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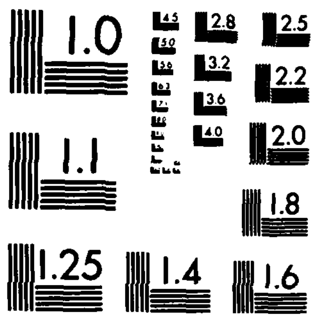
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A computer program incorporating the least squares stepwise multiple regression procedure has been used to derive polynomial equations for converting coordinates from one geodetic datum to another (datum shifts) as a function of latitude and longitude. Reference coordinate differences throughout the geographic area or datum are used for the regression. Therefore, the regression exhibits sensitivity to regional variations in the coordinate differences. (These variations are closely related to changes in the geodetic

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GEODETIC DATUM TRANSFORMATION
BY
MULTIPLE REGRESSION EQUATIONS

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ABSTRACT

A computer program incorporating the least squares stepwise multiple regression procedure has been used to derive polynomial equations for converting coordinates from one geodetic datum to another (datum shifts) as a function of latitude and longitude. Reference coordinate differences throughout the geographic area or datum are used for the regression. Therefore, the regression exhibits sensitivity to regional variations in the coordinate differences. (These variations are closely related to changes in the geodetic control in localized areas.) The resulting equations reflect this in precision. Contrariwise, the traditionally used Molodensky Coordinate Transformation Formulas, as conventionally applied over a geographic area, utilize area average rectangular coordinate differences ($\overline{\Delta X}$, $\overline{\Delta Y}$, $\overline{\Delta Z}$).

The stepwise regression program evaluates as many variables as desired (typically 100); e.g., $U^7 V^5$ is a single variable, where U and V are normalized latitude and longitude, respectively. It sequentially incorporates into the equation the variable providing the most improvement in fitting the reference coordinate differences. After such incorporation of a variable, all variables previously incorporated into the equation are examined, and any no longer significant are removed. This continues until an equation of specified precision is obtained. Thus, an equation of given precision contains a minimum number of terms and is therefore relatively computer efficient. This has particular relevance to near real time applications involving computer storage and computation time constraints.

INTRODUCTION

During the last two decades, considerable progress has been made within the Department of Defense (DoD) in reducing the number of geodetic datums used for mapping, charting, and geodetic (MC&G) purposes. This has been accomplished through the development and use of various world geodetic systems, the latest being DoD World Geodetic System 1972 (WGS 72), (Reference 1). Although the number of geodetic datums actively used by the DoD has decreased considerably, multiple datums are still in use for many geographic areas and the transformation of the geodetic coordinates of sites from one datum to another is often required. These coordinate transformations are accomplished using the Molodensky Coordinate Transformation Formulas. Another technique for accomplishing coordinate transformations, multiple regression formulas (equations), is examined in this paper for its applicability to provide precise coordinate transformations in near real time.

REGRESSION PROCEDURE

The terms $\Delta\phi$, $\Delta\lambda$, ΔH, ΔX, ΔY, and ΔZ represent reference coordinate differences (reference datum shifts) as well as regression equation computed datum shifts. This is applicable to geodetic coordinates latitude (ϕ), longitude (λ), height (H), and rectangular coordinates X, Y, and Z. Derived datum shift regression equations provide datum shifts to the equation user at any point within the applicable regression area. These equations are derived by regressing, for known orientation (reference) stations throughout the area, the reference coordinate difference dependent variables $\Delta\phi$, $\Delta\lambda$, ΔH, ΔX, ΔY, and ΔZ individually on selective variables, sometimes called independent variables. For the application subsequently presented herein, these latter variables consist of products of powers of normalized latitude (U) and normalized longitude (V); e.g., $U^3 V^4$ is a single variable. Since regression is on these polynomial two-dimensional variables, the resulting regression equations contain these variables.

The basic idea of the stepwise multiple regression procedure used for this paper is to perform the regression as a series of straight line regressions (steps). As many variables as desired are evaluated in the regression, but only a relatively small number are normally incorporated in the derived equation. The stepwise multiple regression procedure sequentially adds one variable at a time (step) to the equation; namely, the variable that provides the greatest improvement in fitting the reference coordinate differences. After a variable is added, all variables previously incorporated into the equation are examined for significance, and if any is no longer significant it is removed (another step). Correlations and F-tests provide the basis for entering and removing variables. The correlation coefficients are adjusted at each step. This stepwise regression continues until statistical parameters (F-values), used in the F-tests, are satisfied; in actual practice, until the desired equation precision is obtained. The greater the number of variables in the regression equation, the more precise (better fitting) is the equation. Coefficients for each equation variable, and a constant term, are determined.

This stepwise addition and removal of variables assures that only significant variables are retained in the final equation. Thus, a derived equation of given precision contains a minimum number of terms and therefore is relatively computer efficient. This has particular relevance to near real time applications involving computer storage and computation time constraints. For maximum computer efficiency in the computation of datums shifts, the coefficients and exponents of the variables in the set(s) of regression equations are utilized as data in an efficient algorithm.

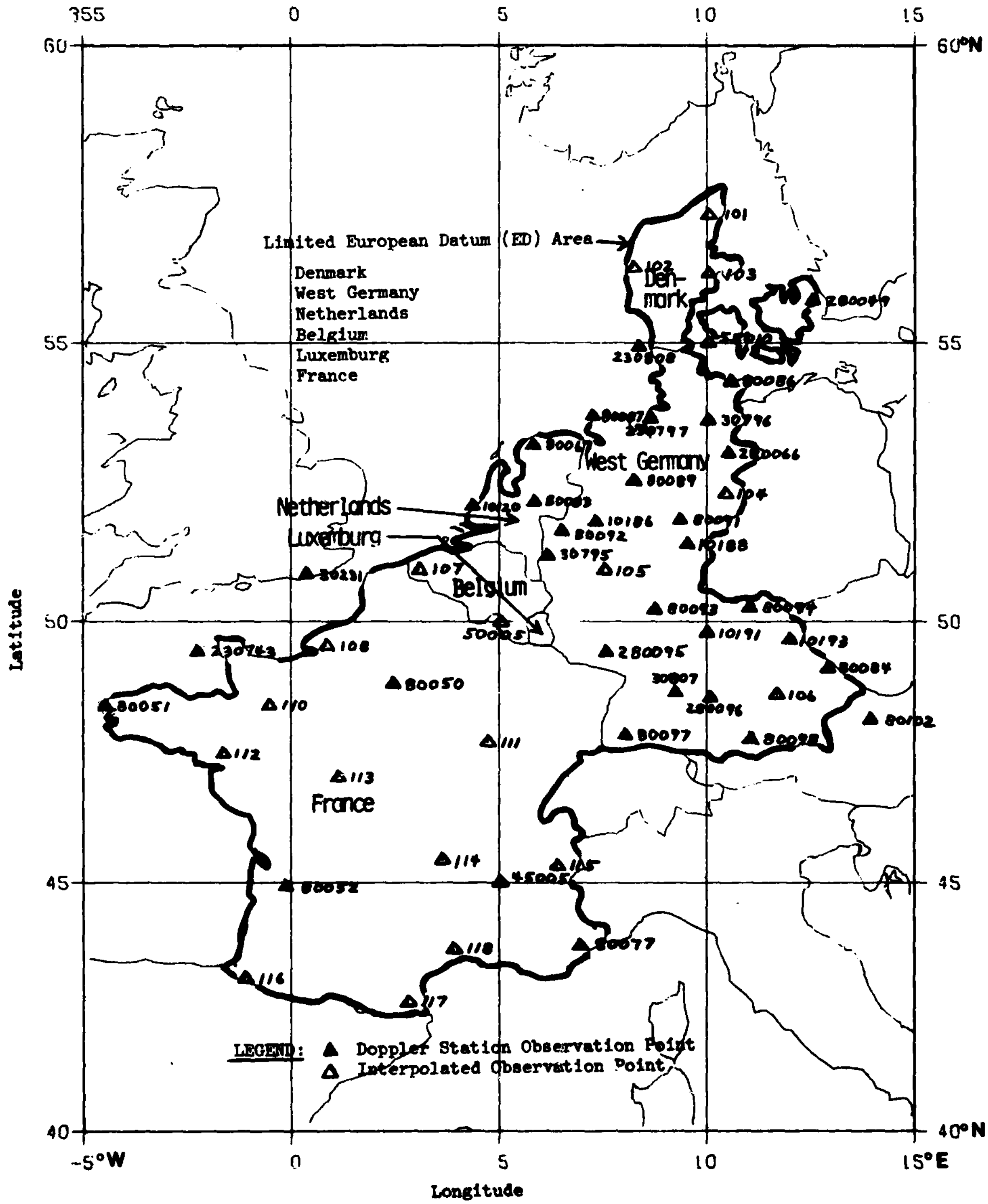
The stepwise multiple regression procedure utilized herein enjoys relatively high favor in the literature. Alternative multiple regression procedures include backward elimination, forward selection, stagewise, all possible, and variations thereof. Procedures are described in Reference 2.

REGRESSION APPLICATION

Datum shift regression equations herein provide shifts between a local geodetic datum and a world geodetic systém; namely, between European Datum 1950 (ED 50) and WGS 72. The equations cover a "limited ED 50 area" consisting of Denmark, West Germany, Netherlands, Belgium, Luxemburg, and France, as outlined in Figure 1.

FIGURE 1

LIMITED EUROPEAN DATUM AREA WITH REGRESSION OBSERVATION POINTS



Herein, latitude implies geodetic latitude, and longitude implies geodetic (and geocentric) longitude. Table 1 contains limited ED 50 area datum shift equations for geodetic coordinates latitude (ϕ), longitude (λ), and height (H), and rectangular coordinates X, Y, and Z. The equations were derived to provide a maximum deviation from the reference coordinate differences of 1.5 meters.

These equations are used as shown in Table 1 when transforming from ED 50 to WGS 72 (WGS 72 minus ED 50), and are used with a change of sign when transforming from WGS 72 to ED 50 (ED 50 minus WGS 72). The latter can be readily accomplished by merely changing the sign of the equation datum shift result. Subsequently discussed precision analysis provides verification for the dual direction utility, wherein the latitude and longitude on either datum may be used regardless of the direction of transformation. In practice, latitude and longitude values are generally available on the datum that is being transformed, and are used.

Although variables composed of powers of latitude and longitude may be used in the regression, it is generally more efficient and convenient to use a normalized latitude (U) and a normalized longitude (V) as shown in Table 1. For example, in Table 1 the normalized latitude $U = 3\phi - 2.61$ is obtained from $U = 3(\phi - 0.87)$, where 0.87 is the approximate average latitude in radians over the regression area, and 3 is a convenient factor which inhibits large values of equation coefficients. Variables evaluated in the regressions total 99 and consist of all product combinations of U and V containing single digit exponents, selections from which were made for the Table 1 equations.

Figure 1, which outlines the limited ED 50 area, also shows the 53 observation points at which reference coordinate differences were used in the regressions to derive the equations. Table 2 contains this reference data. The first 33 observation points are Doppler stations at which reference differences consist of the differences between ED 50 coordinates obtained from ground survey and WGS 72 coordinates obtained from satellite Doppler observations. The final 20 observation points were located to provide more complete area coverage, and reference coordinate differences thereat were obtained by interpolation. This interpolation was from the reference coordinate differences at the 33 Doppler stations contained in Figure 1 and Table 2 as well as additional (not shown) Doppler stations external to the limited ED 50 area.

The Defense Mapping Agency Aerospace Center (DMAAC) Datum Transformation Stepwise Regression Program was used to derive the datum shift regression equations. The reference Doppler station data was provided by Mr. J. F. Vines, DMAAC, who obtains most of such data from the Satellite Records Desk of the DMA Hydrographic Topographic Center, which accumulates it from various agencies and governments. Mr. D. N. Huber, DMAAC, performed quality evaluation of this data. Aforementioned interpolated reference coordinate differences at 20 observation points were interpolated using datum shift contour charts prepared by Messrs. Huber and Vines using a Point Plotting and Contouring Program developed by the Ohio State University. Mr. D. Holland, DMAAC, performed the Molodensky Formula computations discussed at the end of this paper.

Table 3 is a summary of subsequently discussed tables and contains deviations of regression equation datum shifts relative to reference coordinate differences for each

TABLE 1

Datum Shift Regression Equations Between Limited ED 50 Area and WGS 72

Limited ED 50 Area: Denmark, West Germany, Netherlands, Belgium, Luxemburg, and France.

ED50: European Datum 1950. Identical to the terminology European Datum (ED).

WGS 72: World Geodetic System 1972.

Geodetic Latitude Datum Shift ($\Delta\phi$) in seconds (")

$$\Delta\phi('') = -3.17250 + 1.96761\,U + 0.747893\,V - 0.252615\,V^2 + 4.68674\,U^2 V^2$$

Geodetic (and Geocentric) Longitude Datum Shift ($\Delta\lambda$) in seconds (")

$$\Delta\lambda('') = -5.03830 - 1.40710\,U + 1.60471\,V - 0.521318\,U^2 + 0.263364\,V^2$$

Geodetic Height Datum Shift (ΔH) in meters (m)

$$\Delta H(m) = 47.1915 - 35.1158\,U - 18.2122\,V + 15.8592\,U^2 + 264.165\,U^5$$

X Rectangular Coordinate Datum Shift (ΔX) in meters (m)

$$\Delta X(m) = -83.7539 - 1.98841\,U + 4.26886\,V$$

Y Rectangular Coordinate Datum Shift (ΔY) in meters (m)

$$\Delta Y(m) = -107.458 + 10.2703\,U - 12.8061\,U\,V + 46.6228\,U^2 V$$

Z Rectangular Coordinate Datum Shift (ΔZ) in meters (m)

$$\Delta Z(m) = -121.619 + 1.72649\,V - 4.42630\,V^2 - 625.330\,U^6 - 1292.75\,U^3 V^4 + 10532.7\,U^9$$

where U = Normalized latitude = $3\phi - 2.61$
where ϕ = Geodetic latitude in radians.

V = Normalized longitude = $3\lambda - 0.24$
where λ = Geodetic (and geocentric) longitude in radians.

Use positive λ from 0° to 180° east of Greenwich.
Use negative λ from 0° to 180° west of Greenwich.

ϕ and λ on either datum (ED 50 or WGS 72) may be used regardless of datum shift direction. There is no significant difference in the computed datum shift.

NOTES:

1. For datum shifts from ED 50 to WGS 72 (WGS 72 minus ED 50), use equations as shown above.

2. For datum shifts from WGS 72 to ED 50 (ED 50 minus WGS 72), use above equations with a change of sign. This can be readily accomplished by changing only the sign of the equation datum shift result.

TABLE 2

LIMITED EUROPEAN DATUM AREA

DATA FOR OBSERVATION POINTS

DIFFERENCES (WGS 72 MINUS LOCAL DATUM)

OBSER. SEQUENCE NO.	OBSER. POINT NO.	GEODETIC COORDINATES LATITUDE SECONDS	GEODETIC COORDINATES LONGITUDE SECONDS	GEODETIC COORDINATES HEIGHT METERS	RECTANGULAR COORDINATES X METERS	RECTANGULAR COORDINATES Y METERS	RECTANGULAR COORDINATES Z METERS
1	280049	-2.224	-4.773	30.62	-83.20	-103.75	-122.85
2	30231	-3.252	-5.395	48.07	-85.62	-106.02	-123.08
3	10120	-2.959	-5.261	43.96	-83.52	-106.73	-121.63
4	10186	-2.906	-4.958	41.57	-82.34	-106.28	-122.24
5	10188	-2.834	-4.719	39.79	-83.06	-106.38	-121.88
6	10191	-3.011	-4.588	42.10	-82.25	-107.65	-122.07
7	10193	-2.955	-4.401	39.40	-82.63	-107.71	-122.90
8	30795	-2.938	-5.079	44.39	-83.82	-108.18	-120.10
9	30796	-2.554	-4.907	36.65	-82.84	-106.18	-121.37
10	30807	-3.114	-4.483	45.10	-83.24	-106.39	-120.93
11	80067	-2.747	-5.218	40.57	-84.28	-105.90	-121.34
12	80083	-2.901	-5.104	42.99	-82.79	-105.91	-121.35
13	80084	-2.945	-4.249	41.93	-81.80	-107.05	-120.29
14	80086	-2.460	-4.848	34.96	-82.97	-104.57	-121.80
15	80087	-2.669	-5.082	38.42	-83.32	-104.54	-122.13
16	80089	-2.744	-4.921	39.37	-83.49	-105.74	-121.61
17	80091	-2.793	-4.740	39.37	-83.12	-105.59	-121.85
18	80092	-2.911	-5.000	41.65	-84.17	-106.30	-122.12
19	80093	-3.000	-4.684	42.43	-82.95	-106.69	-121.97
20	80094	-2.930	-4.468	40.49	-82.19	-106.12	-122.12
21	80097	-3.269	-4.551	47.71	-82.54	-107.13	-121.56
22	80098	-3.164	-4.303	44.36	-82.59	-107.31	-121.80
23	80102	-3.020	-4.115	41.82	-81.75	-107.86	-121.03
24	230797	-2.614	-4.995	36.67	-83.51	-105.39	-122.50
25	230808	-2.480	-5.187	36.63	-82.52	-105.44	-121.45
26	280066	-2.594	-4.814	36.94	-83.05	-106.55	-121.26
27	280095	-3.118	-4.706	46.07	-82.53	-106.60	-120.88
28	280096	-3.128	-4.461	43.05	-83.04	-107.56	-122.68
29	80050	-3.337	-5.161	50.53	-85.34	-108.94	-121.51
30	80051	-3.692	-5.621	58.19	-86.94	-109.11	-122.77
31	80052	-3.873	-5.088	62.77	-82.94	-111.38	-121.96
32	80077	-3.698	-4.428	55.70	-82.61	-109.85	-122.59
33	230743	-3.556	-5.585	53.69	-85.05	-109.24	-123.90
34	107	-3.100	-5.240	46.00	-84.29	-107.00	-122.00
35	101	-2.150	-5.240	32.10	-82.93	-103.43	-122.00
36	102	-2.330	-5.210	34.60	-82.71	-104.04	-122.00
37	103	-2.320	-5.040	33.10	-83.00	-103.65	-122.00
38	104	-2.690	-4.740	37.90	-82.59	-106.06	-122.00
39	105	-2.930	-4.870	42.50	-82.90	-106.62	-122.00
40	106	-3.030	-4.330	42.30	-82.15	-107.19	-121.29
41	50005	-3.130	-5.040	46.50	-83.74	-107.56	-122.00
42	55010	-2.450	-4.930	34.20	-83.00	-104.00	-122.00
43	108	-3.360	-5.300	50.80	-85.33	-107.69	-122.33
44	110	-3.520	-5.330	54.20	-85.35	-108.23	-122.56
45	111	-3.400	-4.870	51.40	-83.33	-108.72	-122.00
46	112	-3.640	-5.350	57.20	-85.26	-108.92	-122.76
47	113	-3.590	-5.150	55.90	-84.44	-109.48	-122.08
48	114	-3.660	-4.810	57.00	-83.19	-110.22	-122.24
49	115	-3.580	-4.560	54.20	-82.73	-109.38	-122.00
50	116	-4.050	-5.100	65.20	-84.53	-114.00	-123.86
51	117	-4.010	-4.750	61.50	-83.87	-112.33	-125.27
52	118	-3.810	-4.700	58.80	-83.27	-111.00	-123.50
53	45005	-3.630	-4.670	56.20	-82.88	-109.91	-122.19

TABLE 3

REGRESSION EQUATION DATUM SHIFT PRECISION

Summary at 53 Observation Points Over Limited European Datum Area

Coordinate	Deviation between Regression Equation Datum Shifts and Reference Coordinate Differences			
	* ED 50 to WGS 72		** WGS 72 to ED 50	
	RMS Meters	Maximum Meters	RMS Meters	Maximum Meters
Geodetic Latitude	0.63	1.21	0.63	1.21
Geodetic Longitude	0.63	1.38	0.63	1.38
Geodetic Height	0.67	1.34	0.67	1.34
X	0.53	1.36	0.53	1.36
Y	0.60	1.46	0.60	1.46
Z	0.57	1.41	0.57	1.41
Overall	0.61	1.46	0.61	1.46

* ED 50 geodetic latitude and longitude used for regression equations.

** WGS 72 geodetic latitude and longitude used for regression equations.

coordinate. Transforming from ED 50 to WGS 72 using ED 50 geodetic latitudes and longitudes for the equations results in an overall root mean square (RMS) deviation of 0.61 meter and an overall maximum deviation of 1.46 meters. These same overall deviations are obtained when transforming from WGS 72 to ED 50 using WGS 72 geodetic latitudes and longitudes for the equations.

For each coordinate, Tables 4 through 9 contain results at each of the 53 observation points when transforming from ED 50 to WGS 72 (WGS 72 minus ED 50) using ED 50 geodetic latitudes and longitudes for the regression equations. The tables contain the reference coordinate differences, the regression equation datum shifts, and the deviations of the latter from the former. At the bottom of each table are listed the RMS deviation and maximum deviation for the 53 points. The tables also contain normalized weights used in the equation derivations.

Similar tables, not here presented, were obtained using the same regression equations, with sign change, for transformation in the opposite direction; namely, from WGS 72 to ED 50 (ED 50 minus WGS 72) using WGS 72 latitudes and longitudes for the equations. The maximum difference of results between the two directions at the 53 points for the six coordinates is 0.02 meter. Thus, the same equations, with the appropriate sign, may be used for transformation in both directions.

Table 10 contains the Standard and Abridged Molodensky Coordinate Transformation Formulas. The Standard Molodensky Formulas are longer and provide slightly better precision than the Abridged Molodensky Formulas. For geodetic coordinates, Table 11 contains a summary of deviations of Standard Molodensky Formula datum shifts from the previously discussed 53 reference coordinate differences over the limited ED 50 area. A single set of area average rectangular coordinate differences was used as data ($\overline{\Delta X}$ = -83.39 meters, $\overline{\Delta Y}$ = -107.27 meters, and $\overline{\Delta Z}$ = -122.07 meters). Transforming from ED 50 to WGS 72 results in an overall RMS deviation of 1.58 meters and an overall maximum deviation of 6.45 meters. In comparison, overall regression equation deviations in Table 3 are 0.61 meter RMS and 1.46 meters maximum. Thus, in this illustration, regression equation precision is about three times better than that of the Standard Molodensky Formulas.

Since reference coordinate differences throughout the area are used for the regression, the regression exhibits sensitivity to regional variations in the coordinate differences. (These variations, transmitted from the local ED 50 coordinates, are closely related to changes in the geodetic control in localized areas.) The resulting datum shift regression equations reflect this in precision. Contrariwise, the traditionally used Molodensky Coordinate Transformation Formulas, as conventionally applied over a geographic area, utilize area average rectangular coordinate differences ($\overline{\Delta X}$, $\overline{\Delta Y}$, $\overline{\Delta Z}$).

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1. The Department of Defense World Geodetic System 1972; Headquarters, Defense Mapping Agency, Washington, D.C.; May 1974. (Prepared by the World Geodetic System Committee. Presented by Mr. Thomas O. Seppelin at the International Symposium on Problems Related to the Redefinition of North American Geodetic Networks; Fredericton, New Brunswick, Canada; 20-25 May 1974.)

2. Draper, N.R. and H. Smith; Applied Regression Analysis; John Wiley and Sons, Inc.; New York, New York; 1966.

TABLE 4

L I M I T E D   E U R O P E A N   D A T U M   A R E A

R E S U L T S   A T   O B S E R V A T I O N   P O I N T S

LATITUDE REFERENCE VS REGRESSION DATUM SHIFTS FROM LOCAL DATUM TO WGS 72 (WGS 72 MINUS LOCAL DATUM)

OBSERVATION SEQUENCE NO.	OBSERVATION POINT NO.	NORMALIZED WEIGHT	REFERENCE SECONDS	REGRESSION EQUATION SECONDS	DEVIATION SECONDS	DEVIATION METERS
1	280049	.930	-2.224	-2.222	.002	.06
2	30231	.930	-3.252	-3.245	.007	.21
3	10120	.930	-2.959	-2.949	.010	.30
4	10186	1.860	-2.906	-2.867	.039	1.20
5	10178	.930	-2.834	-2.833	.001	.04
6	10191	.930	-3.011	-2.987	.024	.74
7	10193	.930	-2.955	-2.939	.016	.49
8	30795	.930	-2.938	-2.974	-.036	-1.11
9	30796	.930	-2.554	-2.576	-.022	-.67
10	30807	.930	-3.114	-3.125	-.011	-.34
11	80067	.930	-2.747	-2.780	-.033	-1.03
12	80083	.930	-2.901	-2.885	.016	.50
13	80084	.930	-2.945	-2.966	-.021	-.66
14	80086	.930	-2.460	-2.477	-.017	-.52
15	80087	.930	-2.669	-2.672	-.003	-.09
16	80089	.930	-2.744	-2.757	-.013	-.41
17	80091	.930	-2.793	-2.792	.001	.02
18	80092	.930	-2.911	-2.915	-.004	-.12
19	80093	.930	-3.000	-2.983	.017	.51
20	80094	.930	-2.930	-2.907	.023	.72
21	80097	.930	-3.269	-3.248	.021	.64
22	80098	.930	-3.164	-3.154	.010	.31
23	80102	.930	-3.020	-3.031	-.011	-.34
24	230797	.930	-2.614	-2.623	-.009	-.28
25	230808	.930	-2.480	-2.499	-.020	-.60
26	280066	.930	-2.594	-2.623	-.029	-.88
27	280095	.930	-3.119	-3.104	.015	.46
28	280096	.930	-3.128	-3.107	.021	.66
29	80050	.930	-3.337	-3.363	-.026	-.82
30	80051	.930	-3.692	-3.728	-.036	-1.10
31	80052	.930	-3.873	-3.862	.011	.35
32	80077	.930	-3.698	-3.705	-.007	-.22
33	230743	2.789	-3.556	-3.517	.039	1.21
34	107	.930	-3.100	-3.120	-.020	-.63
35	122	.930	-2.150	-2.167	-.017	-.54
36	132	.930	-2.330	-2.356	-.026	-.80
37	123	1.860	-2.320	-2.285	.035	1.10
38	104	.930	-2.690	-2.706	-.016	-.49
39	105	.930	-2.930	-2.950	-.020	-.62
40	106	.930	-3.030	-3.052	-.022	-.69
41	50003	.930	-3.130	-3.141	-.011	-.33
42	55010	.930	-2.450	-2.422	.028	.85
43	108	.930	-3.360	-3.360	.000	.01
44	110	.930	-3.520	-3.537	-.017	-.53
45	111	.930	-3.400	-3.385	.015	.46
46	112	.930	-3.640	-3.679	-.039	-1.19
47	113	.930	-3.590	-3.601	-.011	-.35
48	114	.930	-3.660	-3.663	-.003	-.11
49	115	.930	-3.580	-3.567	.013	.40
50	116	.930	-4.050	-4.061	-.011	-.35
51	117	.930	-4.010	-3.984	.026	.80
52	118	.930	-3.810	-3.835	-.025	-.76
53	45005	.930	-3.650	-3.656	-.006	-.17

LATITUDE DATUM SHIFT ROOT MEAN SQUARE DEVIATION .020438 SECONDS .631276 METERS

LATITUDE DATUM SHIFT MAXIMUM DEVIATION .039193 SECONDS 1.210582 METERS

TABLE 5

L I M I T E D   E U R O P E A N   D A T U M   A R E A

R E S U L T S   A T   O B S E R V A T I O N   P O I N T S

LONGITUDE REFERENCE VS REGRESSION DATUM SHIFTS FROM LOCAL DATUM TO WGS 72 (WGS 72 MINUS LOCAL DATUM)

OBSERVATION SEQUENCE NO.	OBSERVATION POINT NO.	NORMALIZED WEIGHT	REFERENCE SECONDS	REGRESSION EQUATION SECONDS	D E V I A T I O N SECONDS	EQUATOR EQUIVALENT SECONDS	METERS
1	280049	.964	-4.773	-4.812	-.039	-.022	-.67
2	30231	.964	-5.395	-5.458	-.063	-.040	-1.23
3	10120	.964	-5.263	-5.236	.027	.017	.51
4	10186	.964	-4.956	-4.956	.002	.001	.04
5	10188	.964	-4.719	-4.726	-.007	-.004	-.14
6	10191	.964	-4.588	-4.560	.028	.018	.56
7	10193	.964	-4.401	-4.367	.034	.022	.69
8	30795	2.891	-5.079	-5.009	.070	.044	1.35
9	30796	.964	-4.907	-4.861	.046	.027	.85
10	30807	.964	-4.483	-4.550	-.067	-.045	-1.38
11	80067	.964	-5.218	-5.199	.019	.011	.35
12	80083	.964	-5.106	-5.116	-.010	-.006	-.18
13	80084	.964	-4.249	-4.241	.008	.006	.17
14	80056	.964	-4.646	-4.670	-.022	-.014	-.40
15	80087	.964	-5.082	-5.117	-.035	-.021	-.63
16	80089	.964	-4.921	-4.933	-.012	-.008	-.23
17	80091	.964	-4.740	-4.777	-.037	-.023	-.71
18	80092	.964	-5.000	-5.014	-.014	-.009	-.27
19	80093	.964	-4.684	-4.705	-.021	-.014	-.42
20	80096	.964	-4.468	-4.501	-.033	-.021	-.65
21	80097	.964	-4.551	-4.603	-.052	-.035	-1.07
22	80098	.964	-4.303	-4.323	-.020	-.014	-.42
23	80102	.964	-4.115	-4.072	.043	.029	.89
24	230797	.964	-4.995	-4.991	.004	.002	.08
25	230808	.964	-5.187	-5.124	.062	.036	1.1[illegible]
26	280066	.964	-4.814	-4.769	.045	.027	.84
27	280095	.964	-4.706	-4.752	-.046	-.030	-.92
28	280026	.964	-4.461	-4.467	-.006	-.004	-.14
29	80050	.964	-5.161	-5.144	.017	.011	.35
30	80051	.964	-5.621	-5.639	-.018	-.012	-.36
31	80052	.964	-5.088	-5.091	-.003	-.002	-.07
32	80077	.964	-4.428	-4.441	-.013	-.010	-.30
33	230743	.964	-5.585	-5.551	.035	.023	.70
34	10[illegible]	.964	-5.640	-5.248	-.008	-.005	-.16
35	101	.964	-5.240	-5.181	.059	.032	.99
36	102	.964	-5.610	-5.260	-.050	-.028	-.86
37	103	.964	-5.340	-5.388	-.048	-.027	-.82
38	104	.964	-4.740	-4.716	.024	.015	.46
39	105	.964	-4.870	-4.870	-.000	.000	-.00
40	106	.964	-4.330	-4.340	.010	.007	.21
41	45[illegible]	.964	-5.040	-5.014	.026	.016	.51
42	45010	.964	-4.930	-4.980	-.050	-.028	-.86
43	108	.964	-5.300	-5.321	-.021	-.016	-.63
44	110	.964	-5.330	-5.348	-.018	-.012	-.37
45	111	.964	-4.870	-4.878	-.008	-.005	-.16
46	112	.964	-5.350	-5.370	-.020	-.014	-.42
47	113	.964	-5.150	-5.166	.016	.016	.50
48	114	.964	-4.610	-4.623	-.013	-.009	-.27
49	115	.964	-4.560	-4.601	-.041	-.018	-.40
50	116	.964	-5.100	-5.068	.032	.022	.69
51	117	.964	-4.757	-4.728	.029	.018	.47
52	118	.964	-4.700	-4.697	.003	.002	.07
53	45005	.964	-4.672	-4.660	-.010	-.007	-.21

LONGITUDE DATUM SHIFT ROOT MEAN SQUARE DEVIATION .032782 SECONDS .023382 EQUATOR EQUIVALENT SECONDS .629549 METERS

LONGITUDE DATUM SHIFT MAXIMUM DEVIATION .069551 SECONDS .044548 EQUATOR EQUIVALENT SECONDS 1.375960 METERS

TABLE 6

L I M I T E D   E U R O P E A N   D A T U M   A R E A

R E S U L T S   A T   O B S E R V A T I O N   P O I N T S

GEODETIC HEIGHT REFERENCE VS REGRESSION DATUM SHIFTS FROM LOCAL DATUM TO WGS 72 (WGS 72 MINUS LOCAL DATUM)

OBSERVATION SEQUENCE NO.	OBSERVATION POINT NO.	NORMALIZED WEIGHT	REFERENCE METERS	REGRESSION EQUATION METERS	DEVIATION METERS
1	280049	.883	30.62	31.06	.44
2	30231	1.767	48.07	49.40	1.33
3	10120	.883	43.96	43.50	-.46
4	10186	.883	41.57	41.15	-.42
5	10198	.883	39.79	39.72	-.07
6	10191	.883	42.10	42.15	.05
7	10193	.883	39.60	40.68	1.08
8	30795	.883	44.39	43.31	-1.08
9	30796	.883	36.65	35.77	-.88
10	30807	.883	45.10	44.98	-.12
11	80067	.883	40.57	40.41	-.16
12	80083	.883	42.99	41.98	-1.01
13	80084	.883	41.93	40.59	-1.34
14	80086	.883	34.96	34.33	-.63
15	80087	.883	38.42	38.30	-.12
16	80089	.883	39.37	39.08	-.29
17	80091	.883	39.37	39.15	-.22
18	80092	.883	41.65	42.22	.57
19	80093	.883	42.43	42.56	.13
20	80094	.883	40.49	40.32	-.17
21	80097	.883	47.71	47.72	.01
22	80098	.883	44.36	45.00	.64
23	80102	.883	41.82	41.48	-.34
24	230797	.883	36.67	37.03	.36
25	230808	.883	36.63	35.74	-.89
26	280066	.883	36.94	36.16	-.78
27	280095	.883	46.07	45.11	-.96
28	280096	1.767	43.05	44.35	1.30
29	80050	.883	50.55	51.16	.61
30	80051	.883	58.19	58.59	.40
31	80052	5.300	62.77	61.51	-1.26
32	80077	.883	55.70	56.90	1.20
33	230743	.883	53.69	54.52	.83
34	127	.883	46.00	46.68	.68
35	101	.883	32.10	33.09	.99
36	102	.883	34.60	34.85	.25
37	103	.883	33.10	33.18	.08
38	104	.883	37.90	37.34	-.56
39	105	.883	42.50	42.44	-.06
40	106	.883	42.30	42.73	.43
41	50075	.883	46.50	46.51	.01
42	55010	.883	34.20	34.08	-.12
43	108	.883	30.80	31.32	.52
44	110	.883	54.20	54.61	.41
45	111	.883	51.40	51.14	-.26
46	112	.883	57.20	57.70	.50
47	113	.883	55.90	55.96	.06
48	114	.883	57.00	56.67	-.33
49	115	.883	54.30	54.47	.17
50	116	.883	65.20	65.56	.36
51	117	.883	61.50	62.45	.95
52	118	.883	58.80	59.95	1.15
53	45005	.883	56.20	56.45	.25

GEODETIC HEIGHT DATUM SHIFT ROOT MEAN SQUARE DEVIATION .666167 METERS

GEODETIC HEIGHT DATUM SHIFT MAXIMUM DEVIATION 1.337848 METERS

TABLE 7

LIMITED EUROPEAN DATUM AREA

RESULTS AT OBSERVATION POINTS

X RECTANGULAR COORDINATE REFERENCE VS REGRESSION DATUM SHIFTS FROM LOCAL DATUM TO WGS 72 (WGS 72 MINUS LOCAL DATUM)

OBSERVATION SEQUENCE NO.	OBSERVATION POINT NO.	NORMALIZED WEIGHT	REFERENCE METERS	REGRESSION EQUATION METERS	DEVIATION METERS
1	[illegible]	.964	-83.20	-82.60	.60
2	30231	.964	-85.62	-84.81	.81
3	10120	.964	-83.82	-84.35	-.53
4	10196	.964	-82.34	-83.35	-1.01
5	10198	.964	-83.07	-82.82	.25
6	10191	.964	-82.25	-82.54	-.29
7	10193	.964	-83.65	-83.39	.26
8	30725	.964	-83.62	-83.35	.27
9	30726	.964	-82.84	-82.94	-.10
10	30727	.964	-83.24	-82.60	.64
11	60047	.964	-84.28	-83.83	.45
12	80083	.964	-82.79	-83.72	-.93
13	80084	.964	-81.50	-81.53	-.03
14	80086	.964	-82.97	-82.89	.09
15	80087	.964	-83.32	-83.56	-.24
16	80089	.964	-83.49	-83.22	.27
17	80091	.964	-83.12	-82.90	.22
18	80092	.964	-86.17	-85.52	.65
19	80093	.964	-82.95	-82.87	.09
20	80094	.964	-84.19	-84.36	-.17
21	80097	.964	-84.52	-84.78	-.26
22	80098	.964	-82.59	-82.10	.49
23	80102	.964	-81.75	-81.49	.26
24	230797	.964	-83.51	-83.25	.26
25	230878	.964	-82.52	-83.44	-.92
26	260066	.964	-83.05	-82.77	.28
27	280095	.964	-82.53	-83.05	-.52
28	280096	.964	-83.04	-82.40	.64
29	80050	.964	-85.34	-84.13	1.21
30	80051	.964	-86.94	-85.64	1.30
31	80052	2.891	-82.94	-84.30	-1.36
32	80077	.964	-82.61	-82.60	.01
33	230743	.964	-85.05	-85.24	-.19
34	107	.964	-84.29	-84.21	.08
35	101	.964	-82.93	-83.31	-.38
36	102	.964	-83.71	-83.72	-.01
37	103	.964	-83.00	-83.20	-.20
38	104	.964	-82.59	-82.71	-.12
39	105	.964	-82.90	-83.22	-.32
40	106	.964	-83.15	-83.04	.11
41	50005	.964	-83.74	-83.68	.06
42	55010	.964	-83.00	-83.08	-.08
43	108	.964	-85.15	-84.38	.77
44	110	.964	-85.35	-84.75	.60
45	111	.964	-83.33	-83.50	-.17
46	112	.964	-85.26	-84.91	.35
47	113	.964	[illegible]	[illegible]	.50
48	114	.964	-83.19	-83.55	-.36
49	115	.964	-82.73	-82.88	-.15
50	116	.964	-84.53	-84.33	.20
51	117	.964	-84.07	-83.60	.47
52	118	.964	-83.27	-83.27	.00
53	45005	.964	-82.88	-83.16	-.28

X RECTANGULAR COORDINATE DATUM SHIFT ROOT MEAN SQUARE DEVIATION .528629 METERS

X RECTANGULAR COORDINATE DATUM SHIFT MAXIMUM DEVIATION 1.355336 METERS

TABLE 8

L I M I T E D   E U R O P E A N   D A T U M   A R E A

R E S U L T S   A T   O B S E R V A T I O N   P O I N T S

Y RECTANGULAR COORDINATE REFERENCE VS REGRESSION DATUM SHIFTS FROM LOCAL DATUM TO WGS 72 (WGS 72 MINUS LOCAL DATUM)

OBSERVATION SEQUENCE NO.	OBSERVATION POINT NO.	NORMALIZED WEIGHT	REFERENCE METERS	REGRESSION EQUATION METERS	DEVIATION METERS
1	280049	.914	-103.75	-104.09	-.34
2	30231	.914	-106.02	-106.79	-.77
3	10120	.914	-106.73	-106.23	.50
4	10186	.914	-106.28	-106.51	-.23
5	10198	.914	-106.38	-106.80	-.42
6	10191	.914	-107.65	-107.48	.18
7	10193	.914	-107.71	-107.51	.20
8	30795	.914	-108.18	-106.78	1.40
9	30796	.914	-106.18	-105.62	.56
10	30817	.914	-106.39	-107.85	-1.46
11	80067	.914	-105.90	-105.71	.20
12	80083	.914	-105.91	-106.26	-.35
13	80084	.914	-107.05	-107.60	-.56
14	80086	.914	-104.57	-105.19	-.62
15	80087	.914	-104.54	-105.48	-.94
16	80089	.914	-105.74	-106.17	-.43
17	80091	.914	-105.59	-106.58	-.99
18	80092	.914	-106.30	-106.57	-.27
19	80093	.914	-106.69	-107.31	-.62
20	80094	.914	-106.12	-107.32	-1.20
21	80097	.914	-107.13	-108.19	-1.06
22	80098	.914	-107.31	-107.92	-.61
23	80172	.914	-107.86	-107.63	.22
24	230797	.914	-105.39	-105.55	-.15
25	230808	.914	-105.44	-104.75	.69
26	280066	.914	-106.55	-105.99	.56
27	280095	.914	-106.60	-107.63	-1.03
28	280096	.914	-107.56	-107.83	-.27
29	80050	.914	-106.94	-106.09	.85
30	80051	.914	-109.11	-108.82	.29
31	80052	.914	-111.38	-111.69	-.31
32	80077	.914	-109.85	-109.65	.20
33	230743	5.483	-109.24	-107.79	1.45
34	100	.914	-107.00	-106.82	.18
35	101	.914	-103.45	-102.96	.49
36	102	.914	-104.04	-103.80	.24
37	103	.914	-103.65	-103.79	-.14
38	104	.914	-106.06	-106.39	-.33
39	105	.914	-106.62	-106.95	-.33
40	106	.914	-107.19	-107.74	-.55
41	530035	.914	-107.56	-107.38	.18
42	550010	.914	-106.00	-106.70	-.70
43	108	.914	-107.69	-107.66	.03
44	110	.914	-108.23	-108.56	-.33
45	111	.914	-106.72	-106.58	.14
46	112	.914	-108.92	-109.47	-.55
47	113	.914	-109.48	-109.68	-.20
48	114	.914	-110.22	-110.10	.12
49	115	.914	-109.38	-109.30	.08
50	116	.914	-114.00	-114.17	-.17
51	117	.914	-112.33	-112.43	-.10
52	118	.914	-111.00	-111.10	-.10
53	45005	.914	-109.91	-109.93	-.02

Y RECTANGULAR COORDINATE DATUM SHIFT ROOT MEAN SQUARE DEVIATION .596744 METERS

Y RECTANGULAR COORDINATE DATUM SHIFT MAXIMUM DEVIATION 1.459124 METERS

TABLE 9

L I M I T E D   E U R O P E A N   D A T U M   A R E A

R E S U L T S   A T   O B S E R V A T I O N   P O I N T S

Z RECTANGULAR COORDINATE REFERENCE VS REGRESSION DATUM SHIFTS FROM LOCAL DATUM TO WGS 72 (WGS 72 MINUS LOCAL DATUM)

OBSERVATION SEQUENCE NO.	OBSERVATION POINT NO.	NORMALIZED WEIGHT	REFERENCE METERS	REGRESSION EQUATION METERS	DEVIATION METERS
1	280049	.914	-122.85	-123.06	-.21
2	30231	.914	-123.08	-122.22	.86
3	10120	.914	-121.63	-121.64	-.02
4	10186	.914	-122.24	-121.46	.78
5	10188	.914	-121.88	-121.47	.41
6	10191	.914	-122.07	-121.48	.58
7	10193	.914	-122.90	-121.61	1.29
8	30795	5.483	-120.10	-121.51	-1.41
9	30796	.914	-121.37	-121.58	-.21
10	30877	.914	-120.93	-121.46	-.53
11	80067	.914	-121.34	-121.55	-.21
12	80083	.914	-121.35	-121.53	-.18
13	80086	.914	-120.29	-121.70	-1.41
14	80096	.914	-121.60	-121.55	.05
15	80097	.914	-122.13	-121.51	.63
16	80089	.914	-121.61	-121.46	.15
17	80091	.914	-121.85	-121.47	.38
18	80092	.914	-122.12	-121.49	.63
19	80093	.914	-121.97	-121.45	.52
20	80094	.914	-122.12	-121.54	.59
21	80097	.914	-121.56	-121.45	.11
22	80098	.914	-121.80	-121.52	.28
23	80102	.914	-121.03	-121.78	-.76
24	230797	.914	-122.50	-121.51	1.00
25	230878	.914	-121.45	-121.64	-.19
26	280066	.914	-121.26	-121.58	-.31
27	280095	.914	-120.88	-121.46	-.58
28	280096	.914	-122.68	-121.48	1.20
29	80050	.914	-121.51	-121.87	-.36
30	80051	.914	-122.77	-122.61	-.65
31	80052	.914	-122.96	-122.47	-.51
32	80077	.914	-122.59	-122.49	.11
33	230765	.914	-123.90	-122.81	1.08
34	107	.914	-122.00	-121.79	.21
35	101	.914	-122.00	-122.04	-.04
36	102	.914	-122.00	-121.84	.16
37	103	.914	-122.00	-122.11	-.11
38	104	.914	-122.00	-121.53	.47
39	105	.914	-122.00	-121.46	.54
40	106	.914	-121.29	-121.58	-.29
41	50005	.914	-122.00	-121.58	.42
42	55010	.914	-122.00	-121.81	.19
43	108	.914	-122.33	-122.13	.20
44	110	.914	-122.58	-122.40	.18
45	111	.914	-122.00	-121.61	.39
46	112	.914	-122.78	-122.65	.13
47	113	.914	-122.08	-122.08	.00
48	114	.914	-122.24	-121.83	.41
49	115	.914	-122.00	-121.63	.37
50	116	.914	-123.86	-124.19	-.33
51	117	.914	-123.27	-123.34	-.07
52	118	.914	-123.50	-122.79	.71
53	45005	.914	-122.19	-121.80	.39

Z RECTANGULAR COORDINATE DATUM SHIFT ROOT MEAN SQUARE DEVIATION .570811 METERS

Z RECTANGULAR COORDINATE DATUM SHIFT MAXIMUM DEVIATION 1.408364 METERS

Table 10
COORDINATE TRANSFORMATION FORMULAS
GEODETIC DATUM TO WGS 72

A. The Standard Molodensky Formulas

$$\Delta\phi'' = \{-\Delta X \sin\phi \cos\lambda - \Delta Y \sin\phi \sin\lambda + \Delta Z \cos\phi$$
$$+ \Delta a (R_N e^2 \sin\phi \cos\phi)/a$$
$$+ \Delta f [R_M (a/b) + R_N (b/a)] \sin\phi \cos\phi\} \bullet [(R_M + H) \sin 1'']^{-1}$$

$$\Delta\lambda'' = [-\Delta X \sin\lambda + \Delta Y \cos\lambda] \bullet [(R_N + H) \cos\phi \sin 1'']^{-1}$$

$$\Delta H = \Delta X \cos\phi \cos\lambda + \Delta Y \cos\phi \sin\lambda + \Delta Z \sin\phi$$
$$-\Delta a (a/R_N) + \Delta f (b/a) R_N \sin^2\phi$$

B. The Abridged Molodensky Formulas

$$\Delta\phi'' = [-\Delta X \sin\phi \cos\lambda - \Delta Y \sin\phi \sin\lambda + \Delta Z \cos\phi + (a\Delta f + f\Delta a) \sin 2\phi]$$
$$\bullet [R_M \sin 1'']^{-1}$$

$$\Delta\lambda'' = [-\Delta X \sin\lambda + \Delta Y \cos\lambda] \bullet [R_N \cos\phi \sin 1'']^{-1}$$

$$\Delta H = \Delta X \cos\phi \cos\lambda + \Delta Y \cos\phi \sin\lambda + \Delta Z \sin\phi + (a\Delta f + f\Delta a) \sin^2\phi - \Delta a$$

C. Definition of Terms in the Molodensky Formulas

ϕ, λ, H = geodetic coordinates (old ellipsoid)

ϕ = geodetic latitude. The angle between the earth's equatorial plane and the ellipsoidal normal at a point (measured positive north from the equator, negative south).

λ = geodetic longitude. The angle between the plane of the Greenwich meridian and the plane of the geodetic meridian of the point (measured in the plane of the equator, positive east from Greenwich).

H = the distance of a point from the ellipsoid measured along the ellipsoidal normal through the point.

$H = N + {}^{*}h$

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*Indicates parameters which do not appear in the Abridged Molodensky Formulas.

Table 10 (Cont'd)

N = geoid-ellipsoid separation. The distance of the geoid above (+N) or below (-N) the ellipsoid.

*h = distance of a point from the geoid (elevation above or below mean sea level).

$\Delta\phi$, $\Delta\lambda$, ΔH = corrections to transform the geodetic coordinates from the old datum to WGS.

ΔX, ΔY, ΔZ = shifts between ellipsoid centers of the old datum and WGS.

a = semimajor axis of the old ellipsoid.

*b = semiminor axis of the old ellipsoid.

*$b/a = 1 - f$

f = flattening of the old ellipsoid.

Δa, Δf = differences between the parameters of the old ellipsoid and the WGS ellipsoid (WGS minus old).

e = eccentricity.

$e^2 = 2f - f^2$

R_N = radius of curvature in the prime vertical.

**$R_N = a/(1-e^2 \sin^2 \phi)^{1/2}$

R_M = radius of curvature in the meridian.

**$R_M = a(1-e^2)/(1-e^2 \sin^2 \phi)^{3/2}$

NOTE: All Δ-quantities are formed by subtracting old ellipsoid values from WGS ellipsoid values.

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*Indicates parameters which do not appear in the Abridged Molodensky Formulas.

**For desk calculator computations involving commonly used ellipsoids, these values are given in Latitude Function Tables, i.e., Latitude Functions Clarke 1866 Spheroid, AMS TM No. 68, 1957.

TABLE 11

STANDARD MOLODENSKY COORDINATE TRANSFORMATION FORMULA DATUM SHIFT PRECISION

Summary at 53 Points over Limited European Datum Area

Coordinate	Deviation between Standard Molodensky Formula Datum Shifts and Reference Coordinate Differences * ED 50 to WGS 72	
	RMS Meters	Maximum Meters
Geodetic Latitude	1.07	2.81
Geodetic Longitude	2.26	6.45
Geodetic Height	1.12	2.77
Overall	1.58	6.45

* ED 50 geodetic latitude and longitude, and a single set of area average $\overline{\Delta X}$, $\overline{\Delta Y}$, $\overline{\Delta Z}$ rectangular coordinate differences used for Standard Molodensky Formulas.