SECTION 1

WGS 84

EARTH-CENTERED, EARTH-FIXED (ECEF) COORDINATE SYSTEM* (AND ASSOCIATED REFERENCE FRAMES)

* ANALOGOUS TO THE BIH-DEFINED CONVENTIONAL TERRESTRIAL SYSTEM (CTS), OR BTS, 1984.0.

Origin = Earth's Center of Mass ≡ Geometric Center of WGS 84 Ellipsoid

Z-Axis = Parallel to the Direction of the Conventional Terrestrial Pole (CTP) for Polar Motion, as Defined by the Bureau International de L'Heure (BIH) on the Basis of the Coordinates Adopted for the BIH Stations ≡ Rotation Axis (Z-Axis) of WGS 84 Ellipsoid

X-Axis = Intersection of the WGS 84 Reference Meridian Plane and the Plane of the CTP's Equator, the Reference Meridian Being Parallel to the Zero Meridian Defined by the BIH on the Basis of the Coordinates Adopted for the BIH Stations ≡ X-Axis of WGS 84 Ellipsoid.

Y-Axis = Completes a Right-Handed, Earth Centered, Earth Fixed (ECEF) Orthogonal Coordinate System, Measured in the Plane of the CTP Equator, 90° East of the X-Axis ≡ Y-Axis of WGS 84 Ellipsoid

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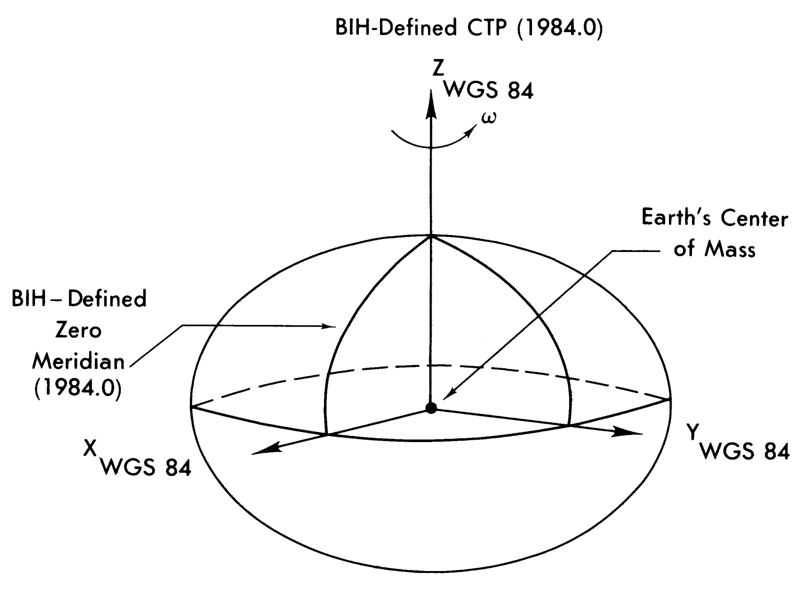
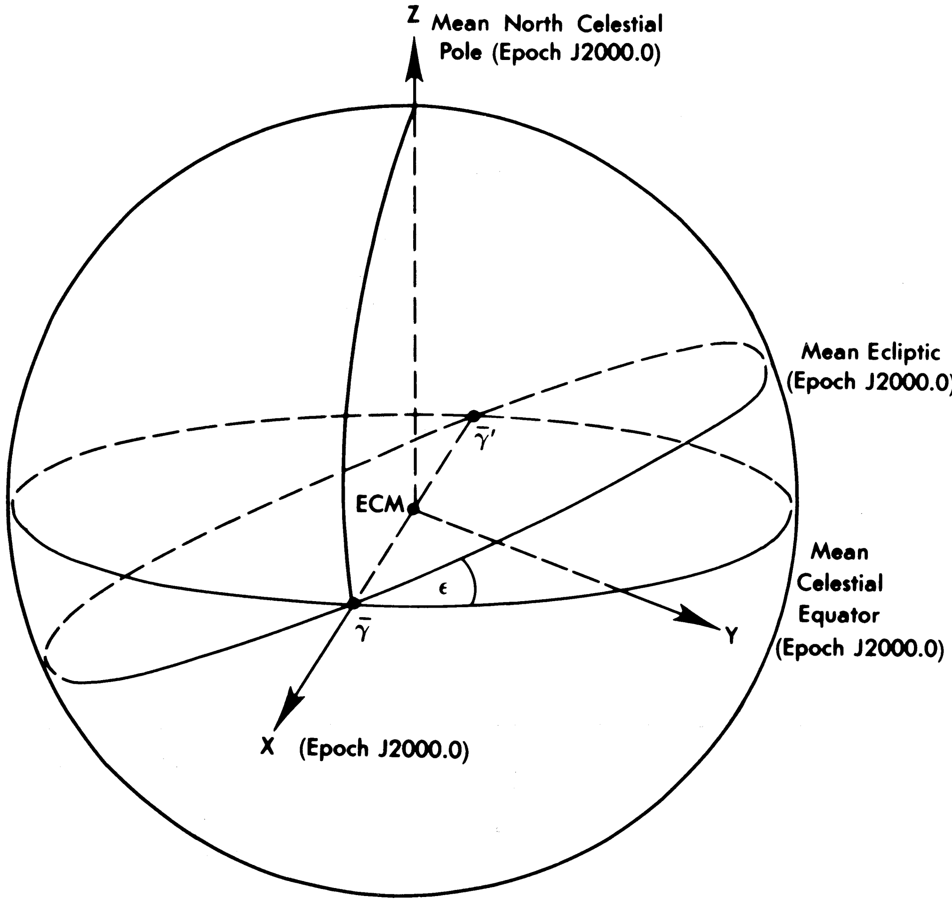


Figure 1.1. WGS 84 Reference Frame



$\bar{\gamma}$ = Mean Vernal Equinox (Epoch J2000.0)
$\bar{\gamma}'$ = Mean Autumnal Equinox (Epoch J2000.0)
ECM = Earth's Center of Mass
ϵ = Obliquity of the Ecliptic
$\epsilon \approx 23°27'$

Figure 1.2. Pictorial Definition of the Conventional Inertial System [Stellar (FK5), Epoch J2000.0]

Three Reference Systems

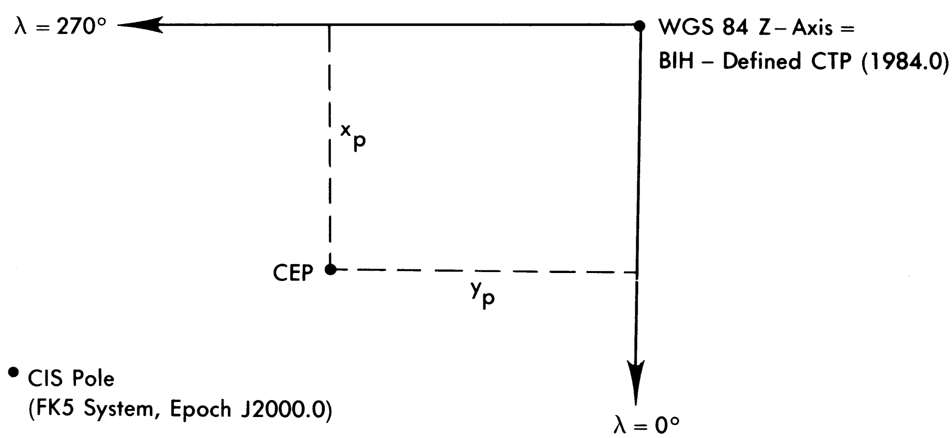
- Conventional Terrestrial System (CTS) = WGS 84
- Instantaneous Terrestrial System (ITS) = Not Realizable in a Measurement Sense. However, an Approximation to the ITS Pole, the Celestial Epheremis Pole (CEP), is Used Instead.
- Conventional Inertial System (CIS)

CTS (WGS 84) = [A] [B] [C] [D] CIS

Rotation Matrices:

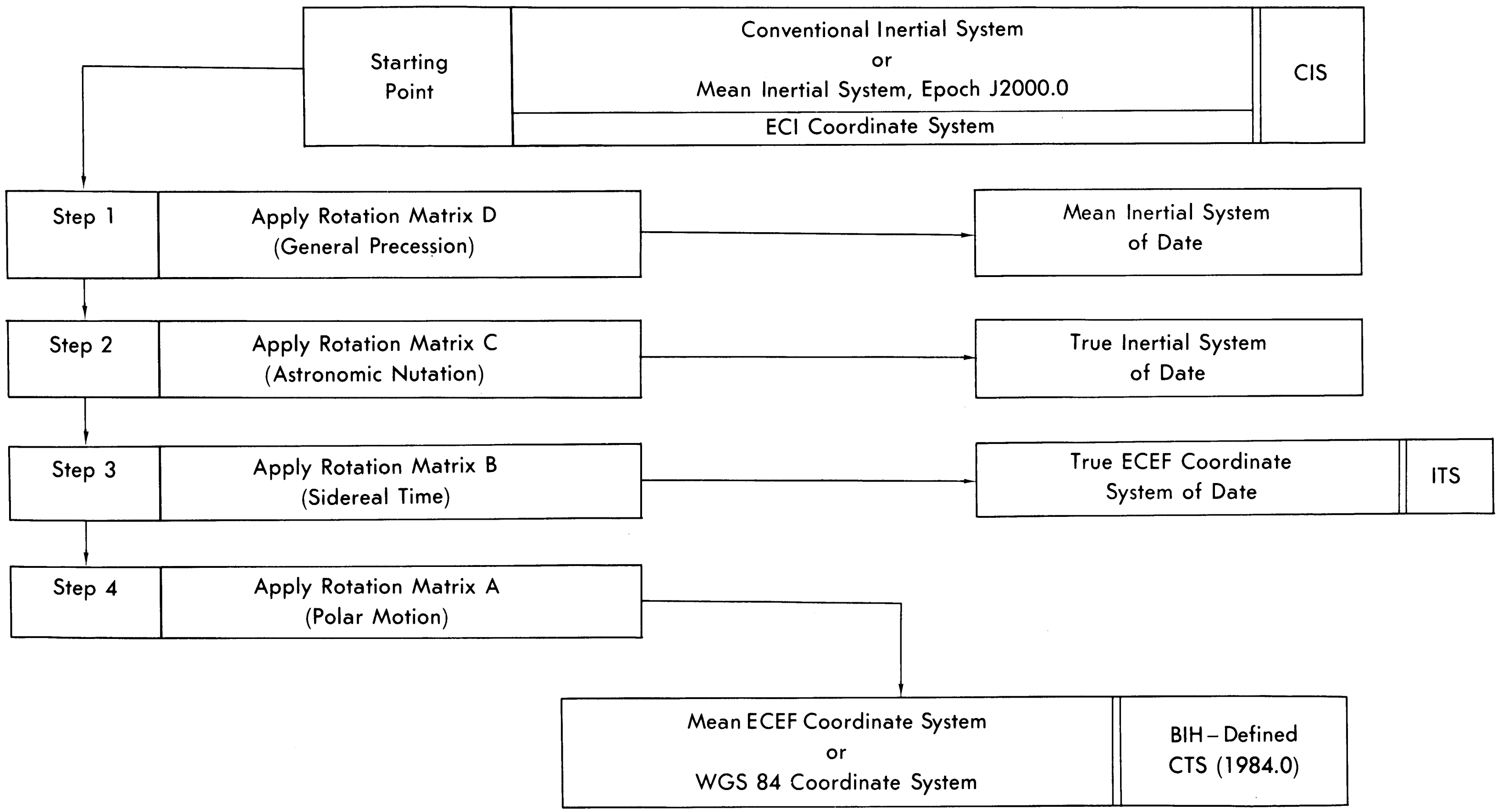
D = Precession
C = Astronomic Nutation
B = Sidereal Time
A = Polar Motion

[See Appendix to Reference 2.]



[x_p, y_p = Polar Motion Parameters; λ = Astronomic Longitude]

Figure 1.3. Mathematical and Pictorial Relationship Between WGS 84 and Associated Reference Frames (Systems)



[See Appendix to Reference 2.]

Figure 1.4. CIS-to-WGS 84 (CIS-to-CTS) Transformation

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SECTION 2

WGS 84 ELLIPSOID

- DEFINING PARAMETERS, ASSOCIATED CONSTANTS, ETC. -

Table 2.1

WGS 84 Ellipsoid
- Four Defining Parameters -

Parameters	Notation	Magnitude	Accuracy (1σ)
Semimajor Axis	a	6378137 m	±2 m
Normalized Second Degree Zonal Harmonic Coefficient of the Gravitational Potential	$\bar{C}_{2,0}$	$-484.16685 \times 10^{-6}$	$\pm 1.30 \times 10^{-9}$
Angular Velocity of the Earth	ω	7292115×10^{-11} rad s^{-1}	$\pm 0.1500 \times 10^{-11}$ rad s^{-1}
The Earth's Gravitational Constant (Mass of Earth's Atmosphere Included)	GM	3986005×10^{8} m^3 s^{-2}	$\pm 0.6 \times 10^{8}$ m^3 s^{-2}
Parameter Values for Special Applications			
The Earth's Gravitational Constant (Mass of Earth's Atmosphere Not Included)	GM'	3986001.5×10^{8} m^3 s^{-2}	$\pm 0.6 \times 10^{8}$ m^3 s^{-2}
Angular Velocity of the Earth (In a Precessing Reference Frame)	ω^*	$(7292115.8553 \times 10^{-11}$ $+ 4.3 \times 10^{-15}\ T_U)$ rad s^{-1}	$\pm 0.1500 \times 10^{-11}$ rad s^{-1}

T_U = Julian Centuries From Epoch J2000.0

$T_U = d_U/36525$

d_U = Number of Days of Universal Time (UT) From Julian Date (JD) 2451545.0 UT1, Taking on Values of ±0.5, ±1.5, ±2.5, ..

d_U = JD - 2451545

Table 2.2

WGS 84 Ellipsoid
- Derived Geometric Constants -

Constants	Notation	Value
Flattening (Ellipticity)	f	1/298.257223563 (0.00335281066474)
Semiminor Axis	b	6356752.3142 m
First Eccentricity	e	0.0818191908426
First Eccentricity Squared	e^2	0.00669437999013
Second Eccentricity	e'	0.0820944379496
Second Eccentricity Squared	e'^2	0.00673949674227
Linear Eccentricity	E	521854.0084 m
Polar Radius of Curvature	c	6399593.6258 m
Axis Ratio	b/a	0.996647189335
Mean Radius of Semiaxes	R_1	6371008.7714 m
Radius of Sphere With Equal Area	R_2	6371007.1809 m
Radius of Sphere With Equal Volume	R_3	6371000.7900 m

Table 2.3

WGS 84 Ellipsoid
- Derived Physical Constants -

Constants	Notation	Value
Theoretical (Normal) Gravity Potential of the Ellipsoid	U_o	62636860.8497 $m^2 s^{-2}$
Theoretical (Normal) Gravity at the Equator (on the Ellipsoid)	γ_e	9.7803267714 $m s^{-2}$
Theoretical (Normal) Gravity at the Poles (on the Ellipsoid)	γ_p	9.8321863685 $m s^{-2}$
Mean Value of Theoretical (Normal) Gravity	$\overline{\gamma}$	9.7976446561 $m s^{-2}$
Theoretical (Normal) Gravity Formula Constant	k	0.00193185138639
Mass of Earth (Includes the Atmosphere)	M	5.9733328 x 10^{24} kg
$m = \omega^2 a^2 b/GM$	m	0.00344978600313

Table 2.4
Relevant Miscellaneous Constants
and Conversion Factors

Constant	Symbol	Numerical Value
Velocity of Light (in a Vacuum)	c	299792458 $m\ s^{-1}$
Dynamical Ellipticity	H	1/305.4413
Earth's Angular Velocity [for Satellite Applications; See Equation (3-22) of Reference 2.]	ω^*	$(7292115.8553 \times 10^{-11} + 4.3 \times 10^{-15}\ T_U)\ rad\ s^{-1}$
Universal Constant of Gravitation	G	$6.673 \times 10^{-11} m^3 s^{-2} kg^{-1}$
GM of the Earth's Atmosphere	GM_A	$3.5 \times 10^8 m^3 s^{-2}$
Earth's Gravitational Constant (Excluding the Mass of the Earth's Atmosphere)	GM'	$3986001.5 \times 10^8 m^3 s^{-2}$
Earth's Principal Moments of Inertia (Dynamic Solution)	A B C	$8.0091029 \times 10^{37}\ kg\ m^2$ $8.0092559 \times 10^{37}\ kg\ m^2$ $8.0354872 \times 10^{37}\ kg\ m^2$

Conversion Factors	
1 Meter	= 3.28083333333 US Survey Feet
1 Meter	= 3.28083989501 International Feet
1 International Foot	= 0.3048 Meter (Exact)
1 US Survey Foot	= 1200/3937 Meter (Exact)
1 US Survey Foot	= 0.30480060960 Meter
1 Nautical Mile	= 1852 Meters (Exact) = 6076.10333333 US Survey Feet = 6076.11548556 International Feet
1 Statute Mile	= 1609.344 Meters (Exact) = 5280 International Feet (Exact)

T_U = Julian Centuries from Epoch J2000.0

Table 2.5

Differences
- WGS 84 And WGS 72 Ellipsoid Parameters -

Parameters	Notation	WGS 84	WGS 72 [4]	Differences*
Semimajor Axis	a	6378137 m	6378135 m	2 m
Normalized Second Degree Zonal	$\bar{C}_{2,0}$	$-484.16685 \times 10^{-6}$	-484.1605×10^{-6}	-0.00635×10^{-6}
Angular Velocity	ω	7292115×10^{-11} rad s^{-1}	$7292115.147 \times 10^{-11}$ rad s^{-1}	-0.147×10^{-11} rad s^{-1}
Gravitational Constant (Mass of Earth's Atmosphere Included)	GM	$3986005 \times 10^{8}\ m^3\ s^{-2}$	$3986008 \times 10^{8}\ m^3\ s^{-2}$	$-3 \times 10^{8}\ m^3\ s^{-2}$
Gravitational Constant (Without Mass of Earth's Atmosphere)	GM'	$3986001.5 \times 10^{8}\ m^3\ s^{-2}$	$3986005 \times 10^{8}\ m^3\ s^{-2}$	$-3.5 \times 10^{8}\ m^3\ s^{-2}$
Angular Velocity (Precessing Reference Frame)	ω^*	$(7292115.8553 \times 10^{-11} + 4.3 \times 10^{-15}\ T_U)$ rad s^{-1} [See Table 2.1]	----	----
Flattening	f	1/298.257223563	1/298.26	0.3121057×10^{-7}
Semiminor Axis	b	6356752.3142 m	6356750.5 m	1.8142 m
First Eccentricity Squared	e^2	0.00669437999013	0.006694317778	0.6221213×10^{-7}

* WGS 84 Minus WGS 72

Table 2.6

Arc Distances on the WGS 84 Ellipsoid Corresponding to One Arc Second of Geodetic Latitude and Geodetic Longitude

Geodetic Latitude	Arc Distance		Geodetic Latitude	Arc Distance	
	S_ϕ	S_λ		S_ϕ	S_λ
0°	30.7151 m	30.9221 m	50°	30.8970 m	19.9155 m
5	30.7174	30.8052	55	30.9232	17.7761
10	30.7244	30.4554	60	30.9479	15.5000
15	30.7357	29.8751	65	30.9702	13.1043
20	30.7512	29.0686	70	30.9895	10.6074
25	30.7702	28.0417	75	31.0051	8.0283
30	30.7923	26.8017	80	31.0167	5.3871
35	30.8168	25.3578	85	31.0237	2.7040
40	30.8430	23.7205	90	31.0261	0.0000
45	30.8699	21.9019			

S_ϕ = Meters in One Arc Second of Geodetic Latitude (Along Meridians of Longitude; WGS 84 Ellipsoid)

S_λ = Meters in One Arc Second of Geodetic Longitude (Along Parallels of Latitude; WGS 84 Ellipsoid)

Table 2.7

WGS 84 Ellipsoid

- Geocentric Radius and Radii of Curvature -

Geodetic Latitude (Degrees)	Geocentric Radius (Meters)	Radius of Curvature (Meters)	
		In the Meridian	In the Prime Vertical
0	6378137.0000	6335439.3273	6378137.0000
1	6378130.5409	6335458.7045	6378143.5026
2	6378111.1715	6335516.8129	6378163.0025
3	6378078.9145	6335613.5837	6378195.4764
4	6378033.8085	6335748.9017	6378240.8852
5	6377975.9070	6335922.6064	6378299.1746
6	6377905.2787	6336134.4912	6378370.2744
7	6377822.0077	6336384.3044	6378454.0995
8	6377726.1928	6336671.7491	6378550.5491
9	6377617.9481	6336996.4835	6378659.5074
10	6377497.4021	6337358.1216	6378780.8437
11	6377364.6984	6337756.2331	6378914.4121
12	6377219.9947	6338190.3444	6379060.0523
13	6377063.4634	6338659.9389	6379217.5892
14	6376895.2907	6339164.4574	6379386.8336
15	6376715.6771	6339703.2990	6379567.5820
16	6376524.8365	6340275.8217	6379759.6172
17	6376322.9964	6340881.3429	6379962.7080
18	6376110.3976	6341519.1405	6380176.6104
19	6375887.2938	6342188.4534	6380401.0668
20	6375653.9513	6342888.4825	6380635.8071

Table 2.7 (Cont'd)

WGS 84 Ellipsoid

- Geocentric Radius and Radii of Curvature -

Geodetic Latitude (Degrees)	Geocentric Radius (Meters)	Radius of Curvature (Meters)	
		In the Meridian	In the Prime Vertical
21	6375410.6488	6343618.3916	6380880.5487
22	6375157.6772	6344377.3084	6381134.9968
23	6374895.3390	6345164.3252	6381398.8447
24	6374623.9481	6345978.5003	6381671.7746
25	6374343.8296	6346818.8587	6381953.4572
26	6374055.3189	6347684.3936	6382243.5527
27	6373758.7621	6348574.0671	6382541.7112
28	6373454.5151	6349486.8118	6382847.5726
29	6373142.9430	6350421.5317	6383160.7676
30	6372824.4203	6351377.1037	6383480.9177
31	6372499.3300	6352352.3787	6383807.6359
32	6372168.0634	6353346.1832	6384140.5270
33	6371831.0193	6354357.3200	6384479.1883
34	6371488.6040	6355384.5707	6384823.2098
35	6371141.2307	6356426.6959	6385172.1749
36	6370789.3185	6357482.4377	6385525.6607
37	6370433.2928	6358550.5203	6385883.2387
38	6370073.5841	6359629.6521	6386244.4751
39	6369710.6277	6360718.5272	6386608.9316
40	6369344.8632	6361815.8264	6386976.1657

Table 2.7 (Cont'd)

WGS 84 Ellipsoid

- Geocentric Radius and Radii of Curvature -

Geodetic Latitude (Degrees)	Geocentric Radius (Meters)	Radius of Curvature (Meters)	
		In the Meridian	In the Prime Vertical
41	6368976.7342	6362920.2195	6387345.7313
42	6368606.6873	6364030.3664	6387717.1791
43	6368235.1720	6365144.9187	6388090.0576
44	6367862.6397	6366262.5217	6388463.9130
45	6367489.5439	6367381.8156	6388838.2901
46	6367116.3386	6368501.4376	6389212.7331
47	6366743.4789	6369620.0231	6389586.7856
48	6366371.4195	6370736.2075	6389959.9916
49	6366000.6147	6371848.6282	6390331.8958
50	6365631.5175	6372955.9257	6390702.0442
51	6365264.5795	6374056.7459	6391069.9849
52	6364900.2496	6375149.7413	6391435.2682
53	6364538.9744	6376233.5727	6391797.4477
54	6364181.1968	6377306.9112	6392156.0804
55	6363827.3557	6378368.4396	6392510.7274
56	6363477.8860	6379416.8540	6392860.9546
57	6363133.2170	6380450.8658	6393206.3329
58	6362793.7729	6381469.2028	6393546.4391
59	6362459.9716	6382470.6113	6393880.8561
60	6362132.2244	6383453.8572	6394209.1738

Table 2.7 (Cont'd)

WGS 84 Ellipsoid

- Geocentric Radius and Radii of Curvature -

Geodetic Latitude (Degrees)	Geocentric Radius (Meters)	Radius of Curvature (Meters)	
		In the Meridian	In the Prime Vertical
61	6361810.9354	6384417.7282	6394530.9893
62	6361496.5012	6385361.0346	6394845.9074
63	6361189.3100	6386282.6116	6395153.5412
64	6360889.7416	6387181.3202	6395453.5128
65	6360598.1664	6388056.0488	6395745.4533
66	6360314.9452	6388905.7150	6396029.0037
67	6360040.4289	6389729.2663	6396303.8151
68	6359774.9577	6390525.6823	6396569.5492
69	6359518.8607	6391293.9754	6396825.8788
70	6359272.4556	6392033.1923	6397072.4882
71	6359036.0485	6392742.4153	6397309.0735
72	6358809.9330	6393420.7633	6397535.3430
73	6358594.3901	6394067.3932	6397751.0178
74	6358389.6878	6394681.5011	6397955.8318
75	6358196.0808	6395262.3228	6398149.5323
76	6358013.8102	6395809.1355	6398331.8802
77	6357843.1028	6396321.2581	6398502.6506
78	6357684.1714	6396798.0529	6398661.6324
79	6357537.2140	6397238.9255	6398808.6294
80	6357402.4138	6397643.3264	6398943.4599

Table 2.7 (Cont'd)

WGS 84 Ellipsoid

- Geocentric Radius and Radii of Curvature -

Geodetic Latitude (Degrees)	Geocentric Radius (Meters)	Radius of Curvature (Meters)	
		In the Meridian	In the Prime Vertical
81	6357279.9389	6398010.7513	6399065.9574
82	6357169.9422	6398340.7417	6399175.9705
83	6357072.5608	6398632.8861	6399273.3632
84	6356987.9162	6398886.8197	6399358.0151
85	6356916.1143	6399102.2255	6399429.8215
86	6356857.2446	6399278.8347	6399488.6937
87	6356811.3806	6399416.4267	6399534.5589
88	6356778.5796	6399514.8296	6399567.3603
89	6356758.8826	6399573.9206	6399587.0574
90	6356752.3142	6399593.6258	6399593.6258

SECTION 3

WGS 84

ELLIPSOIDAL GRAVITY FORMULA

Table 3.1

WGS 84

Ellipsoidal Gravity Formula

Provides Gravity Values at (on) the Surface of the WGS 84 Ellipsoid
Notation γ = Theoretical acceleration of a unit test mass due to gravity. γ_e = Theoretical acceleration at the equator (on the WGS 84 Ellipsoid) of a unit test mass due to gravity. k = Constant $k = (b\gamma_p/a\gamma_e)-1$ a = Semimajor axis (WGS 84 Ellipsoid) b = Semiminor axis (WGS 84 Ellipsoid) γ_p = Theoretical gravity at the poles (on the WGS 84 Ellipsoid) ϕ = Geodetic latitude. e^2 = First eccentricity squared (WGS 84 Ellipsoid).
Analytical Form $\gamma = \gamma_e (1 + k \sin^2\phi) / (1 - e^2 \sin^2\phi)^{1/2}$
Numerical Form $\gamma = 978032.67714 (1 + 0.00193185138639 \sin^2\phi) / (1-0.00669437999013 \sin^2\phi)^{1/2}$ milligals
1 milligal = An acceleration due to gravity of 1×10^{-3} centimeters/second^2.

Table 3.2

Values of Theoretical Gravity
- Surface of WGS 84 Ellipsoid -

Geodetic Latitude	Theoretical Gravity (Milligals)	Geodetic Latitude	Theoretical Gravity (Milligals)	Geodetic Latitude	Theoretical Gravity (Milligals)
0°	978032.67714				
1	978034.24974	31°	979403.86004	61°	981995.59523
2	978038.96567	32	979484.30639	62	982071.68403
3	978046.81924	33	979566.21467	63	982146.01155
4	978057.80102	34	979649.38295	64	982218.48652
5	978071.89781	35	979733.74468	65	982289.01996
6	978089.09264	36	979819.19757	66	982357.52520
7	978109.36485	37	979905.63796	67	982423.91805
8	978132.69006	38	979992.96095	68	982488.11691
9	978159.04021	39	980081.06051	69	982550.04280
10	978188.38360	40	980169.82963	70	982609.61957
11	978220.68492	41	980259.16044	71	982666.77388
12	978255.90532	42	980348.94434	72	982721.43539
13	978294.00240	43	980439.07211	73	982773.53680
14	978334.93030	44	980529.43408	74	982823.01394
15	978378.63975	45	980619.92024	75	982869.80585
16	978425.07811	46	980710.42038	76	982913.85487
17	978474.18944	47	980800.82421	77	982955.10672
18	978525.91458	48	980891.02151	78	982993.51054
19	978580.19118	49	980980.90228	79	983029.01898
20	978636.95383	50	981070.35682	80	983061.58824
21	978696.13407	51	981159.27595	81	983091.17815
22	978757.66052	52	981247.55104	82	983117.75221
23	978821.45895	53	981335.07423	83	983141.27763
24	978887.45237	54	981421.73853	84	983161.78537
25	978955.56108	55	981507.43794	85	983179.07021
26	979025.70285	56	981592.06760	86	983193.29073
27	979097.79292	57	981675.52392	87	983204.36939
28	979171.74416	58	981757.70469	88	983212.29249
29	979247.46717	59	981838.50923	89	983217.05027
30	979324.87035	60	981917.83850	90	983218.63685

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SECTION 4

WGS 84

EARTH GRAVITATIONAL MODEL

Table 4.1

Form of the WGS 84
Earth Gravitational Model

$$V = \frac{GM}{r}\left[1 + \sum_{n=2}^{n_{max}} \sum_{m=0}^{n} \left(\frac{a}{r}\right)^n \bar{P}_{n,m} (\sin \phi') (\bar{C}_{n,m} \cos m\lambda + \bar{S}_{n,m} \sin m\lambda)\right]$$

Parameter	Definition
V	= Gravitational potential function
GM	= Earth's gravitational constant
r	= Radius vector from the earth's center of mass
a	= Semimajor axis of the WGS 84 Ellipsoid
n,m	= Degree and order, respectively
ϕ'	= Geocentric latitude
λ	= Geocentric longitude = geodetic longitude
$\bar{C}_{n,m}, \bar{S}_{n,m}$	= Normalized gravitational coefficients*
$\bar{P}_{n,m} (\sin \phi')$	= Normalized associated Legendre function
	$= \left[\frac{(n-m)!\ (2n+1)k}{(n+m)!}\right]^{1/2} P_{n,m}(\sin \phi')$
$P_{n,m} (\sin \phi')$	= Associated Legendre function

* See next page.

Table 4.1 (Cont'd)

Form of the WGS 84
Earth Gravitational Model

Parameter	Definition
$P_{n,m}(\sin\phi')$	$= (\cos\phi')^m \dfrac{d^m}{d(\sin\phi')^m}[P_n(\sin\phi')]$
$P_n(\sin\phi')$	= Legendre polynomial
$P_n(\sin\phi')$	$= \dfrac{1}{2^n n!}\dfrac{d^n}{d(\sin\phi')^n}(\sin^2\phi' - 1)^n$

*Note:

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

where

$C_{n,m}, S_{n,m}$ = Conventional gravitational coefficients

$m=0,\ k=1;$

$m\neq0,\ k=2.$

Table 4.2

WGS 84
Earth Gravitational Model
(Truncated at n=m=18)

Degree and Order		Normalized Gravitational	Coefficients	Degree and Order		Normalized Gravitational	Coefficients
n	m	$\bar{C}_{n,m}$	$\bar{S}_{n,m}$	n	m	$\bar{C}_{n,m}$	$\bar{S}_{n,m}$
2	0	-0.48416685E-03		6	3	0.53370577E-07	0.61334720E-08
2	1	--------------	--------------	6	4	-0.88694856E-07	-0.47260945E-06
2	2	0.24395796E-05	-0.13979548E-05	6	5	-0.26818820E-06	-0.53491073E-06
3	0	0.95706390E-06		6	6	0.10237832E-07	-0.23741002E-06
3	1	0.20318729E-05	0.25085759E-06	7	0	0.85819217E-07	
3	2	0.90666113E-06	-0.62102428E-06	7	1	0.27905196E-06	0.94231346E-07
3	3	0.71770352E-06	0.14152388E-05	7	2	0.32873832E-06	0.88835092E-07
4	0	0.53699587E-06		7	3	0.24940240E-06	-0.21223369E-06
4	1	-0.53548044E-06	-0.47420394E-06	7	4	-0.27123034E-06	-0.12696607E-06
4	2	0.34797519E-06	0.65579158E-06	7	5	0.10246290E-08	0.17321672E-07
4	3	0.99172321E-06	-0.19912491E-06	7	6	-0.35843745E-06	0.15202633E-06
4	4	-0.18686124E-06	0.30953114E-06	7	7	-0.20991457E-08	0.22805664E-07
5	0	0.71092048E-07		8	0	0.42979835E-07	
5	1	-0.64185265E-07	-0.92492959E-07	8	1	0.18889342E-07	0.47856967E-07
5	2	0.65184984E-06	-0.32007416E-06	8	2	0.73553952E-07	0.47867693E-07
5	3	-0.44903639E-06	-0.21328272E-06	8	3	-0.12132459E-07	-0.83461853E-07
5	4	-0.29719055E-06	0.53213480E-07	8	4	-0.24208264E-06	0.71603924E-07
5	5	0.17523221E-06	-0.67059456E-06	8	5	-0.24966587E-07	0.87751047E-07
6	0	-0.15064821E-06		8	6	-0.65093424E-07	0.30904202E-06
6	1	-0.74180259E-07	0.32780040E-07	8	7	0.66323292E-07	0.74661766E-07
6	2	0.51824409E-07	-0.35866634E-06	8	8	-0.12372281E-06	0.12210258E-06

E-03 = X 10^{-3}; E-05 = X 10^{-5}; Etc.

Table 4.2 (Cont'd)

WGS 84
Earth Gravitational Model
(Truncated at n=m=18)

Degree and Order	Normalized Gravitational	Coefficients	Degree and Order	Normalized Gravitational	Coefficients
n m	$\bar{C}_{n,m}$	$\bar{S}_{n,m}$	n m	$\bar{C}_{n,m}$	$\bar{S}_{n,m}$
9 0	0.33173231E-07		11 2	0.21716225E-07	-0.10224810E-06
9 1	0.14747969E-06	0.23894354E-07	11 3	-0.30023695E-07	-0.13422019E-06
9 2	0.22052093E-07	-0.26876665E-07	11 4	-0.30407161E-07	-0.69823333E-07
9 3	-0.16256047E-06	-0.85928431E-07	11 5	0.35104609E-07	0.49175170E-07
9 4	-0.17193827E-07	0.26077030E-07	11 6	-0.37911105E-08	0.36848522E-07
9 5	-0.16902791E-07	-0.50337365E-07	11 7	0.25774039E-08	-0.88658395E-07
9 6	0.65717910E-07	0.22275858E-06	11 8	-0.71396627E-08	0.23243077E-07
9 7	-0.11648016E-06	-0.97298769E-07	11 9	-0.30246313E-07	0.41776400E-07
9 8	0.18896045E-06	-0.31026222E-08	11 10	-0.53424279E-07	-0.18716766E-07
9 9	-0.48275744E-07	0.96381072E-07	11 11	0.47514858E-07	-0.70415796E-07
10 0	0.50931575E-07		12 0	0.34073235E-07	
10 1	0.88706517E-07	-0.12536457E-06	12 1	-0.60609926E-07	-0.38189082E-07
10 2	-0.82375203E-07	-0.38280049E-07	12 2	0.74200188E-08	0.24640620E-07
10 3	-0.13137371E-07	-0.15553732E-06	12 3	0.42149817E-07	0.32189594E-07
10 4	-0.87424319E-07	-0.79215732E-07	12 4	-0.64346831E-07	-0.25364931E-08
10 5	-0.53980821E-07	-0.46294947E-07	12 5	0.33126200E-07	-0.40658586E-09
10 6	-0.42371448E-07	-0.79680607E-07	12 6	0.86981502E-08	0.36711094E-07
10 7	0.83736045E-08	-0.25636582E-08	12 7	-0.16598048E-07	0.34475954E-07
10 8	0.41239589E-07	-0.92269095E-07	12 8	-0.26843700E-07	0.17838309E-07
10 9	0.12539514E-06	-0.37687117E-07	12 9	0.42293015E-07	0.27107811E-07
10 10	0.10124370E-06	-0.24874984E-07	12 10	-0.44237357E-08	0.30823394E-07
11 0	-0.58114696E-07		12 11	0.96462514E-08	-0.60711291E-08
11 1	0.95375839E-08	-0.22094828E-07	12 12	-0.30878714E-08	-0.10932316E-07

E-03 = X 10^{-3}; E-05 = X 10^{-5}; Etc.

Table 4.2 (Cont'd)

WGS 84
Earth Gravitational Model
(Truncated at n=m=18)

Degree and Order		Normalized Gravitational	Coefficients	Degree and Order		Normalized Gravitational	Coefficients
n	m	$\bar{C}_{n,m}$	$\bar{S}_{n,m}$	n	m	$\bar{C}_{n,m}$	$\bar{S}_{n,m}$
13	0	0.48159534E-07		14	7	0.39355808E-07	-0.52187212E-08
13	1	-0.47921675E-07	0.34957177E-07	14	8	-0.31866053E-07	-0.16609601E-07
13	2	0.48705121E-07	-0.63933232E-07	14	9	0.30182993E-07	0.23942248E-07
13	3	-0.17219549E-07	0.82465794E-07	14	10	0.36008306E-07	-0.43924872E-09
13	4	-0.92616056E-08	-0.98249479E-09	14	11	0.16006347E-07	-0.40475033E-07
13	5	0.58545255E-07	0.66075856E-07	14	12	0.79810549E-08	-0.31068551E-07
13	6	-0.28548757E-07	-0.13018250E-07	14	13	0.33446421E-07	0.44622344E-07
13	7	0.10048687E-07	-0.12672050E-07	14	14	-0.52174166E-07	-0.48789452E-08
13	8	-0.12236037E-07	-0.11680475E-07	15	0	-0.55534001E-08	
13	9	0.25798630E-07	0.46771958E-07	15	1	0.77027909E-08	0.12667983E-07
13	10	0.42112066E-07	-0.35203559E-07	15	2	-0.13310361E-07	-0.25570239E-07
13	11	-0.44423472E-07	-0.63137559E-08	15	3	0.53469109E-07	0.21540830E-07
13	12	-0.31610688E-07	0.86378230E-07	15	4	-0.35485140E-07	-0.38325971E-08
13	13	-0.61019573E-07	0.68712423E-07	15	5	0.80670670E-08	0.95367405E-08
14	0	-0.25559279E-07		15	6	0.28835774E-07	-0.29584853E-07
14	1	-0.10581256E-07	0.22739082E-07	15	7	0.55297561E-07	0.12688881E-07
14	2	-0.32588467E-07	-0.45984585E-08	15	8	-0.26866012E-07	0.28508669E-07
14	3	0.33411750E-07	0.72271094E-08	15	9	0.15229368E-07	0.40242957E-07
14	4	0.34163340E-08	-0.23062568E-07	15	10	0.78226264E-08	0.16482104E-07
14	5	0.21777499E-07	-0.44340974E-08	15	11	-0.45323941E-08	0.16379211E-07
14	6	-0.23022045E-07	0.79137357E-08	15	12	-0.34310516E-07	0.13248557E-07

E-03 = X 10^{-3}; E-05 = X 10^{-5}; Etc.

Table 4.2 (Cont'd)

WGS 84
Earth Gravitational Model
(Truncated at n=m=18)

Degree and Order		Normalized Gravitational	Coefficients	Degree and Order		Normalized Gravitational	Coefficients
n	m	$\bar{C}_{n,m}$	$\bar{S}_{n,m}$	n	m	$\bar{C}_{n,m}$	$\bar{S}_{n,m}$
15	13	-0.27865470E-07	-0.51124016E-08	17	0	0.27418160E-07	
15	14	0.58007239E-08	-0.24830947E-07	17	1	-0.17492372E-07	-0.29004434E-07
15	15	-0.18756974E-07	-0.53745848E-08	17	2	-0.24972136E-07	0.52345300E-08
16	0	0.96352958E-08		17	3	0.75958226E-08	0.13161951E-07
16	1	0.16657011E-07	0.32088971E-07	17	4	-0.35567936E-08	0.29108859E-07
16	2	-0.22051986E-07	0.26286204E-07	17	5	-0.16440517E-07	0.15666155E-07
16	3	-0.29514849E-07	-0.95827659E-08	17	6	-0.29053420E-08	-0.41239945E-07
16	4	0.37621131E-07	0.55477548E-07	17	7	0.30327591E-07	-0.54652615E-08
16	5	-0.10479239E-07	-0.27382338E-08	17	8	0.26828952E-07	-0.69634040E-08
16	6	0.97407454E-08	-0.43087957E-07	17	9	-0.74685923E-09	-0.31300568E-07
16	7	-0.12168169E-07	-0.56636996E-08	17	10	-0.10536220E-08	0.18628074E-07
16	8	-0.25034024E-07	0.22895737E-08	17	11	-0.13049234E-07	0.13662390E-07
16	9	-0.17908785E-07	-0.29938908E-07	17	12	0.32820228E-07	0.17654374E-07
16	10	-0.10129689E-07	0.12404473E-07	17	13	0.17049873E-07	0.19279770E-07
16	11	0.19053980E-07	-0.17354590E-08	17	14	-0.14027974E-07	0.11214602E-07
16	12	0.18888013E-07	0.46949615E-08	17	15	0.56624501E-08	0.56527252E-08
16	13	0.15158142E-07	-0.17410596E-09	17	16	-0.32153542E-07	0.33341657E-08
16	14	-0.19416172E-07	-0.38724225E-07	17	17	-0.37961677E-07	-0.17192537E-07
16	15	-0.14400649E-07	-0.33151819E-07	18	0	0.10196218E-07	
16	16	-0.40920912E-07	0.23449430E-08	18	1	0.85717760E-08	-0.32887288E-07

E-03 = X 10^{-3}; E-05 = X 10^{-5}; Etc.

Table 4.2 (Cont'd)

WGS 84
Earth Gravitational Model
(Truncated at n=m=18)

Degree and Order	Normalized Gravitational	Coefficients	Degree and Order	Normalized Gravitational	Coefficients
n m	$\bar{C}_{n,m}$	$\bar{S}_{n,m}$	n m	$\bar{C}_{n,m}$	$\bar{S}_{n,m}$
18 2	0.11021506E-07	0.96877203E-08	18 11	-0.92784417E-08	0.11278314E-08
18 3	-0.78128408E-08	-0.16263649E-07	18 12	-0.29997564E-07	-0.13762992E-07
18 4	0.50107239E-07	-0.35094534E-08	18 13	-0.61616779E-08	-0.34022737E-07
18 5	-0.35408518E-08	0.26790491E-07	18 14	-0.77166667E-08	-0.13392253E-07
18 6	0.12489735E-07	-0.12526195E-07	18 15	-0.38973604E-07	-0.20668220E-07
18 7	0.14813821E-07	-0.18829836E-08	18 16	0.10273437E-07	0.69198054E-08
18 8	0.35285229E-07	0.13368789E-08	18 17	0.33491685E-08	0.54056479E-08
18 9	-0.24544444E-07	0.25745394E-07	18 18	0.11121796E-08	-0.94806182E-08
18 10	0.84106552E-09	-0.44929528E-08			

E-03 = X 10^{-3}; E-05 = X 10^{-5}; Etc.

Table 4.3

WGS 84 EGM
Gravity Anomaly Degree Variances (c_n)*

Degree	Degree Variances	Degree	Degree Variances	Degree	Degree Variances
2	7.6	41	2.8	80	2.3
3	33.9	42	2.7	81	2.6
4	19.2	43	2.4	82	2.8
5	21.0	44	2.8	83	2.7
6	19.4	45	2.7	84	2.4
7	19.3	46	2.7	85	2.2
8	10.9	47	3.1	86	2.7
9	11.5	48	2.5	87	2.4
10	9.7	49	2.5	88	2.2
11	6.4	50	2.8	89	2.0
12	2.6	51	2.8	90	2.0
13	7.4	52	2.6	91	2.3
14	3.2	53	3.1	92	2.0
15	3.4	54	2.8	93	2.2
16	3.9	55	3.0	94	2.0
17	3.6	56	3.0	95	1.8
18	3.6	57	3.0	96	2.0
19	3.3	58	2.6	97	1.9
20	3.1	59	3.0	98	2.1
21	3.2	60	2.6	99	1.7
22	3.6	61	2.5	100	1.8
23	2.7	62	2.9	101	1.7
24	2.6	63	2.5	102	2.1
25	2.9	64	2.7	103	2.3
26	2.4	65	2.1	104	1.8
27	1.9	66	2.6	105	1.8
28	2.4	67	2.5	106	1.7
29	2.4	68	2.6	107	1.8
30	2.8	69	2.9	108	1.9
31	2.9	70	2.3	109	2.0
32	4.1	71	2.3	110	2.0
33	3.4	72	2.7	111	1.7
34	5.0	73	2.4	112	1.6
35	4.4	74	2.6	113	1.8
36	3.6	75	2.2	114	1.6
37	3.4	76	2.3	115	1.9
38	2.8	77	2.3	116	1.7
39	3.5	78	2.4	117	1.7
40	3.6	79	2.2	118	1.6

Units = milligals^2

* See next page.

Table 4.3 (Cont'd)

WGS 84 EGM
Gravity Anomaly Degree Variances (c_n)*

Degree	Degree Variances	Degree	Degree Variances	Degree	Degree Variances
119	1.6	140	1.3	161	0.9
120	1.6	141	1.1	162	0.8
121	1.5	142	1.0	163	0.9
122	1.3	143	1.1	164	1.0
123	1.6	144	1.1	165	0.9
124	1.6	145	1.0	166	0.8
125	1.5	146	1.0	167	0.9
126	1.3	147	1.0	168	0.8
127	1.5	148	1.2	169	0.8
128	1.2	149	1.0	170	0.8
129	1.4	150	1.0	171	0.9
130	1.3	151	1.0	172	0.7
131	1.3	152	1.0	173	0.8
132	1.4	153	1.0	174	0.8
133	1.4	154	1.0	175	0.8
134	1.2	155	0.9	176	0.8
135	1.2	156	1.0	177	0.6
136	1.2	157	0.8	178	0.7
137	1.3	158	0.8	179	0.8
138	1.3	159	0.8	180	0.8
139	1.2	160	0.9		

*Formula for computing gravity anomaly degree variances (c_n):

$$c_n = \bar{\gamma}^2 (n-1)^2 \sum_{m=0}^{n} (\bar{C}_{n,m}^2 + \bar{S}_{n,m}^2)$$

c_n = Gravity anomaly degree variance in milligals^2 for degree n

$\bar{\gamma}$ = Average value of theoretical gravity

$\bar{\gamma}$ = 979764.46561 milligals (based on WGS 84 Ellipsoidal Gravity Formula)

$\bar{C}_{n,m}$, $\bar{S}_{n,m}$ = Normalized gravitational coefficients of degree n and order m

Table 4.4

Comments on the WGS 84
Earth Gravitational Model

The official WGS 84 Earth Gravitational Model (EGM) is complete through degree (n) and order (m) 180 and is comprised of 32755 gravitational coefficients. While such a model is needed for certain applications on the earth's surface and in near-earth space, it is not required and is impractical to apply for many applications. However:

1. The WGS 84 EGM through n=m=180 is to be used when calculating:

a. WGS 84 geoid heights via a spherical harmonic expansion.

b. WGS 84 gravity disturbance components (or deflection of the vertical components) via a spherical harmonic expansion.

c. WGS 84 $1^\circ x 1^\circ$ mean gravity anomalies via a spherical harmonic expansion.

Expansions to this degree and order (n=m=180), and higher, are needed to accurately model variations in the earth's gravitational field on or near the earth's surface.

2. The WGS 84 EGM through n=m=41, which reflects the contribution of ground-based satellite tracking data (as does the complete n=m=180 model), is more appropriate for satellite orbit calculation and prediction purposes. The use of higher degree and order models for such applications is not recommended at this time. However, for each satellite orbit class, DMA and other DoD users will need to conduct orbital analyses to ascertain the EGM truncation level that is "best" for the satellite involved, document results, coordinate recommendations (as necessary), and then use this particular truncated EGM for the satellite being analyzed.

Table 4.4 (Cont'd)

Comments on the WGS 84
Earth Gravitational Model

The WGS 84 EGM coefficients through n=m=41 were obtained from a weighted least squares solution of a normal equation matrix developed by combining individual normal equation matrices formed from Doppler satellite tracking data, satellite laser ranging data, surface gravity data, oceanic geoid heights deduced from satellite radar altimeter data, NAVSTAR Global Positioning System (GPS) data, and "lumped coefficients". The effect (contribution) of coefficients through n=m=41 was removed from a worldwide 1°x1° mean gravity anomaly field leaving a worldwide residual 1°x1° mean gravity anomaly field. The WGS 84 EGM coefficients from n=42, m=0 through n=m=180 were then determined independently via harmonic analysis using the residual field. The coefficients through n=m=41 from the weighted least squares solution and the coefficients above n=m=41 from the independent harmonic analysis comprise the n=m=180 WGS 84 EGM.

The WGS 84 EGM through n=m=180 is available on magnetic tape in normalized form. The WGS 84 EGM through n=m=41 is available on a separate magnetic tape in both normalized and conventional form. However, only the WGS 84 EGM through n=m=18 is provided in this report (in normalized form). Requesters with a need for a higher degree and order portion of the model should make their requirements known to the address provided in the PREFACE.

Accuracy values are not available for all the individual WGS 84 EGM coefficients. However, an error covariance matrix is available for those coefficients through n=m=41 determined from the weighted least squares solution. Requesters having a need for this error data should also forward their correspondence to the address provided in the PREFACE.

Table 4.4 (Cont'd)

Comments on the WGS 84
Earth Gravitational Model

SECURITY CLASSIFICATION

The WGS 84 EGM (n=m=180) is classified CONFIDENTIAL, with the exception that the portion of the model through n=m=18 is UNCLASSIFIED. However, the UNCLASSIFIED portion of the EGM is authorized for use only in two instances:

- When a situation or application requires the use of an UNCLASSIFIED EGM, thereby precluding use of the CLASSIFIED WGS 84 EGM.

- When satellite orbital analyses conducted under Statement 2., above, reveal that the WGS 84 EGM truncated at n=m=18 (or lower) provides results of acceptable accuracy.

Error values for the WGS 84 EGM coefficients above n=m=18 are classified CONFIDENTIAL.

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SECTION 5

WGS 84 GEOID

Table 5.1

The WGS 84 Geoid

General Definition
Definition 1 - That particular equipotential surface of the earth that coincides with mean sea level over the oceans and extends hypothetically beneath all land surfaces.   Definition 2 - In a mathematical or geometric sense, the geoid is defined as so many meters above (+N) or below (-N) the ellipsoid.
Function/Purpose of the Geoid
. Represents the earth's mean sea level surface and also serves: - In land areas (if conventional leveling is not available) as the vertical datum or reference surface to which height-above-mean sea level values are referenced.   - In ocean areas as the geodetic height of points on the ocean's surface.   . Indicates how well the mathematical figure of the earth (the ellipsoid) fits the earth's mean sea level surface.
Formula Used to Compute WGS 84 Geoid Heights
$N = \frac{GM}{r\gamma}\left[\sum_{n=2}^{180}\sum_{m=0}^{n}\left(\frac{a}{r}\right)^n(\bar{C}_{n,m}\cos m\lambda + \bar{S}_{n,m}\sin m\lambda)\,\bar{P}_{n,m}(\sin\phi')\right]$ N = WGS 84 Geoid Height (calculated using a spherical harmonic expansion and WGS 84 EGM coefficients through n=m=180) γ = Value of theoretical gravity calculated using the WGS 84 Ellipsoidal Gravity Formula   All other parameters in this formula are defined as in Table 4.1 for the WGS 84 Earth Gravitational Model. [To apply this formula, see Sections 6.2.1 and 6.2.2 of Reference 2.]

Table 5.2

WGS 84 Geoid Heights
(n=m=180, 10°x10° Grid, Units = Meters)

Latitude (Degrees)	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°	160°	170°
90°	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
80°	33	34	28	23	17	13	9	4	4	1	-2	-2	0	2	3	2	1	1
70°	51	43	29	20	12	5	-2	-10	-14	-12	-10	-14	-12	-6	-2	3	6	4
60°	47	41	21	18	14	7	-3	-22	-29	-32	-32	-26	-15	-2	13	17	19	6
50°	47	48	42	28	12	-10	-19	-33	-43	-42	-43	-29	-2	17	23	22	6	2
40°	52	48	35	40	33	-9	-28	-39	-48	-59	-50	-28	3	23	37	18	-1	-11
30°	36	28	29	17	12	-20	-15	-40	-33	-34	-34	-28	7	29	43	20	4	-6
20°	31	26	15	6	1	-29	-44	-61	-67	-59	-36	-11	21	39	49	39	22	10
10°	22	23	2	-3	-7	-36	-59	-90	-95	-63	-24	12	53	60	58	46	36	26
0°	18	12	-13	-9	-28	-49	-62	-89	-102	-63	-9	33	58	73	74	63	50	32
-10°	12	13	-2	-14	-25	-32	-38	-60	-75	-63	-26	0	35	52	68	76	64	52
-20°	17	23	21	8	-9	-10	-11	-20	-40	-47	-45	-25	5	23	45	58	57	63
-30°	22	27	34	29	14	15	15	7	-9	-25	-37	-39	-23	-14	15	33	34	45
-40°	18	26	31	33	39	41	30	24	13	-2	-20	-32	-33	-27	-14	-2	5	20
-50°	25	26	34	39	45	45	38	39	28	13	-1	-15	-22	-22	-18	-15	-14	-10
-60°	16	19	25	30	35	35	33	30	27	10	-2	-14	-23	-30	-33	-29	-35	-43
-70°	16	16	17	21	20	26	26	22	16	10	-1	-16	-29	-36	-46	-55	-54	-59
-80°	-4	-1	1	4	4	6	5	4	2	-6	-15	-24	-33	-40	-48	-50	-53	-52
-90°	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30

Longitude (Degrees)

Table 5.2 (Cont'd)

WGS 84 Geoid Heights
(n=m=180, 10°x10° Grid, Units = Meters)

Latitude (Degrees)	180°	190°	200°	210°	220°	230°	240°	250°	260°	270°	280°	290°	300°	310°	320°	330°	340°	350°
90°	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
80°	3	1	-2	-3	-3	-3	-1	3	1	5	9	11	19	27	31	34	33	34
70°	2	2	1	-1	-3	-7	-14	-24	-27	-25	-19	3	24	37	47	60	61	58
60°	2	9	17	10	13	1	-14	-30	-39	-46	-42	-21	6	29	49	65	60	57
50°	-8	8	8	1	-11	-19	-16	-18	-22	-35	-40	-26	-12	24	45	63	62	59
40°	-12	-10	-13	-20	-31	-34	-21	-16	-26	-34	-33	-35	-26	2	33	59	52	51
30°	-7	-5	-8	-15	-28	-40	-42	-29	-22	-26	-32	-51	-40	-17	17	31	34	44
20°	5	10	7	-7	-23	-39	-47	-34	-9	-10	-20	-45	-48	-32	-9	17	25	31
10°	13	12	11	2	-11	-28	-38	-29	-10	3	1	-11	-41	-42	-16	3	17	33
0°	22	16	17	13	1	-12	-23	-20	-14	-3	14	10	-15	-27	-18	3	12	20
-10°	36	22	11	6	-1	-8	-10	-8	-11	-9	1	32	4	-18	-13	-9	4	14
-20°	51	27	10	0	-9	-11	-5	-2	-3	-1	9	35	20	-5	-6	-5	0	13
-30°	46	22	5	-2	-8	-13	-10	-7	-4	1	9	32	16	4	-8	4	12	15
-40°	21	6	1	-7	-12	-12	-12	-10	-7	-1	8	23	15	-2	-6	6	21	24
-50°	-15	-18	-18	-16	-17	-15	-10	-10	-8	-2	6	14	13	3	3	10	20	27
-60°	-45	-43	-37	-32	-30	-26	-23	-22	-16	-10	-2	10	20	20	21	24	22	17
-70°	-61	-60	-61	-55	-49	-44	-38	-31	-25	-16	-6	1	4	5	4	2	6	12
-80°	-53	-54	-55	-52	-48	-42	-38	-38	-29	-26	-26	-24	-23	-21	-19	-16	-12	-8
-90°	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30

Longitude (Degrees)

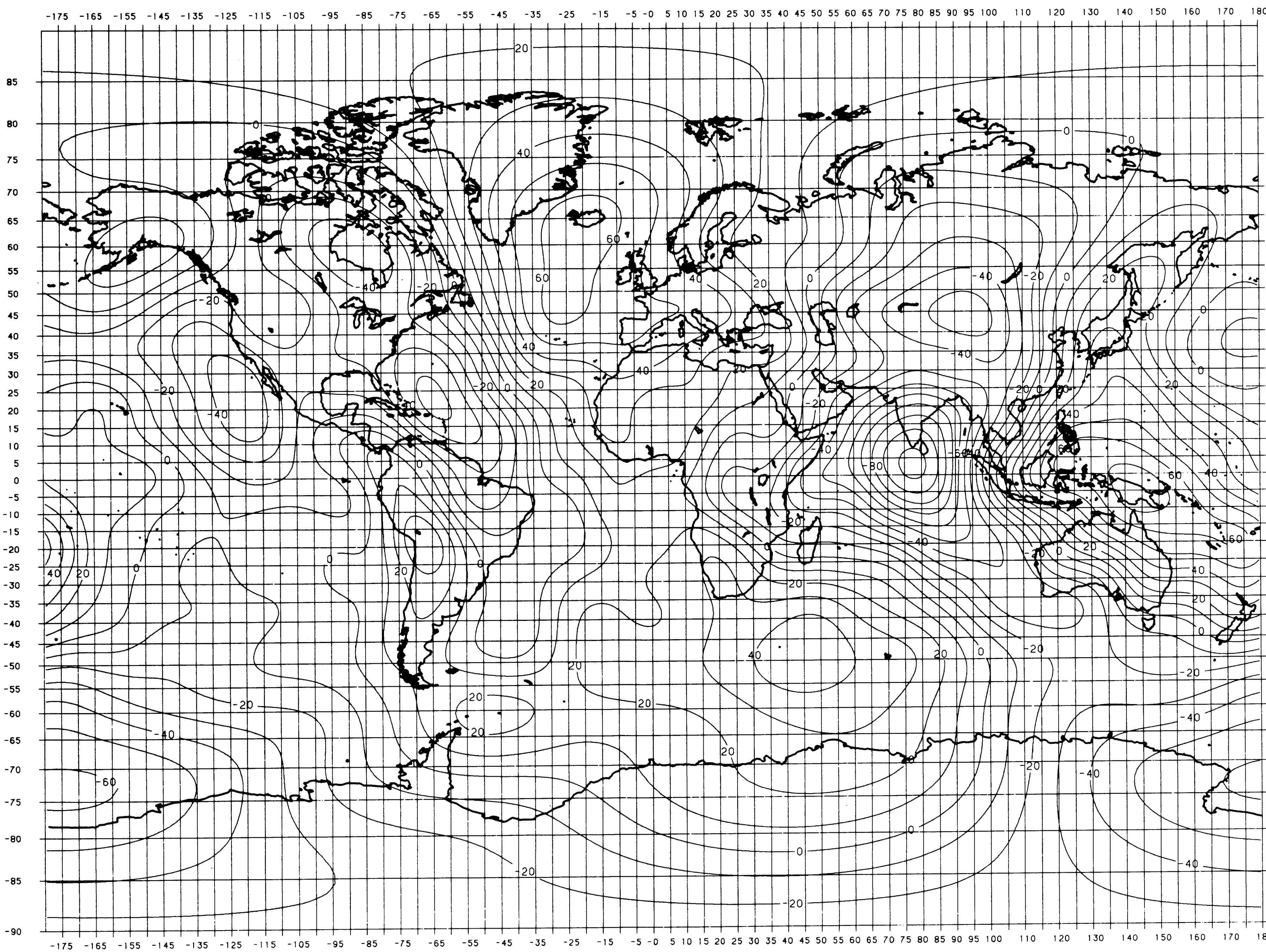

Figure 5.1. WGS 84 Geoid (n=m=18 Truncation) Referenced to WGS 84 Ellipsoid ($\delta\bar{C}_{4,0}$, $\delta\bar{C}_{6,0}$, $\delta\bar{C}_{8,0}$ and $\delta\bar{C}_{10,0} \neq 0$; Units = Meters)

Table 5.3

Interpolation of WGS 84 Geoid Heights

Bi-Linear Interpolation Method (Formula)
$N_P(\phi,\lambda) = a_0 + a_1X + a_2Y + a_3XY$
$N_P(\phi,\lambda)$ = Geoid height (N) to be interpolated at Point P (ϕ,λ)
$a_0 = N_1$
$a_1 = N_2 - N_1$
$a_2 = N_4 - N_1$
$a_3 = N_1 + N_3 - N_2 - N_4$
$X = (\lambda - \lambda_1)/(\lambda_2 - \lambda_1)$
$Y = (\phi - \phi_1)/(\phi_2 - \phi_1)$
ϕ = Geodetic latitude of Point P
λ = Geodetic longitude of Point P
N_1, N_2, N_3, N_4 = Known geoid heights at grid points used in the interpolation process
[See Associated Coordinate System, Figure 5.2]

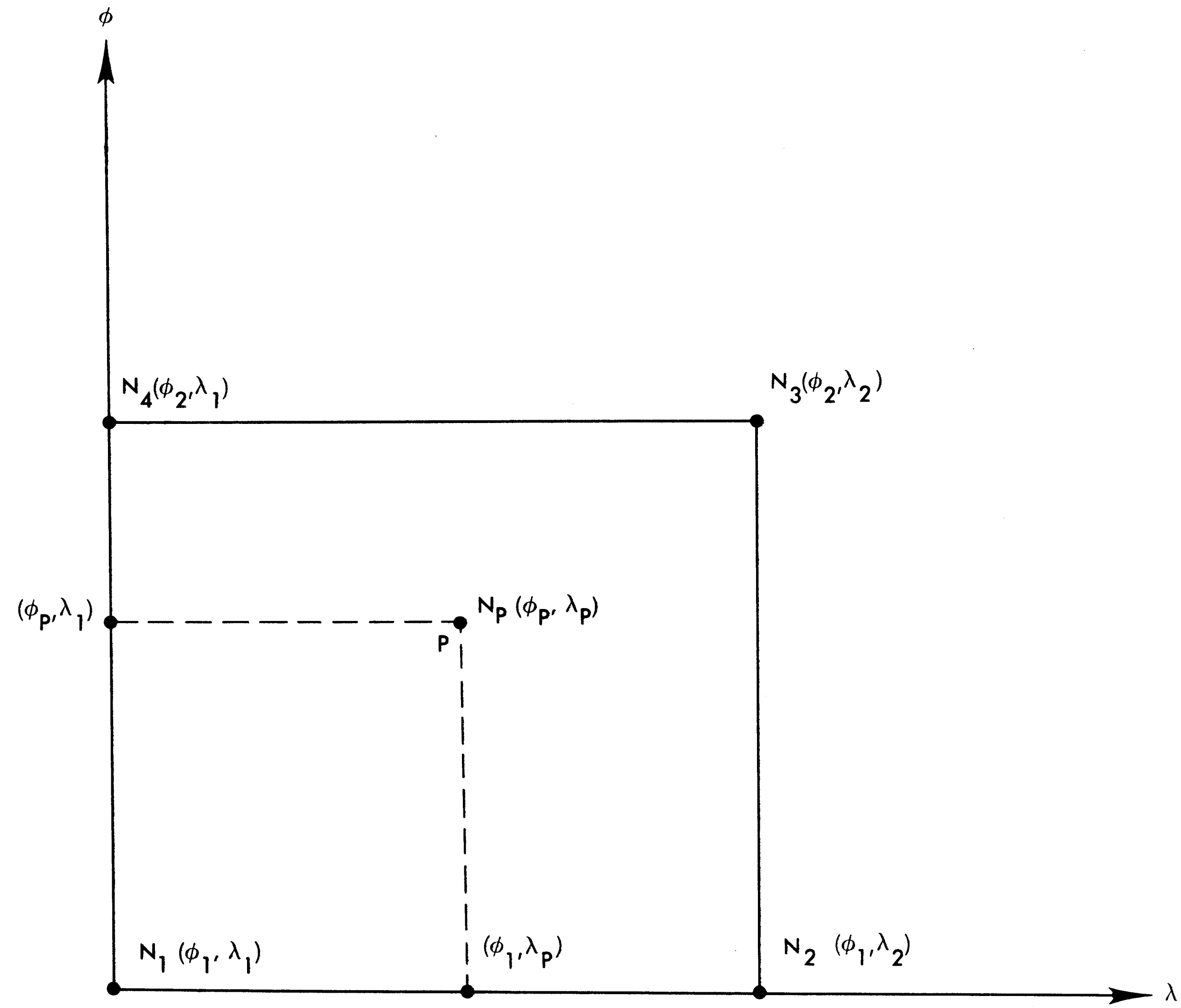

Figure 5.2. Coordinate System Associated With Geoid Height Bi-Linear Interpolation Scheme

Table 5-4

Comments on the WGS 84 Geoid

Geoid heights forming the WGS 84 Geoid were calculated using a spherical harmonic expansion and the WGS 84 EGM through n=m=180. The geodetic or gravimetric application involved dictates the geoid representation or product of most value to the user.

WGS 84 Geoid Height data and products that can be provided to requesters include:

1. A worldwide WGS 84 Geoid Height Contour Chart, contour interval = 5 meters. (See Reference 3.) If needed, contour charts of various physical size can be provided based on other contour intervals and scales, and for specific geographic areas.

2. A magnetic tape containing the worldwide 1°x1° grid of WGS 84 Geoid Heights used in developing the worldwide WGS 84 Geoid Height Contour Chart.

3. A magnetic tape containing a worldwide 30'x30' grid of WGS 84 Geoid Heights appropriate for use with the Bi-Linear Interpolation Method (Table 5.3; Figure 5.2) for interpolating WGS 84 Geoid Heights at random points. This interpolation scheme has an interpolation error (RMS difference) of ±0.09 meter based on a comparison between 259,200 calculated and interpolated WGS 84 Geoid Heights. Only 32 geoid height differences exceeded 1 meter, the largest difference being 1.55 meters. (See Reference 2.)

4. A computer program for calculating WGS 84 Geoid Heights at specified grid intervals or at random points. Associated documentation and appropriate test cases are an integral part of the computer program package.

Table 5.4 (Cont'd)

Comments on the WGS 84 Geoid

Requesters needing WGS 84 Geoid Height data and products not satisfied by either References 2 or 3 should make their requirements known to the address given in the PREFACE.

SECURITY CLASSIFICATION

A grid or database of WGS 84 Geoid Heights for a large geographic area, or for an aggregation of small areas equaling in size a large geographic area of continuous boundary, is classified CONFIDENTIAL. However, WGS 84 Geoid Heights are UNCLASSIFIED:

- When expressed in the form of a 10°x10° grid (Table 5.2), but only for a 10°x10° grid having those specific geodetic coordinates.

- At random points, except when CLASSIFIED on the basis of the site to which they refer.

- When calculated using the WGS 84 EGM truncated at $n=m\leq 18$ in a spherical harmonic expansion. (See Figure 5.1, for example.)

To avoid a possible security violation, users wishing to use WGS 84 Geoid Heights in an UNCLASSIFIED mode at random points or for small geographic areas should make their situation known to the address given in the PREFACE.

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