_GKNA- CWU_TSLS	2175	0.00	0.10	0.828	-0.03	0.35	0.853
CWU_GKNA- CWU_TSKF	2175	0.00	0.11	0.771	0.02	0.38	0.879
CWU_GKNA- CWU_GKIG	2175	-0.03	0.07	0.439	0.25	0.31	0.631
CWU_TSLS- CWU_TSKF	2731	0.00	0.13	1.108	0.04	0.37	1.111
CWU_TSLS- CWU_GKIG	2175	-0.03	0.12	0.941	0.28	0.47	1.143
CWU_TSKF- CWU_GKIG	2175	-0.03	0.13	0.888	0.22	0.47	1.078
CWU_GKNA- CWU_2023	2141	-0.00	0.10	0.593	-0.01	0.38	0.727
CWU_GKNA- CWU_2022	2130	-0.00	0.11	0.673	-0.01	0.42	0.786
CWU_GKNA- CWU_2021	2117	-0.00	0.13	0.759	-0.05	0.44	0.793
CWU_GKNA- CWU_2020	2117	-0.01	0.15	0.854	-0.13	0.48	0.852
CWU_GKNA- CWU_2019	2134	-0.01	0.18	1.031	-0.09	0.55	0.949
CWU_GKNA- PBO_2018	2130	-0.02	0.23	1.280	0.11	0.69	1.161

Comparison with rotation and translation alignment

CWU_GKNA- CWU_TSLS	2175	0.00	0.10	0.827	-0.04	0.34	0.850
CWU_GKNA- CWU_TSKF	2175	-0.00	0.11	0.770	0.00	0.37	0.874
CWU_GKNA- CWU_GKIG	2175	0.00	0.00	0.025	-0.00	0.00	0.009
CWU_TSLS- CWU_TSKF	2731	-0.00	0.13	1.108	0.03	0.37	1.107
CWU_TSLS- CWU_GKIG	2175	-0.00	0.10	0.796	0.04	0.35	0.841
CWU_TSKF- CWU_GKIG	2175	0.00	0.11	0.751	-0.00	0.38	0.867
CWU_GKNA- CWU_2023	2141	0.00	0.10	0.589	-0.02	0.38	0.725
CWU_GKNA- CWU_2022	2130	0.00	0.11	0.671	-0.03	0.42	0.777
CWU_GKNA- CWU_2021	2117	0.00	0.13	0.758	-0.04	0.44	0.793
CWU_GKNA- CWU_2020	2117	0.00	0.14	0.845	-0.08	0.47	0.831
CWU_GKNA- CWU_2019	2134	0.00	0.18	0.987	-0.08	0.54	0.930
CWU_GKNA- PBO_2018	2130	0.00	0.22	1.248	0.02	0.67	1.135

Table 3: Comparison of North and East velocities similar to Table 1, except we limit the stations to those that have horizontal and vertical velocities sigmas both less than the median horizontal and vertical velocity sigmas. (The reason there are fewer than 1176 stations 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 0.13 and 0.13 mm/yr, respectively, and the height velocity sigma must be 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
CWU_GKNA- CWU_TSLS	748	-0.01	0.07	0.777	-0.00	0.08	0.822
CWU_GKNA- CWU_TSKF	748	-0.01	0.07	0.591	-0.01	0.07	0.598
CWU_GKNA- CWU_GKIG	748	-0.02	0.05	0.386	-0.05	0.08	0.648
CWU_TSLS- CWU_TSKF	748	0.01	0.07	0.946	-0.00	0.07	0.955
CWU_TSLS- CWU_GKIG	748	-0.01	0.08	0.780	-0.04	0.11	1.065
CWU_TSKF- CWU_GKIG	748	-0.02	0.08	0.685	-0.04	0.10	0.890
CWU_GKNA- CWU_2023	743	-0.01	0.06	0.488	-0.01	0.06	0.481
CWU_GKNA- CWU_2022	747	-0.01	0.07	0.534	-0.01	0.07	0.498
CWU_GKNA- CWU_2021	747	-0.00	0.08	0.590	-0.01	0.08	0.560
CWU_GKNA- CWU_2020	748	-0.03	0.09	0.638	-0.00	0.08	0.595
CWU_GKNA- CWU_2019	748	-0.05	0.12	0.812	0.01	0.11	0.751
CWU_GKNA- PBO_2018	748	-0.06	0.15	0.995	0.00	0.14	0.948
with rotation and translation alignment							
CWU_GKNA- CWU_TSLS	748	0.00	0.07	0.766	-0.00	0.08	0.821
CWU_GKNA- CWU_TSKF	748	0.00	0.07	0.586	-0.00	0.07	0.590
CWU_GKNA- CWU_GKIG	748	0.00	0.00	0.032	0.00	0.00	0.031
CWU_TSLS- CWU_TSKF	748	-0.00	0.07	0.939	-0.00	0.07	0.951
CWU_TSLS- CWU_GKIG	748	-0.00	0.07	0.723	0.00	0.08	0.774
CWU_TSKF- CWU_GKIG	748	-0.00	0.07	0.557	0.00	0.07	0.564
CWU_GKNA- CWU_2023	743	0.00	0.06	0.472	-0.00	0.06	0.471
CWU_GKNA- CWU_2022	747	0.00	0.07	0.528	-0.00	0.06	0.493
CWU_GKNA- CWU_2021	747	0.00	0.08	0.601	-0.00	0.08	0.557
CWU_GKNA- CWU_2020	748	0.01	0.08	0.591	-0.00	0.08	0.606
CWU_GKNA- CWU_2019	748	0.00	0.10	0.692	-0.00	0.11	0.742
CWU_GKNA- PBO_2018	748	-0.00	0.13	0.888	-0.00	0.14	0.932

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
CWU_GKNA- CWU_TSLS	748	-0.01	0.07	0.800	-0.05	0.27	0.915
CWU_GKNA- CWU_TSKF	748	-0.01	0.07	0.594	-0.02	0.26	0.829
CWU_GKNA- CWU_GKIG	748	-0.04	0.07	0.533	0.23	0.30	0.823
CWU_TSLS- CWU_TSKF	748	0.00	0.07	0.951	0.02	0.23	1.031
CWU_TSLS- CWU_GKIG	748	-0.03	0.09	0.934	0.29	0.43	1.412
CWU_TSKF- CWU_GKIG	748	-0.03	0.09	0.794	0.26	0.41	1.295
CWU_GKNA- CWU_2023	743	-0.01	0.06	0.485	-0.02	0.28	0.717
CWU_GKNA- CWU_2022	747	-0.01	0.07	0.516	-0.04	0.28	0.706
CWU_GKNA- CWU_2021	747	-0.01	0.08	0.575	-0.09	0.32	0.758
CWU_GKNA- CWU_2020	748	-0.02	0.09	0.617	-0.15	0.35	0.823
CWU_GKNA- CWU_2019	748	-0.02	0.11	0.782	-0.12	0.38	0.870
CWU_GKNA- PBO_2018	748	-0.03	0.14	0.972	0.03	0.45	1.002
Comparison with rotation and translation alignment							
CWU_GKNA- CWU_TSLS	748	0.00	0.07	0.794	-0.04	0.27	0.906
CWU_GKNA- CWU_TSKF	748	-0.00	0.07	0.588	-0.00	0.26	0.825
CWU_GKNA- CWU_GKIG	748	0.00	0.00	0.031	-0.00	0.00	0.011
CWU_TSLS- CWU_TSKF	748	-0.00	0.07	0.945	0.03	0.22	1.023
CWU_TSLS- CWU_GKIG	748	-0.00	0.08	0.749	0.04	0.27	0.893
CWU_TSKF- CWU_GKIG	748	0.00	0.07	0.561	0.01	0.26	0.814
CWU_GKNA- CWU_2023	743	0.00	0.06	0.472	-0.03	0.28	0.713
CWU_GKNA- CWU_2022	747	0.00	0.07	0.511	-0.04	0.28	0.691
CWU_GKNA- CWU_2021	747	0.00	0.08	0.579	-0.04	0.31	0.730
CWU_GKNA- CWU_2020	748	0.00	0.08	0.598	-0.08	0.32	0.756
CWU_GKNA- CWU_2019	748	0.00	0.10	0.717	-0.06	0.37	0.830
CWU_GKNA- PBO_2018	748	-0.00	0.13	0.910	0.01	0.45	1.002

Overall, the agreement between the different methods of estimating the velocities is very good, with the WRMS difference in the NE components typically <0.3 mm/yr with the comparison to the CWU 2019-2023 velocities all being less than 0.2 mm/yr, Hz, and 0.55 mm/yr (vertical). The comparison to the 2018 combined CWU and NMT solution is only slightly greater than to the CWU-only solutions. Re-aligning the reference frames makes little difference to the WRMS differences and slightly degrades the vertical differences because the horizontal components carry the most weight in estimating the transformation parameters.

As noted above, stations have been removed from the GLOBK Kalman filter estimation if the Horizonal Random Walk (HRW) value with >2 mm^2/yr. Velocity estimates for these stations only appear in the time series-based analyses.

To show the distribution of the stations in the velocity field estimates, we show in Figure 1 the vertical rates of the 2172 stations with standard deviations less than 5 mm/yr. Due to the process noise limits in the solution, only three stations have standard deviations in the vertical rates larger than this value.

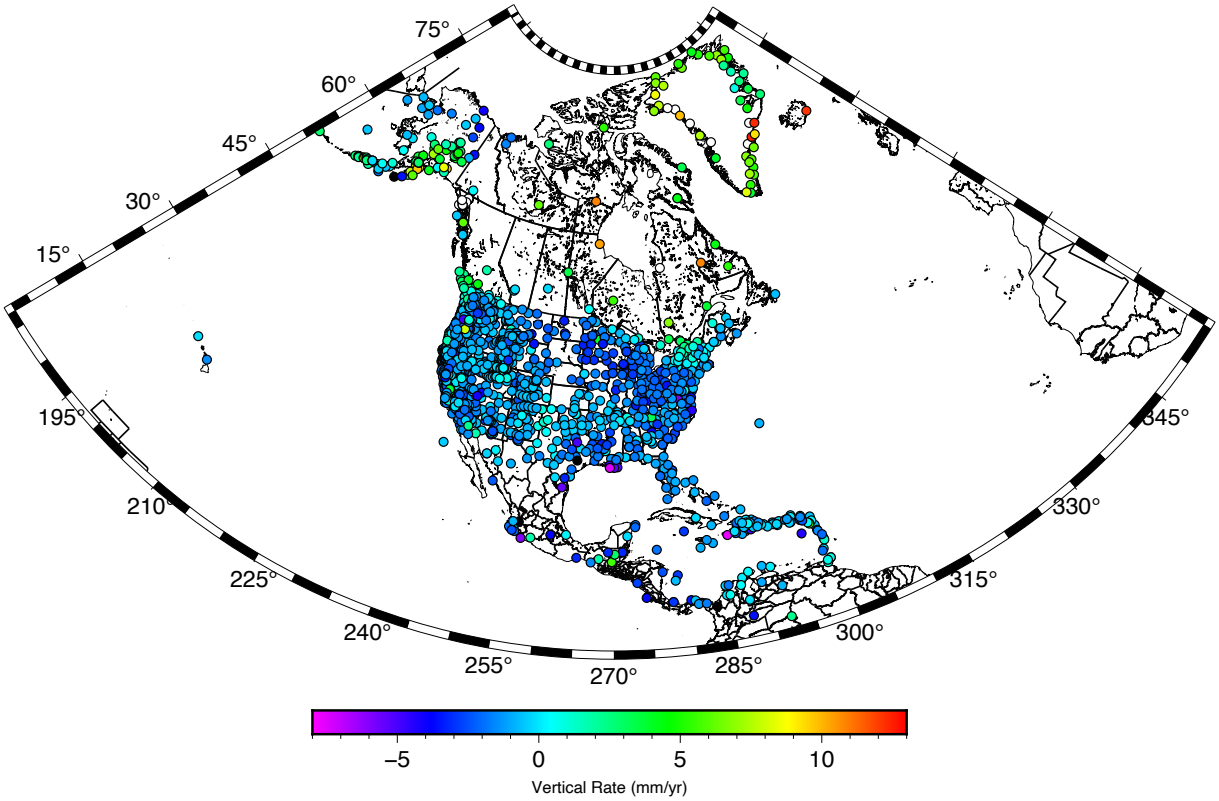

Figure 1: Vertical rate estimates for the 2172 stations in the CWU NAM14 solution with vertical velocity standard deviations of less than 5 mm/yr. (The whole solution contains 2175 stations). The KF time series solutions contain 2676 stations with vertical velocity standard deviations less than 5 mm/yr and 55 stations with standard deviations greater than this.

ANT processing

The Antarctica processing is much simpler than the NA processing because of the much smaller number of stations and, to a lesser degree, the shorter duration of the data: GPS week 1304 (Feb-12-2005) to week 2346 (Dec-28-2024). In the time series analysis, 77 sites are included, but in the GLOBK SINEX file, a combination of 71 stations is included. The six additional sites in the time series analysis have larger systematics that will likely corrupt the combined analysis even with large process noise values assigned to these stations. As with the NA analysis we compare the results of different analysis types (SINEX versus time series) and with the earlier 2018 combined CWU analysis results. The comparison statistics are given in Tables 5-8, which are similar to Tables 1-4 for the NA analysis.

Table 5: Comparison of North and East velocities between different velocity field determination methods for the ANT analysis. No transformation parameters between the fields have been estimated. The codes for the solutions are: CCC_TTYY where CCC is the center CWU or the combined PBO analysis; TT is the type of analysis:
GK – GLOBK Kalman filter; TS – time series fit; and YY is the combination method and reference frame: LS – least squares, KF – Kalman filter; AN – ANT14, IG – IGS14 rotated to NA. CWU_2022 is last year's solution and is highlighted in yellow. The final entry PBO_2019 is the PBO full solution generated in June 2019. # is the number of common stations 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
CWU_GKAN- CWU_TSLS	71	0.00	0.19	1.294	-0.02	0.18	1.330
CWU_GKAN- CWU_TSKF	71	-0.03	0.29	1.639	-0.01	0.25	1.543
CWU_GKAN- CWU_GKIG	71	-0.02	0.32	1.706	0.08	0.14	0.762
CWU_TSLS- CWU_TSKF	77	-0.02	0.19	1.386	0.01	0.15	1.177
CWU_TSLS- CWU_GKIG	71	-0.04	0.39	2.504	0.09	0.24	1.613
CWU_TSKF- CWU_GKIG	71	0.00	0.43	2.424	0.08	0.31	1.772
CWU_GKAN- CWU_2023	71	-0.00	0.02	0.114	-0.01	0.02	0.120
CWU_GKAN- CWU_2022	71	-0.01	0.10	0.520	0.02	0.09	0.497
CWU_GKAN- CWU_2021	71	-0.01	0.07	0.365	0.02	0.09	0.513
CWU_GKAN- CWU_2020	71	0.02	0.15	0.788	-0.00	0.12	0.677
CWU_GKAN- CWU_2019	71	-0.00	0.13	0.643	0.03	0.11	0.609

Comparison with rotation and translation alignment

CWU_GKAN- CWU_TSLS	71	-0.02	0.18	1.246	0.00	0.18	1.288
CWU_GKAN- CWU_TSKF	71	-0.01	0.27	1.570	-0.01	0.24	1.470
CWU_GKAN- CWU_GKIG	71	-0.00	0.00	0.022	0.00	0.00	0.026
CWU_TSLS- CWU_TSKF	77	0.02	0.19	1.365	-0.01	0.14	1.103
CWU_TSLS- CWU_GKIG	71	0.02	0.19	1.259	-0.00	0.19	1.272
CWU_TSKF- CWU_GKIG	71	0.01	0.28	1.558	0.01	0.25	1.456
CWU_GKAN- CWU_2023	71	-0.00	0.02	0.110	-0.00	0.02	0.113
CWU_GKAN- CWU_2022	71	0.00	0.09	0.471	-0.00	0.08	0.481
CWU_GKAN- CWU_2021	71	-0.00	0.07	0.365	0.00	0.09	0.483
CWU_GKAN- CWU_2020	71	-0.01	0.14	0.717	0.00	0.11	0.626
CWU_GKAN- CWU_2019	71	0.01	0.12	0.612	0.01	0.10	0.542

Table 6: Similar to Table 5 except here the mean horizontal velocity (HzMean, HzWRMS, HzNRMS) and vertical velocity (U columns) are compared.

Soln1 - Soln2	#	HzMean (mm/yr)	HzWRMS (mm/yr)	HzNRMS	U Mean (mm/yr)	U WRMS (mm/yr)	U NRMS
CWU_GKAN- CWU_TSLS	71	-0.01	0.19	1.312	-0.14	0.45	0.970
CWU_GKAN- CWU_TSKF	71	-0.02	0.27	1.592	-0.07	0.57	1.164
CWU_GKAN- CWU_GKIG	71	0.03	0.24	1.321	-0.24	0.72	1.304
CWU_TSLS- CWU_TSKF	77	-0.00	0.17	1.286	0.08	0.34	0.863
CWU_TSLS- CWU_GKIG	71	0.03	0.32	2.106	-0.12	0.79	1.675
CWU_TSKF- CWU_GKIG	71	0.05	0.37	2.124	-0.18	0.99	1.999
CWU_GKAN- CWU_2023	71	-0.00	0.02	0.117	-0.01	0.10	0.174
CWU_GKAN- CWU_2022	71	0.01	0.09	0.509	0.05	0.29	0.509
CWU_GKAN- CWU_2021	71	0.01	0.08	0.445	-0.01	0.26	0.453
CWU_GKAN- CWU_2020	71	0.01	0.14	0.734	-0.18	0.64	1.091
CWU_GKAN- CWU_2019	71	0.01	0.12	0.626	0.00	0.51	0.879

Comparison with rotation and translation alignment

CWU_GKAN- CWU_TSLS	71	-0.01	0.18	1.267	-0.00	0.44	0.935
CWU_GKAN- CWU_TSKF	71	-0.01	0.26	1.521	0.03	0.55	1.121
CWU_GKAN- CWU_GKIG	71	0.00	0.00	0.024	0.00	0.01	0.009
CWU_TSLS- CWU_TSKF	77	0.00	0.17	1.241	0.05	0.31	0.779
CWU_TSLS- CWU_GKIG	71	0.01	0.19	1.265	0.01	0.44	0.941
CWU_TSKF- CWU_GKIG	71	0.01	0.26	1.508	-0.02	0.56	1.118
CWU_GKAN- CWU_2023	71	-0.00	0.02	0.112	-0.01	0.10	0.175
CWU_GKAN- CWU_2022	71	0.00	0.09	0.476	0.02	0.26	0.459
CWU_GKAN- CWU_2021	71	0.00	0.08	0.428	-0.01	0.25	0.439
CWU_GKAN- CWU_2020	71	-0.00	0.13	0.673	-0.01	0.60	1.018
CWU_GKAN- CWU_2019	71	0.01	0.11	0.578	0.03	0.49	0.848

Table 7: Comparison of North and East velocities similar to Table 5, except we limit the stations to those that have horizontal and vertical velocities sigmas, both less than the median horizontal and vertical velocity sigmas. (The reason there are fewer than 35 stations 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 0.18 mm/yr, respectively, and the height velocity sigma must be less than 0.48 mm/yr.

Soln1 - Soln2	#	N mean (mm/yr)	N WRMS (mm/yr)	N NRMS	E mean (mm/yr)	E WRMS (mm/yr)	E NRMS
CWU_GKAN- CWU_TSLS	24	-0.01	0.10	0.997	-0.01	0.09	1.001
CWU_GKAN- CWU_TSKF	24	-0.06	0.14	1.178	-0.01	0.12	1.062
CWU_GKAN- CWU_GKIG	24	-0.14	0.25	1.875	0.08	0.13	1.062
CWU_TSLS- CWU_TSKF	24	-0.04	0.08	0.835	0.01	0.07	0.839
CWU_TSLS- CWU_GKIG	24	-0.14	0.30	2.813	0.09	0.16	1.591
CWU_TSKF- CWU_GKIG	24	-0.08	0.29	2.302	0.09	0.19	1.592
CWU_GKAN- CWU_2023	24	-0.00	0.02	0.131	-0.01	0.02	0.129
CWU_GKAN- CWU_2022	24	-0.01	0.03	0.194	0.01	0.05	0.371
CWU_GKAN- CWU_2021	24	-0.01	0.05	0.342	0.01	0.05	0.386
CWU_GKAN- CWU_2020	24	0.01	0.07	0.527	-0.00	0.06	0.497
CWU_GKAN- CWU_2019	24	-0.01	0.07	0.500	0.02	0.06	0.471
Comparison with rotation and translation alignment							
CWU_GKAN- CWU_TSLS	24	-0.01	0.09	0.883	-0.00	0.08	0.846
CWU_GKAN- CWU_TSKF	24	0.00	0.10	0.825	-0.01	0.09	0.771
CWU_GKAN- CWU_GKIG	24	-0.00	0.00	0.028	0.00	0.00	0.037
CWU_TSLS- CWU_TSKF	24	0.01	0.06	0.636	-0.01	0.06	0.706
CWU_TSLS- CWU_GKIG	24	0.01	0.09	0.861	0.00	0.08	0.815
CWU_TSKF- CWU_GKIG	24	-0.00	0.10	0.787	0.01	0.09	0.747
CWU_GKAN- CWU_2023	24	-0.01	0.02	0.117	-0.00	0.01	0.113
CWU_GKAN- CWU_2022	24	0.00	0.02	0.141	0.00	0.04	0.319
CWU_GKAN- CWU_2021	24	-0.00	0.05	0.353	0.00	0.04	0.322
CWU_GKAN- CWU_2020	24	0.00	0.06	0.470	0.01	0.04	0.294
CWU_GKAN- CWU_2019	24	0.01	0.07	0.518	0.01	0.05	0.353

Table 8: Same as Table 7 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
CWU_GKAN- CWU_TSLS	24	-0.01	0.10	0.999	-0.08	0.30	0.926
CWU_GKAN- CWU_TSKF	24	-0.04	0.13	1.122	-0.02	0.37	1.085
CWU_GKAN- CWU_GKIG	24	-0.03	0.20	1.524	-0.06	0.47	1.221
CWU_TSLS- CWU_TSKF	24	-0.02	0.07	0.837	0.06	0.23	0.902
CWU_TSLS- CWU_GKIG	24	-0.02	0.24	2.285	-0.01	0.50	1.522
CWU_TSKF- CWU_GKIG	24	0.01	0.24	1.979	-0.05	0.67	1.936
CWU_GKAN- CWU_2023	24	-0.01	0.02	0.130	-0.01	0.06	0.161
CWU_GKAN- CWU_2022	24	0.00	0.04	0.296	0.00	0.13	0.319
CWU_GKAN- CWU_2021	24	0.00	0.05	0.365	-0.03	0.16	0.391
CWU_GKAN- CWU_2020	24	0.00	0.07	0.512	-0.19	0.29	0.689
CWU_GKAN- CWU_2019	24	0.00	0.07	0.486	0.01	0.21	0.523
Comparison with rotation and translation alignment							
CWU_GKAN- CWU_TSLS	24	-0.00	0.08	0.865	0.01	0.30	0.926
CWU_GKAN- CWU_TSKF	24	-0.00	0.09	0.798	0.02	0.35	1.029
CWU_GKAN- CWU_GKIG	24	-0.00	0.00	0.033	-0.00	0.01	0.015
CWU_TSLS- CWU_TSKF	24	-0.00	0.06	0.672	0.01	0.19	0.747
CWU_TSLS- CWU_GKIG	24	0.00	0.09	0.838	-0.01	0.30	0.926
CWU_TSKF- CWU_GKIG	24	0.01	0.09	0.767	-0.02	0.36	1.030
CWU_GKAN- CWU_2023	24	-0.00	0.01	0.115	-0.02	0.06	0.152
CWU_GKAN- CWU_2022	24	0.00	0.03	0.246	-0.01	0.10	0.259
CWU_GKAN- CWU_2021	24	0.00	0.04	0.338	-0.04	0.15	0.367
CWU_GKAN- CWU_2020	24	0.00	0.05	0.392	-0.03	0.19	0.465
CWU_GKAN- CWU_2019	24	0.01	0.06	0.443	-0.01	0.22	0.535

The agreement between the different analysis methods and earlier solutions is at the 0.25 mm/yr and 1.0 mm/yr levels in the horizontal and vertical components. The NRMS scatter of the sites with better than the median horizontal and vertical sigmas are similar to NRMS values of all stations, suggesting the sigmas are scaled consistently. Figures 2 and 3 show the horizontal and vertical motions of the 71 sites included in the GLOBK SINEX analysis.

References

Altamimi, Zuheir, Paul Rebischung, Laurent Métivier, and Xavier Collilieux. (2016) "ITRF2014: A New Release of the International Terrestrial Reference Frame Modeling Nonlinear Station Motions." *Journal of Geophysical Research: Solid Earth* 121 (8): 6109–31. https://doi.org/10.1002/2016JB013098.

Altamimi, Zuheir, Laurent Métivier, Paul Rebischung, Hélène Rouby, and Xavier Collilieux. (2017) "ITRF2014 Plate Motion Model." *Geophysical Journal International* 209 (3): 1906–12. https://doi.org/10.1093/gji/ggx136.

Herring, T.A., T. I. Melbourne, M. H. Murray, M. A. Floyd, W. M. Szeliga, R. W. King, D. A. Phillips, C. M. Puskas, M. Santillan, and L. Wang, (2016) Plate Boundary Observatory and Related Networks: GPS Data Analysis Methods and Geodetic Products, *Rev. Geophys*., 54, doi:10.1002/2016RG000529. http://onlinelibrary.wiley.com/doi/10.1002/2016RG000529/full

Floyd, M.A., and T. A. Herring (2019) Fast Statistical Approaches to Geodetic Time Series Analysis in "Geodetic Time Series Analysis in Earth Sciences)", Eds. J.-P. Montillet and M. Bos, Springer Nature Switzerland, *in press.* doi: 10.1007/978-3-030-21718-1

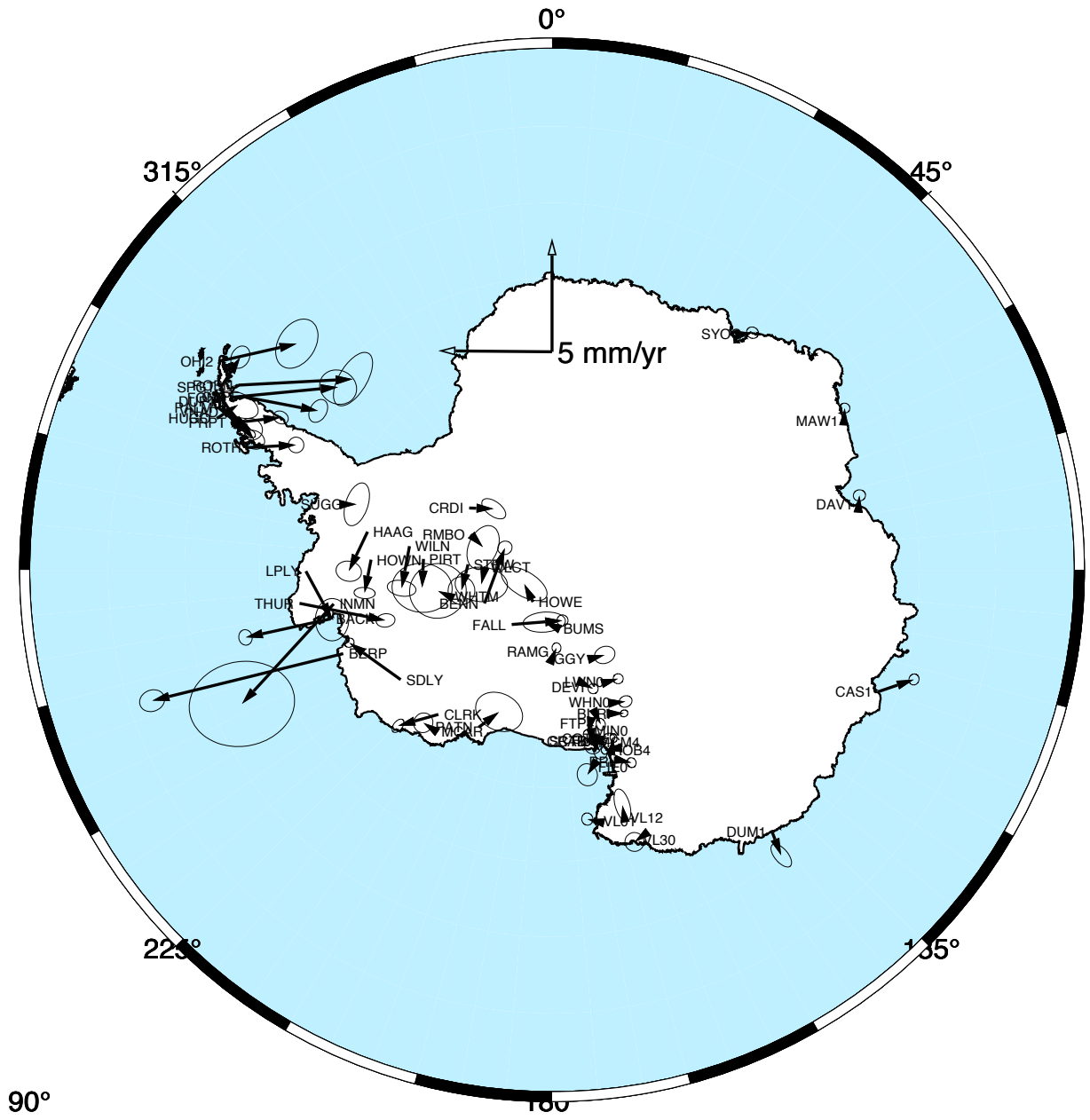

Figure 2: Horizontal motions in the ITRF2014 Antarctica fixed reference frame from the GLOBK SINEX file analysis (GKAN).

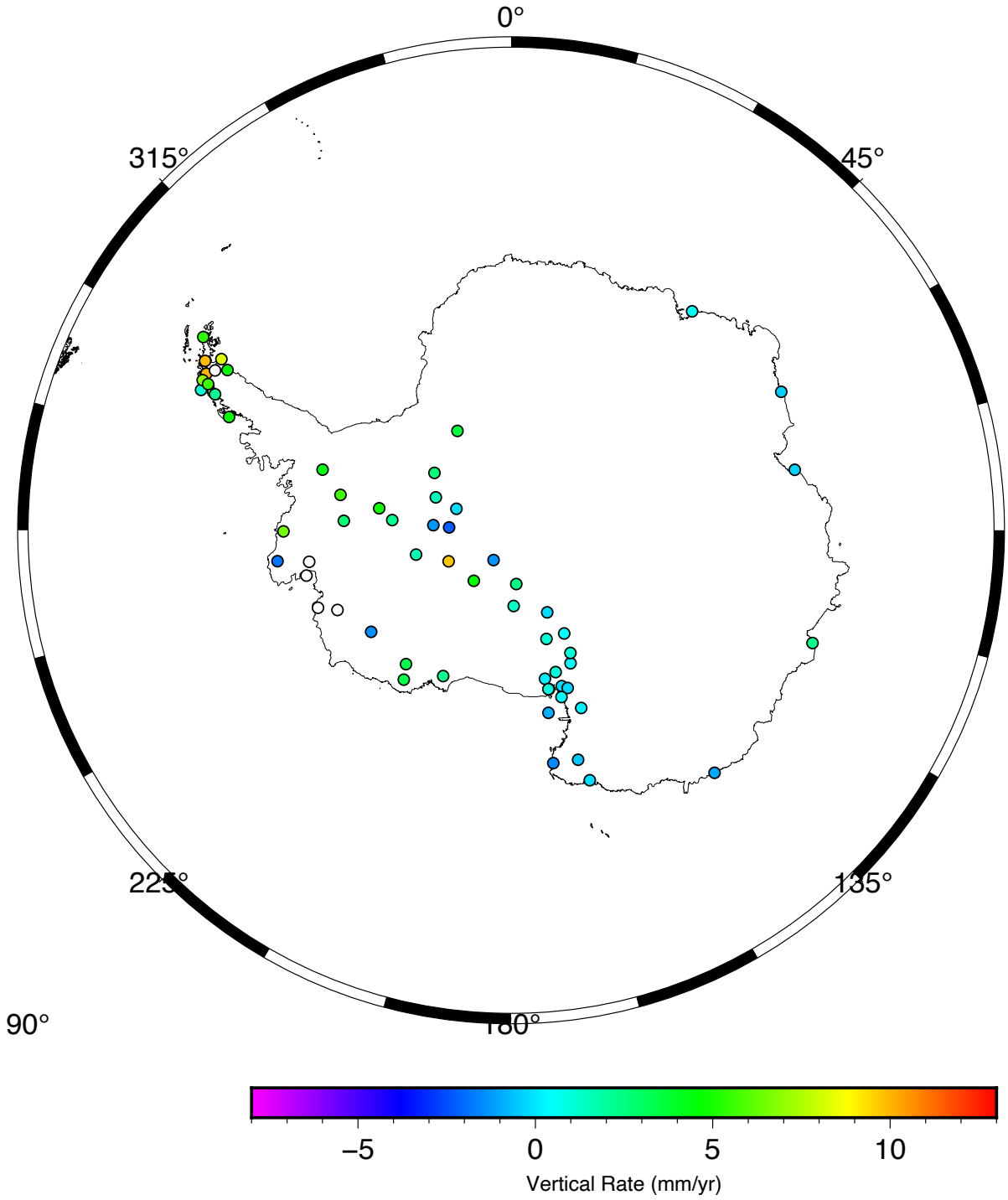

Figure 3: Vertical motions from the GLOBK SINEX file analysis (GKAN). The sites shown with white circles are offset scale and are uplifting at rates as high as 33±1 mm/yr (INMN).