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A CATALOG OF STATION COORDINATES FOR GEOS–C ORBIT DETERMINATION

Abstract

Center–of–mass coordinates for 57 tracking sites participating in the GEOS–C mission are given in a unified system having a common origin and scale. The positions were obtained either directly from analyses of satellite observations or from survey ties to colocated sites with coordinates previously determined by various investigators from optical, laser of doppler data. The uncertainty of the positions in nearly all cases is 5m in each coordinate. Data reductions show that station coordinates of this quality introduce a rapidly changing error into the altitude of a satellite unless global tracking constrains the orbit.

Section 1 . 0

Introduction

The GEOS–C satellite (to be launched in the Spring of 1975) will carry equipment for doppler, laser, and C–Band and S–Band radar tracking. To determine definitive orbits from combinations of these data, it is necessary for the coordinates of the tracking instruments to be referred to a common origin and to have a common scale. This catalog is consistent with the GSFC 1973 solution of Marsh, Douglas, and Klosko (1973). For those cases where satisfactory center–of–mass (COM) coordinates were unavailable, coordinates were obtained from survey ties to colocated stations with known center–of–mass positions. In the few cases where survey coordinates are currently unavailable, we quote the (COM–local) differences which can be applied when surveys have been made. All survey information was taken from the NASA Directory of Observation Station Locations (1973).

Section 2.0

Computation of Station Coordinates

The primary source for this catalog was the global optical/laser solution GSFC 1973 obtained by Marsh, Douglas, and Klosko (1973). This solution used optical and laser data to estimate dynamically center–of–mass coordinates for 58 optical and 14 laser stations. These sufficed to provide coordinates or (COM–local) differences for 48 of the 80 stations listed in this catalog. The GSFC 1973 solution is referred to as G 73 in the lists of sources.

Other solutions were used to obtain coordinates or (COM–local) differences for the remaining stations. The island Unified S–Band (USB) radar sites were obtained from the Lunar Module surface tracking data solution (W74) of Walls (1974) after adjustment for a longitude rotation. GEOS–C calibration area laser and C–Band radar site coordinates were taken from the combined laser/C–Band radar solution (MDW74) of Marsh, Douglas, and Walls (1974) with adjustment of the latitudes for consistency with G73. The position of the C–Band radar site at Antigua was given in the G73 system by the (KK) solution of Krabill and Klosko (1974). Doppler station coordinates were taken in certain cases from the (NWL) solution of Anderle and Tanenbaum (1974) after adjustment for scale and longitude origin, unfortunately introducing additional error due to the uncertainty of the transformation. In other cases, doppler stations were obtained from survey data to colocated G73 stations. Unfortunately, survey data or COM coordinates are not available for many of the doppler sites.

At this writing, some instruments have not been moved to planned GEOS–C sites. For these cases, the (COM–local) difference is given so that center–of–mass coordinates can be calculated when surveys become available. These cases are obvious in the tables since the differences are always less than 1000 m in absolute value.

The values of the (COM–local) differences used to compute station coordinates are given in Table 1. Tables 2–6 present the coordinates or (COM–local) differences for the participating stations given in the *GEOS–C Mission Plan* (1974). Only a slight degradation of accuracy over the original solutions upon which this catalog is based should have occurred except as previously noted. Thus in most cases, the positions in this catalog should be essentially as accurate as the solutions used in their derivation. The uncertainty of the positions is estimated to be 5 m in each coordinate except as shown.

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Section 3 . 0

Orbit Determination Accuracy

In the early phase of the GEOS–C mission, the altimeter will be used heavily in the altimeter calibration area off the southeast coast of the United States in order to verify the performance of the altimeter system. For logistical reasons it is attractive to determine orbits from data in the calibration area alone. Thus, it is important to consider what effect station coordinate uncertainty will have on the position of a satellite whose orbit is determined only with calibration area data. To investigate this we considered a 2–revolution GEOS–2 orbit determined from 3 passes of data over the calibration area. On the first pass there was simultaneous tracking from one Wallops radar, both Bermuda radars, and the instrument at Grand Turk. These stations also tracked on the next pass with the addition of the radar at Merritt Island. On the final pass there was laser tracking from Mt. Hopkins and radar data from Merritt Island. This orbit was determined twice with only the spheroid height of the Wallops radar (4860) differing by three meters between the solutions. The effect of this difference on the height of the satellite is shown in Figure 1. Note that during a pass the difference in height between the two solutions changes by about 8m. However, the overall rms fit for the 2 solutions differed negligibly, i.e., from a statistical point of view one solution would not be favored over the other. It is obvious that orbits determined this way are unsuitable for altimetric investigations of geoidal undulations.

The reason for the rapidly changing error is to be found in the dynamics of the orbit determination process. In order to minimize residuals in the presence of model error, orbit uncertainty becomes very large where there is no tracking. The dynamical properties of the orbit cause the model error effect to be sinusoidal (as in Figure 1) with the result that the error is small, but *changing rapidly* during the tracking periods. Marsh and Douglas (1971) demonstrated that for arc lengths of a few revolutions, if tracking coverage is global the height uncertainty of the satellite varies slowly, a much more favorable situation for studying variations of the geoid with altimeter data.

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REFERENCES

1.– R.J. ANDERLE, "Transformation of Terrestrial Survey Data to Doppler Satellite Datum", presented at the IAG Symposium on Computation Methods in Geometric Geodesy, Oxford, September 1973, also to be published in the Journal of Geophysical Research.

2.– R.J. ANDERLE, M.G. TANENBAUM, "Practical Realization of a Reference System for Earth Dynamics by Satellite Methods", NWL TR–3166, June 1974.

3.– ."GEOS–C Mission Plan" TK–6340–001, Wallops Station, May 1974.

4.– W.B. KRABILL, S.M. KLOSKO, "C–Band Station Coordinate Determination for the GEOS–C Altimeter Calibration Area", NASA TMS–69356, October 1974.

5.– J.G. MARSH, B.C. DOUGLAS, "Ocean Height Measurement by Satellite Altimetry", Journal of Spacecraft and Rockets, Vol. 8, No. 5, May 1971, pp. 543 – 546.

6.– J.G. MARSH, B.C. DOUGLAS, S.M. KLOSKO, "A Global Station Coordinate Solution Based upon Camera and Laser Data – GSFC 1973", GSFC Document X–592–73–171, May 1973.

7.– J.G. MARSH, B.C. DOUGLAS, D.M. WALLS, "Station Coordinates for GEOS–C Altimeter Calibration and Experimentation", GSFC Document X–921–74242, August 1974.

8.– "NASA Directory of Observation Station Locations", prepared by Computer Sciences Corporation for Goddard Space Flight Center, November 1973.

9.– D.M. WALLS, N.L. BOULWARE, "Final Technical Report for Station Coordinates from USB Range Rate Tracking of a Lunar Transponder", NASA/GSFC Contract Number NAS 5–11942 Task 105, July 1974.

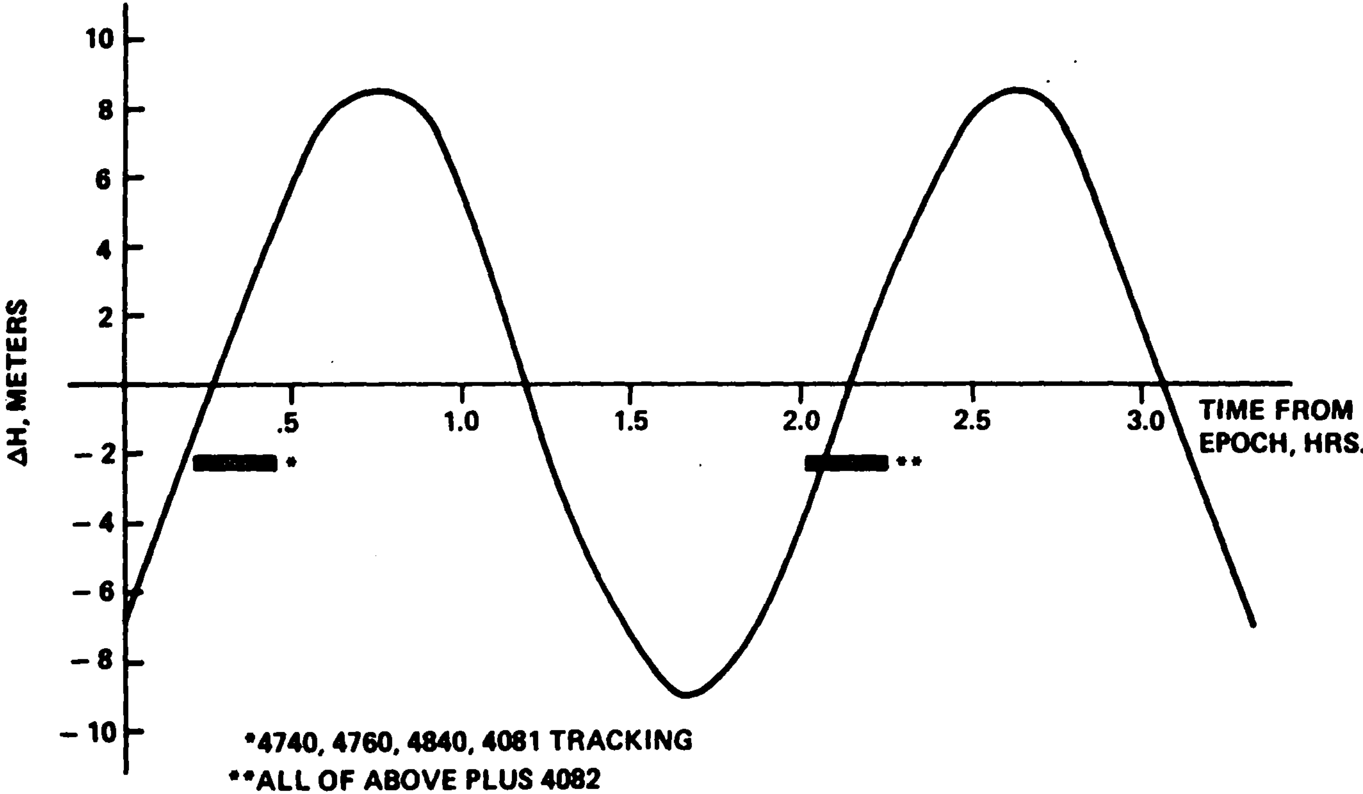

Figure 1. Effect on Satellite Height of a 3m Error at Wallops Island

TABLE 1. (COM-LOCAL) DIFFERENCES, METERS

Station (NASA Directory I.D.)	Source	Datum	Δx	Δy	Δz
1024	G73	AGD	-139.3	-43.6	137.1
1028	G73	SAD69	-78.2	11.4	-21.2
1030	G73	NAD27	-19.0	145.0	182.4
1033	G73	NAD27	-12.6	147.3	180.8
1035	G73	EUR50	-80.1	-99.5	-112.1
1036	G73	NAD27	-13.9	133.6	182.2
1038	G73	AGD	-137.1	-41.4	138.7
1042	G73	NAD27	-8.4	158.3	178.1
1043	G73	TANAN	-179.3	-239.1	-111.6
7039	G73	BER57	-70.8	218.7	301.3
7050*	G73	NAD27	-15.5	163.2	190.9
7054	G73	AGD	-129.4	-39.6	138.1
7060	G73	GUAM	-102.2	-243.9	252.3
8010	G73	EUR50	-82.3	-97.7	-107.4
8019	G73	EUR50	-79.3	-100.1	-111.7
9001	G73	NAD27	-12.0	143.1	178.4
9002	G73	ARC	-131.3	-111.1	-297.3
9004	G73	EUR50	-88.8	-113.0	-124.6
9005	G73	TOKYO	-156.2	495.5	679.6
9009	G73	SAD69	-37.1	4.7	-28.9
9021	G73	NAD27	-15.3	148.3	178.8
9023	G73	AGD	-139.4	-43.7	137.1
9427	G73	JHSTN61	194.3	-88.1	-206.4
9907	G73	SAD69	-69.8	7.8	-47.8
4081	MDW**	NAD27	-9.0	171.1	171.6
4082	MDW**	NAD27	-7.0	159.1	176.6
4740	MDW**	BER57	-72.7	222.4	301.6
4860	MDW**	NAD27	-15.2	163.8	187.2
USB6	W74***	ASC58	-216.2	101.7	62.1
USB11	W74***	OLD HAW	42.9	-286.5	-192.1
2727	NWL-9D	GRACIOSA IS.	-101.5	161.0	-36.1

* Height from Marsh and Vincent (1974).

** 0".15 added to latitudes to coincide with GSFC 1973.

*** Rotated into the G73 system.

TABLE 2. C-BAND RADARS

Station (NASA Directory I.D.)	Name	Location	Source	X (Meters)	Y (Meters)	Z (Meters)
4061	ETRANT	Antig.Is.,WIAS	KK	2881623.3	-5372504.0	1868030.5
4080*	ETRAS8	Ascension Is.	W74(USB6)	6118533.1	-1571119.1	-878787.2
4081	ETRGRT	Grand Turk Is., Bahama Is.	MDW	1920444.2	-5619408.7	2319134.3
4082	ETRMRT	Merritt Is.,Fla.	MDW	910594.9	-5539103.8	3017972.6
4148	WSG218	Utah	G73(9021)	-15.3(NAD27)	148.3	178.8
4143	WSC113	White Sands,N.M.	G73(9021)	-15.3(NAD27)	148.3	178.8
4260	WTRPPQ	Pillar Pt., Calif.	G73(1030)	-19.0(NAD27)	145.0	182.4
4280	WTRVAN	Vandenberg AFB,Ca.	G73(1030)	-2671855.2	-4521206.1	3607487.2
4282	WTRKPT	Hawaii	W74(USB11)	42.9(OLD HAW)	-286.5	-192.1
4451*	PMRJI3	Johnston Is.	G73(9427)	-6006908.2	-1111984.6	1827283.7
4690	NELYNV	Ely, Nevada	G73(1030)	-2096149.1	-4477498.5	4020662.3
4741	NTANAN	Tananarive, Madagascar	G73(1043)	4090867.3	4435523.3	-2063951.1
4760	NBEROS	Bermuda	MDW	2308916.2	-4874292.4	3393089.8
4761	NCARNV	Carnarvon, Australia	G73(7054)	-2328440.2	5299967.0	-2668667.2
4860	NWALI3	Wallops Is.,Va.	MDW	1261604.9	-4881553.3	3893200.5
4946	WOOR38	Woomera,Aust.	G73(1024)	-3999046.4	3750326.4	-3248682.3
4948	RAEAB4	England	G73(1035)	-80.1(EUR50)	-99.5	-112.1
8501*	KOUROU	Kourou,Fr.Guiana	G73(9009)	-37.1(SAD69)	4.7	-28.9
4954	HOURTN	France	G73(8019)	-79.3(EUR50)	-100.1	-111.7
4959	AZORES	Azores	NWL-9D(2727)	-101.5 (GRACIOSA IS.)	161.0	-36.1
4960	MUNICH	Germany	G73(8010)	-82.3(EUR50)	-97.7	-107.4
	PRMPMI	Pt. Mugu, Calif.	G73(1030)	-19.0(NAD27)	145.0	182.4
	AECM35	Nevada	G73(1030)	-19.0(NAD27)	145.0	182.4
	HUELVA	Huelva, Spain	G73(9004)	-88.8(EUR50)	-113.0	-124.6
	ETR313	Grand Bahama Is.	MDW(4082)	-7.0(NAD27)	159.1	176.6

*10 meter associated uncertainty

TABLE 3. LASER RANGING STATIONS

Station (NASA Directory I.D.)	Name	Location	Source	X (Meters)	Y (Meters)	Z (Meters)
7063	STALAS	Greenbelt, Md.	G73(7050)	1130710.8	-4831371.0	3994095.6
7066	WFCLAS	Wallops Is.,Va.	MDW(4860)	-15.2(NAD27)	163.8	187.2
7067	ML0103	Bermuda	MDW(7039)	2308542.4	-4874081.0	3393636.8
7068	ML0204	Grand Turk,Bah.Is.	MDW(4081)	-9.0(NAD27)	171.1	171.6
7069	RAMLAS	Patrick AFB, Fla.	MDW(4082)	-7.0(NAD27)	159.1	176.6
7070	ML0203	Wallops Is.,Va.	MDW(4860)	1261563.2	-4881570.2	3893183.2
7080	ML0301	Greenbelt, Md.	G73(7050)	-15.5(NAD27)	163.2	190.9
7081	ML0302	Patrick AFB, Fla.	MDW(4082)	-7.0(NAD27)	159.1	176.6
8021	MICLAS	St.Michel,France	G73(8019)	4578356.7	457982.3	4403181.2
8022	SALLAS	Salisbury,Aust.	G73(1024)	-3939163.4	3467057.0	-3613265.6
8804	SAFLAS	San Fernando,Spain	G73	5105613.6	-555238.5	3769645.1
9902	OLILAS	Olifantsfontein, Rep.of So.Africa	G73	5056127.0	2716522.1	-2775767.4
9907	ARELAS	Arequipa,Peru	G73	1942789.5	-5804079.4	-1796924.4
9921	HOPLAS	Mt.Hopkins,Ariz.	G73	-1936766.1	-5077708.3	3331923.3
9925	DODLAS	Dodaira, Japan	G73(9005)	-3910434.2	3376352.4	3729220.4
9929	NATLAS	Natal, Brazil	G73	5186473.6	-3653860.3	-654326.9
9930	GRELAS	Dionysos, Greece	G73	4595219.4	2039458.0	3912620.4

TABLE 4. DOPPLER TRACKING SITES (PARTIAL LIST)

Station (NASA Directory I.D.)	Name	Location	Source	X (Meters)	Y (Meters)	Z (Meters)
2008	SANHES	São Jose Dos Campos, Brazil	G73(SAD69)	4083885.8	-4209797.3	-2499129.2
2013	MISAWA	Misawa AFB, Japan	G73(9005)	-3779659.3	3024698.5	4138997.0
2014	ANCHOR	Anchorage, Alaska	G73(1036)	-2656182.3	-1544370.7	5570650.5
2018*	THOLEG	Thule, Greenland	NWL-9D	539401.0	-1388382.4	6181057.1
2019*	MCMRDO	McMurdo St., Ant.	NWL-9D	-1310715.4	310468.3	-6213371.8
2020*	MAHEIS	Mahe Is., Seychelle Is.	NWL-9D	3602889.4	5238227.6	-515938.4
2103	LACRES	Las Cruces, N.M.	G73(9001)	-1556205.7	-5169455.3	3387255.1
2106	LASHAM	Lasham, England	G73(1035)	4005448.8	-71760.5	4946720.5
2111	APLMND	Howard Co., Md.	G73(7050)	1122652.3	-4823041.8	4006475.1
2112	SMITHF	Smithfield, Aust.	G73(9023)	-3942245.0	3468860.8	-3608206.5
2115	PRETOR	Pretoria, Rep. of SA	G73(9002)	5051983.9	2725644.8	-2774464.0
2117*	ASAMOA	Tafuna, Am. Samoa	NWL-9D	-6100021.1	-997187.1	-1568467.0
2203	WALDOP	Wallops Is., Va.	MDW(4860)	-15.2(NAD27)	163.8	187.2
2708*	WAKEIS	Wake Is.	NWL-9D	-5858519.8	1394534.8	2093938.5
2717*	SEYCHL	Mahé, Seychelles	NWL-9D	3602884.4	5238228.5	-515925.6
2722*	ASCION	Ascension Is.	NWL-9D	6118439.6	-1571570.2	-878448.0
2727*	TERCRA	Terceira, Azores	NWL-9D	4433609.0	-2268168.0	3971698.8
2739*	SHEMAL	Shemya Is., Alaska	NWL-9D	-3851523.7	397254.6	5051465.0
2850	BERDOP	Bermuda Is.	MDW(4740)	-72.7(BER57)	222.4	301.6
2851	GTKDOP	Grand Turk Is., Bahama Is.	MDW(4081)	-9.0(NAD27)	171.1	171.6
2852	MLADOP	Merritt Is., Fla.	MDW(4082)	-7.0(NAD27)	159.1	176.6

*10 meter associated uncertainty because of transformation uncertainty.

TABLE 5. S-BAND RADARS

Station (NASA Directory I.D.)	Name	Location	Source	X (Meters)	Y (Meters)	Z (Meters)
USB1	MILTKS	Merritt Is., Fla.	MDW(4082)	907077.1	-5535214.3	3026098.3
USB3	BDATKS	Bermuda	MDW(4740)	2308455.0	-4874294.1	3393402.2
USB6*	ACNTKS	Ascension Is.	W74	6121225.2	-1563372.5	-876906.0
USB7	MADTKS	Madrid, Spain	G73(9004)	4847823.3	-353327.8	4117135.9
USB9	GWMTKS	Guam	G73(7060)	-5068921.3	3584111.3	1458902.8
USB11	HAWTKS	Kauai, Hawaii	W74	-5543855.1	-2054562.8	2387796.0
USB12	GD8TKS	Goldstone, Calif.	G73(1030)	-2354767.4	-4646790.7	3669386.9
USB17	GD3TKS	Goldstone, Calif.	G73(1030)	-2354711.0	-4646814.4	3669383.7
USB19	AGOTKS	Santiago, Chile	G73(1028)	1769860.6	-5044474.8	-3468402.6
1128 *	ULASKR	Fairbanks, Alaska	G73(1033)	-2282495.0	-1453369.7	5756717.2
1126	ROSRAN	Rosman, N.C.	G73(1042)	647204.8	-5178328.1	3656140.9
1123	TANANR	Tananarive, Mad.	G73(1043)	4091337.1	4434236.5	-2065958.0
S40 3	QUITKS	Quito, Ecuador	G73(9907)	1263418.3	-6255038.5	-68952.3
S85 4	ORRTKS	Orroral, Australia	G73(1038)	-4447391.3	2676809.3	-3695447.5

*10 meter associated uncertainty

TABLE 6. SATELLITE-TO-SATELLITE EXPERIMENT STATIONS

Station (NASA Directory I.D.)	Name	Location	Source	X (Meters)	Y (Meters)	Z (Meters)
S40 5	ATSMOJ	Goldstone, Calif.	G73(1030)	-2356175.4	-4646759.5	3668471.2
S85 2	ATSROS	Rosman, N.Carolina	G73(1042)	647213.4	-5178148.1	3656416.4
	ATSMAD	Madrid	G73(9004)	-88.8(EUR50)	-113.0	-124.6