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PRELIMINARY EASTERN INDIAN OCEAN GEOID FROM GEOS-3 DATA, (U)  
JUN 77 S L SMITH, A C CHAPPELL  
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PRELIMINARY  
EASTERN INDIAN OCEAN GEOID  
FROM GEOS-3 DATA

by  
SAMUEL L. SMITH, III  
ALAN C. CHAPPELL  
Warfare Analysis Department

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PRELIMINARY EASTERN INDIAN OCEAN GEOID

FROM GEOS-3 DATA

Samuel L. Smith, III  
Alan C. Chappell

Warfare Analysis Department

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

*(See 1493)*

FORWORD

This work was performed in the Ocean Geodesy Branch, Astronautics and Geodesy Division of the Warfare Analysis Department, NSWC/DL. The authors wish to acknowledge the work of L. Beuglass, M. Douglas and their group in providing orbit ephemerides and the work of G. West, T. Hicks, R. McDaniel and V. McCracken for preliminary filtering and reduction of the radar altimetry data to along track sea surface height. Appreciation is also extended to Dr. J. G. Marsh of NASA/Goddard Space Flight Center for providing the Marsh and Chang 1976 Geoid used for comparison, and Dr. T. Davis of the Naval Oceanographic Office for providing the bottom topography charts of the Indian Ocean. This report was reviewed by R. J. Anderle of the Astronautics & Geodesy Division.

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## INTRODUCTION

The use of satellite radar altimeter measurements to derive an ocean geoid that contains geoid undulation information at much shorter wavelengths than can be obtained from classical analysis of satellite orbit perturbations has been postulated for a number of years, e.g. references 1 and 2. Some experiments in this direction were carried out with radar altimeter data from Skylab, e.g. references 3 and 4, but the amount of Skylab radar altimeter data and the lack of accuracy of the Skylab orbital ephemerides precluded geoid determination over any appreciable area.

The GEOS-3 satellite was launched on 9 April 1975, carrying a radar altimeter with both short pulse and long pulse capability, laser retroreflectors and a Doppler beacon to allow precise orbit determination. GEOS-3 has produced radar altimeter data of both good quality and quantity for over a year. Both theoretical studies, reference 5 and preliminary evaluations, reference 6, of the GEOS-3 data showed that the short pulse radar altimeter data had a lower noise level than the long pulse data and would result in more precise derived geoids.

This paper develops the preliminary derivation of a local geoid in the Eastern Indian Ocean from 94 passes of short pulse GEOS-3 radar altimeter data received by the DoD telemetry station at Perth, Australia. This data was taken over a 34 day period in July-August 1975. The orbital ephemerides used in the analysis were obtained from Doppler tracking data and have an estimated accuracy of 2 meters in the radial component, reference 7.

This preliminary derivation of the geoid does not consider tide effects on the altimeter measurements which could introduce uncertainties of about 0.5 meters. Also, the standard tropospheric range correction used on the data could result in errors in individual measurements of up to 25 centimeters. A technique for reducing all the biases by analyzing the radar altimeter measurements at track intersections is employed. A later analysis is planned that will include data from other telemetry stations in the area whose coverage overlaps the Perth coverage and extends the total time span of the data set to several months. It will include tidal corrections to the data before the bias removal and geoid derivation is carried out.

The preliminary GEOS-3 geoid derived in the paper is compared with the Marsh and Chang 1976 Geoid, ref. 8. Correlations of larger features in the GEOS-3 geoid with bottom topography are also given.

## PROCEDURE

### Averaging at Intersections

Ninety-four passes of short pulse radar altimetry data were taken by the Perth, Australia telemetry station and processed at NSW/DL using precise short-arc Doppler derived satellite ephemerides. For each pass time, latitude, longitude, geoid height and along-track deflections of the vertical were computed at 0.1 second time intervals. Details of this processing, including the Wiener filter used, may be found in reference 9. Nine of the passes contained data too fragmented for efficient operation of the Wiener filter and were eliminated from the following analysis. The remaining 85 passes were used. The ground tracks of these passes are given in Figure 1. The differences in geoid height at each of the 716 intersections of these passes are given in Table 1. The average difference of geoid height over all the intersections is 75 cm with a standard deviation with respect to the mean of 2.3 meters. The maximum difference is 7.83 meters. As a first approximation to the geoid, the average of the two geoid heights at each intersection is taken as the geoid height and contours of constant geoid height plotted. Since along-track deflection of the vertical is available for each track at each intersection, the surface gradient at each intersection may be computed. This is used as an interpolation aid in plotting the geoid height contours. A geoid derived in this manner is given in Figure 2. The +'s in Figure 2 represent the location of the intersections. The contour interval in Figure 2 is 2 m. The General Purpose Contouring Program by California Computer Products was used to generate the contours in Figure 2 and all subsequent contour plots.

### Bias Removal

If one studies the intersections in Table 1, it is seen that some passes have all positive differences, e.g. descending pass 1580, or all negative differences, e.g. descending pass 1837. Since pass 1580 is intersected by 19 other passes taken over a time span of 33 days and pass 1837 is intersected by 16 other passes taken over a time span of 32 days, one could assume that different tidal phases, different deviations from the standard troposphere, different orbit uncertainties on the crossing passes would be sampled. Therefore the intersections would be expected to be more random unless the single pass, i.e. 1580 or 1837, was biased with respect to the other passes. Using this assumption each pass in Table 1 has been adjusted so that the sum of the intersection differences with the crossing passes have been minimized. The mean bias adjustment is 0 cm; thus the mean

geoid is not changed. The standard deviation of the biases is 2.2 m. The amount of the adjustment of each pass is given in Table 2. The intersection differences after applying the adjustments are presented in Table 3, where the average difference summed over all intersections is now 9 cm with a standard deviation of 83 cm with respect to the mean and a maximum difference of 3.15 m. The geoid heights are again taken as the midpoint at each intersection and a contour map is made as before using the surface gradient at each intersection to aid in interpolation.

## RESULTS

### Comparison With the Marsh and Chang 1976 Geoid

The preliminary eastern Indian Ocean geoid derived from the GEOS-3 measurements using the bias removal technique described above is given in Figure 3. The +'s plotted on Figure 3 indicate the locations of the intersections. Figure 4 is a plot of the Marsh and Chang 1976 Geoid. A contour plot of the differences between the GEOS-3 Geoid after bias removal and the Marsh and Chang 1976 Geoid is given in Figure 5. The contour interval in Figures 3, 4, and 5 is 2 m. In general the agreement is good, with major features such as the through running from the southwestern tip of Australia toward the northwest, and the saddle point south of Australia comparing well. The maximum difference between the two geoids is 7 m. To further compare the two geoids, the along-track geoid heights (after bias removal) from pass 1419 and descending pass 1724 are compared in Figures 6 and 7, with the Marsh and Chang 1976 geoid heights along these tracks. Again the agreement is quite good, with the GEOS-3 along-track data showing more fine structure than was apparent in the overall geoid plots, since the GEOS-3 contour plots used information only at the intersections instead of at every point along-track. Both the GEOS-3 Geoids and the Marsh and Chang 1976 Geoid were referenced to an ellipsoid with a semi-major axis of 6378.135 km and a flattening reciprocal of 298.26.

### Comparison with Bottom Topography

Comparison of the GEOS-3 Geoid was made with larger bottom topography features of the eastern Indian Ocean. Figure 8 is a contour map of a small area of the geoid with a one meter interval between contour lines. Figure 9 is a three dimensional projection of the same area shown in Figure 8. Comparison of Figures 3, 8 and 9 with ocean bottom charts shows good agreement with large features. An attempt was made to correlate the GEOS-3 Geoid with finer scale bottom topographic features

shown on a detailed charts supplied by the Naval Oceanographic Office without much success, probably due to the smoothing of the GEOS-3 Geoid by using data only at intersections in its construction. Much success was had by making along-track comparisons where the short wavelength information is not lost. Figure 10 shows an along-track comparison of bottom topography and geoid heights for pass 1746. Geoid heights are plotted for the GEOS-3 Geoid after bias removal as well as the along-track satellite data. The lack of short wavelength information in the GEOS-3 Geoid is evident. Correlation of the three curves is very good. The sea mount near the middle of the pass shows up clearly in the two geoid height curves. The sea mount is located approximately at latitude  $-22^{\circ}2$  and longitude  $104^{\circ}6$ . The geoid undulations caused by this sea mount can be seen in figures 2,3,4,8, and 9.

#### CONCLUSIONS

Careful processing of GEOS-3 radar altimetry data with good orbit ephemerides can result in a derived ocean geoid that is accurate to about one meter. It is expected that greater accuracy will be obtained in the GEOS-3 Geoid with the analysis of additional data in the area from other telemetry stations whose coverage partially overlaps Perth and which will provide data over a longer time frame. Also the inclusion of tide and sea state corrections and a bias rate term in the analysis should result in greater accuracy in the derived geoid. The use of along-track data (instead of using only intersection data) should improve the accuracy and the short wavelength structure of the GEOS-3 Geoid.

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GEOS-3 SHORT PULSE DATA FROM PERTH

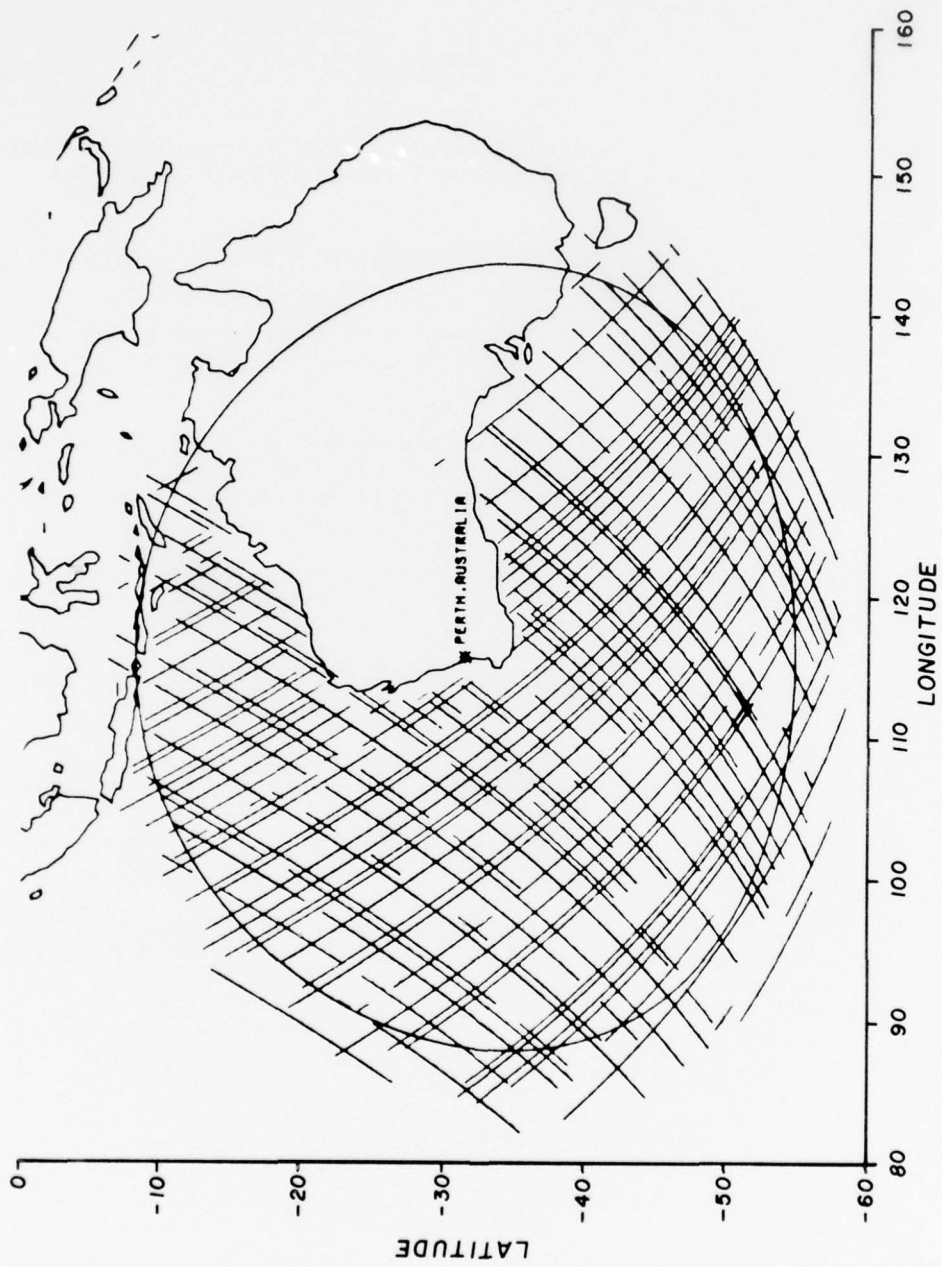


Figure 1

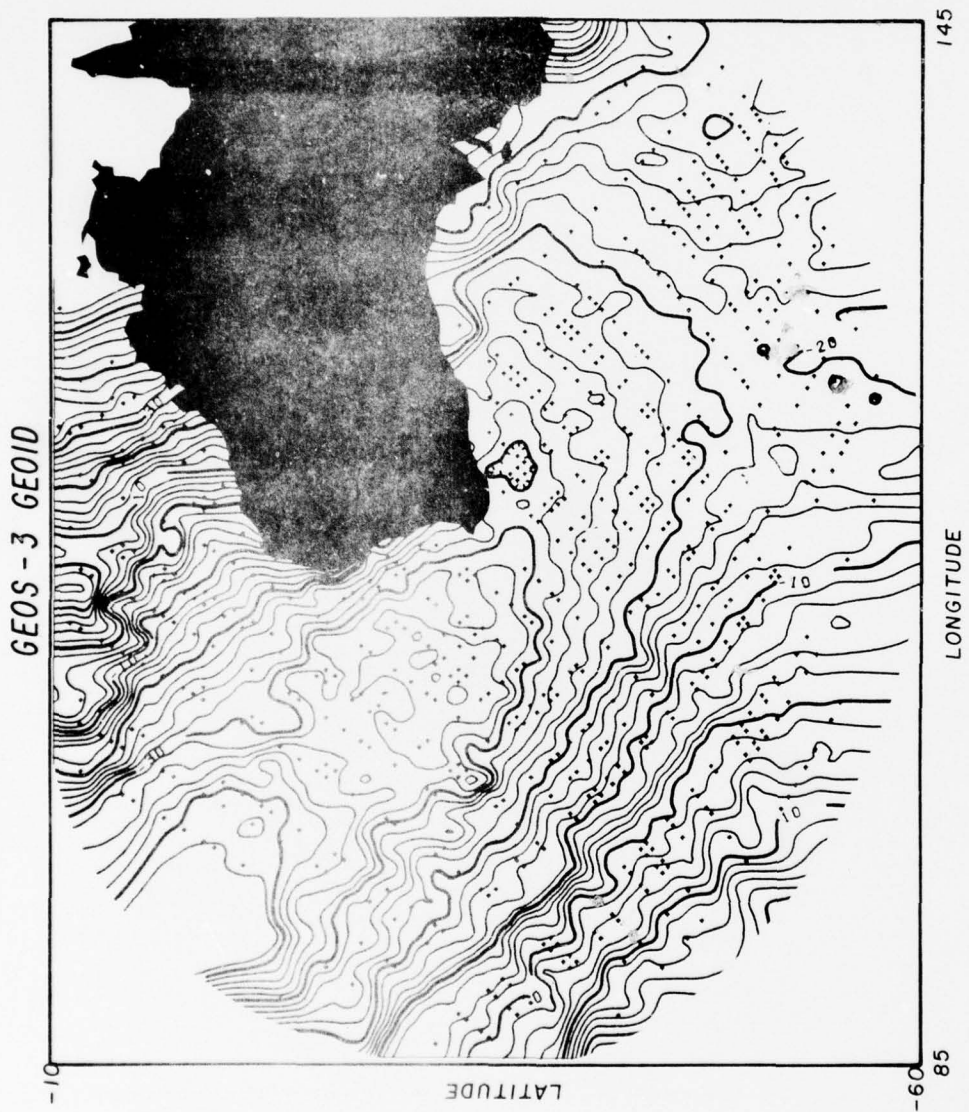


Figure 2

GEOS-3 GEOID AFTER BIAS REMOVAL

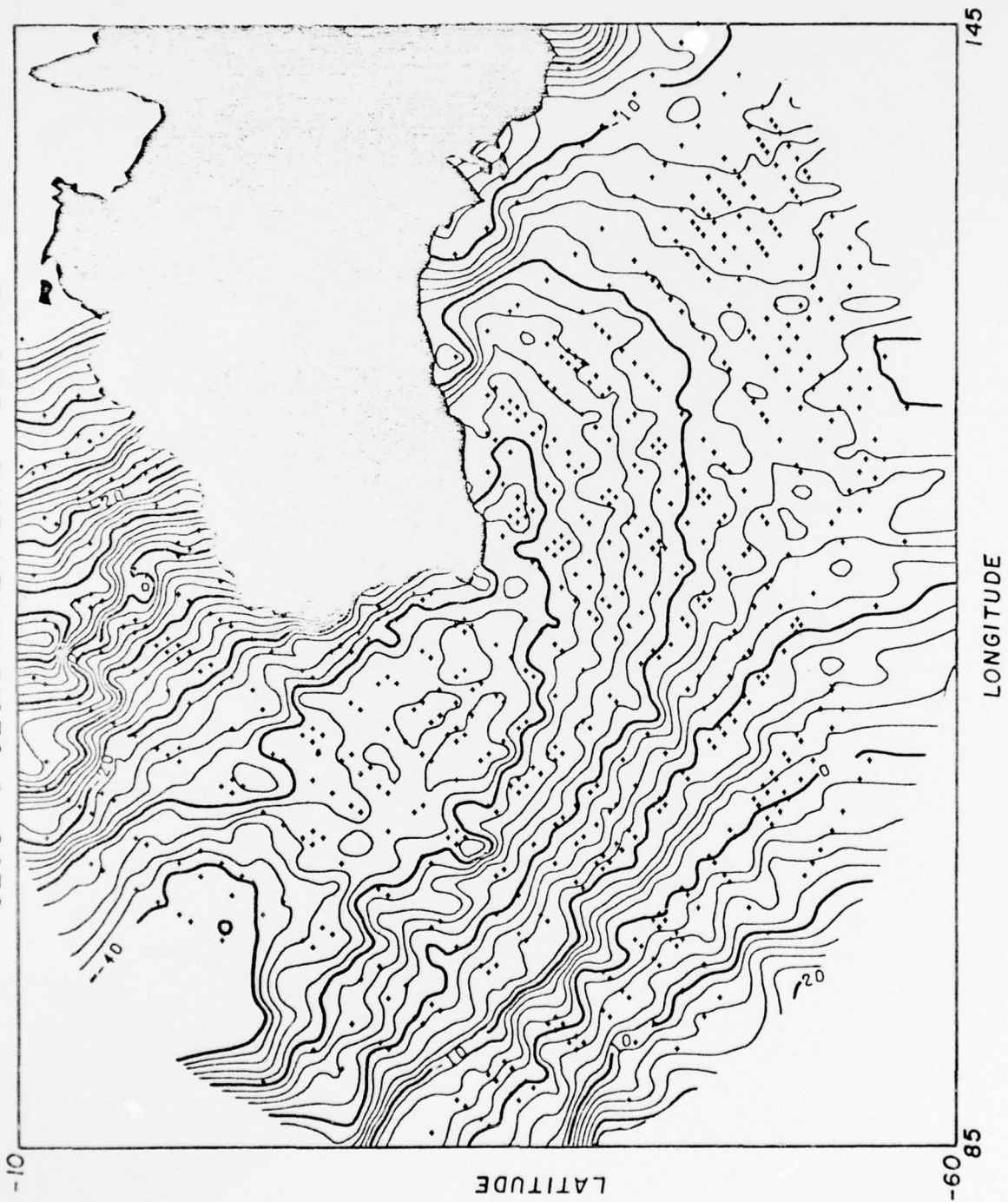


Figure 3

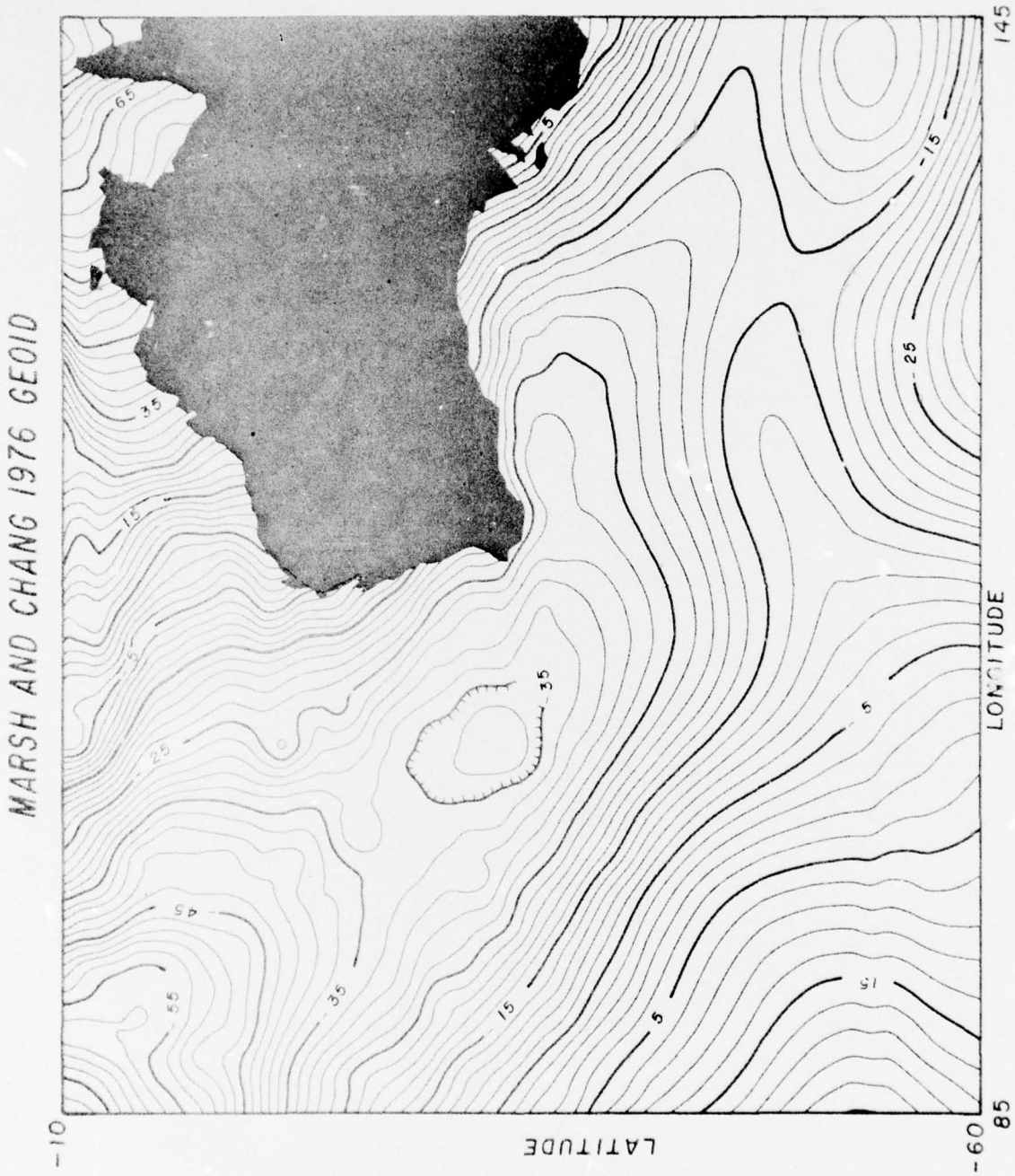


Figure 4

GEOS-3 GEOID AFTER BIAS REMOVAL MINUS THE MARSH AND CHANG 1976 GEOID



Figure 5

ALONG TRACK COMPARISON OF PASS 1419 AND THE MARSH AND  
CHANG 1976 GEOID

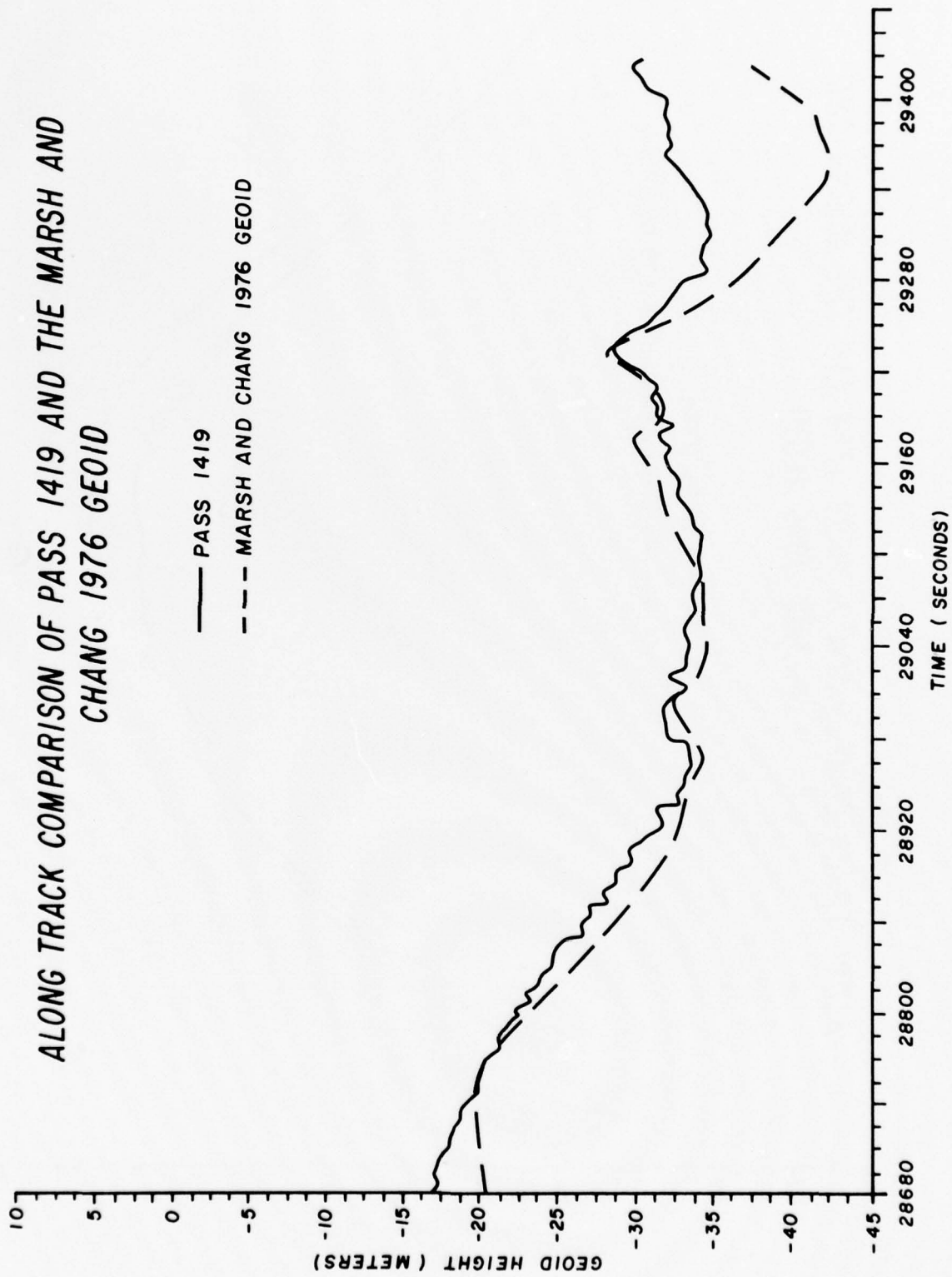


Figure 6

ALONG TRACK COMPARISON OF PASS 1724 AND THE MARSH AND  
CHANG 1976 GEOID

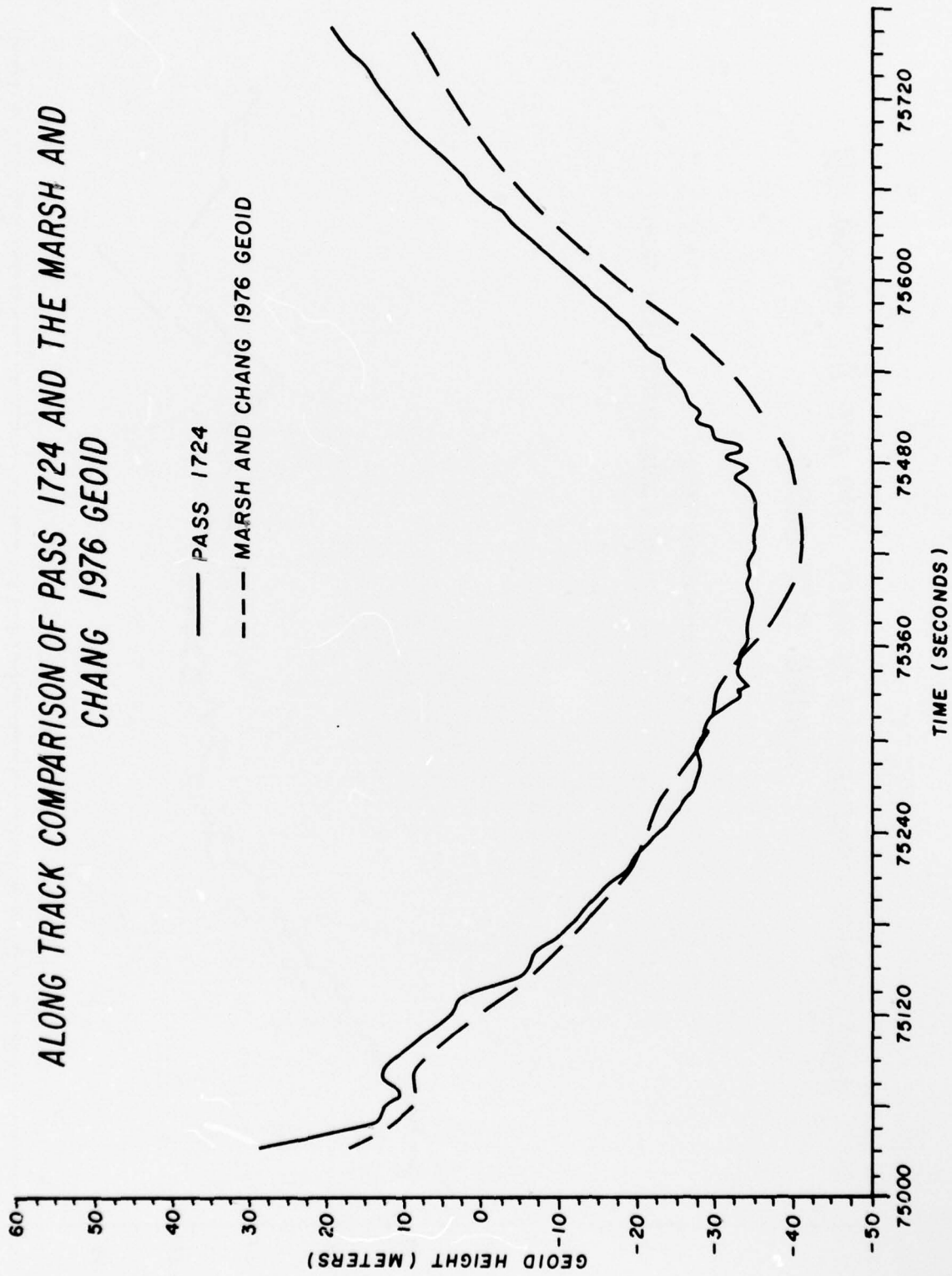


Figure 7

DETAILED CONTOUR MAP OF GEOS-3 GEOID

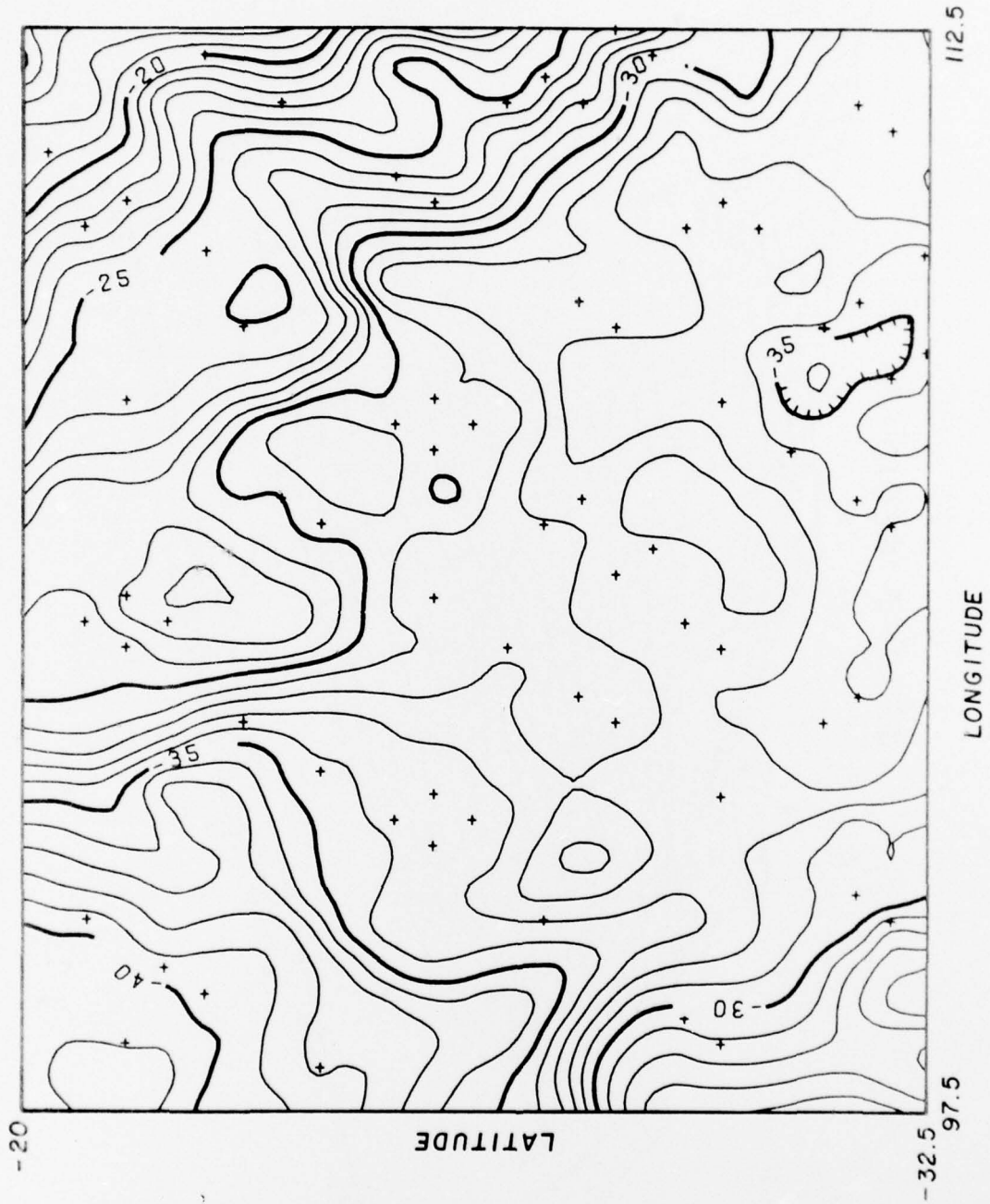


Figure 8

GEOS -3 GEOID

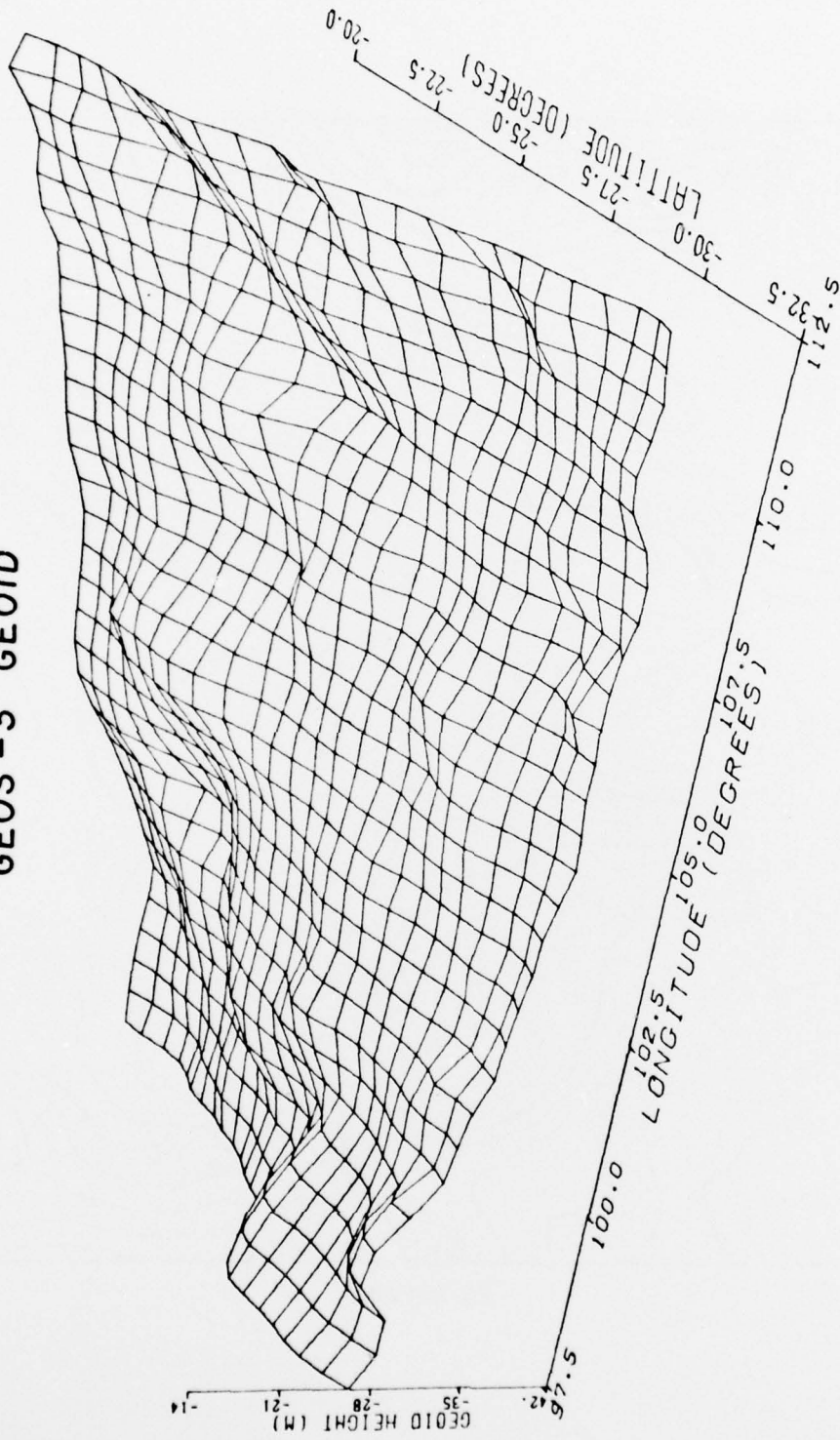


Figure 9

ALONG TRACK COMPARISON OF PASS 1746 AND  
BOTTOM TOPOGRAPHY

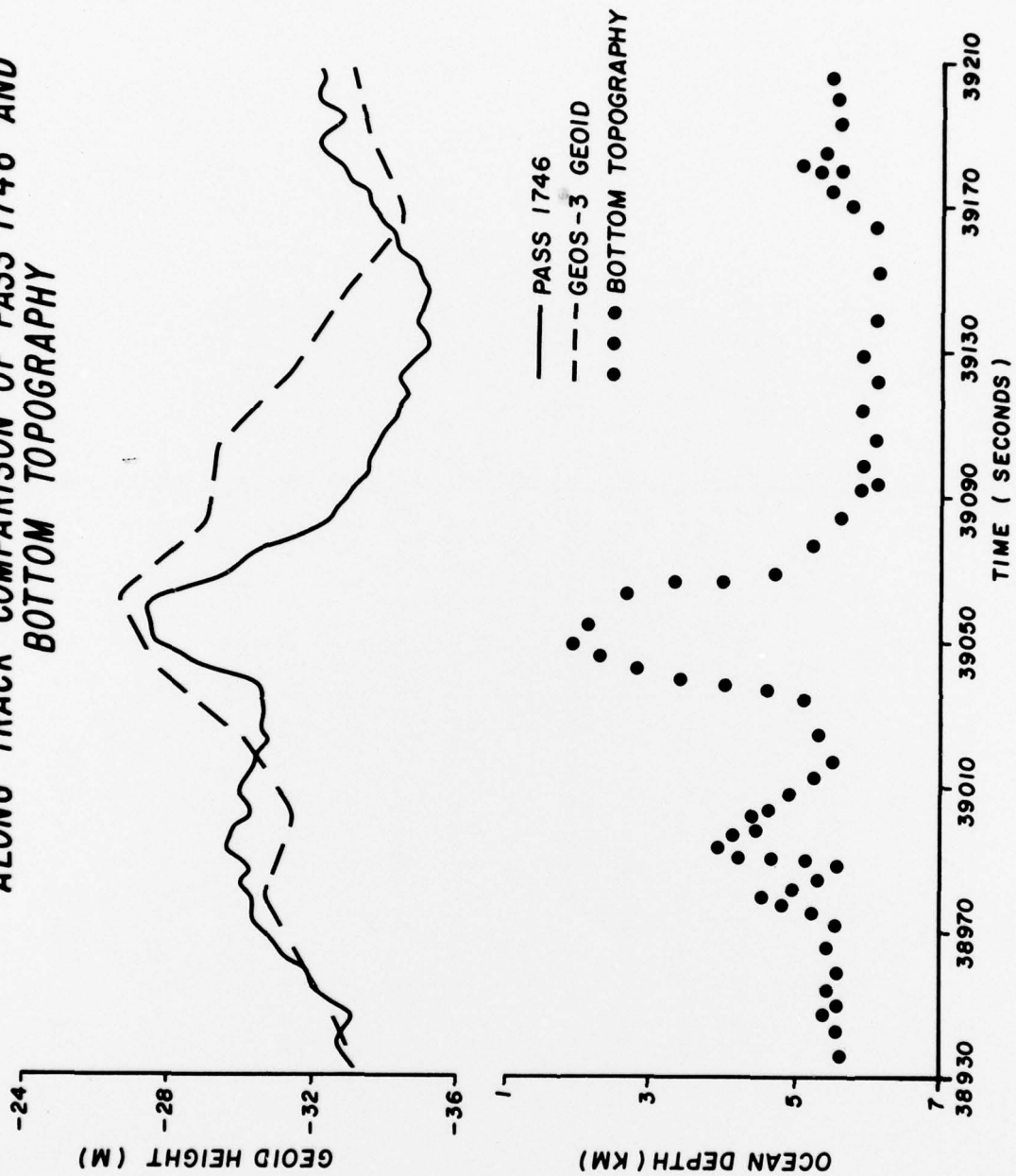


Figure 10

TABLE 1  
 GEOID HEIGHT DIFFERENCES AT INTERSECTIONS (METERS)

Descending Passes	DESCENDING PASSES																								
	1354	1368	1382	1383	1396	1397	1410	1411	1424	1425	1426	1566	1568	1580	1581	1624	1637	1651	1652	1653	1665	1666	1667	1680	
1347				1.97				3.22			2.76		2.61		.28	1.02				2.92				2.33	2.7
1349				1.42				1.84					2.43	3.25	-.93						.66			1.85	2.5
1376	.70		-2.14											4.17						1.92			3.16	4.60	1.5
1390					.70	2.88	2.61							2.87			4.99	2.18	-.71	3.67	1.92	2.35	1.85	2.83	2.7
1391					-.33	-.42	1.36			2.26							3.50	2.49	.86	.86	.35	-.60	3.16	4.60	1.5
1391	-2.14	-4.90			-2.78	-1.04																			
1404	-4.99																								
1405																									
1406	-1.18	-4.05		-1.34	-1.82		.08	-.61																	
1418								3.90																	
1419																									
1420																									
1433																									
1434																									
1447																									
1561	1.76																								
1575																									
1633																									
1646																									
1647																									
1660																									
1661																									
1662																									
1674																									
1675																									
1676																									
1689																									
1703																									
1704																									
1717																									
1718																									
1731																									
1732																									
1745																									
1746																									
1747																									
1759																									
1775																									
1803																									
1831																									

Ascending Passes

2

TABLE 1

HEIGHT DIFFERENCES AT INTERSECTIONS (METERS)

DESCENDING PASSES																							
	1652	1653	1665	1666	1667	1680	1681	1682	1694	1696	1708	1709	1710	1722	1723	1724	1736	1737	1738	1739	1752	1809	1837
51		2.92			2.33		2.70												2.00				
18	-.71		.66		1.85	2.83	2.90			-1.24		-1.99	1.46			3.58			2.68			2.18	-1.90
70	.86	3.67	1.92	2.35	3.16	4.60	1.96			1.37	2.04	-1.96	2.44	1.52	-.74		1.06		1.99				
49		.86	.35	.60	.62	3.15			4.14		3.78		3.65	2.23	.95	4.94	2.74	2.82					
19	-3.18	-1.10		-2.17	-1.48	-1.45	-1.49		.49	-3.07		-5.08	-2.11	1.29	-3.47	2.55	1.86	1.15	.97			-1.13	-6.57
	-2.06	-.44	.67		-1.99	2.05	-.83		2.75		2.53			.69			1.22		-1.21			-2.34	
		3.15			-1.05	1.52			2.28			-4.20	-1.15		-1.75	.14		.56	-1.23			-4.48	-5.16
					-3.13											3.19							
	-2.15	.31		-.69	-.24	1.66	-.08		1.94	-.94		-4.15	.06		-2.20	1.52		.39	.15				-5.77
	.63				3.52	3.30			1.98			-.73	1.85		.98	4.01			3.19				-1.74
19		4.18	2.23	2.17	3.08	4.73			5.03	2.79	4.61		3.73	3.46	.64	5.08	3.03	3.57				2.86	-2.09
32		3.82		1.59	2.58		3.12			2.13		-1.03	2.35		.53	3.58		2.25	2.87				
75		2.10	1.72	1.73	1.65	4.49			4.34		4.23		1.91	2.58	.37	3.71	2.46	2.69	2.06				
89	-1.41	1.65	.50	-.25	1.14	2.49	.97	1.15	2.16	-.29	1.67	-3.23	.77	4.60	1.19	4.59	3.55	3.98	3.32			.93	-4.21
		2.18			1.94								2.26		-.45	3.78		.49	1.45				
57			-.15		-1.33		.27							.35									
	-1.80	.41		-.68	-.04	1.13	.06	1.83	-1.60	2.24	-3.54	-.74	1.19	-1.93	1.31	.59		.01	-.41			-1.74	
	-.01			.85	2.26		-2.38				-1.29	1.24		-.24	2.57			1.56	-.36			.35	-5.03
72	-2.49	-.43		-.90	-1.02	.58		1.12	-1.82	1.06	-4.63	-1.25	.12	-3.02	.32				2.06			-3.55	-6.55
	.26	2.18		.99	2.36		-1.37		.72		-1.21	.81		.02	2.96			2.10	2.34			-1.07	-2.43
11	-1.25	1.89	.17	.43	.54	2.45	.84	2.04	.83		-3.08	1.49	.82	-1.45	2.59	1.51		1.51			1.10		-5.38
77	.73	3.18	2.63	2.65	2.53	4.50		4.83		4.60		3.16	2.92	1.01	4.31	3.21	3.44						
98	-.95	2.93		.37	2.14		1.21	3.01	2.40	1.60	2.86	-2.69	1.97	-1.06	3.21	.74	2.18	2.59		2.59		1.52	
		-.27			-.61										1.38				-.18				
52	-1.71	-.99	.23	-.54	.64	1.29	.44	1.90	-.29	1.65	-3.72	.37	.55	-1.44	1.81		.20		-.76			.26	
					-3.57		-2.84								1.61				-2.87			-3.92	
	-3.11	-.38	-.07	-1.56	-1.31	.07		.93	-2.21	1.21	-4.69	-1.50	.40	-2.70	.09	.67	-.60		-.57				-5.99
	-2.08	.89	-.62	-.44	.15		-.17	1.62	-.76	1.63	-4.16	.04	.67	-2.31	1.40	.62	.09						-5.26
	1.01			2.00	4.24		3.63	3.61	4.30	2.40		-.74	2.56		1.20	4.18		2.92	3.75				-1.25
										1.02					-.96	2.91		.95	2.25			1.92	
91	-1.69	.39	.54	-.43	.17	1.84	.17	1.83	-1.61	2.12	-3.84	-.26	1.42	-1.37	1.03	.81	.47		.10			-.11	-5.03
44	.36	3.73	2.14	1.93	2.87	3.84		4.24			3.95		3.10	2.51	.56	4.63	2.48	2.48					

TABLE 2  
BIASES (METERS)

<u>Ascending Passes</u>		<u>Descending Passes</u>	
<u>Pass No.</u>	<u>Bias</u>	<u>Pass No.</u>	<u>Bias</u>
1347	2.0255	1354	2.0087
1349	1.4120	1368	2.8957
1362	.8006	1382	3.6436
1376	2.6962	1383	-.7709
1390	1.1268	1396	.7984
1391	-2.6197	1397	-.8719
1404	.1451	1410	-.9172
1405	-1.5824	1411	-.5216
1406	2.7338	1424	-2.4272
1418	-2.8210	1425	1.5748
1419	-1.1408	1426	-.7826
1420	1.5730	1566	-2.7478
1433	2.9797	1568	-1.2155
1434	1.5557	1580	-2.8077
1447	2.3771	1581	1.4333
1561	2.0308	1624	1.1353
1575	3.6217	1637	-3.2068
1633	.1213	1651	-2.2751
1646	1.9914	1652	1.2811
1647	-.0689	1653	-1.3553
1660	-.8489	1665	-.7464
1661	-.6609	1666	-.2933
1662	.3416	1667	-.7286
1674	-3.9360	1680	-2.3492
1675	-1.5822	1681	-.2807
1676	.7676	1682	-2.2569
1689	-.0942	1694	-2.5601
1703	2.9032	1696	.0629
1704	1.0856	1708	-2.4820
1717	-.6313	1709	3.1803
1718	-.1651	1710	-.9380
1731	-4.4150	1722	-1.3373
1732	-1.6223	1723	1.0554
1745	2.5125	1724	-2.2592
1746	-.8584	1736	-1.6476
1747	2.3044	1737	-1.1118
1759	-3.2807	1738	-.5532
1775	.7127	1739	-2.2550
1803	-.5055	1752	4.2271
1831	2.3792	1809	.5532
		1837	4.4850





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standard deviation of less than 1 m. A comparison of the GEOS-3 Geoid is made with the NASA Marsh and Chang 1976 Geoid. The GEOS-3 Geoid correlates well with the larger features of the local bottom topography.