X-553-71-427

PREPRINT

NASA TM X- 65855

THE RELATION OF THE EUROPEAN DATUM TO A GEOCENTRIC REFERENCE SYSTEM

J. G. MARSH
B. C. DOUGLAS
S. M. KLOSKO

OCTOBER 1971

GSFC
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

23p.

X-553-71-427

THE RELATION OF THE EUROPEAN DATUM TO A GEOCENTRIC REFERENCE SYSTEM

by

J. G. Marsh

Geodynamics Branch
Trajectory Analysis and Geodynamics Division
Goddard Space Flight Center
Greenbelt, Maryland

B. C. Douglas

S. M. Klosko

Wolf Research and Development Corporation
Riverdale, Maryland 20840

Presented at the International Union of Geodesy and Geophysics Meeting
in Moscow, U.S.S.R., August 1971

PRECEDING PAGE BLANK NOT FILMED

A RELATION OF THE EUROPEAN DATUM TO A GEOCENTRIC REFERENCE SYSTEM

J. G. Marsh
B. C. Douglas
S. M. Klosko

ABSTRACT

Over 31,000 precision reduced optical observations of GEOS-I and II in 70 two-day orbital arcs have been used at Goddard Space Flight Center (GSFC) in a dynamical solution to determine center-of-mass coordinates for 15 tracking stations on the European Datum. Comparisons with the results obtained at Centre National d'Etudes Spatiales (CNES) give agreement of about 1.5 ppm for chord lengths. After considering a scale correction to the European Datum (ED) of 1950 to account for the absence of geoid heights at the time of its reduction, agreement to a few ppm between the CNES/GSFC and the ED chords is obtained. However, a small systematic difference between survey and satellite results remains for stations in south-eastern France and Switzerland.

PRECEDING PAGE BLANK NOT FILMED

CONTENTS

TABLES

ILLUSTRATIONS

THE RELATION OF THE EUROPEAN DATUM TO A GEOCENTRIC REFERENCE SYSTEM

INTRODUCTION

Prior to the work presented here, two investigations of geodetic parameters on the European Datum using optical flash data had been published. Gaposchkin and Lambeck (1970) at the Smithsonian Astrophysical Observatory (SAO) performed what was essentially a geometric solution for optical stations and two French lasers in Europe having first dynamically estimated certain Baker-Nunn camera positions in the area. Lambeck (1971) later used these results to determine the orientation and scale of the European Datum with respect to the global center-of-mass system. At Centre National d'Etudes Spatiales (CNES) in France, Cazenave and her associates (1971) used purely geometric techniques with optical and laser data to recover the chord distances between San Fernando, Spain and eight other sites in Europe. By comparing their chord lengths with those of the surveys, CNES determined a scale parameter for the European Datum. The scale recovered by CNES differs from that of Lambeck (1971) by 20×10^{-6}. The results described here agree with those of CNES to better than 1.5×10^{-6}.

In our work, the center-of-mass coordinates of the European optical sites have been estimated dynamically. In contrast, the French sought relative station positions, while Lambeck's use of center-of-mass Baker-Nunn positions held constrained in his geometric recovery permitted the entire European Datum to be estimated in the geocentric system. The present solution used a total of 70 two-day arcs of GEOS-I and II optical data in a simultaneous dynamical solution for the station coordinates.

All of the European stations except Malvern and Winkfield, England were allowed to adjust independently in our dynamical solution. Due to their proximity and the small amount of Malvern data available, Malvern and Winkfield were constrained to adjust in parallel. The arc length of two days gives enough data (an average of 480 observations/arc) for the dynamical determination of the satellite orbit without gravity model errors becoming excessive. The arcs were selected to optimize the tracking geometry, with those stations tracking both GEOS-I and II having data on all sides of the station and in opposing directions. This gave a beneficial cancelling of model error effects. For the stations which tracked GEOS-II alone, this requirement could not be met because of satellite viewing conditions. Three conditions helped reduce the effect of model errors for these GEOS-II stations. First, the strong presence of the well-determined GEOS-I and GEOS-II stations at San Fernando, Haute Provence, Winkfield, Malvern, Naini Tal, and Addis Ababa in the solutions kept the orbital error small over Europe. Second, the arcs were selected so that the well-determined stations in the Republic of South Africa (1JOBUR and 1OLFAN) and Madagascar (1TANAN) were tracking on the same satellite revolution as that of the European optical stations. This selection of arcs containing South African optical data helped to reduce the satellite position error over Europe. As important as either of these steps is that the GEOS-II stations had large amounts of data simultaneous with other stations for which good coverage existed.

Table 1 presents the number of observations in our final solution for the European stations which are shown in Figure 1. In addition, about 25,000 observations from a world-wide network of stations (held fixed) (Marsh, Douglas and Klosko, 1971) were used in the two day arcs. The values obtained in this solution are presented in Table 2. Their corresponding survey positions on the European Datum are presented in Table 3.

EVALUATION OF THE RESULTS

Table 4 presents the translation, scale, orientation parameters and correlation coefficients relating our dynamical positions to those on the uncorrected* European Datum. Table 5 presents a list of the stations used with associated residuals for this solution. As readily seen in Table 4, all of the rotation parameters are very highly correlated with the translation parameters. The 5.2 x 10^{-6} value for the scale for the uncorrected datum obtained by GSFC agrees very well with the CNES value, the difference of approximately 2.5 x 10^{-6} being primarily due to the Riga and Greece chords (Table 6). These results are in disagreement with the scale value of -12.4 x 10^{-6} obtained by Lambeck from the SAO solution. Comparison by Vincent, Strange, and Marsh (1971) of SAO station heights with the SAO (1969) Standard Earth geoid indicated a systematic height difference of about 20 meters for the European stations. This difference and the scale result may be related.

Table 6 compares the chord lengths obtained from the GSFC dynamical solution with the geometric solutions of SAO and CNES. The agreement between GSFC and CNES is very good, 6 of 8 chords agreeing to better than 3.5m. This result is especially significant because of the very different estimation techniques employed by CNES and ourselves. The disagreement of the chords to Riga, Latvia, and Dionysos, Greece deserves mention. In the case of Riga, Latvia, the same local survey was used by GSFC and CNES, but the accuracy of the survey was not available. Therefore, the survey value cannot be used to resolve the GSFC-CNES disagreement. The disagreement at Dionysos, Greece is probably caused by Greece being on the periphery of the geometric net and therefore

*Uncorrected for scale introduced by absence of geoid height information (Bomford 1971).

being constrained in only limited directions in the CNES solution; i.e., a majority of the usable data is on one side of the station. However, the mean agreement between the CNES and GSFC results, including these two questionable sites, is still only five meters.

Due to scarcity of data, the GSFC solutions for Oslo (Norway), Naini Tal (India) and Meudon (France) are weaker than the others. The GSFC solution in particular, differs by about 40 m in the Z component from the Naini Tal solution given by SAO. Further investigation is required to resolve this discrepancy. Delft (Netherlands) also had limited data in our solutions, but the geometry is excellent and the data is simultaneous with other European stations. The uncertainties in the ties to the European Datum for Riga, Latvia and Addis Ababa, Ethiopia, are reflected in the results. These sites are believed to have strong dynamical solutions.

According to Bomford (1971), the European Datum contains a systematic scale error due to the unavailability of the geoid heights throughout this system at the time of its reduction in 1950. When the baseline distances were reduced to the International Ellipsoid, the geoidal height variation in Europe from Potsdam was of necessity omitted. With more recent work on the European continent and the availability of geoid heights, distances in Europe should be corrected by +1 ppm for every +6.4 m by which the geoid is actually above the spheroid. When the GSFC and CNES chords from San Fernando are compared with survey chords corrected in this manner, the large discrepancy between satellite and surveyed distances is reduced. These corrected values are shown in Table 6.

As seen in Table 6, the chord lengths to San Fernando obtained from the SAO Standard Earth (Gaposchkin and Lambeck, 1970) are in disagreement with those obtained by CNES and GSFC. The SAO chords are smaller than the surveys, the satellite-determined chords are larger for the GSFC and CNES solutions. While the correction indicated by Bomford removes much of the disagreement between CNES and GSFC chord lengths compared to those of the surveys, the SAO scale factor becomes further in disagreement. Therefore, no further comparisons are made in this text between SAO chords and those of the corrected surveys.

Table 7 presents a comparison of the differences between the chord lengths of GSFC with corrected and uncorrected ground surveys throughout the European Datum. Those chords which are clearly doubtful are shaded; DEZEIT (Addis Ababa, Ethiopia) and RIGALA (Riga, Latvia) are tied to the European Datum with uncertain accuracy. As shown in Table 7, surveyed chords corrected for scale as recommended by Bomford are in better agreement with the GSFC satellite solution. Table 8 presents a similar comparison for SAO considering only the uncorrected ground survey. Figure 2 presents a series of histograms of GSFC and SAO's chords compared with those of the European Datum, also showing GSFC compared with the corrected surveyed chords. The GSFC chords agree with the corrected ED chord lengths to better than 10 meters in 44 of 66 cases. This is consistent with our accuracy estimates for our satellite solutions which indicated that our recovered station locations are normally accurate from between 2 to 7 meters in each coordinate.

Concerning Shiraz, Iran, and Naini Tal, India, according to Bomford (1971) these sites were tied to the European Datum in the middle 1960's with geoid height information available. Therefore, chords to these two sites require no additional scale correction related to geoid height.

Figures 3, 4 and 5 present the shifts in the rectangular coordinates for the dynamically recovered stations from the uncorrected European Datum to the geocentric system. Note that the Baker-Nunn camera position at San Fernando, Spain, is systematically different in ΔX from those sites nearest to it. We further note that the station positions located in southeastern France and Switzerland seem somewhat inconsistent in ΔX, with systematic differences of about 10 m apparent. This systematic variation in ΔX in central Western Europe is not explained by the geoid height offset in the area. Due to a scarcity of station positions, this result is not conclusively demonstrated throughout Europe along this parallel.

CONCLUSIONS

This paper demonstrates that satellite geodesy can approach the level of accuracy long associated with classical surveying techniques. Other investigators in the past have used satellite data to connect isolated tracking stations with major geodetic systems, but this is believed to be the first time that satellite solutions have successfully been used to detect systematic errors within a major geodetic datum. Dynamic satellite techniques provide the advantage that large surface areas can be adjusted simultaneously with an accuracy almost independent of distances between stations. Previous solutions by CNES and SAO did not consider a scale correction to the survey chords due to the absence of geoid height information at the time of the reduction of the European Datum in 1950. Agreement of the GSFC and CNES solutions with the survey improved significantly when this correction was added. A systematic difference remains for stations in southeastern France and Switzerland. Comparisons of GSFC's results with those of CNES give general agreement of 1.5 ppm or better for chord lengths and suggests that the previously published SAO solution, which differs by 20 ppm in scale from the French results, contains systematic errors. When surveyed lengths are corrected as suggested by Bomford, the GSFC solution agrees with surveyed distances to a few ppm.

ACKNOWLEDGEMENT

We would like to thank Jan Rolff, the Executive Director of the Central Bureau of Satellite Geodesy for his most valuable cooperation and assistance in supplying us with information concerning the preprocessing of the International optical data. In addition, we would especially like to thank Brigadier G. Bomford for his enlightening comments on our work.

REFERENCES

1. Bomford, Brigader G., private communication, 1971.

2. Cazenave, A., Dargnies, O., Balmino, G., Lefebrve, M., "Geometrical Adjustment with Simultaneous Laser and Photographic Observations. (Results on the European Datum)," Paper Presented at the Third Symposium on the Uses of Artificial Satellites for Geodesy, Washington, D. C., 1971.

3. Gaposchkin, E. M., Lambeck, K., "1969 Smithsonian Standard Earth (II)," Smithsonian Astrophysical Observatory Special Report 315, May 1970.

4. Lambeck, K., "The Relation of Some Geodetic Datums to a Global Geocentric Reference System," Bulletin Geodesique 99, March 1971.

5. Marsh, J. G., Douglas, B. C., Klosko, S. M., "Satellite Derived Tracking Station Coordinates on a Unified World Datum," Paper Presented at the Third Symposium on the Uses of Artificial Satellites for Geodesy, Washington, D. C., 1971.

6. "NASA Directory of Tracking Station Locations," prepared by Computer Sciences Corporation for Data Evaluation Branch, Manned Flight Planning and Analysis Division, Goddard Space Flight Center, November 1970.

7. Vincent, S. F., Strange, W. E., Marsh, J. G., "A Comparison and Evaluation of Satellite Derived Positions of Tracking Stations," Goddard Space Flight Center Document X-553-71-257, June 1971.

Table 1

Number of Optical Observations per Station
Used in Dynamical Solution

LOCATION	CODE NAME	STATION NUMBER	OBSERVATIONS
Winkfield, England	1WNKFL	1035	611
Delft, Netherlands	DELFTH	8009 (9065)	144
Zimmerwald, Switzerland	ZIMWLD	8010 (9066)	481
Malvern, England	MALVRN	8011 (9080)	87*
Haute Provence, France	HAUTEP	8015	779
Nice, France	NICEFR	8019	999
Meudon, France	MUDONI	8030	203
San Fernando, Spain	1SPAIN	9004	1750
Naini Tal, India	1NATOL	9006	161
Shiraz, Iran	1SHRAZ	9008	41**
Addis Ababa, Ethiopia	DEZEIT	9028	337
Dionysos, Greece	GREECE	9091	1027
Oslo, Norway	OSLONR	9426	28**
Riga, Latvia	RIGALA	9431 (9074)	453
Uzhgorod, U.S.S.R.	UZHGOR	9432 (9077)	395

*1MALVRN was held constrained to 1WNKFL

**Only one right ascension and declination observation was precisely reduced for each pass of data from these stations in this time period.

Table 2-a

Estimated Station Coordinates (X, Y, Z)

Station		X (M)	Y (M)	Z (M)
Name	Number			
1WNKFL	1035	3983102	-48512	4964720
DELFTH	8009	3923391	299885	5002982
ZIMWLD	8010	4331307	567522	4633122
MALVRN	8011	3920151	-134739	5012737
HAUTEP	8015	4578335	457982	4403200
NICEFR •	8019	4579471	586614	4386422
MUDONI	8030	4205620	163727	4776555
1SPAIN	9004	5105586	-555238	3769681
1NATOL	9006	1018208	5471117	3109585
1SHRAZ	9008	3376880	4403985	3136261
DEZEIT	9028	4903769	3965210	963853
GREECE	9091	4595174	2039458	3912663
OSLONR	9426	3121268	592634	5512724
RIGALA	9431	3183873	1421477	5322789
UZHGOR	9432	3907419	1602436	4763906

Table 2-b

Estimated Station Coordinates (ϕ, λ, h)*

Station		Geodetic Latitude			East Longitude			Ellipsoid Height (Meters)
Name	Number	Deg	Mn	Second	Deg	Mn	Second	
1WNKFL	1035	51	26	46.40	359	18	7.93	90
DELFTH	8009	52	0	6.76	4	22	15.29	46
ZIMWLD	8010	46	52	37.18	7	27	53.35	933
MALVRN	8011	52	8	36.42	358	1	53.31	137
HAUTEP	8015	43	55	57.55	5	42	44.74	694
NICEFR	8019	43	43	33.05	7	17	58.58	405
MUDONI	8030	48	48	22.64	2	13	45.94	190
1SPAIN	9004	36	27	46.99	353	47	36.31	55
1NATOL	9006	29	21	33.31	79	27	27.07	1856
1SHRAZ	9008	29	38	13.80	52	31	11.25	1564
DEZEIT	9028	8	44	50.71	38	57	32.98	1901
GREECE	9091	38	4	44.39	23	55	58.43	490
OSLONR	9426	60	12	39.50	10	45	2.69	595
RIGALA	9431	56	56	55.32	24	3	32.17	-15
UZHGOR	9432	48	38	1.46	22	17	54.88	205

*a_e = 6378155 meter., f = 1/298.255

Table 3

Station Coordinates on the European Datum

Station		X (M)	Y (M)	Z (M)
Name	Number			
1WNKFL	1035	3983202.6	-48394.5	4964835.4
DELFTH	8009	3923486.0	300006.0	5003095.8
ZIMWLD	8010	4331390.6	567637.4	4633235.9
MALVRN	8011	3920250.8	-134624.4	5012852.2
HAUTEP	8015	4578413.0	458091.0	4403312.0
NICEFR	8019	4579554.2	586729.1	4386535.6
MUDONI	8030	4205717.7	163840.9	4776660.8
1SPAIN	9004	5105680.1	-555102.9	3769799.3
1NATOL	9006	1018274.4	5471244.5	3109773.8
1SHRAZ	9008	3376966.7	4404122.1	3136407.9
DEZEIT	9028	4903853.4	3965302.9	964020.8
GREECE	9091	4595251.4	2039577.4	3912795.2
OSLONR	9426	3121372.8	592748.1	5512837.5
RIGALA	9431	3183998.7	1421638.2	5322894.3
UZHGOR	9432	3907494.2	1602533.2	4764034.8

Table 4

Transformation Parameters Between the Uncorrected European Datum and the Geocentric Reference System

Delta X	Delta Y	Delta Z	Scale	Omega	Psi	Epsilon
-111.1 ±3.4 m	-111.5 ±3.2 m	-142.6 ±3.4 m	(5.2 ±0.4) x 10^{-6}	1.57" ±0.1"	0.19" ±0.13"	1.05" ±0.09"

	Correlation Coefficients					
	Epsilon	Psi	Omega	Delta L	Delta Z	Delta Y
Delta X	0.04	0.85	-0.20	-0.51	-0.45	-0.13
Delta Y	-0.76	-0.12	0.78	-0.06	0.09	
Delta Z	0.04	-0.84	0.13	-0.52		
Scale	0.00	0.00	0.00			
Omega	-0.22	-0.16				
Psi	0.03					

Table 5

Stations in Transformation Solution
with Their Associated Residuals

	Residual (meters)		
	X	Y	Z
Malvern, England	3.4	-2.2	3.3
Nice, France	-3.9	-5.9	-4.6
Zimmerwald, Switzerland	-4.7	-2.4	-3.7
Dionysos, Greece	1.8	3.3	3.4
Delft, Netherlands	2.0	6.7	-0.6
San Fernando, Spain	1.4	0.6	2.3
RMS of fit	3.1	4.1	3.3

Table 6

Comparison of Chord Distances from Station 9004 (San Fernando, Spain) on the Corrected and Uncorrected European Datum of 1950

STATION	NUMBER	CNES survey-sat(m)	CNES survey-sat (ppm)	CNES corrected (ppm)	GSFC survey-sat(m)	GSFC survey-sat (ppm)	GSFC corrected (ppm)	SAO survey-sat(m)	SAO survey-sat (ppm)	SAO corrected (ppm)	GSFC-CNES (m)	GSFC-SAO (m)	CNES agreement with GSFC (ppm)
HAUTEP	8015	-17.8	-13.6	-10.2	-15.9	-12.2	- 8.8	3.1	2.4	5.8	1.9	-19.0	1.5
NICEFR	8019	-15.5	-11.1	- 7.6	-13.6	- 9.7	- 6.2	3.4	2.4	5.9	1.9	-17.0	1.4
GREECE	9091	-25.0	- 9.4	- 6.1	-11.0	- 4.2	- 0.9	27.0	10.2	13.5	14.0	-38.0	5.3
DELFTH	8009	- 6.6	- 3.5	- 0.8	- 9.4	- 4.9	- 2.2	22.0	11.5	14.2	- 2.8	-31.4	•1.5
ZIMWLD	8010	-15.0	[illegible]	[illegible]	-13.9	- 8.6	- 5.9	8.9	5.5	8.2	1.1	-22.8	0.7
RIGALA	9431	-22.0	- 7.0	- 5.6	- 9.3	- 2.9	- 1.5	32.3	10.2	11.6	12.7	-41.6	4.0
UZHGOR	9432	-21.0	- 7.9	- 5.9	-17.9	- 6.7	- 4.7	22.0	8.3	10.3	3.1	-39.9	1.2
MALVRN	8011	-12.6	- 7.1	- 4.6	-10.1	- 5.7	- 3.2	18.9	10.7	13.2	2.5	-29.0	1.4

Table 7

Differences Between GSFC Satellite and Ground Survey Chord Lengths (Meters)

	ISPAIN	HAUTEP	NICEFR	ZIMWLD	MUDONI	DELFTH	MALVRN	OSLONR	GREECE	UZHGOR	ISHRAZ	INATOL	RIGALA
HAUTEP	-15.9												
NICEFR	-13.6	5.3											
ZIMWLD	-13.9	-3.2	-1.6										
MUDONI	-19.3	-17.7	-11.5	-7.6									
DELFTH	-9.4	-13.2	-10.2	-10.4	8.6								
MALVRN	-10.1	-13.4	-7.6	-7.1	3.5	7.2							
OSLONR	-17.9	-19.8	-17.3	-15.9	-1.6	-9.7	-3.7						
GREECE	-11.0	3.5	-1.6	-2.9	-9.5	-15.9	-8.1	-24.1					
UZHGOR	-17.9	-4.4	-5.7	-8.3	-12.2	-25.8	-18.1	-35.3	7.1				
ISHRAZ	1.2	12.6	9.1	10.0	8.5	1.9	11.2	0.1	6.8	22.7			
INATOL	3.2	5.4	4.2	3.3	5.3	-3.7	5.9	-6.2	4.3	8.2	13.7		
RIGALA	-9.4	-12.3	-16.9	-7.2	16.9	13.8	28.9	48.2	-63.2	-66.1	-46.0	-37.1	
DEZEIT	-61.8	-50.7	-54.1	-53.5	-60.1	-60.2	-53.2	-60.5	-44.1	-33.4	-11.0	36.0	-87.5

CORRECTED SURVEYED DISTANCES

	ISPAIN	HAUTEP	NICEFR	ZIMWLD	MUDONI	DELFTH	MALVRN	OSLONR	GREECE	UZHGOR	ISHRAZ
HAUTEP	-11.5										
NICEFR	-8.8	5.5									
ZIMWLD	-9.6	-2.9	-1.4								
MUDONI	-14.5	-16.9	-10.6	-7.2							
DELFTH	-4.2	-12.2	-9.7	-10.1	9.0						
MALVRN	-5.8	-12.0	-6.2	-6.3	4.1	7.4					
OSLONR	-12.9	-19.5	-17.7	-16.0	-1.4	-9.9	-4.0				
GREECE	-2.3	6.1	0.4	-1.3	-7.2	-15.1	-5.8	-24.7			
UZHGOR	-12.6	-4.1	-5.2	-8.5	-12.2	-26.2	-18.2	-35.5	7.0		
ISHRAZ	1.2	12.6	9.1	10.0	8.5	1.9	11.2	0.1	6.8	22.7	
INATOL	3.2	5.4	4.2	3.3	5.3	-3.7	5.9	-6.2	4.3	8.2	13.7

Table 8

Differences Between SAO Satellite and Ground Survey Chord Lengths (Meters)

	ISPAIN	HAUTEP	NICEFR	ZIMWLD	DELFTH	MALVRN	OSLONR	GREECE	UZHGOR	ISHRAZ	INATOL	RIGALA
HAUTEP	3.1											
NICEFR	3.5	5.8										
ZIMWLD	8.9	8.0	15.6									
DELFTH	22.0	19.3	26.2	8.8								
MALVRN	18.9	20.7	28.6	12.5	10.7							
OSLONR	-5.9	-5.5	1.7	-13.1	-27.2	-21.7						
GREECE	27.0	22.7	15.8	27.0	31.8	39.4	21.8					
UZHGOR	22.0	18.1	17.8	15.5	13.0	22.7	6.4	18.1				
ISHRAZ	22.6	15.1	9.7	17.0	17.2	25.3	22.3	0.1	1.6			
INATOL	23.4	17.2	13.9	17.8	16.2	23.2	32.2	8.0	2.6	0.2		
RIGALA	32.3	18.3	17.0	15.5	35.0	54.1	86.2	-28.8	43.1	-57.8	-39.9	
DEZEIT	-28.8	-26.3	-33.8	-16.7	-8.2	-5.4	-8.1	-29.8	-14.8	31.4	40.1	-62.0

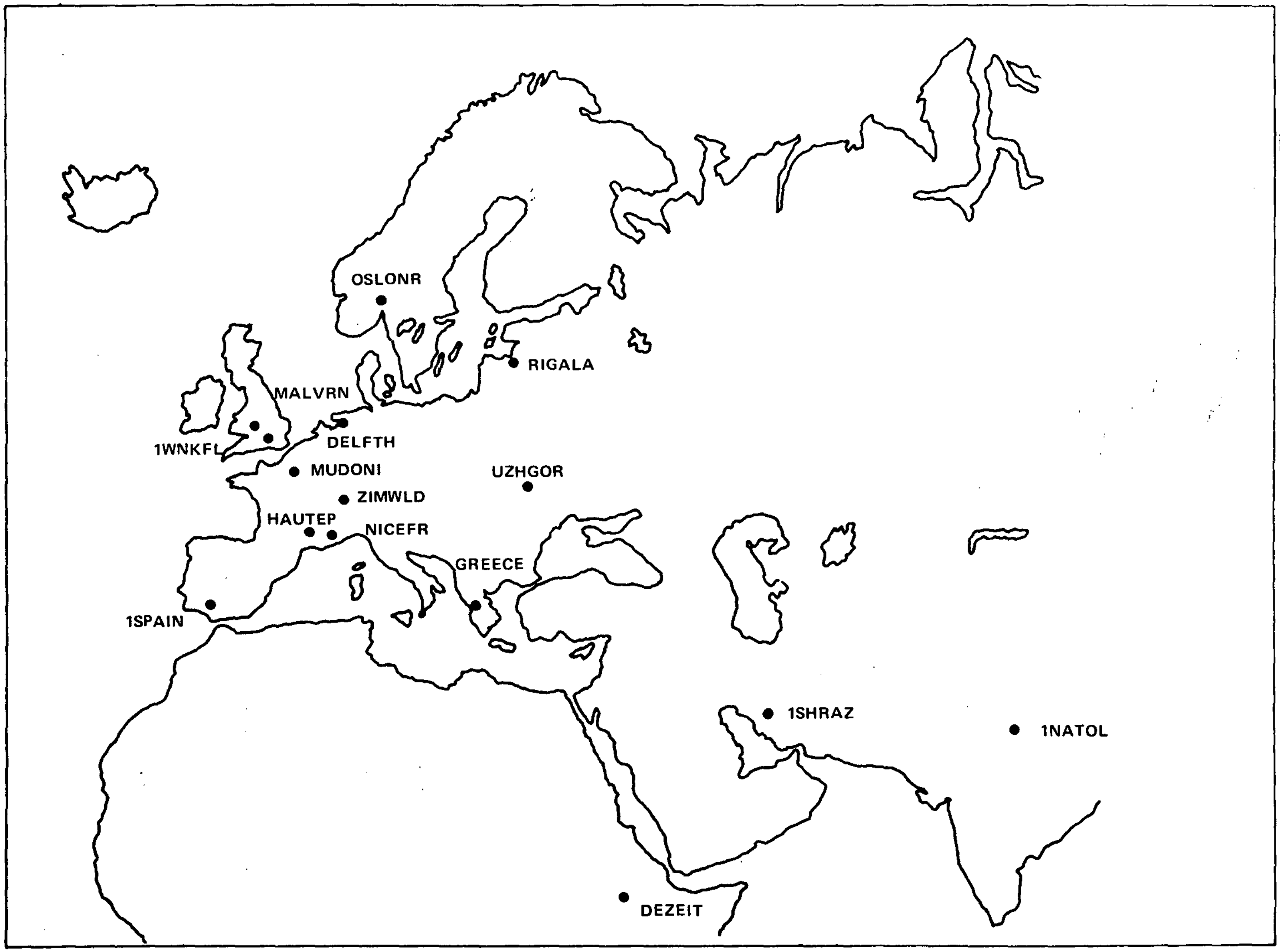

Figure 1. Stations on the European Datum

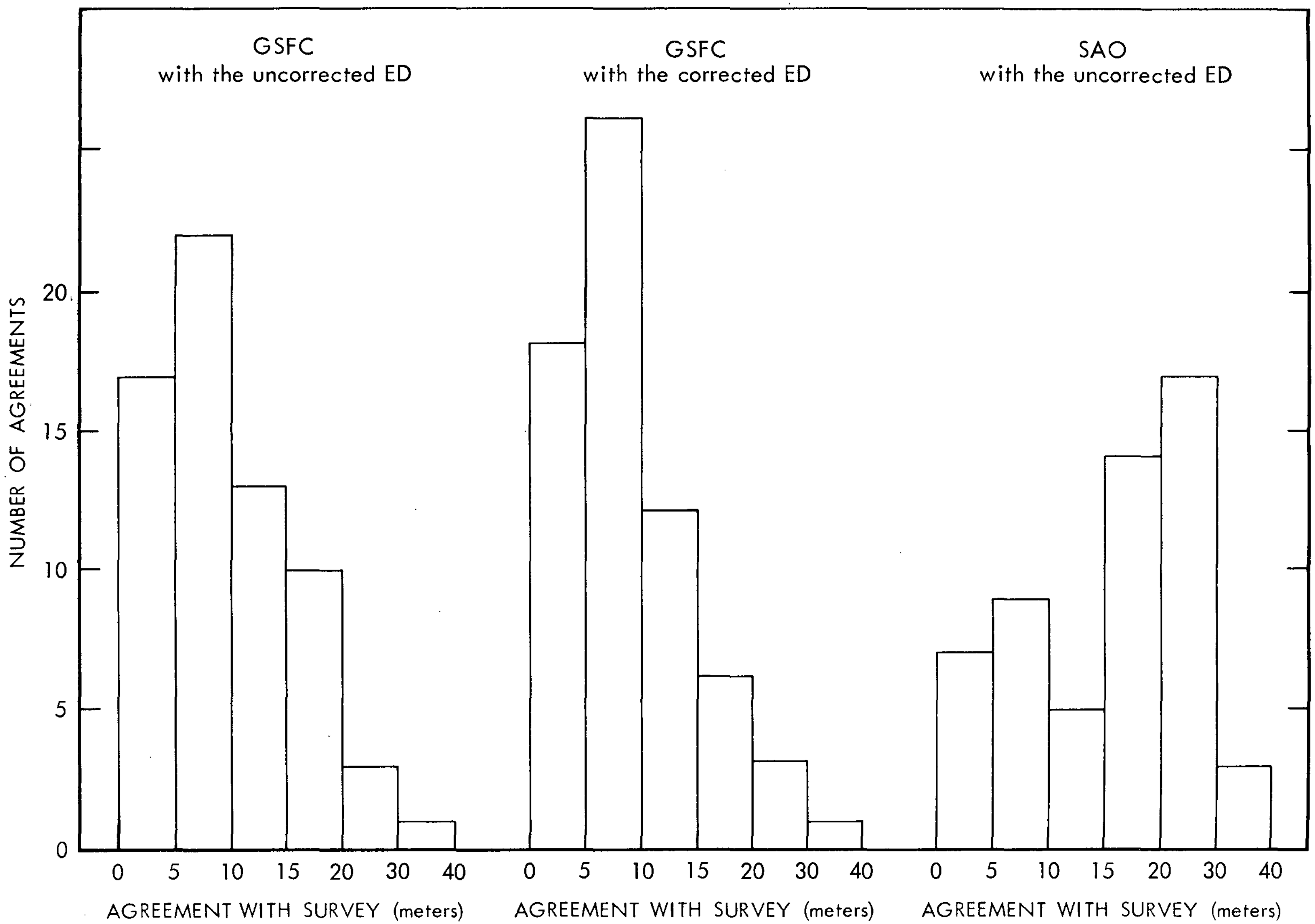

Figure 2. Histogram of the Difference Between Surveyed and Satellite Derived Chord Lengths on the European Datum

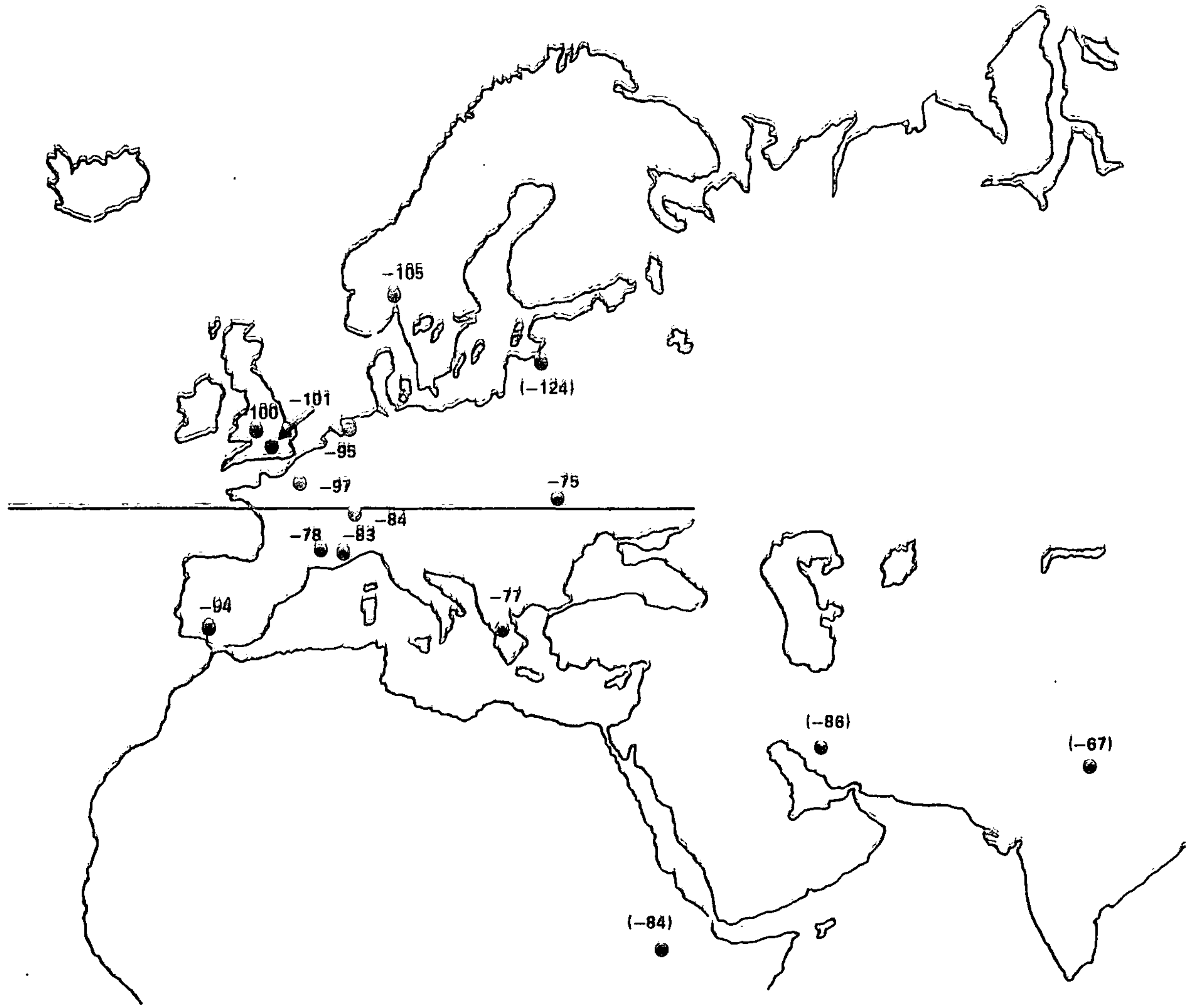

Figure 3. Adjustments in the X-Coordinate (Satellite-Survey Solution) in Meters

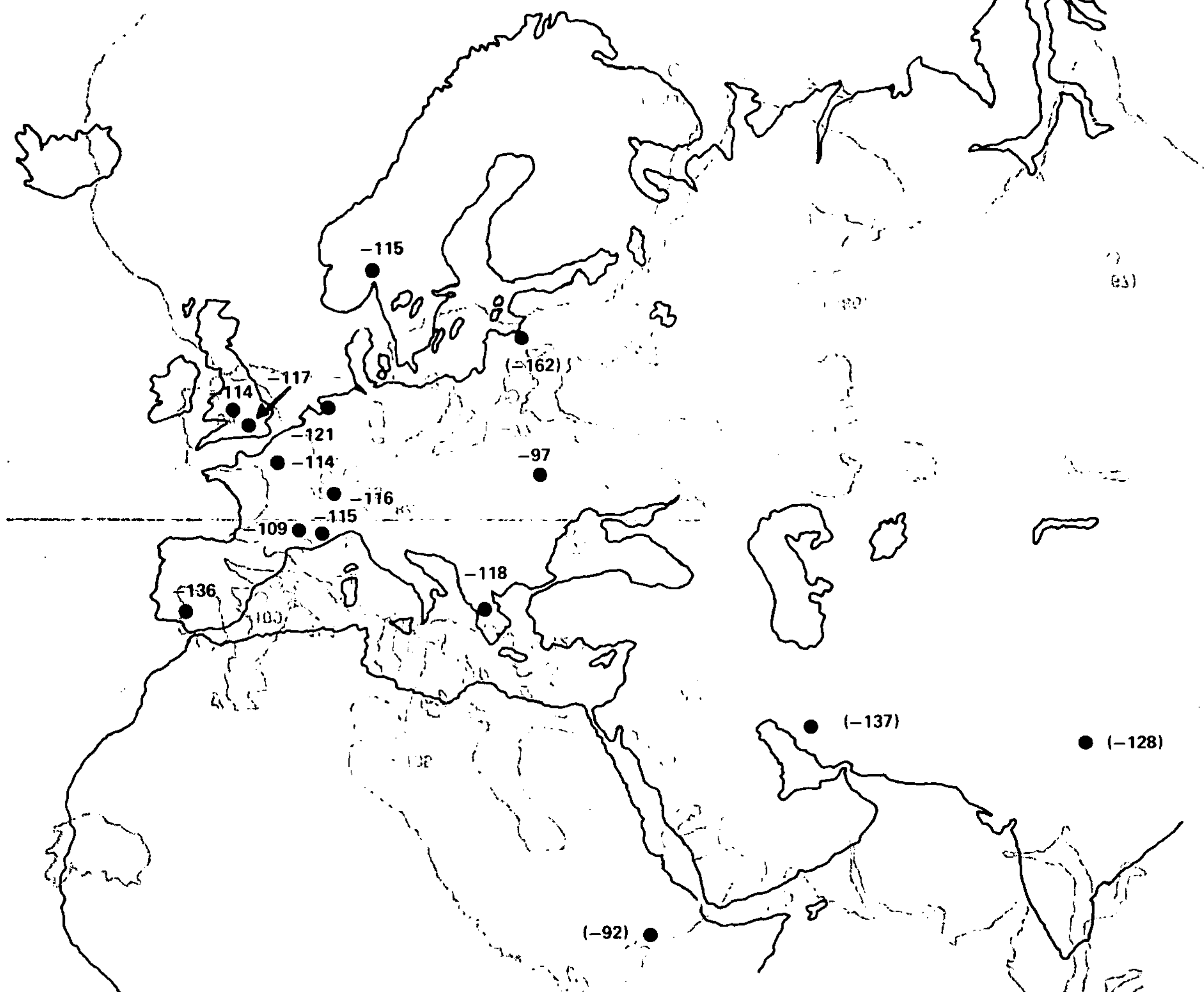

Figure 4. Adjustments in the Y-Coordinate (Satellite-Survey Solution) in Meters

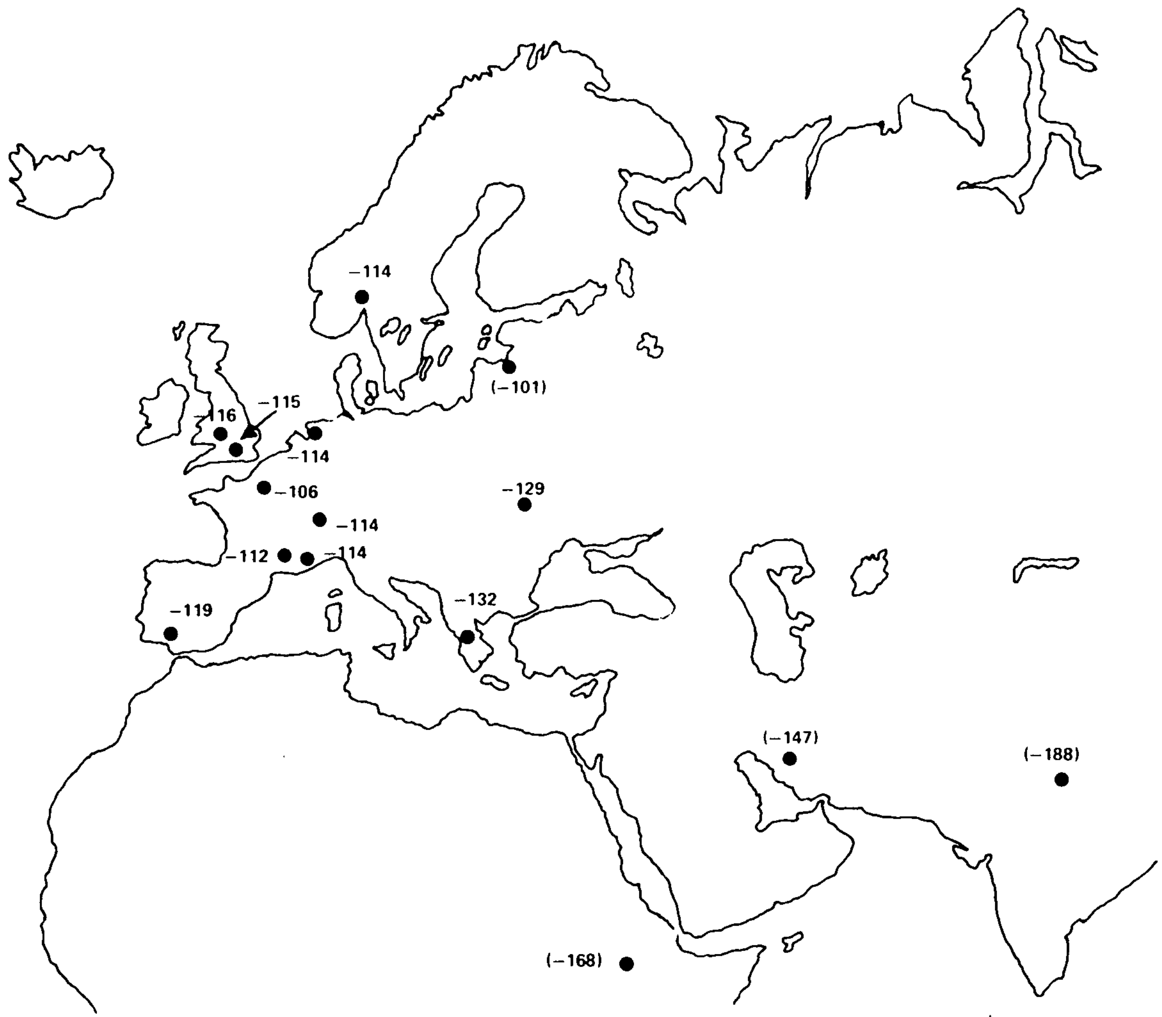

Figure 5. Adjustments in the Z-Coordinate (Satellite-Survey Solution) in Meters