Reports of the Department of Geodetic Science
Report No. 188

FREE ADJUSTMENT OF A GEOMETRIC GLOBAL SATELLITE NETWORK (SOLUTION MPS-7)

by
Ivan I. Mueller and Marvin C. Whiting

Prepared for
National Aeronautics and Space Administration
Washington, D.C.

Contract No. NGR 36-008-093
OSURF Project No. 2514

The Ohio State University
Research Foundation
Columbus, Ohio 43212

October, 1972

Reports of the Department of Geodetic Science

Report No. 188

FREE ADJUSTMENT OF A GEOMETRIC GLOBAL SATELLITE NETWORK (SOLUTION MPS-7)

by

Ivan I. Mueller and Marvin C. Whiting

Prepared for

National Aeronautics and Space Administration
Washington, D. C.

Contract No. NGR 36-008-093
OSURF Project No. 2514

The Ohio State University
Research Foundation
Columbus, Ohio 43212

October, 1972

PREFACE

This project is under the supervision of Ivan I. Mueller, Professor of the Department of Geodetic Science at The Ohio State University, and is under the technical direction of James P. Murphy, Special Programs, Code ES, NASA Headquarters, Washington, D. C. The contract is administered by the Office of University Affairs, NASA, Washington, D. C., 20546.

TABLE OF CONTENTS

1. INTRODUCTION

The basic purpose of this experiment was to compute reduced normal equations from the observational data of several different systems described below to combine them eventually with the normal equations of the Wild BC-4 observations taken in the DOD/DOC cooperative worldwide geodetic satellite program and provide station coordinates from a single least squares adjustment. The solution described in this paper is a partial one obtained without the use of the BC-4 data. The observational systems combined were the Baker-Nunn simultaneous camera observations from the SAO worldwide network; the C-Band range observations from the NASA network; the MOTS and PC-1000 optical observations in North America; miscellaneous camera observations in Europe which were included in the SAO 69 solution; and, lastly, a group of optical observations where Baker-Nunn cameras observed simultaneously with MOTS and/or PC-1000 cameras in the previously mentioned group.

2. DESCRIPTION OF DATA

2.1 Smithsonian Data

A set of optical observations was obtained from the Smithsonian Astrophysical Observatory. These included 14,356 simultaneous observations from 28 stations in the SAO 69 Network. For each observation the track angle was provided along with the uncertainties along and across the track. The variances and covariances, in terms of right ascension and declination, were computed as described in [Girnius and Joughlin, 1968].

2.2 MOTS and PC-1000 Data

The set of optical observations used here was the same as that used in the NA6 adjustment described in [Mueller et al., 1969]. The observations had been previously screened and a set of reduced normal equations, referenced to the North American Datum, obtained.

In the meantime [Vincent et al., 1971] published a geoidal map based on gravimetric and satellite data. By an iterative procedure a new solution was computed which constrained the new undulations, and thus a set of geocentric coordinates was obtained [Mueller et al., 1972]. With these coordinates as initial values, but with the original set of observations, new reduced normal equations were computed to be used in the solution described in this paper.

2.3 C-Band Observations

The C-Band solution is a least squares adjustment of the range observations from twenty-eight C-Band radar stations operated by NASA in a worldwide network, which resulted in distances between the stations and a set of coordinates of the stations on the SAO C-6 ellipsoid along with their standard deviations [Brooks and Leitao, 1970]. Upon request, NASA/Wallops Island kindly sent us the correlation matrix for these solutions, which enabled us to reconstruct the full variance-covariance matrix.

Some of the stations in this adjustment could be related through ground triangulation to nearby Baker-Nunn, MOTS or PC-1000 cameras, thus the inter-station distances provided indirectly the scale of the solution. The C-Band data was treated as though they were length observations between the stations. A program was developed that computed the normal equations that would correspond to these length observations utilizing also the reconstructed variance-covariance matrix.

The computed lengths are listed in Table 1.

Table 1

Stations	Length (m)
Merritt Island (4082) to Pretoria (4050)	10,909,592
Merritt Island (4082) to Kauai (4742)	7,362,142
Merritt Island (4082) to Bermuda (4740)	1,593,106
Merritt Island (4082) to Grand Turk (4081)	1,230,691
Merritt Island (4082) to Antigua (4061)	2,288,026
Kauai H.I. (4742) to Vandenberg AFB (4280)	3,977,684

2.4 Mixed Optical Observations

We also received from the NASA, National Space Science Data Center a magnetic tape containing records of optical observations on GEOS-I from November of 1965 to August of 1966. These included 2322 simultaneous observations between Baker-Nunn cameras, MOTS cameras and PC-1000 cameras located on and around the North American continent.

It being intended to combine the normal equations developed from the above observations with a set of normal equations developed from a much larger set of observations described in Sections 2.1 and 2.2, the possibility of duplicating observations had to be considered.

In the case of the majority of the MOTS and PC-1000 and all of the Baker-Nunn observations, the few duplicated observations were overwhelmed by the large number of other observations at these stations. However, a number of MOTS and PC-1000 stations in the Caribbean area contributed only a few observations to the North American normal equations. Any duplicated observations here would have had an inordinate effect. Therefore, all such observations were eliminated.

3. CONSTRAINTS

3.1 Inner Adjustment Constraints (Free Adjustment)

The large number of optical observations effectively determined the orientation of the total network while the C-Band observations provided a scale. Only the origin remained undetermined. To define the origin of the system in its most favorable position (from the error propagation point of view) we imposed "Inner Adjustment Constraints" compelling the trace of the variance-covariance matrix to be a minimum [Blaha, 1971].

3.2 Length Constraints

The C-Band observations described earlier introduced scale into our adjustments. They also provided much needed extra connections from Africa across the Atlantic and to the Caribbean Islands, and the length Kauai to Vandenberg Air Force Base greatly strengthened the geometry in the western United States.

In addition to the C-Band scale we also introduced a weighted chord length constraint between Homestead, Florida and Greenbelt, Maryland derived from updated Cape Canaveral datum coordinates of these two stations determined from the high precision geodimeter traverse in the eastern United States.

3.3 Height Constraints

At all stations, a weighted height constraint was imposed. The heights above mean sea level were obtained from [NASA, 1971] and to these, the undulations referred to the SAO 69 ellipsoid were added. The undulations were determined from a number of sources. Between North America and Europe the geoid of [Vincent et al., 1971] was used. In this report, the undulations of some stations were also tabulated (computed). These tabulated values were constrained with weights corresponding to a standard deviation of 3 m. Other station undulations were interpolated from the geoid map itself and, allowing for interpolation errors, received assigned standard deviations of 5 m except in those areas near the Caribbean where, because of large geoidal gradients, a standard deviation of 8 m was estimated. For stations in other parts of the world (not covered by the above geoid map) the undulations were obtained from the SAO 69 geoid map, and standard deviations from 8 m to 15 m were assigned depending upon the number of gravity measurements available in the surrounding area. All heights constrained (H) are shown in Table 2.

These height constraints, which are in effect independent observations, provided a valuable strengthening of an otherwise weak geometric network. A test adjustment was run (MPS9) in which all previously described constraints were held except the height constraints and in this adjustment the final standard deviations of the coordinates were more than doubled and at poorly determined stations more than tripled.

3.4 Relative Position Constraints

These weighted constraints were used to tie together the C-Band radar stations with nearby camera stations through the connecting triangulation, and also helped to connect the Baker-Nunn stations with nearby MOTS and/or PC-1000 stations.

In every case, Cartesian coordinate differences were computed on the local datum and the weights determined from standard deviations computed from a

Table 2

Height Constraints and Undulations

(all units in meters)

Number	Station	Constraints		N	
		H	σ	MPS7	[Vincent et al., 1971]
1021	Blossom Pt., Md.	- 20	3	- 30	- 26
1022	Fort Myers, Fla.	- 13	3	- 18	- 18
1030	Goldstone, Cal.	902	3	- 27	- 27
1032	St. John's, Nswf.	82	5	12	14
1033	Fairbanks, Alaska	188	15	4	
1034	E. Grand Forks, Minn.	238	3	- 15	- 18
1042	Rosman, N.C.	887	3	- 24	- 22
3106	Antigua, W.I.	- 37	3	- 41	- 39
3334	Stoneville, Miss.	20	5	- 20	- 19
3400	Colorado Springs, Col.	2173	5	- 8	- 11
3401	Bedford, Mass.	63	5	- 28	- 20
3402	Semmes, Alabama	55	3	- 24	- 18
3404	Swan Island	31	15	- 38	
3405	Grand Turk, B.I.	- 29	3	- 39	- 31
3406	Curacao, N. Antilles	- 19	8	- 29	- 26
3407	Trinidad, T. & T.	221	8	- 59	- 34
3648	Hunter AFB, Georgia	- 12	3	- 25	- 24
3657	Aberdeen, Md.	- 20	3	- 26	- 26
3861	Homestead, Fla.	- 22	3	- 24	- 22
3902	Cheyenne, Wyo.	1872	5	- 11	- 10
3903	Herndon, Va.	142	5	- 33	- 26
4082	Merritt Island, Fla.	- 12	3	- 27	- 23
4280	Vandenberg AFB, Cal.	91	3	- 30	- 32
4050	Pretoria, S.A.	1604	6	- 1	
4742	Kauai, H.I.	1157	9	- 4	
7036	Edinburg, Texas	48	3	- 11	- 12
7037	Columbia, Mo.	249	3	- 20	- 24
7039	Bermuda	- 5	3	- 37	- 36
7040	San Juan, P.R.	9	3	- 41	- 41
7043	Greenbelt, Md.	27	3	- 29	- 26

Table 2 (continued)

Number	Station	Constraints		N	
		H	σ	MPS7	[Vincent et al., 1971]
7045	Denver, Col.	1767	3	- 13	- 13
7072	Jupiter, Fla.	- 10	3	- 26	- 24
7075	Sudbury, Canada	251	3	- 30	- 31
7076	Kinsgton, Jamaica	423	3	- 22	- 23
8009	Delft, Holland	72	3	48	47
8010	Zimmerwald, Swiss.	957	3	51	54
8011	Malvern, England	165	5	57	52
8015	Haute Provence, Fr.	702	3	59	
8019	Nice, France	432	3	45	55
8030	Meudon, France	214	5	47	
9001	Organ Pass, N.M.	1633	3	- 16	- 18
9002	Pretoria, S.A.	1564	6	0	
9004	San Fernando, Spain	81	3	45	55
9005	Tokyo, Japan	99	6	41	
9006	Naini Tal, India	1874	8	- 45	
9007	Arequipa, Peru	2477	9	19	
9008	Shiraz, Iran	1588	10	- 20	
9009	Curacao, N. Antilles	- 19	5	- 29	- 26
9010	Jupiter, Fla.	- 9	3	- 27	- 24
9011	Villa Dolores, Arg.	618	8	6	
9012	Maui, Hawaii	3036	9	19	
9021	Mt. Hopkins, Ariz.	2362	3	- 37	- 22
9028	Addis Ababa, Ethiopia	1911	10	52	
9029	Natal, Brazil	37	10	- 12	
9031	Comodoro Rivadavia, Arg.	215	15	- 9	
9051	Athens, Greece	242	5	46	54
9091	Dionysos, Greece	454	3	78	54
9424	Cold Lake, Canada	684	6	- 30	
9425	Edwards AFB, Cal.	756	3	- 24	- 28
9426	Harestua, Norway	622	3	45	46
9427	Johnston Island	17	10	28	
9431	Riga, Latvia	32	3	22	24
9432	Uzhgorod, USSR	236	3	45	47

formula given in [Simmons, 1950]. This estimate was used in all cases except between Merritt Island and Jupiter, Florida, where the uncertainty was estimated to be one part in 750,000. The relative constraints used and their weights ($1/\sigma^2$) are all given in Table 3.

4. THE ADJUSTMENT

The four sets of normal equations (see Section 2), and the previously explained constraint equations were added together and a single solution was obtained for the combined systems.

We decided to run three different adjustments to investigate the effects of the constraints we were using: MPS7 was ultimately chosen as the best adjustment. It contained all the constraints previously explained, inner adjustment plus height constraints. MPS8 included the height constraints but without inner adjustment. MPS9 was run with inner adjustment constraints but without holding the heights.

After MPS7 was run, we immediately computed the undulations (N) at selected stations and compared them with the values given in [Vincent et al., 1971]. This comparison is given in Table 2. There are some discrepancies, but generally the fit is good, indicating that despite the free adjustment, the height constraints had held (thus our origin is reasonably close to the center of mass).

The results of the MPS7 adjustment are tabulated in Appendix 1. The number of degrees of freedom was 10586; the quadratic sum of all the residuals 12201; and the standard deviation of unit weight 1.07.

5. COMPARISONS WITH OTHER SOLUTIONS

Table 4 summarizes the transformation parameters (systematic differences) between the MPS7 coordinates and those published in [Gaposchkin and Lambeck, 1970], and in [Marsh et al., 1971], for the global network and for both the European and American nets. Two sets of parameters are listed. The first was obtained

Table 3

Relative Position Constraints

Distances	Relative Coordinates (meters) ΔX	ΔY	ΔZ	Weights $(1/\sigma^2)$		
4082 Merritt Island to 9010 Jupiter, Florida	- 65710.36	62288.42	137731.50	130.3	145.2	29.7
4280 Vandenberg AFB to 9113 Rosamund, California	- 221861.70	103220.29	- 27546.03	0.2	0.6	3.5
4050 Pretoria, S.A. to 9002 Olifantsfontein, S.A.	- 4499.99	10094.48	1602.05	39.2	13.3	155.5
4742 Kauai, Hawaiian Island to 9012 Maui, Hawaiian Island	- 77906.67	349733.48	145327.36	0.9	0.1	0.4
3406 Curacao PC-1000 9009 Curacao Baker Nunn	- 10.00	3.00	28.00	135194.0	673180.0	34257.0
7072 Jupiter MOTS 40 9010 Jupiter Baker Nunn	- 14.81	1.98	7.84	80051.0	1170662.0	187019.0
4081 Grand Turk C-Band 3405 Grand Turk PC-1000	928.47	1760.31	3352.71	321.6	147.0	58.0
4740 Bermuda C-Band 7039 Bermuda MOTS 40	674.25	- 700.53	- 1476.11	492.6	468.2	173.3
4061 Antigua C-Band 3106 Antigua PC-1000	- 245.92	- 359.44	- 514.23	1890.5	1139.7	707.0

Table 4

Transformation Parameters

		GLOBAL		EUROPE			NORTH AMERICA		
		MPS7-GSFC	MPS7-SAO	MPS7-GSFC	MPS7-SAO	MPS7-ED50	MPS7-NAD	MPS7-GSFC	MPS7-SAO
No. Stations		15	20	11	9	14	28	16	15
Wt. Factor*		25.0	1.42	18.0	0.86	1.08	0.67	17.24	0.36
3 Parameter Transf.	ΔX (m)	-19.3 ± 2.6	-12.1 ± 2.4	- 2.8 ± 2.5	- 3.5 ± 2.6	- 90.6 ± 3.2	- 39.6 ± 1.26	-18.7 ± 1.2	-12.6 ± 1.3
	ΔY (m)	0.6 ± 2.9	- 5.4 ± 2.6	- 17.5 ± 2.7	- 9.7 ± 3.2	-138.6 ± 3.5	142.9 ± 1.04	-18.1 ± 1.4	-12.5 ± 1.2
	ΔZ (m)	29.7 ± 2.9	29.4 ± 2.5	31.1 ± 2.7	49.7 ± 2.9	- 85.5 ± 3.3	201.8 ± 1.17	22.5 ± 1.4	20.5 ± 1.3
7 Parameter Transformation**	ΔX (m)	-10.1 ± 3.8	- 4.3 ± 2.9	- 34.2 ± 7.8	-50.7 ± 8.1	-112.6 ± 7.5	- 45.4 ± 3.5	3.2 ± 3.5	- 8.2 ± 3.7
	ΔY (m)	5.2 ± 4.2	0.5 ± 3.1	- 50.1 ± 7.8	34.8 ± 12.0	-165.5 ± 6.2	150.1 ± 3.7	-33.4 ± 4.0	-49.6 ± 3.9
	ΔZ (m)	33.6 ± 4.4	25.4 ± 3.0	135.8 ± 8.1	15.6 ± 8.6	- 90.3 ± 7.1	223.3 ± 3.7	38.3 ± 4.6	40.1 ± 4.4
	θ_Z (″)	0.48 ± 0.07	0.30 ± 0.04	- 1.60 ± 0.22	1.20 ± 0.30	- 0.66 ± 0.18	- 0.60 ± 0.09	0.51 ± 0.10	0.10 ± 0.10
	θ_Y (″)	0.30 ± 0.08	0.53 ± 0.06	- 3.34 ± 0.30	- 0.33 ± 0.33	- 0.53 ± 0.24	0.48 ± 0.07	0.27 ± 0.09	0.06 ± 0.09
	θ_X (″)	- 0.40 ± 0.09	- 0.14 ± 0.05	0.05 ± 0.22	- 0.98 ± 0.32	0.55 ± 0.15	- 0.75 ± 0.10	- 0.12 ± 0.16	0.21 ± 0.14
	ϵ ($\times 10^6$)	0.62 ± 0.37	1.11 ± 0.23	- 7.64 ± 0.92	8.91 ± 0.85	3.29 ± 0.81	- 1.00 ± 0.50	- 2.85 ± 0.48	- 6.65 ± 0.50

* Weight Factor = $P_{MPS7}/P_1 = \sigma_1^2/\sigma_{MPS7}^2$

** Rotation Parameters and Scale Factor Constrained through the assumption that only translations exist between the sets of coordinates. In the second solution, the rotations and the scale factor were first computed through respective direction cosines and chord distances, both independent of translations. Subsequently the general seven-parameter transformation was carried out with the three rotation parameters and the scale factor constrained with their respective variance-covariances obtained in the direction cosine or chord distances solutions. Appendix 2 gives the general solutions and variance-covariance and correlation coefficient matrices obtained in each case.

REFERENCES

Blaha, Georges (1971). "Inner Adjustment Constraints with Emphasis on Range Observations," Reports of the Department of Geodetic Science, 148, The Ohio State University, Columbus.

Brooks, R. L. and C. D. Leitao (1969). C-Band Radar Network Intersite Distances, A Status Report, presented at the National Fall Meeting of the American Geophysical Union, San Francisco, California.

Gaposchkin, E. M. and K. Lambeck (1970). "The 1969 Smithsonian Standard Earth (II)," SAO Special Report, 315, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts.

Girnius, A. and W. L. Joughin (1968). "Optical Simultaneous Observations," SAO Special Report, 226, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts.

Marsh, J. G., B. C. Douglas and S. M. Klosko (1971). "A Unified Set of Tracking Station Coordinates Derived from Geodetic Satellite Tracking Data," Report X-553-71-320, Goddard Space Flight Center, Greenbelt, Maryland, July.

Mueller, Ivan I., James P. Reilly and Charles R. Schwarz (1969). "The North American Datum in View of GEOS I Observations," Reports of the Department of Geodetic Science, 125, The Ohio State University, Columbus.

Mueller, Ivan I., James P. Reilly and T. Soler (1972). "Geodetic Satellite Observations in North America (Solution NA9)," Reports of the Department of Geodetic Science, 187, The Ohio State University, Columbus.

NASA: Directory of Observation Station Locations (1971). Goddard Space Flight Center, Greenbelt, Maryland, second edition.

Simmons, L. G. (1950). "How Accurate is First-Order Triangulation?" The Journal, Coast and Geodetic Survey, 3, pp. 53-56.

Vincent, S., W. E. Strange and J. G. Marsh (1971). A Detailed Gravimetric Geoid from North America to Europe, presented at the National Fall Meeting of the American Geophysical Union, San Francisco, California.

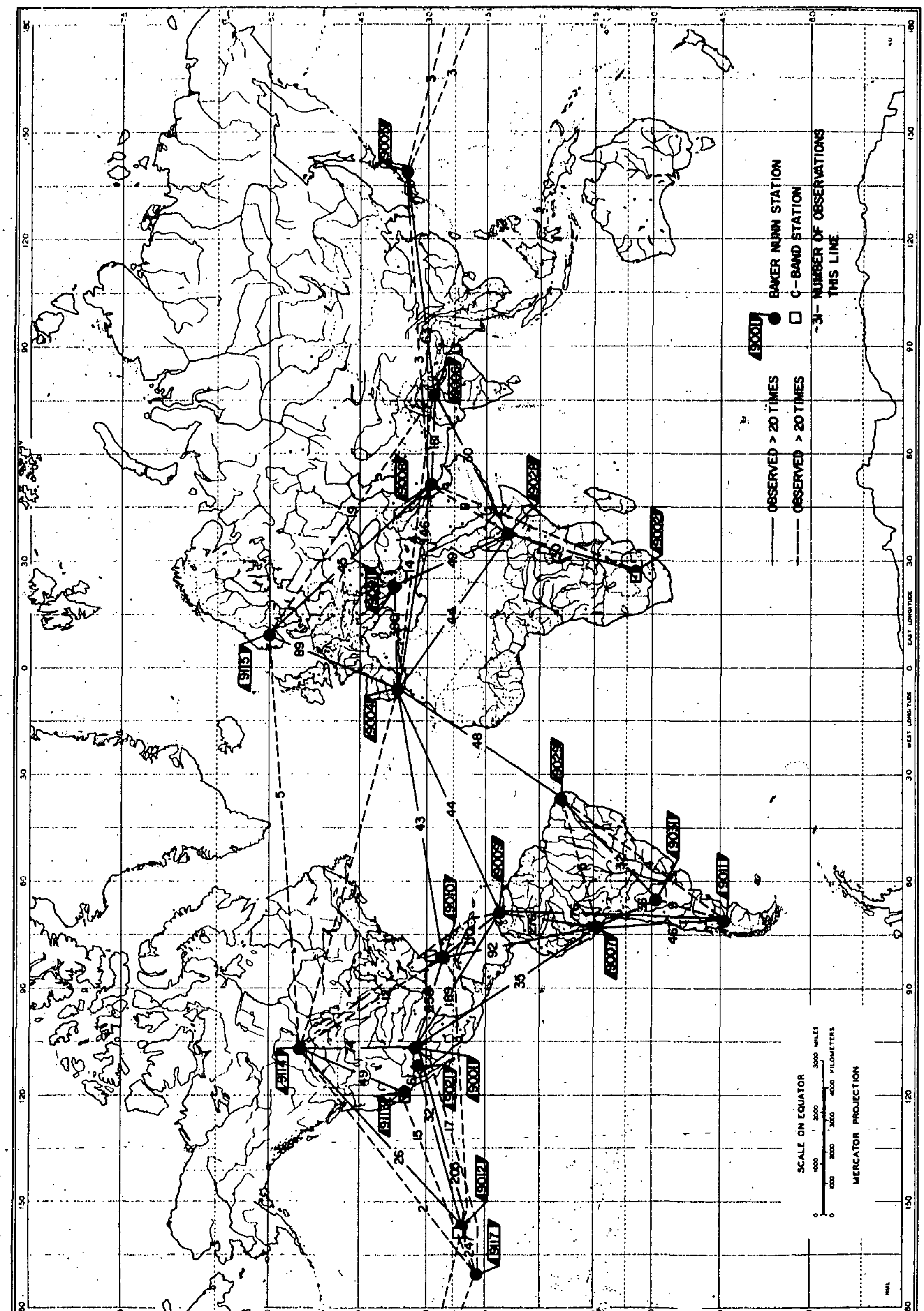
APPENDIX 1.

(all coordinates in meters)

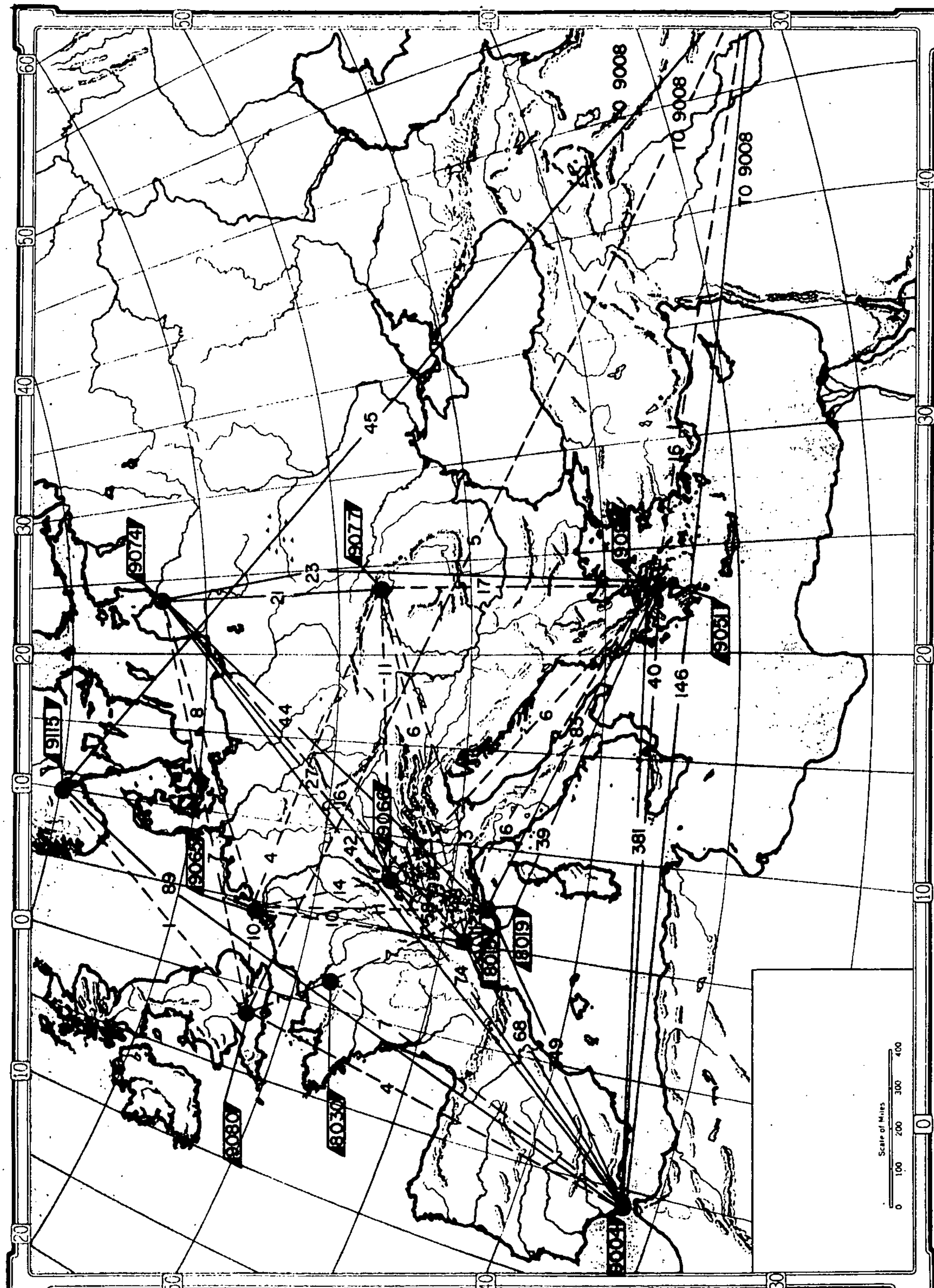
Number	Station	Adjusted Coordinates X	Y	Z	Std. Deviations σ_x	σ_y	σ_z
1021	Blossom Pt., Md.	1118016.7	-4876329.9	3942995.5	3.5	3.1	3.4
1022	Fort Meyers, Fla.	807846.0	-5651996.5	2833530.9	2.9	2.2	2.8
1030	Goldstone, Cal.	-2357257.9	-4646331.9	3668326.7	6.1	3.6	3.5
1032	St. John's, Newf.	2602683.3	-3419225.8	4697569.9	42.6	47.4	14.1
1033	Fairbanks, Alaska	-2299317.9	-1445559.6	5751828.3	11.5	38.4	13.7
1034	E. Grand Forks, Minn.	-521712.2	-4242063.1	4718744.3	3.5	3.4	3.3
1042	Rosman, N.C.	647491.0	-5177940.8	3656736.9	3.3	2.6	3.3
3106	Antigua, W.I.	2881837.1	-5372177.3	1868571.6	2.9	2.9	3.9
3334	Stoneville, Miss.	-84984.7	-5327981.0	3493457.1	13.9	7.5	9.2
3400	Colorado Springs	-1275222.3	-4798026.2	3994233.0	10.0	6.3	6.2
3401	Bedford, Mass.	1513129.5	-4463580.1	4283085.3	3.8	4.4	3.8
3402	Semmes, Alabama	167252.0	-5481977.9	3245067.7	4.3	2.9	3.8
3404	Swan Island	642480.2	-6053937.3	1895713.5	5.1	4.6	5.3
3405	Grand Turk, B.I.	1919479.4	-5621107.9	2315814.2	3.2	3.2	3.8
3406	Curacao, N. Antilles	2251798.4	-5816922.7	1327223.1	3.3	2.9	4.1
3407	Trinidad, Tobago	2979881.3	-5513537.6	1181174.5	6.1	5.5	8.2
3648	Hunter AFB	832557.9	-5349547.9	3360619.5	4.4	3.3	4.5
3657	Aberdeen, Md.	1186781.3	-4785200.2	4032914.3	3.7	3.6	3.5
3861	Homestead, Fla.	961762.5	-5679164.3	2729915.6	3.5	2.5	3.3
3902	Cheyenne, Wyo.	-1234709.7	-4651233.3	4174784.6	6.3	7.7	6.6
3903	Herndon, Va. (PC 1000)	1088975.7	-4843012.0	3991811.2	12.4	8.4	9.1
4050	Pretoria	5051652.3	2726611.7	-2774095.9	10.7	25.6	41.9
4061	Etrant	2881591.1	-5372536.8	1868057.4	2.9	2.9	3.9
4081	Etrgrt	1920407.8	-5619437.6	2319166.9	3.2	3.2	3.8
4082	Merritt Island	910560.9	-5539119.7	3017995.7	2.7	1.9	2.8
4280	Vandenberg AFB	-2671875.1	-4521211.5	3607501.1	3.8	4.0	5.4
4740	NBER34 (Bermuda)	2308881.6	-4874308.3	3393115.2	3.0	3.1	4.0
4742	Kauai, H.I.	-5543992.5	-2054530.5	2387507.0	3.2	4.8	5.7
7036	Edinburg, Tex.	-828496.2	-5657473.7	2816842.0	3.8	2.5	3.3
7037	Columbia, Mo.	-191298.9	-4967296.5	3983281.6	3.3	2.6	3.0

Number	Station	Adjusted Coordinates			Std. Deviations		
		X	Y	Z	σ_x	σ_y	σ_z
7039	Bermuda	2308207.3	-4873607.7	3394591.3	3.0	3.1	4.0
7040	San Juan, P.R.	2465045.1	-5534940.7	1985546.2	4.1	2.8	4.2
7043	Greenbelt, Md.	1130702.7	-4831335.5	3994165.6	3.6	3.0	3.1
7045	Denver, Colorado	-1240478.3	-4760235.0	4049005.3	4.4	3.3	3.4
7072	Jupiter, Fla.	976256.5	-5601406.1	2880272.1	2.7	1.9	2.8
7075	Sudbury, Canada	692613.0	-4347078.5	4600504.7	4.1	4.3	3.9
7076	Kingston, Jamaica	1384151.8	-5905668.6	1966574.0	4.5	3.1	5.3
8009	Delft, Holland	3923404.9	299893.1	5003006.0	8.9	9.0	7.2
8010	Zimmerwald, Swiss.	4331314.8	567511.5	4633143.6	6.3	7.3	5.9
8011	Malvern, England	3920162.5	-134776.4	5012767.8	9.6	14.9	7.7
8015	Haute Provence, Fr.	4578327.6	457960.1	4403226.7	4.9	7.5	4.9
8019	Nice, France	4579468.4	586590.9	4386452.4	4.7	7.0	4.6
8030	Meudon, France	4205633.6	163703.8	4776572.7	12.0	13.4	11.2
9001	Organ Pass, N.M.	-1535755.8	-5167010.8	3401063.1	4.6	3.1	3.3
9002	Pretoria, S. Africa	5056152.3	2716517.3	-2775698.0	10.7	25.6	41.9
9004	San Fernando, Spain	5105533.0	-555249.3	3769709.5	3.6	10.8	4.2
9005	Tokyo, Japan	-3946676.9	3366331.3	3698850.8	40.1	36.3	15.6
9006	Naini Tal, India	1018160.1	5471113.3	3109661.1	18.2	10.0	8.9
9007	Arequipa, Peru	1942759.2	-5804094.9	-1796887.1	3.7	4.2	8.8
9008	Shiraz, Iran	3376879.6	4403978.9	3136293.5	8.8	8.7	8.0
9009	Curacao, Antilles	2251808.4	-5816925.7	1327195.1	3.3	2.9	4.1
9010	Jupiter, Fla.	976271.3	-5601408.1	2880264.3	2.7	1.9	2.8
9011	Villa Dolores, Arg.	2280578.1	-4914575.5	-3355384.4	4.1	7.3	13.6
9012	Maui, Hawaii	-5466085.8	-2404265.0	2242180.0	3.3	4.6	5.5
9021	Mt. Hopkins, Ariz.	-1936846.4	-5077676.3	3331962.4	23.0	16.2	11.9
9028	Addis Ababa, Ethiopia	4903733.1	3965196.4	963921.6	7.4	8.7	13.8
9029	Natal, Brazil	5186470.6	-3653872.6	-654316.6	12.1	15.7	30.6
9031	Comodoro Rivadavia, Arg.	1693787.4	-4112338.2	-4556657.5	9.6	12.7	17.3
9051	Athens, Greece	4606873.2	2029713.1	3903605.4	6.9	18.2	6.9
9091	Dionysos, Greece	4595146.4	2039429.7	3912690.8	4.9	10.5	4.3

Number	Station	Adjusted Coordinates			Std. Deviations		
		X	Y	Z	σ_x	σ_y	σ_z
9424	Cold Lake, Canada	-1264833.9	-3466895.7	5185470.7	5.3	6.5	6.0
9425	Rosamund, Cal.	-2450015.8	-4624431.3	3635047.1	4.1	3.9	5.3
9426	Harestua, Norway	3121266.9	592626.2	5512755.3	9.9	9.6	6.6
9427	Johnston Island, Pac.	-6007455.1	-1111783.5	1825717.5	10.1	22.1	10.3
9431	Riga, Latvia	3183899.5	1421444.1	5322835.5	14.0	8.6	8.0
9432	Uzghorod, USSR	3907422.3	1602398.4	4763955.5	9.0	9.7	6.2



OBSERVED > 20 TIMES
OBSERVED > 20 TIMES
BAKER NUNN STATION
C-BAND STATION
NUMBER OF OBSERVATIONS THIS LINE
SCALE ON EQUATOR
MERCATOR PROJECTION
EAST LONGITUDE
WEST LONGITUDE



TO 9008
TO 9008
TO 9008
9074
9077
9115
9051
8019
8030
9004
Scale of Miles

APPENDIX 2

TRANSFORMATION PARAMETERS: MPS7-GSFC (Global)

Scale Factor and Rotation Parameters Constrained to Independently Determined Values (Section 5).

ΔX METERS	ΔY METERS	ΔZ METERS	ϵ (10.D+5)	θ_Z SECONDS	θ_Y SECONDS	θ_X SECONDS
-10.06	5.25	33.55	0.62	0.48	0.30	-0.40

VARIANCE – COVARIANCE MATRIX

0.144D+02	-0.638D+00	0.359D+00	-0.214D-06	0.405D-06	0.216D-06	-0.216D-07
-0.638D+00	0.180D+02	-0.176D+00	0.481D-06	0.429D-07	-0.432D-07	-0.264D-06
0.359D+00	-0.176D+00	0.196D+02	-0.291D-06	0.522D-07	-0.200D-06	-0.568D-06
-0.214D-06	0.481D-06	-0.291D-06	0.154D-12	-0.362D-14	-0.195D-14	0.690D-15
0.405D-06	0.429D-07	0.522D-07	-0.362D-14	0.124D-12	0.900D-14	-0.163D-13
0.216D-06	-0.432D-07	-0.200D-06	-0.195D-14	0.900D-14	0.154D-12	0.253D-13
-0.216D-07	-0.264D-06	-0.568D-06	0.690D-15	-0.163D-13	0.253D-13	0.172D-12

COEFFICIENTS OF CORRELATION

0.100D+01	-0.396D-01	0.214D-01	-0.154D+00	0.303D+00	0.145D+00	-0.137D-01
-0.396D-01	0.100D+01	-0.933D-02	0.310D+00	0.287D-01	-0.260D-01	-0.150D+00
0.214D-01	-0.933D-02	0.100D+01	-0.180D+00	0.335D-01	-0.115D+00	-0.309D+00
-0.154D+00	0.310D+00	-0.180D+00	0.100D+01	-0.281D-01	-0.136D-01	0.454D-02
0.303D+00	0.287D-01	0.335D-01	-0.281D-01	0.100D+01	0.652D-01	-0.111D+00
0.145D+00	-0.260D-01	-0.115D+00	-0.136D-01	0.652D-01	0.100D+01	0.155D+00
-0.137D-01	-0.150D+00	-0.309D+00	0.454D-02	-0.111D+00	0.155D+00	0.100D+01

TRANSFORMATION PARAMETERS: MPS7-SAO (Global)

Scale Factor and Rotation Parameters Constrained to Independently Determined Values (Section 5).

ΔX METERS	ΔY METERS	ΔZ METERS	ϵ (10.D+5)	θ_Z SECONDS	θ_Y SECONDS	θ_X SECONDS
-4.32	0.51	25.41	1.11	0.30	0.53	-0.14

VARIANCE - COVARIANCE MATRIX

0.821D+01	-0.194D+00	0.114D-01	-0.716D-07	0.133D-06	0.143D-06	0.156D-07
-0.194D+00	0.954D+01	-0.147D+00	0.173D-06	0.308D-07	-0.239D-07	-0.122D-06
0.114D-01	-0.147D+00	0.892D+01	-0.143D-06	0.532D-08	-0.891D-07	-0.149D-06
-0.716D-07	0.173D-06	-0.143D-06	0.528D-13	-0.762D-15	-0.440D-15	0.170D-15
0.133D-06	0.308D-07	0.532D-08	-0.762D-15	0.462D-13	0.508D-14	-0.345D-14
0.143D-06	-0.239D-07	-0.891D-07	-0.440D-15	0.508D-14	0.611D-13	0.118D-13
0.156D-07	-0.122D-06	-0.149D-06	0.170D-15	-0.345D-14	0.118D-13	0.560D-13

COEFFICIENTS OF CORRELATION

0.100D+01	-0.220D-01	0.134D-02	-0.109D+00	0.216D+00	0.202D+00	0.230D-01
-0.220D-01	0.100D+01	-0.160D-01	0.243D+00	0.465D-01	-0.313D-01	-0.167D+00
0.134D-02	-0.160D-01	0.100D+01	-0.208D+00	0.829D-02	-0.121D+00	-0.210D+00
-0.109D+00	0.243D+00	-0.208D+00	0.100D+01	-0.154D-01	-0.774D-02	0.313D-02
0.216D+00	0.465D-01	0.829D-02	-0.154D-01	0.100D+01	0.956D-01	-0.677D-01
0.202D+00	-0.313D-01	-0.121D+00	-0.774D-02	0.956D-01	0.100D+01	0.201D+00
0.230D-01	-0.167D+00	-0.210D+00	0.313D-02	-0.677D-01	0.201D+00	0.100D+01

TRANSFORMATION PARAMETERS: MPS7-GSFC (European)

Scale Factor and Rotation Parameters Constrained to Independently Determined Values (Section 5).

ΔX METERS	ΔY METERS	ΔZ METERS	ϵ (10.D+5)	θ_Z SECONDS	θ_Y SECONDS	θ_X SECONDS
-34.19	-50.06	135.64	-7.64	-1.60	-3.34	0.05

VARIANCE - COVARIANCE MATRIX

0.603D+02	0.115D+02	-0.243D+02	-0.375D-05	0.663D-07	0.896D-05	-0.189D-05
0.115D+02	0.610D+02	-0.144D+02	-0.505D-06	0.586D-05	0.285D-05	-0.622D-05
-0.243D+02	-0.144D+02	0.663D+02	-0.383D-05	-0.978D-06	-0.980D-05	0.281D-05
-0.375D-05	-0.505D-06	-0.383D-05	0.845D-12	0.179D-13	0.229D-13	-0.214D-14
0.663D-07	0.586D-05	-0.978D-06	0.179D-13	0.113D-11	0.171D-12	-0.227D-12
0.896D-05	0.285D-05	-0.980D-05	0.229D-13	0.171D-12	0.213D-11	-0.468D-12
-0.189D-05	-0.622D-05	0.281D-05	-0.214D-14	-0.227D-12	-0.468D-12	0.115D-11

COEFFICIENTS OF CORRELATION

0.100D+01	0.190D+00	-0.384D+00	-0.525D+00	0.802D-02	0.791D+00	-0.227D+00
0.190D+00	0.100D+01	-0.226D+00	-0.704D-01	0.765D+00	0.250D+00	-0.742D+00
-0.384D+00	-0.226D+00	0.100D+01	-0.511D+00	-0.113D+00	-0.825D+00	0.322D+00
-0.525D+00	-0.704D-01	-0.511D+00	0.100D+01	0.182D-01	0.171D-01	-0.217D-02
0.802D-02	0.765D+00	-0.113D+00	0.182D-01	0.100D+01	0.110D+00	-0.199D+00
0.791D+00	0.250D+00	-0.825D+00	0.171D-01	0.110D+00	0.100D+01	-0.299D+00
-0.227D+00	-0.742D+00	0.322D+00	-0.217D-02	-0.199D+00	-0.299D+00	0.100D+01

TRANSFORMATION PARAMETERS: MPS7-SAO (European)

Scale Factor and Rotation Parameters Constrained to Independently Determined Values (Section 5).

ΔX METERS	ΔY METERS	ΔZ METERS	ϵ (10.D+5)	θ_Z SECONDS	θ_Y SECONDS	θ_X SECONDS
-50.67	34.78	15.58	8.91	1.20	-0.33	-0.98

VARIANCE - COVARIANCE MATRIX

0.654D+02	0.499D+02	-0.363D+02	-0.325D-05	0.448D-05	0.110D-04	-0.631D-05
0.499D+02	0.142D+03	-0.564D+02	-0.429D-06	0.143D-04	0.119D-04	-0.163D-04
-0.363D+02	-0.564D+02	0.736D+02	-0.325D-05	-0.571D-05	-0.120D-04	0.733D-05
-0.325D-05	-0.429D-06	-0.325D-05	0.725D-12	0.198D-13	0.463D-14	0.265D-13
0.448D-05	0.143D-04	-0.571D-05	0.198D-13	0.213D-11	0.118D-11	-0.114D-11
0.110D-04	0.119D-04	-0.120D-04	0.463D-14	0.118D-11	0.258D-11	-0.148D-11
-0.631D-05	-0.163D-04	0.733D-05	0.265D-13	-0.114D-11	-0.148D-11	0.247D-11

COEFFICIENTS OF CORRELATION

0.100D+01	0.517D+00	-0.523D+00	-0.472D+00	0.380D+00	0.845D+00	-0.497D+00
0.517D+00	0.100D+01	-0.551D+00	-0.422D-01	0.824D+00	0.619D+00	-0.867D+00
-0.523D+00	-0.551D+00	0.100D+01	-0.445D+00	-0.457D+00	-0.868D+00	0.544D+00
-0.472D+00	-0.422D-01	-0.445D+00	0.100D+01	0.159D-01	0.339D-02	0.198D-01
0.380D+00	0.824D+00	-0.457D+00	0.159D-01	0.100D+01	0.503D+00	-0.500D+00
0.845D+00	0.619D+00	-0.868D+00	0.339D-02	0.503D+00	0.100D+01	-0.588D+00
-0.497D+00	-0.867D+00	0.544D+00	0.198D-01	-0.500D+00	-0.588D+00	0.100D+01

TRANSFORMATION PARAMETERS: MPS7-ED50 (European)

Scale Factor and Rotation Parameters Constrained to Independently Determined Values (Section 5).

ΔX METERS	ΔY METERS	ΔZ METERS	ϵ (10.D+5)	θ_Z SECONDS	θ_Y SECONDS	θ_X SECONDS
-112.60	-165.52	-90.27	3.29	-0.66	-0.53	0.55

VARIANCE - COVARIANCE MATRIX

0.556D+02	-0.444D+00	-0.137D+02	-0.280D-05	-0.281D-05	0.598D-05	-0.151D-05
-0.444D+00	0.382D+02	0.390D+01	-0.107D-05	0.258D-05	-0.427D-06	-0.188D-05
-0.137D+02	0.390D+01	0.510D+02	-0.283D-05	0.199D-05	-0.561D-05	0.200D-05
-0.280D-05	-0.107D-05	-0.283D-05	0.662D-12	-0.580D-14	-0.564D-14	0.417D-14
-0.281D-05	0.258D-05	0.199D-05	-0.580D-14	0.763D-12	-0.459D-12	0.104D-12
0.598D-05	-0.427D-06	-0.561D-05	-0.564D-14	-0.459D-12	0.131D-11	-0.329D-12
-0.151D-05	-0.188D-05	0.200D-05	0.417D-14	0.104D-12	-0.329D-12	0.549D-12

COEFFICIENTS OF CORRELATION

0.100D+01	-0.964D-02	-0.257D+00	-0.462D+00	-0.431D+00	0.702D+00	-0.272D+00
-0.964D-02	0.100D+01	0.885D-01	-0.212D+00	0.477D+00	-0.605D-01	-0.411D+00
-0.257D+00	0.885D-01	0.100D+01	-0.487D+00	0.319D+00	-0.687D+00	0.377D+00
-0.462D+00	-0.212D+00	-0.487D+00	0.100D+01	-0.817D-02	-0.606D-02	0.691D-02
-0.431D+00	0.477D+00	0.319D+00	-0.817D-02	0.100D+01	-0.460D+00	0.161D+00
0.702D+00	-0.605D-01	-0.687D+00	-0.606D-02	-0.460D+00	0.100D+01	-0.389D+00
-0.272D+00	-0.411D+00	0.377D+00	0.691D-02	0.161D+00	-0.389D+00	0.100D+01

TRANSFORMATION PARAMETERS: MPS7-NAD (North America)

Scale Factor and Rotation Parameters Constrained to Independently Determined Values (Section 5).

ΔX METERS	ΔY METERS	ΔZ METERS	ϵ (10.D+5)	θ_Z SECONDS	θ_Y SECONDS	θ_X SECONDS
−45.37	150.08	223.33	−1.00	−0.60	0.48	−0.75

VARIANCE – COVARIANCE MATRIX

0.124D+02	0.240D+01	0.416D+01	−0.128D−06	0.110D−05	0.602D−06	−0.766D−06
0.240D+01	0.140D+02	0.642D+00	0.131D−05	0.479D−06	0.164D−06	−0.106D−05
0.416D+01	0.642D+00	0.136D+02	−0.923D−06	0.603D−06	0.189D−06	−0.152D−05
−0.128D−06	0.131D−05	−0.923D−06	0.256D−12	−0.167D−14	−0.113D−15	0.152D−14
0.110D−05	0.479D−06	0.603D−06	−0.167D−14	0.191D−12	0.353D−13	−0.120D−12
0.602D−06	0.164D−06	0.189D−06	−0.113D−15	0.353D−13	0.122D−12	−0.444D−13
−0.766D−06	−0.106D−05	−0.152D−05	0.152D−14	−0.120D−12	−0.444D−13	0.302D−12

COEFFICIENTS OF CORRELATION

0.100D+01	0.182D+00	0.320D+00	−0.720D−01	0.713D+00	0.490D+00	−0.396D+00
0.182D+00	0.100D+01	0.465D−01	0.693D+00	0.293D+00	0.126D+00	−0.517D+00
0.320D+00	0.465D−01	0.100D+01	−0.493D+00	0.373D+00	0.147D+00	−0.749D+00
−0.720D−01	0.693D+00	−0.493D+00	0.100D+01	−0.754D−02	−0.639D−03	0.545D−02
0.713D+00	0.293D+00	0.373D+00	−0.754D−02	0.100D+01	0.232D+00	−0.499D+00
0.490D+00	0.126D+00	0.147D+00	−0.639D−03	0.232D+00	0.100D+01	−0.232D+00
−0.396D+00	−0.517D+00	−0.749D+00	0.545D−02	−0.499D+00	−0.232D+00	0.100D+01

TRANSFORMATION PARAMETERS: MPS7-GSFC (North America)

Scale Factor and Rotation Parameters Constrained to Independently Determined Values (Section 5).

ΔX METERS	ΔY METERS	ΔZ METERS	ϵ (10.D+5)	θ_Z SECONDS	θ_Y SECONDS	θ_X SECONDS
3.25	-33.45	38.30	-2.85	0.51	0.27	-0.12

VARIANCE - COVARIANCE MATRIX

0.121D+02	0.245D+01	0.404D+01	-0.547D-07	0.124D-05	0.815D-06	-0.761D-06
0.245D+01	0.158D+02	0.609D+01	0.117D-05	0.405D-06	0.180D-06	-0.199D-05
0.404D+01	0.609D+01	0.211D+02	-0.785D-06	0.575D-06	0.265D-06	-0.298D-05
-0.547D-07	0.117D-05	-0.785D-06	0.226D-12	-0.600D-15	-0.889D-15	0.341D-16
0.124D-05	0.405D-06	0.575D-06	-0.600D-15	0.216D-12	0.381D-13	-0.113D-12
0.815D-06	0.180D-06	0.265D-06	-0.889D-15	0.381D-13	0.179D-12	-0.530D-13
-0.761D-06	-0.199D-05	-0.298D-05	0.341D-16	-0.113D-12	-0.530D-13	0.583D-12

COEFFICIENTS OF CORRELATION

0.100D+01	0.177D+00	0.253D+00	-0.331D-01	0.768D+00	0.554D+00	-0.287D+00
0.177D+00	0.100D+01	0.334D+00	0.617D+00	0.219D+00	0.107D+00	-0.655D+00
0.253D+00	0.334D+00	0.100D+01	-0.360D+00	0.269D+00	0.136D+00	-0.848D+00
-0.331D-01	0.617D+00	-0.360D+00	0.100D+01	-0.272D-02	-0.442D-02	0.941D-04
0.768D+00	0.219D+00	0.269D+00	-0.272D-02	0.100D+01	0.194D+00	-0.317D+00
0.554D+00	0.107D+00	0.136D+00	-0.442D-02	0.194D+00	0.100D+01	-0.164D+00
-0.287D+00	-0.655D+00	-0.848D+00	0.941D-04	-0.317D+00	-0.164D+00	0.100D+01

TRANSFORMATION PARAMETERS: MPS7-SAO (North America)

Scale Factor and Rotation Parameters Constrained to Independently Determined Values (Section 5).

ΔX METERS	ΔY METERS	ΔZ METERS	ϵ (10.D+5)	θ_Z SECONDS	θ_Y SECONDS	θ_X SECONDS
-8.21	-49.56	40.14	-6.65	0.10	0.06	0.21

VARIANCE - COVARIANCE MATRIX

0.140D+02	0.313D+01	0.483D+01	-0.787D-07	0.140D-05	0.952D-06	-0.929D-06
0.313D+01	0.156D+02	0.427D+01	0.129D-05	0.524D-06	0.249D-06	-0.174D-05
0.483D+01	0.427D+01	0.191D+02	-0.871D-06	0.679D-06	0.321D-06	-0.251D-05
-0.787D-07	0.129D-05	-0.871D-06	0.251D-12	-0.947D-16	-0.253D-15	-0.129D-14
0.140D-05	0.524D-06	0.679D-06	-0.947D-16	0.240D-12	0.527D-13	-0.135D-12
0.952D-06	0.249D-06	0.321D-06	-0.253D-15	0.527D-13	0.197D-12	-0.695D-13
-0.929D-06	-0.174D-05	-0.251D-05	-0.129D-14	-0.135D-12	-0.695D-13	0.497D-12

COEFFICIENTS OF CORRELATION

0.100D+01	0.212D+00	0.296D+00	-0.420D-01	0.765D+00	0.574D+00	-0.352D+00
0.212D+00	0.100D+01	0.247D+00	0.652D+00	0.270D+00	0.142D+00	-0.624D+00
0.296D+00	0.247D+00	0.100D+01	-0.399D+00	0.317D+00	0.166D+00	-0.815D+00
-0.420D-01	0.652D+00	-0.399D+00	0.100D+01	-0.386D-03	-0.114D-02	-0.366D-02
0.765D+00	0.270D+00	0.317D+00	-0.386D-03	0.100D+01	0.242D+00	-0.392D+00
0.574D+00	0.142D+00	0.166D+00	-0.114D-02	0.242D+00	0.100D+01	-0.222D+00
-0.352D+00	-0.624D+00	-0.815D+00	-0.366D-02	-0.392D+00	-0.222D+00	0.100D+01