X-921-74-242

PREPRINT

NASA TM X- 70762

STATION COORDINATES FOR GEOS-C ALTIMETER CALIBRATION AND EXPERIMENTATION

J. G. MARSH
B. C. DOUGLAS
D. M. WALLS

(NASA-TM-X-70762) STATION COORDINATES FOR GEOS-C ALTIMETER CALIBRATION AND EXPERIMENTATION (NASA) 26 p HC $3.75 CSCL 14B
N75-10413
Unclas
G3/35 53704

AUGUST 1974

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

For information concerning availability
of this document contact:

Technical Information Division, Code 250
Goddard Space Flight Center
Greenbelt, Maryland 20771

(Telephone 301-982-4488)

STATION COORDINATES

FOR GEOS-C

ALTIMETER CALIBRATION

AND EXPERIMENTATION

J. G. Marsh
Goddard Space Flight Center

B. C. Douglas*
D. M. Walls
Wolf Research and Development Corporation

August 1974

*Presently with the National Oceanic and Atmospheric Administration/National Ocean Survey, Rockville, Maryland.

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

STATION COORDINATES FOR GEOS-C ALTIMETER CALIBRATION AND EXPERIMENTATION

J. G. Marsh
Goddard Space Flight Center

B. C. Douglas*
D. M. Walls
Wolf Research and Development Corporation

ABSTRACT

Station coordinates are given for the C-Band radar GEOS-C altimeter calibration sites at Bermuda, Merritt, Grand Turk, and Wallops Islands. The coordinates were estimated in a multi-arc dynamic solution using GEOS-2 C-Band radar and laser ranges with a priori information from the GSFC-1973 station coordinate solution. Comparisons with other solutions suggest a relative uncertainty of a few meters in each coordinate. Data reductions show that station coordinates of this quality can introduce a rapidly changing error into the altitude of a satellite whose orbit is determined from calibration area data alone. In contrast, global tracking constrains the orbit and results in slowly varying satellite position error.

*Presently with the National Oceanic and Atmospheric Administration/National Ocean Survey, Rockville, Maryland.

ECEDING PAGE BLANK NOT FILMED

CONTENTS

ILLUSTRATIONS

TABLES

STATION COORDINATES
FOR GEOS-C
ALTIMETER CALIBRATION
AND EXPERIMENTATION

INTRODUCTION

The GEOS-C altimeter will measure sea-surface topography over a large portion of the globe. For this data to reach its full potential the instrument must be calibrated, requiring accurate knowledge of satellite position during the calibration phase of the mission. To minimize the effects of geopotential uncertainty, heavily tracked orbital arcs of a few revolutions will probably be used to determine orbits. However, such arcs can be significantly degraded due to uncertainty of the tracking station coordinates. Thus we undertook a project to review, and improve if possible, the quality of tracking station coordinates for the critical GEOS-C altimeter calibration area. The sites considered were at Wallops, Bermuda, Merritt, and Grand Turk Islands. Antigua, in close proximity to the altimeter calibration area, was also considered. However, only five passes of C-Band data from this station were available to us which could be included in the analysis. Therefore the adjusted coordinate values for this station are not presented.

The solution presented here is accurate to perhaps two meters (relatively) in each coordinate with possible systematic errors of equal or larger magnitude. This is an improvement over previously available results, but not as accurate as required to extract all of the information inherent in the GEOS-C altimeter data. Further improvement awaits tracking data from other systems, i.e., lasers, USB-Radars, and Doppler in addition to the C-Band data taken during the GEOS-C mission.

CURRENT STATUS OF CALIBRATION SITE COORDINATES

Many investigators have determined North American Datum (NAD) or Center of Mass (COM) coordinates for C-Band radar stations in the calibration area. However, there has been no single solution in a center of mass system for all 4 sites. Table 1 lists the available solutions and presents some of their details.

Evaluation of the existing solutions is difficult because in only two cases can comparisons independent of satellite data be made. One case is the chord between the Wallops and Merritt Island sites. The recent geodimeter traverse (Meade, 1974) showed that NAD 1927 chord lengths up the East Coast of the United States were too small by 11m for the Wallops-Merritt chord. Table 2 presents the differences between satellite-derived chords and the geodimeter traverse result. The new solution presented in this paper gives agreement to 2.7m for this chord.

The second independent comparison is with the detailed gravimetric geoid of Marsh and Vincent (1974). This global $1^{\circ} \times 1^{\circ}$ geoid was computed from a combination of satellite and surface gravity data and has a precision of about 2m over well surveyed land areas and perhaps twice this figure in ocean areas where surface gravity data is available. Note in Table 3 that differences exist of up to 7m in slope between the detailed geoid and the satellite-derived geocentric solutions. (Not all solutions are shown in Table 3 because some of the available solutions are given on the NAD and cannot be compared in this fashion.)

ESTIMATION OF DATA BIASES

The GEOS-2 C-Band Experiment showed that biases of several meters can exist in the range data. This is serious because a range bias resembles station height error for high elevation data. In fact we could not obtain an unambiguous simultaneous solution for station heights and range biases from our data set.

Direct evidence of range bias can be seen for the Bermuda and Wallops Island sites. There are two C-Band radars at each of these sites and on some occasions simultaneous tracking was achieved. During simultaneous tracking the difference in bias between colocated radars is real regardless of the position uncertainty of the satellite. Table 4 shows the biases obtained for these sites from a 10 arc solution for biases and station coordinates. Notice that the bias differences for the Bermuda and Wallops radars are smaller than the absolute biases, suggesting that the biases are contaminated by satellite and/or station position error.

The Merritt and Grand Turk instruments are more difficult to evaluate. However, it was found that for these sites the smallest apparent biases (1-3 meters) were obtained when the station heights were held fixed at the heights implied by the station mean sea level heights and the gravimetric geoid heights of Marsh and Vincent (1974). Apparently our solution is not strong enough to permit recovery of station heights and biases simultaneously. But the average bias obtained with the heights fixed for all but the Bermuda site was 3m or less, indicating that substantial error in the heights of Wallops, Merritt and Grand Turk due to data bias is unlikely. In the case of Bermuda, biases were adjusted on each pass of data because of the demonstrated existence of biases of up to 8-9 meters.

DETERMINATION OF STATION COORDINATES

Our investigation took two steps. The first was an attempt to determine station coordinates from February and October 1969 C-Band radar and laser data taken during the GEOS-II C-Band Radar Experiment. The second effort involved combining these data with selected a priori information about the station coordinates. The latter solution is superior because the range data alone cannot correctly position the stations in a center-of-mass system. In both solutions the adjustments of the colocated Bermuda and Wallops sites were constrained through local survey data.

The scheme used for determination of station coordinates was to use multiple (10) 1-2 revolution arcs in a simultaneous adjustment of orbit elements, most of the station coordinates, and biases at the Bermuda stations. The experience of Smith, et al (1973) and Tapley and Schutz (1973) demonstrates that orbital arcs of a few revolutions contain much information. Such arcs also minimize satellite position error due to geopotential uncertainty. In addition, the data was originally taken in such a fashion that longer arcs would contain very long periods without tracking. Figure 1 shows the geometry of the passes over the calibration area.

Considering Figure 1, note that virtually all of the passes are in the same direction, and in the case of Bermuda, are West of the station. Coverage of the other stations is somewhat better with passes at least on both sides of the stations. Our previous experience (Marsh, et al., 1973) has demonstrated that the best solutions are obtained with passes in both directions on all sides of a station. Such coverage leads to a favorable cancelling of the effect of satellite position error on station coordinate estimates. The coverage for this solution is clearly less than optimum, but good results were obtainable through the use of a priori information, which consisted of fixing the longitudes of the Wallops and Bermuda sites at values implied by the GSFC-1973 solution.

Table 5 gives the details of each arc. Note that 4 passes of laser tracking from the SAO laser at Mt. Hopkins, Arizona and one pass from Goddard Space Flight Center were used in the solution. The coordinates for the lasers were held fixed at values derived by Marsh, et al (1973) except at Goddard where the height implied by the Marsh and Vincent geoid (1974) was adopted. Thus the laser data not only served to strengthen the solution but also positioned the C-Band sites in the GSFC-1973 reference system.

RESULTS AND COMPARISONS

Table 6 presents the C-Band station coordinate values derived as a result of this study. These coordinates are referenced to a geocentric system with the same longitude origin as the GSFC-1973 solution. Table 7 presents a comparison (in terms of latitude, longitude and height above the ellipsoid) of the C-Band solution with the GSFC-1973 and GEM-6 (Lerch et al, 1974) values. The differences in latitude show a mean offset of -0.2" for GEM-6 and -0.1" for GSFC-1973. However, the relative differences are small and generally less than 3 meters. The reason for the mean offset is not known at this time but may be due to errors in modeling polar motion since the various solutions contain data recorded at times different by as much as several years. As noted earlier, the longitudes for Wallops Island and Bermuda were held fixed at values implied by the GSFC-1973 solution. The longitude for Merritt Island was permitted to adjust and the resulting agreement with GSFC-1973 is better than two meters. Longitude comparisons with the GEM-6 solution show a rotation of 0.47". This rotation was noted earlier in Marsh, Douglas and Klosko (1973) and is also unexplained. The relative longitude differences are less than two meters.

The agreement in height for the three solutions is better than 3 meters for every station. The other solutions listed in Table 1 referenced to the NAD or the Cape Canaveral Datum were not included in the above comparisons since the differences would depend on the parameters used to transform the values to a geocentric system. However, comparisons have been made

(Table 8) with chord distances, which are of course, not dependent upon the location of the origin of the reference system. Chord differences are generally less than five meters except in two cases. In the first case, Bermuda to Merritt Island, the difference with the ACIC chord is over 16 meters. Since the differences with the other solutions are small, it is concluded that the ACIC chord is in error. The GSFC Geometric Chord from Merritt Island to Wallops Island is also suspect since the value differs from the two dynamic solutions by more than 10 meters and more than 8 meters with respect to the C-Band solution, while the C-Band value differs by less than a meter from recent precision geodimeter results.

An independent comparison has been made with the detailed gravimetric geoid heights of Marsh and Vincent (1974) described earlier. The results of this comparison are presented in Figure 2. The differences are two meters or less for all stations, well within the uncertainty of the gravimetric geoid heights.

CONCLUSIONS

A consistent set of geocentric coordinates has been derived for the C-Band and radar stations, i.e., Wallops Island, Bermuda, Merritt Island and Grand Turk in the GEOS-C altimeter calibration area. Comparisons with other solutions and with independent data suggest a relative uncertainty of about two meters in each coordinate. A comparable systematic difference between this C-Band solution and other center-of-mass solutions may exist.

It is important to consider what effect an uncertainty of this magnitude will have on the position of a satellite whose orbit is determined with calibration area data alone. 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 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. The dotted lines in Figure 1 show the passes in detail. 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 3. 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 3), 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 orbit is tightly constrained, and the height uncertainty of the satellite varies only very slowly, a much more favorable situation for studying variations of the geoid with altimeter data.

REFERENCES

1. ACIC, "Geodetic Positioning with the PC-1000 Camera System", (November 1968 Revision), ACIC Technical Report No. 105, Aeronautical Chart and Information Center, St. Louis, Missouri, October 1966.

2. Bush, N., et al, "Mistram MRS Survey Improvement Study," Report ETR-TR-69-6, Pan American World Airways, Inc., Aerospace Services Division, Patrick Air Force Base, Florida, October 1969.

3. Hadgigeorge, G., "Improvement of the GEOS-1 North American Tracking Network from Multiple Short Arc Geodetic Adjustments," AFCRL-70-0090, Air Force Cambridge Research Laboratories, L. G. Hanscom Field, Bedford, Massachusetts, February, 1970.

4. Huber, D., et al, "Bermuda Adjustment and Radar Calibration Projects," ACIC Technical Report No. 106, ACIC, St. Louis, Missouri, January 1968.

5. Lerch, F. J., et al, "Gravitational Field Models GEM-5 and GEM-6," Goddard Space Flight Center Contribution to the National Geodetic Satellite Program Final Report, 1974.

6. Marsh, J. G., Douglas, B. C., "Ocean Height Measurement by Satellite Altimetry", Journal of Spacecraft and Rockets, Vol. 8, No. 5, May 1971, pp. 543-546.

7. Marsh, J. G., Douglas, B. C., Klosko, S. M., "A Global Station Coordinate Solution Based Upon Camera and Laser Data - GSFC 1973," GSFC Document X-592-73-171, also included in the Goddard Space Flight Center Contribution to the National Geodetic Satellite Program Final Report, May 1973.

8. Marsh, J. G., Vincent, S., "Global Detailed Geoid Computation and Model Analysis," GSFC Document X-921-74-131, March 1974 also to be published in Geophysical Surveys 1, pp. 67-97, 1974.

9. Meade, B., Private Communication, 1974

10. Reece, J. S., Marsh, J. G., "Simultaneous Observation Solutions for NASA-MOTS and Speopt Station Positions on the North American Datum," Bulletin Geodesique, No. 111, pp. 53-71, March 1974.

11. Tapley, B. D., Schutz, B. E., "A Comparison of Estimation Methods for the Reduction of Laser Range Observations", paper presented at the International Association of Geodesy Symposium on the Earth's Gravitational Field and Secular Variations in Position, The University of New South Wales, Sydney, Australia, November 26-30, 1973.

12. Smith, D. E., Kolenkiewicz, R., Agreen, R. W., Dunn, P. J., "Dynamic Techniques for Studies of Secular Variations in Position from Ranging to Satellites", GSFC Document X-921-74-161, May 1974, Also Presented at the International Association of Geodesy Symposium on the Earth's Gravitational Field and Secular Variations in Position, Sydney, Australia, November 26-30, 1973.

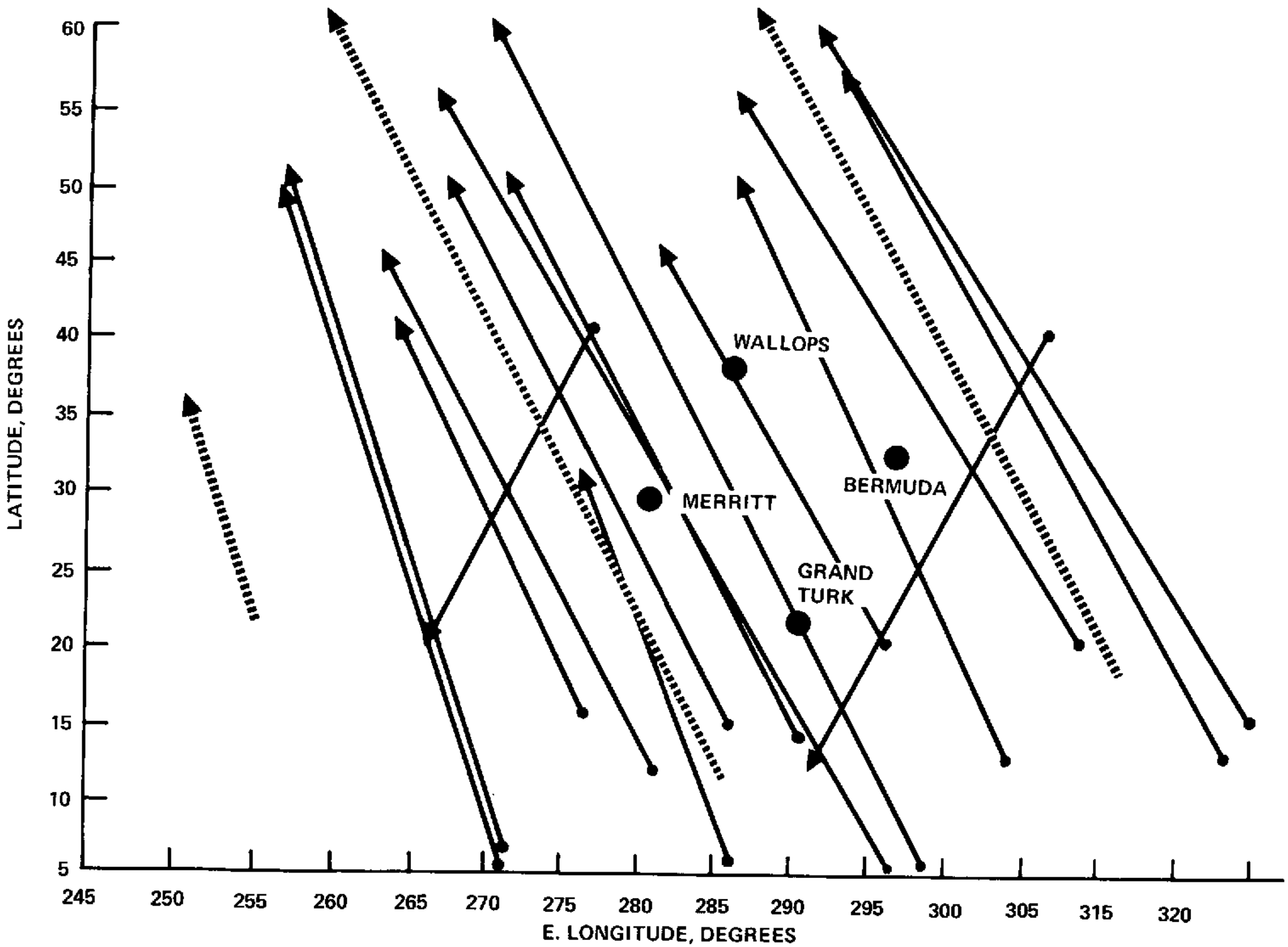
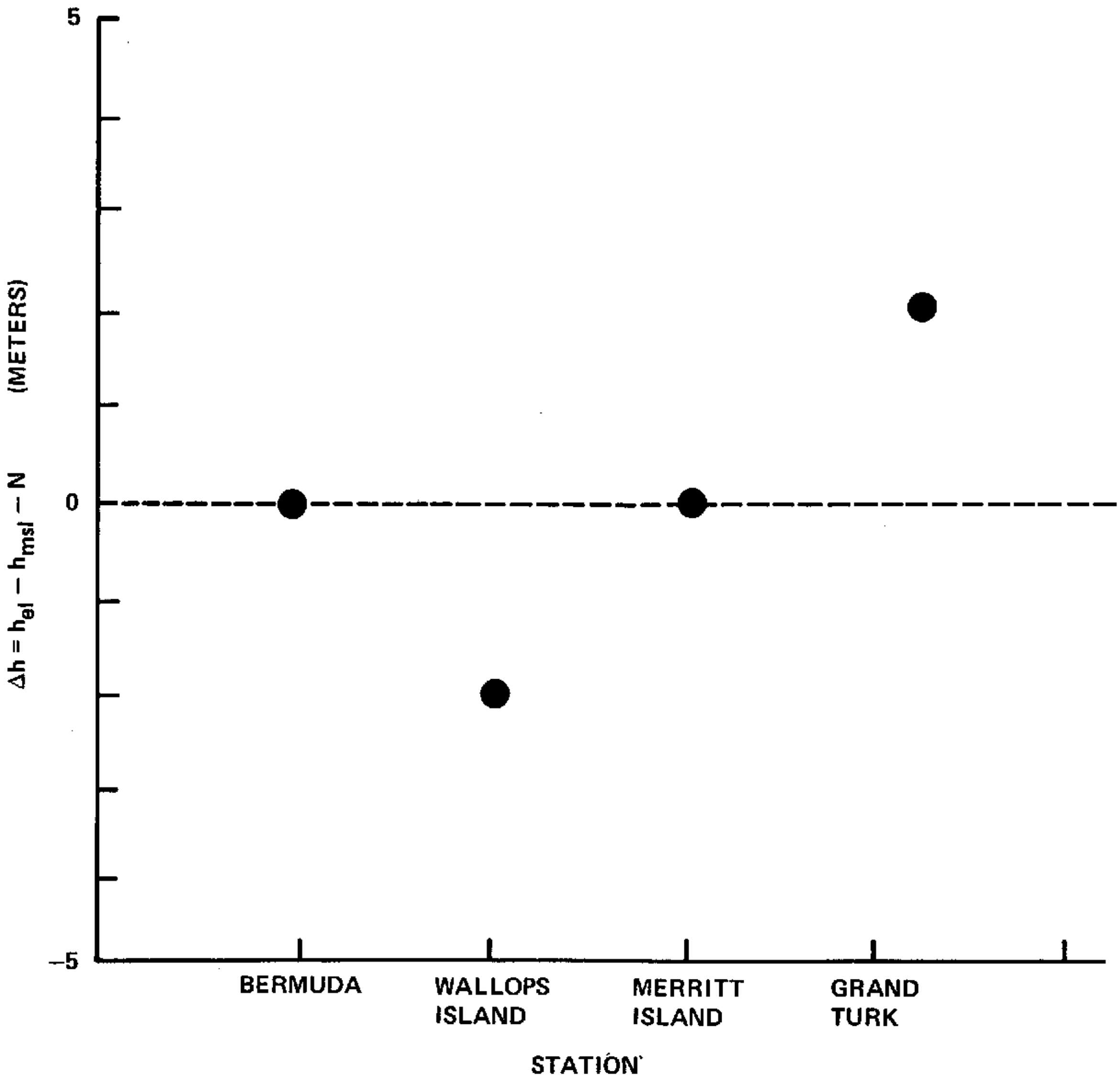


Figure 1. Satellite Ground Tracks



h_{el} = Dynamically Determined Height of the Tracking Station Above the Reference Ellipsoid (a_e = 6378.142 km.) 1/f = 298.255)

h_{msl} = Survey Height of Station Above Mean Sea Level.

N = Detailed Gravimetric Geoid Height (Marsh and Vincent, 1974).

Figure 2. Geoid Height Comparison. The Dots for the Respective Stations Represent the Differences Between the Geoid Heights Implied by the Dynamical Solution and Gravimetrically Derived Geoid Heights.

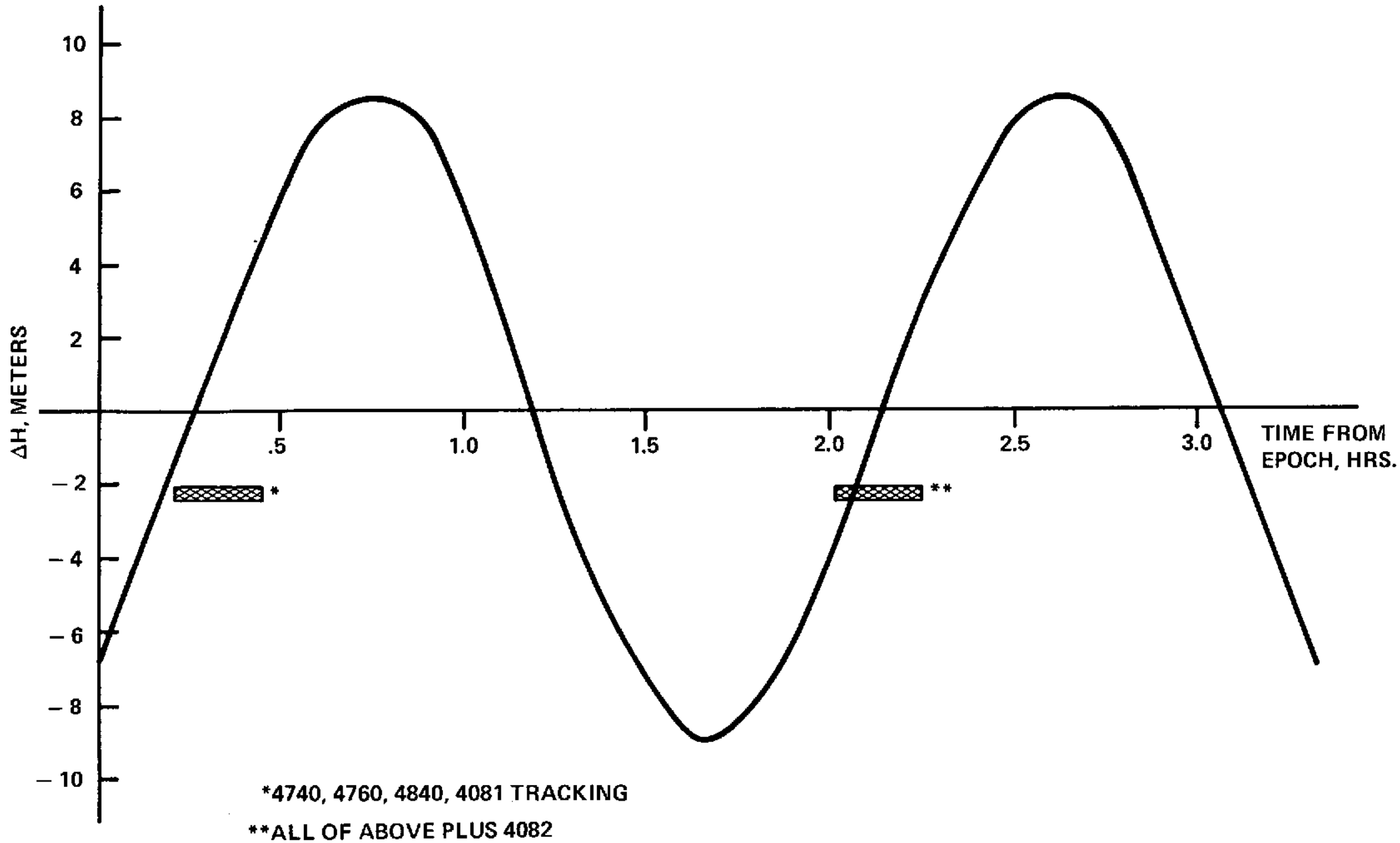


Figure 3. Effect on Satellite Height of a 3m Error at Wallops Island

Table 1

Summary of Previous Solutions for the Coordinates
of Stations in the GEOS-C Calibration Area

Investigation	Technique	Data Used	Reference System
Air Force Eastern Test Range (AFETR), (Bush, 1969)	Short Arc	Electronic and Optical	Cape Canaveral Datum
Aeronautical Chart and Information Center (ACIC), (ACIC, 1966), (Huber, 1968)	Geometric	Optical	NAD-27
Air Force Cambridge Research Laboratory, (AFCRL), (Hadgigeorge, 1970)	Short Arc	Electronic and Optical	NAD-27
Goddard Space Flight Center (GSFC-1973), (Marsh, Douglas and Klosko, 1973)	Long Arc-Dynamic	Optical and Laser	Geocentric
Goddard Space Flight Center (GEM-6), (Lerch, et al. 1974)	Long Arc-Dynamic	Electronic, Laser and Optical	Geocentric
Goddard Space Flight Center (Geometric), (Reece and Marsh, 1974)	Geometric	Optical and Laser	Geocentric

Table 2

Comparison of Satellite Chords
from Merritt Island to Wallops Island
with the Precision Geodimeter Traverse
(Geodimeter Traverse - Satellite Solutions)

Satellite Solution	Difference (Meters)
GSFC-1973	-2
GEM-6	-3.4
GSFC Geometric	10.9
GSFC C-Band	2.7

Table 3

Spheroid Height Comparisons. This table presents a comparison of the GEM-6 and GSFC-1973 dynamically derived heights with the quantity (h_{msl} + N), where h_{msl} is the survey height of the station above mean sea level and N is the detailed gravimetric geoid height of Marsh and Vincent (1974). Units are meters.

Station	Dynamically Derived Spheroid Heights		(h_{msl} + N)	ΔGEM-6	ΔGSFC 1973
	GEM-6	GSFC-1973			
Bermuda (4740)	-27	-29	-32	5	3
Wallops Island (4840)	-39	-43	-39	0	-4
Merritt Island (4082)	-31	-35	-36	5	1

Table 4

Apparent Range Biases and Differences for the
Bermuda and Wallops Island Colocated Stations

ARC	4740*	4760*	Δ	4840**	4860**	Δ
1	- 1 -11	- 2 -10	1 -1	-- 11	13 6	-- 5
2				- 3 0		
3				4 7	4 7	0 0
4				0	0 - 8	0
5	-10 - 9	-11 - 6	1 -3	2 9		
6	- 7 -16	- 7 -22	0 6	6 - 5	3 - 1	3 -4
7	- 7 - 2	-13 -10	6 8		- 1 3	
8	-18			5	8	
9	- 4 - 8			4 4		
10	-12 1	- 3 - 1	-9 2	2 5		
Average	- 8	- 9		3	3	

*Bermuda
**Wallops Island

Table 5

Summary of Orbital Arcs. This table presents a summary of the times in 1969 for the ten arcs used in the solution along with the total number of passes of data per station.

Starting Time	End Time	RMS of Fit (meters)
February 8, 23^h	February 9, 1^h	2.2
October 8, 17^h	19^h	2.1
October 9, 17^h	19^h	2.3
October 10, 15^h	17^h	4.3
October 13, 16^h	18^h	2.3
October 16, 16^h	20^h	2.2
October 17, 16^h	20^h	2.6
October 21, 17^h	19^h	2.4
October 22, 16^h	18^h	2.5
October 24, 16^h	18^h	2.7

	Station							
	Bermuda (4740)	Bermuda (4760)	Wallops (4840)	Wallops (4860)	Merritt Island	Goddard (Laser)	Grand Turk	Mt. Hopkins (Laser)
Total No. of Passes	13	10	16	10	16	1	13	4

Table 6

Coordinates for Tracking Stations. Values are presented for the C-Band Radar Stations in the GEOS-C Altimeter Calibration Area. For reference purposes GSFC-1973 values are presented for other U. S. laser and electronic stations which will be involved in the calibration of the altimeter.

Station		Rectangular Coordinates		
Location	Number	X (m)	Y (m)	Z (m)
Bermuda	4740	2308908.6	-4874288.5	3393098.6
Bermuda	4760	2308917.2	-4874294.6	3393085.9
Wallops Island, Va.	4840	1263990.6	-4882267.8	3891536.7
Wallops Island, Va.	4860	1261605.6	-4881556.0	3893196.8
Merritt Island, Fla.	4082	910595.3	-5539105.9	3017968.5
Grand Turk	4081	1920444.7	-5619410.3	2319130.0
Greenbelt, Md. **	7050	1130688.7	-4831360.7	3994112.1
Rosman, N. C. (R/RR)*	1126	647204.8	-5178328.1	3656140.9
Rosman, N. C. (ATS)*		647213.4	-5178148.1	3656416.4
Mt. Hopkins, Ariz. *	7921	-1936766.1	-5077708.3	3331923.3
		Geodetic Coordinates †		
Location	Number	Geodetic Latitude (Deg, Min, Sec)	E. Longitude (Deg, Min, Sec)	Height Above Ellipsoid (meters)
Bermuda	4740	32 20 53.22	295 20 47.45	-31.5
Bermuda	4760	32 20 52.72	295 20 47.65	-30.5
Wallops Island, Va.	4840	37 50 28.80	284 30 53.47	-41.4
Wallops Island, Va.	4860	37 51 36.92	284 29 26.31	-38.4
Merritt Island, Fla.	4082	28 25 28.82	279 20 8.07	-36.3
Grand Turk	4081	21 27 45.24	288 52 4.68	-29.0
Greenbelt, Md. **	7050	39 01 14.27	283 10 18.96	7.0
Rosman, N. C. (R/RR)*	1126	35 12 45.47	277 07 26.68	826.4
Rosman, N. C. (ATS) *		35 11 56.10	277 07 27.90	840.5
Mt. Hopkins, Ariz. *	7921	31 11 3.19	249 7 18.79	2338.0

*Derived in the GSFC 1973 solution.

**Latitude and longitude are from the GSFC 1973 solution with the height derived from the mean sea level survey height and the geoid height of Marsh and Vincent, 1974.

†a_e = 6378155m, 1/f = 298.255

Table 7

Comparison of C-Band Solution with Other Solutions. Differences in latitude, longitude and height between the C-Band solution and two dynamical solutions, GEM-6 and GSFC 1973 are presented. After removal of mean rotations, the differences are generally less than 3 meters.

(C-Band - GEM-6, GSFC-1973)				
GEM-6				
Station	Latitude	Longitude	Height Above Ellipsoid	
				(+)
Bermuda	-.11 arc sec	.54 arc sec	-4.6 m	-1.9 m
Wallops Island	-.36	.46	-2.0	0.7
Merritt Island	-.13	.42	-5.6	-2.9
GSFC-1973				
Bermuda	-.08	*	-2.9	
Wallops Island	-.23	*	1.7	
Merritt Island	-.03	-.06	-1.3	

*Longitudes for Bermuda and Wallops Island from the GSFC-1973 solution were used as constraints in the C-Band Solution.

+Modified to account for different value of GM used in the GEM-6 solution.

Table 8

Comparison of Chord Distances (Meters)

(C-Band Solution - Solution$_i$)

CHORD	AFETR	ACIC	AFCRL	GSFC 1973	GEM-6	GSFC GEO-METRIC
Bermuda to Merritt Island	- 0.3m	16.6m	1.9	0.6m	2.2m	1.8m
Bermuda to Grand Turk	8.8	20.1	8.6			
Bermuda to Wallops Island				-2.3	-2.1	-6.6
Merritt Island to Grand Turk	1.2	2.2	1.9			
Merritt Island to Wallops				-4.7	-6.6	8.2