AMENDMENT 1

3 January 2000

DEPARTMENT OF DEFENSE WORLD GEODETIC SYSTEM 1984
Its Definition and Relationships with Local Geodetic Systems

This amendment forms a part of NIMA TR8350.2, dated 4 July 1997, and is approved for use by all Departments and Agencies of the Department of Defense.

For each correction listed below, an insertable replacement page is attached.

PAGE xi

In the 5th paragraph, change the sentence "The model, complete through degree (n) and order (m) 360, is comprised of 130,676 coefficients." to read "The model, complete through degree (n) and order (m) 360, is comprised of 130,317 coefficients.".

PAGE 3-7

In Table 3.4, change the value of U_0 from 62636860.8497 m^2/s^2 to 62636851.7146 m^2/s^2.

PAGE 4-4

Change Equation (4-9) from "$\beta = \arctan\left(\frac{z\sqrt{u^2+E^2}}{u\sqrt{x^2+y}}\right)$" to read "$\beta = \arctan\left(\frac{z\sqrt{u^2+E^2}}{u\sqrt{x^2+y^2}}\right)$".

PAGE 5-1

In the first paragraph, change the sentence "The WGS 84 EGM96, complete through degree (n) and order (m) 360, is comprised of 130,321 coefficients." to read "The WGS 84 EGM96, complete through degree (n) and order (m) 360, is comprised of 130,317 coefficients.".

PAGE 5-3

At the end of the definition of terms for Equation (5-3), change the definition of the "k" term from "For $m=0$, $k=1$; $m>1$, $k=2$" to read "For $m=0$, $k=1$; $m\neq0$, $k=2$".

PAGE 7-2

In the next to the last paragraph, change the sentences "Note that the National Map Accuracy Standard requires points to be horizontally accurate to 0.51 mm (1/50 in.) for scales of 1:20,000 or larger and 0.84 mm (1/30 in.) for scales less than 1:20,000. For example, this corresponds to 2.5 m at 1:5,000 and 42 m at 1:50,000." to read "Note that the National Map Accuracy Standard requires test points to be horizontally accurate to 0.85 mm (1/30 in.) for scales of 1:20,000 or larger and 0.51 mm (1/50 in.) for scales less than 1:20,000. For example, this corresponds to 4.2 m at 1:5,000 and 25 m at 1:50,000.".

PAGE R-4

Change the title of the paper in reference number 40. from "Status of the World Geodetic System 1984" to read "Refinements to The World Geodetic System 1984".

PAGE B-3

In the second paragraph of Section 1, change the sentence "there are 109 local geodetic datums ...." To read "There are 112 local geodetic datums ....".

PAGE B.1-2

Add the Korean Geodetic System 1995.

PAGE B.1-3

Add the Old Hawaiian datum using the International 1924 ellipsoid.

PAGE B.1-4

Add the South American Geocentric Reference System (SIRGAS).

PAGE B.3-2

The old Cycle 0 transformation parameters for the INDIAN 1975 datum in Thailand were added and the code for the Cycle 1 parameters was changed from "INH-A" to "INH-A1".

PAGE B.3-3

Add the Korean Geodetic System 1995 for South Korea.

PAGE B.3-5

The old Cycle 0 transformation parameters for the TOKYO datum in South Korea were added and the code for the Cycle 1 parameters was changed from "TOY-B" to "TOY-B1".

PAGE B.7-6

Add the South American Geocentric Reference System for South America.

PAGE B.10-5

Add the Old Hawaiian datum using the International 1924 ellipsoid.

NIMA/Geodesy and Geophysics Department

EXECUTIVE SUMMARY

The global geocentric reference frame and collection of models known as the World Geodetic System 1984 (WGS 84) has evolved significantly since its creation in the mid-1980s. The WGS 84 continues to provide a single, common, accessible 3-dimensional coordinate system for geospatial data collected from a broad spectrum of sources. Some of this geospatial data exhibits a high degree of 'metric' fidelity and requires a global reference frame which is free of any significant distortions or biases. For this reason, a series of improvements to WGS 84 were developed in the past several years which served to refine the original version.

A consistent global set of 3-dimensional station coordinates infers the location of an origin, the orientation of an orthogonal set of Cartesian axes and a scale. In essence, a set of station coordinates infers a particular realization of a reference frame. The station coordinates which compose the operational WGS 84 reference frame are those of the permanent DoD GPS monitor stations.

Within the last three years, the coordinates for these DoD GPS stations have been refined two times, once in 1994 and again in 1996. The two sets of self-consistent GPS-realized coordinates (Terrestrial Reference Frames) derived to date have been designated 'WGS 84 (G730)' and 'WGS 84 (G873)', where the 'G' indicates these coordinates were obtained through GPS techniques and the number following the 'G' indicates the GPS week number when these coordinates were implemented in the NIMA precise GPS ephemeris estimation process. The dates when these refined station coordinate sets were implemented in the GPS Operational Control Segment (OCS) were 29 June 1994 and 29 January 1997, respectively.

These reference frame enhancements, as well as the previous set of enhancements, implemented in 1994, are negligible (less than 30 centimeters) in the context of mapping, charting and enroute navigation. Therefore, users should consider the WGS 84 reference frame unchanged for applications involving mapping, charting and enroute navigation.

In addition to these reference frame enhancements, an intensive joint effort has been conducted during the last three years involving analysts and resources of NIMA, the NASA Goddard Space Flight Center (GSFC) and The Ohio State University. The result of this joint effort is a new global model of the Earth's gravitational field: Earth Gravitational Model 1996 (EGM96). In the case of DoD applications, this model replaces the now-outdated original WGS 84 gravitational model developed more than ten years ago. The form of the EGM96 model is a spherical harmonic expansion of the gravitational potential. The model, complete through degree (n) and order (m) 360, is comprised of 130,317 coefficients. NIMA recommends use of an appropriately truncated (less than or equal to n=m=70) copy of this geopotential model for high accuracy orbit determination.

A refined WGS 84 geoid has been determined from the new gravitational model and is available as a 15 minute grid of geoid undulations which exhibit an absolute

Table 3.3
WGS 84 Ellipsoid Derived Geometric Constants

Constant	**Notation**	**Value**
Second degree Zonal Harmonic	$\overline{C}_{2,0}$	$-0.484166774985 \times 10^{-3}$
Semi-minor Axis	b	6356752.3142 m
First Eccentricity	e	$8.1819190842622 \times 10^{-2}$
First Eccentricity Squared	e^2	$6.69437999014 \times 10^{-3}$
Second Eccentricity	e'	$8.2094437949696 \times 10^{-2}$
Second Eccentricity Squared	e'^2	$6.73949674228 \times 10^{-3}$
Linear Eccentricity	E	$5.2185400842339 \times 10^{5}$
Polar Radius of Curvature	c	6399593.6258 m
Axis Ratio	b/a	0.996647189335
Mean Radius of Semi-axes	R_1	6371008.7714 m
Radius of Sphere of Equal Area	R_2	6371007.1809 m
Radius of Sphere of Equal Volume	R_3	6371000.7900 m

Table 3.4
Derived Physical Constants

Constant	**Notation**	**Value**
Theoretical (Normal) Gravity Potential of the Ellipsoid	U_0	62636851.7146 m^2/s^2
Theoretical (Normal) Gravity at the Equator (on the Ellipsoid)	γ_e	9.7803253359 m/s^2
Theoretical (Normal) Gravity at the pole (on the Ellipsoid)	γ_p	9.8321849378 m/s^2
Mean Value of Theoretical (Normal) Gravity	$\overline{\gamma}$	9.7976432222 m/s^2
Theoretical (Normal) Gravity Formula Constant	k	0.00193185265241
Mass of the Earth (Includes Atmosphere)	M	5.9733328×10^{24} kg
$m=\omega^2 a^2 b/GM$	m	0.00344978650684

$$\beta = \arctan\left(\frac{z\sqrt{u^2+E^2}}{u\sqrt{x^2+y^2}}\right) \tag{4-9}$$

$$w = \sqrt{\frac{u^2+E^2\sin^2\beta}{u^2+E^2}} \tag{4-10}$$

$$q = \frac{1}{2}\left[\left(1+3\frac{u^2}{E^2}\right)\arctan\left(\frac{E}{u}\right)-3\frac{u}{E}\right] \tag{4-11}$$

$$q_o = \frac{1}{2}\left[\left(1+3\frac{b^2}{E^2}\right)\arctan\left(\frac{E}{b}\right)-3\frac{b}{E}\right] \tag{4-12}$$

$$q' = 3\left[1+\frac{u^2}{E^2}\right]\cdot\left[1-\frac{u}{E}\arctan\left(\frac{E}{u}\right)\right]-1 \tag{4-13}$$

The rectangular coordinates (x,y,z) required in Equations (4-8) and (4-9) can be computed from known geodetic coordinates (ϕ ,λ ,h) through the equations:

$$\begin{aligned} x &= (N+h)\cos\phi\cos\lambda \\ y &= (N+h)\cos\phi\sin\lambda \\ z &= \left(\left(b^2/a^2\right)\cdot N+h\right)\sin\phi \end{aligned} \tag{4-14}$$

where the radius of curvature in the prime vertical (N) is defined by the equation:

$$N = \frac{a}{\left(1-e^2\sin^2\phi\right)^{1/2}} \quad . \tag{4-15}$$

The description of the coordinate system defined by Equations (4-14) is given in Chapter 2.

To compute the component γ_h at point P in Figure 4.2 exactly, (account for the angle ε in Figure 4.2 that is being treated as negligible in Equation (4-4)), the ellipsoidal normal gravity components γ_u and γ_β are rotated to a spherical coordinate system (r, ψ ,λ) resulting in the spherical normal gravity components, γ_r and γ_ψ. Then, the spherical components are projected onto the geodetic normal line through point P using the angular difference ($\alpha = \phi - \psi$) between geodetic (ϕ) and geocentric (ψ) latitudes. The equations to calculate the exact value of γ_h at point P follow:

5. WGS 84 EGM96 GRAVITATIONAL MODELING

5.1 Earth Gravitational Model (EGM96)

The form of the WGS 84 EGM96 Earth Gravitational Model is a spherical harmonic expansion (Table 5.1) of the gravitational potential (V). The WGS 84 EGM96, complete through degree (n) and order (m) 360, is comprised of 130,317 coefficients.

EGM96 was a joint effort that required NIMA gravity data, NASA/GSFC satellite tracking data and DoD tracking data in its development. The NIMA effort consisted of developing worldwide 30′ and 1° mean gravity anomaly databases from its Point Gravity Anomaly file and 5′ x 5′ mean GEOSAT Geodetic Mission geoid height file using least-squares collocation with the Forsberg Covariance Model [32] to estimate the final 30′ x 30′ mean gravity anomaly directly with an associated accuracy. The GSFC effort consisted of satellite orbit modeling by tracking over 30 satellites including new satellites tracked by Satellite Laser Ranging (SLR), Tracking and Data Relay Satellite System (TDRSS) and GPS techniques in the development of EGM96S (the satellite only model of EGM96 to degree and order 70). The development of the combination model to 70 x 70 incorporated direct satellite altimetry (TOPEX/POSEIDON, ERS-1 and GEOSAT) with EGM96S and surface gravity normal equations. Major additions to the satellite tracking data used by GSFC included new observations of Lageos, Lageos-2, Ajisai, Starlette, Stella, TOPEX and GPSMET along with GEOS-1 and GEOSAT. Finally, GSFC developed the high degree EGM96 solution by blending the combination solution to degree and order 70 with a block diagonal solution from degree and order 71 to 359 and a quadrature solution at degree and order 360. A complete description of EGM96 can be found in [41].

The EGM96 through degree and order 70 is recommended for high accuracy satellite orbit determination and prediction purposes. An Earth orbiting satellite's sensitivity to the geopotential is strongly influenced by the satellite's altitude range and other orbital parameters. DoD programs performing satellite orbit determination are advised to determine the maximum degree and order that is most appropriate for their particular mission and orbit accuracy requirements.

The WGS 84 EGM96 coefficients through degree and order 18 are provided in Table 5.1 in normalized form. An error covariance matrix is available for those coefficients through degree and order 70 determined from the weighted least squares combination solution. Coefficient sigmas are available to degree and order 360. Gravity anomaly degree variances are given in Table 5.2 for the WGS 84 EGM96 (degree and order 360). Requesters having a need for the full WGS 84 EGM96, its error data and associated software should forward their correspondence to the address listed in the PREFACE.

$\overline{P}_{nm}(\sin\phi')$ = Normalized associated Legendre function

$$= \left[\frac{(n-m)!(2n+1)k}{(n+m)!}\right]^{1/2} P_{nm}(\sin\phi')$$

$P_{nm}(\sin\phi')$ = Associated Legendre function

$$= (\cos\phi')^{m} \frac{d^{m}}{d(\sin\phi')^{m}}[P_{n}(\sin\phi')]$$

$P_{n}(\sin\phi')$ = Legendre polynomial

$$= \frac{1}{2^{n}\, n!} \frac{d^{n}}{d(\sin\phi')^{n}}(\sin^{2}\phi' - 1)^{n}$$

Note:

$$\begin{vmatrix}\overline{C}_{nm}\\ \overline{S}_{nm}\end{vmatrix} = \left[\frac{(n+m)!}{(n-m)!(2n+1)k}\right]^{1/2} \begin{vmatrix}C_{nm}\\ S_{nm}\end{vmatrix}$$

where:

C_{nm}, S_{nm} = Conventional gravitational coefficients

For $m = 0, k = 1;$

$m \neq 0, k = 2$

The series is theoretically valid for r ≥ a, though it can be used with probably negligible error near or on the Earth's surface, i.e., r ≥ Earth's surface. But the series should not be used for r < Earth's surface.

on a horizontal adjustment of conventional survey data and the inclusion of Transit Satellite Doppler data and Very Long Baseline Interferometry (VLBI) data. The global Doppler and VLBI observations were used to orient the NAD 83 reference frame to the BIH Terrestrial System of 1984. The orientation of the ECEF coordinate axes of the NAD 83 reference frame is identical to that of the *original* WGS 84 reference frame.

NAD 83 uses the Geodetic Reference System 1980 (GRS 80) ellipsoid as its reference ellipsoid with the geometric center of the ellipsoid coincident with the center of mass of the Earth and the origin of the coordinate system. The semi-major axis and flattening parameters are adopted directly as

$$a = 6378137 \text{ m}$$

$$1/f = 298.257222101$$

The WGS 84 Ellipsoid is for all practical purposes identical to the GRS 80 ellipsoid. They use the same value for the semi-major axis and have the same orientation with respect to the center of mass and the coordinate system origin. However, WGS 84 uses a derived value for the flattening that is computed from the normalized second degree zonal harmonic gravitational coefficient $\overline{C}_{2,0}$. $\overline{C}_{2,0}$ was derived from the GRS 80 value for J_2 and truncated to 8 significant digits as:

$$\overline{C}_{2,0} = -J_2/(5)^{1/2} \tag{7-1}$$

The resulting WGS 84 value for 1/f is 298.257223563. The difference between the GRS 80 and WGS 84 values for f creates a difference of 0.1 mm in the derived semi-minor axes of the two ellipsoids.

Based on these definitions, geodetic positions determined with respect to NAD 83 or WGS 84 have uncertainties of about one meter in each component. For mapping, charting and navigation, the two systems are indistinguishable at scales of 1:5,000 or smaller and with accuracies of about 2 m. Note that the National Map Accuracy Standard requires test points to be horizontally accurate to 0.85 mm (1/30 in.) for scales of 1:20,000 or larger and 0.51 mm (1/50 in.) for scales less than 1:20,000. For example, this corresponds to 4.2 m at 1:5,000 and 25 m at 1:50,000. For geodetic applications, one can expect to see a difference of a meter or more between the WGS 84 and NAD 83 positions of the same point. This is due to the uncertainty associated with each independent determination and the fact that the errors are additive when comparing the difference in the coordinates.

WGS 84 has undergone several enhancements since its original definition. The practical realization of the reference frame is determined by a network of permanent GPS tracking stations which are aligned with the ITRF, the successor to the BIH Terrestrial System, through a globally distributed set of stations with very high accuracy

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37. Molodensky, M.S., Eremeev, V.F., and Yurkina, M.I.; Methods for Study of the External Gravitational Field and Figure of the Earth; Israel Program for Scientific Translations; Jerusalem, Israel; 1962. (Available from the National Technical Information Service; United States Department of Commerce; Washington, DC).

38. Appelbaum, L.T.; "Geodetic Datum Transformation By Multiple Regression Equations"; Proceedings of the Third International Geodetic Symposium on Satellite Doppler Positioning; New Mexico State University; Physical Science Laboratory; Las Cruces, New Mexico; 8-12 February 1982.

39. Malys, S., Bredthauer, D., and Deweese, S.; "Error Budget for the DMA GPS Geodetic Point Positioning Algorithm Through Monte Carlo Simulation"; Proceedings of ION-GPS-93; Salt Lake City, Utah; September, 1993.

40. Malys, S., Slater, J., Smith, R., Kunz, L., Kenyon, S.; "Refinements to The World Geodetic System 1984"; Proceedings of GPS ION-97; Kansas City, MO; September 1997.

41. Lemoine, F.G., Kenyon, S.C., Trimmer, R., Factor, J., Pavlis, N.K., Klosko, S.M., Chinn, D.S., Torrence, M.H., Pavilis, E.C., Rapp. R.H., and Olson, T.R.; "EGM96 The NASA GSFC and NIMA Joint Geopotential Model"; NASA Technical Memorandum; 1997.

DATUM TRANSFORMATION CONSTANTS
GEODETIC DATUMS/SYSTEMS TO WGS 84
(THROUGH SATELLITE TIES)

1. GENERAL

This appendix provides the details about the reference ellipsoids (Appendix A) which are used as defining parameters for the geodetic datums and systems.

There are 112 local geodetic datums which are currently related to WGS 84 through satellite ties.

2. LOCAL DATUM ELLIPSOIDS

Appendix B.1 lists, alphabetically, the local geodetic datums with their associated ellipsoids. Two letter ellipsoidal codes (Appendix A) have also been included against each datum to indicate which specific "version" of the ellipsoid was used in determining the transformation constants.

3. TRANSFORMATION CONSTANTS

Appendices B.2 through B.7 list the constants for local datums for continental areas. The continents and the local geodetic datums are arranged alphabetically.

Appendices B.8 through B.10 list the constants for local datums which fall within the ocean areas. The ocean areas and the geodetic datums are also arranged alphabetically.

The year of initial publication and cycle numbers have been provided as a new feature in this edition. This makes it possible for a user to determine when a particular set of transformation parameters first became available and if the current set has replaced an outdated set.

A cycle number of zero indicates that the set of parameters is as it was published in DMA TR 8350.2, Second Edition, 1 September 1991 including Insert 1, 30 August 1993 or that the parameters are new to this edition (1997 Publication Date). A cycle number of one indicates that the current parameters have replaced outdated parameters that were in the previous edition.

If transformation parameter sets are updated in future editions of this publication, the cycle numbers for each parameter set that is updated will increment by one.

4. ERROR ESTIMATES

The 1σ error estimates for the datum transformation constants ($\Delta X, \Delta Y, \Delta Z$), obtained from the computed solutions, are also tabulated. These estimates do not include

Appendix B.1
Geodetic Datums/Reference Systems Related to World Geodetic System 1984 (Through Satellite Ties)

Local Geodetic Datum	Associated*Reference Ellipsoid	Code
Adindan	Clarke 1880	CD
Afgooye	Krassovsky 1940	KA
Ain el Abd 1970	International 1924	IN
American Samoa 1962	Clarke 1866	CC
Anna 1 Astro 1965	Australian National	AN
Antigua Island Astro 1943	Clarke 1880	CD
Arc 1950	Clarke 1880	CD
Arc 1960	Clarke 1880	CD
Ascension Island 1958	International 1924	IN
Astro Beacon "E" 1945	International 1924	IN
Astro DOS 71/4	International 1924	IN
Astro Tern Island (FRIG) 1961	International 1924	IN
Astronomical Station 1952	International 1924	IN
Australian Geodetic 1966	Australian National	AN
Australian Geodetic 1984	Australian National	AN
Ayabelle Lighthouse	Clarke 1880	CD
Bellevue (IGN)	International 1924	IN
Bermuda 1957	Clarke 1866	CC
Bissau	International 1924	IN
Bogota Observatory	International 1924	IN
Campo Inchauspe	International 1924	IN
Canton Astro 1966	International 1924	IN
Cape	Clarke 1880	CD
Cape Canaveral	Clarke 1866	CC
Carthage	Clarke 1880	CD
Chatham Island Astro 1971	International 1924	IN
Chua Astro	International 1924	IN
Co-Ordinate System 1937 of Estonia	Bessel 1841	BR
Corrego Alegre	International 1924	IN
Dabola	Clarke 1880	CD
Deception Island	Clarke 1880	CD
Djakarta (Batavia)	Bessel 1841	BR
DOS 1968	International 1924	IN
Easter Island 1967	International 1924	IN

* See Appendix A.1 for associated constants a,f.

Appendix B.1

Geodetic Datums/Reference Systems
Related to World Geodetic System 1984
(Through Satellite Ties)

Local Geodetic Datum	Associated*Reference Ellipsoid	Code
European 1950	International 1924	IN
European 1979	International 1924	IN
Fort Thomas 1955	Clarke 1880	CD
Gan 1970	International 1924	IN
Geodetic Datum 1949	International 1924	IN
Graciosa Base SW 1948	International 1924	IN
Guam 1963	Clarke 1866	CC
GUX 1 Astro	International 1924	IN
Hjorsey 1955	International 1924	IN
Hong Kong 1963	International 1924	IN
Hu-Tzu-Shan	International 1924	IN
Indian	Everest	EA/EC**
Indian 1954	Everest	EA
Indian 1960	Everest	EA
Indian 1975	Everest	EA
Indonesian 1974	Indonesian 1974	ID
Ireland 1965	Modified Airy	AM
ISTS 061 Astro 1968	International 1924	IN
ISTS 073 Astro 1969	International 1924	IN
Johnston Island 1961	International 1924	IN
Kandawala	Everest	EA
Kerguelen Island 1949	International 1924	IN
Kertau 1948	Everest	EE
Korean Geodetic System 1995	WGS 84	WE
Kusaie Astro 1951	International 1924	IN
L. C. 5 Astro 1961	Clarke 1866	CC
Leigon	Clarke 1880	CD
Liberia 1964	Clarke 1880	CD
Luzon	Clarke 1866	CC
Mahe 1971	Clarke 1880	CD
Massawa	Bessel 1841	BR
Merchich	Clarke 1880	CD
Midway Astro 1961	International 1924	IN
Minna	Clarke 1880	CD

* See Appendix A.1 for associated constants a,f.

** Due to different semi-major axes. See Appendix A.1.

Appendix B.1

Geodetic Datums/Reference Systems
Related to World Geodetic System 1984
(Through Satellite Ties)

Local Geodetic Datum	Associated*Reference Ellipsoid	Code
Montserrat Island Astro 1958	Clarke 1880	CD
M'Poraloko	Clarke 1880	CD
Nahrwan	Clarke 1880	CD
Naparima, BWI	International 1924	IN
North American 1927	Clarke 1866	CC
North American 1983	GRS 80**	RF
North Sahara 1959	Clarke 1880	CD
Observatorio Meteorologico 1939	International 1924	IN
Old Egyptian 1907	Helmert 1906	HE
Old Hawaiian	Clarke 1866	CC
Old Hawaiian	International 1924	IN
Oman	Clarke 1880	CD
Ordnance Survey of Great Britain 1936	Airy 1830	AA
Pico de las Nieves	International 1924	IN
Pitcairn Astro 1967	International 1924	IN
Point 58	Clarke 1880	CD
Pointe Noire 1948	Clarke 1880	CD
Porto Santo 1936	International 1924	IN
Provisional South American 1956	International 1924	IN
Provisional South Chilean 1963***	International 1924	IN
Puerto Rico	Clarke 1866	CC
Qatar National	International 1924	IN
Qornoq	International 1924	IN
Reunion	International 1924	IN
Rome 1940	International 1924	IN
S-42 (Pulkovo 1942)	Krassovsky 1940	KA
Santo (DOS) 1965	International 1924	IN
Sao Braz	International 1924	IN
Sapper Hill 1943	International 1924	IN

* See Appendix A.1 for associated constants a,f.

** Geodetic Reference System 1980

*** Also known as Hito XVIII 1963

Appendix B.1

Geodetic Datums/Reference Systems
Related to World Geodetic System 1984
(Through Satellite Ties)

Local Geodetic Datum	Associated*Reference Ellipsoid	Code
Schwarzeck	Bessel 1841	BN
Selvagem Grande 1938	International 1924	IN
Sierra Leone 1960	Clark 1880	CD
S-JTSK	Bessel 1841	BR
South American 1969	South American 1969	SA
South American Geocentric Reference System (SIRGAS)	GRS 80**	RF
South Asia	Modified Fischer 1960	FA
Timbalai 1948	Everest	EB
Tokyo	Bessel 1841	BR
Tristan Astro 1968	International 1924	IN
Viti Levu 1916	Clarke 1880	CD
Voirol 1960	Clarke 1880	CD
Wake-Eniwetok 1960	Hough 1960	HO
Wake Island Astro 1952	International 1924	IN
Zanderij	International 1924	IN

* See Appendix A.1 for associated constants a,f.

** Geodetic Reference System 1980

Appendix B.3

Transformation Parameters
Local Geodetic Datums to WGS 84

Continent: ASIA

Local Geodetic Datums		Reference Ellipsoids and Parameter Differences			No. of Satellite Stations Used	Transformation Parameters				
Name	**Code**	**Name**	**Δa(m)**	**Δf x 10^4**		**Cycle Number**	**Pub. Date**	**ΔX(m)**	**ΔY(m)**	**ΔZ(m)**
INDIAN	IND	Everest								
Bangladesh	IND-B	Everest (1830)	860.655*	0.28361368	6	0	1991	282 ±10	726 ±8	254 ±12
India and Nepal	IND-I	Everest (1956)	835.757*	0.28361368	7	0	1991	295 ±12	736 ±10	257 ±15
INDIAN 1954	INF	Everest (1830)	860.655*	0.28361368						
Thailand	INF-A				11	0	1993	217 ±15	823 ±6	299 ±12
INDIAN 1960	ING	Everest (1830)	860.655*	0.28361368						
Vietnam (near 16°N)	ING-A				2	0	1993	198 ±25	881 ±25	317 ±25
Con Son Island (Vietnam)	ING-B				1	0	1993	182 ±25	915 ±25	344 ±25
INDIAN 1975	INH	Everest (1830)	860.655*	0.28361368						
Thailand	INH-A				6	0	1991	209 ±12	818 ±10	290 ±12
Thailand	INH-A1				62	1	1997	210 ±3	814 ±2	289 ±3

* See Appendix A

Appendix B.3

Transformation Parameters

Local Geodetic Datums to WGS 84

Continent: ASIA

Local Geodetic Datums		**Reference Ellipsoids and Parameter Differences**			**No. of Satellite Stations Used**	**Transformation Parameters**				
Name	**Code**	**Name**	**Δa(m)**	**$\Delta f \times 10^4$**		**Cycle Number**	**Pub. Date**	**ΔX(m)**	**ΔY(m)**	**ΔZ(m)**
INDONESIAN 1974	IDN	Indonesian 1974	-23	-0.00114930						
Indonesia					1	0	1993	-24 ±25	-15 ±25	5 ±25
KANDAWALA	KAN	Everest (1830)	860.655*	0.28361368						
Sri Lanka					3	0	1987	-97 ±20	787 ±20	86 ±20
KERTAU 1948	KEA	Everest (1948)	832.937*	0.28361368						
West Malaysia and Singapore					6	0	1987	-11 ±10	851 ±8	5 ±6
KOREAN GEODETIC SYSTEM 1995	KGS	WGS 84	0	0						
South Korea					29	0	1997	0 ±1	0 ±1	0 ±1

* See Appendix A

Appendix B.3

Transformation Parameters
Local Geodetic Datums to WGS 84

Continent: ASIA

Local Geodetic Datums		Reference Ellipsoids and Parameter Differences			No. of Satellite Stations Used	Transformation Parameters				
Name	Code	Name	Δa(m)	Δf x 10^4		Cycle Number	Pub. Date	ΔX(m)	ΔY(m)	ΔZ(m)
NAHRWAN	NAH	Clarke 1880	-112.145	-0.54750714						
Masirah Island (Oman)	NAH-A				2	0	1987	-247 ±25	-148 ±25	369 ±25
United Arab Emirates	NAH-B				2	0	1987	-249 ±25	-156 ±25	381 ±25
Saudi Arabia	NAH-C				3	0	1991	-243 ±20	-192 ±20	477 ±20
OMAN	FAH	Clarke 1880	-112.145	-0.54750714						
Oman					7	0	1987	-346 ±3	-1 ±3	224 ±9
QATAR NATIONAL	QAT	International 1924	-251	-0.14192702						
Qatar					3	0	1987	-128 ±20	-283 ±20	22 ±20
SOUTH ASIA	SOA	Modified Fischer 1960	-18	0.00480795						
Singapore					1	0	1987	7 ±25	-10 ±25	-26 ±25

* See Appendix A

Appendix B.3

Transformation Parameters

Local Geodetic Datums to WGS 84

Continent: ASIA

Local Geodetic Datums		Reference Ellipsoids and Parameter Differences			No. of Satellite Stations Used	Transformation Parameters				
Name	**Code**	**Name**	**Δa(m)**	**$\Delta f \times 10^4$**		**Cycle Number**	**Pub. Date**	**ΔX(m)**	**ΔY(m)**	**ΔZ(m)**
TIMBALAI 1948	TIL	Everest	838.444*	0.28361368						
Brunei and East Malaysia (Sarawak and Sabah)					8	0	1987	-679 ±10	669 ±10	-48 ±12
TOKYO	TOY	Bessel 1841	739.845	0.10037483						
Mean Solution (Japan, Okinawa and South Korea)	TOY-M				31	0	1991	-148 ±20	507 ±5	685 ±20
Japan	TOY-A				16	0	1991	-148 ±8	507 ±5	685 ±8
Okinawa	TOY-C				3	0	1991	-158 ±20	507 ±5	676 ±20
South Korea	TOY-B				12	0	1991	-146 ±8	507 ±5	687 ±8
South Korea	TOY-B1				29	1	1997	-147 ±2	506 ±2	687 ±2

Appendix B.7

Transformation Parameters
Local Geodetic Datums to WGS 84

Continent: SOUTH AMERICA										
Local Geodetic Datums		**Reference Ellipsoids and Parameter Differences**			**No. of Satellite Stations Used**	**Transformation Parameters**				
Name	**Code**	**Name**	**Δa(m)**	**Δf x 10^4**		**Cycle Number**	**Pub. Date**	**ΔX(m)**	**ΔY(m)**	**ΔZ(m)**
SOUTH AMERICAN GEOCENTRIC REFERENCE SYSTEM (SIRGAS)	SIR	GRS 80	0	-0.00000016						
South America					66	0	1997	0 ±1	0 ±1	0 ±1
ZANDERIJ	ZAN	International 1924	-251	-0.14192702						
Suriname					5	0	1987	-265 ±5	120 ±5	-358 ±8

Appendix B.10
Transformation Parameters
Local Geodetic Datums to WGS 84

Continent: PACIFIC OCEAN

Local Geodetic Datums		Reference Ellipsoids and Parameter Differences			No. of Satellite Stations Used	Transformation Parameters				
Name	**Code**	**Name**	**Δa(m)**	**$\Delta f \times 10^4$**		**Cycle Number**	**Pub. Date**	**ΔX(m)**	**ΔY(m)**	**ΔZ(m)**
OLD HAWAIIAN	OHI	International 1924	-251	-0.14192702						
Mean Solution	OHI-M				15	0	2000	201 ±25	-228 ±20	-346 ±20
Hawaii	OHI-A				2	0	2000	229 ±25	-222 ±25	-348 ±25
Kauai	OHI-B				3	0	2000	185 ±20	-233 ±20	-337 ±20
Maui	OHI-C				2	0	2000	205 ±25	-233 ±25	-355 ±25
Oahu	OHI-D				8	0	2000	198 ±10	-226 ±6	-347 ±6
PITCAIRN ASTRO 1967	PIT	International 1924	-251	-0.14192702						
Pitcairn Island					1	0	1987	185 ±25	165 ±25	42 ±25
SANTO (DOS) 1965	SAE	International 1924	-251	-0.14192702						
Espirito Santo Island					1	0	1987	170 ±25	42 ±25	84 ±25
VITI LEVU 1916	MVS	Clarke 1880	-112.145	-0.54750714						
Viti Levu Island (Fiji Islands)					1	0	1987	51 ±25	391 ±25	-36 ±25

Appendix B.10
Transformation Parameters
Local Geodetic Datums to WGS 84

Continent: PACIFIC OCEAN

Local Geodetic Datums		Reference Ellipsoids and Parameter Differences			No. of Satellite Stations Used	Transformation Parameters				
Name	**Code**	**Name**	**Δa(m)**	**Δf x 10⁴**		**Cycle Number**	**Pub. Date**	**ΔX(m)**	**ΔY(m)**	**ΔZ(m)**
WAKE-ENIWETOK 1960	ENW	Hough	-133	-0.14192702						
Marshall Islands					10	0	1991	102 ±3	52 ±3	-38 ±3
WAKE ISLAND ASTRO 1952	WAK	International 1924	-251	-0.14192702						
Wake Atoll					2	0	1991	276 ±25	-57 ±25	149 ±25

Appendix B.10
Transformation Parameters
Local Geodetic Datums to WGS 84

Continent: PACIFIC OCEAN

Local Geodetic Datums		Reference Ellipsoids and Parameter Differences			No. of Satellite Stations Used	Transformation Parameters				
Name	**Code**	**Name**	**Δa(m)**	**Δf x 10⁴**		**Cycle Number**	**Pub. Date**	**ΔX(m)**	**ΔY(m)**	**ΔZ(m)**
LUZON	LUZ	Clarke 1866	-69.4	-0.37264639						
Phillippines (Excluding Mindanao Island)	LUZ-A				6	0	1987	-133 ±8	-77 ±11	-51 ±9
Mindanao Island	LUZ-B				1	0	1987	-133 ±25	-79 ±25	-72 ±25
MIDWAY ASTRO 1961	MID	International 1924	-251	-0.14192702						
Midway Islands					1	1	2003	403 ±25	-81 ±25	277 ±25
Midway Islands					1	0*	1987	912 ±25	-58 ±25	1227 ±25

***NOTE**: The cycle number 0 parameters for Midway Astro 1961 are provided for historical purposes only. These parameters should not be used.

Appendix B.10
Transformation Parameters
Local Geodetic Datums to WGS 84

Continent: PACIFIC OCEAN

Local Geodetic Datums		Reference Ellipsoids and Parameter Differences			No. of Satellite Stations Used	Transformation Parameters				
Name	Code	Name	Δa(m)	Δf x 10^4		Cycle Number	Pub. Date	ΔX(m)	ΔY(m)	ΔZ(m)
PITCAIRN ASTRO 1967	PIT	International 1924	-251	-0.14192702						
Pitcairn Island					1	0	1987	185 ±25	165 ±25	42 ±25
SANTO (DOS) 1965	SAE	International 1924	-251	-0.14192702						
Espirito Santo Island					1	0	1987	170 ±25	42 ±25	84 ±25
VITI LEVU 1916	MVS	Clarke 1880	-112.145	-0.54750714						
Viti Levu Island (Fiji Islands)					1	0	1987	51 ±25	391 ±25	-36 ±25
WAKE-ENIWETOK 1960	ENW	Hough	-133	-0.14192702						
Marshall Islands					10	0	1991	102 ±3	52 ±3	-38 ±3
WAKE ISLAND ASTRO 1952	WAK	International 1924	-251	-0.14192702						
Wake Atoll					2	0	1991	276 ±25	-57 ±25	149 ±25

Appendix B.10
Transformation Parameters
Local Geodetic Datums to WGS 84

Continent: PACIFIC OCEAN

Local Geodetic Datums		Reference Ellipsoids and Parameter Differences			No. of Satellite Stations Used	Transformation Parameters				
Name	Code	Name	Δa(m)	Δf x 10⁴		Cycle Number	Pub. Date	ΔX(m)	ΔY(m)	ΔZ(m)
OLD HAWAIIAN	OHA	Clarke 1866	-69.4	-0.37264639						
Mean Solution	OHA-M				15	0	1987	61 ±25	-285 ±20	-181 ±20
Hawaii	OHA-A				2	0	1991	89 ±25	-279 ±25	-183 ±25
Kauai	OHA-B				3	0	1991	45 ±20	-290 ±20	-172 ±20
Maui	OHA-C				2	0	1991	65 ±25	-290 ±25	-190 ±25
Oahu	OHA-D				8	0	1991	58 ±10	-283 ±6	-182 ±6
OLD HAWAIIAN	OHI	International 1924	-251	-0.14192702						
Mean Solution	OHI-M				15	0	2000	201 ±25	-228 ±20	-346 ±20
Hawaii	OHI-A				2	0	2000	229 ±25	-222 ±25	-348 ±25
Kauai	OHI-B				3	0	2000	185 ±20	-233 ±20	-337 ±20
Mauai	OHI-C				2	0	2000	205 ±25	-233 ±25	-355 ±25
Oahu	OHI-D				8	0	2000	198 ±10	-226 ±6	-347 ±6

5.2 Gravity Potential (W)

The Earth's total gravity potential (W) is defined as:

$$W = V + \Phi \qquad (5\text{-}1)$$

where Φ is the potential due to the Earth's rotation. If ω is the angular velocity (Equation (3-6)), then:

$$\Phi = \frac{1}{2}\,\omega^2(x^2 + y^2) \qquad (5\text{-}2)$$

where x and y are the geocentric coordinates of a given point in the WGS 84 reference frame (See Figure 2.1).

The gravitational potential function (V) is defined as:

$$V = \frac{GM}{r}\left[1 + \sum_{n=2}^{n_{max}} \sum_{m=0}^{n} \left(\frac{a}{r}\right)^n \overline{P}_{nm}(\sin\phi')\left(\overline{C}_{nm}\cos m\lambda + \overline{S}_{nm}\sin m\lambda\right)\right] \qquad (5\text{-}3)$$

where:

V = Gravitational potential function (m^2/s^2)

GM = Earth's gravitational constant

r = Distance from the Earth's center of mass

a = Semi-major axis of the WGS 84 Ellipsoid

n,m = Degree and order, respectively

ϕ' = Geocentric latitude

λ= Geocentric longitude = geodetic longitude

$\overline{C}_{nm}, \overline{S}_{nm}$ = Normalized gravitational coefficients