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ABSTRACT

This study is concerned with a comparison of sets of satellite tracking station coordinate values published in the past few years by a number of investigators, i.e. Goddard Space Flight Center, Smithsonian Astrophysical Observatory, Ohio State University, The Naval Weapons Laboratory, Air Force Cambridge Research Laboratories, Wallops Island.

The comparisons have been made in terms of latitude longitude and height. The results of the various solutions have been compared directly and also with external standards such as local survey data and gravimetrically derived geoid heights. After taking into account systematic rotations, latitude and longitude agreement on a global basis is generally 15 meters or better, on the North American Datum agreement is generally better than 10 meters. Allowing for scale differences (of the order of 2 ppm) radial agreement is generally of the order of 10 meters.

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A COMPARISON AND EVALUATION OF SATELLITE DERIVED POSITIONS OF TRACKING STATIONS

INTRODUCTION

Positions of a large number of satellite tracking stations have been published by a number of investigators using several different analytical techniques and different types of tracking data. The results reported here represent an attempt to obtain an estimate of the accuracy of the various sets of results through intercomparison of the different sets of results with one another and with external standards. The comparisons have been made in terms of latitude, longitude and geoid height rather than Cartesian coordinates. The choice of comparison coordinates was made on the basis of the fact that there is reason to believe that in this coordinate system the accuracies of the three components of position as determined by the satellite may differ. Also the external comparison standards naturally break down into such a coordinate system. The external comparison standard chosen for the radial coordinate was gravimetrically derived geoid heights. The external comparison standard chosen for latitude and longitude comparisons was the local survey positions.

BASIC DATA

The basic data used in these comparisons were the results reported in references 1-13. These results have been reported in a number of different coordinate systems. In every case the results have been converted to geocentric latitude, longitude and ellipsoid height referenced to an ellipsoid with a semi major axis of 6.378155×10^6 meters and a flattening of $1/f = 298.25$. Where the original author presented results on a local datum such as the North American Datum this entailed an assumption as to the proper NAD to geocentric transformation parameters. In those cases where NAD positions were published, these were converted to the geocentric C-6 system through translations given by

$$\Delta X = -26 \text{ meters}, \quad \Delta Y = +155 \text{ meters}, \quad \Delta Z = +185 \text{ meters}.$$

The geocentric latitude, longitude, and ellipsoid height values used by us for each investigator in these comparisons are given in Appendix A.

METHOD OF ANALYSIS FOR RADIAL POSITION COMPARISON

The computation of gravimetric geoid heights was carried out using a computer program which accepts as input spherical harmonic geopotential coefficients, reference ellipsoid parameters and an estimate of the mean sea level value of the geopotential. In the present analysis the spherical harmonic coefficients of the SAO Standard Earth II (Gaposchkin and Lambeck, 1970) were used in conjunction with the C-6 ellipsoid parameters, A = 6378.155 meters, 1/f = 298.25, and the sea level equipotential value of W = 6263675.7 kgal m obtained from Rapp (1966) to derive gravimetric geoid heights for comparative purposes. The choice of this particular system rather than some other system is purely arbitrary; however, the choice of the C-6 ellipsoid is convenient since a number of major investigators do publish their results in the C-6 system.

Several questions might arise in conjunction with the use of a gravimetric geoid derived in the above manner. First, it can be noted that in order to compute geoid heights a value must be chosen for the geoidal potential. If this value is selected incorrectly the gravimetric geoid heights will be systematically in error. Since the geoidal potential at present is not sufficiently accurately known, a gravimetric geoid cannot be set as an absolute comparison standard. Each investigator's geoidal heights must have a constant added to them so that the mean of their differences with the gravimetric geoid are zero before analyses can be carried out. The differences which remain can then be taken as a measure of the internal precision of the investigator's results. The differences between the constants obtained for the various investigators can be considered as systematic scale differences.

RESULTS OF RADIAL POSITION COMPARISONS

The relative gravimetric geoid heights derived by using the SAO Standard Earth (II) potential coefficients are estimated to provide relative geoid heights accurate to ±10 meters or better on the average. This estimate was arrived at by comparison of the gravimetric geoid with detailed astrogeodetic geoids and detailed gravimetric geoids. Table 1 shows such a comparison with the astrogeodetic geoid of Fischer (1967) in the United States. Note that nowhere do the two differ by more than 12 meters and the average agreement is considerably better than 10 meters. Based on the above estimate of ±10 meters for the accuracy of the gravimetric geoid variations, one would expect the differences between the gravimetric geoid heights and those of an investigator (after correcting for the systematic difference) would seldom exceed ±20 meters and, in general, the agreement would be better than ±15 meters, provided the investigators station positions are accurate to ±10 meters or better.

In Table 2 we present geoid height comparisons for all those stations which we considered that are located in the United States. As may be seen from this table most investigators geoid heights for the United States agree with the gravimetric geoid heights to better than ±10 meters and only very seldom do the differences exceed ±15 meters by any substantial amount. The mean absolute values of the differences are listed on the table for each investigator.

Table 3 is similar to Table 2 except that it extends the comparison to a worldwide basis. Again the degree of agreement is compatible with the assumption that the results of most investigators provide answers which are accurate to about 10 meters or better. However, in this case certain unexplained, apparently systematic, differences of the order of 10 to 20 meters occur. This may be seen in the case of SAO where the geoid heights at all European stations are systematically negative with respect to the gravimetric geoid and in the case of Marsh, Douglas, Klosko, where all southern hemisphere stations are systematically positive.

When two or more investigators agree with the gravimetric determination but another investigator disagrees, the result of this investigator for that station should then be subjected to closer scrutiny. We see examples of this for many stations around the world. In Table 3, to take a few examples, let us look at stations 3405, Grand Turk, 1021, Blossom Point, 1042, Rosman N.C., and 7039 Bermuda in all these cases it is the question of one investigator disagreeing with at least three others. Many more examples like this occur in the table.

Two other points were also noted. When the tracking instrumentation was improved as it was for some of Marsh's stations when GRARR and Laser data were used (Table 4) the average geoidal heights improved noticeably, in this case to 5 meters versus the optical which is 10 meters. The second observation was that J.P.L.'s station radius vectors (Table 5) disagree in general with the gravimetric solutions. Since other investigators with solutions at the same location had relatively good agreement with the gravimetric values but at the same time agreed well with J.P.L. values in computing distances from spin axis we suspected that the Z values published by J.P.L. were less accurate. To remedy this we modified J.P.L. Z values with those of GSFC and SAO where applicable and solved for radius vectors. In almost all cases the J.P.L. geoid height comparisons improved, as is seen in Table 5.

Turning to the question of scale differences, we note that the constants which were required to remove the systematic differences between the geoid heights of various investigators and the gravimetric geoid heights differed from investigator to investigator. These constant values were SAO, 22 meters; Marsh, Douglas and Klosko, 17 meters; C-band, 18 meters; and NWL, 8 meters. This comparison demonstrates a scale difference of about 2 ppm between the results of NWL and those of other investigators using GM to scale their answers. This is true even though the GM value used by NWL did not differ significantly from that of other investigators.

Allowing for scale differences, the average agreement between gravimetric and satellite derived radius vector magnitudes for most investigators was found to be of the order of 10 meters. This analysis provides a strong independent verification for the conclusion that present knowledge of the gravity field is sufficient to allow station positioning at the 10 meter or better accuracy level.

LATITUDE AND LONGITUDE POSITION COMPARISONS

At the present time there are four sets of solutions for station locations which are world wide in scope. These are:

(1) Station locations obtained by SAO and reported by Gaposchkin and Lambeck (1970)

(2) Station locations obtained at NASA GSFC and reported by Marsh and Douglas and Klosko (1971-a) and Marsh, Douglas and Klosko (1971-b)

(3) Station locations obtained at NASA Wallops Island and reported by Leitao and Brooks (1970)

(4) Station locations obtained by the Naval Weapons Lab and reported by Anderle and Smith (1967) and Bomford (per. comm.)

The SAO solution has obtained positions for the Baker Nunn cameras of SAO and the Air Force, certain NASA cameras and International cameras in Europe as well as a few lasers.

The GSFC solution has obtained positions for NASA, SAO and International cameras, GRARR systems, and lasers.

The Wallops Island solution has obtained positions for a number of C band radars.

The NWL solution has obtained positions for a number of Doppler Tranet stations.

One mode of estimating the accuracy of the various investigators is to compare their results. In carrying out such comparisons we must include stations which are not collocated but are in the near vicinity of one another. This has been carried out in the following manner. For stations within 100 kilometers of one another on a common datum the relative positions obtained by ground survey should be accurate to a meter or two. Also the difference in shift in geodetic latitude and longitude from the local datum to a geocentric system is negligible over this short distance. Thus the degree to which the shifts in latitude and longitude for nearby stations agree is a good measure of the agreement between solutions.

Tables 6 and 7 list the indicated latitude and longitude shifts for the near-coincident stations. First consider the indicated longitude shifts for GSFC, SAO, and Wallops Island. In no case do the longitudes differ by more than 15 meters (0."5 to 0."6) the average difference is no more than 10 meters (0."3 to 0."4). There is a clear systematic difference between the NWL results and the other results. This systematic difference was recognized by Gaposchkin (1967) when he solved for a few of the Doppler station positions and found a systematic longitude difference between the SAO and NWL coordinate systems of 0."7. The average difference found in the present case was 0."8 which is in excellent agreement with the results of Gaposchkin. Note there are two exceptions Johnson Island and Puerto Rico. The reason for this is clearly the fact that the positions for these stations reported by Anderle and Smith (1967) were not positions obtained in the NWL 8-D or later solutions as were the remainder of the positions presented in the table but were taken from a much earlier, 1965, NWL solution. Apparently this solution either had a different systematic longitude shift and/or was considerably less accurate. The stations from this earlier NWL solution are not considered further. After applying a systematic 0."8 longitude shift to the NWL results they agree with the other solutions as well as these agree with one another.

In the case of latitude the agreement between the solutions of GSFC and SAO are all within 10 meters except for England where they disagree by some 40 meters (1".37). No explanation for this large disagreement is evident. Again the C-band results are generally within 15 meters (0".5) with two cases of disagreement of 0".6 and 0".75. In the case of the NWL latitude results it can be seen that the agreement is reasonable except for Australia where there is a clear systematic difference between the NWL results and other solutions. There is no clear reason for this systematic difference. However, it can be noted that the Australian results provided by Bomford of the Australian National Survey were from a NWL 8D-4 solution of November 1967 rather than the January 1967 NWL 8D solution of Anderle and Smith (1967). Gaposchkin (1967) has noted that the January 1967 solution was with respect to a different mean pole than the SAO solution and thus rotations about equatorial axes are also needed to bring the two into agreement. Perhaps the November 1967 solution has yet a different pole. In any case the systematic difference of 0".7 exists and must be accounted for to bring agreement.

In summary the four worldwide solutions are in general in agreement everywhere to better than 15 meters after taking into account systematic rotations in the NWL results — one of which has been clearly established and the other of which clearly exists but for which there is insufficient information to establish a reason. Since the correct solution is likely to lie somewhere between the various solutions and the solutions rarely show a maximum spread in excess of 15 meters it is not unreasonable to assume that in so far as latitude and longitude is concerned worldwide 10 meter accuracy is possible.

At this point it is well to focus on the North American datum area where several additional investigators have obtained results. These include Hadgigeorge (1970), Mueller et al. (1970) and Berbert et al. (1970). In the case of these localized solutions using geometric and short arc solutions systematic differences are to be expected. Tables 8 and 9 present comparisons of geodetic longitude after taking out systematic variations of +0.″2 in the results of Hadgigeorge and -0.″2 in the results of Mueller et al. The geometric results of Mueller et al. were used rather than the short arc results since geoid undulation comparisons indicated the orbital solution was less accurate than the geometric solution. From this table we note that except for two positions the maximum spread between the four investigators does not exceed 15 meters. (0.″50 to 0.″60) and averages about 8 meters (0.″30). The GSFC and SAO positions agree even better having an average difference of about 5 meters. The latitude comparisons are similar. Making the reasonable assumption that the true value lies somewhere between the different solutions it therefore seems fair to say that we now have satellite stations on the North American datum whose relative positions can be established with an accuracy of at least ±5 meters.

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Table 1

Differences Between Fisher's Astro Geodetic Geoid Height and Gravimetric for Stations in the U.S.

Station No.	Fishers Astro.	Gravimetric Geoid. Height	Gravimetric - Astro.	Station Name
1021	-31	-37	-6	Blossom Pt., Md.
1022	-20	-31	-11	Ft. Myers, Fla.
1030	-34	-28	+6	Goldstone, Cal.
1034	-28	-22	+6	Grand Fks, N. Dakota
1042	-25	-31	-6	Rosman, N. Car.
7036	-25	-16	+9	Edinburg, Texas
7037	-31	-26	+5	Columbia, Mo.
7045	-18	-19	-1	Denver, Col.
7075	-34	-29	+5	Sudbury, Canada
7072	-23	-34	-11	Jupiter, Fla.
7052	-33	-38	-5	Wallops, Va.
9001	-23	-21	+2	Organ Pass, N. Mex.
9021	-30	-25	+5	Mt. Hopkins, Ariz.
9050	-24	-36	-12	Harvard, Mass.
9113	-35	-30	+5	Rosamund, Cal.
3402	-31	-25	+6	Semmes, Ala.
3648	-32	-30	+2	Hunter AFB, Ga.
3657	-34	-39	-5	Aberdeen, Md.
3861	-27	-32	-5	Homestead, Fla.
3333	-27	-25	+2	Greenville, Miss.
5001	-31	-36	-5	Herndon, Va.
3401	-34	-36	-2	Bedford, Mass.
6003	-25	-15	+10	Moses Lake, Wash.
6002	-31	-36	-5	Beltsville, Md.

Standard deviation = ± 9 meters

Table 2

Comparison Between Corrected Station Geoid Heights for the U.S.

Station No.	Gravimetric Geoid Ht.	Corrected Marsh, Douglas, Klosko—Grav.	Corrected Orbital Mueller—Grav.	Corrected Geom. Mueller—Grav.	Corrected N.W.L.—Grav.	Corrected SAO—Grav.	Corrected Hadgigeorge—Grav.	Corrected C-Band—Grav.	Corrected Berbert—Grav.	Corrected ACIC—Grav.	Corrected Mancini—Grav.	Station Name
1021	-37	-6	4	-1		14	0		15			Blossom Pt., Md.
1022	-31	1	13	9			0		3			Ft. Myers, Fla.
1030	-28	-8	-2	4	-17				4			Goldstone, Cal.
1034	-22	-11	2	10	-10	9	1		-5			Grand Fk, N. Dakota
1042	-31	-11	-16	1		1	3		-1			Rosman, N.C.
7036	-16	-19	9	7		1	-3		-5			Edinburg, Tex.
7037	-26	-17	1	7		4	-3		-7			Columbia, Mo.
7045	-19	-9	12	17		18	9		6			Denver, Col.
7072	-34	0	14	6		12	6		-2			Jupiter, Fla.
7052	-38	-17						-14				Wallops
7050	-36	1				14		4				Goddard Space Flight Center
3402	-26		-20	-9	-17					-9		Semmes, Ala.
3648	-33		4	-1	2		1			-2		Hunter, AFB, Ga.
3657	-37		-2	2			0			-1		Aberdeen, Md.
3861	-32		6	0	4		5			4		Homestead, AFB, Fla.

Table 2 (Continued)

Station Name	Corrected Mancini—Grav.	Corrected ACIC—Grav.	Corrected Berbert—Grav.	Corrected C-Band—Grav.	Corrected Hadgigeorge—Grav.	Corrected SAO—Grav.	Corrected N.W.L.—Grav.	Corrected Geom. Mueller—Grav.	Corrected Orbital Mueller—Grav.	Corrected Marsh, Douglas, Klosko—Grav.	Gravimetric Geoid Ht.	Station No.
Austin, Tex.							10				-20	2
Las Cruces, N. M.							-11				-21	103
Howard County, Md.							-2				-37	111
Point Mugu, Cal.				15			-14				-34	200
Winter Harbour, Maine							-4				-28	400
Ft. Wayne, Ind.							-6				-26	710
Stillwater, Okla.							6				-26	711
Pt. Arguello, Calif.							1				-35	720
Moses Lake, Wash.	-8						-9				-15	738
Organ Pass, N. Mexico							-5				-21	741
Beltsville, Md.	15						-3				-36	742
Warren AFB, Wyoming							-7				-17	747
Mt. Hopkins, Ariz.						2				-1	-25	9021
Harvard, Mass.						9					-36	9050
Rosamund, Calif.						11					-30	9113

Table 2 (Continued)

Station No.	Gravimetric Geoid Ht.	Corrected Marsh, Douglas, Klosko—Grav.	Corrected Orbital Mueller—Grav.	Corrected Geom. Mueller—Grav.	Corrected N.W.L.—Grav.	Corrected SAO—Grav.	Corrected Hadgigeorge—Grav.	Corrected C-Band—Grav.	Corrected Berbert—Grav.	Corrected ACIC—Grav.	Corrected Mancini—Grav.	Station Name
9114	-19					4						Cold Lake, Canada
5001	-36						-4					Herndon, Va.
5333	-25				-9		1			-5		Greenville, Miss.
3401	-36		18				4					Bedford, Mass.
4082	-33							5				Merrit Is., Fla.
3647	-26											Dauphin Is., Ala.
3404	-11		-27	-36			-3			-18		Swan Is.

Average Differences:

Marsh, Douglas, Klosko	=	9.0 meters	N.W.L.	=	8.0 meters	Berbert	=	5.0 meters
Mueller Orbital	=	11.0 meters	SAO	=	8.0 meters	ACIC	=	7.0 meters
Mueller Geom.	=	9.0 meters	Hadgigeorge	=	3.0 meters	Mancini	=	12.0 meters
			C-Band	=	9.0 meters			

Table 3

Comparisons Between Corrected Station Geoid Heights for the World

Station No.	Gravimetric Geoid Ht.	Corrected Marsh, Douglas, Klosko—Grav.	Corrected SAO—Grav.	Corrected Orbital Mueller—Grav.	Corrected Geom. Mueller—Grav.	Corrected Hagigeorge—Grav.	Corrected C-Band—Grav.	Corrected N.W.L.—Grav.	Corrected ACIC—Grav.	Corrected Mancini—Grav.	Corrected Berbert—Grav.	Station Name
1021	-37	-6	14	4	-1	0					15	Blossom Pt., Md.
1022	-31	1		13	9	0					3	Ft. Myers, Fla.
1024	1	13	6				-15	2				Woomera, Australia
1028	19	15										Santiago, Chile
1030	-28	-8	11	-2	4			-17			4	Goldstone, Cal.
1031	21	15	-11				-2					Johannesburg, Rep. of S. Africa
1032	12	8										St. Johns, Newfl.
1034	-22	-11	9	2	10	1		-11			-5	E. Grand Fks, N.D.
1035	55	-15										Winkfield, England
1038	15	20						2				Orroral, Australia
1042	-31	-11	1	-16	1	3					-1	Rosman, N.C.
1043	-5	4					14					Tannanarive, Madagascar
1123	-5	4										Madgar (Grarr)
1126	-30	-8										Rosman (Grarr)
1128	15	-5										Alaska (Grarr)

Table 3 (Continued)

Station No.	Gravimetric Geoid Ht.	Corrected Marsh, Douglas, Klosko—Grav.	Corrected SAO—Grav.	Corrected Orbital Mueller—Grav.	Corrected Geom. Mueller—Grav.	Corrected Hagigeorge—Grav.	Corrected C-Band—Grav.	Corrected N.W.L.—Grav.	Corrected ACIC—Grav.	Corrected Mancini—Grav.	Corrected Berbert—Grav.	Station Name
3402	-26			-20	-9	-4		-17	-9			Semmes, Ala.
3648	-33			4	(-1)	1		2	-2			Hunter, AFB, Georgia
3657	-37			-2	2	0			-1			Aberdeen, Md.
3861	-32			6	0	5		4	4			Homestead AFB, Fla.
3404	-11			-27	-37	-3			-18			Swan Is.
3405	-44			-3	-19	0	-30		8			Grand Turk
3106	-26	18	14	-26	-6	-19			-1			Curacao, Neth. Antill.
3401	-48			-3	2	1	8		28			Antigua Is.
3401	-36					4						Bedford, Mass.
5333	-33					-26			5			Trinidad
5333	-25					1		-9	-5			Greenville, Miss.
3647	-43								-7			Dauphin Is.
5001	-36					-4						Herndon, Va.
4080	1						3					Ascension Is.
6001	16									-30		Thule, Greenland
6002	-36							-3		15		Beltsville, Md.

Table 3 (Continued)

Station No.	Gravimetric Geoid Ht.	Corrected Marsh, Douglas, Klosko—Grav.	Corrected SAO—Grav.	Corrected Orbital Mueller—Grav.	Corrected Geom. Mueller—Grav.	Corrected Hagigeorge—Grav.	Corrected C-Band—Grav.	Corrected N.W.L.—Grav.	Corrected ACIC—Grav.	Corrected Mancini—Grav.	Corrected Berbert—Grav.	Station Name
6003	-15							-9		-8		Moses Lake, Wash.
6004	7							-3		8		Shemya, Alaska
6006	34									-5		Tromso, Norway
6007	53									25		Azores
6011	4		14							-6		Maui, Hawaii
6012	9									17		Wake Is.
6015	-20									8		Mashhud, Iran
6016	37									8		Catania, Sicily
6038	-31									24		Mexico
6065	47									-16		Hohen, W. Germany
4082	-33						5					Merrit Is., Florida
4720	33						17					Canary Is.
4742	8						13	12		-16		Kaui, Hawaii
4860	-38	-14					-14					Wallops Is., Va.
7036	-16	-19	1	9	7	-3					-5	Edinburg, Tex.
7037	-26	-17	4	1	7	-3					-7	Columbia, Mo.

Table 3 (Continued)

Station No.	Gravimetric Geoid Ht.	Corrected Marsh, Douglas, Klosko—Grav.	Corrected SAO—Grav.	Corrected Orbital Mueller—Grav.	Corrected Geom. Mueller—Grav.	Corrected Hagigeorge—Grav.	Corrected C-Band—Grav.	Corrected N.W.L.—Grav.	Corrected ACIC—Grav.	Corrected Mancini—Grav.	Corrected Berbert—Grav.	Station Name
7039	-38	5	21	-9	-5	3	-5			-3	-3	Bermuda Is.
7040	-49	-2	14	21	8	4		16			-13	San Juan, Puerto Rico
7045	-19	-9	18	12	17	9					6	Denver, Colo.
7075	-29	-15	-4	3	0	-3						Sudbury, Canada
7072	-29	-5	12	14	6	6					-2	Jupiter, Fla.
7076	-26	2	35	30	18	18					-7	Jamaica, B.W.I.
7054	-15	-4										Carnarvon, Australia
7050	-36	1	14	-26	-9	-1	4				2	Goddard Space Flight Center
2	-20							10				Austin, Tex.
10	4							6				South Pt, Hawaii
14	19							-16				Anchorage, Alaska
17	27							4				Tafuna, Samoa
100	-6							13				Wahiawa, Hawaii
9001	-21	2	4					-5				Organ Pass N.M.
9004	59	-7	-15									San Fernando, Spain
9005	40		5									Tokyo, Japan

Table 3 (Continued)

Station No.	Gravimetric Geoid Ht.	Corrected Marsh, Douglas, Klosko—Grav.	Corrected SAO—Grav.	Corrected Orbital Mueller—Grav.	Corrected Geom. Mueller—Grav.	Corrected Hagigeorge—Grav.	Corrected C-Band—Grav.	Corrected N.W.L.—Grav.	Corrected ACIC—Grav.	Corrected Mancini—Grav.	Corrected Berbert—Grav.	Station Name
9006	-50	-4	7									Naini Tal, India
9007	26	27	21									Arequipa, Peru
9008	-5	-10	-10									Shiraz, Iran
9011	21	35	32									Villa Dolores, Arg.
9021	-25	-1	2									Mt. Hopkins, Ariz.
9023	5	20	15									Island Lagoon, Australia
9025	40		-46									Dodaira, Japan
9028	-15	10	-15									Addis Ababa, Ethiopia
9029	-4	20	-10									Natal, Brazil
9031	18		-12									Comodoro Rivadavia
9065	50	-12	-23									Delft, Netherlands
9066	51	-4	-18									Zimmerwald, Switz.
9074	29		-36									Riga, Latvia
9077	43	-10	-25									Uzghorod, U.S.S.R.
9080	55	-14	-14									Malvern, England
9091	31	9	-25									Dionysos, Greece

Table 3 (Continued)

Station No.	Gravimetric Geoid Ht.	Corrected Marsh, Douglas, Klosko—Grav.	Corrected SAO—Grav.	Corrected Orbital Mueller—Grav.	Corrected Geom. Mueller—Grav.	Corrected Hagigeorge—Grav.	Corrected C-Band—Grav.	Corrected N.W.L.—Grav.	Corrected ACIC—Grav.	Corrected Mancini—Grav.	Corrected Berbert—Grav.	Station Name
9113	-30		11									Rosamund, Calif.
9114	-19		4									Cold Lake, Canada
9115	38	-2	-9									Harvestua, Norway
9117	16		2					6				Johnston Is.
4280	-36						15	1				Vandenberg AFB
8015	55	-1	-2									Haute Provence, France
8019	53	-5	-13									Nice, France
8030	52	-10										Meudon, France
103	-21							-11				Las Cruces, N.M.
111	-36							-2				Howard County, Md.
400	-28							-4				Winter Harbour, Me.
702	24							-14				Marcus Is.
706	23							-18				Canton Is.
710	-26							-6				Ft. Wayne, Ind.
711	-26							6				Stillwater, Okla.
712	45							4				Iwo Jima

Table 3 (Continued)

Station No.	Gravimetric Geoid Ht.	Corrected Marsh, Douglas, Klosko—Grav.	Corrected SAO—Grav.	Corrected Orbital Mueller—Grav.	Corrected Geom. Mueller—Grav.	Corrected Hagigeorge—Grav.	Corrected C-Band—Grav.	Corrected N.W.L.—Grav.	Corrected ACIC—Grav.	Corrected Mancini—Grav.	Corrected Berbert—Grav.	Station Name
713	27							3				Okinawa
715	45							10				Guam Is.
724	-5							11				Midway Is.
740	11							-9				Nome, Alaska
747	-17							-7				Warren AFB
112	-1							-2				Smithfield, Aust.
707	45							8				Darwin, Aust.
709	-26							-3				Muchea, Aust.
723	-31							-22				CoCos, Aust.
725	51							2				Townsville, Aust.
726	76							10				Manus, Aust.
744	73							24				Thursday, Aust.
805	30							34				Culgoora, Aust.

Absolute Averages:

Marsh	= 10 meters	Mueller Geom.	= 9 meters
SAO	= 14 meters	Hadgigeorge	= 5 meters
Mueller Orbital	= 12 meters	Berbert	= 6 meters
		C-Band	= 10 meters
Mancini	= 18 meters		
ACIC	= 8 meters		
N.W.L.	= 9 meters		

Table 4

Differences Between Geoid Heights Derived by Marsh, Douglas and Klosko and Gravimetric Geoid Heights

Station No.	Gravimetric			Marsh				Station Name
	Mean Sea Level	Height Above Ellips.	Geoid Height	Geoid Height	Height Above Ellips.	Marsh — Grav.	Corrected Value	
1123	1399	1394	-5	-17	1382	-12	9	Madgar (Grarr)
1126	874	844	-30	-55	819	-25	-4	Rosman (Grarr)
1128	347	362	15	-7	340	-22	-1	Alaska (Grarr)
7052	9	-29	-38	-69	-60	-31	-10	Wallops (Laser)
7054	31	16	-15	-36	-5	-21	0	Carnarvon (Laser)
7050	55	19	-36	-52	3	-16	5	Goddard (Laser)

Average = 5 meters

Table 5

Comparison of J.P.L. Station Geoid Height (meters)

Station No.	Grav. Geoid Height	J.P.L. Geoid Height	GSFC* Modified J.P.L. Height	SAO** Modified J.P.L. Height	J.P.L. – Grav.	GSFC Modified – Grav.	SAO Modified – Grav.	J.P.L. – Grav.†	GSFC J.P.L. – Grav.††	SAO J.P.L. – Grav.†††	Station Name
12	-27	-48	-50	-45	-21	-23	-18	-19	-16	-5	Goldstone, California
41	0	12	-4	-3	12	-4	-3	14	3	10	Woomera, Australia
42	15	35	15		20	0		22	7		Orroral, Australia
51	20	28	19	18	8	-1	-2	10	6	-11	Johannesburg, Union of South Africa
61	59	32		18	-27		-31	-25		-18	Madrid, Spain
							Mean Absolute Value	18	8	11	

*Used GSFC (Marsh) datum shift to modify J.P.L. Z value.

**Used SAO datum shift to modify J.P.L. Z value.

† After removal of +2 meter scale factor

†† After removal of +7 meter scale factor

††† After removal of +13 meter scale factor

Table 6

Longitude Shift Comparisons (Center of Mass — Local Datum Value)

Station Location	Station Numbers	Longitude Shift (Seconds of Arc)			
		GSFC	SAO	C-Band	NWL*
South Africa	1031	-1.71			
	9002		-160		
	4050			-1.65	
Madagascar	1043	-1.16			
	1123	-1.16			
	4741			-1.59	
Woomera, Australia	1024	+4.12			
	9003		+4.30		
	9023		+4.31		
	9946			+4.68	
	743				+4.17
Carnarvon, Australia	7054	+4.01		+4.71	
	4761			+3.94	
Orroral, Australia	1038	+4.15			
	749				+3.62
England	1035	-6.20			
	8011		-6.08		
Hawaii	9012	+10.04	+9.40		
	4742			+9.14	
	4402			+9.06	
	719				+9.01
	10				+9.42
	100				+9.21

*Longitude Shift of 0."8 Applied

Table 6 (Continued)

Station Location	Station Numbers	Longitude Shift (Seconds of Arc)			
		GSFC	SAO	C-Band	NWL*
Johnston Island	9427		+3.05		
	4451			+4.00	
	718			+2.18	
California	1030	-3.81			
	9113		-4.04		
	4280			-3.73	
	200				-3.98
	737				-4.02
Florida	1022	+0.24			
	7072	+0.24			
	9010		+0.20		
	4082			-0.18	
	734				+0.19
Grand Forks	1034	-2.05	-1.98		
	748				-1.84
Maryland and Virginia	1021	+0.39	+0.15		
	7050	+0.40	+0.25		
	7052	+0.62			
	4860			+0.66	
	4840			+0.72	
	1				+0.39
	111				+0.53
	742				+0.58
Bermuda	7039	+0.91	+1.13		
	4740			+0.48	
	4760			+0.49	

*Longitude Shift of 0.″8 Applied

Table 7

Latitude Shift Comparisons (Center of Mass — Local Datum Value)

Station Location	Station Numbers	Latitude Shift (Seconds of Arc)			
		GSFC	SAO	C-Band	NWL
South Africa	1031	+2.58			
	9002		+2.66		
	4050			+3.36	
Madagascar	1043	+5.50			
	1123	+5.20			
	4741			+6.01	
Woomera, Australia	1024	-4.19			
	9003		-4.10		
	9023		-4.09		
	4946			-4.10	
	743				-4.20
Carnarvon, Australia	7054	-3.52		-3.04	
	4761			-3.36	
Orroral, Australia	1038	-4.80			
	749				-4.61
England	1035	-2.71			
	8011		-4.08		
Hawaii	9012	-11.83	-11.90		
	4742			-12.43	
	4402			-12.18	
	719				-11.22
	10				-10.85
	100				-11.44

Table 7 (Continued)

Station Location	Station Numbers	Latitude Shift (Seconds of Arc)			
		GSFC	SAO	C-Band	NWL
Johnston Island	9427		-6.95		
	4451			+15.75	
	718				-6.21
California	1030	-0.19			
	9113		-0.27		
	4280			+0.27	
	200				+0.13
	737				+0.03
Florida	1022	+1.25			
	7072	+1.00			
	9010		+1.04		
	4082			+0.97	
	734				+1.53
Grand Forks	1034	+0.13	-0.20		
	748				+0.03
Maryland and Virginia	1021	+0.16	+0.45		
	7050	+0.40	+0.38		
	7052	+0.60			
	4860			+0.49	
	4840			+0.51	
	1				+0.30
	111				+0.46
	742				+0.47
Bermuda	7039	+5.40	+5.06		
	4740			+4.87	
	4760			+4.87	

Table 8

North American Longitude Comparisons*

Station No.	NAD Convert to Geocent.	Marsh	SAO	Mueller Orbit	Mueller Geom.	Berbert	Hadgi-george
1021	48.41	48.61	48.37	47.79	48.30	48.84	48.43
1022	3.63	4.16		3.78	3.72	3.80	3.71
1030	58.95	58.92		57.23	58.59	58.45	
1034	19.22	19.51	19.58	18.88	19.19	19.07	19.13
1042	40.58	40.86	40.83	40.55	40.22	40.92	40.55
7036	7.16	7.25	7.12	6.89	7.17	6.89	7.09
7037	40.64	40.87	40.83	40.54	40.54	40.63	40.62
7039	35.94	35.41	35.62	35.12	35.23	36.15	34.76
7040	23.34	23.53	23.64	21.88	23.51	22.04	23.35
7043				20.89	19.80	19.80	
7045	38.37	38.47	38.40	37.99	38.69	38.20	38.41
7050		18.44	18.29				
7072	12.35	12.73		11.67	12.40	12.50	12.31
7075	10.08	10.41		10.40			10.32
7076	26.34	27.13	27.16	26.12	26.95	27.58	26.79

*Numbers given are seconds of longitude for satellite solutions.

Table 9

North American Latitude Comparisons*

Station No.	Marsh	SAO	Mueller Orbit	Mueller Geom.	Berbert	Hadgi-george
1021	49.79	50.08	50.62	50.08	49.74	49.69
1022	53.14		53.66	53.15	53.36	53.03
1030	47.89		47.70	47.63	47.91	
1034	21.53	21.20	22.04	21.11	21.46	21.09
1042	7.29	7.16	7.73	7.39	7.39	7.08
7036	46.52	46.26	46.84	46.50	46.80	46.39
7037	36.24	35.90	36.51	35.97	36.06	35.76
7039	49.93	49.59	49.98	49.33	49.38	49.54
7040	28.58	28.20	30.01	28.50	26.60	28.61
7043			16.28	15.78	15.50	
7045	48.14	47.97	48.57	47.91	47.90	47.64
7050	14.10	14.06				
7072	14.16		14.17	14.32	14.42	14.19
7075	21.53		21.98	21.23		21.08
7076	34.46	33.91	35.63	34.72	34.97	34.61

*Numbers given are seconds of latitude for satellite solutions.

APPENDIX A

BASIC DATA

Table A-1

Geocentric Station Positions

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
1021	38	25	49.79	282	54	48.61	-54	5.8
1022	26	32	53.14	278	8	4.16	-42	4.8
1024	-31	23	25.88	136	52	15.14	130	133
1028	-33	8	58.87	289	19	53.65	710	693.4
1030	35	19	47.89	243	5	58.92	876	929.1
1031	-25	53	1.44	27	42	26.21	1541	1522.3
1032	47	44	29.27	307	16	46.14	48	69
1034	48	1	21.53	262	59	19.51	203	252.6
1035	51	26	46.40	359	18	7.93	90	67.4
1037	35	12	7.28	277	7	41.16	850	909.3
1038	-35	37	32.68	148	57	14.85	950	932
1042	35	12	7.30	277	7	40.86	850	909.4
1043	-19	0	32.59	47	17	59.29	1360	1377.9
7036	26	22	46.52	261	40	7.25	8	59.6
7037	38	53	36.24	267	47	40.87	213	272.7
7039	32	21	49.93	295	20	35.41	-27	31.2
7040	18	15	28.58	294	0	23.53	-18	49.7
7045	39	38	48.14	255	23	38.47	1745	1789.6
7072	27	1	14.16	279	53	12.73	-37	14.2
7075	46	27	21.53	279	3	10.41	221	281.9
7076	18	4	34.46	283	11	27.13	405	445.9
8009	52	00	6.76	4	22	15.29	46	24.7
8010	46	52	37.18	7	27	53.35	933	903
8011	52	08	36.41	358	01	53.30	137	113
8015	43	55	57.55	5	42	44.74	694	657
8019	43	43	33.05	7	17	58.68	405	374

Table A-1 (Continued)

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
8030	48	48	22.64	2	13	45.94	190	165.4
9002	-25	57	36.66	28	14	52.35	1570	1544
9004	36	27	46.99	353	47	36.31	55	20
9006	29	21	33.31	79	27	27.07	1856	1927
9007	-16	27	57.20	288	30	24.53	2488	2452
9008	29	38	13.80	52	31	11.25	1564	1596
9009	12	5	25.04	291	9	44.66	-22	7
9011	-31	56	35.07	294	53	36.74	638	599
9012	20	42	25.67	203	44	34.12	3032	3034
9021	31	41	2.95	249	7	18.36	2339	2382
9028	8	44	50.71	38	57	32.98	1901	1923
9029	-5	55	41.39	324	50	7.21	44	43
9091								
9426	60	12	39.50	10	45	2.69	595	575.9
9432	48	38	1.46	22	17	54.88	205	190

Positions from Marsh, Douglas and Klosko (1971)

Reference ellipsoid: $a_e = 6.378155 \times 10^6$ m

$1/f = 298.25$

Table A-2

Geocentric Station Positions

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
7050	39	1	14.10	283	10	18.40	3	54.8
7052	37	51	36.00	284	29	24.00	-60	8.6
7054	-24	54	16.40	113	42	57.90	-5	31.4
1123	-19	1	14.50	47	18	11.40	1382	1399.0
1126	35	11	45.60	277	7	25.80	819	873.9
1128	64	58	19.00	212	29	12.10	340	346.6
1152	-24	54	11.40	113	42	58.90	1	37.9

Positions from Marsh, Douglas and Klosko (1971)

Reference ellipsoid: $a_e = 6.378155 \times 10^6$ m

$1/f = 298.25$

Table A-3

Geocentric Station Positions

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
1021	38	25	50.08	282	54	48.37	-36	5.8
1034	48	1	21.20	262	59	19.58	221	252.6
1042	35	12	7.16	277	7	40.83	860	909.4
7036	26	22	46.26	261	40	7.12	26	59.6
7037	38	53	35.90	267	47	40.83	231	272.7
7039	32	21	49.59	295	20	35.62	-5	31.2
7040	18	15	28.20	294	0	23.64	-3	49.7
7045	39	38	47.97	255	23	38.40	1769	1789.6
7050	39	1	14.06	283	10	18.29	13	54.8
7075	46	27	21.25	279	3	10.75	228	281.9
7076	18	4	33.91	283	11	27.16	436	445.9
7815	43	55	55.20	5	42	43.22	675	?
7816	37	45	13.29	22	49	39.06	801	?
7818	31	43	14.61	357	34	47.93	891	?
7901	32	25	24.63	253	26	48.37	1616	1651.3
8009	52	00	5.42	4	22	15.05	32	24.7
8010	46	52	36.38	7	27	52.82	917	903
8011	52	8	35.05	358	1	53.39	134	113.2
8015	43	55	57.15	5	42	44.08	677	647.0

Table A-3 (Continued)

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
8019	43	43	32.78	7	17	58.05	394	377.0
9001	32	25	24.63	253	26	48.37	1616	1651.3
9002	-25	57	36.51	28	14	52.31	1561	1544.0
9003	-31	6	3.16	136	47	3.00	157	162.0
9004	36	27	46.50	353	47	36.70	51	25.9
9005	35	40	22.53	139	32	15.92	87	59.8
9006	29	21	34.51	79	27	27.16	1866	1927
9007	-16	27	57.07	288	30	24.18	2481	2451.9
9008	29	38	13.39	52	31	10.67	1563	1596.0
9009	12	5	24.72	291	9	44.19	-23	7.4
9010	27	1	13.92	279	53	13.21	-24	15.1
9011	-31	56	35.27	294	53	36.52	632	598
9012	20	42	25.60	203	44	33.48	3033	3034.1
9021	31	41	2.87	249	7	18.17	2340	2382.0
9023	-31	23	26.73	136	52	43.33	138	141.0
9025	36	0	19.83	139	11	30.92	885	910.0
9028	8	44	51.40	38	57	33.15	1888	1923.0
9029	-5	55	40.21	324	50	7.25	21	45.0
9031	-45	53	12.70	292	23	9.56	186	200 (approx)

Table A-3 (Continued)

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
9050	42	30	21.28	288	26	30.48	138	184.0
9424	54	44	33.96	249	57	22.68	670	704.6
9425	34	57	50.47	242	5	7.54	747	784.2
9426	60	12	38.66	10	45	3.16	584	575.9
9427	16	44	38.44	190	29	8.64	5	5.0
9428	56	56	54.55	24	3	29.90	-19	8.0
9432	48	38	1.33	22	17	53.08	187	189.0

Positions from Gaposchkin and Lambeck (1969)

Reference ellipsoid $a_e = 6.378155 \times 10^6$ m

$1/f = 298.25$

Table A-4

Geocentric Station Positions

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
4050	-25	56	38.70	28	21	28.30	1585	1584.0
4061	17	8	36.80	298	12	26.00	-19	42.0
4080	-7	58	21.20	345	35	54.60	121	125.0
4081	21	27	45.10	288	52	3.40	-58	36.0
4082	28	25	28.90	279	20	7.20	-35	11.0
4280	34	39	57.40	239	25	6.70	84	123.0
4402	22	8	2.60	200	16	18.30	478	?
4451	16	45	53.40	190	28	59.30	-14	7.0
4610	39	18	30.20	244	54	47.10	2762	?
4720	27	45	46.60	344	21	58.10	186	?
4740	32	20	52.90	295	20	46.80	-41	20.0
4741	-19	0	7.00	47	18	52.60	1329	1338.0
4742	22	7	23.40	200	20	3.10	1158	1155.0
4760	32	20	52.40	295	20	47.00	-40	21.0
4761	-24	53	47.40	113	43	1.70	39	49.0
4840	37	50	28.90	284	30	53.10	-54	12.0
4860	37	51	37.00	284	29	25.90	-52	15.0
4946	-30	49	6.90	136	50	17.80	98	128.0
7054	-24	54	16.87	113	42	58.60	0	11.0

Positions from Leitao and Brooks (1970)

Reference ellipsoid: $a_e = 6.378155 \times 10^6$ m

$1/f = 298.25$

TABLE A-5

GEOCENTRIC STATION POSITIONS

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
3648	32	00	6.45	278	50	46.12	-35	13
5001	38	59	37.95	282	40	16.87	73	128
5333	33	25	32.80	269	05	9.88	-1	39
5861	25	29	22.52	279	37	39.27	-37	6
7051	35	11	46.74	277	07	25.74	835	879
3405	21	25	48.59	288	51	14.59	-58	2
3402	30	46	49.96	271	44	51.48	27	73
3657	39	28	19.14	283	55	44.76	-49	6
3106	17	08	54.69	298	12	39.50	-61	2
3401	42	27	17.82	288	43	35.42	35	83
7040	18	15	28.61	294	00	23.35	-10	50
1022	26	32	53.03	278	08	3.71	-33	5
1034	48	01	21.09	262	59	19.13	216	253
7037	38	53	35.75	267	47	40.62	228	273
7036	26	22	46.39	261	40	07.09	28	60
7039	32	21	49.54	295	20	34.76	-20	31
7075	46	27	21.08	279	03	10.32	233	28
3649	27	01	14.28	279	53	12.67	-32	15
3404	17	24	19.16	276	03	29.25	11	40
3406	12	05	25.76	291	09	44.05	-54	7

TABLE A-5 - (CONTINUED)

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
3407	10	44	35.54	298	23	24.33	180	255
1021	38	25	49.69	282	54	48.43	-47	6
7043	39	01	15.37	283	10	20.62	-1	54
7045	39	38	47.64	255	23	38.41	1764	1790
7072	27	01	14.19	279	53	12.31	-30	14
7076	18	04	34.61	283	11	26.79	422	446

Positions from Hadgigeorge (1970)

Reference ellipsoid: a_e = 6378155 m

$1/f$ = 298.25

TABLE A-6

GEOCENTRIC STATION POSITIONS

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
3402	30	46	50.21	271	44	51.32	6	73
3648	32	0	6.61	278	50	46.29	-55	13
3657	39	28	19.49	283	55	44.77	-66	6
3861	25	30	26.29	279	36	42.94	-62	0
3404	17	24	19.33	276	3	28.86	-35	40
3405	21	25	48.32	288	51	14.87	-91	2
3406	12	5	26.23	291	9	43.83	-54	7
3106	17	8	54.95	298	12	39.47	-73	2
1030	35	19	47.63	243	5	58.59	871	929
1021	38	25	50.08	282	54	48.30	-67	6
1034	48	1	21.11	262	59	19.19	203	253
1042	35	12	7.39	277	7	40.22	845	909
7036	26	22	46.50	261	40	7.17	19	60
7037	38	53	35.97	267	47	40.54	220	273
7039	32	21	49.33	295	20	35.23	-45	31
7040	18	15	28.50	294	0	23.51	-20	50
7043	39	1	15.78	283	10	20.38	-28	54
7045	39	38	47.91	255	23	38.69	1753	1790
7072	27	1	14.32	279	53	12.40	-46	14
7075	46	27	21.23	279	3	10.14	222	282
7076	18	4	34.72	283	11	26.95	408	446
3401	42	27	20.63	288	43	35.89	75	83
1022	26	32	53.15	278	8	3.72	-48	5

Positions from Mueller, et al, (Geom.) (1970)

Reference ellipsoid a_e = 6378155 m

$1/f$ = 298.25

TABLE A-

GEOCENTRIC STATION POSITION

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
3402	30	46	50.48	271	44	51.07	0	73
3648	32	0	7.06	278	50	46.31	-44	13
3657	39	28	20.05	283	55	44.75	-62	6
3861	25	30	26.76	279	36	43.00	-51	0
3404	17	24	20.60	276	3	28.92	-25	40
3405	21	25	49.66	288	51	13.85	-72	2
3406	12	5	27.11	291	9	43.30	-74	7
3106	17	8	56.50	298	12	38.61	-76	2
1030	35	19	47.7	243	5	57.23	872	929
1021	38	25	50.61	282	54	47.8	-54	6
1034	48	1	22.04	262	59	18.90	206	253
7036	26	22	46.84	261	40	6.90	26	60
7037	38	53	36.51	267	47	40.53	221	273
7039	32	21	49.98	295	20	35.12	-43	31
7040	18	15	30.01	294	0	21.88	-5	50
7043	39	1	16.28	283	10	20.89	-37	54
7045	39	38	48.57	255	23	37.99	1752	1790
7072	27	1	14.17	279	53	11.67	-33	14
7075	46	27	21.98	279	3	10.39	228	282
7076	18	4	35.63	283	11	26.11	423	446
3401	42	27	18.76	288	43	34.92	38	83
1022	26	32	53.66	278	8	3.78	-40	5

Positions from Mueller, et.al. (orbital) (1970)

Reference ellipsoid a_e = 6378155 m

$1/f$ = 298.25

TABLE A-7

GEOCENTRIC STATION POSITIONS

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
1021	38	25	49.74	282	54	48.84	-34	6
7072	27	01	14.42	279	53	12.49	-40	14
1022	26	32	53.36	278	08	3.80	-44	5
7039	32	21	48.38	295	20	36.15	-28	31
7037	38	53	36.06	267	47	40.63	222	273
7045	39	38	47.90	255	23	38.20	1760	1790
7036	26	22	46.80	261	40	6.89	21	60
1034	48	01	21.46	262	59	19.07	208	253
7076	18	04	34.97	283	11	27.58	395	446
1030	35	19	47.91	243	05	58.45	887	929
7040	18	15	26.60	294	00	22.04	31	50
1042	35	12	7.39	277	07	40.9	856	909

Positions from Loveless, et al (1970)

Reference ellipsoid a_e = 6378155 m

$1/f$ = 298.25

TABLE A-8

GEOCENTRIC STATION POSITIONS

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
6001	76	30	4.68	291	27	54.43	178	215
6002	39	1	39.23	283	10	27.36	1	44
6003	47	11	6.50	240	39	42.70	325	369
6004	52	42	48.01	174	7	26.04	30	37
6006	69	39	45.24	18	56	25.69	67	106
6007	38	45	35.36	332	54	23.67	110	53
6011	20	42	26.64	203	44	37.69	3027	3049
6012	19	17	28.25	166	36	39.79	10	4
6015	36	14	23.12	59	37	47.09	992	991
6016	37	26	37.79	15	2	43.10	33	9
6038	18	43	58.18	249	2	41.02	-4	23
6065	47	48	2.79	11	1	24.01	940	943

Position from Mancini, et al (1970)

Reference ellipsoid a_e = 6378155 m

1/5 = 298.25

TABLE A-9

GEOCENTRIC STATION POSITIONS

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
3333	33	28	49.40	268	59	47.74	-5	40
3402	30	46	50.09	271	44	51.05	23	2
3647	30	14	48.95	271	55	17.07	-47	1
3648	32	0	6.50	278	50	45.76	-38	13(app.)
3657	39	28	19.05	283	55	45.31	-49	6
3861	25	30	26.05	279	36	42.85	-42	1
3404	17	24	19.17	276	3	29.53	-4	40
3405	21	25	49.02	288	51	14.72	-49	2
3406	12	5	25.59	291	9	44.89	-35	7
3106	17	8	54.65	298	12	39.54	-34	73
3407	10	44	34.51	298	23	22.51	212	255

Positions from ACIC Technical Report No. 105

Reference ellipsoid a_e = 6378155 m

$1/f$ = 298.25

Table A-10

Geocentric Station Positions

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
2	30	17	18.28	262	16	4.07	170	184
10	18	56	19.16	204	19	4.20	99	92
14	61	16	59.99	210	10	27.78	66	68
17	-14	19	50.19	189	17	2.02	34	6
49	18	27	18.23	293	47	8.40	-26	8
100	21	31	15.42	202	0	9.04	404	388
103	32	16	44.09	253	14	44.71	1167	1203
111	39	9	48.29	283	6	10.80	102	145
200	34	6	40.95	240	53	8.14	-49	3
400	44	24	21.22	292	1	9.85	-13	21
702	24	17	40.72	153	58	54.56	12	6
706	-2	47	35.25	188	20	3.37	7	5
710	41	4	44.34	275	3	22.24	213	249
711	36	7	29.65	262	47	3.21	292	316
712	24	46	49.08	141	19	37.93	159	114
713	26	21	48.20	127	44	14.60	41	15
715	13	28	3.04	144	43	27.25	241	189
718	16	44	4.61	190	28	31.01	28	8
719	22	7	34.68	200	20	3.82	1168	1150

Table A-10 (Continued)

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
720	34	37	1.98	239	26	22.99	273	311
724	28	11	48.79	182	36	40.13	8	6
734	25	30	27.26	279	36	42.58	−24	8
735	32	0	4.65	278	50	42.19	−16	19
736	30	46	50.69	271	44	50.62	32	79
737	35	18	10.99	243	12	49.22	979	1028
738	47	11	7.21	240	39	42.10	344	372
739	52	42	55.27	174	6	38.46	43	44
740	64	29	47.47	194	36	0.97	11	14
741	32	25	24.67	253	26	48.63	1624	1655
742	39	1	39.93	283	10	27.03	6	50
745	33	25	31.91	269	5	8.74	6	44
747	41	8	0.10	255	7	53.51	1860	1888
748	47	56	38.63	262	37	7.27	239	277
112	-34	40	26.37	138	39	15.85	20	27
707	-12	27	13.17	130	48	54.73	57	18
709	-31	36	25.66	115	55	51.79	49	92
723	-12	11	44.91	96	50	3.45	−40	27

Table A-10 (Continued)

Station No.	Latitude			Longitude			Height Above Ellipsoid (meters)	Height Above MSL (meters)
	Deg.	Min.	Seconds	Deg.	Min.	Seconds		
725	-19	15	24.74	146	42	58.23	51	13
726	-2	3	2.69	147	21	36.65	129	57
743	-31	23	25.62	136	52	41.26	132	143
744	-10	35	0.75	142	12	39.21	142	59
749	-35	24	12.97	148	58	55.58	649	646
805	-30	18	33.43	149	33	39.02	266	250

Reference ellipsoid a_e = 6378155

$1/f$ = 298.25

Stations: 112, 707, 709, 723, 725, 726, 743, 744, 749, 805 from Bomford (1970)

All others from Anderle et al. (1967)