Addendum to NIMA TR 8350.2:
Implementation of the World Geodetic System 1984 (WGS 84) Reference Frame G1150

Introduction

The **National Geospatial-Intelligence Agency** (**NGA**) has updated the control station coordinates that define the WGS 84 Reference Frame. This update is part of **NGA**'s commitment to maintain the highest possible accuracy and stability for the WGS 84 Reference Frame [2]. This update does not affect the fundamental definition of the WGS 84. The latest realization of the WGS 84 Reference Frame is designated as WGS 84 (G1150). The GPS Operational Control Segment (OCS) implemented it on 20 January 2002. The implementation of improved methodologies has increased the accuracy of the coordinates of the U. S. Air Force (USAF) and **NGA** Global Positioning System (GPS) monitor stations.

G1150 is the third update to the realization of the WGS 84 Reference Frame. The previous realizations were designated WGS 84 (G730) and WGS 84 (G873). The "G" indicates that GPS measurements were used to obtain the coordinates. The number following the "G" indicates the GPS week number of the week during which the coordinates were implemented in the **NGA** GPS precise ephemeris estimation process [1]. The GPS OCS implemented WGS 84 (G730) and WGS (G873) on 29 June 1994 and 29 January 1997, respectively.

Methodology

The Naval Surface Warfare Center Dahlgren Division (NSWCDD) and **NGA** personnel used GPS observations from the USAF and **NGA** permanent GPS monitor stations (Figure 1) and selected International GPS Service for Geodynamics (IGS) stations (Figure 2) to estimate refined coordinates for the USAF and **NGA** stations. The **NGA** sites included **NGA** GPS Monitor Station Network (MSN) stations and Differential GPS Reference Stations (DGRS) located at remote **NGA** geodetic survey offices.

- Data was collected from all sites for the period 14-28 February 2001.
- A set of 49 IGS stations was selected to serve as control in the Reference Frame solution. The International Terrestrial Reference Frame (ITRF) 2000 coordinates of these stations were held fixed during the estimation. The ITRF2000 coordinates are referenced to epoch 1997.0. The

IGS station positions were propagated forward in time to the data collection period using the station velocities provided with the ITRF2000 coordinates.

- Meteorological data were utilized for all stations. Data from nearby sites or default values were used when meteorological data was not collected at the GPS station.

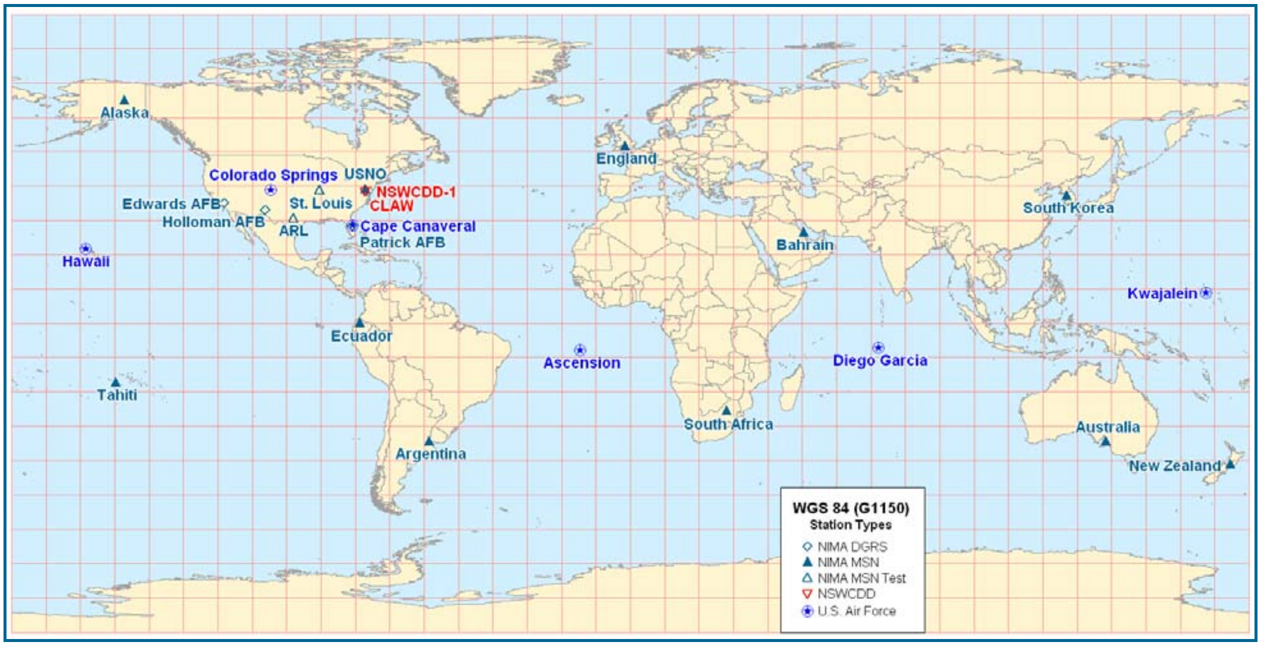

Figure 1. WGS 84 (G1150) Reference Frame stations

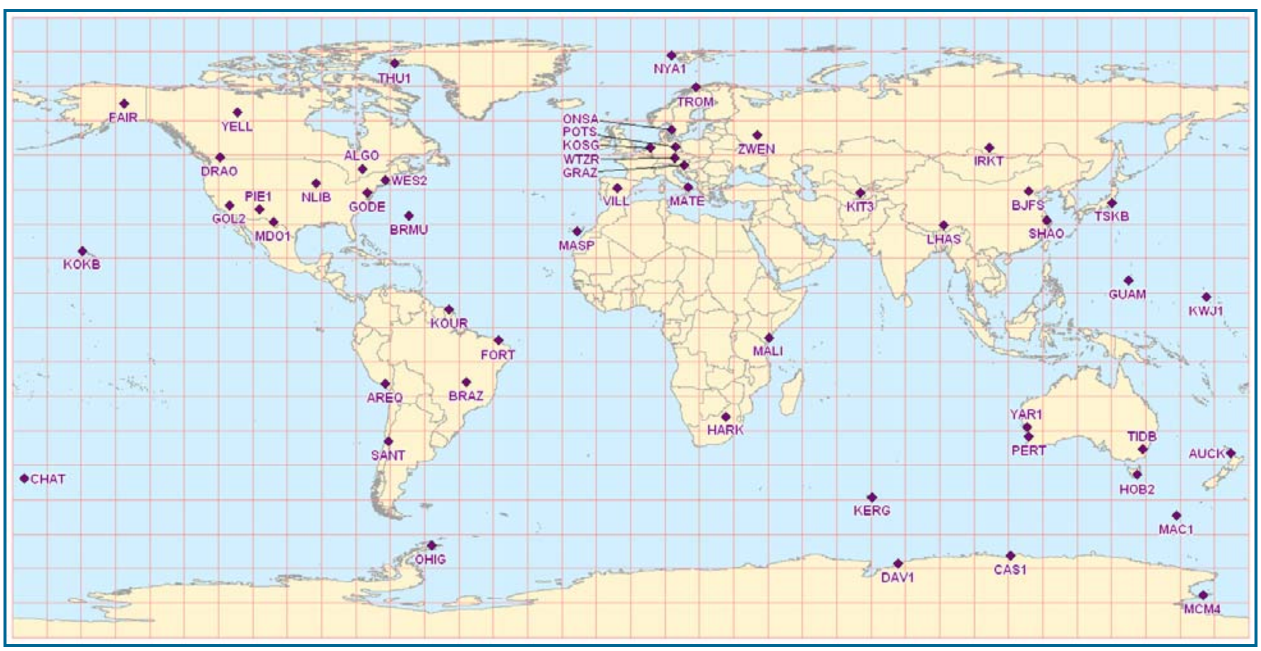

Figure 2. International GPS Service (IGS) fiducial stations

The WGS 84 (G1150) realization included a much larger set of IGS stations and the best-known velocities of the stations [2], rather than relying solely on the NNR-NUVEL1A plate motion model [5]. In particular, the station velocities of Ecuador and New Zealand, which are located on plate boundaries, were not derived from the NNR-NUVEL1A model. The velocities of the USAF and **NGA** stations that were used in this realization are given in Table 4. The process, methodology, results and analysis of the computations are reported in [2]. Site information for IGS stations may be obtained through the IGS website currently at http://igscb.jpl.nasa.gov.

NSWCDD and **NGA** have also made improvements to the geophysical modeling used in the estimation process. Examples include:

- integration of the IERS tide model,
- inclusion of pole tide effects,
- integration of a tropospheric refraction model that estimates the horizontal gradient.

Results

The additional data and improved methodologies resulted in significant improvements in station position accuracy and the overall alignment of WGS 84 with the ITRF. The estimated accuracy of WGS 84 (G1150) is on the order of one centimeter (one standard deviation) in each coordinate component for each of the USAF and **NGA** stations [2]. By comparison, the WGS 84 (G730) and WGS (G873) accuracies were estimated at 10 cm [4] and 5 cm [3], respectively. Each realization of the WGS 84 Reference Frame has shown a remarkable increase in precision.

The coordinates of the USAF and **NGA** GPS monitor stations are given in Cartesian (Table 1) and geodetic (Table 2) coordinates. Station velocities are also given in Table 1. The differences between WGS 84 (G1150) and WGS 84 (G873) coordinates (Table 3) were computed by first referencing them to the same epoch using station velocities in order to remove the effects of plate tectonic motion. These differences then illustrate the relative precision of WGS 84 (G873). The mean difference in the coordinates is five centimeters. This substantiates the five centimeter estimated accuracy of WGS 84 (G873).

Table 1. WGS 84 (G1150) Cartesian coordinates* and velocities for epoch 2001.0

Station Location	NIMA Station Number	X (km)	Y (km)	Z (km)	$\dot{X}$ (cm/yr)	$\dot{Y}$ (cm/yr)	$\dot{Z}$ (cm/yr)
Air Force Stations							
Colorado Springs	85128	-1248.597295	-4819.433239	3976.500175	-1.8	0.1	-0.4
Ascension	85129	6118.524122	-1572.350853	-876.463990	-0.3	-0.5	1.0
Diego Garcia	85130	1916.197142	6029.999007	-801.737366	-4.2	2.0	3.1
Kwajalein	85131	-6160.884370	1339.851965	960.843071	2.1	6.7	2.7
Hawaii	85132	-5511.980484	-2200.247093	2329.480952	-1.0	6.3	3.0
Cape Canaveral	85143	918.988120	-5534.552966	3023.721377	-1.0	-0.2	0.2
NGA Stations							
Australia	85402	-3939.182131	3467.075376	-3613.220824	-4.08	0.36	4.73
Argentina	85403	2745.499065	-4483.636591	-3599.054582	0.21	-1.00	0.70
England	85404	3981.776642	-89.239095	4965.284650	-1.38	1.65	0.77
Bahrain	85405	3633.910757	4425.277729	2799.862795	-2.97	0.91	2.53
Ecuador	85406	1272.867310	-6252.772219	-23.801818	0.30	0.04	0.99
US Naval Observatory	85407	1112.168358	-4842.861664	3985.487174	-1.48	-0.01	0.10
Alaska	85410	-2296.298410	-1484.804985	5743.080107	-2.22	-0.36	-0.92
Alaska**	85410	-2296.298460	-1484.805050	5743.080090	-2.22	-0.36	-0.92
New Zealand	85411	-4780.787068	436.877203	-4185.258942	-2.35	1.92	2.20
South Africa	85412	5066.232133	2719.226969	-2754.392735	0.01	2.09	1.40
South Korea	85413	-3067.861732	4067.639179	3824.294063	-2.90	-0.76	-1.02
Tahiti	85414	-5246.403866	-3077.285554	-1913.839459	-4.25	4.68	2.91

* Coordinates are for the electrical phase centers of the antennas.

** Post 3 November 2002 earthquake. Steady-state velocity is assumed to be unchanged.

Table 2. WGS 84 (G1150) geodetic coordinates* for epoch 2001.0

Station Location	NIMA Station Number	Latitude (dec deg)	Longitude (dec deg)	Ellipsoid Height (m)
Air Force Stations				
Colorado Springs	85128	38.80305456	255.47540844	1911.755
Ascension	85129	-7.95132970	345.58786950	106.558
Diego Garcia	85130	-7.26984347	72.37092177	-64.063
Kwajalein	85131	8.72250074	167.73052625	39.927
Hawaii	85132	21.56149086	201.76066922	426.077
Cape Canaveral	85143	28.48373800	279.42769549	-24.005
NGA Stations				
Australia	85402	-34.72900041	138.64734499	38.155
Argentina	85403	-34.57370168	301.48070059	48.747
England	85404	51.45374284	358.71610888	163.097
Bahrain	85405	26.20914020	50.60814451	-13.872
Ecuador	85406	-0.21515762	281.50639169	2922.626
US Naval Observatory	85407	38.92045032	282.93377525	59.098
Alaska	85410	64.68794095	212.88703308	176.552
Alaska**	85410	64.68794025	212.88703366	176.570
New Zealand	85411	-41.27264851	174.77870673	46.902
South Africa	85412	-25.74634609	28.22403736	1416.405
South Korea	85413	37.07756793	127.02403180	48.876
Tahiti	85414	-17.57703053	210.39381438	99.927

* Coordinates are for the electrical phase centers of the antennas.

** Post 3 November 2002 earthquake.

Table 3. WGS 84 (G1150) minus WGS 84 (G873) for epoch 1997.0

Station Location	NIMA Station Number	ΔX (cm)	ΔY (cm)	ΔZ (cm)	Total (cm)
Air Force Stations*					
Colorado Springs	85128	-0.2	0.3	-0.3	0.5
Ascension	85129	-8.2	-0.5	5.8	10.1
Diego Garcia	85130	-1.2	-7.0	2.8	7.6
Kwajalein	85131	10.8	1.0	-1.4	10.9
Hawaii	85132	2.6	1.7	-4.5	5.5
NGA Stations					
Australia	85402	-0.8	2.1	-2.2	3.2
Argentina	85403	3.7	-0.2	-5.8	6.9
England	85404	2.1	0.8	-1.0	2.5
Bahrain	85405	3.5	1.3	-1.7	4.1
Ecuador	85406	-2.0	-4.6	-3.2	6.0
US Naval Observatory	85407	2.4	-5.0	3.3	6.5
Alaska	85410	0.5	0.4	0.4	0.8
Alaska**	85410	-4.5	-6.1	-1.3	7.7
New Zealand	85411	0.0	2.5	-1.6	3.0
South Africa	85412	1.3	3.9	-4.6	6.2
South Korea	85413	-4.3	-0.3	2.8	5.2
Tahiti	85414	-1.2	-3.2	0.5	3.4

* Cape Canaveral was not included in the WGS 84 (G873) values.
** Post 3 November 2002 earthquake.

Alaskan Earthquake

Maintaining one-centimeter accuracy for a terrestrial reference frame, like WGS 84 (G1150), introduces special challenges. A case in point is the coordinate change for NGA's Alaska station due to an approximately eight-centimeter displacement caused by a 7.9 magnitude earthquake on 3 November 2002. A re-determination was necessary for this station to maintain the stated accuracy. The new coordinates were determined and moved to epoch 2001.0 to maintain consistency in the reference epoch for all NIMA station coordinates. The steady-state velocity of the Alaska station is assumed to be unchanged due to the earthquake. Since the epoch 2001.0 position for this station is artificial, the coordinates will be updated if it is determined that the steady-state velocity of the station has changed. Data before day 307 of 2002 should be processed using the initial set of G1150 2001.0 coordinates for the Alaska station. Data after day 307 should be processed using the updated set of G1150 2001.0 coordinates for the Alaska station.

Agreement with ITRF

The WGS 84 (G1150) Reference Frame, after the adjustment of a best fitting 7-parameter transformation and accounting for epoch differences (ITRF2000 is referenced to epoch 1997.0), compared to ITRF2000 shows a RMS difference of one centimeter per component. To quantify differences between the WGS 84 (G1150) and ITRF2000 reference frames, comparisons were made between the NGA and USAF stations and a subset of the IGS stations that were used to develop ITRF2000. Subsequent comparisons between the NGA GPS precise ephemerides, referenced to WGS 84 (G1150), and IGS GPS precise ephemerides, referenced to ITRF2000, validate that the two reference systems are consistent. This indicates that these two reference frames are essentially identical with differences being statistically insignificant for most applications. A similar analysis of the WGS 84 (G730) Reference Frame compared with ITRF92 showed an agreement of ~10 cm [6]. Comparisons between the WGS 84 (G873) and ITRF94 reference frames showed their agreement on the order of 2 cm [7]. This shows that the WGS 84 Reference Frame has maintained consistency with ITRF.

Temporal Effects

The fidelity of the current realization of the WGS 84 Reference Frame is now on the order of a centimeter, which is significantly smaller than previous solutions. Precise geodetic applications must account for temporal effects, such as plate tectonic motion and tidal effects, which is discussed in NIMA TR 8350.2, chapter 2. A good example of this is the displacement of the Alaska station that is already noted. Temporal effects may require an epoch designation and station velocities for any set of absolute station coordinates. The epochs of the WGS 84 (G730), WGS 84 (G873), and WGS 84 (G1150) Reference Frames are 1994.0, 1997.0 and 2001.0, respectively. Tidal effects and the mathematical relationship between the Conventional Celestial Reference System (CCRS) and the WGS 84 Coordinate System affect WGS 84 (G1150) the same way as previous realizations as documented in NIMA TR 8350.2, chapter 2. The NNR-NUVEL1A model remains the recommended model for plate tectonic motion. However, this model was not used in its entirety for the development of the G1150 coordinate solution because of the known model deficiencies for two of the NGA stations, Ecuador and New Zealand, due to their location on plate boundaries. It is at the discretion of the user to ensure that the velocity model used meets accuracy requirements.

Summary

Improved station coordinate sets, in particular WGS 84 (G1150), represent the most recent realization(s) of the WGS 84 Reference Frame. Further improvements and future realizations of the WGS 84 Reference Frame are anticipated, as stated in NIMA TR 8350.2. When new stations are added to the permanent DoD GPS tracking network or when existing stations (and/or antennas) are moved or replaced, new station coordinates will be required. As these changes occur, NGA will take steps to ensure that the highest possible degree of fidelity is maintained and changes are identified to the appropriate organizations.

References

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