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Datum Transformations of GPS Positions

Application Note

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1 ECEF Coordinate System

The Cartesian coordinate frame of reference used in GPS is called Earth-Centered, Earth-Fixed (ECEF). ECEF uses three-dimensional XYZ coordinates (in meters) to describe the location of a GPS user or satellite. The term "Earth-Centered" comes from the fact that the origin of the axis (0,0,0) is located at the mass center of gravity (determined through years of tracking satellite trajectories). The term "Earth-Fixed" implies that the axes are fixed with respect to the earth (that is, they rotate with the earth). The Z-axis pierces the North Pole, and the XY-axis defines the equatorial plane. (Figure 1)

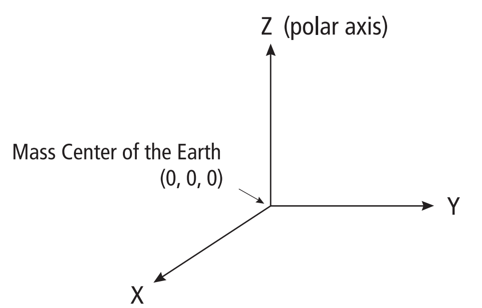
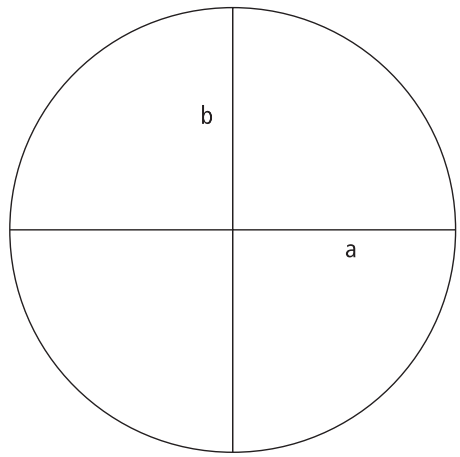


Figure 1: ECEF Coordinate Reference Frame

ECEF coordinates are expressed in a reference system that is related to mapping representations. Because the earth has a complex shape, a simple, yet accurate, method to approximate the earth's shape is required. The use of a reference ellipsoid allows for the conversion of the ECEF coordinates to the more commonly used geodetic-mapping coordinates of Latitude, Longitude, and Altitude (LLA). Geodetic coordinates can then be converted to a second map reference known as Mercator Projections, where smaller regions are projected onto a flat mapping surface (that is, Universal Transverse Mercator – UTM or the USGS Grid system).

A reference ellipsoid can be described by a series of parameters that define its shape and which include a semi-major axis (a), a semi-minor axis (b) and its first eccentricity (e) and its second eccentricity (e') as shown in Figure 2. Depending on the formulation used, ellipsoid flattening (f) may be required.



WGS84 Parameters

$$
\begin{aligned}
a &= 6378137 \\
b &= a\,(1-f) \\
&= 6356752.31424518 \\
f &= \frac{1}{298.257223563} \\
e &= \sqrt{\frac{a^2-b^2}{a^2}} \\
e' &= \sqrt{\frac{a^2-b^2}{b^2}}
\end{aligned}
$$

Figure 2: Ellipsoid Parameters

For global applications, the geodetic reference (datum) used for GPS is the World Geodetic System 1984 (WGS84). This ellipsoid has its origin coincident with the ECEF origin. The X-axis pierces the Greenwich meridian (where longitude = 0 degrees) and the XY plane make up the equatorial plane (latitude = 0 degrees). Altitude is described as the perpendicular distance above the ellipsoid surface (which not to be confused with the mean sea level datum).

2 Conversion between ECEF and Local Tangential Plane

2.1 LLA to ECEF

The conversion between the two reference coordinate systems can be performed using closed formulas (although iteration methods also exist). The conversion from LLA to ECEF (in meters) is shown below.

$$
\begin{aligned}
X &= (N+h)\cos\varphi\cos\lambda \\
Y &= (N+h)\cos\varphi\sin\lambda \\
Z &= (\frac{b^2}{a^2}N+h)\sin\varphi
\end{aligned}
$$

where

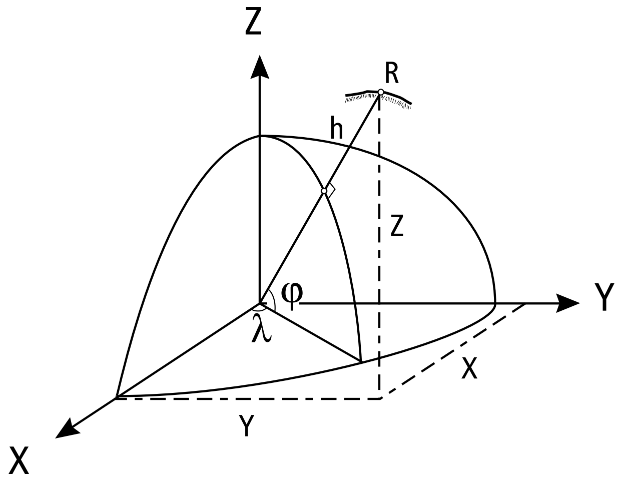


Figure 3: ECEF and Reference Ellipsoid

$$\begin{aligned}\varphi &= \text{latitude}\\ \lambda &= \text{longitude}\\ h &= \text{height above ellipsoid (meters)}\\ N &= \text{Radius of Curvature (meters), defined as:}\\ &= \frac{a}{\sqrt{1-e^2\sin^2\varphi}}\end{aligned}$$

2.2 ECEF to LLA

The conversion between XYZ and LLA is slightly more involved but can be achieved using one of the following methods:

By iteration for φ and h. There is quick convergence for $h \ll N$ starting at $h_0 = 0$.

$$\begin{aligned}\lambda &= \arctan\frac{Y}{X}\\ \text{Start with } h_0 = 0 &\\ \varphi_0 &= \arctan\frac{Z}{p\,(1-e^2)}\\ \text{Iterate } \varphi \text{ and } h &\\ N_i &= \frac{a}{\sqrt{1-e^2\sin^2\varphi_i}}\\ h_{i+1} &= \frac{p}{\cos\varphi_i} - N_i\\ \varphi_{i+1} &= \arctan\frac{Z}{p\left(1-e^2\frac{N_i}{N_i+h_{i+1}}\right)}\end{aligned}$$

Or by closed formula set.

$$\lambda = \arctan\frac{Y}{X}$$

$$
\begin{aligned}
\varphi &= \arctan \frac{Z + e'^2 b \sin^3 \theta}{p - e^2 a \cos^3 \theta} \\
h &= \frac{p}{\cos \varphi} - N
\end{aligned}
$$

Where auxiliary values are:

$$
\begin{aligned}
p &= \sqrt{X^2 + Y^2} \\
\theta &= \arctan \frac{Za}{pb}
\end{aligned}
$$

2.3 GPS Heights

The height determined by GPS measurements relates to the perpendicular distance above the reference ellipsoid and should not be confused with the more well-known height datum Mean Sea Level (MSL). The datum that defines the MSL (also called the geoid) is a complex surface that requires dense and accurate gravity data to define its shape. The WGS84 ellipsoid approximates the geoid on a worldwide basis with deviations between the two datums never exceeding 100 meters. The transformation between the two surfaces is illustrated in Figure 4.

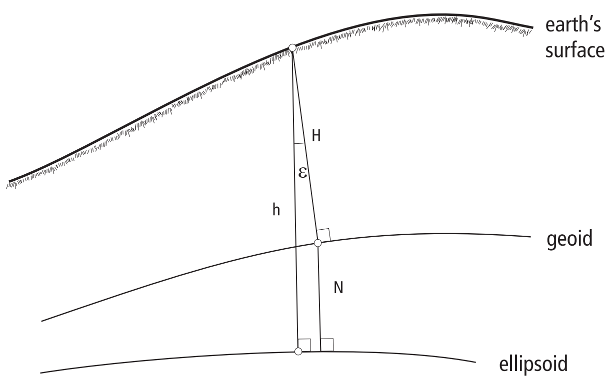


Figure 4: Ellipsoid and MSL Reference Datums

The conversion between the two reference datums is shown by:

$$
h = H + N
$$

where h = ellipsoidal height (Geodetic), H = orthometric height (MSL), N = geoid separation (undulation) and ε = deflection of the vertical.

Note – *The ellipsoid/geoid separation ranges from a value of +100 meters to -100 meters.*

Although the conversion between the different height datums is straightforward, the accuracy at which the undulation is known (N) varies greatly with gravity measurement data density. It is even more difficult to determine in mountainous regions where mass distribution can vary rapidly.

2.4 Converting ECEF Velocities to Local Tangent Plane Velocities

GPS also resolves the speed and direction of travel in the ECEF XYZ reference frame. To convert these values to a local tangent plane (LTP), the velocity vector must be rotated to reflect directions in terms more usable to the user. The LTP uses the orientation of North, East, and Down, which is consistent with the geodetic coordinates LLA. To transform the velocity vector, you use the following direction cosine matrix (North, East, Down) and solving for each component results in the following equations:

$$
\begin{aligned}
V_{north} &= -V_x \sin\varphi \cos\lambda - V_y \sin\varphi \sin\lambda + V_z cos\varphi \\
V_{east} &= -V_x \sin\lambda + V_y \cos\lambda \\
V_{down} &= -V_x \cos\varphi \cos\lambda - V_y \cos\varphi \sin\lambda - V_z \sin\varphi
\end{aligned}
$$

2.5 Speed and Heading Computations

The speed and heading data can be derived from the velocity information. Because we have already transformed the velocity vector into the local frame of east, north, and down, out speed and velocity are also in the local frame.

$$
\begin{aligned}
Speed &= \sqrt{V_{north}^2 + V_{east}^2} \\
Heading &= \arctan \frac{V_{east}}{V_{north}}
\end{aligned}
$$

Note – *The C programming function* `atan2` *returns a value between π and $-\pi$ (+180 and -180 degrees). If the value is negative then 2π (360 degrees) must be added to the results to get a positive full circle value. The heading is generally denoted in degrees as a full-circle azimuth ranging from 0 – 360 degrees (i.e., north = 0 degrees, south = 180 degrees).*

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3 Transformation to Other Reference Datums

Many reference ellipsoids are used throughout the world. The main reason for choosing a reference datum other than WGS84 is to minimize the local differences between the geoid and the ellipsoid separation or other mapping distortions. Table 1 lists several of the reference ellipsoids in use worldwide and their associated parameters.

Name	a	b	1/f
Airy	6377563.396	6356256.909	299.324965
Airy (Modified)	6377340.189	6356034.448	299.324965
Australian National	6378160.000	6356774.719	298.250000
Bessel 1841	6377397.155	6356078.963	299.152813
Bessel 1841 (Namibia)	6377483.865	6356165.383	299.152813
Clarke 1866	6378206.400	6356583.800	294.978698
Clarke 1880	6378249.145	6356514.870	293.465000
Everest (Sabah & Sarawak)	6377298.556	6356097.550	300.801700
Everest 1830	6377276.345	6356075.413	300.801700
Everest 1948	6377304.063	6356103.039	300.801700
Everest 1956	6377301.243	6356100.228	300.801700
Everest 1969	6377295.664	6356094.668	300.801700
Fischer 1960	6378166.000	6356784.284	298.300000
Fischer 1960 (Modified)	6378155.000	6356773.320	298.300000
Fischer 1968	6378150.000	6356768.337	298.300000
GRS 1980	6378137.000	6356752.314	298.257222
Helmert 1906	6378200.000	6356818.170	298.300000
Hough	6378270.000	6356794.343	297.000000
International	6378388.000	6356911.946	297.000000
Krassovsky	6378245.000	6356863.019	298.300000
SGS 85	6378136.000	6356751.302	298.257000
South American 1969	6378160.000	6356774.719	298.250000
WGS 60	6378165.000	6356783.287	298.300000
WGS 66	6378145.000	6356759.769	298.250000
WGS 72	6378135.000	6356750.520	298.260000
WGS 84	6378137.000	6356752.314	298.257224

Reference: DoD, WGS84, DMA TR 8350.2-B,1 Sept. 1991

Table 1: Commonly Used Ellipsoids

3.1 Datum Translations

Many other datums worldwide use the ellipsoid parameters shown in Table E-1 but do not have the same origin (that is, the centre of the ellipsoid does not coincide with the defined ECEF XYZ origin at the mass center of the earth). This creates a translation of the XYZ which must be performed prior to computing the geodetic positions and velocities. Table E-2 contains a list of datums, their associated ellipsoid, and the XYZ translation between the ECEF origin and the center of the ellipsoid.

To convert the ECEF coordinates to a geodetic datum, the translation vector must be applied prior to converting the LLA of the selected datum. The formulation for this conversion is shown in the following formulas.

To translate between two datums A $\Rightarrow$ B in ECEF :

$$
\begin{aligned}
X_{datum_B} &= X_{datum_A} - D_{X,AB} \\
Y_{datum_B} &= Y_{datum_A} - D_{Y,AB} \\
Z_{datum_B} &= Z_{datum_A} - D_{Z,AB}
\end{aligned}
$$

Note – *The Dx, Dy, and Dz values shown in Table 2 are defined as* from *any datum* to *ECEF.*

Example: Translate from WGS84 (datum A) to Tokyo-Korea (datum B)

1. Identify the Tokyo-Korea datum in Table 2
   Reference ellipsoid is Bessel 1841 (a = 6377397.155, b = 6356078.963)
   XYZ Translation (Dx = 146, Dy = 507, Dz = 685)
2. Give an ECEF coordinate X = 2686727, Y = -4304285, Z = 3851643

$$
\begin{aligned}
X_{Tokyo-Korea} &= -2686727 - (-146) = -2686581 \\
Y_{Tokyo-Korea} &= -4304285 - (507) = -4304792 \\
Z_{Tokyo-Korea} &= 3851643 - (685) = 3850958
\end{aligned}
$$

3. Convert to LLA using Bessel 1841 ellipsoid parameters.

3.2 Common Datum Shift Parameters

Datum	Reference Ellipsoid	D_x	D_y	D_z
Adindan - Burkina Faso	Clarke 1880	-118	-14	218
Adindan - Ethiopia	Clarke 1880	-165	-11	206
Adindan - Ethiopia, Sudan	Clarke 1880	-166	-15	204
Adindan - Mali	Clarke 1880	-123	-20	220
Adindan - Regional Mean	Clarke 1880	-166	-15	204
Adindan - Senegal	Clarke 1880	-128	-18	224
Adindan - Sudan	Clarke 1880	-161	-14	205
Adindan - Cameroon	Clarke 1880	-134	-2	210
Afgooye - Somalia	Krassovsky	-43	-163	45
Ain el Abd 1970 - Bahrain	International	-150	-251	-2
Ain el Abd 1970 - Saudi Arabia	International	-143	-236	7
American Samoa 1962 - Samoa Islands	Clarke 1866	-115	118	426
Anna 1 Astro 1965 - Cocos Islands	Australian National	-491	-22	435
Antigua Island Astro 1965 - Leward Islands	Clarke 1880	-270	13	62
Arc 1950 - Botswana	Clarke 1880	-138	-105	-289
Arc 1950 - Burundi	Clarke 1880	-153	-5	-292
Arc 1950 - Lesotho	Clarke 1880	-125	-108	-295
Arc 1950 - Malawi	Clarke 1880	-161	-73	-317
Arc 1950 - Regional Mean	Clarke 1880	-143	-90	-294
Arc 1950 - Swaziland	Clarke 1880	-134	-105	-295
Arc 1950 - Zaire	Clarke 1880	-169	-19	-278
Arc 1950 - Zambia	Clarke 1880	-147	-74	-283
Arc 1950 - Zimbabwe	Clarke 1880	-142	-96	-293
Arc 1960 - Kenya	Clarke 1880	-157	-2	-299

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Datum	Reference Ellipsoid	D_x	D_y	D_z
Arc 1960 - Kenya, Tanzania	Clarke 1880	-160	-6	-302
Arc 1960 - Tanzania	Clarke 1880	-175	-23	-303
Ascension Island 1958	International	-191	103	51
Astro Beacon E 1945 - Iwo Jima	International	145	75	-272
Astro DOS 71/4 St Helena Island	International	-320	550	-494
Astro Tern Island (FRIG) 1961	International	114	-116	-333
Astronomical Station 1952 - Marcus Island	International	124	-234	-25
Australian Geodetic 1966	Australian National	-133	-48	148
Australian Geodetic 1984	Australian National	-134	-48	149
Ayabelle Lighthouse - Djibouti	Clarke 1880	-79	-129	145
Bellevue (IGN)	International	-127	-769	472
Bermuda 1957 Bermuda	Clarke 1866	-73	213	296
Bissau - Guinea-Bissu	International	-173	253	27
Bogota Observatory - Colombia	International	307	304	-318
Bukit Rimpah Indonesia	Bessel 1841	-384	664	-48
Camp Area Astro - Antarctica	International	-104	-129	239
Campo Inchauspe - Argentina	International	-148	136	90
Canton Astro 1966 - Phoenix Islands	International	298	304	-375
Cap - South Africa	Clarke 1880	-136	108	-292
Cape Canaveral - Bahamas, Florida	Clarke 1866	-2	151	181
Carthage Tunisia	Clarke 1880	-263	6	431
Chatham Island Astro 1971 - New Zealand	International	175	-38	113
Chua Astro Paraguay	International	-134	229	-29
Corrego Alegre Brazil	International	-206	172	-6
Dabola Guinea	Clarke 1880	-83	37	124
Deception Island - Deception Island	Clarke 1880	260	12	-147
Djakarta (Batavia)	Bessel 1841	-377	681	-50
DOS 1968 - New Georgia Islands	International	230	-199	-752
Easter Island 1967 - Easter Island	International	211	147	111
Estonia Coordinate System 1937	Bessel 1841	374	150	588
European 1950 - Cyprus	International	-104	-101	-140
European 1950 - Eastern Regional Mean	International	-87	-96	-120
European 1950 - Egypt	International	-130	-117	-151
European 1950 - Finland, Norway	International	-87	-95	-120
European 1950 - Greece	International	-84	-95	-130
European 1950 - Iran	International	-117	-132	-164
European 1950 - Italy (Sardinia)	International	-97	-103	-120
European 1950 - Italy (Sicily)	International	-97	-88	-135
European 1950 - Malta	International	-107	-88	-149
European 1950 - Northern Regional Mean	International	-86	-96	-120
European 1950 - Portugal, Spain	International	-84	-107	-120
European 1950 - Southern Regional Mean	International	-103	-106	-141
European 1950 - Tunisia	International	-112	-77	-145
European 1950 - Western Regional Mean	International	-87	-98	-121
European 1979 - Central Regional Mean	International	-86	-98	-119
Fort Thomas 1955 - Nevis, St Kitts	Clarke 1880	-7	215	225
Gan 1970 - Republic of Maldives	International	-133	-321	50
Geodetic Datum 1949 - New Zealand	International	84	-22	209

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Datum	Reference Ellipsoid	D_x	D_y	D_z
Graciosa Base SW 1948 - Azores	International	-104	167	-38
Guam 1963 - Guam	Clarke 1866	-100	-248	259
Gunung Segara - Indonesia	Bessel 1841	-403	684	41
GUX 1 Astro - Guadalcanal Island	International	252	-209	-751
Herat North - Afganistan	International	-333	-222	114
Hermannskogel Datum - Croatia, Serbia	Bessel 1841	653	-212	449
Hjorsey 1955 - Iceland	International	-73	46	-86
Hong Kong 1963 - Hong Kong	International	-156	-271	-189
Hu-Tsu-Shan - Taiwan	International	-637	-549	-203
Indian - Bangladesh	Everest 1830	282	726	254
Indian - India, Nepal	Everest 1956	295	736	257
Indian - Pakistan	Everest (Pakistan)	283	682	231
Indian 1954 - Thailand, Vietnam	Everest 1830	218	816	297
Indian 1960 -	Everest 1830	198	881	317
Indian 1960 - Vietnam (Con Son Islands)	Everest 1830	182	915	344
Indian 1975 - Thailand	Everest 1830	209	818	290
Indonesian 1974 - Indonesia	Indonesian 1974	-24	-15	5
Ireland 1965 - Ireland	Modified Airy	506	-122	611
ISTS 061 Astro 1968 - South Georgia Islands	International	-794	119	-298
ISTS 073 Astro 1969 - Diego Garcia	International	208	-435	-229
Johnston Island 1961 -Johnston Island	International	189	-79	-202
Kandawala - Sri Lanka	Everest 1830	-97	787	86
Kerguelen Island 1949	International	145	-187	103
Kertau 1948 - West Malaysia & Singapore	Everest 1948	-11	851	5
Korean Geodetic System - South Korea	GRS 1980	0	0	0
Kusaie Astro 1951 - Caroline Islands	International	647	1777	-1124
L. C. 5 Astro 1961 - Cayman Brac Islands	Clarke 1866	42	124	147
Legion - Ghana	Clarke 1880	-130	29	364
Liberia 1964 - Liberia	Clarke 1880	-90	40	88
Luzon - Philippines	Clarke 1866	-133	-77	-51
Luzon - Philippines (Mindanao)	Clarke 1866	-133	-79	-72
Mahe 1971 - Mahe Island	Clarke 1880	41	-220	-134
Massawa - Ethiopia (Eritrea)	Bessel 1841	639	405	60
Merchich - Morocco	Clarke 1880	31	146	47
Midway Astro 1961 - Midway Islands	International	912	-58	122
7 Minna - Cameroon	Clarke 1880	-81	-84	115
Minna - Nigeria	Clarke 1880	-92	-93	122
Montserrat Island Astro 1958	Clarke 1880	174	359	365
M'Poraloko - Gabon	Clarke 1880	-74	-130	42
Nahrwan - Oman (Masirah Island)	Clarke 1880	-247	-148	369
Nahrwan - Saudi Arabia	Clarke 1880	-243	-192	477
Nahrwan - United Arab Emirates	Clarke 1880	-249	-156	381
Naparima BWI - Trinidad & Tobago	International	-10	375	165
North American 1927 - Alaska	Clarke 1866	-5	135	172
North American 1927 - Alaska (Aleutian Islands E)	Clarke 1866	-2	152	149
North American 1927 - Alaska (Aleutian Islands W)	Clarke 1866	2	204	105
North American 1927 - Bahamas	Clarke 1866	-4	154	178
North American 1927 - Bahamas (San Salvador)	Clarke 1866	1	140	165

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Datum	Reference Ellipsoid	D_x	D_y	D_z
North American 1927 - Canada (Yukon)	Clarke 1866	-7	139	181
North American 1927 - Canal Zone	Clarke 1866	0	125	201
North American 1927 - Central America	Clarke 1866	0	125	194
North American 1927 - Central Canada	Clarke 1866	-9	157	184
North American 1927 - Cuba	Clarke 1866	-9	152	178
North American 1927 - East Canada	Clarke 1866	-22	160	190
North American 1927 - East of Mississippi	Clarke 1866	-9	161	179
North American 1927 - Greenland	Clarke 1866	11	114	195
North American 1927 - Gulf of Mexico	Clarke 1866	-3	142	183
North American 1927 - Mean for Canada	Clarke 1866	-10	158	187
North American 1927 - Mean for Conus	Clarke 1866	-8	160	176
North American 1927 - Mexico	Clarke 1866	-12	130	190
North American 1927 - Northwest Canada	Clarke 1866	4	159	188
North American 1927 - West Canada	Clarke 1866	-7	162	188
North American 1927 - West of Mississippi	Clarke 1866	-8	159	175
North American 1983 - Alaska, Canada, Conus	GRS 1980	0	0	0
North American 1983 - Aleutian Islands	GRS 1980	-2	0	4
North American 1983 - Central America, Mexico	GRS 1980	0	0	0
North American 1983 - Hawaii	GRS 1980	1	1	-1
North Sahara - Algeria	Clarke 1880	-186	-93	310
Observatorio Metereo 1939 - Azores	International	-425	-169	81
Old Egyptian 1907 - Egypt	Helmert 1906	-130	110	-13
Old Hawaiian - Hawaii	Clarke 1866	89	-279	-183
Old Hawaiian - Kauai	Clarke 1866	45	-290	-172
Old Hawaiian - Maui	Clarke 1866	65	-290	-190
Old Hawaiian - Oahu	Clarke 1866	58	-283	-182
Old Hawaiian - Regional Mean	Clarke 1866	61	-285	-181
Oman - Oman	Clarke 1880	-346	-1	224
Ord. Survey G. Britain 1936 - England	Airy	371	-112	434
Ord. Survey G. Britain 1936 - Isle of Man	Airy	371	-111	434
Ord. Survey G. Britain 1936 - Regional Mean	Airy	375	-111	431
Ord. Survey G. Britain 1936 - Scotland, Shetland	Airy	384	-111	425
Ord. Survey G. Britain 1936 - Wales	Airy	370	-108	434
Pico de las Nieves - Canary Islands	International	-307	-92	127
Pitcairn Astro 1967 - Pitcairn Island	International	185	165	42
Point 58 - Mean for Burkina Faso & Niger	Clarke 1880	-106	-129	165
Pointe Noire 1948 - Congo	Clarke 1880	-148	51	-291
Porto Santo 1936 - Maderia Islands	International	-499	-249	314
Provisional S. American 1956 - Bolivia	International	-270	188	-388
Provisional S. American 1956 - Chile (Northern)	International	-270	183	-390
Provisional S. American 1956 - Chile (Southern)	International	-305	243	-442
Provisional S. American 1956 - Colombia	International	-282	169	-371
Provisional S. American 1956 - Ecuador	International	-278	171	-367
Provisional S. American 1956 - Guyana	International	-298	159	-369
Provisional S. American 1956 - Peru	International	-279	175	-379
Provisional S. American 1956 - Regional Mean	International	-288	175	-376
Provisional S. American 1956 - Venezuela	International	-295	173	-371
Provisional S. Chilean 1963 - Chile	International	16	196	93

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Datum	Reference Ellipsoid	D_x	D_y	D_z
Puerto Rico - Virgin Islands	Clarke 1866	11	72	-101
Pulkovo 1942 - Russia	Krassovsky 1940	28	-130	-95
Qatar National - Qatar	International	-128	-283	22
Qornoq - Greenland (South)	International	164	138	-189
Reunion - Mascarene Islands	International	94	-948	-1262
Rome 1940 - Italy (Sardinia)	International	-225	-65	9
S-42 (Pulkovo 1942) - Albania	Krassovsky 1940	24	-130	-92
S-42 (Pulkovo 1942) - Czechoslovakia	Krassovsky 1940	26	-121	-78
S-42 (Pulkovo 1942) - Hungary	Krassovsky 1940	28	-121	-77
S-42 (Pulkovo 1942) - Kazakhstan	Krassovsky 1940	15	-130	-84
S-42 (Pulkovo 1942) - Latvia	Krassovsky 1940	24	-124	-82
S-42 (Pulkovo 1942) - Poland	Krassovsky 1940	23	-124	-82
S-42 (Pulkovo 1942) - Romania	Krassovsky 1940	28	-121	-77
Santo (DOS) 1965 - Espirito Santo Island	International	170	42	84
Sao Braz - Azores	International	-203	141	53
Sapper Hill 1943 - East Falkland Island	International	-355	21	72
Schwarzeck - Namibia	Bessel 1841 (Namibia)	616	97	-251
Selvagem Grande - Salvage Islands	International	-289	-124	60
SGS 85 - Soviet Geodetic system 1985	S85	3	9	-9
Sierra Leone 1960 - Sierra Leone	Clarke 1880	-88	4	101
S-JTSK - Czechoslovakia (prior to Jan 1993)	Bessel 1841	589	76	480
South American 1969 - Argentina	South American 1969	-62	-1	-37
South American 1969 - Bolivia	South American 1969	-61	2	-48
South American 1969 - Brazil	South American 1969	-60	-2	-41
South American 1969 - Chile	South American 1969	-75	-1	-44
South American 1969 - Colombia	South American 1969	-44	6	-36
South American 1969 - Ecuador	South American 1969	-48	3	-44
South American 1969 - Ecuador (Baltra, Galapagos)	South American 1969	-47	27	-42
South American 1969 - Guyana	South American 1969	-53	3	-47
South American 1969 - Paraguay	South American 1969	-61	2	-33
South American 1969 - Peru	South American 1969	-58	0	-44
South American 1969 - Regional Mean	South American 1969	-57	1	-41
South American 1969 - Trinidad & Tobago	South American 1969	-45	12	-33
South American 1969 - Venezuela	South American 1969	-45	8	-33
South Asia - Singapore	Modified Fischer 1960	7	-10	-26
Tananarive Observatory 1925 - Madagascar	International	-189	-242	-91
Timbalai 1948 - Brunei, East Malaysia	Everest (Sabah, Sarawak)	-679	669	-48
Tokyo - Japan	Bessel 1841	-148	507	685
Tokyo - Korea	Bessel 1841	-146	507	687
Tokyo Okinawa	Bessel 1841	-158	507	676
Tokyo - Regional Mean	Bessel 1841	-148	507	685
Tokyo - South Korea	Bessel 1841	-147	506	687
Tristan Astro 1968 - Tristan da Cunha	International	-632	438	-609
Viti Levu Fiji	Clarke 1880	51	391	-36
Voirol 1960 Algeria	Clarke 1880	-123	-206	219
Wake Island Astro 1952 - Wake Atoll	International	276	-57	149
Wake-Eniwetok 1960 - Marshall Islands	Hough	102	52	-38
WGS 1972 Global Definition	WGS 72	0	0	0

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Datum	Reference Ellipsoid	D_x	D_y	D_z
WGS 1984 Global Definition	WGS 84	0	0	0
Yacare Uruguay	International	-155	171	37
Zanderij Suriname	International	-265	120	-358

Table 2: Translation Components for Selected Reference Datums