(U) Recent Update to WGS 84 Reference Frame
and
NGA Transition to IGS ANTEX

Office of Geomatics / GNSS Division
National Geospatial-Intelligence Agency

(U) The National Geospatial-Intelligence Agency (NGA), Office of Geomatics, Global Navigation Satellite Systems (GNSS) Division is responsible for maintaining the World Geodetic System 1984 (WGS 84) Reference Frame used by U.S. Department of Defense for its geolocation needs. Realization of the WGS 84 RF is through US Space Force and NGA Monitor Station Network (MSN) GPS tracking antenna coordinates, specifically at the antenna reference point. USSF/MSN tracking data, along with NGA's Earth Gravity Model and other global geophysical models, is used by the GPS Operational Control Segment to generate the GPS broadcast navigation message and to monitor its integrity, thereby connecting GPS to WGS 84.

(U) NGA keeps the WGS 84 RF closely aligned to the International Terrestrial Reference Frame (ITRF). This ensures adherence to international standards and facilitates interoperability with other GNSS. In this pursuit, a new realization of WGS 84 RF was introduced on January 3, 2021 that removed small systematic biases with respect to ITRF. Accordingly, the current frame is designated *WGS 84(G2139)* and replaces *WGS 84(G1762')*. WGS 84(G2139) is coincident with ITRF14(IGb14) for the purposes of positioning and navigation.

(U) Table 1 lists the 7-parameter transformation for *(G1762') – to – (G2139)*. Using a mean Earth radius of 6,371,000 meters; the translations are sub-centimeter and the rotations are negligible but the scale change imparts a height adjustment of -2.8 centimeters at this mean radius.

Translation in x	**0.0058** meters
Translation in y	**-0.0064** meters
Translation in z	**0.0070** meters
Angular displacement in x	**0.08** milli-arc-seconds
Angular displacement in y	**0.04** milli-arc-seconds
Angular displacement in z	**0.12** milli-arc-seconds
Scale factor	**-4.4** parts-per-billion

Table 1. 7-parameter transformation from WGS 84(G1762') to WGS 84(G2139)

(U) To take maximum advantage of the new frame alignment, NGA transitioned to using The International GNSS Service (IGS) definition for the GPS satellites' L-band transmitting antenna phase center offsets (APO) from center of mass. This transition occurred on March 28, 2021. Up to then, NGA used APO consistent with the GPS Control Segment.

(U) Improvements to geolocation from the new frame and satellite APO are illustrated by use of Precise Point Positioning (PPP) of twenty-eight IGS sites. A PPP solution for each station was computed using NGA GPS orbit/clock estimates first generated with (G1762') then again using (G2139) for 22 Sept – 12 Oct 2019. These station coordinate solutions were compared to those published in the IGS SINEX. Individual differences and their averages are tabulated and plotted here. Mean values are highlighted in red in both tables and plots.

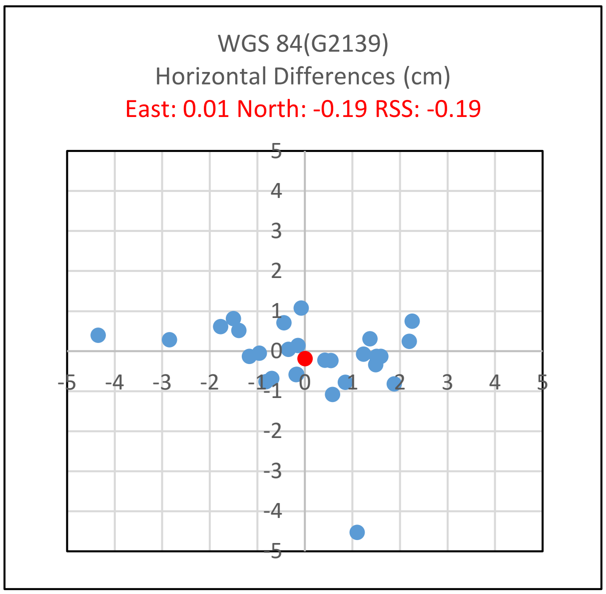

figure 1a

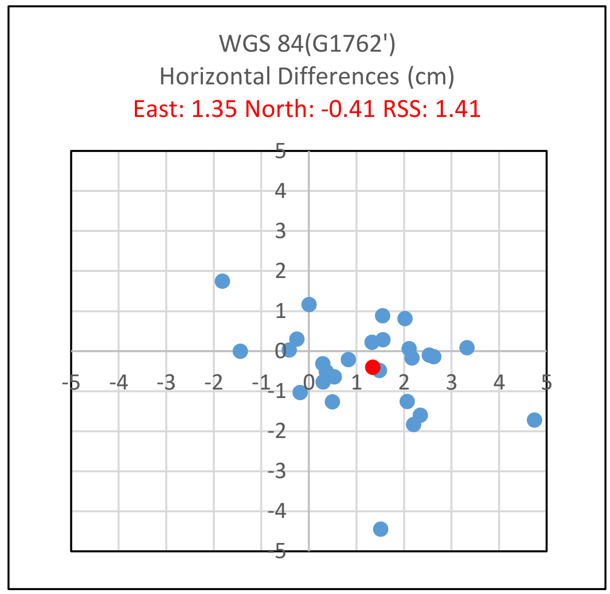

figure 1b

(U) Comparing figures 1a with 1b, it can be seen the latest WGS 84-to-ITRF alignment eliminated an East component bias in the WGS 84 frame from 1.35 centimeters to practically zero, with the shift in the North component being reduced to a mere two millimeters.

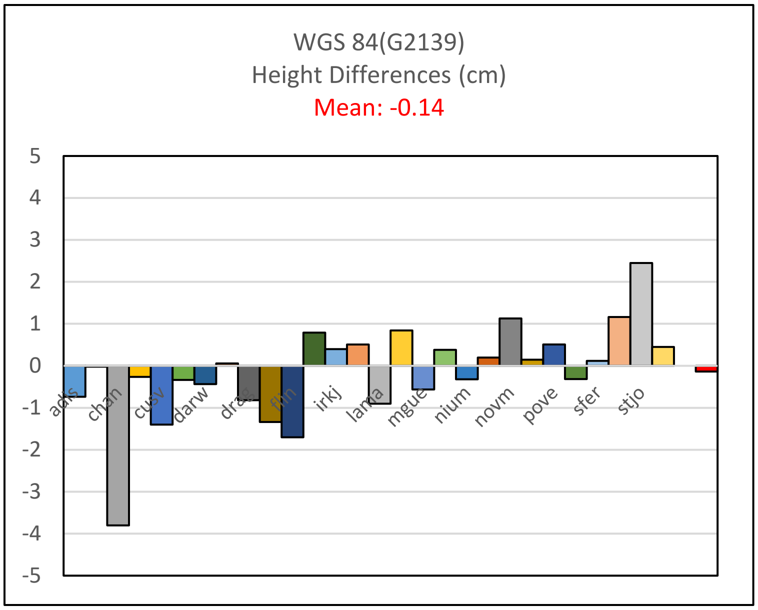

figure 2a

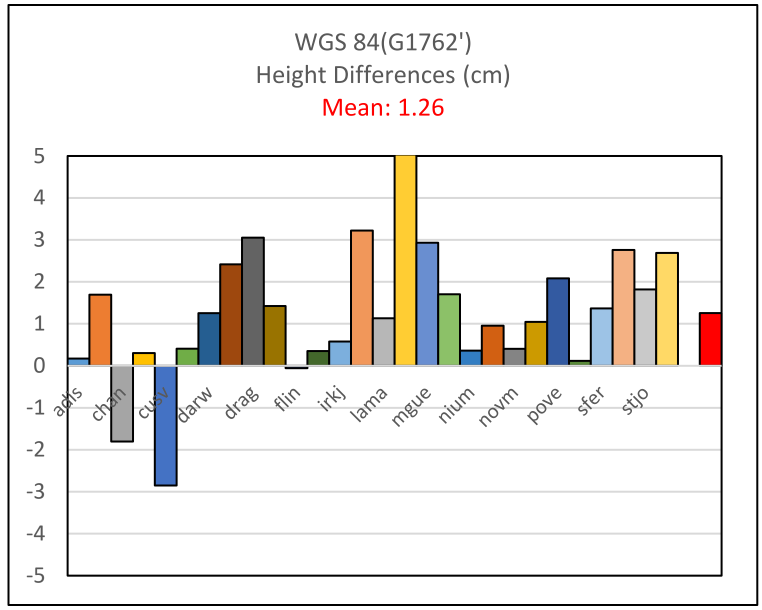

figure 2b

(U) The height bias is reduced from 1.26 centimeters to under two millimeters. Notice also the scatter in the plots tightened up, showing the standard deviations diminished as well.

	adis	brst	chan	ckis	cusv	dakr	darw	dgar	drag	falk	flin	glps	irkj	kiri
North	0.2	0.8	-0.8	-0.8	0.1	0.3	0.3	-0.8	0.7	0.5	-0.2	-0.1	-0.2	-0.1
East	2.2	-1.5	1.9	-0.8	-0.1	-2.8	1.4	0.9	2.3	-1.4	0.5	1.2	0.4	-1.0
Up	-0.7	0.0	-3.8	-0.3	-1.4	-0.3	-0.4	0.1	-0.8	-1.3	-1.7	0.8	0.4	0.5

	lama	maui	mgue	nano	nium	nnor	novm	nrc1	pove	quin	sfer	ssia	stjo	zamb
North	1.1	-1.1	0.7	-0.6	0.4	-0.3	-0.1	-0.1	0.0	-0.6	0.6	-4.5	-0.7	-0.1
East	-0.1	0.6	-0.4	-0.2	-4.3	1.5	1.6	1.5	-0.3	-0.2	-1.8	1.1	-0.7	-1.2
Up	-0.9	0.8	-0.6	0.4	-0.3	0.2	1.1	0.1	0.5	-0.3	0.1	1.2	2.5	0.5

Table 2a. WGS 84(G2139): Individual IGS stations' North, East, Up differences (cm)

	adis	brst	chan	ckis	cusv	dakr	darw	dgar	drag	falk	flin	glps	irkj	kiri
North	-0.1	0.3	-1.8	0.8	-1.0	0.0	-0.5	-1.6	0.1	1.2	-0.2	-0.1	-1.3	0.3
East	2.6	-0.3	2.2	2.0	-0.2	-1.4	5.5	2.3	3.3	0.0	0.8	2.5	0.5	1.6
Up	0.2	1.7	-1.8	0.3	-2.9	0.4	1.3	2.4	3.1	1.4	-0.1	0.4	0.6	3.2

	lama	maui	mgue	nano	nium	nnor	novm	nrc1	pove	quin	sfer	ssia	stjo	zamb
North	0.2	-0.5	0.9	-0.6	1.7	-1.7	-1.3	0.1	-0.2	-0.5	0.0	-4.4	-0.8	-0.3
East	1.3	1.5	1.6	0.5	-1.8	4.7	2.1	2.1	2.2	0.4	-0.4	1.5	0.3	0.3
Up	1.1	5.6	2.9	1.7	0.4	1.0	0.4	1.0	2.1	0.1	1.4	2.8	1.8	2.7

Table 2b. WGS 84(G1762'): Individual IGS stations' North, East, Up differences (cm)

(U) Other frame alignment metrics, such as the 7-parameter transformation with IGS GPS orbits and Earth Orientation parameters, also improved. Only PPP results are shown here because seeing the improvements to precise geolocation is the most impactful.

(U) The combination of better USSF/NGA station coordinates and switch to IGS satellite APO makes the use of NGA GPS Precise Ephemeris indistinguishable from the ground network on which it rests, and has the great advantage of being publicly accessible.

But, there's a price…

(U) The differences in APO are, in reality, distances. Counter-intuitively, using one set of APO over another result in differences in the satellite's clock estimates. This is due to the basic nature of a GPS measurement, a measured distance is the transit time of the signal multiplied by the speed of light. Thus, a one-meter error in distance versus a three-nanosecond error in clock offset leads to the same measurement collected by the user. Since a GPS satellite's clock offset is much more variable than its orbit, it is seen as the more likely source of ranging error. So, unfortunately, the APO changes are immediately aliased into clock biases.

(U) For the best geolocation results, NGA's PPP software should use a precise ephemeris consistent with the international/scientific APO. This transition took place on March 28 2021. Due to this, users will see a one-time jump in satellite clock states that compensate for the sudden switch in APO.

(U) Table 3 enumerates the changes implemented with the APO switch and the subsequent satellite clock discontinuities to be expected. Note the wide range in adjustments due to APO differences, which are satellite specific. Averages are not as interesting as individual shifts since a universal mean clock adjustment is not that helpful.

(U) Additionally, there will be no adjustment to GPS III satellites, SVNs 74, 75, 76 and 77, due to the IGS ANTEX files use of identical numbers for those SVs. In those cases, the GPS Control Segment values, provided by satellite's manufacturer, is considered more reliable. NGA will reach out to the IGS for discussions about possible updates to those values if new estimated APOs become available for these or other vehicles.

SV Antenna Phase Offsets GPS-vs-IGS (equivalent to SV Body-Frame Z axis offset)					
PRN	SVN	GPS(m)	IGS(m)	GPS-IGS(m)	Adjustment(ns)
1	63	1.091	1.502	-0.411	-1.370
2	61	-0.082	0.729	-0.811	-2.705
3	69	1.091	1.551	-0.460	-1.534
4	74	1.090	1.232	0*	0*
5	50	-0.017	0.778	-0.795	-2.651
6	67	1.092	1.467	-0.375	-1.252
7	48	0.001	0.822	-0.822	-2.741
8	72	1.086	1.501	-0.416	-1.387
9	68	1.092	1.523	-0.430	-1.436
10	73	1.083	1.515	-0.432	-1.441
12	58	-0.094	0.768	-0.861	-2.873
13	43	1.614	1.348	0.266	0.886
14	77	1.099	1.232	0*	0*
15	55	-0.012	0.623	-0.635	-2.118
16	56	1.663	1.469	0.194	0.648
17	53	-0.101	0.771	-0.872	-2.908
18	75	1.074	1.232	0*	0*
19	59	-0.018	0.808	-0.826	-2.756
20	51	1.614	1.314	0.301	1.002
21	45	1.584	1.359	0.225	0.750
22	47	0.060	0.851	-0.791	-2.638
23	76	1.062	1.232	0*	0*
24	65	1.093	1.407	-0.314	-1.048
25	62	1.093	1.517	-0.424	-1.416
26	71	1.093	1.504	-0.411	-1.370
27	66	1.090	1.522	-0.432	-1.441
28	44	1.513	1.000	0.514	1.713
29	57	-0.015	0.792	-0.807	-2.692
30	64	1.090	1.522	-0.432	-1.440
31	52	-0.058	0.913	-0.970	-3.236
32	70	1.084	1.535	-0.451	-1.503

Table 3. GPS satellite body fixed frame Z-axis antenna phase offsets used by GPS and IGS.
Note*: GPS III satellites, highlighted in yellow, will get no adjustment.

(U) Detailed information for APO used by GPS Control Segment and IGS can be found at:

(U) https://navcen.uscg.gov/?pageName=gpsTechnicalReferences
(U) https://www.ngs.noaa.gov/ANTCAL/