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ANALYSIS OF SOVIET GEODETIC SATELLITE DATA

Donald J. Warcham

Defense Mapping Agency Aerospace Center
St. Louis Air Force Station, Missouri

October 1972

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13. ABSTRACT

An investigation has been made of Soviet camera sites at Riga and Uzhgorod and the site at Helsinki, Finland to determine the geodetic quality of their optical satellite observations with respect to seven other co-observing camera sites in Western Europe. The primary objectives were to improve the geodetic coordinates of the two Soviet sites and the site at Helsinki with respect to the European Datum and to ascertain the quality of the instrumentation used at the Soviet sites. The objectives regarding the Soviet sites have been met with reasonable assurance:

1. The Soviet camera systems are capable of producing accurate geodetic coordinates.
2. The European Datum 50 position determined for Riga could be the most accurate thus far produced by investigators using satellite data.
3. Uzhgorod agreed well with its initial European Datum 50 coordinates.

The position at Helsinki, due to fairly poor geometry, is not given the same degree of reliance as the Soviet positions.

Results of the analysis with respect to the European Datum also revealed a change in geodetic height at Station Malvern, England. Adjustments made on the geocentric SAO Standard Earth II Datum support the findings of other investigators regarding a scale variance between satellite adjustments limited to the European area and those on the global, geocentric SAO Standard Earth II Datum.

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ANALYSIS OF SOVIET GEODETIC SATELLITE DATA

OCTOBER 1972

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NOTICES

This report supersedes ACIC Technical Report No 72-4, Analysis of Soviet and Western European Geodetic Satellite Data, December 1971. It is issued to present to organizations and individuals concerned with the quality of Soviet camera systems the results of investigations using these and other camera systems in a Western European geodetic satellite triangulation network. Nothing herein is to be construed as Defense Mapping Agency doctrine.

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ABSTRACT

An investigation has been made of Soviet camera sites at Riga and Uzhgorod and the site at Helsinki, Finland to determine the geodetic quality of their optical satellite observations with respect to seven other co-observing camera sites in Western Europe. The primary objectives were to improve the geodetic coordinates of the two Soviet sites and the site at Helsinki with respect to the European Datum and to ascertain the quality of the instrumentation used at the Soviet sites. The objectives regarding the Soviet sites have been met with reasonable assurance:

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ANALYSIS OF SOVIET GEODETIC SATELLITE DATA

INTRODUCTION

The Defense Mapping Agency Aerospace Center (DMAAC) has completed an analysis of satellite tracking data from the Soviet camera systems at Riga and Uzhgorod and from Helsinki, Finland. Each of these stations observed GEOS II in a cooperative effort with a Western European tracking network as shown in the figure on page 2. The other participants include Dionysos (near Athens, Greece), Zimmerwald (Switzerland), Nice and Haute Provence (France), San Fernando (Spain), Delft (Netherlands), and Malvern (England).

The primary objectives of the DMAAC analysis were to improve the geodetic coordinates of the two Soviet sites and the site at Helsinki with respect to the European Datum and to ascertain the quality of the instrumentation used at the two Soviet sites. The data used in the DMAAC adjustment consists entirely of simultaneous photographic observations made during the period from February 1968 to July 1969. This data was obtained from the National Aeronautics and Space Administration (NASA), National Space Science Data Center.

DISCUSSION

1. Camera Systems Used

Station Delft was equipped with a Bouwers-Maksutov concentric mirror type sidereally driven camera having a 1200mm focal length and a 210mm aperture [1]. Schmidt cameras (focal length = 1040mm; aperture = 340mm)

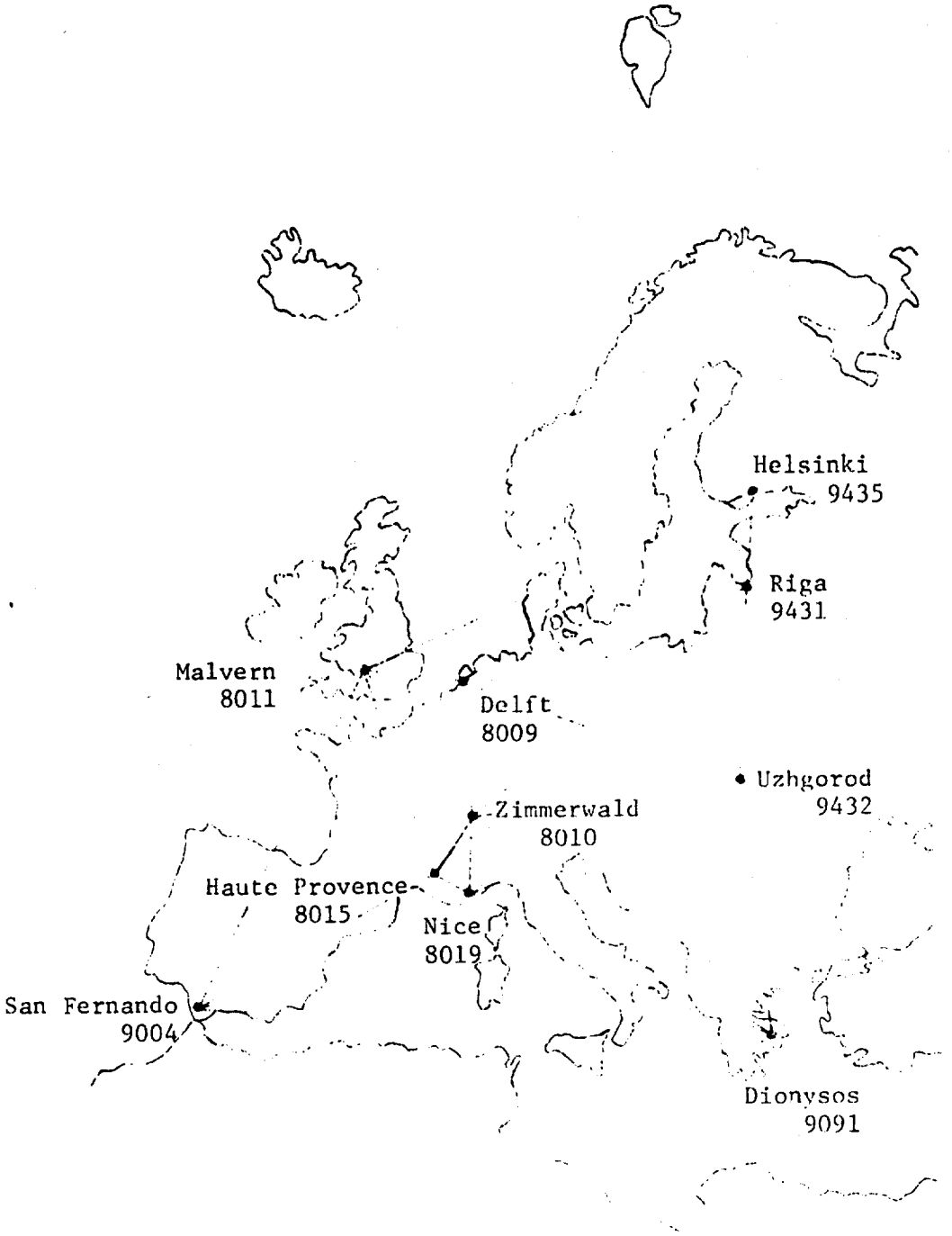

Figure. DMAAC Western European Geodetic Satellite Adjustment.

were used at Zimmerwald and at Malvern [2]. The NASA Geodetic Satellite Observation Station Directory [3], November 1970, indicates that a Schmidt D camera occupied the station at Haute Provence. Station Nice [4] was occupied by a three-axis tracking camera with a 900mm focal length and a 300mm aperture. Stations San Fernando and Dionysos [4] were equipped with Baker-Nunn cameras which have 500mm focal lengths and apertures. Both Riga and Uzhgorod were equipped with Soviet AFU-75 cameras having a focal length of 736mm and an aperture of 210mm [5]. The Helsinki Station was occupied by a sidereally driven camera (Schmidt-Vaisala) of 1032mm focal length and 350mm aperture [2].

2. Method of Data Analysis

As is noted in the report by Ehrnsperger, et al [6], the station sites used in the various Western European adjustments differed widely in the types of camera and timing systems used and in their adopted methods of data reduction. In order to use such heterogeneous data, the data first had to be brought into homogenity at the time of the observation. This required knowledge of the extent to which the reduction had thus far been performed by the agency which recorded the data. Since this was not known for every instance, other US agencies which had successfully used the data were contacted to determine the reduction methods they had used in processing the data. Mr John G. Marsh, Goddard Space Flight Center (GSFC), NASA, was of special assistance in providing most of the needed information. The Smithsonian Astrophysical Observatory (SAO) furnished further guidelines. The techniques contained in the Ohio State University (OSU) Report 82 [7] were also used in preprocessing the data.

Experimental methods of applying various reduction corrections for stellar data were used to determine as accurately as possible what corrections were needed for reduction of data at stations where some uncertainties still existed. This process failed to isolate only the minute effects of the parallactic refraction correction. A temperature of 10°C and an atmospheric pressure of 760mm were assumed to furnish an "average" parallactic refraction correction to certain of the stations known or presumed not to have applied it. As pointed out in the report by Weightman and Hewitt [8]; however, the parallactic refraction correction and phase angle correction (not applicable to active satellites) "have only very small effects upon the final direction cosines and, while they may explain some of the minor discrepancies, are almost negligible."

The DMAAC UNIVAC 1108 Computer Program, COBAN, was used in the preprocessing stage for correcting the observational data to the time of observation. This program is based on work previously done by Hotter [7]. COBAN has options for correcting for the use of atomic time, removal of provisional annual aberration (Baker-Nunn), annual aberration, precession and nutation, diurnal aberration, light travel time, parallactic refraction, and the time conversion from UTC to UT1. The corrections and applications are given in Table 1.

Following the preprocessing accomplished with the COBAN Program, and during the experimental stage, each event comprising two or more stations having simultaneous observations of the GEOS II satellite was assembled and analyzed for its acceptability. The DMAAC EDWARDS (flash-coordinates)

Table 1

Corrections Used for Completion of Data Preprocessing

Corrections	Stations									
	9004	9091	9431	9432	9435	8009	8010	8011	8015	8019
Atomic Time AS - UTC	X	X								
Provisional Aberration	X	X								
Annual Aberration	X	X	X	X	X	X			X	X
Precession	X	X	X	X	X	X	X		X	X
Nutation	X	X	X	X	X	X	X		X	X
Diurnal Aberration	X	X	X	X	X	X			X	X
Light Time	X	X								
Parallactic Refraction	X	X	X	X	X	X			X	X
UT1 - UTC	X	X	X	X	X	X	X	X	X	X

Program was used in this assessment. The program computes satellite coordinates and the slant ranges (station to satellite) for the stations participating in an event and provides an error analysis which shows, in terms of standard errors, the precision of the intersection made by observations at a single point - the satellite flash. Gross errors and quality of data and geometry were detected in this stage based on each event.

Having survived this test, the acceptable events (some of which by their sigmas revealed poor geometry but had otherwise acceptable observational accuracies) became eligible for an iterative least-squares satellite triangulation adjustment. This stage of the analysis was performed with DMAAC's geometric satellite triangulation program, SATIN. This adjustment provides a further check on the quality and geometry of the events in terms of the entire agglomerate of the participating events in the geometric network. Observations for which the residuals exceeded three times the standard error of unit weight (computed for each iteration) were eliminated. Table 2 shows the usable data after the EDWARDS and SATIN edits. A GEOS event may have seven usable points. At least three of the seven were required for an event to be acceptable for the DMAAC adjustments.

3. Weighting of Observations

All observations were of necessity assumed to be of equal accuracy in the DMAAC adjustments for the following reasons:

a. The right ascension (RA) and declination (DEC) sigmas (standard errors) were not furnished with the 9000 series observations.

Table 2

Usable Events After EDWARDS and SATIN Edits*

Station		8010	8011	8015	8019	9004	9091	9431	9432	9435
Delft	(8009)	13(15)	5(6)	6(9)	14(14)	6(7)	3(3)	5(7)	3(3)	0(0)
Zimmerwald	(8010)		8(10)	23(27)	47(54)	22(24)	9(9)	16(19)	9(10)	8(8)
Malvern	(8011)			5(8)	11(13)	3(3)	0(0)	4(5)	4(4)	2(2)
Haute Provence	(8015)				41(58)	21(25)	10(14)	13(15)	3(7)	5(5)
Nice	(8019)					49(56)	19(19)	25(28)	9(10)	7(7)
San Fernando	(9004)						62(82)	12(13)	11(13)	1(1)
Dionysos	(9091)							7(10)	12(12)	1(1)
Riga	(9431)								16(17)	10(18)
Uzhgorod	(9432)									4(5)
Helsinki	(9435)									

*Events prior to editing appear in parentheses.

b. One of the 8000 series stations had many observations with sigma values under 0".20 (seconds of arc). One particular event had DEC sigmas of 0".07 which would have weighted the observations for that event to an extreme. Since a polynomial fit is not involved in the reduction of active satellite flash points, sigmas of this magnitude were considered to be optimistic.

c. Observations for another 8000 series station were all accompanied by sigmas that were obviously estimations rather than derived from a rigorous error analysis. (Most of the sigmas were 2".00 for both the RA's and DEC's.)

4. Initial Geodetic and Geocentric Datums and Coordinates

Most initial European Datum 1950 (ED 50) coordinates (Table 3) used in the DMAAC adjustments were originally taken from the ED 50 coordinates used by Cazenave, et al [9]. There were two distinct exceptions, however, plus some changes specifically in the heights of certain of the stations: the coordinates at Riga are those obtained from the results of Cazenave's adjustment, and the coordinates at Helsinki (not used by Cazenave) were taken from the NASA Directory [3]. The changes were made in the initial coordinates at Delft and in the European Datum spheriodal heights at Zimmerwald, Malvern, Nice, and Dionysos as well as at Delft according to the second edition of the NASA Directory of Tracking Station Locations [10], November 1971, and as recommended in the report by Ehrnsperger, et al [6]. Additional verification of station coordinates was made through the Geodetic Office, Feltham, England by DMAAC's Research and Liaison Activity.

The DMAAC adjustments, which are referenced to the 1969 Smithsonian Standard Earth II (SAO SE II), use as initial coordinates the rectangular

Table 3

Initial Coordinates (ED 50)

Station		Geodetic			Space Rectangular		
		Latitude	Longitude	height (Meters)	X (Meters)	Y (Meters)	Z (Meters)
Delft	(8009)	52°00'09".20 N*	4° 21'21".29 E*	20.7*	3923485.6	300005.4	5003093.2
Zimmerwald	(8010)	46 52 40.32	7 27 58.24	900.3*	4331391.4	567637.5	4633236.9
Malvern	(8011)	52 08 39.12	358 01 59.49	108.6*	3920249.3	- 134624.4	5012850.3
Haute Provence	(8015)	43 56 01.13	5 42 49.27	646.8	4578413.0	458090.9	4403312.0
Nice	(8019)	43 43 36.50	7 18 03.31	369.4*	4579557.5	586729.5	4386539.0
San Fernando	(9004)	36 27 51.37	353 47 42.09	- 12.0	5105680.1	- 555102.9	3769799.3
Dionysos	(9091)	38 04 48.24	23 56 01.61	459.0*	4595245.9	2039574.8	3912790.1
Riga	(9431)•	56 56 56.09	24 03 32.41	- 19.2	3183998.7	1421538.2	5322894.5
Uzhgorod	(9432)	48 38 04.56	22 17 57.[illegible]	190.0	3907494.2	1602533.2	4764034.8
Helsinki	(9435)**	60 09 44.06	24 52 11.07	40.0	2584624.5	1342247.4	5509646.3

Notes:

Initial coordinates are those used by Cazenave et al except as noted:

*These values are corrected as per second edition of the NASA Directory of Tracking Station Locations, dated November 1971, and as noted in report by Lärnsperger et al.

•Initial coordinates for Station Riga were taken from adjustment results of Cazenave et al.

**Initial coordinates for Station Helsinki are on an unknown datum (from NASA Directory).

geocentric values taken from the adjustment results furnished in SAO Special Report 315 [11]. These are given in Table 4. The SAO SE II ellipsoid has a semi-major axis of 6378155 meters and a flattening of 1/298.25. Since Station Helsinki was not used in the SAO adjustment, the NASA Directory coordinates (presumed for the purpose of conversion to be located on the European Datum) were converted to the SAO SE II. Consequently, Helsinki was considerably less constrained (to a 1000 meter spherical allowance) to permit free movement within the SAO SE II adjustments and negligible influence to these adjustments.

It has been confirmed that the SAO code numbers given in Table 4 for Riga, Uzhgorod, Zimmerwald, and Delft refer to those same stations (Table 3) as listed and coded in the NASA Directory and indicate the same respective physical locations [12]. To avoid confusion, the NASA code numbers are used throughout the remainder of this report.

5. Origin and Baselines

Although Zimmerwald (8010), which is centrally located in the station network and closer to the origin of the European Datum, seemed a best choice for the origin of the adjustment, Nice (8019) had participated in 138 acceptable events as compared to the 90 acceptable events at Zimmerwald, thus making Nice the more attractive candidate. Since Nice is also in close proximity to the center of the network, it was chosen as the origin.

The short chord distance ($\sim$130km) between Haute Provence (8015) and Nice was held fixed both to eliminate the effects of a poor geometrical relationship existing between these stations and the satellite flash points and to provide scale for the network. A second adjustment held fixed the chord distance between Zimmerwald and Nice in addition to the

Table 4

Initial Coordinates (1969 Smithsonian Standard Earth II)

Station		Geodetic			Space Rectangular		
		Latitude	Longitude	Height* (Meters)	X (Meters)	Y (Meters)	Z (Meters)
Delft	(9065)	52°00'05".53 N	4°22'15".05 E	29.0	3923411.0	299882.0	5002945.0
Zimmerwald	(9066)	46 52 36 50	7 27 52.82	913.5	4331310.0	567511.0	4633093.0
Malvern	(8011)	52 08 35.17	358 01 53.39	131.4	3920178.0	- 134738.0	5012708.0
Haute Provence	(8015)	43 55 57.27	5 42 44.08	674.0	4578328.0	457966.0	4403179.0
Nice	(8019)	43 43 23.90	7 17 58.05	391.0	4579466.0	586599.0	4386408.0
San Fernando	(9004)	36 27 46.61	353 47 36.70	47.6	5105588.0	- 555228.0	3769667.0
Dionysos	(9091)	38 04 44.65	23 55 57.47	459.4	4595157.0	2039425.0	3912650.0
Riga	(9074)	56 56 54.66	24 03 29.89	- 21.3	3183901.0	1421448.0	5322772.0
Uzhgorod	(9077)	48 38 01.45	22 17 53.08	184.3	3907421.0	1602397.0	4763890.0

*Geodetic height with respect to the Smithsonian Standard Earth (II) Ellipsoid.

Haute Provence - Nice chord. The additional constraint improved the precision of the resulting adjustment substantially as revealed in the comparison of final sigmas (spherical error of internal consistency) for each participant in the adjustment. These final sigmas and the a priori sigmas for each adjustment made by DMAAC are given in Table 5.

6. Adjustment Results

The DMAAC adjustment results are presented in Tables 6, 7, 8, and 9. Results listed under "Height" (geodetic) include the height of camera. The initial ED 50 coordinates from Table 3 were used for the two European Datum adjustments. The initial geocentric coordinates from Table 4 were used in the SAO SE II adjustments. The standard error of unit weight (representing the internal consistency) for each of the four adjustments was 10.2 meters. A total of 3065 acceptable coplanar conditions was satisfied for use in each of the European Datum adjustments. (Multiple events were treated as a combination of pairs.) This total was raised slightly to 3076 acceptable coplanar conditions for the SAO SE II adjustments.

The constraints upon each of the participant stations for each adjustment are indicated by the a priori sigma values assigned. See Table 5. The use of an additional fixed chord in the second adjustments (i.e. line 8010 - 8019) made a substantial improvement in the final sigmas but resulted in a deterioration of the closures at some of the stations. This occurred on both the ED 50 and the SAO SE II datums and is probably due to the relaxing of the a priori sigmas at four stations. The closure at San Fernando improved on the European Datum but degenerated on the SAO SE II datum with the additional baseline.

Table 5

Adjustment A Priori and Final Sigmas in Meters

Station	First Adjustment ED 50		Second Adjustment ED 50		First Adjustment Standard Earth II		Second Adjustment Standard Earth II	
	A Priori	Final	A Priori	Final	A Priori	Final	A Priori	Final
8009	10.0	6.7	100.0	3.1	10.0	6.7	100.0	3.1
8010	10.0	2.9	5.0	1.3	10.0	2.9	10.0	1.3
8011	10.0	8.4	100.0	3.5	10.0	8.4	100.0	3.5
8015	10.0	1.4	5.0	1.3	10.0	1.4	10.0	1.3
9004	10.0	9.2	100.0	3.6	10.0	9.2	100.0	3.6
9051	10.0	8.5	100.0	3.4	10.0	8.5	100.0	3.4
9131	100.0	13.2	100.0	4.6	100.0	13.3	100.0	4.6
9132	100.0	8.9	100.0	3.4	100.0	8.9	100.0	3.4
9135	100.0	15.1	100.0	5.8	1000.0	15.1	1000.0	5.8
8019	Fixed	--	Fixed	--	Fixed	--	Fixed	--

Fixed Baselines

8015 to 8019	8010 to 8019	8015 to 8019	8010 to 8019
	8015 to 8019		8015 to 8019

Table 6

Results of First DMAAC European Datum 50 Adjustment

Station	Latitude (φ)	σ_ϕ	Longitude (λ)	σ_λ	Height (Meters)	σ_H
8009	52°00' 09".05N	±.27	04°22' 20".96E	±.19	29.9	±8.2
8010	46 52 40.37	.12	07 27 58.35	.07	905.1	3.6
8011	52 08 39.02	.27	358 01 59.86	.45	123.6	8.2
8015	43 56 01.24	.06	05 42 49.30	.01	643.9	2.0
9004	36 27 51.24	.23	353 47 41.62	.54	-17.3	6.9
9091	38 04 48.18	.21	23 56 01.68	.69	452.6	6.9
9431	56 56 56.74	.49	24 03 35.29	.72	-3.4	13.2
9432	48 38 04.34	.25	22 17 57.93	.61	197.4	7.3
9435	60 09 43.66	.60	24 57 10.22	.72	28.9	15.6

Coordinate Differences (Adjusted Minus Initial Coordinates)

Station	Δφ		Δλ		ΔH
	Sec	Meters	Sec	Meters	Meters
8009	-0.15	-4.6	-0.24	-4.5	9.2
8010	0.05	1.5	0.11	2.3	4.8
8011	-0.10	-3.0	0.37	7.0	15.0
8015	0.11	3.3	0.02	0.4	-2.9
9004	-0.13	-4.0	-0.67	-13.6	-5.3
9091	-0.07	-2.1	0.07	1.7	-6.4
9431	-0.19	-5.6	-1.56	-26.2	-22.0
9432	-0.22	-6.7	0.05	1.0	7.4
9435	-0.40	-12.3	-0.85	-13.0	-11.1

Comparison of Chord Distances from [illegible] (8-19)

Line	Chord Distance		Adjusted	Ratio
	Standard	Adjusted	[illegible]	
8009-8019	944870.4	944867.7	[illegible]	1:361204.
8010-8019	350443.6	350445.5	1.9	1:178344.
8011-8019	1160734.5	1160729.0	-5.4	1:214795.
9004-8019	1400340.7	1400351.6	10.9	1:127449.
9091-8019	1528215.8	1528217.5	[illegible]	1:872113.
9432-8019	1275158.5	1275156.9	[illegible]	1:3061569.

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Table 7

Results of Second DMAAC European Datum 50 Adjustment

Station	Latitude (ϕ)	σ_ϕ	Longitude (λ)	σ_λ	Height (Meters)	σ_H
8009	52°00' 08".91N	±".12	04°22' 21".01E	±".12	29.7	3.5
8010	46 52 40.31	.04	07 27 58.34	.06	905.1	1.3
8011	52 08 38.88	.11	358 02 00.02	.20	123.2	3.3
8015	43 56 01.23	.06	05 42 49.29	.01	644.1	1.9
9004	36 27 51.37	.10	353 47 41.80	.20	-17.9	2.9
9091	38 04 48.28	.09	23 56 01.42	.24	451.8	2.7
9431	56 56 56.55	.17	24 03 34.92	.25	-4.7	4.6
9432	48 38 04.27	.10	22 17 57.66	.22	196.8	2.9
9435	60 09 43.42	.23	24 57 09.79	.32	27.2	6.0

Coordinate Differences (Adjusted Minus Initial Coordinates)

Station	$\Delta\phi$		$\Delta\lambda$		ΔH
	Sec	Meters	Sec	Meters	Meters
8009	-0.29	-8.9	-0.19	-3.6	9.0
8010	-0.01	-0.3	0.10	2.1	4.8
8011	-0.24	-7.4	0.53	10.0	14.6
8015	0.10	3.0	0.02	0.4	-2.7
9004	0.00	0.0	-0.29	-7.1	-5.9
9091	0.04	1.2	-0.19	-4.6	-7.3
9431	-0.38	-11.7	-1.93	-32.4	-23.3
9432	-0.29	-8.9	-0.22	-4.7	6.8
9435	-0.64	-19.7	-1.28	19.6	-12.8

Comparison of Chord Distances from Nice (8019)

Line	Chord Distance		Adjusted -Standard	Ratio
	Standard	Adjusted		
8009-8019	944870.4	944863.4	-6.9	1:136359.
8011-8019	1160734.5	1160723.9	-10.5	1:109566.
9004-8019	1400340.7	1400345.5	4.8	1:290939.
9091-8019	1528215.8	1528210.4	-5.3	1:286595.
9432-8019	1275158.5	1275152.1	-6.3	1:199951.

Table 8

Results of First DMAAC SAO Standard Earth II Adjustment

Station	Latitude (ϕ)	σ_ϕ	Longitude (λ)	σ_λ	Height (Meters)	σ_H
8009	52°00' 04".96N	±".27	04°22' 15".00E	±".19	37.9	±8.2
8010	46 52 36.62	.12	07 27 52.77	.07	919.4	3.6
8011	52 08 34.58	.27	358 01 54.51	.45	138.4	8.2
8015	43 55 57.56	.06	05 42 44.14	.01	666.7	2.0
9004	36 27 47.66	.23	353 47 37.75	.54	37.6	6.9
9091	38 04 45.70	.21	23 55 56.09	.69	455.1	6.9
9431	56 56 53.71	.49	24 03 27.13	.72	-32.4	13.2
9432	48 38 01.30	.25	22 17 51.30	.61	186.1	7.3
9435	60 09 40.63	.60	24 57 01.25	.83	-4.3	15.7

Coordinate Differences (Adjusted Minus Initial Coordinates)

Station	$\Delta\phi$		$\Delta\lambda$		ΔH
	Sec	Meters	Sec	Meters	Meters
8009	-0.57	-17.5	-0.05	-0.9	8.9
8010	0.12	3.7	-0.05	-1.0	5.9
8011	-0.59	-18.2	1.12	21.2	7.0
8015	0.29	8.9	0.06	1.3	-7.3
9004	1.05	32.4	1.05	26.0	-10.0
9091	1.05	32.4	-1.38	-33.5	-4.2
9431	-0.95	-29.3	-2.76	-46.4	-11.1
9432	-0.15	-4.6	-1.78	-36.3	1.8

Comparison of Chord Distances from Nice (8019)

*Line	Chord Distance		Adjusted -Standard	Ratio
	Standard	Adjusted		
8010-8019	350427.2	350431.2	4.0	1:87340.
8009-8019	944845.3	944829.2	-16.0	1:58982.
8011-8019	1160706.4	1160679.8	-26.5	1:43654.
9432-8019	1275140.3	1275104.9	-35.3	1:36055.
9004-8019	1400336.6	1400295.0	-41.5	1:33674.
9091-8019	1528200.3	1528154.9	-45.3	1:33683.
9431-8019	1876526.6	1876471.8	-54.7	1:34281.

*Ordered by length of line.

Table 9

Results of Second DMAAC SAO Standard Earth II Adjustment

Station	Latitude (φ)	σ_φ	Longitude (λ)	σ_λ	Height (Meters)	σ_H
8009	52°00' 04".65N	±".12	04°22' 15".10E	±".12	37.4	±3.5
8010	46 52 36.49	.04	07 27 52.73	.06	919.3	1.3
8011	52 08 34.28	.11	358 01 54.88	.20	137.3	3.3
8015	43 55 57.53	.06	05 42 44.13	.01	666.9	1.8
9004	36 27 47.94	.10	353 47 38.17	.20	36.2	2.9
9091	38 04 45.94	.09	23 55 55.51	.24	453.1	2.7
9431	56 56 53.28	.17	24 03 26.30	.25	-35.2	4.6
9432	48 38 01.16	.10	22 17 50.68	.22	184.8	2.9
9435	60 09 40.10	.23	24 57 00.29	.32	-8.2	6.0

Coordinate Differences (Adjusted Minus Initial Coordinates)

Station	$\Delta\varphi$		$\Delta\lambda$		ΔH
	Sec	Meters	Sec	Meters	Meters
8009	-0.88	-27.1	0.05	0.9	8.4
8010	-0.01	-0.3	-0.09	-1.8	5.8
8011	-0.89	-27.4	1.50	28.4	5.9
8015	0.26	8.0	0.05	1.1	-7.1
9004	1.33	41.0	1.47	36.4	-11.3
9091	1.29	39.8	-1.96	-47.6	-6.2
9431	-1.38	-42.6	-3.59	-60.4	-13.9
9432	-0.29	-8.9	-2.40	-48.9	0.5

Comparison of Chord Distances from Nice (8019)

*Line	Chord Distance		Adjusted -Standard	Ratio
	Standard	Adjusted		
8009-8019	944845.3	944819.5	-25.7	1:36700.
8011-8019	1160706.4	1160668.0	-38.3	1:30258.
9432-8019	1275140.3	1275091.4	-48.8	1:26078.
9004-8019	1400336.6	1400281.2	-55.3	1:25293.
9091-8019	1528200.3	1528138.8	-61.4	1:24862.
9431-8019	1876526.6	1876452.2	-74.3	1:25223.

*Ordered by length of line.

7. Analysis of Results (ED 50)

Of the seven Western European stations in the ED 50 adjustments (barring mention of Helsinki, Riga, and Uzhgorod for the moment), Malvern wanted to move more than expected. Although Malvern lies on the perimeter of the station configuration, the geometry of its location with respect to the other six is better than that for Dionysos or San Fernando. As for the quantity of data between Malvern and the others, it cannot compare, for example, with San Fernando, but the amount that was used (Table 2) was sufficient. Not only does the quantity support the sufficiency conclusion, but so also does the quality of the Malvern data which appeared relatively good. This relative goodness was evident in the pre-adjustment editing phase and in the size of the residuals from the adjustment which reflect how well the coplanar condition was met by data from a simultaneous observation between two stations. The residuals averaged out to 5.3 meters for the observations between Malvern and the five Western European stations observed by Malvern. (Malvern did not observe GEOS II simultaneously with Dionysos.)

Of the three additional stations (Riga, Uzhgorod, and Helsinki), Uzhgorod has the best fit with its initial ED 50 coordinates. The following tables (Tables 10 and 11) show the number of events and average residuals for events occurring between co-observers with Stations Riga (Table 10), which compared rather poorly with its initial coordinates, and Uzhgorod (Table 11), which agreed well with its initial ED 50 coordinates. The compatibility between residuals in the two tables (where the lines are arranged in order of increasing lengths) is good, indicating that the internal consistency of the

Table 10

Averages of the Residuals
From Geometric Adjustment of
GEOS II Events -- Station Riga (9431)

Line	Events	Residual Averages (Meters)
9431 - 8009	5	6
9431 - 8010	16	10
9431 - 8011	4	10
9431 - 8019	25	10
9431 - 8015	13	9
9431 - 9091	7	12
9431 - 9004	12	14

Table 11

Averages of the Residuals
From Geometric Adjustment of
GEOS II Events -- Station Uzhgorod (9432)

Line	Events	Residual Averages (Meters)
9432 - 8010	9	7
9432 - 9091	12	8
9432 - 8019	9	7
9432 - 8009	3	10
9432 - 8015	3	9
9432 - 8011	4	12
9432 - 9004	11	13

adjustment for Riga is about equivalent to that for Uzhgorod.

Marsh, et al (1971) [13] included a table (Table 7) in which they compared differences between chords determined with ED 50 coordinates and those resulting from three different "satellite" solutions. The satellite solutions were made by Cazenave, et al (1971) [9] in France, Marsh, et al (GSFC), NASA, and Gaposhckin and Lambeck (1970) (SAO) [11]. As a matter of interest, Table 12 below compares the chord differences computed by the French, GSFC, and DMAAC. To make the comparison, DMAAC computed chords between San Fernando and seven other stations. Riga and Helsinki were not included because their initial coordinates (Table 3) did not compare favorably with the DMAAC adjustments.

Table 12

Chord Differences to San Fernando (9004)
Survey (ED 50) - Satellite Adjustment
in Meters

Station		French	GSFC	DMAAC No 1	DMAAC No 2
Haute Provence	(8015)	-17.8	-15.9	-12.9	-6.4
Nice	(8019)	-15.5	-13.6	-10.9	-4.8
Zimmerwald	(8010)	-15.0	-13.9	-13.4	-5.8
Malvern	(8011)	-12.6	-10.1	- 5.6	2.4
Delft	(8009)	- 6.6	- 9.4	- 2.4	6.2
Dionysos	(9091)	-25.0	-11.0	-11.6	0.3
Uzhgorod	(9432)	-21.0	-17.9	-10.6	1.4

The marked difference between the first (No 1) and second (No 2) DMAAC satellite adjustment chord differences to San Fernando (Table 12) is further evidence of the relative improvement of San Fernando's [illegible] adjustment. The other peripheral stations

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in the DMAAC second ED 50 adjustment are generally somewhat poorer in the comparison of their adjusted coordinates with the initial coordinates.

The variances of unit weight produced from the residuals for the DMAAC No 2 and No 1 adjustments were the same. This means that the added baseline (8010 - 8019) in the No 2 did not detract from the consistency of No 1 with just the (8015 - 8019) baseline. The smaller sigmas for latitude, longitude, and height in No 2 are then the direct result of the added baseline condition which produces smaller values along the diagonal of the normal inverse. [illegible] second ED 50 adjustment results depends, then [illegible] confidence one gives to the chord distance [illegible] differences found between ED 50 and the [illegible] for the first and [illegible]

8. [illegible]

[illegible] of [illegible] in Tables 8 and 9, [illegible] variances [illegible]

[illegible]

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globe, whereas the European Datum is a geodetic adjustment for a limited area. Gaposchkin and Lambeck do state that the SAO SE II reference ellipsoid is probably "too large by about 15 meters."

CONCLUSIONS

The instrumentation used at Riga and Uzhgorod for acquiring optical data, along with their plate measurements and reductions, has produced satellite data precise enough for accurate geodetic work.

With respect to ED 50, the position determined for the camera station at Riga, in the first DMAAC adjustment, could be the most accurate of those produced by investigators using satellite data. No similar claim can be made for Helsinki because of fairly weak geometry. The initial coordinates for Uzhgorod seem to be good.

The adjusted longitude for San Fernando, in the first DMAAC adjustment, appears to be weak. The station was on the perimeter and there were only three events between it and Malvern creating a weak geometric tie. Adding extra strength in the form of another baseline moved the station into better relative agreement.

The initial geodetic height (ED 50) used for Malvern is questioned. Results from the two adjustments show that a value above 120 meters would be more accurate than the 108.6 meters (Table 3) employed.

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