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SUMMARY OF SKYLAB S-193

ALTIMETER ALTITUDE RESULTS

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16. Abstract

This document presents the SKYLAB S-193 altimeter altitude results in a concise format for further use and analysis by the scientific community. The altimeter mission and instrumentation is described. The altimeter processing techniques and values of parameters used for processing are included. The determination of reference orbits is discussed and the tracking systems utilized for the results in this document are tabulated. Techniques for determining satellite pointing are presented and a tabulation of pointing for each data mission included. The geographical location, the ocean bottom topography, the altimeter determined ocean surface topography and the altimeter automatic gain control history is presented. Finally, some typical applications of this data are suggested.

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Other contributions have come from NASA Wallops Flight Center personnel. In particular R. G. Forsythe has been instrumental in making the waveform processing software operational and has provided assistance in the processing of the data.

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INTRODUCTION

Purpose

The purpose of this document is to present the SKYLAB S-193 altimeter altitude results in a concise format for further use and analysis by the Scientific Community. Therefore, extreme care has been used to preserve the integrity of this data. The instrument and processing techniques are described for the users benefit. In addition, errors and techniques required to use these measurements in geodetic applications are discussed.

Scope

The data contained in this report has been obtained from all three SKYLAB missions (SL-2, SL-3, SL-4). No attempt is being made to present a complete analysis of all the data or to suggest the proper interpretation. However, some suggestions that might be useful to the data user are made and it is hoped that these will be helpful. All results included are based on work done at Wallops Flight Center.

MISSION DESCRIPTION

The SKYLAB altimeter was the first of a series of satellite altimeters planned over the next decade devoted primarily to geodesy and oceanography [1]. This paper will describe the design criteria and the role of the operating modes of the SKYLAB instrument. The sensor technology to be gained by this instrument is described along with the status of results. Some of the present and possible near future applications for the data are presented and some of the current capabilities for fulfilling these applications are mentioned. In addition the prime objectives related to altimetry in the NASA Earth and Ocean Physics Program are highlighted. Throughout this paper an effort is made to show how the SKYLAB mission fits into the overall program.

The S-193 altimeter experiment was conceived to develop satellite altimeter sensor technology for a series of altimeter missions including GEOS-C (1975), SEASAT-A (1978) and SEASAT-B (1980's). The long term objectives of satellite altimetry were stated in the 1969 Williamstown study [2] on Solid Earth and Ocean Physics and the 1972 Earth and Ocean Physics Applications Program (EOPAP) report. These studies call for development of a synoptic satellite altimeter exhibiting 10 cm accuracy with at least 1° (100 km) spacial resolution.

As one can readily see the goals are not merely the development of instrumentation but must include the techniques required to make the whole satellite system perform to the requirements. Models were developed for mean waveshapes, radar cross sections (σ_o), pointing, sea state, and time correlation. In addition, a system error budget was developed. The SKYLAB altimeter experiment was designed with system flexibility oriented so that experience with various possible error sources might be obtained. For example, pointing effects were studied by moving the antenna, footprint and bandwidth were studied by varying pulsewidth and bandwidth. Time correlation was studied by varying pulse spacing with a double pulse transmission. Return signals from conventional and pulse compression transmission techniques are also compared.

INSTRUMENT DESCRIPTION

Geometrically the instrument system consisted of a space platform (the SKYLAB satellite) and a radar altimeter oriented to make vertical (nadir) measurements of the distance from the satellite to the ocean surface. While the SKYLAB orbit (440 km height, eccentricity .001 and inclination 50°) was not an ideal reference system for long arc geodetic measurements, it did represent an excellent test bed for altimeter sensor development and short arc topography measurements. The low orbit, payload weight, and size capacity made it possible to build a radar system with good signal-to-noise and instrument versatility and flexibility. Therefore, the S-193 altimeter system was optimized to provide a variety of measurements under various operating parameters. Within the hardware [1,2] five basic modes were developed to perform various pre-set data taking and calibration operations to gather data needed to design improved altimeters for future space missions. Basically, the five experimental modes can be summarized as follows: (For more detail see Table 2.)

TABLE 1. SKYLAB ALTIMETER MODES

Mode	Unique Features	Prime Data Generated
1. Pulse Shape	.5° Step in Antenna Position Wide Receiver Bandwidth	Sample and Hold Altitude AGC
2. σ_o (Radar-Cross-Section)	12 db Step (AGC Calibration) Antenna Position 0°, 1/2°, 15.6°, 8°, 3°, 1.5°, 0°	Sample and Hold AGC
3. Time Correlation	Two Pulsewidths Double Pulse Operation Spacings 1, 19.2, 76.8, 153.6, 408.6, 819.1 (Micro Seconds)	Sample and Hold Altitude
5. Pulse Compression	Three Pulsewidths 10 ns 10 ns (compressed) 100 ns	Sample and Hold AGC Altitude
6. Nadir Alignment	Slow Spiral Drive	AGC

The most important measurements provided by the altimeter consist of altitude, waveforms and Automatic Gain Control voltage (AGC). The altitude measurements are made approximately 8 times per second with a 2 Hz bandwidth tracking system. The spatial footprint (spot size) was about a 3 km radius for the narrow pulse operation which represents a two dimensional filter for topography mapping missions. Wide pulse operation represents about an 8 km radius filter.

The waveforms were sampled by eight moveable sample-and-hold gates placed at regular intervals on the return signals. These gates can sample the return waveform 100 times per second and can be utilized for wave height and antenna pointing angle estimation.

The AGC is available approximately 4 times per second and is useful to calibrate the above waveforms and to detect clouds, rain and other anomalies which affect signal strength.

DATA PROCESSING

The PCM analog tape was converted by NASA Johnson Space Center to a digital format and both editing and decommutation were performed (see JSC TR 524 documentation). In addition, the airlock module time (AMT) of each frame of data was converted to GMT. The raw altimeter two-way range bit data (20 bits) was converted to measured altitude bit data (21 bits) by making the 21st high order bit a one if the 20th high order bit was a zero. Finally, the following algorithm was used to convert bits to kilometers [1]:

$$A_m = [(21 \text{ bits}) \times BW + ID] \times (C/2)$$

where:

BW = bit weight, 2.5×10^{-9} sec/bit,

ID = estimate of the internal system delay
40×10^{-9} sec for SL-2, 3
-195×10^{-9} sec for SL-4, and

C = speed of light, 299792.5 km/sec.

A processed digital tape with frame GMT, measured altitude and other altimeter measurements, statuses and housekeeping data was sent to approved investigators.

After the tape was received from Johnson Space Center, it was converted to a format compatible with Wallops Honeywell 625 Computer. Then, the following algorithm was used to preprocess the altitude data:

$$A_c = A_m - (ID \times \frac{C}{2}) + (PMICM - M1CDS3) + MC\text{-}R$$

where A_c = corrected altitude,

A_m = measured altitude provided by Johnson Space Center

$ID \times \frac{C}{2}$ = correction to remove internal system delay correction made by Johnson Space Center,

PMICM = premission internal system calibrate measurement broken down as follows:

2624000 ns base delay

-95 ns { calibrate vs data path difference (-85 ns); rectangular vs triangular pulse difference (-10 ns)

2623905 ns

MICDS3 = measurement obtained in MODE 1, calibration Data Step 3 (altitude calibrate mode used to gather). This measured approximately 2624105 ns, (data on altimeter aging effects).

MC = error caused by switching pulsewidths, bandwidths, and pointing with certain modes and submodes, and

R = tropospheric refraction correction.

The magnitudes of the different corrections vary. For example, the system inflight calibration correction obtained was approximately 30 m with an uncertainty of less than 20 cm detected in evaluating the third term in the algorithm. The pulsewidth/bandwidth correction varies from 0 to 103 ns (0-16 m) depending on the mode and submode used, and the pointing angle correction being used in Mode 1 is approximately 13 ns (2 m). The refraction model,

$$R = \frac{2.77(N)}{328.5\ (.026) + \sin E},$$

assumes a constant surface refractivity of 340 N units, and E is 90 degrees when looking at nadir. This results in a correction of 2.79 m.

Unified S-Band (USB) data was used to estimate orbital parameters. The orbital elements are used as initial conditions to integrate an orbit from which altimeter measurement residuals are calculated. The residuals are the differences between the altimeter measurements to the sea surface and the calculated altitude from the spacecraft to the ellipsoid. Finally, the altitude residuals, and both the GEM 6 geoid and ocean bottom topography along the subsatellite track were merged and plotted for further analysis. Figure 1 illustrates the data flow.

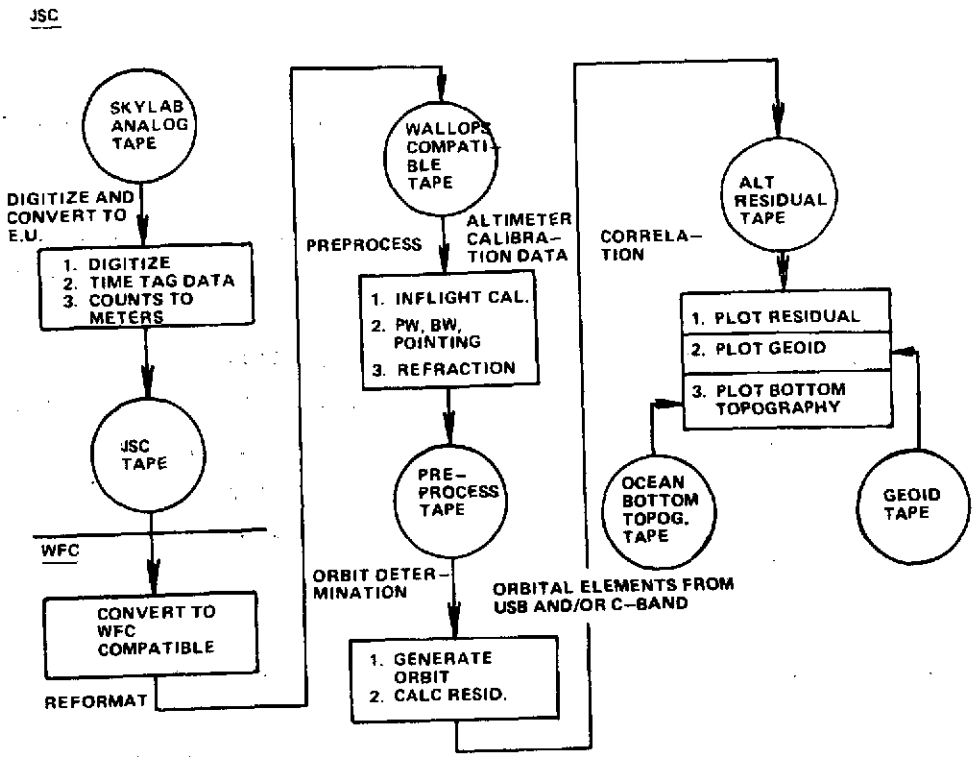

Figure 1 Skylab Altitude Data Flow

MODE CHANGE CORRECTIONS

Mode change corrections are applied during automatic processing to correct for pulsewidth, bandwidth, and other operating parameter changes that cause altitude bias. The corrections utilized were based on pre-mission measurements. These corrections were not sufficient because the mission operating parameters were slightly different from the pre-mission conditions. For example, satellite pointing errors often changed the radar return waveforms significantly. Therefore, the best mode change corrections were felt to be available from the data itself. These were obtained by differencing the mean residuals on each side of a known mode change. It should be noted that mode changes should not produce a bias from data pass to data pass since all altimeter modes start out with the same basic operating parameters. Any altimeter bias noted from pass to pass is probably due to pointing errors, and the correction for this effect is discussed in the Pointing Determination Section.

To assist the user of the results in this report, a set of typical mode times sequences is supplied in Table 2. If one suspects that an altitude jump is due to a mode change, the appropriate AGC plot should be examined for sharp change in signal level. In addition, these changes in signal level can be aligned with the Table 2 events to confirm a mode change.

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Table 2

Altimeter Modes

MODE 1 PULSE SHAPE EXPERIMENT														
TRANSMITTER				ANT.	RECEIVER		SIGNAL PROC.	SQUARE LAW SAMPLING						
SUB-MODE	PULSE MODE	FREQ. GHz	PULSE WIDTH NSEC.	POINTING ANGLE DEGREES	IF FILTER BANDWIDTH MHz	CAL. PATH ATTN. dB	ALTITUDE TRACK OR COUNTER	# OF SAMPLE POSITIONS	# OF S&H GATES PER POSITION	S&H GATE SPACING NSEC.	RETURNS SAMPLED PER FRAME	# OF FRAMES OF DATA	# OF SAMPLES OBTAINED	TYPICAL RUNNING TIME SEC.
(0) DAS-1	Single-250 pps	13.9	100	Sub-Satellite	10	N/A	Alt. Track	3	8	25	104	50	41,600	52.00
(1) DAS-2	"	"	"	"	100	"	"	"	"	"	"	61	50,752	63.44
(2) DAS-3	"	"	"	0.431^{o} Pitch	"	"	"	"	"	"	"	61	50,752	63.44
(3) CDS-1	"	"	"	N/A	"	*	Alt. Counter	2	"	"	"	7	5,824	7.28
(4) CDS-2	"	"	"	"	10	*	"	"	"	"	"	5	4,160	5.2
(5) CDS-3	"	"	"	"	"	*	Alt. Track	"	"	"	"	5	4,160	5.2

NOTES:
- 1 Frame = 1.04 SEC. (192 INCL 2 DUMMY +)
- DATA/TOTAL FRAMES: 172/192 (1 END OF MODE FRAMES)
- TOTAL RUNNING TIME FOR DATA FRAMES: 178:88 SEC
- TOTAL MODE RUNNING TIME: 199.68 SEC. (INCL. DUMMY + EOM FRAMES)
- SAMPLE GATE POSITIONS RELATIVE TO THE TRACKER POSITION ARE INDEXED BY S^2M.

* W/G Attenuation
nominal = 119 ± 1 dB

S-193 SN1 Atten. = 118.49 dB

Table 2

Altimeter Modes (Continued)

MODE 2 CROSS-SECTION EXPERIMENT														
	TRANSMITTER			ANT.	RECEIVER		SIGNAL PROC.	SQUARE LAW SAMPLING						
SUB-MODE	PULSE MODE	FREQ. GHz	PULSE WIDTH NSEC.	POINTING ANGLE DEGREES	IF FILTER BANDWIDTH MHz	CAL. PATH ATTEN. dB	ALTITUDE TRACK OR COUNTER	# OF SAMPLE POSITIONS	# OF S&H GATES PER POSITION	S&H GATE SPACING NSEC.	RETURNS SAMPLED PER FRAME	# OF FRAMES OF DATA	# OF SAMPLES OBTAINED	TYPICAL RUNNING TIME SEC.
(0) DAS-1	Single-250 pps	13.9	100	Sub-Satellite	10	N/A	Alt. Track	3	8	25	104	10	8.320	10.4
(1) DAS-2	"	"	"	0.431°	"	"	Disabled, held at DAS-1 Range	1	"	"	"	30	24,960	31.2
(2) DAS-3	"	"	"	15.6°	"	"	"	"	"	"	"	30	24,960	31.2
(3) DAS-4	"	"	"	7.564°	"	"	"	"	"	"	"	30	24,960	31.2
(4) DAS-5	"	"	"	2.652°	"	"	"	"	"	"	"	30	24,960	31.2
(5) DAS-6	"	"	"	1.3°	"	"	"	"	"	"	"	30	24,960	31.2
(6) DAS-7	"	"	"	Sub-Satellite	"	"	Alt. Track	3	"	"	"	7	5,824	7.28
(7) CDS-1	"	"	"	N/A	"	** (~130dB)	Alt. Counter	2	"	"	"	7	5,824	7.28
(8) CDS-2	"	"	"	"	100	** (~130dB)	"	3	"	10	"	7	5,824	7.28
(9) CDS-3	"	"	"	"	"	* (~119dB)	"	"	"	"	"	7	5,824	7.28

NOTES:
- 1 FRAME = 1.04 SEC.
- DATA/TOTAL FRAMES: 167/191 (INCLUDES 2 DUMMY + 1 EOM FRAMES)
- TOTAL RUNNING TIME FOR DATA FRAMES: 173:68 SEC.
- TOTAL MODE RUNNING TIME = 198.64 (INCLUDING DUMMY & EOM FRAME)
- SAMPLE GATE POSITIONS RELATIVE TO THE TRACKER POSITION ARE INDEXED BY S^2M.

** Internal ALT + W/G Attenuation in Cal Submodes
nominal = (11 ± 1)dB + (119 ± 1)dB
S-193 SNI Atten = 10.6 ‡ dB + 118.49 dB = 129.09 dB

* W/G Attn in Cal Submode = 119 ± 1dB (nominal)
S-193 SMI Attn = 118.49 dB

‡ 10.8 dB @ -20°C & +50°C

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Table 2

Altimeter Modes (Continued)

MODE 3 TIME CORRELATION EXPERIMENT														
TRANSMITTER				ANT.	RECEIVER		SIGNAL PROC.	SQUARE LAW SAMPLING						
SUB-MODE	PULSE MODE	FREQ. GHz	PULSE WIDTH NSEC.	POINTING ANGLE DEGREES	IF FILTER BANDWIDTH	CAL. PATH ATTEN. dB	ALTITUDE TRACK OR COUNTER	** # OF SAMPLE POSITIONS	# OF S&H GATES PER POSITION	S&H GATE SPACING NSEC.	RETURNS SAMPLED PER FRAME	# OF FRAMES OF DATA	# OF SAMPLES OBTAINED	TYPICAL RUNNING TIME SEC.
(0) CDS-1	DUAL-250 pulse pairs/sec	13.9	100	N/A	100	*	Alt. Counter	6	4	25	208	23	19,136	23.92
(1) CDS-2	"	"	20	"	"	*	"	8	"	10	"	25	20,800	26.0
(2) CDS-3	Single 250 pps	"	100	"	10	*	"	2	8	25	104	3	2,496	3.12
(3) DAS-1	"	"	"	Sub-Satellite	"	N/A	Alt. Track	3	"	"	"	16	13,312	16.64
(4) DAS-2	DUAL-250 pulse pairs/sec	"	"	"	100	"	"	8	4	"	208	25	20,800	26.0
(5) DAS-3	"	"	20	"	"	"	"	16	"	10	"	98	81,536	101.92
(6) CDS-4	"	"	100	N/A	"	*	Alt. Counter	6	"	25	"	20	16,640	20.8
(7) CDS-5	"	"	20	"	"	*	"	8	"	10	"	25	20,800	26.0

* W/G Attenuation in Cal Submodes
nominal = 119 ± 1 dB
S-193 SN1: Attn = 118.49 dB

** Number of sample positions are doubled for Dual Pulse SMs (i.e. Start of each S&H group is considered a gate position)

NOTES:
- 1 FRAME = 1.04 SEC.
- DATA/TOTAL FRAMES 139/238(238 INCL. 2 DUMMY + 1 EOM)
- TOTAL RUNNING TIME FOR DATA FRAMES: 144.56 SEC.
- TOTAL MODE RUNNING TIME = 247.52 SEC (INCL DUMMY & EOM FRAMES)
- PULSE PAIRS IN SM'S 0,1,4,5,6 & 7 HAVE PULSE SEPARATIONS 819.25, 409.65, 153.65, 76.85, 19.25, 1.05 MSEC IN CONSECUTIVE ORDER INDEXED BY THE S^3M.
- SAMPLE GATE POSITIONS RELATIVE TO THE TRACKER POSITION ARE INDEXED BY THE S^2M.

Table 2

Altimeter Modes (Continued)

MODE 5 PULSE COMPRESSION - 20 NANOSECOND EXPERIMENT														
	TRANSMITTER			ANT.	RECEIVER		SIGNAL PROC.	SQUARE LAW SAMPLING						
SUB-MODE	PULSE MODE	FREQ. GHz	PULSE WIDTH NSEC.	POINTING ANGLE DEGREES	IF FILTER BANDWIDTH MHz	CAL. PATH ATTEN. db	ALTITUDE TRACK OR COUNTER	# OF SAMPLE POSITIONS	# OF S&H GATES PER POSITION	S&H GATE SPACING NSEC.	RETURNS SAMPLED PER FRAME	# OF FRAMES OF DATA	# OF SAMPLES OBTAINED	TYPICAL RUNNING TIME SEC.
(0) DAS-1	Single-250 pps	13.9	100	Sub-Satellite	10	N/A	Alt. Track	3	8	25	104	16	13,312	16.64
(1) DAS-2	"	"	130 (PC)	"	100	"	"	4	"	10	104	99	82,368	102.96
(2) DAS-3	"	"	20	"	"	"	"	"	"	"	104	51	42,432	53.04
(3) CDS-1	"	"	"	N/A	"	*	Alt. Counter	2	"	"	104	7	5,824	7.28
(4) CDS-2	"	"	130 (PC)	"	"	*	"	3	"	"	104	7	5,824	7.28
(5) CDS-3	"	"	100	"	10	*	"	2	"	25	104	5	4,160	5.20

NOTES:
- 1 FRAME = 1.04 SEC.
- DATA/TOTAL FRAMES: 166/188 (188 INCL. 2 DUMMY & 1 EOM FRAMES)
- TOTAL RUNNING TIME FOR DATA FRAMES: 172.64 SEC.
- TOTAL MODE RUNNING TIME: 195.52 SEC (INCL DUMMY + EOM FRAME)
- SAMPLE GATE POSITIONS ARE INDEXED BY S^2M

* W/G Attenuation in Cal Submodes
nominal = 119 ± 1 dB
S-193 SN 1 Attn = 118.89 dB

NADIR ALIGN														
(0) N/A	Single-250 pps	13.9	100	Scanning	10	N/A	Free to Track *	N/A	N/A	N/A	N/A	192	None	199.68

* TRACKING NOT REQUIRED FOR MODE SEQUENCING TO OCCUR
NOTE: 1 FRAME = 1.04 SEC. MODE RUNNING TIME = 202.8 SEC. (INCL. 2 DUMMY & 1 EOM FRAME)

ORBIT DETERMINATION

Analysis and evaluation of the SKYLAB altimeter data can best be accomplished by reducing the measurements to quantities which can be compared with independently derived data. Since the ocean surface, except for tidal and wind effects, follows an equipotential surface, it is convenient to derive an estimate of the geoid height from the altimeter altitude measurements. These can then be compared with an independent determination of the geoid height. The relationship between geoid height (h_g) and satellite altitude measurements is given by:

$$h_g = h_s - h_a - \Delta h$$

Where h_s = satellite height above a reference spheriod obtained from the satellite orbit determined from tracking data,

h_a = satellite altitude measured by the altimeter,

and Δh = dynamic ocean effects of tides, winds and currents.

The relationship of these quantities is shown in Figure 2.

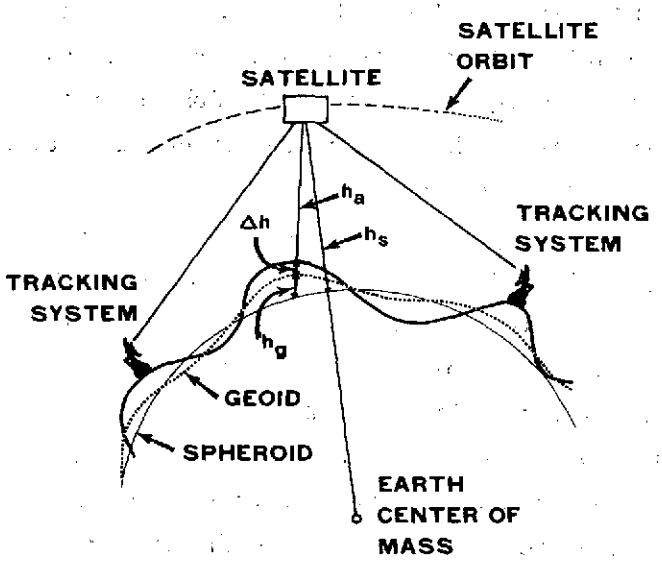

Figure 2 The Determination of Geoid Heights From Altimeter Data

It is obvious from this relationship that any radial orbit errors will propagate directly into errors in geoid heights determined from the data. Therefore, for analysis and evaluation of the SKYLAB altimeter data it was necessary to obtain the most accurate orbit possible from the available tracking data.

Several factors make the determination of accurate SKYLAB orbits a difficult task. The altitude of the SKYLAB orbit was approximately 440 KM and its effective area was 293 square meters with a mass of 87,441 kg. These factors meant that atmospheric drag has a large effect on the satellite orbit. In addition, thrusting is used for spacecraft maneuvers both before and after the altimeter data is acquired. The tracking data was provided by the Goddard Space Flight Center, unified S-Band System (USB) with some C-Band support. The USB system is a worldwide system, but due to workload and scheduling every station did not track at every opportunity, and hence the density of tracking data was sometimes sparse in the vicinity of an altimeter data take.

Error analyses have shown [3] that in order to minimize systematic error effects due to drag, thrusting and geopotential errors, the length of arc fitted should be kept as short as possible. The arc length necessary to be able to determine an orbit with reasonably low error depends on the available tracking coverage. Experience has shown that this can vary from 2 hours (SL-2 Pass 6) to 25 hours (SL-2 Pass 4). The difference in the effects of systematic errors on these two orbits is estimated to be less than a meter due to drag on the 2 hour orbit and 50 meters on the 25 hour orbit.

The tracking station locations and other relevant constants used for orbit determination are presented in Table 3. The gravity field used was the complete GEM-1 model described in [4]. The tracking data used for each orbit is summarized on pages 17 to 44. Table 3 on the following page entitled "Orbit Comparisons for SKYLAB" illustrates the success of this approach to orbit determination for altimeter data analysis. The table compares the GEM-1 short arc results with two day orbital fits using the GEM-6 model and additionally with the model used by Johnson Space Center to obtain SKYBET (SKYLAB Best Estimate of Trajectory Computer Program) orbits. The Johnson Space Center model is a very truncated five term gravity model which is adequate for operational orbits but clearly inadequate for detailed altimeter data analysis.

For each orbit obtained, a comparison error analysis was performed. The effects of station location errors, gravity model errors and refraction errors were calculated and propagated into effects on the calculated satellite altitude. The maximum value during an altimeter data take was used as an orbit quality number. This orbit quality number is listed on the "Pointing Correction Summary Tables."

For short data spans, radial orbit errors can introduce a bias and tilt in a geoid obtained from the altimeter observations. As an illustration, Figure 3 shows the altimeter geoid obtained from two different orbits with different arc lengths and different amounts of tracking data.

While some of the differences between the altimeter geoid and the GEM-6 geoid can be explained by orbit error, there are others which could be due to medium wavelength GEM-6 geoid errors. Figure 4 illustrates such a case with two segments of altimeter data in an area northwest of Australia.

LOCATION	GEODETIC LATITUDE			EAST LONGITUDE			SPHEROID HEIGHT	ABBREVIATION
	DEG	MN	SECONDS	DEG	MN	SECONDS	(METERS)	
GOLDSTONE, California	35	20	29.647	243	7	35.0	928.6	GDS
TEXAS, Corpus Christie	27	39	13.0	262	37	16.9	– 36.4	TEX
BERMUDA ISLAND	32	21	5.0	295	20	31.9	– 22.4	BDA
MADRID, Spain	40	27	19.9	355	49	53.5	824.5	MAD
HONEYSUCKLE, Australia	–35	–35	– 0.0	148	58	40.1	1141.3	HSK
HAWAII ISLAND	22	7	34.1	200	20	5.4	1145.6	HAW
CANARY ISLAND	27	45	52.4	344	21	57.8	190.2	CYI
CARNARVON, Australia	–24	–54	–23.7	113	43	32.0	16.8	CRO
GUAM ISLAND	13	18	38.1	144	44	12.5	125.3	GWM
MERRITT ISLAND, Florida	28	30	29.7	279	18	23.8	– 54.8	MIL
ASCENSION ISLAND	– 7	–57	–17.2	345	40	22.5	538.2	ACN

CONSTANTS USED FOR ORBIT DETERMINATION

Semi Major Axis = 6378155.00 meters
Flattening = 1./298.255
Drag Coefficient = 2.0000
Reflectivity = 1.500
Satellite Cross Sectional Area = 293.3 m^2
Satellite Mass (Kilograms) = 87440 Kg

TABLE 3. TRACKING STATION LOCATIONS AND ABBREVIATIONS USED FOR ORBIT DETERMINATION

Y M D 73 09 13	GEM 1 SHORT ARC	GEM 6 2 DAY ARC ORBIT 1	GEM 6 2 DAY ARC ORBIT 2	HOUSTON GRAV 2 DAY ARC ORBIT 1	HOUSTON GRAV 2 DAY ARC ORBIT 2
		COMPUTED	SKYLAB ALTITUDE	(METERS)	
$19^h\ 43^m$	431616.2	431628.6	431597.9	431678.6	431680.6
44^m	891.1	902.1	873.0	958.7	962.6
45^m	432120.8	432130.2	432102.7	432193.0	432198.8
46^m	278.7	314.5	288.7	383.2	390.7
47^m	451.9	457.9	434.0	532.2	541.5
48^m	560.3	564.7	542.8	644.5	655.5
		DIFFERENCES FROM GEM 1 SHORT ARC			
$19^h\ 43^m$		12.4	−18.3	62.4	64.4
44^m		11.0	−18.1	67.6	71.5
45^m		9.4	−18.1	72.2	78.0
46^m		7.7	−18.1	76.4	83.9
47^m		6.0	−17.9	80.3	89.6
48^m		4.4	−17.5	84.2	95.2

TABLE 4. ORBIT COMPARISONS FOR SKYLAB

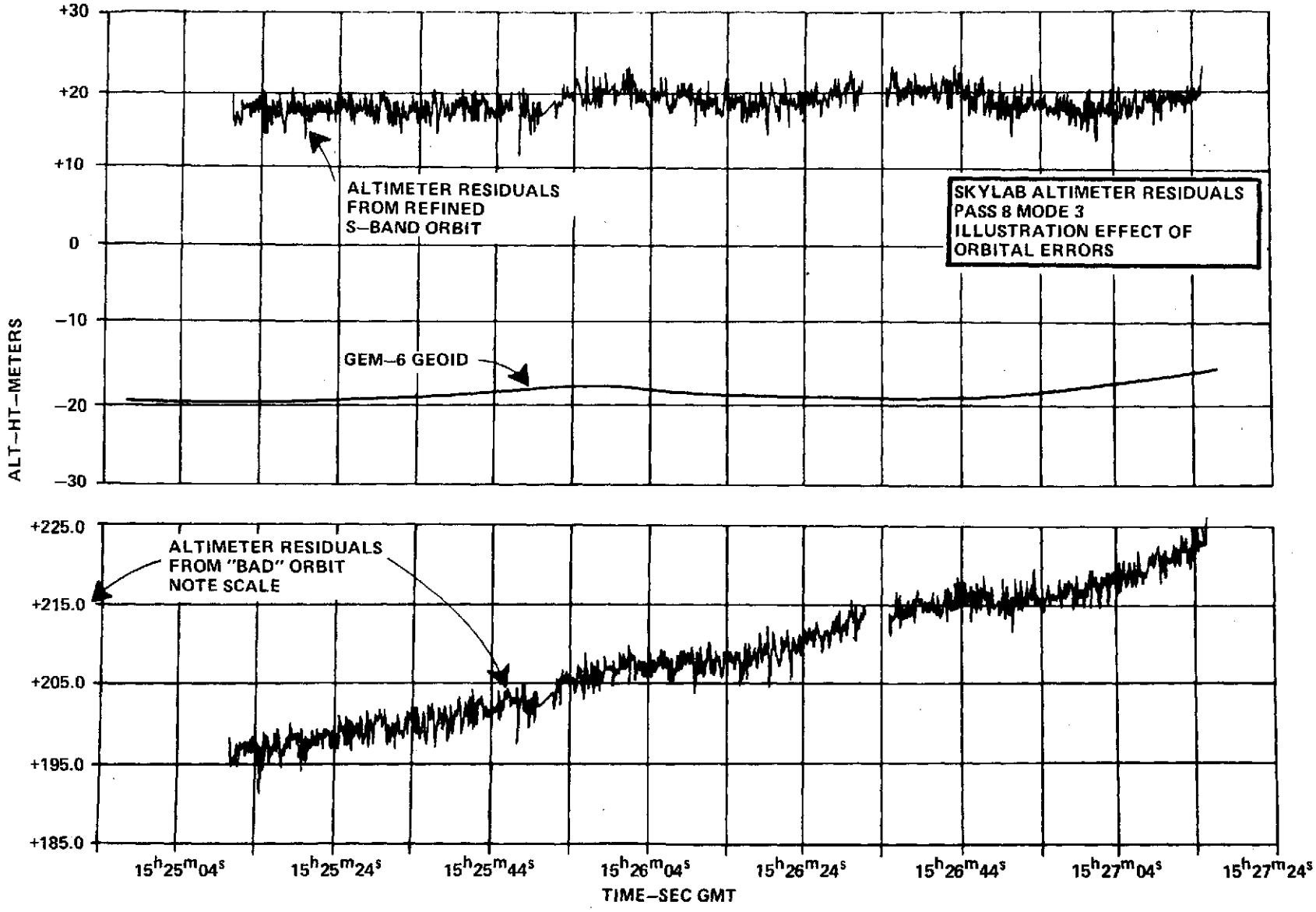

FIGURE 3. ILLUSTRATION EFFECT OF ORBITAL ERRORS

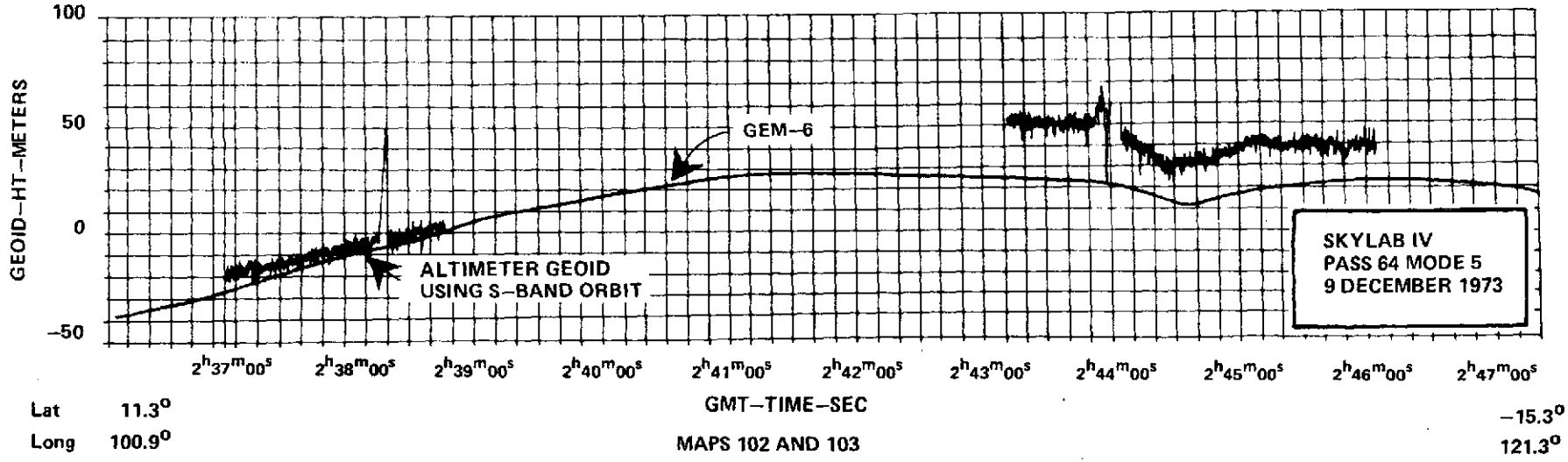

FIGURE 4. COMPARISON OF GEM–6 GEOID AND ALTIMETER GEOID FOR 2 DATA SEGMENTS OF PASS 64

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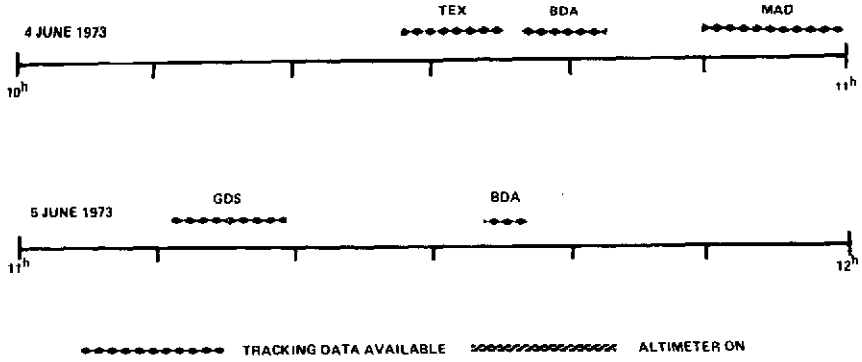
ARC LENGTH FOR ORBIT DETERMINATION 0^h33^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–2 PASS 1 30 MAY 1973

MAP 1

ARC LENGTH FOR ORBIT DETERMINATION 0^h13^m
TRACKING SCHEDULE AND ALTIMETRY DATA TAKES
SL–2 PASS 2 2 JUNE 1973

MAP 2



ARC LENGTH FOR ORBIT DETERMINATION 1^h08^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–2 PASS 4 4 JUNE 1973
MAPS 3 AND 4

ARC LENGTH FOR ORBIT DETERMINATION 0^h15^m
TRACKING SCHEDULE AND ALTIMETRY DATA TAKES
SL–2 PASS 6 9 JUNE 1973
MAP 5

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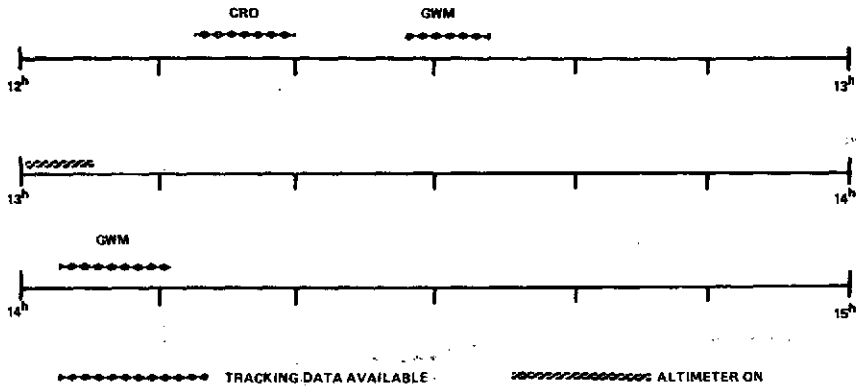
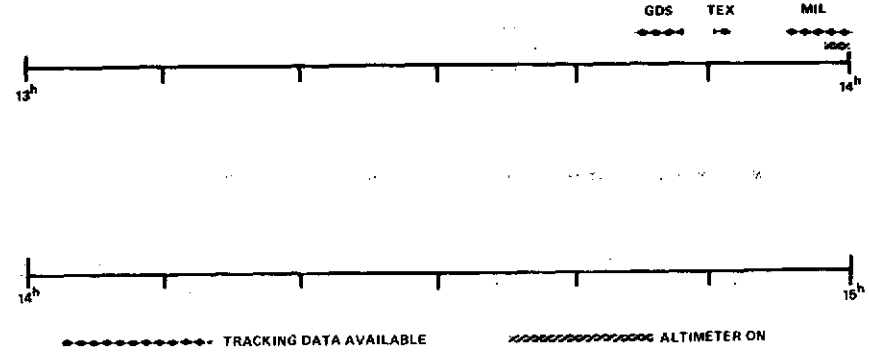
ARC LENGTH FOR ORBIT DETERMINATION 0^h59^m
TRACKING SCHEDULE AND ALTIMETRY DATA TAKES
SL-2 PASS 7 10 JUNE 1973
MAPS 6, 7, 8

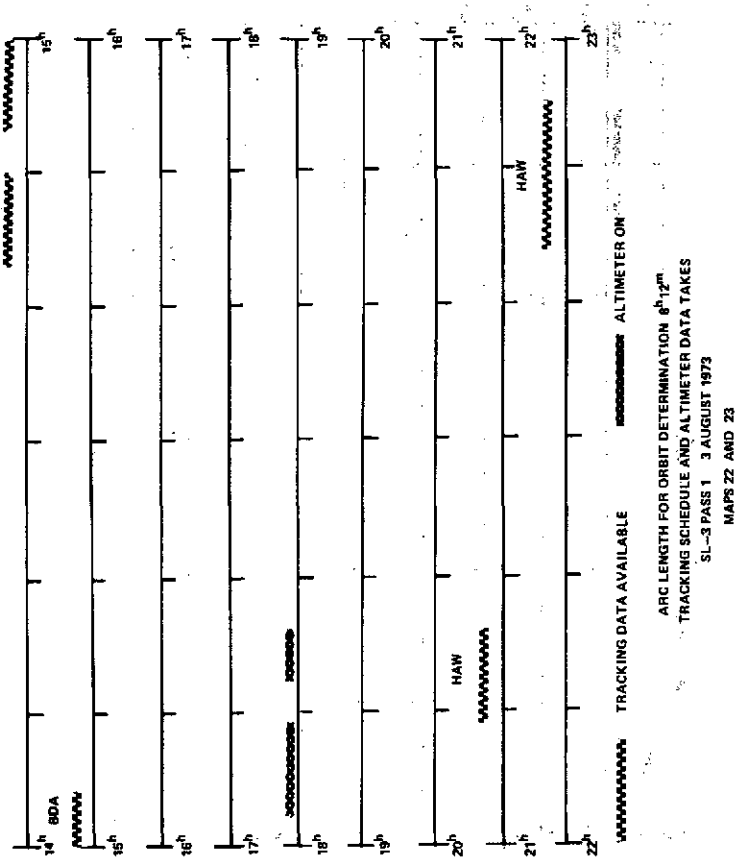
ARC LENGTH FOR ORBIT DETERMINATION 0^h17^m
TRACKING SCHEDULE AND ALTIMETRY DATA TAKES
SL-2 PASS 8 11 JUNE 1973
MAPS 9 AND 10

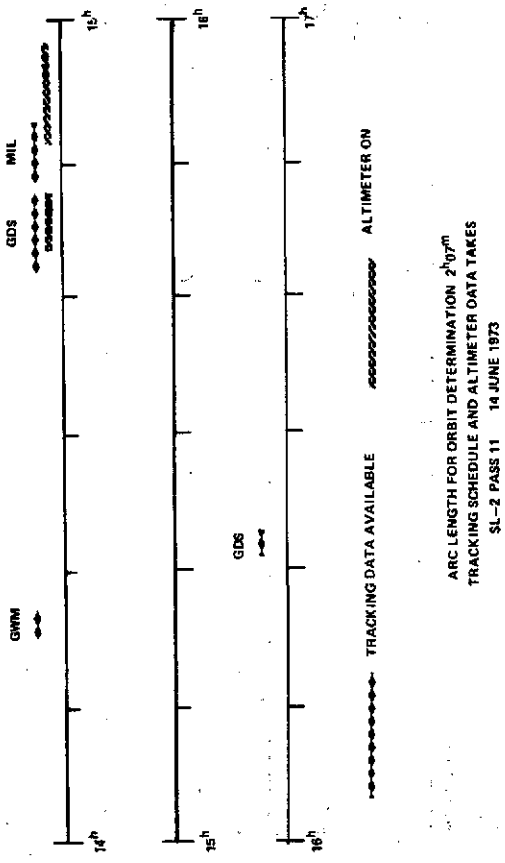


ARC LENGTH FOR ORBIT DETERMINATION 2^h0^m
TRACKING SCHEDULE AND ALTIMETRY DATA TAKES
SL–2 PASS 9 12 JUNE 1973
MAPS 11, 12, 13



ARC LENGTH FOR ORBIT DETERMINATION 0^h17^m
TRACKING SCHEDULE AND ALTIMETRY DATA TAKES
SL–2 PASS 10 13 JUNE 1973
MAPS 14 AND 15





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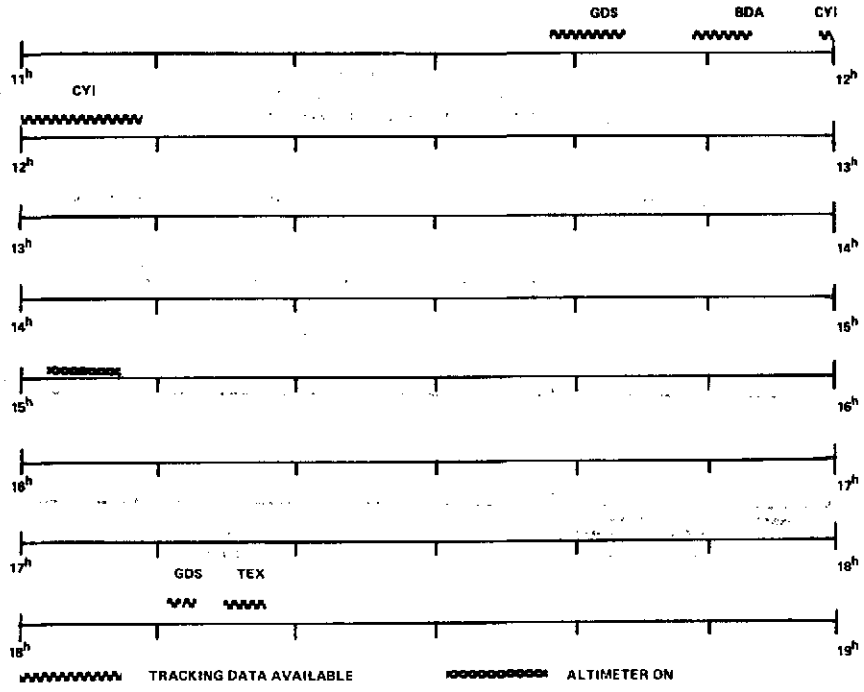
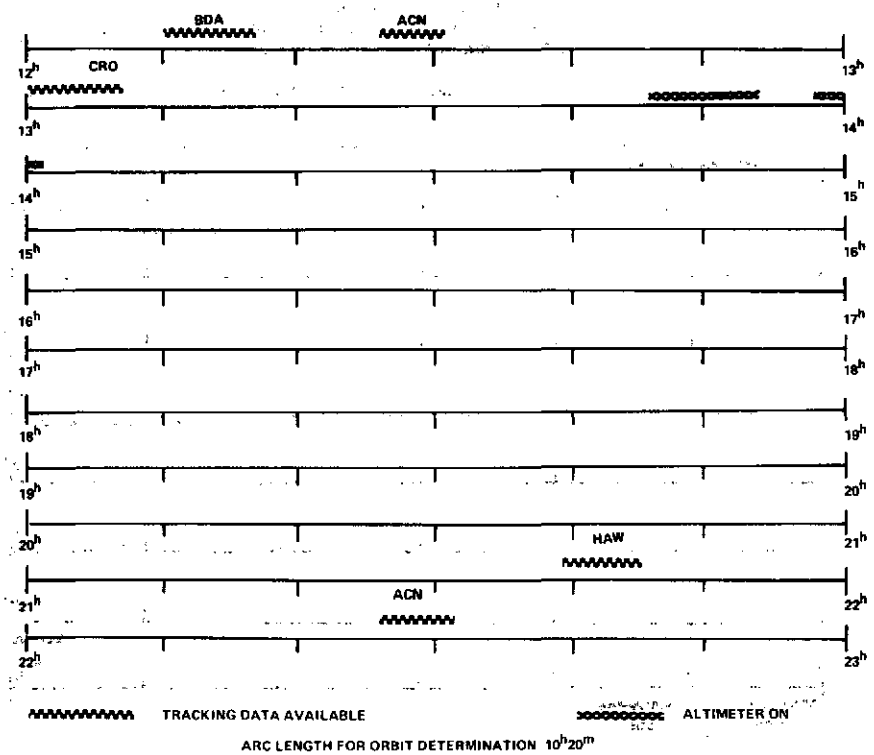


ARC LENGTH FOR ORBIT DETERMINATION 6^h20^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 3 5 AUGUST 1973
MAP 26



ARC LENGTH FOR ORBIT DETERMINATION 10^h20^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 6 9 AUGUST 1973
MAPS 28, 29, 30

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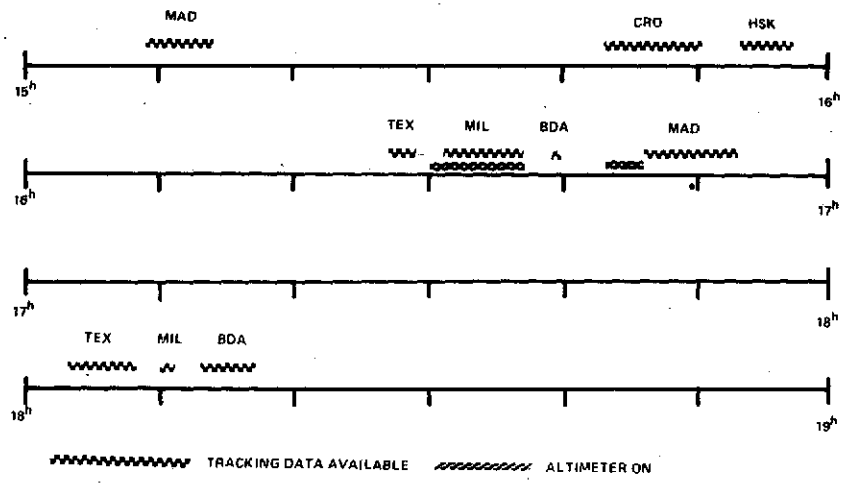
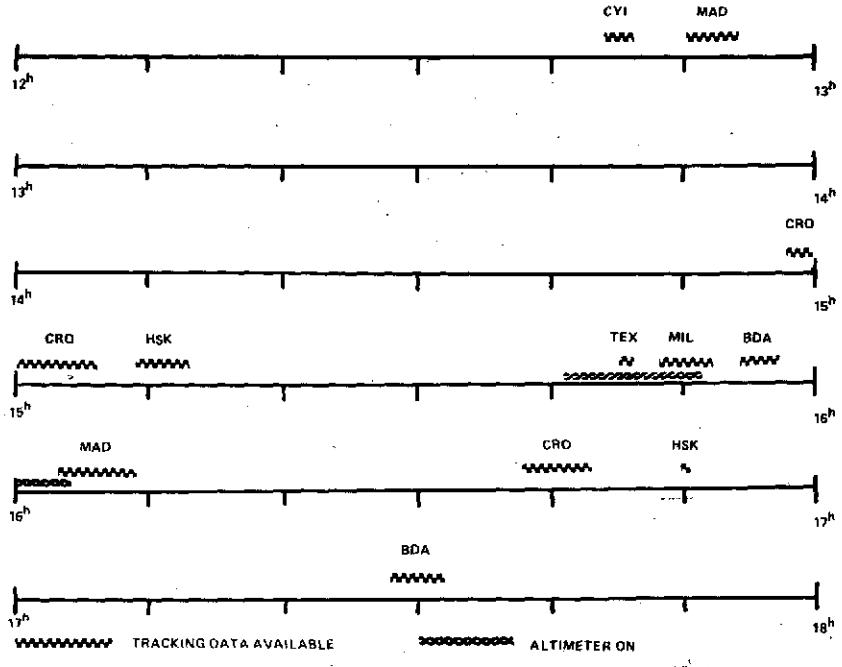
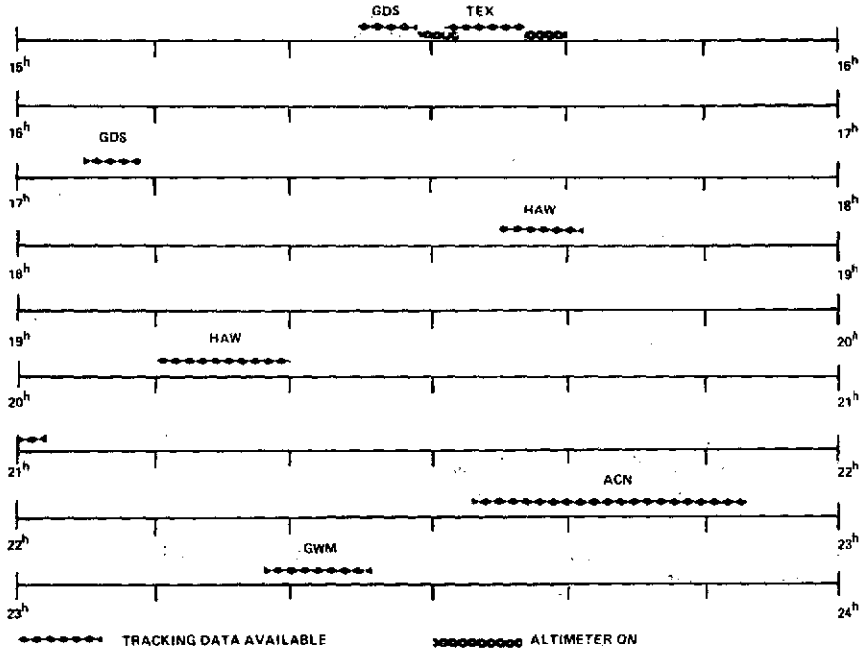


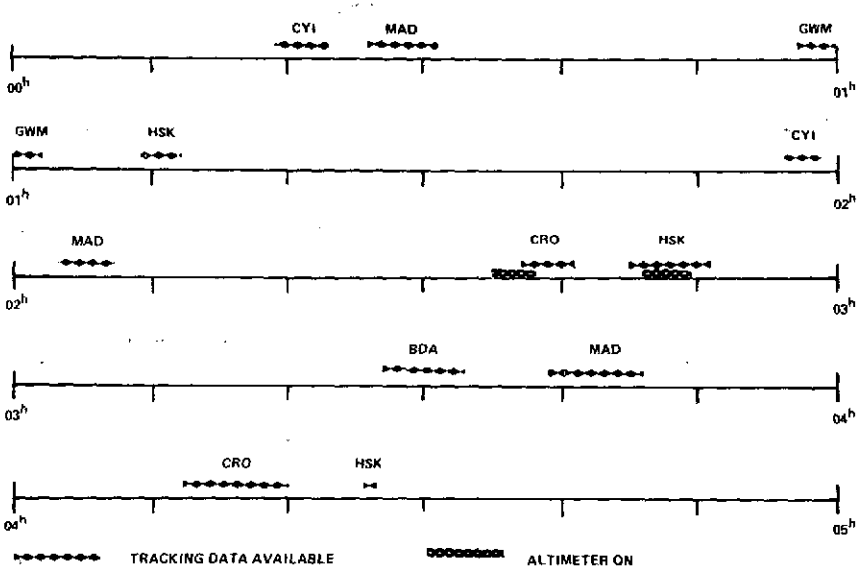
ARC LENGTH FOR ORBIT DETERMINATION 3^h08^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL-4 PASS 78 08 JANUARY 1974
MAPS 127, 128, 129



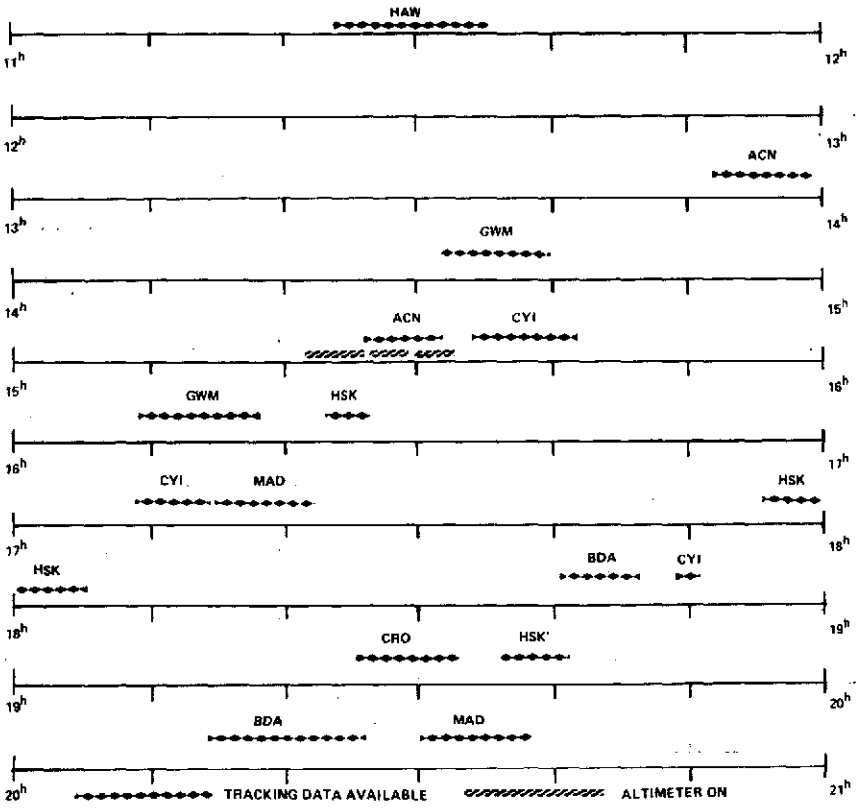
ARC LENGTH FOR ORBIT DETERMINATION 4^h48^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL-4 PASS 79 09 JANUARY 1974
MAPS 131, 132, 133, 134



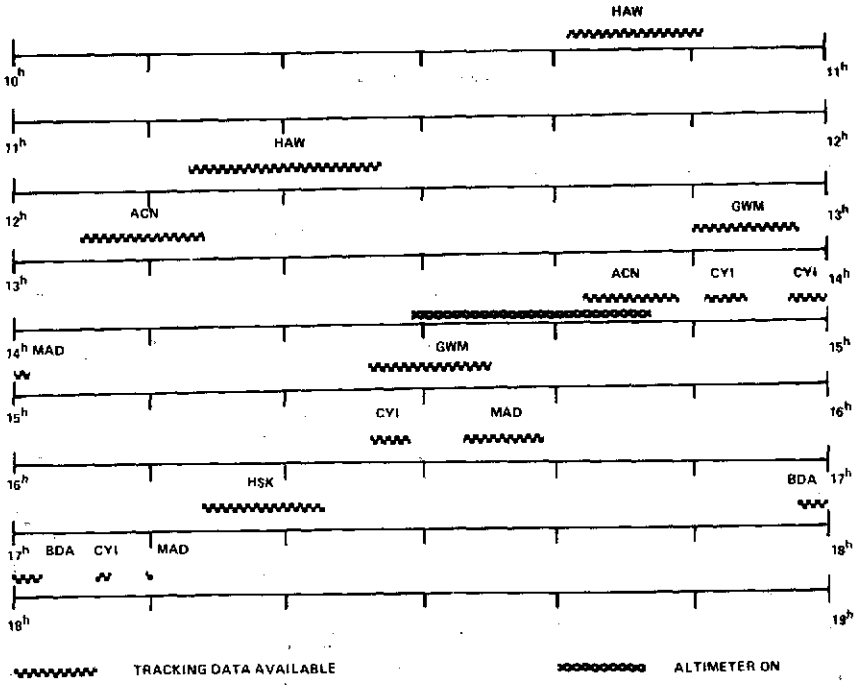
ARC LENGTH FOR ORBIT DETERMINATION 8^h01^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 7 11 AUGUST 1973
MAPS 31 AND 32



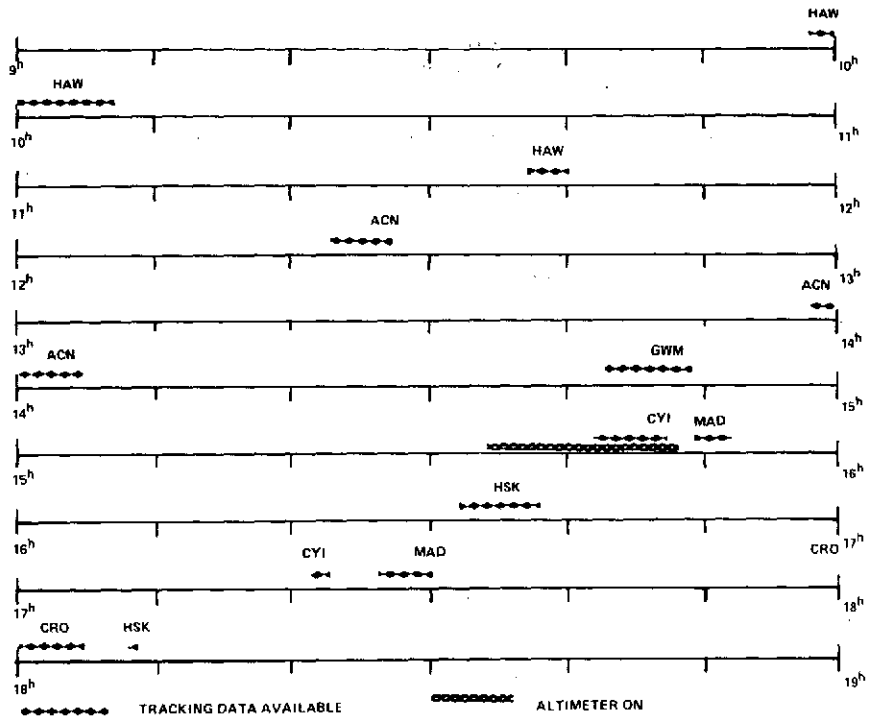
ARC LENGTH FOR ORBIT DETERMINATION 3^h07^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 8 12 AUGUST 1973
MAPS 33 AND 34



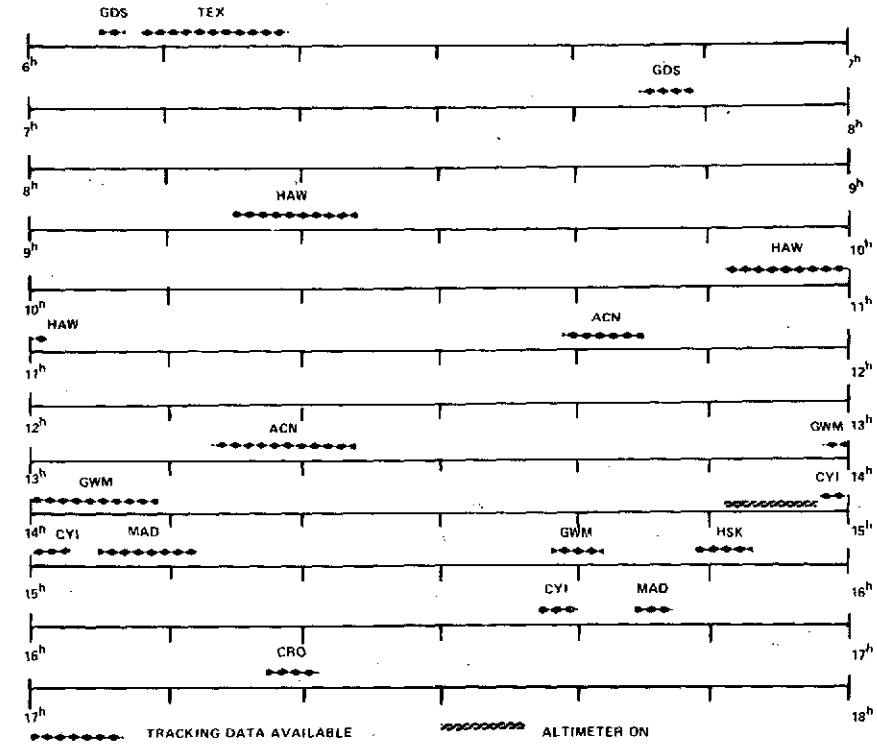
ARC LENGTH FOR ORBIT DETERMINATION 9^h14^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL-3 PASS 10 1 SEPTEMBER 1973
MAPS 35, 36, 37



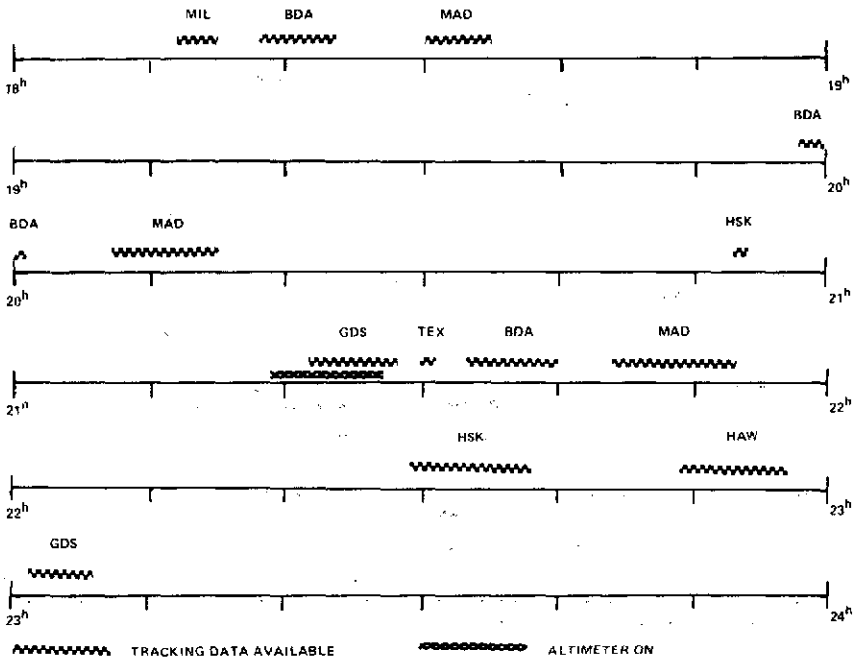
ARC LENGTH FOR ORBIT DETERMINATION 7^h29^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL-3 PASS 11 2 SEPTEMBER 1973
MAPS 38, 39, 40, 41, 42



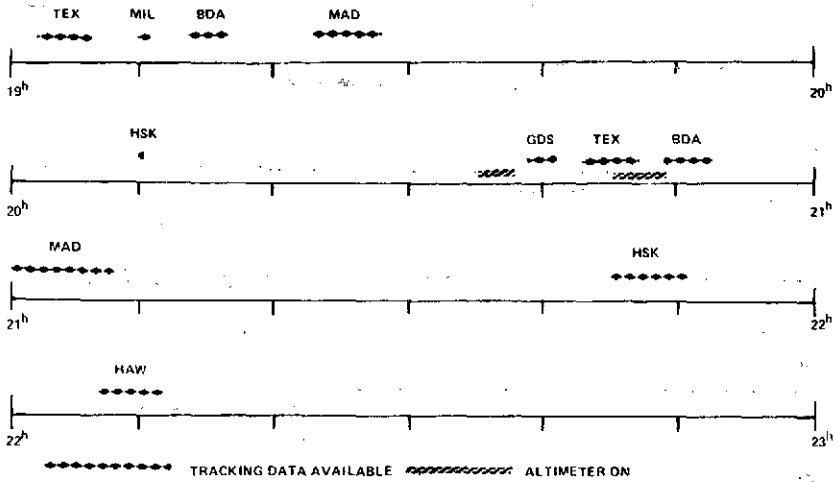
ARC LENGTH FOR ORBIT DETERMINATION 8^h10^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 13 3 SEPTEMBER 1973
MAPS 43, 44, 45



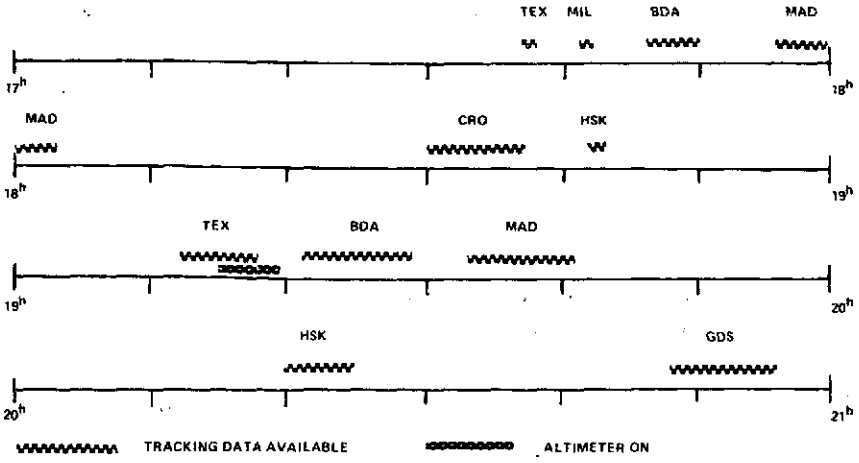
ARC LENGTH FOR ORBIT DETERMINATION 11^h16^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 14 04 SEPTEMBER 1973
MAPS 46 AND 47



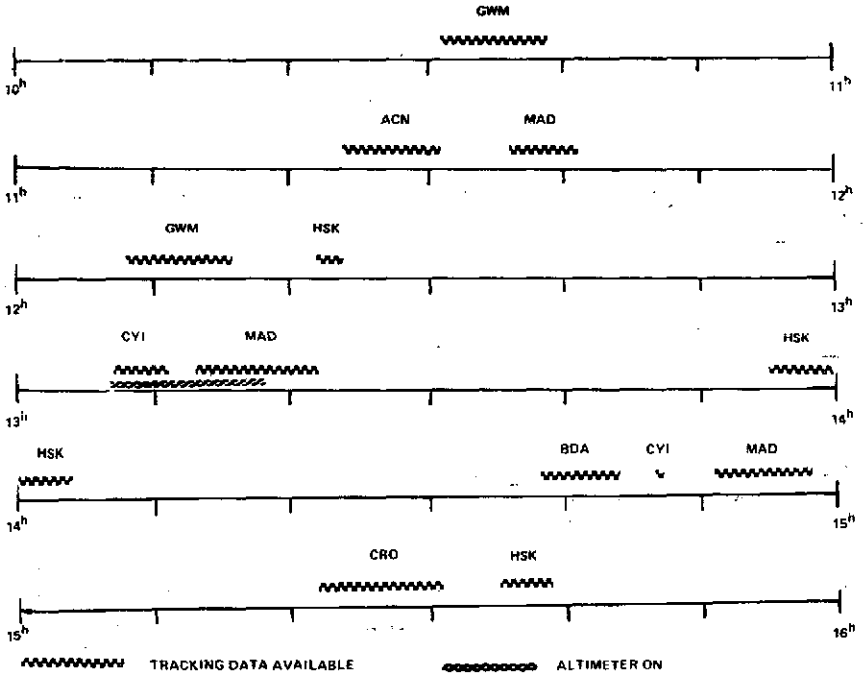
ARC LENGTH FOR ORBIT DETERMINATION 4^h49^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 16 6 SEPTEMBER 1973
MAPS 48 AND 49



ARC LENGTH FOR ORBIT DETERMINATION 3^h10^m
TRACKING SCHEDULE AND ALTIMETRY DATA TAKES
SL–3 PASS 17 7 SEPTEMBER 1973
MAPS 50 AND 51



ARC LENGTH FOR ORBIT DETERMINATION 3^h16^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL-3 PASS 18 9 SEPTEMBER 1973
MAP 52



ARC LENGTH FOR ORBIT DETERMINATION 5^h08^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL-3 PASS 21 11 SEPTEMBER 1973
MAPS 54, 55, 56

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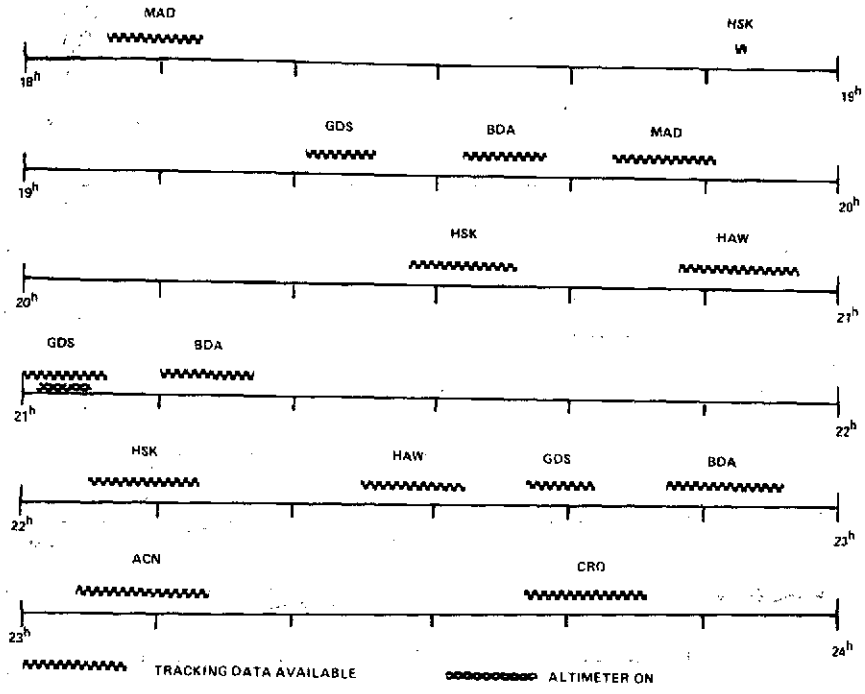
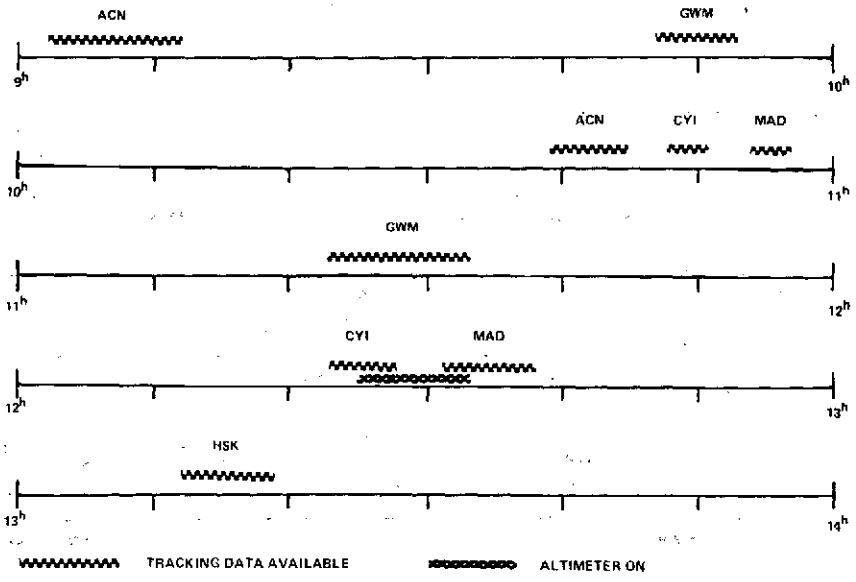
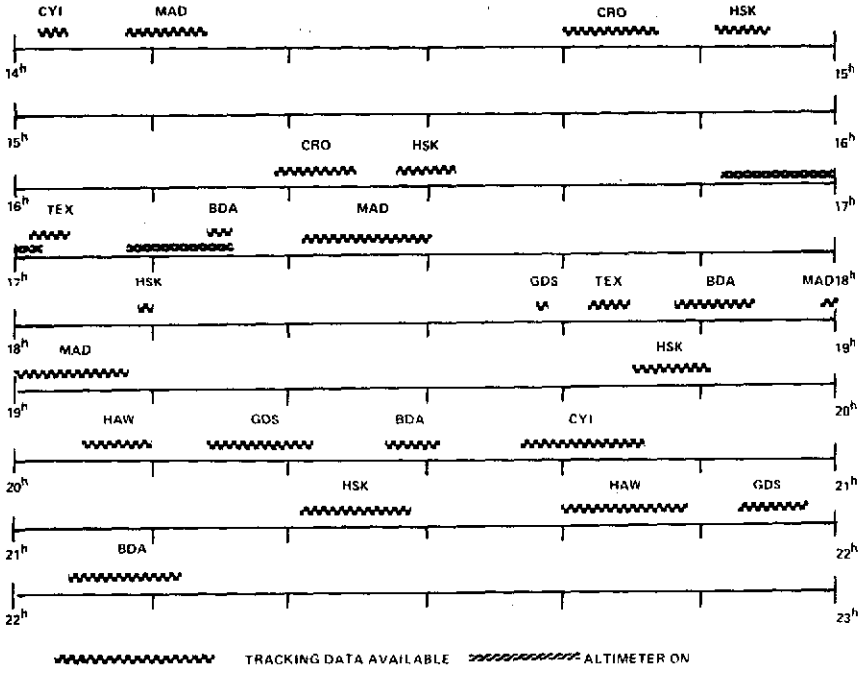


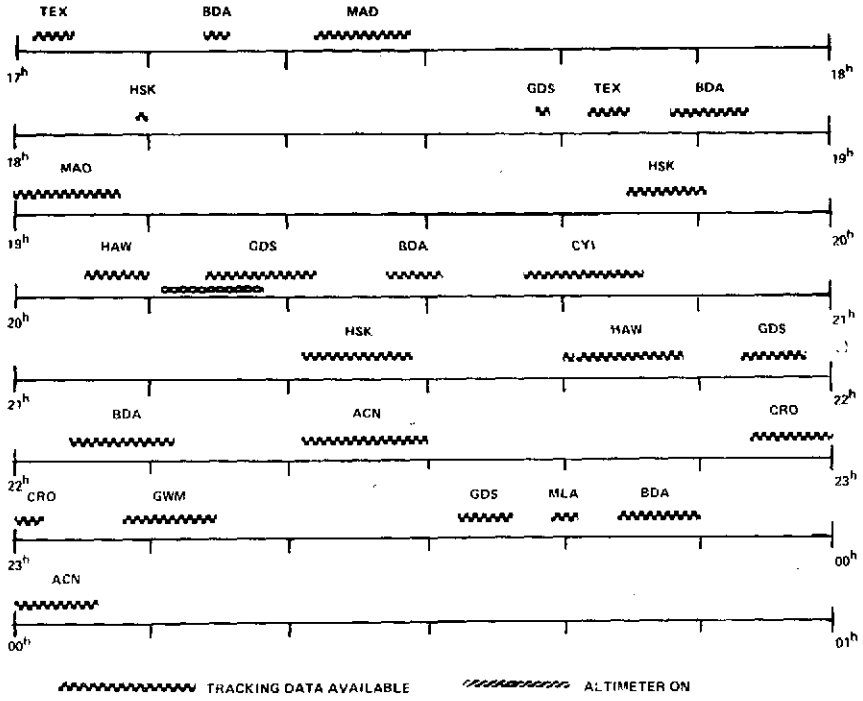
ARC LENGTH FOR ORBIT DETERMINATION 5^h40^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 23 11 SEPTEMBER 1973
MAP 57



ARC LENGTH FOR ORBIT DETERMINATION 4^h17^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 24 12 SEPTEMBER 1973
MAPS 58, 59, 60



ARC LENGTH FOR ORBIT DETERMINATION 8^h10^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 25 12 SEPTEMBER 1973
MAPS 61, 63, 64, 65



ARC LENGTH FOR ORBIT DETERMINATION 7^h05^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 26 12 SEPTEMBER 1973
MAPS 66 AND 67

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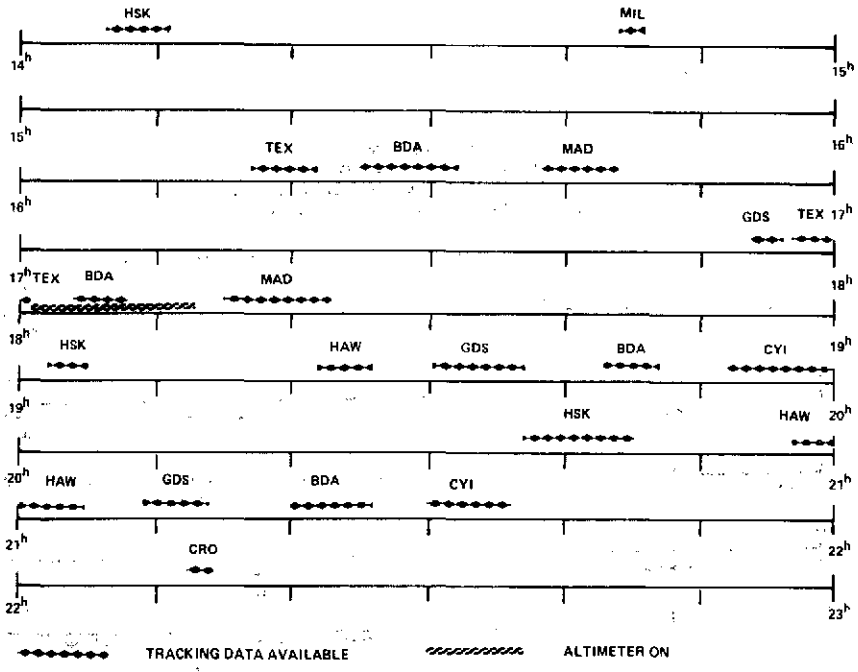
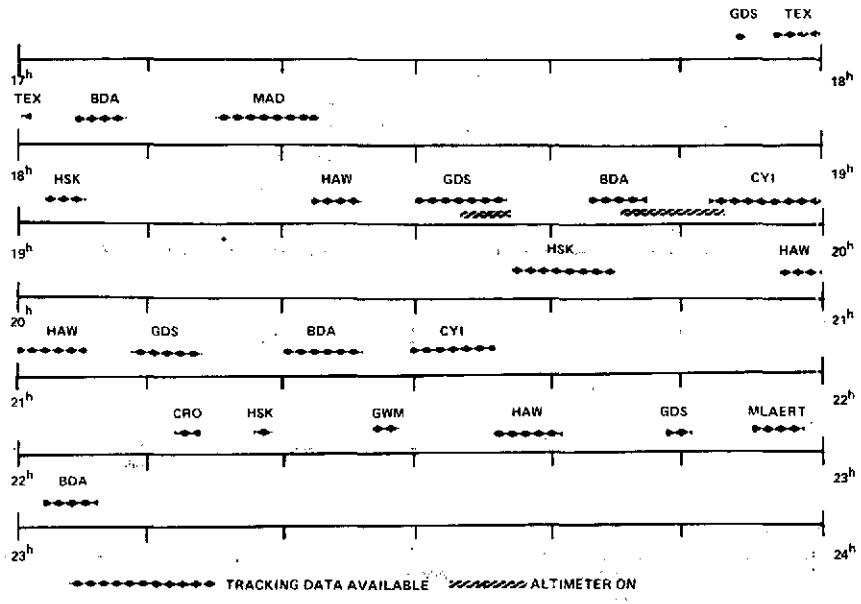
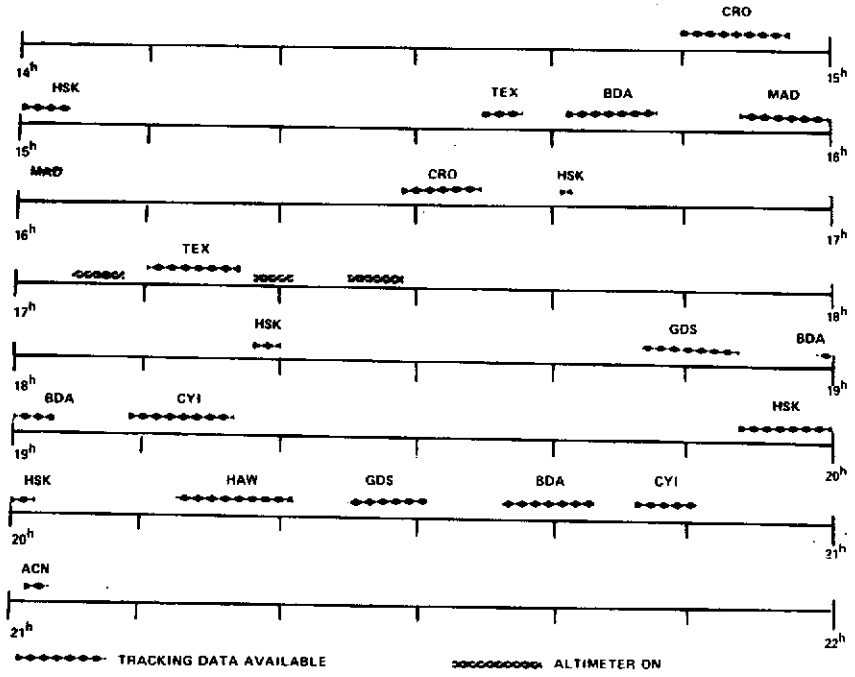


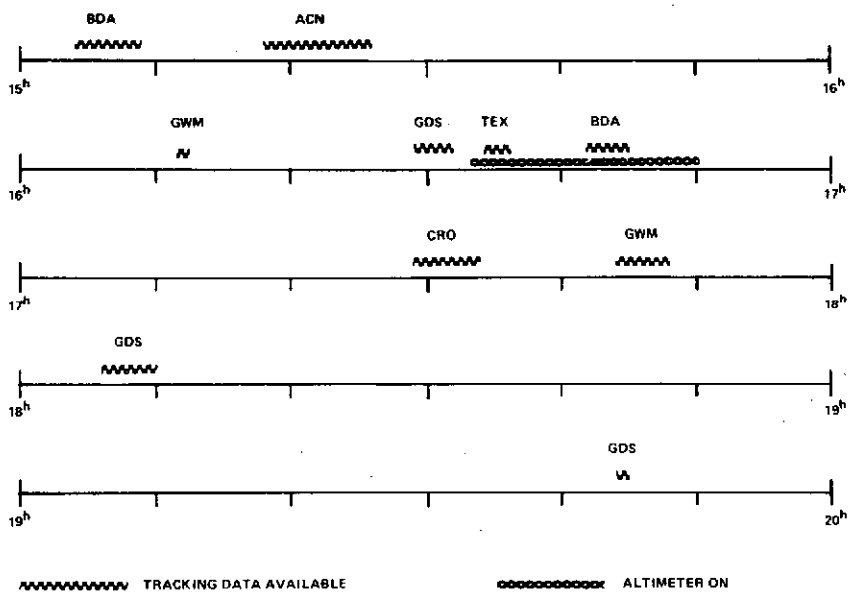
ARC LENGTH FOR ORBIT DETERMINATION 8^h08^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 27 13 SEPTEMBER 1973
MAPS 69, 70, 71



ARC LENGTH FOR ORBIT DETERMINATION 5^h12^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 28 13 SEPTEMBER 1973
MAPS 72, 73, 74



ARC LENGTH FOR ORBIT DETERMINATION 6^h13^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–3 PASS 29 14 SEPTEMBER 1973
MAPS 75 AND 76



ARC LENGTH FOR ORBIT DETERMINATION – 4^h41^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 54 11 NOV 1973
MAPS 81, 83, 84

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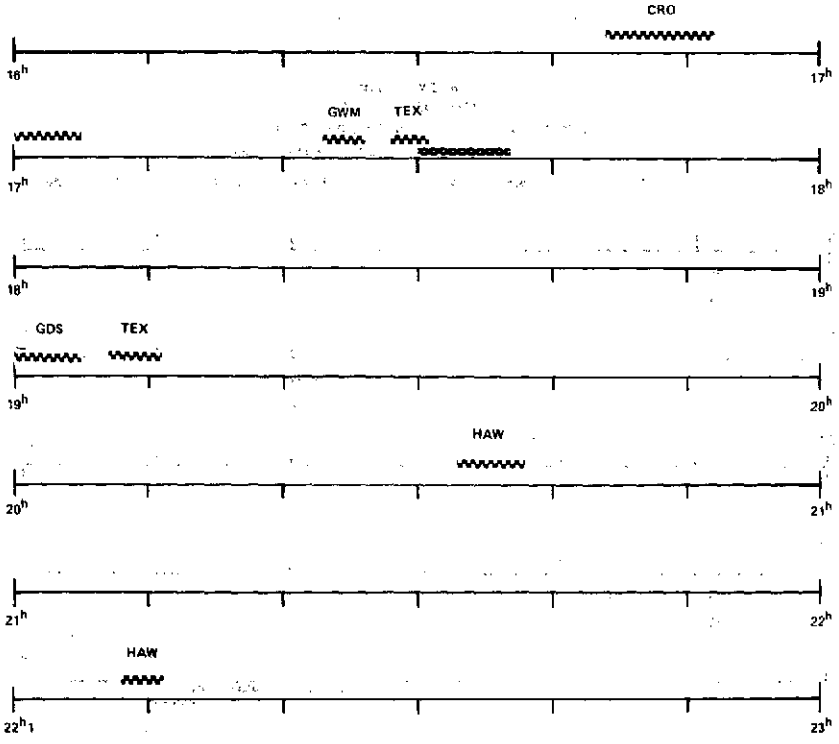
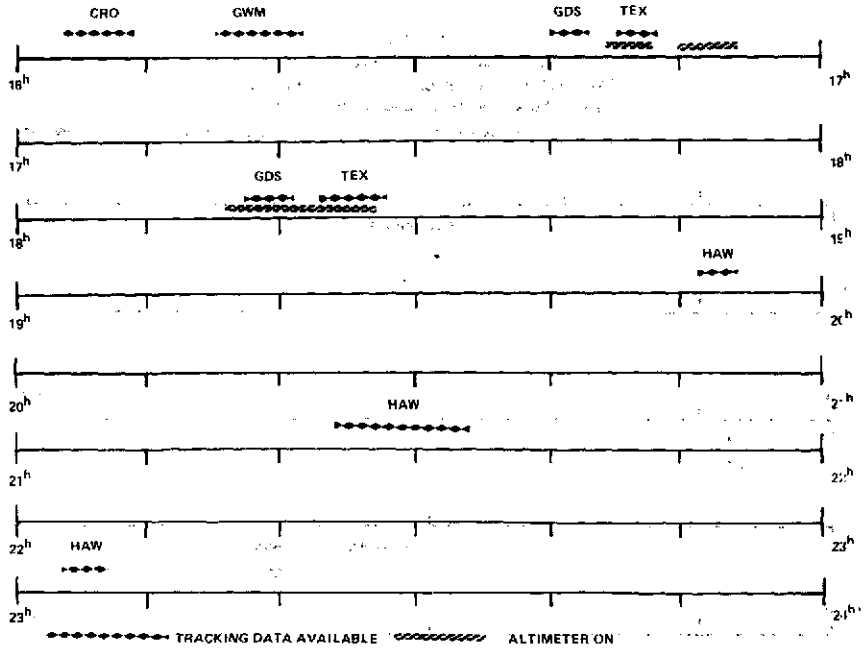


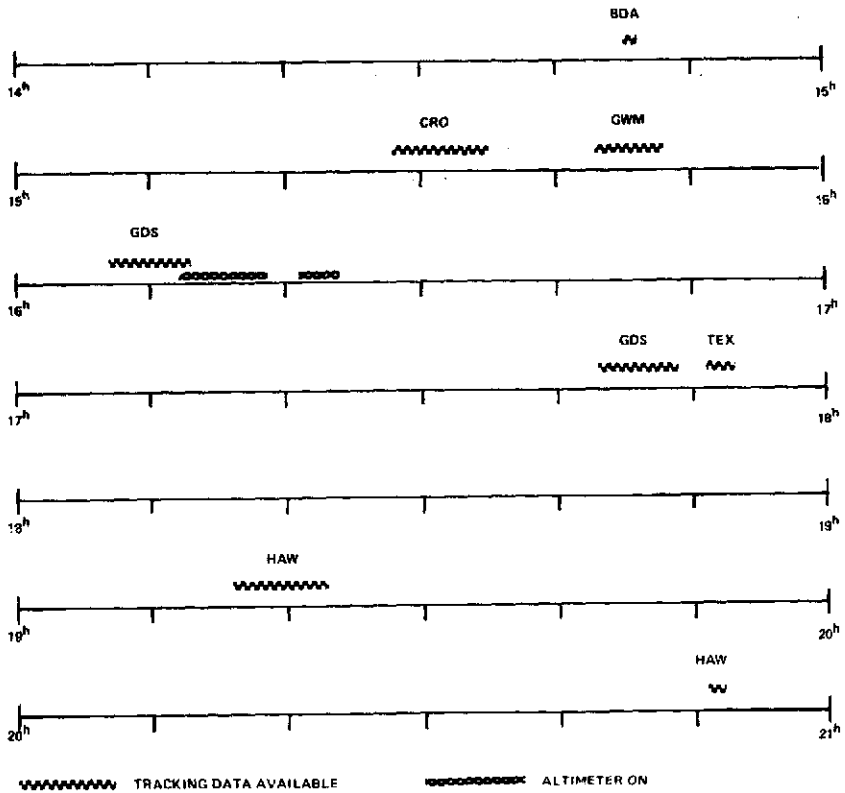
TRACKING DATA AVAILABLE ALTIMETER ON

ARC LENGTH FOR ORBIT DETERMINATION 5^h27^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 55 01 DECEMBER 1973
MAPS 85 AND 86

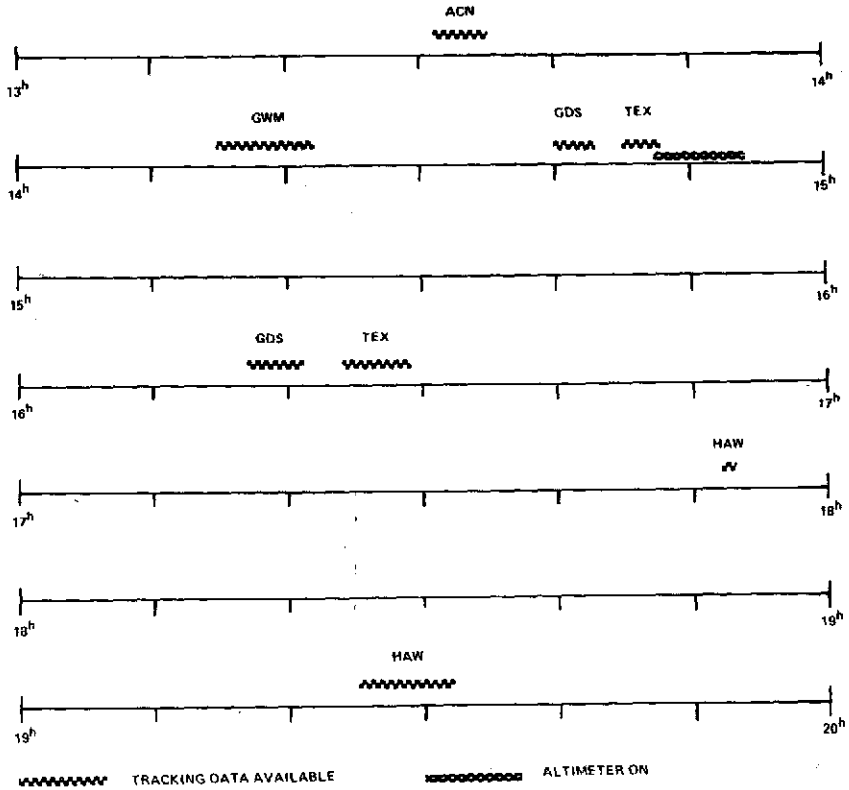


TRACKING DATA AVAILABLE ALTIMETER ON

ARC LENGTH FOR ORBIT DETERMINATION 7^h04^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASSES 56–57 2 DECEMBER 1973
MAPS 89, 91, 92, 93



ARC LENGTH FOR ORBIT DETERMINATION 6^h07^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 61 5 DECEMBER 1973
MAPS 98 AND 99



ARC LENGTH FOR ORBIT DETERMINATION 6^h01^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 62 7 DECEMBER 1973
MAP 100

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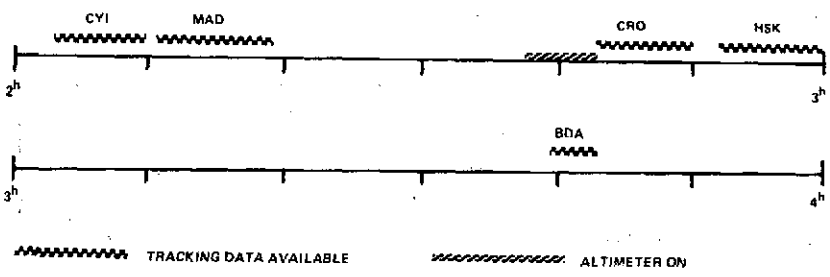
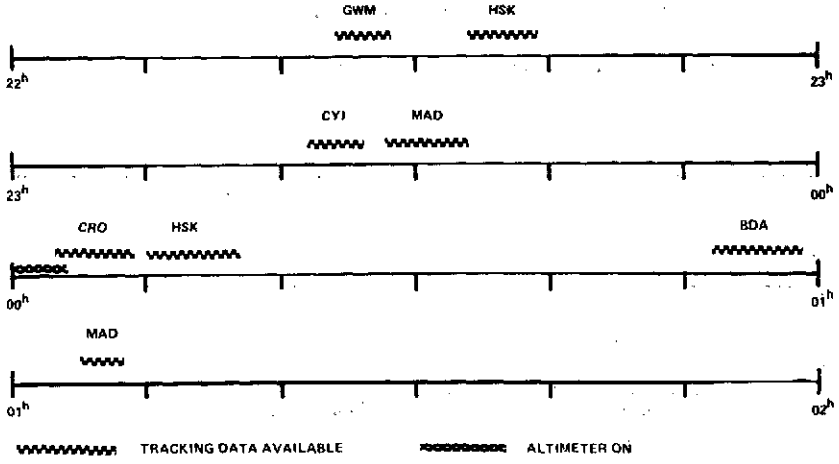
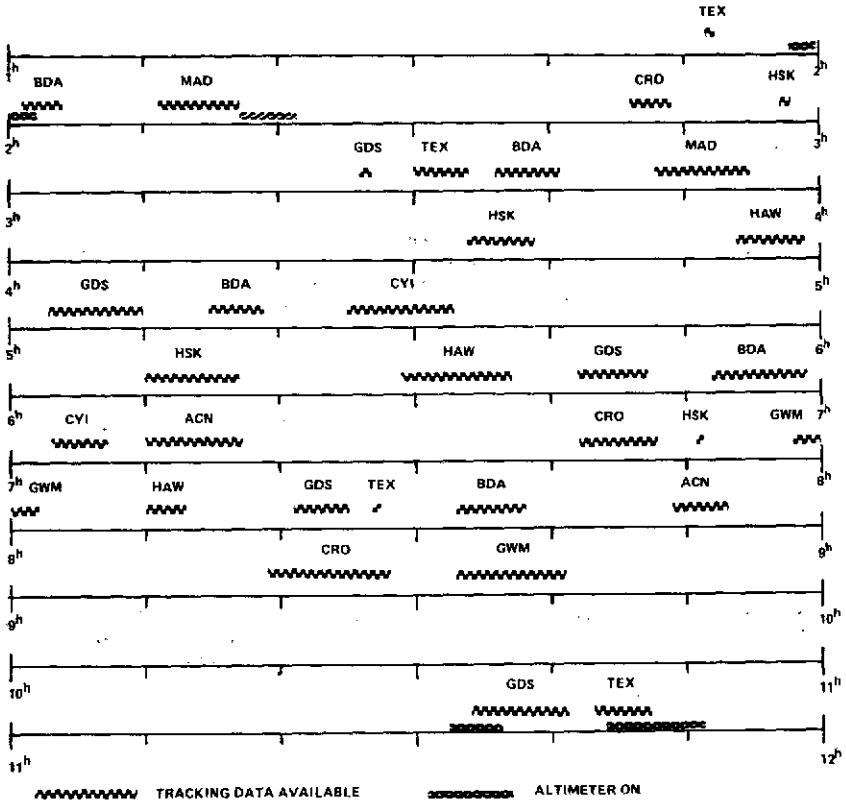


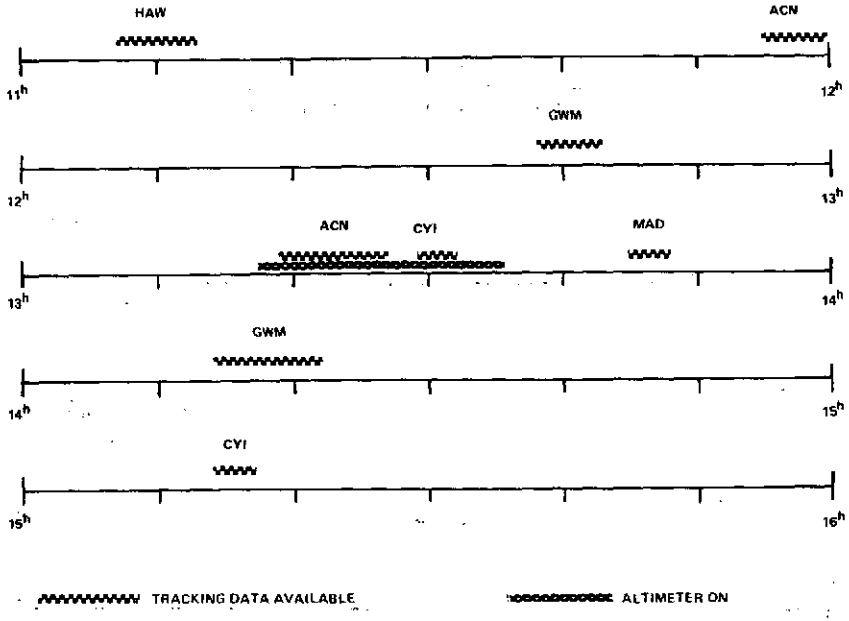
ARC LENGTH FOR ORBIT DETERMINATION $1^h\,39^m$
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 64 9 DECEMBER 1973
MAPS 102, 103, 104



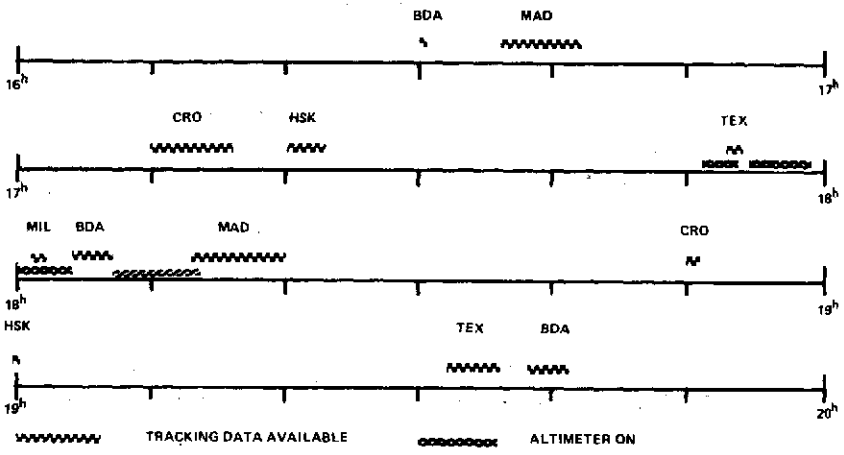
ARC LENGTH FOR ORBIT DETERMINATION $2^h\,44^m$
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 65 15 DECEMBER 1973
MAP 105



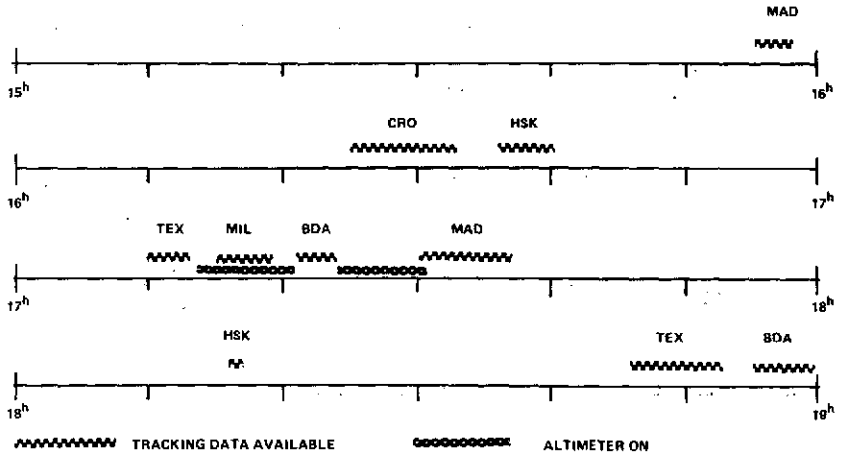
ARC LENGTH FOR ORBIT DETERMINATION 9^h56^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASSES 67–68 18 DECEMBER 1973
MAPS 106, 108, 109, 110



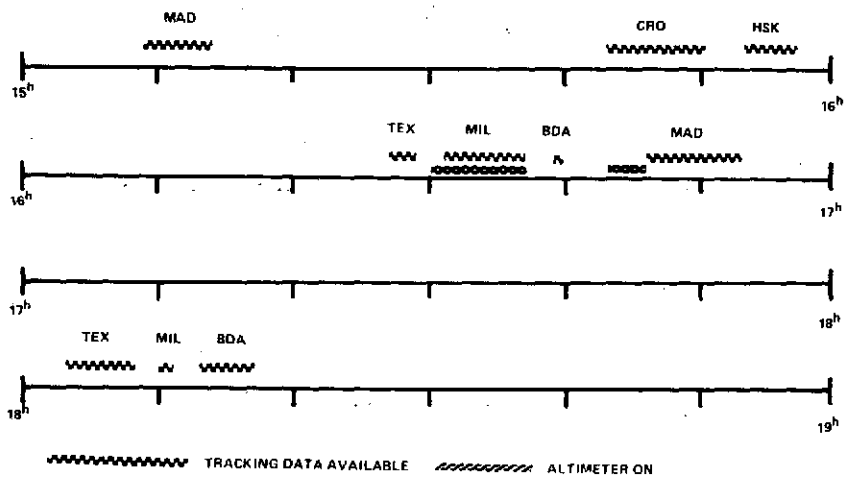
ARC LENGTH FOR ORBIT DETERMINATION 4^h10^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 71 01 JANUARY 1974
MAPS 113, 114, 115



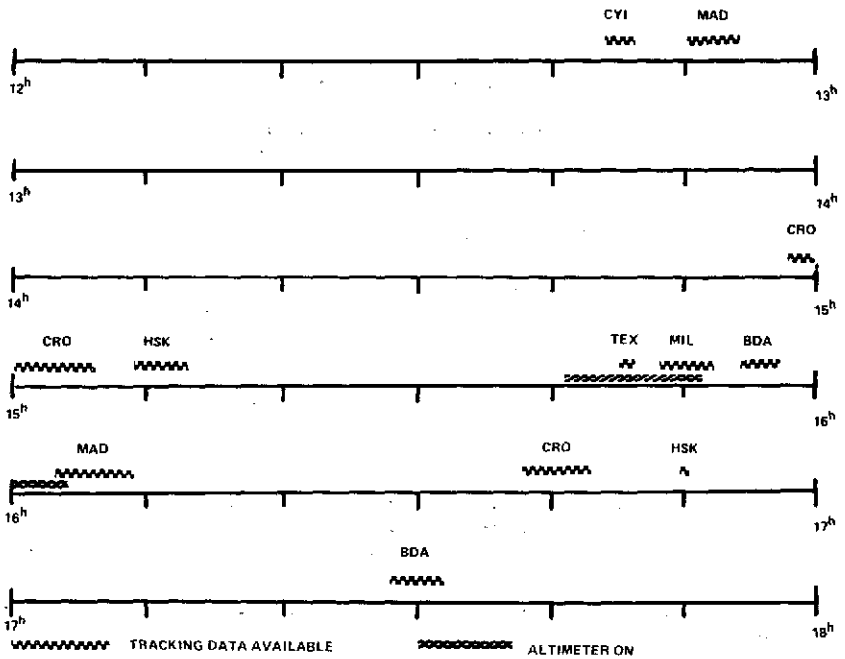
ARC LENGTH FOR ORBIT DETERMINATION 3^h11^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 74 06 JANUARY 1974
MAPS 117, 118, 119, 120, 120A



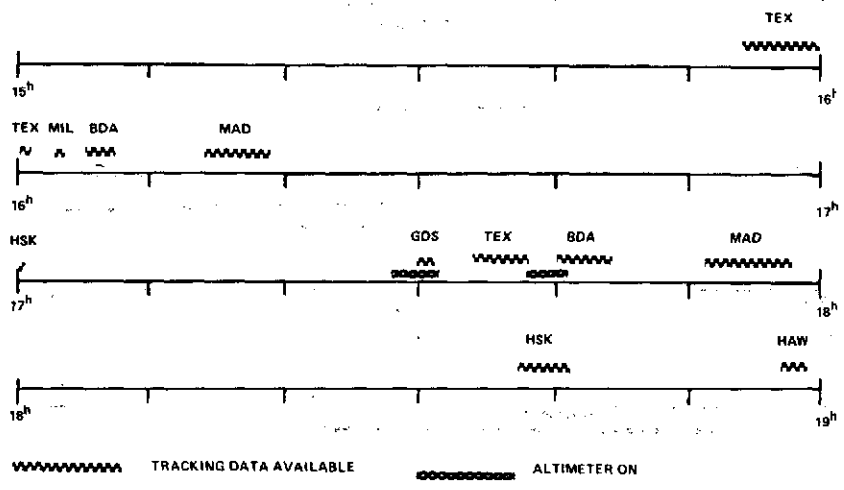
ARC LENGTH FOR ORBIT DETERMINATION 3^h05^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 76 07 JANUARY 1974
MAPS 121, 122, 123, 124



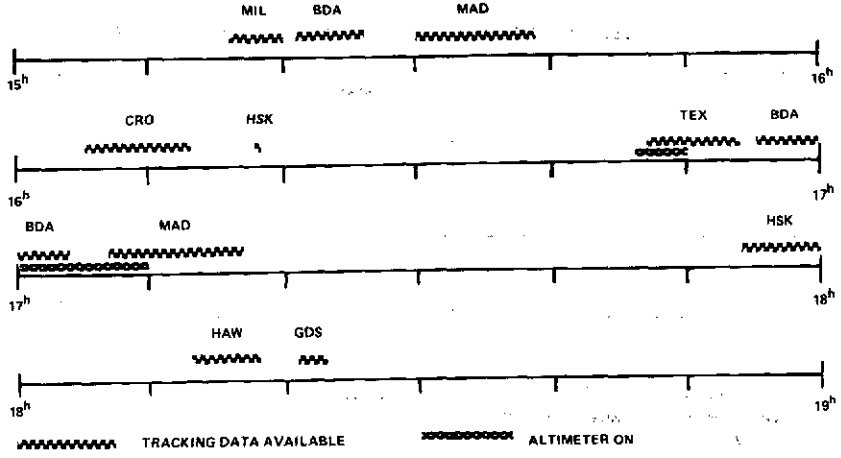
ARC LENGTH FOR ORBIT DETERMINATION 3^h08^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 78 08 JANUARY 1974
MAPS 127, 128, 129



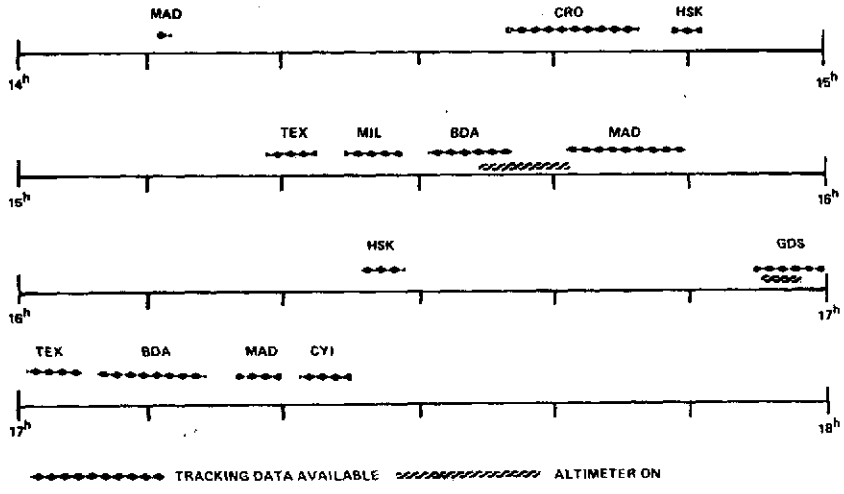
ARC LENGTH FOR ORBIT DETERMINATION 4^h48^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 79 09 JANUARY 1974
MAPS 131, 132, 133, 134



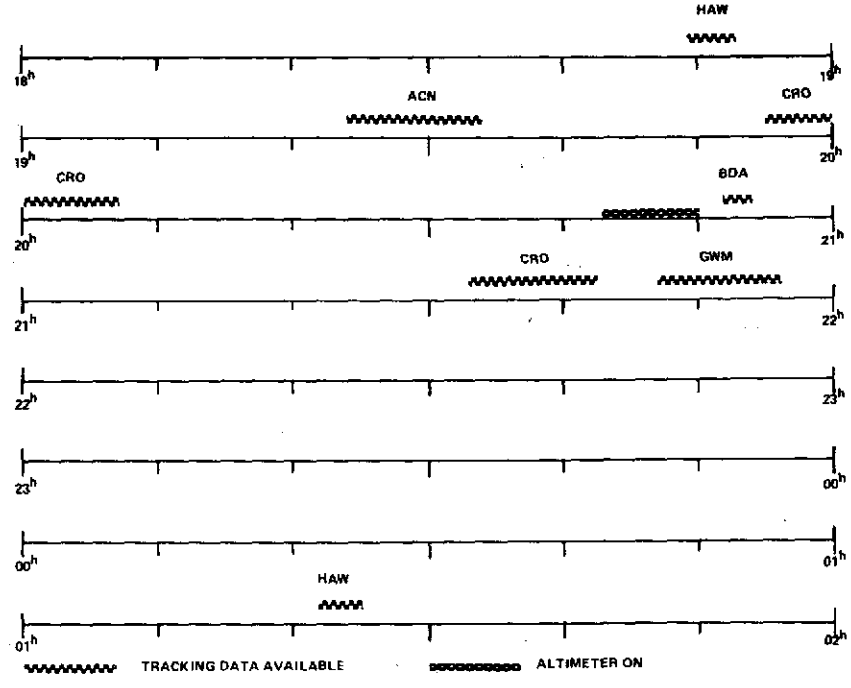
ARC LENGTH FOR ORBIT DETERMINATION 3^h05^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 81 11 JANUARY 1974
MAP 135



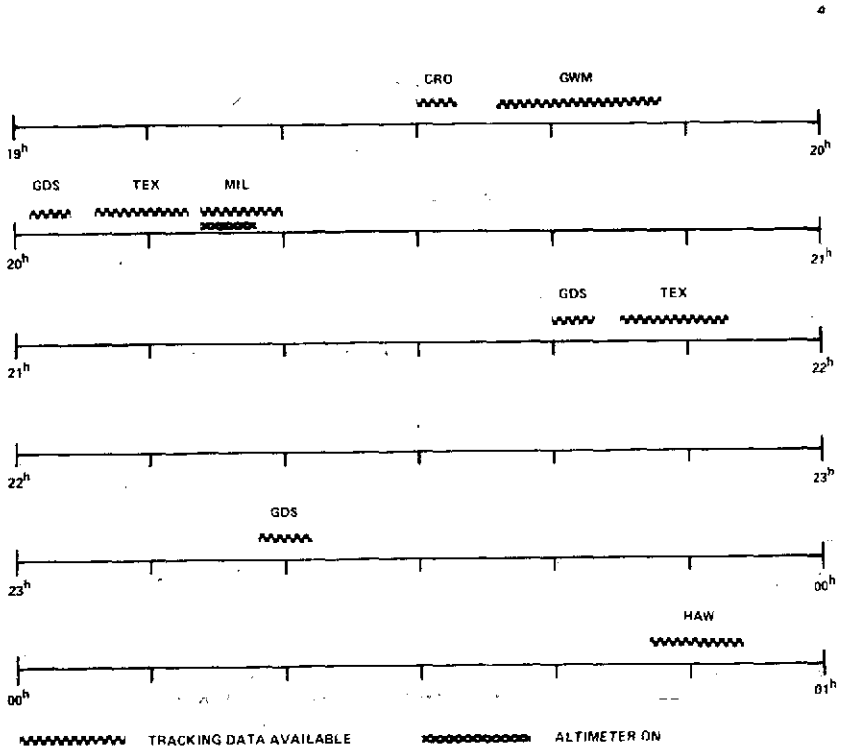
ARC LENGTH FOR ORBIT DETERMINATION 3^h07^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 82 12 JANUARY 1974
MAP 139



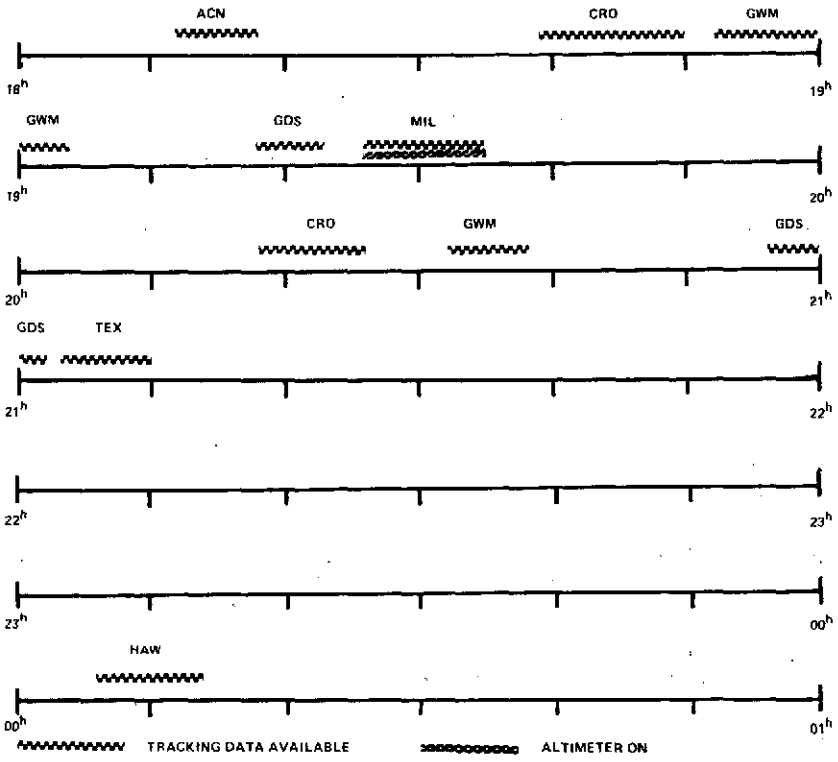
ARC LENGTH FOR ORBIT DETERMINATION 3^h14^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 83 14 JANUARY 1974
MAPS 145, 147, 148



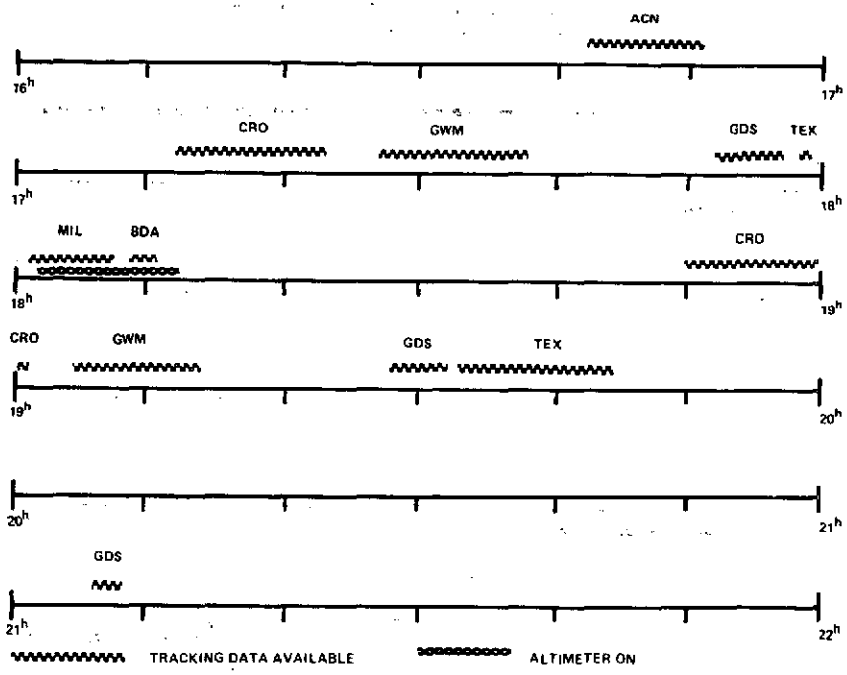
ARC LENGTH FOR ORBIT DETERMINATION 6^h36^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 85 18 JANUARY 1974
MAP 151



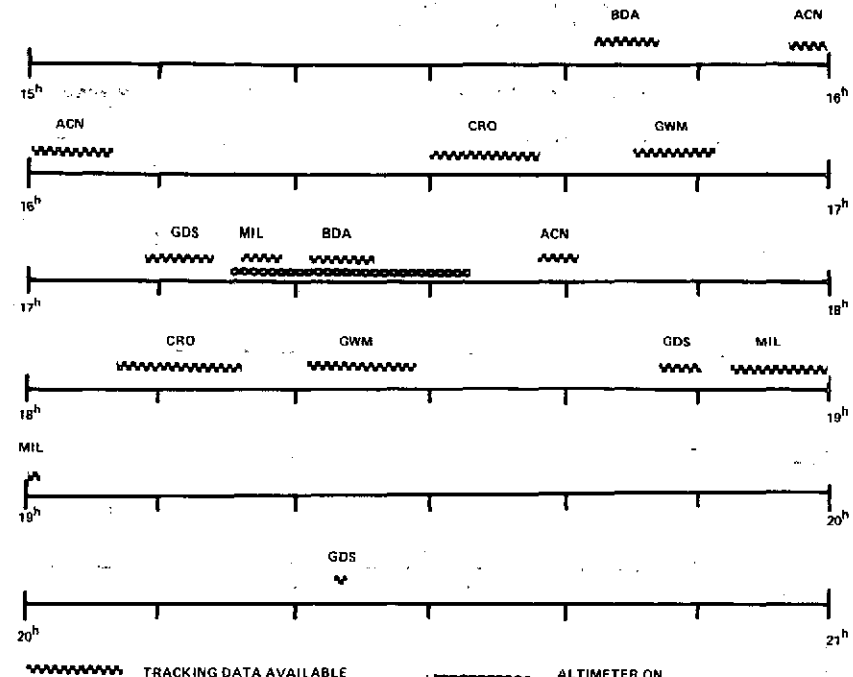
ARC LENGTH FOR ORBIT DETERMINATION 5^h24^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 87 21 JANUARY 1974
MAP 152



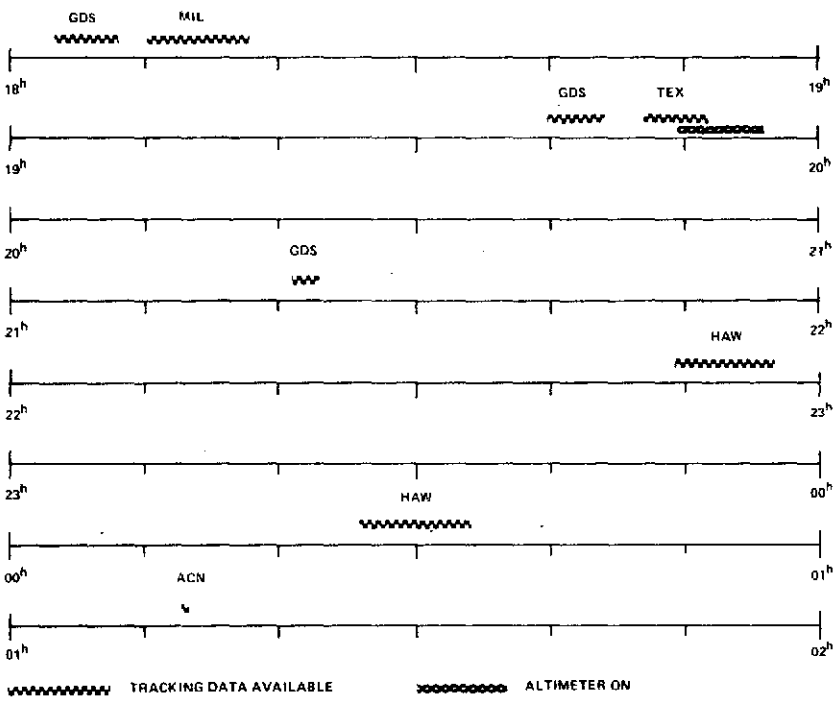
ARC LENGTH FOR ORBIT DETERMINATION 6^h02^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 88 22 JANUARY 1974
MAPS 155 AND 156



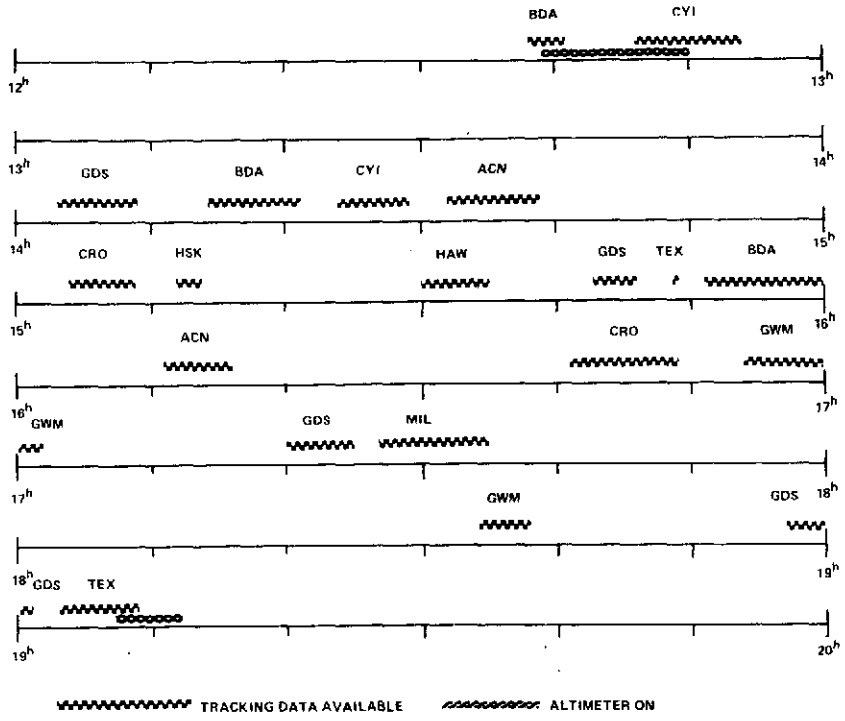
ARC LENGTH FOR ORBIT DETERMINATION 4^h26^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 89 24 JANUARY 1974
MAPS 163 AND 164



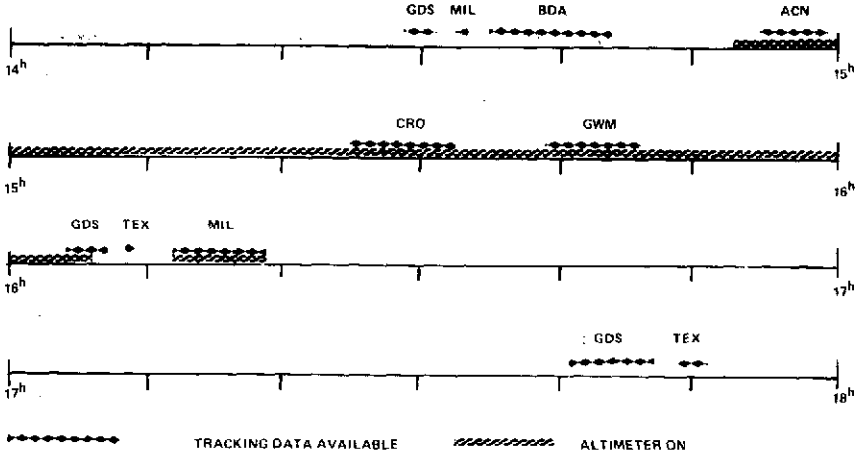
ARC LENGTH FOR ORBIT DETERMINATION 4^h42^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 90 25 JANUARY 1974
MAPS 168 AND 169



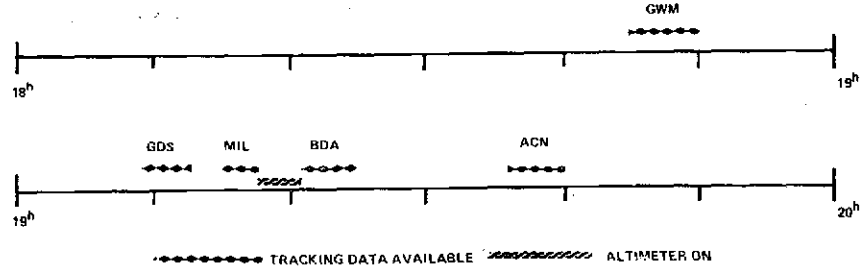
ARC LENGTH FOR ORBIT DETERMINATION 7^h10^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 91 26–27 JANUARY 1974
MAP 175



ARC LENGTH FOR ORBIT DETERMINATION 6^h31^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASSES 92–93 27 JANUARY 1974
MAPS 182 AND 185



ARC LENGTH FOR ORBIT DETERMINATION 3^h22^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 97 31 JANUARY 1974
MAPS 201–218, 222, 223, 225, 226



ARC LENGTH FOR ORBIT DETERMINATION 1^h55^m
TRACKING SCHEDULE AND ALTIMETER DATA TAKES
SL–4 PASS 86 20 JANUARY 1974
MAP 233

POINTING DETERMINATION

Analysis of Waveform Trailing Edge

The antenna beamwidth, pulse width (100 ns Modes) and altitude of the S-193 altimeter give rise to essentially a beamwidth limited system. For such a system, the peak average received power is a very sensitive function of pointing angle with respect to nadir. For example, a 0.75° pointing error can result in an altitude bias of 2 meters and a 4 dB reduction in received power. If these errors are neglected, σ_o measurements will be erroneous and geoid measurements will be compromised. This pointing error problem was further complicated by spacecraft attitude drift (due to a Command Module Gimble (CMG) problem) during all three missions. Thus, it became necessary to devise a method for determining pointing angle which did not depend on the spacecraft as a reference. In the course of comparing measured average return waveforms with theoretical waveforms, it was found that pointing angle could be determined from the shape of the trailing edge of the average return waveform [5]. This observation follows from the convolutional or linear scattering model in which the antenna pattern and the pointing angle are dominant effects in the trailing edge region of the average return, as shown in Figure 5.

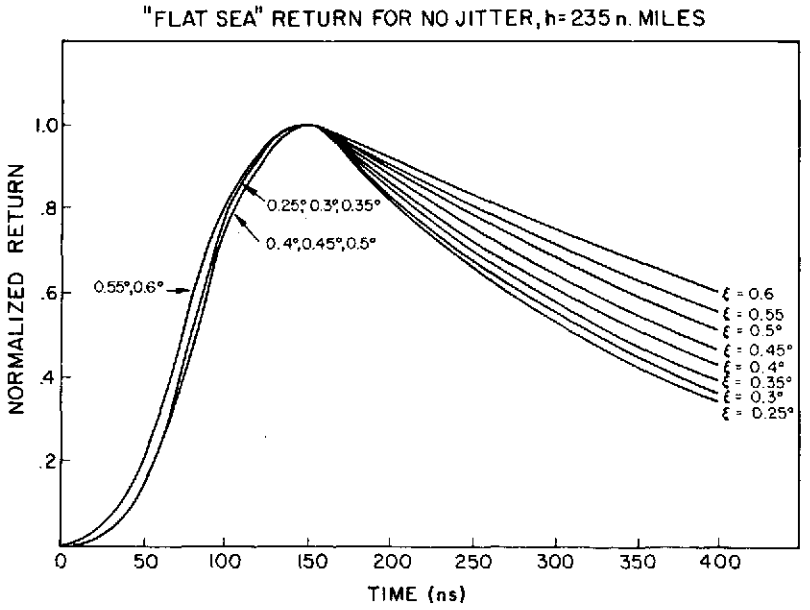


Figure 5

This method applies only over oceans or large water bodies when off-nadir angles are from 0.25° to about 1.2°, and the accuracy of determining pointing angle depends primarily upon the number of individual waveforms averaged and the signal-to-noise ratio. This can be seen in the sample waveforms of Figures 6 and 7. Note the low variance on the trailing edge of the pulses. The results indicate the possibility that properly designed altimeters can also be employed as very accurate attitude sensors with angular accuracies $\leq \pm 0.05°$. A multi-variable χ^2 (chi squared) minimization program has been adapted by Dr. G. S. Hayne for estimating, from the waveforms, pointing error and other parameters of interest. It is important to note that without a pointing angle determination capability, much of the data from the altimeter would have been questionable because pointing is very critical.

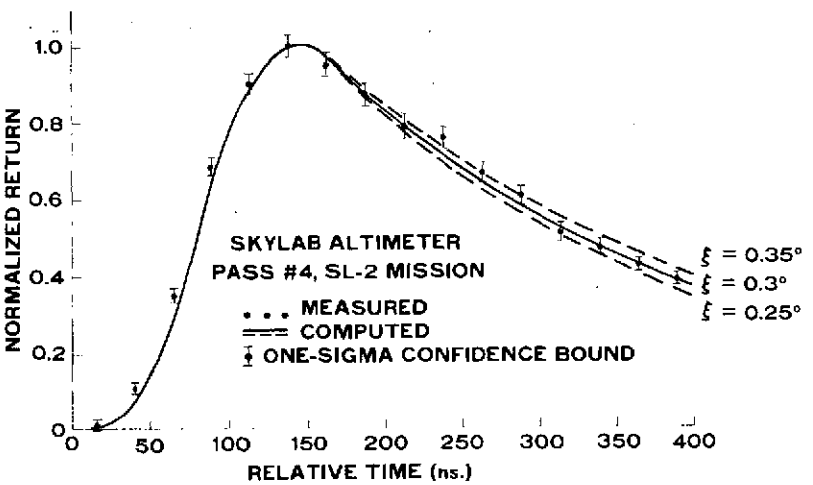


Figure 6 Comparison of Measured and Theoretical Mean Return Waveforms for a 100 ns Transmitted Pulse Width. Pointing .3° Off Nadir.

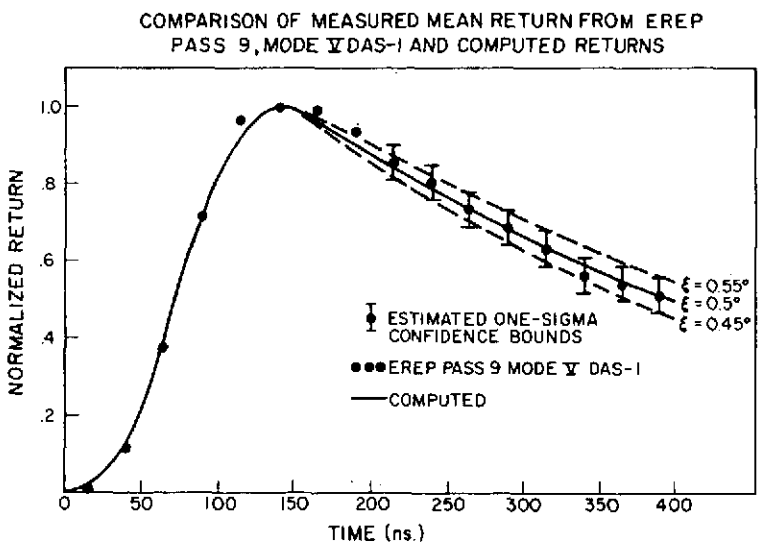


Figure 7 Comparison of Measured Mean Return and Theoretical Return for a 100 ns Transmitted Pulse Width. Pointing .5° Off Nadir.

Analysis of Tracker Response and AGC

By analyzing the altitude tracker response and automatic gain control (AGC) another method is obtained for determining satellite pointing. This technique is not as accurate but is somewhat complimentary to the above method since it appears to be practical with pointing errors from .75° through 1.7°. The accuracy is only a few tenths of a degree. This technique also can be utilized only over broad ocean or large water body areas where uniform reflectance is available.

As was illustrated in the previous section in Figure 5, the leading edge of the pulse does not show much change with pointing for at least the first .75° of error. However, as the pointing moves further off-nadir, both leading edge distortion and signal level drop-off rapidly occur. Figure 8 shows an artist's concept of how pointing might typically affect selected waveforms.

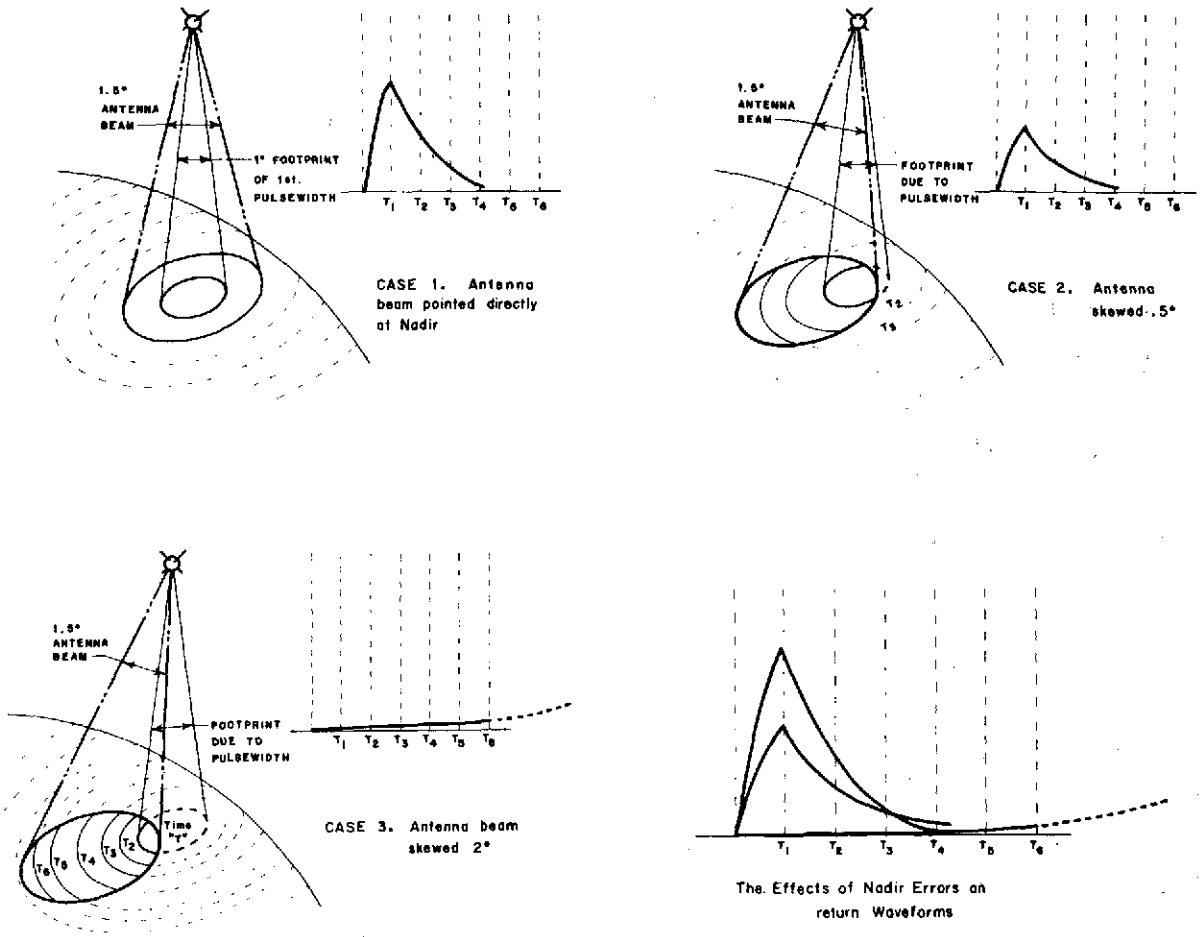


Figure 8

Since the S-193 altitude tracker is a split gate error detector as illustrated in Figure 9 (from [6]),it can be visualized that these more extreme distortions associated with large pointing errors can cause large biases in altitude measurements. In addition, since the rise time of the returns tends to be extended and the amplitude drops, it is then necessary for the AGC to increase the gain in the system to provide a more constant discriminator curve. With this increased gain, the noise is also amplified and the tracker jitter therefore increases (see Figure 10). Since AGC can't completely compensate for the rise-time change, the altitude servo system gets more sluggish (loses frequency response).

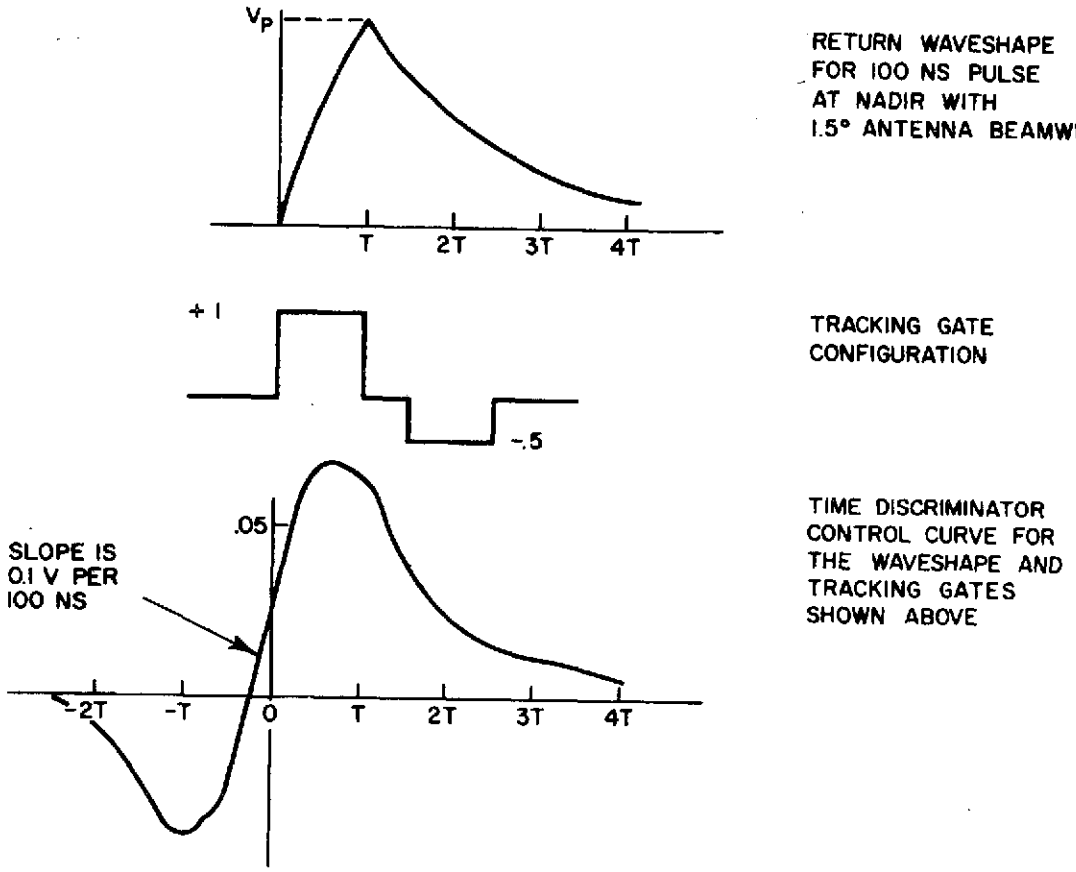


Figure 9 Illustration of Split Gate Error Detector

By modeling the various waveforms and predicting the bias for different pointing conditions, it is possible to produce a correction curve as shown in Figure 11. To utilize this curve for correcting the SKYLAB data, a calibration is needed to relate a particular jitter, servo bandwidth and/or AGC level to a bias condition. By carefully selecting SKYLAB data in regions where the geoid and orbit are well known, some data can be obtained to provide the calibration. It is important to note that the SL-4 mission required an independent calibration, for the antenna feed failure on that mission reduced the gain by 23 db and changed the pattern.

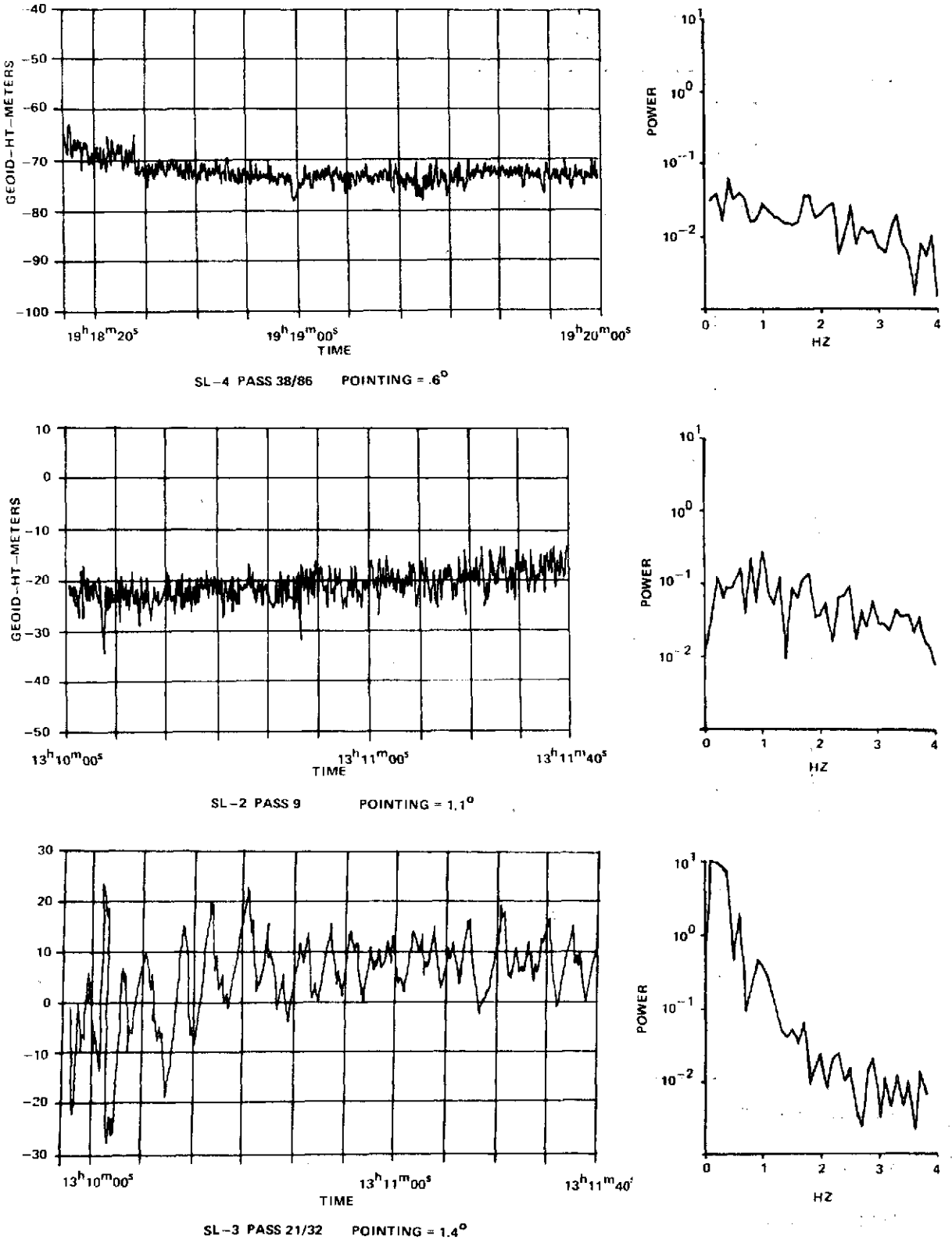
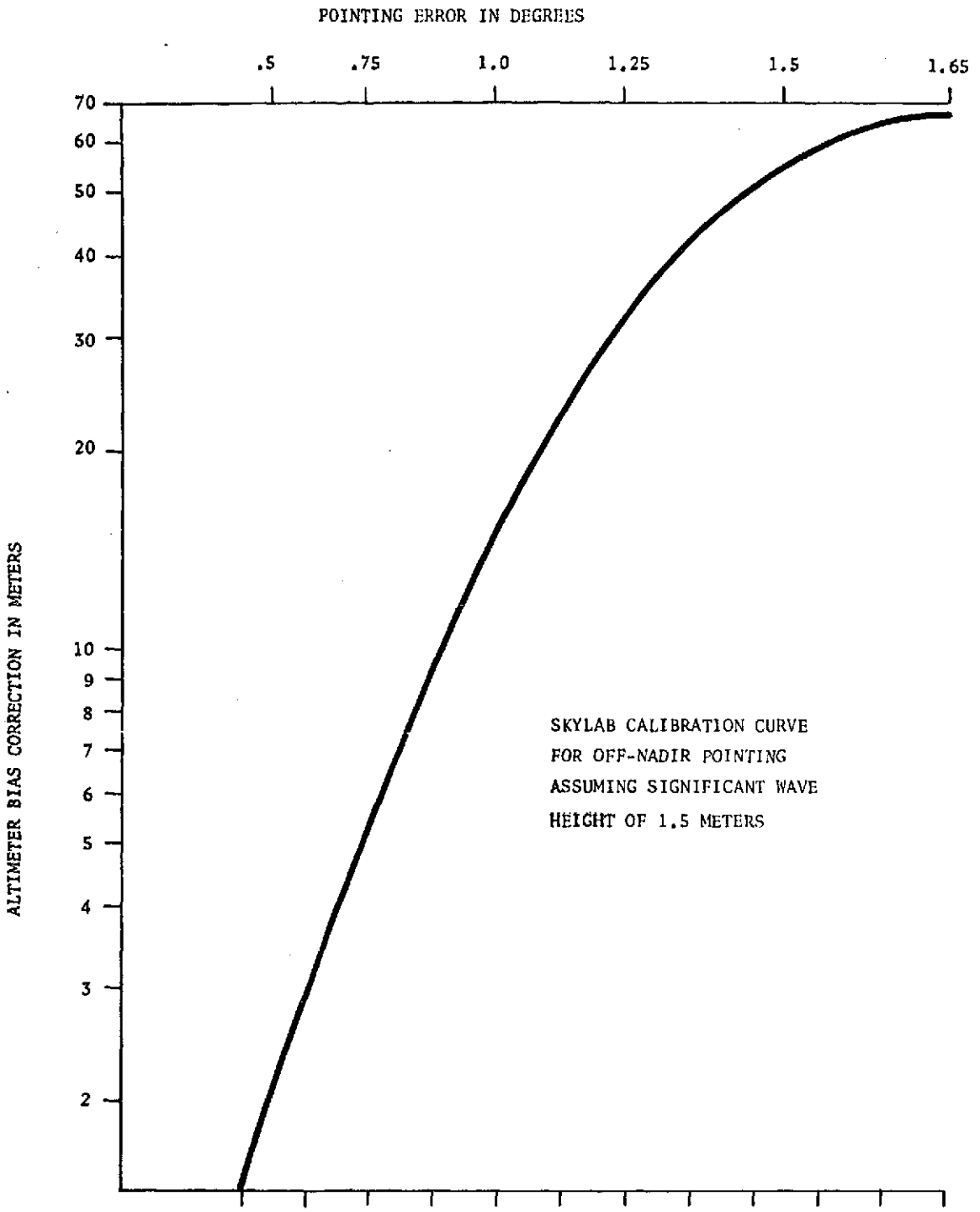


FIGURE 10. OFF NADIR POINTING EFFECTS



SL-2 SL-3	PEAK TO PEAK METERS	4	5	5	7	10	15	30	34	38	42	50	60
	CYCLE COUNTS	22	21	20	18	15	12	9	8	7	6	4	3
	AGC LEVEL IN db	-31	-32	-33	-34	-35	-36	-37	-38	-39	-40	-41	-42
SL-4	PEAK TO PEAK METERS	6	7	10	12	15	20	25	35	40	50	60	70
	CYCLE COUNT	20	19	18	16	15	12	10	8	6	5	4	3
	AGC LEVEL IN db	-54	-55	-56	-57	-58	-59	-60	-61	-62	-63	-64	-65

FIGURE 11

Pointing Data Summary

Using both of the methods discussed, the pointing for all three SKYLAB missions are summarized in Table 5. In the Table, the waveform determined pointing is only partially complete, for that method requires much more time-consuming detailed analysis. Since the pointing has largely been obtained by analysis of the tracker performance, where the technique is largely dependent on empirical data, the accuracy is felt to be only about 5 meters. Therefore, in determining the altitude corrections from the pointing errors, the corrections have been rounded off to the nearest 5 meters to prevent the user for over-estimating the accuracy.

Similiarly,the bias with respect to the existing GEM-6 geoid is also rounded off to the nearest 5 meters. These biases were extracted from the residual plots manually, and are not, therefore, highly accurate. If more accuracy is required, both the pointing and the geoid biases could be refined to under one meter. However, if one reviews the whole SKYLAB altimeter error budget discussed in the Accuracy Section, then it becomes evident that further removal of these errors will not improve the overall accuracy.

The Summary Table contains an orbit quality indicator where the numbers represent the estimated meters of uncertainty in the orbit determination. In addition, the AGC level peak cycle counts (a parameter used to estimate the frequency of direction changes in the altitude servo) and peak-to-peak altitude noise in meters are both put in the Table, for they are the parameters on which the tracker pointing determination is based (see Figure 11). Finally, the table contains the new bias that the data pass would have with respect to the GEM-6 geoid if the pointing bias correction is applied.

MAP NO.	PASS NO.	ORBIT QUALITY	HEIGHT RATE M/SEC	AGC LEVEL	PEAK CYCLE COUNTS	PEAK TO PEAK	BIAS FROM GEM–6	TRACKER DETERMINED POINTING	WAVEFORM DETERMINED POINTING MIN	WAVEFORM DETERMINED POINTING MAX	RECOMMENDED BIAS CORRECTION	NEW BIAS
1	1	5	– 2.9	–36	14	7	–30	1.10		.6°	+20	–10
2	2	13	– 2.9	–36.5	23	5	0	.6°			0	0
3	4	16	– 3.5	–32.5	22	4	–20	.6°	0.25°	.47°	0	–20
4	4	18	– 1.8	–32.5	22	4	–20	.6°		.15°	0	–20
5	6	16	1.1	–33.5	17	6	–35	.8°	.43°	.55°	5	–30
6	7	79	– .5	–37	12	22	–55	1.2°	1.15°	1.2°	+25	–30
7	7	100	1.3	–37	NA	30	–60	1.25°			+30	–30
8	7	120	–20.6	–39	8	50+	–80	1.45°		1.2°	+50	–30
10	8	11	3.6	–33.5	20	6	+40	.75°		.3°	+5	+45
11	9	5	.4	–33	21	4	+10	.6°	.3°	.43°	0	+10
12	9	5	4.5	–35.6	15	12	+20	1.1°		.65°	+22	+42
13	9	6	16.5	–35.5	11	18	0	1.1°		.9°	+20	+20
14	10	11	3.3	–33	19	8	–25	.8°		.5°	+5	–20
15	10	14	5.6	–33	18	8	–5	.8°			+5	0
18	11	200	8.4	–32	15	8	.50	.7°		.62°	5	+55
20	11	200	13.9	–62	12	15	115	1.1°			+20	135
22	12	9	–15.9	–34	20	6	+20	.8°	.55°	.95°	5	+25
23	12	25	– 8.8	–34	18	10	+30	.85°		.8°	+10	+40
26	14	11	–16.2	–35	16	8	+25	1.0°	.55°	.8°	+15	+40
28	17	4	–14.8	–36	7	30	+5	1.3°	.9°	1.0°	+35	+40
29	17	5	–13.9	–35	15	12	+10	1.0°		.82°	+15	+25
30	17	5	– 3.4	–30	18	9	+20	$< .5°$	.65°	.67°	0	+20

TABLE 5. SKYLAB POINTING CORRECTION SUMMARY

MAP NO.	PASS NO.	ORBIT QUALITY	HEIGHT RATE M/SEC	AGC LEVEL	PEAK CYCLE COUNTS	PEAK TO PEAK	BIAS FROM GEM–6	TRACKER DETERMINED POINTING	WAVEFORM DETERMINED POINTING MIN	WAVEFORM DETERMINED POINTING MAX	RECOMMENDED BIAS CORRECTION	NEW BIAS
32	18	5	–7.7	–31	20	4	+25	$<.5^{o}$	$.2^{o}$	$.35^{o}$	+0	+25
33	19	10	8.9	–36	18	12	+35	1.05^{o}	$.8^{o}$	1.15^{o}	+15	+50
34	19	19	–3.2	–35	9	20	+20	1.1^{o}			+20	+40
34A	20	14	–6.3	–33	14	20	+25	1.1^{o}		$.5^{o}$	+20	+45
35	21	5	–14.9	–32	20	4	0	$<.6^{o}$		0^{o}	0	+0
36	21	10	–6.7	–31.1	20	4	+15	$<.5^{o}$		$.1^{o}$	0	+15
37	21	13	–1.1	–29.8	18	5	+25	$.75^{o}$		$.25^{o}$	0	+25
38	22	17	–22.3	–32.2	21	5	–20	$<.6^{o}$	$.3^{o}$	$.35^{o}$	+0	–20
39	22	18	–22.9	–32	18	4	–20	$<.6^{o}$	$.2^{o}$	$.32^{o}$	+0	–20
40	22	18	–19.3	–31	18	5	–5	$<.5^{o}$	$.1^{o}$	$.35^{o}$	+0	–5
41	22	18	–12.4	–30	18	5	+5	$<.5^{o}$	$.0^{o}$	$.45^{o}$	+0	+5
42	22	18	–5.9	–31.2	18	5	+20	$<.5^{o}$	$.0^{o}$	$.55^{o}$	+0	+20
43	24	7	–5.0	–33	18	5	+30	$.8^{o}$		0^{o}	+5	+35
44	24	10	3.7	–33.5	18	5	+50	$.8^{o}$		$.15^{o}$	+5	+55
45	24	12	11.6	–32.5	18	5	+45	$<.6^{o}$		$.35^{o}$	+5	+50
46	25	11	–8.2	–32	20	4	+15	$<.6^{o}$		0	+0	+15
47	25	15	–.7	–30.5	20	4	+20	$<.5^{o}$		$.15^{o}$	+0	+20
48	27	8	6.5	–32.3	18	5	+60	$<.6^{o}$		$.3^{o}$	+0	+60
50	28	3	3.9	–32.2	18	4	+50	$<.6^{o}$		$.15^{o}$	+0	+50
54	32	3	5.1	–39	5	35	–35	1.6^{o}		1.2^{o}	+50	+15
55	32	4	8.6	–35	7	35	–40	1.4^{o}		$>1.3^{o}$	+40	0
58		14	6.7	–39	5	12	–30	1.4^{o}		$\geqslant 1.3^{o}$	+40	+10

TABLE 5. SKYLAB POINTING CORRECTION SUMMARY (Continued)

MAP NO.	PASS NO.	ORBIT QUALITY	HEIGHT RATE M/SEC	AGC LEVEL	PEAK CYCLE COUNTS	PEAK TO PEAK	BIAS FROM GEM–6	TRACKER DETERMINED POINTING	WAVEFORM DETERMINED POINTING MIN	WAVEFORM DETERMINED POINTING MAX	RECOMMENDED BIAS CORRECTION	NEW BIAS
61	36	6	–16.4	–37.7	9	12	–30	1.25°		1.35°	+30	0
62	36	6	–15.2	–37.1	5	15	–45	1.3°			+35	–10
63	36	7	–2.3	–38.4	6	30	–35	1.4°		1.3°	+40	5
65	36	3	9.1	–36	7	20	–40	1.3°		1.3°	+35	–5
66	37	10	5.4	–37.4	5	30	–45	1.3°			+35	–10
67	37	11	7.7	–39	6	35	–40	1.4°		1.4°	+45	+5
70	38	6	6.4	–42	3	60	–70	1.65°			+65	–5
71	38	8	4.1	–39.9	3	30	–75	1.55°		1.35°	+55	–20
73	39	15	2.2	–32	18	7	+40	.85°	.6°	.65°	+10	+50
74	39	15	.5	–36	18	7	+45	.85°	.68°	.75°	+10	+55
75	40	3	–6.9	–37	15	12	–10	1.0°		1.2°	+15	+5
76	40	4	2.3	–36	12	15	10	1.1°			+20	30
83	54	8	2.7	–55	17	7	+5	.75°			+5	+10
84	54	7	5.6	–56	17	10	+20	.75			5	+25
85	55	4	2.8	–54	20	7	–20	< .5°			0	–0
86	55	4	4.6	–53.5	19	7	+5	< .5°			0	+5
89	57	4	3.5	–54	19	8	–5	< .5°			0	–5
91	57	3	3.7	–54	16	8	+10	< .5°			+0	+10
92	57	4	4.9	–54	19	5	–15	< .5			+0	–15

TABLE 5. SKYLAB POINTING CORRECTION SUMMARY (Continued)

MAP NO.	PASS NO.	ORBIT QUALITY	HEIGHT RATE M/SEC	AGC LEVEL	PEAK CYCLE COUNTS	PEAK TO PEAK	BIAS FROM GEM–6	TRACKER DETERMINED POINTING	WAVEFORM DETERMINED POINTING MIN	MAX	RECOMMENDED BIAS CORRECTION	NEW BIAS
93	57	4	6.4	–56	16	10	–10	$<.5$			+5	–5
98	61	5	4.2	–56	12	13	–20	$.85^{o}$			+10	–10
99	61	5	8.9	–57.5	11	25	–15	1.1^{o}			+20	+5
100	62	6	5.1	–59.5	9	40	–15	1.3^{o}			+35	+20
102	64	12	–2.7	–51	10	8	+5	$<.5^{o}$			0	+5
103	64	12	–24.8	–58	17	12	+15	$.75^{o}$			+5	+19
105	65	15	20.7	–54	18	12	+35	$.75^{o}$			+10	+45
106	67	3	2.9	–58	19	9	+5	.75			+5	+10
108	68	6	.7	–58.8	15	12	–30	1.0^{o}			+15	–15
109	68	4	11.1	–55.2	16	8	–5	$.75^{o}$			+5	0
110	68	3	17.7	–55.4	16	8	+0	$.75^{o}$			+5	+5
113	71	7	–17.6	–55.2	16	6	–40	$.75^{o}$			+5	–35
114	71	8	–17.5	–55	17	8	–30	$.75^{o}$			+5	–25
115	71	8	–15.1	–54.5	19	5	–25	$<.5^{o}$			0	–25
117	74	6	–4.3	–55.5	19	5	–5	$<.5^{o}$			0	–5
118	74	7	–5.0	–55.5	16	7	–5	$.75^{o}$			+5	0
119	74	5	–11.1	–59.6	15	12	+5	1.0^{o}			+15	+20
120	74	6	–13.4	–59.6	17	10	–15	1.0^{o}			+15	0
121	76	7	–3.6	–57	15	10	–10	$.9^{o}$			+10	0
122	76	5	–3.8	–58.6	14	15	–15	1.0^{o}			+15	0
123	76	5	–4.7	–57.6	9	25	–25	1.2^{o}			+30	+5
124	76	4	–9.3	–59	12	25	–25				+25	+0

TABLE 5. SKYLAB POINTING CORRECTION SUMMARY (Continued)

MAP NO.	PASS NO.	ORBIT QUALITY	HEIGHT RATE M/SEC	AGC LEVEL	PEAK CYCLE COUNTS	PEAK TO PEAK	BIAS FROM GEM–6	TRACKER DETERMINED POINTING	WAVEFORM DETERMINED POINTING MIN	WAVEFORM DETERMINED POINTING MAX	RECOMMENDED BIAS CORRECTION	NEW BIAS
127	78	7	–2.8	–53.7	16	7	+5	$<.5^{o}$			+0	+15
128	78	6	–3.2	–57	16	6	–5	$.65^{o}$		$.57^{o}$	5	0
129	78	15	–11.7	–57.5	15	9	–20	$.75^{o}$		$.57^{o}$	5	–15
131	79	4	–2.6	–56.5	18	7	0	$.75^{o}$			+5	+5
132	79	3	–2.1	–54.8	17	6	–5	$.5^{o}$		$.60^{o}$	+0	–5
133	79	4	–2.8	–55.2	20	5	+0	$.5^{o}$		$.60^{o}$	+5	+5
134	79	12	–11.4	–58.5	14	10	–15	1.0^{o}			+15	0
135	81	3	– .7	–59	16	10	+5	1.0^{o}			+15	+20
139	82	4	–15.3	–54/–59	7	40	–45	1.3^{o}			+40	–5
145	83	5	–9.8	–58	16	11	–10	$.75^{o}$			+5	–5
145A	83	5	–12.4	–60	18	10	–10	$.75^{o}$			+5	–5
146	83	5	–7.1	–60	17	10	–20	$.75^{o}$			+5	–15
147	83	3	–18.6	–58	18	8	–20	$.70^{o}$		$.48^{o}$	+5	–15
148	83	7	1.9	–57.5	14	16	–10	1.0^{o}			+15	+5
151	85	13	–15.6	–56	17	8	–25	$.75^{o}$			+5	–20
152	87	9	–14.8	–57	16	7	–0	$<.5^{o}$			+0	–0
155	88	4	–17.5	–57.5	10	26	–25	1.25^{o}			+30	+5
156	88	5	23.7	–58	15	15	+20	1.0^{o}			+15	+35
163	89	4	–15.3	–58.0	15	12	–15	$.85^{o}$			+15	0
164	89	4	–13.5	–58	9	15	–15	1.1^{o}			+20	+5
168	90	4	–19.8	–58	7	20	–40	1.3^{o}			+35	–5
169	90	5	–18.3	–58	6	25	–40	1.35^{o}			+40	+0

TABLE 5. SKYLAB POINTING CORRECTION SUMMARY (Continued)

MAP NO.	PASS NO.	ORBIT QUALITY	HEIGHT RATE M/SEC	AGC LEVEL	PEAK CYCLE COUNTS	PEAK TO PEAK	BIAS FROM GEM–6	TRACKER DETERMINED POINTING	WAVEFORM DETERMINED POINTING MIN	MAX	RECOMMENDED BIAS CORRECTION	NEW BIAS
175	91	4	–8.4	–58	8	18	–25	1.25°			+30	+5
182	92	13	–12.8	–49	18	6	–20	.75°			+5	–15
185	93	6	–10.6	–55.8	15	8	–20	.85°			+10	–10
201	97	3	3.8	–57	15		+5	.75°			5	10
202	97	3	7.2	–54	17		+10	.75°			5	15
203	97	3	6.5	–55	18		+15	.75°			5	20
204	97	3	3.3	–57	16		+10	.75°			5	15
205	97	3	– .5	–57	17		–5	.75°			5	0
206	97	3	–4.8	–56	15		0	.75°			5	5
207	97	3	–7.7	–57	16		–5	.75°			5	0
208	97	3	–5.9	–56	18		–10	.75°			+5	–5
209	97	3	–1.4	–55	17		–5	.75°			5	0
210	97	4	4.2	–54	16		5	.75°			5	10
211	97	3	10.4	–54	18		5	.75°			5	10
212	97	3	15.1	–56	16		15	.75°			5	20
213	97	4	17.0	–55	17		10	.75°			5	15
214	97	5	18.7	–55.8	19	+5	.75°				5	10
215	97	4	10.7	–57.7	18	10	+10	.75°			+5	15
216	97	3	4.7	–57	18	8	–0	.75°			+5	5
217	97	3	–1.9	–54	14	10	–10	.85°			+10	0
218	17	3	–6.8	–57	18	8	–10	.75°			+5	–5
222	97	3	–16.6	–49	16	7	–20	.75°			+5	–15

TABLE 5. SKYLAB POINTING CORRECTION SUMMARY (Continued)

MAP NO.	PASS NO.	ORBIT QUALITY	HEIGHT RATE M/SEC	AGC LEVEL	PEAK CYCLE COUNTS	PEAK TO PEAK	BIAS FROM GEM–6	TRACKER DETERMINED POINTING	WAVEFORM DETERMINED POINTING MIN	WAVEFORM DETERMINED POINTING MAX	RECOMMENDED BIAS CORRECTION	NEW BIAS
223	97	3	–16.2	–55	16	10	–15	.75°			+5	–10
225	97	4	–14.5	–55.9	19	6	–5	.6°			+5	0
226	97	4	–12.9	–57	19	8	–5	.75°			+5	0
233	86	4	–23.2	19	6	–5	.6°			.60°	+5	–20

TABLE 5. SKYLAB POINTING CORRECTION SUMMARY (Continued)

ERROR BUDGET

Instrument Errors

Instrument Bias - One of the largest instrument errors is bias. The removal of this error is extremely important to anyone wishing to use the absolute accuracy of the altitude measurements. Since this error is comparatively large with respect to other errors (see Table 6), and is difficult to remove, it often determines the system accuracy.

One of the bias errors is the zero set error (initial alignment) which is a fixed bias for the duration of the satellite life. Internal instrument delay caused by processing transmission methods such as path delays are included in this bias. Field calibration efforts are usually focused on minimizing this error.

These bias errors also change if operating parameters are changed. For example, the changing of a pulsewidth or bandwidth in the altimeter will cause a jump in altitude. These are easy to recognize in SKYLAB data since the altimeter was constrained to a fixed routine, and mode changes had to occur at certain times. The magnitude of these jumps are not necessarily consistent from one pass to the next, for the satellite pointing can change the operating conditions (signal-to-noise, pulseshape, etc.) significantly.

System drift can cause the zero set error to slowly change. In mode 1 calibration, step CDS 3, the altimeter locks on and tracks its own transmitted pulse. This test was instrumented to measure any drift present in the system. SKYLAB results have shown that this error has been only a few centimeters over the whole satellite life.

When the overall SKYLAB mission errors are reviewed, the instrument bias error is found to be under 10 meters. This is a conservative estimate, for the 10 meter error measured includes more than the instrument bias. (See System Accuracy Discussion.)

Timing Bias - The two primary sources of timing bias errors are time tag vs true Greenwich Mean Time (GMT) and the altimeter processor time delay. The time tag error is the bias between the satellite timing system and the GMT time. This error is usually small (approximately 100 microseconds) and can be ignored. However, in a few isolated instances some large timing errors (approximately one second) were found when data processed by Kennedy Space Center was compared with that processed at Johnson Space Center. While there have been extremely careful attempts to locate and remove such errors, the user should be aware that a few passes might still contain errors of this magnitude.

SYSTEM ERROR MODEL AND RESIDUALS

	UNCORRECTED MAGNITUDE	ERROR SOURCE	CORRECT RESIDUALS (THEORETICAL)
1. INSTRUMENT ERRORS Systematic	Up to 50 meters	Zero set error, discriminator drift, servo unbalance, operating parameter changes	< 10 m (Correcting for operating parameters only)
	Up to 1.5 meters	Timing Errors	< 1 m Normally (No correction applied)
	≈ 10 cm peak	Transit Time Error	< 1 cm Normally (No correction applied)
	Up to 35 cm	Dynamic Lag Error K_v = Servo Acceleration Constant (276 per sec) K_a = Servo Velocity Constant (35 per sec^2)	< 10 m Normally (No correction applied)
Random	Up to 80 cm	σh_t = Height Thermal Noise	< 1 m for 1 sec average ≈ 30 cm (where features permit more averaging can be applied)
	Approx. 15 cm	σh_q = Quantizing Error	
2. POINTING	Up to 60 meters	Off Nadir Pointing	< 5 m (Primarily using the tracker response as a pointing indicator)
3. SEA SURFACE	Up to .70 m	Electromagnetic MSL vs MSL	Up to 70 cm (No correction applied)
4. ATMOSPHERE	Up to 3 meters	Atmospheric refraction path delay	< 50 cm (Using mean atmospheric correction)
5. ORBIT	< 10 meters	Uncertainty in orbit height	< 10 m (No correction available)
SYSTEM ACCURACY	< 20 meters	RMS of all errors	< 10 m

TABLE 6

The altimeter processor time delay correction is largely due to the delay characteristics of the on-board averaging operation. The S-193 altitude measurement process is shown in block diagram form below, along with the frequency domain (Fourier) transfer functions $H(j\omega)$ and impulse response

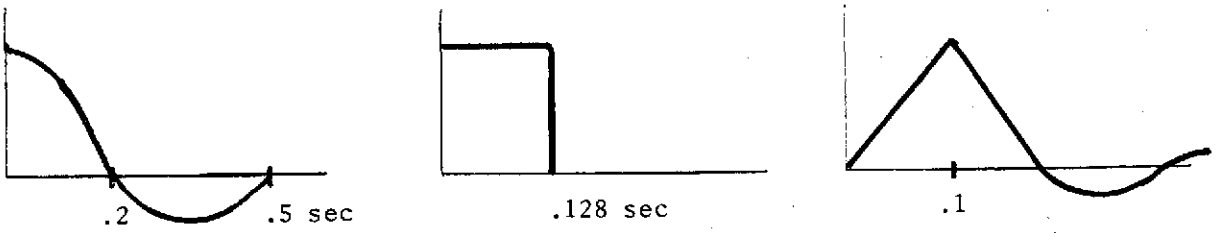
ALTITUDE TRACKER

$$H_T(j\omega) = \frac{280 + j\omega 70}{-8\omega^2 + 71j\omega + 280}$$

.28 sec Averager

$$H_A(j\omega) = \frac{\sin \omega T/2}{\omega T/2} e^{-j\omega T/2}$$

ALT. DATA



tracker time domain response h(t)

averager time domain response

composite time domain response

functions h(t). As shown in these sketches, a particular altitude value represents contributions from a large number of past values, i.e. a given value is not centrally weighted since the tracker cannot be anticipative. As will be discussed, if desired, the non-anticipatory restriction can be removed in computer (non-real time) data processing. A fixed-value time correction is developed in the following paragraphs, which is considered adequate for most altimeter data applications.

The altitude tracker transfer function can be expressed in polar form as

$$H_T(j\omega) = |H_T(j\omega)| \exp\left(-j \tan^{-1} \frac{\omega + 2\omega^3}{280 + 9.75\omega^2}\right)$$

Similarly,

$$H_A(j\omega) = |H_A(j\omega)| e^{-j\omega T/2}$$

where the averaging period T is .128 sec. Since an idealized linear phase-shift device will have a transfer function of the form,

$$H(j\omega) = |H(j\omega)| e^{-jt_o\omega}$$

by analogy, a frequency range can be established over which the altitude data may be considered to be derived from a fixed-time delay system. Using this analogy, the time delay t_o is given by

$$t_o = \frac{1}{\omega} \tan^{-1} \left[\frac{\omega + 2\omega^3}{280 + 9.75\omega^2} \right] + \frac{T}{2}$$

This expression is evaluated in Table 1 with frequency in Hz, ω(omega) in radian/sec., wavelength in km (assuming a ground track velocity of 7.4 km/sec), and time delay t_o in-milliseconds. Analysis shows that

1) the S-193 altimeter behaves essentially as a fixed time delay system for surface wavelengths equal to or greater than ~50 km, with a time delay of ~68 milliseconds, and
2) the time delay of the on-board averaging operation is the dominant effect for the long wavelength case (its time delay alone accounts for 64 ns and the residual delay is essentially the tracker lag error).

For detailed studies of short wavelength geoid and ocean-topographic features, a fixed-value time correction is not recommended. In these cases the altitude time-series can be more accurately corrected by convolving the data with a symmetrical impulse response function (i.e. $h(t) = h(-t)$)*. Such a centrally weighted response may be obtained by convolving the S-193 data with a time-reversed replica of the composite system response.

Under the most extreme conditions (height rates of 20 m/sec) an error of 1.5 meters would be possible. Under normal conditions, the typical error is under 1 meter.

For both of the above errors no correction has been applied. However, if one wishes to make a correction, the following equation can be utilized:

$$h_t = \Delta_t \dot{h} + (\Delta_t)^2 \ddot{h} + \ldots .$$

Δ_t = timing bias
h_t = height error
$\dot{h}$ = height rates
$\ddot{h}$ = height acceleration

The satellite height dynamics for various SKYLAB passes are summarized in Table 5.

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*In such cases the "spot size" spatial filter characteristics should also be considered.

Transit Time Correction - The measurement time tags can be corrected to the time the altimeter pulse arrived at the earth's surface by the relationship:

$$T_c = T_o - h/C$$

where
T_c = corrected observation time (seconds)
T_o = sampled time at radar
C = velocity of light = 299,792.5 km/sec
h = height of satellite over the surface

The error caused by not considering the transit time is dependent on the height dynamics and has the following form:

$$h_{tt} = \frac{1}{C} \dot{h}h + \frac{1}{C} h^2 \ddot{h} \ldots$$

where $\dot{h}$ and $\ddot{h}$ are the height rate and height acceleration respectively. Using a maximum $\dot{h}$ of 50 m/sec and $\ddot{h}$ of 5 m/sec^2 and a nominal satellite height of 500 km an approximate 10 cm error results. Since this error is so insignificant in the total error budget, no transit time correction was applied.

Dynamic Lag Error - The error of the height tracker in following relative motion of the ocean surface undulations and the satellite height variations is defined as the Dynamic Lag Error. These servo lag errors can better be expressed as follows:

$$h_{dL} = \frac{\dot{h}}{Kv} + \frac{\ddot{h}}{Ka} + \ldots$$

h_{dL} = total dynamic lag error
Kv = altitude tracker servo velocity constant
Ka = altitude tracker servo acceleration constant
$\dot{h}$ = height velocity encountered
$\ddot{h}$ = height acceleration encountered

Using 50 meter/sec velocity and 5 meters/sec acceleration, which are conservative values, the dynamic lag error is under 35 centimeters. In the SKYLAB mission, 20 meter/sec velocity caused by the orbit and 1 meter/sec^2 acceleration caused by an ocean feature were the largest dynamics experienced.

No correction has been applied to the data for this error.

Random Error - The total random error is primarily made up of a quantizing error and the thermal noise of the height tracker. These errors are combined as follows:

$$\sigma h = \sqrt{\sigma h_t^2 + \sigma h_q^2}$$

where σh_t = thermal noise

σh_q = quantizing error

The quantizing error is expressed as:

$$\sigma h_q = \sqrt{\sigma h_{q1}^2 + \sigma h_{q2}^2}$$

where σh_{q1} = start of digital delay generator

σh_{q2} = stop of digital delay generator

The typical error for each term is computed as follows:

$$\sigma h_q = \frac{\text{Bit Weight}}{\sqrt{12}}$$

The bit weight is 2.5 n seconds which results in a σh_q of approximately 15 cm.

The σh_t is computed as follows:

$$\sigma h_t = \frac{T\sqrt{7/6 + \frac{6}{S/N} + \frac{8}{(S/N)^2}}}{\sqrt{\frac{prf}{\pi b}}} \times \frac{C}{2}$$

where T = pulsewidth (100 n sec)

S/N = signal to noise (100:1)

prf = 250

b = servo bandwidth (1.3 Hz)

C = 299792.5 Km/sec (speed of light)

Since the above equation yields the noise for each independent sample of the servo, the noise is further divided by the $\sqrt{8}$ to get the one second noise level, providing all 8 samples are independent.

Pointing

As was stated in the Pointing Section of this report, pointing errors cannot only cause an altitude bias but also can cause the altitude tracker to become sluggish. Slight pointing errors (less than .75°) mainly affect the altitude bias and can very accurately be removed by waveform analysis down to a residual of a few centimeters. Larger pointing errors, where the tracker peak jitter increases and the stracker servo becomes sluggish, are not as straightforward to correct. The waveform techniques for determining pointing errors can't be used, and the less accurate tracker performance modeling technique must be utilized. This technique can remove large biases (60 meters or so) and leave the residuals under 5 meters but cannot overcome the lack of response of the servo to higher frequency topographic features. The increased jitter level associated with these large pointing errors also cannot be overcome. However, if the geoid or topographic features being recovered are sufficiently known that the analyst is sure that their wavelength is longer than the wavelength of the frequency response of the tracker, then an appropriate filter can be applied to the data. This filtering can reduce the effects of the jitter and will therefore aid in the recovery of the feature of interest.

Sea Surface

Sea surface error is a bias caused by the difference between the true mean sea level and the mean point that the radar tracks. This error is further complicated by the fact that it probably changes as sea state changes.

By modeling the change of rise time as sea state increases and by considering that the SKYLAB altimeter tracker gate was fixed, it can be seen that the error will increase linearly with significant wave height (SWH). However, real data to confirm the nature of this bias is very sparse. By using some data obtained by Yaplee, et al, (NRL) which indicated approximately 14 cm bias for a 2 meter SWH [5], an extrapolation was made to 70 cm for a 10 meter SWH, but this is felt to be pessimistic. Since the model is somewhat questionable and knowledge of the SWH is very limited, no attempt to correct for this error has been made.

Atmosphere

Without corrections for atmospheric delay, the error would not exceed 3 meters. However, it was decided that a mean correction would be used, which left residual errors of approximately 50 cm.

The refraction model being used to correct the altitude data for tropospheric effects has been defined in the Data Processing Section of the report. The error in this model is about 10% of the total correction assuming no error exists in the pointing or in the surface N unit measurement. However, the value of the surface refractivity used

in the refraction model was fixed at 340 N units. This value was obtained by calculating the average annual value of the surface refractivity over water independent of geographical position. Since instantaneous values of surface refractivity could depart from the mean value used by as much as 40-50 N units, a 15% error in using the average value N unit could result in evaluating the refraction correction equation. These two errors could result in a total error of about 20% in the tropospheric refraction correction applied to all altitude data. Also, no correction was made for ionospheric effects since these were felt to be only a few centimeters. (Reference [7].)

Orbit Error

Not only is orbit error one of the larger sources of error, but also since the orbit is the reference for altimeter measurements, these errors project directly into geoid error.

For each SKYLAB pass, both the bias and the shape error of the orbit can affect the overall system accuracy. The shape error over the duration of an operation (approximately 3 minutes) is generally felt not to exceed 1 meter. This can be confirmed by looking at passes that overlap (see Figures 12 and 13). This error could be larger if insufficient tracking data were available for forming the orbit. The orbit quality indicator on the pointing charts is one attempt to provide the user with an estimate of the uncertainty in the orbit. A higher uncertainty can mean that the data might be both more biased and more trended. However, these computed uncertainties are based on the geometrical strength of the stations in the orbit solution, and do not consider unexpected tracking station errors. Therefore, the user must apply these with caution.

The average orbit bias error based on the overall accuracy histogram of the altimeter system is estimated to be under 10 meters (see Figure 14).

System Accuracy

To establish the overall system accuracy, the altimeter data was compared with the GEM-6 [8] geoid. The differences between the GEM-6 geoid and the altimeter measurements were plotted in the histogram of Figure 14. In the same figure, a histogram of the pointing error corrections was convolved with an assumed 10 meter normal distribution of other errors. It should be noted that the resulting error difference distribution favorably compared with the geoid histogram. Therefore, it can be concluded that the combination of orbit error, uncertainty in the GEM-6 geoid and altimeter bias is under ± 10 meters rms.

It is not possible to break down further these three main errors, but the orbit and geoid errors will probably supply the largest contribution to the data spread. The altimeter instrument bias has an uncertainty of 10 meters since it can not presently be calibrated below this level. However, the instrument is probably consistent within a meter.

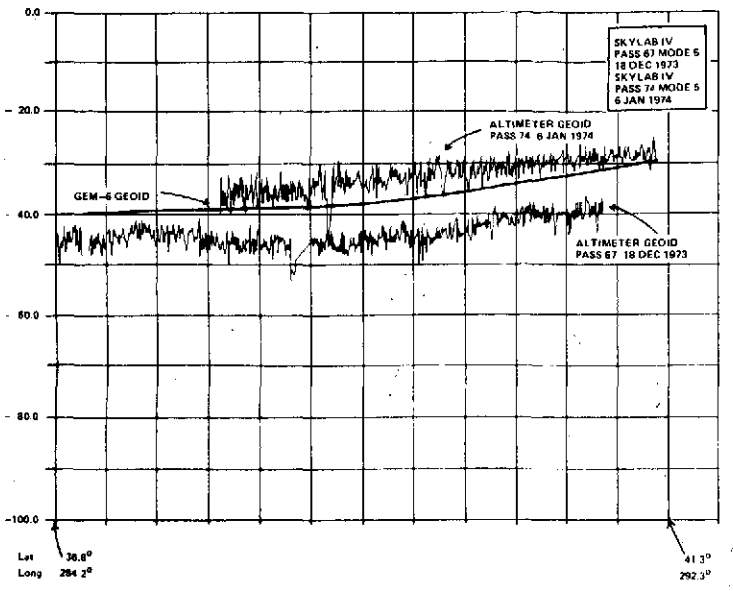

Figure 12 Comparison of Altimeter Geoid With GEM-6 Geoid For 2 Passes over the Same Area

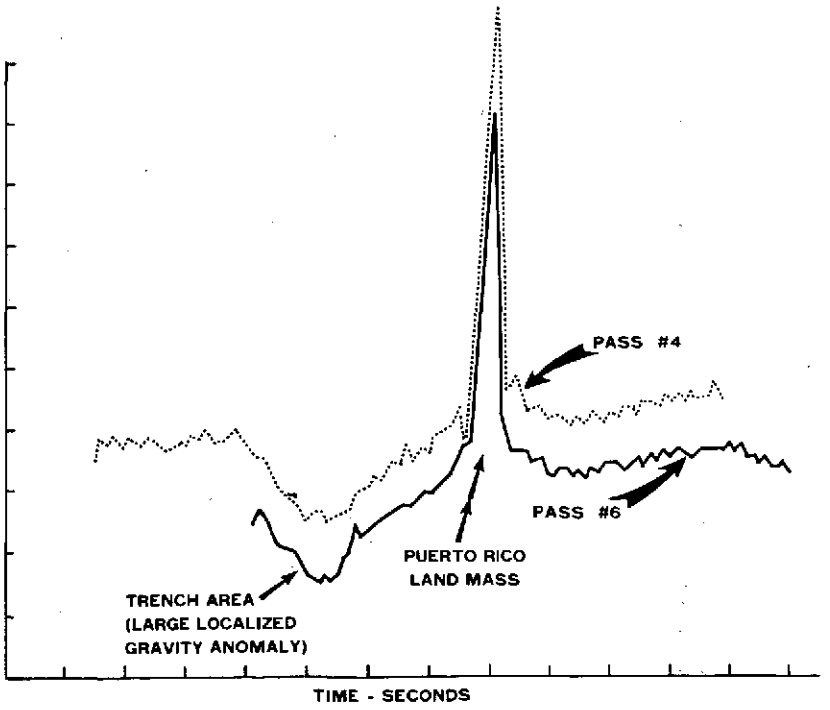

Figure 13 SKYLAB Passes over Puerto Rico Area

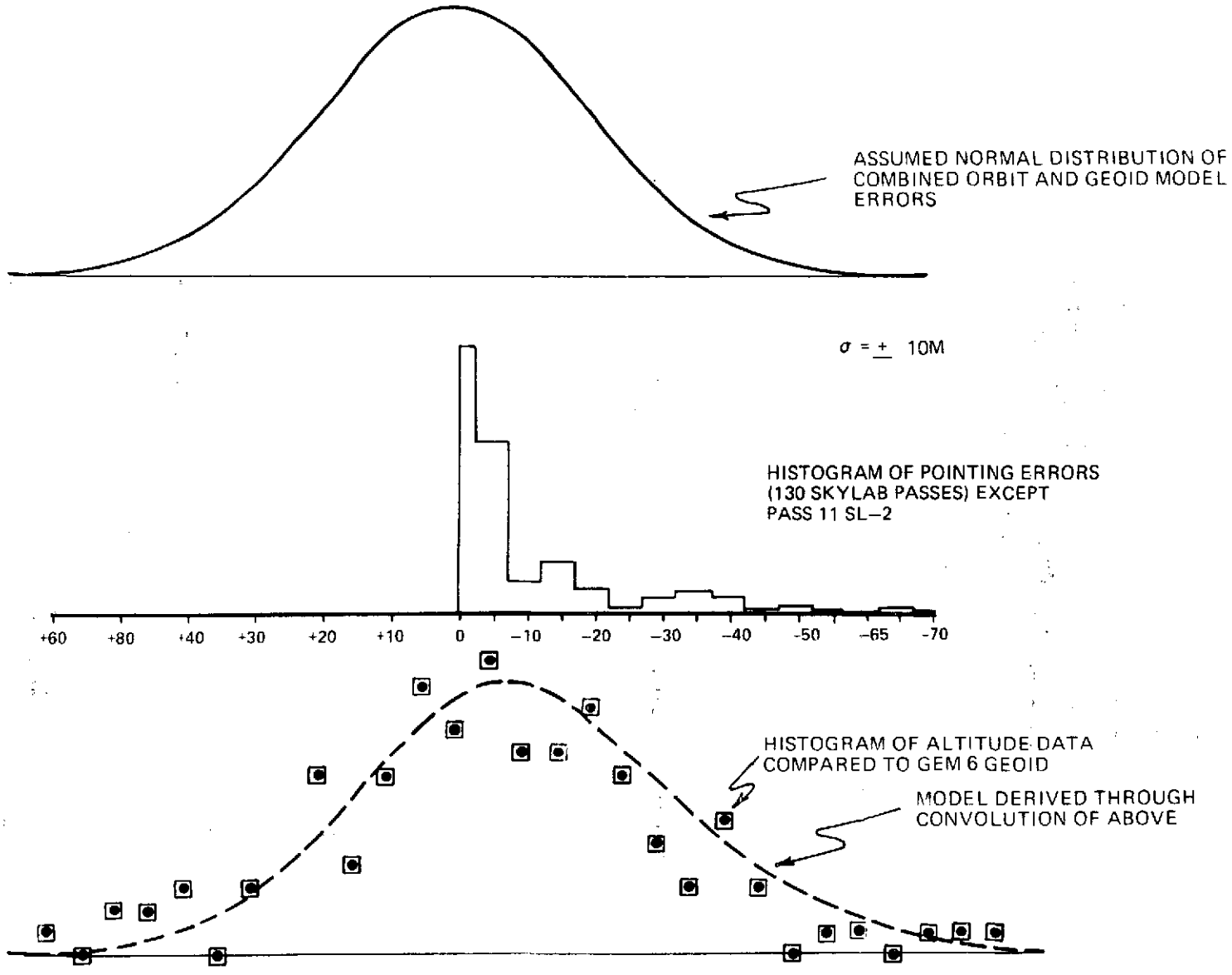

FIGURE 14. DIFFERENCES BETWEEN THE GEM–6 GEOID AND THE ALTIMETER MEASUREMENTS

DATA SUMMARY

Table 7 in this section tabulates the altimeter data passes according to SKYLAB pass number, time, and ground track latitude and longitude. In addition, map numbers are assigned which can be cross-referenced to the ground track plots which immediately follow in this section. The ground tracks are laid out on National Geographic Ocean floor maps so that the data can be compared with ocean floor topographic features.

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DOY	DATE	PASS	MODE	MAP	TIME START	TIME STOP	START LAT	START LONG	STOP LAT	STOP LONG
150	May 30, 1973	1	1	1	20 37 55	20 38 10	43.6	235.2	43.3	235.9
153	June 2, 1973	2	1	2	20 05 40	20 07 10	40.6	232.2	36.8	238.8
155	June 4, 1973	4	1	3	17 11 10	17 14 15	31.1	279.8	23.1	287.9
155	June 4, 1973	4	5	4	17 15 15	17 16 30	19.8	291.4	16.0	294.7
159	June 9, 1973	6	5	5	15 15 30	15 18 20	21.2	290.2	13.6	297.5
160	June 10, 1973	7	1	6	14 28 15	14 31 00	33.6	281.3	26.1	290.0
160	June 10, 1973	7	5	7	14 32 10	14 34 50	23.5	292.7	15.7	299.7
160	June 10, 1973	7	3	8	14 36 30	14 38 50	11.0	303.4	4.2	308.2
161	June 11, 1973	8	1	9	15 19 50	15 20 10	31.6	265.0	30.5	266.4
161	June 11, 1973	8	3	10	15 25 10	15 27 15	16.8	279.8	10.5	284.9
162	June 12, 1973	9	5	11	13 01 35	13 04 25	37.5	285.1	30.5	294.7
162	June 12, 1973	9	3	12	13 10 00	13 12 20	15.3	309.5	8.0	315.5
162	June 12, 1973	9	3	13	13 15 35	13 18 00	−0.9	322.0	−8.3	327.6
163	June 13, 1973	10	1	14	13 58 50	14 01 00	20.5	286.0	17.2	289.0
163	June 13, 1973	10	1	15	14 01 50	14 02 30	11.9	293.2	9.7	295.1
164	June 14, 1973	11	5	18	14 54 00	14 55 35	7.2	278.1	2.7	281.4
164	June 14, 1973	11	3	19	15 02 15	15 02 55	297.1	−52.6	298.0	−61.5
164	June 14, 1973	11	5	20	15 07 05	15 07 50	−29.7	304.2	−31.9	311.8

TABLE 7. SKYLAB DATA SUMMARY

DOY	DATE	PASS	MODE	MAP	TIME START	TIME STOP	START LAT	START LONG	STOP LAT	STOP LONG
215	August 3, 1973	12/SL3/1	1	22	18 06 35	18 09 00	29.1	264.0	23.2	270.1
215	August 3, 1973	12/SL3/1	1	23	18 12 35	18 13 50	12.2	279.7	8.8	282.4
217	August 5, 1973	14/SL3/3	1	26	15 04 00	15 06 30	39.1	283.3	33.2	292.2
221	August 9, 1973	17/SL3/6	1	28	13 47 20	13 49 50	36.4	283.2	31.0	290.4
221	August 9, 1973	17/SL3/6	3	29	13 51 10	13 53 30	27.1	294.9	20.7	301.2
221	August 9, 1973	17/SL3/6	5	30	13 58 30	14 01 20	6.1	313.1	− 2.3	319.5
223	August 11, 1973	18/SL3/7	1	31	15 29 30	15 32 20	33.6	249.3	26.7	257.5
223	August 11, 1973	18/SL3/7	5	32	15 36 50	15 39 40	13.1	269.9	5.2	276.0
224	August 12, 1973	19/SL3/8	1	33	02 35 00	02 38 10	− 4.6	117.6	−13.4	124.5
224	August 12, 1973	19/SL3/8	5	34	02 46 50	02 49 30	−37.5	150.5	−42.4	159.7
224	August 12, 1973	20/SL3/9	1	34A	14 54 40	14 57 30	11.9	275.6	3.5	282.1
244	September 1, 1973	21/SL3/10	5	35	15 22 45	15 25 40	−16.5	322.9	− 8.7	329.2
244	September 1, 1973	21/SL3/10	5	36	15 26 35	15 29 30	− 5.2	332.2	2.0	337.8
244	September 1, 1973	21/SL3/10	5	37	15 30 30	15 31 30	5.7	340.0	9.2	342.7
245	September 2, 1973	22/SL3/11	1	38	14 29 55	14 32 45	−41.9	296.1	−30.1	306.4
245	September 2, 1973	22/SL3/11	1	39	14 33 40	14 36 35	−33.7	309.8	−26.4	318.5
245	September 2, 1973	22/SL3/11	1	40	14 37 20	14 40 15	−24.1	320.8	−16.1	328.1
245	September 2, 1973	22/SL3/11	1	41	14 41 20	14 44 00	−12.7	330.9	− 5.3	336.6
245	September 2, 1973	22/SL3/11	1	42	14 44 45	14 47 35	− 2.3	338.8	5.7	334.8
246	September 3, 1973	24/SL3/13	3	43	15 35 40	15 38 00	− .7	321.1	6.7	326.7
246	September 3, 1973	24/SL3/13	3	44	15 40 05	15 42 30	12.6	331.4	19.4	337.1
246	September 3, 1973	24/SL3/13	3	45	15 44 40	15 47 05	26.4	343.8	31.7	349.8
247	September 4, 1973	25/SL3/14	5	46	14 51 35	14 54 30	−4.2	323.3	4.2	329.7
247	September 4, 1973	25/SL3/14	5	47	14 55 10	14 58 00	5.7	330.8	14.6	337.7

TABLE 7. SKYLAB DATA SUMMARY (Continued)

DOY	DATE	PASS	MODE	MAP	TIME START	TIME STOP	START LAT	START LONG	STOP LAT	STOP LONG
249	September 6, 1973	27/SL3/16	5	48	21 19 45	21 22 25	19.8	233.4	27.6	241.6
249	September 6, 1973	27/SL3/16	1	49	21 24 00	21 26 30	31.1	245.2	37.6	254.3
250	September 7, 1973	28/SL3/17	5	50	20 35 15	20 38 05	15.1	234.2	23.1	241.4
250	September 7, 1973	28/SL3/17	1	51	20 45 40	20 48 45	41.6	266.4	46.8	280.3
252	September 9, 1973	29/SL3/18	1	52	19 15 10	19 18 40	30.5	258.9	38.2	269.7
254	September 11, 1973	32/SL3/21	5	54	13 06 15	13 09 00	20.6	329.4	28.0	336.7
254	September 11, 1973	32/SL3/21	5	55	13 09 45	13 12 30	30.2	339.2	37.2	348.7
254	September 11, 1973	32/SL3/21	5	56	13 13 10	13 15 20	38.7	351.1	43.1	0.0
254	September 11, 1973	34/SL3/23	1	57	21 02 25	21 05 20	−23.7	23.7	−31.7	28.6
255	September 12, 1973	35/SL3/24	5	58	12 25 30	12 28 20	24.9	338.2	32.4	346.6
255	September 12, 1973	35/SL3/24	5	59	12 28 45	12 29 50	33.6	348.3	36.0	351.7
255	September 12, 1973	35/SL3/24	1	60	12 30 10	12 31 35	37.2	353.4	39.8	357.8
255	September 12, 1973	36/SL3/25	5	61	16 52 10	16 55 00	−10.5	238.7	−2.1	245.2
255	September 12, 1973	36/SL3/25	5	63	16 59 20	17 01 40	10.4	254.6	17.2	260.1
255	September 12, 1973	36/SL3/25	1	64	17 09 35	17 11 50	38.2	284.2	42.4	
255	September 12, 1973	36/SL3/25	5	65	17 12 30	17 15 20	44.0	295.9	48.1	309.9
255	September 12, 1973	37/SL3/26	5	66	20 10 35	20 13 30	25.8	220.8	32.4	228.3
255	September 12, 1973	37/SL3/26	1	67	20 14 45	20 16 00	35.7	232.8	38.4	237.0
256	September 13, 1973	38/SL3/27	1	69	18 02 00	18 03 40	42.6	273.8	45.5	281.4
256	September 13, 1973	38/SL3/27	5	70	18 06 25	18 09 30	49.0	296.0	50.2	312.1
256	September 13, 1973	38/SL3/27	5	71	18 09 50	18 12 35	50.2	315.0	48.6	330.0
256	September 13, 1973	39/SL3/28	1	72	19 34 10	19 34 40	40.7	246.0	41.7	248.1
256	September 13, 1973	39/SL3/28	5	73	19 45 50	19 48 25	48.5	307.4	45.1	320.0
256	September 13, 1973	39/SL3/28	5	74	19 49 25	19 52 15	43.4	324.6	37.5	336.0
257	September 14, 1973	40/SL3/29	3	75	17 05 15	17 07 40	6.4	237.5	12.8	242.5
257	September 14, 1973	40/SL3/29	1	76	17 11 10	17 11 40	23.3	251.7	24.7	253.1

TABLE 7. SKYLAB DATA SUMMARY (Continued)

DOY	DATE	PASS	MODE	MAP	TIME START	TIME STOP	START LAT	START LONG	STOP LAT	STOP LONG
334	November 30, 1973	54/SL4 04	RESET	80						
334	November 30, 1973	54/SL4 04	1	81	16 35 40	16 36 00	38.8	269.7	38.1	271.0
334	November 30, 1973	54/SL4 04	1	82						
334	November 30, 1973	54/SL4 04	1	83	16 42 45	16 43 35	20.2	292.2	18.3	293.8
334	November 30, 1973	54/SL4 04	1	84	16 46 45	16 48 00	8.6	301.8	5.2	304.4
335	December 1, 1973	55/SL4 05	1	85	17 30 20	17 33 05	28.6	264.9	21.8	271.8
335	December 1, 1973	55/SL4 05	1	86	17 34 00	17 36 50	18.7	274.6	11.0	281.4
336	December 2, 1973	56/SL4 06	1	87						
336	December 2, 1973	56/SL4 06	5	88						
336	December 2, 1973	57/SL4 07	3	89	18 17 10	18 17 50	38.3	232.8	36.8	235.2
336	December 2, 1973	57/SL4 07	1	90						
336	December 2, 1973	57/SL4 07	1	91	18 22 30	18 23 45	24.9	249.9	21.6	253.0
336	December 2, 1973	57/SL4 07	5	92	18 24 20	18 26 20	19.8	254.7	14.0	259.6
336	December 2, 1973	57/SL4 07	5	93	18 27 05	18 27 30	11.6	261.6	10.6	262.3
337	December 3, 1973	58/SL4 08	1	94						
337	December 3, 1973	58/SL4 08	2	95						
337	December 3, 1973	59/SL4 09	1	96						
339	December 5, 1973	61/SL4 11	1	97						
339	December 5, 1973	61/SL4 11	3	98	16 15 30	16 16 10	22.6	266.3	20.8	268.0
339	December 5, 1973	61/SL4 11	5	99	16 21 05	16 22 20	6.6	279.6	2.7	282.6
341	December 7, 1973	62/SL4 12	1	100	14 48 10	14 48 55	29.0	269.3	26.7	271.7
341	December 7, 1973	62/SL4 12	5	101						
342	December 9, 1973	64/SL4 14	5	102	02 37 05	02 38 45	11.3	100.9	6.3	104.7
342	December 9, 1973	64/SL4 14	1	103	02 43 10	02 46 05	−7.1	114.7	−15.3	121.3
342	December 9, 1973	64/SL4 14	1	104	02 46 55	02 47 45	−17.7	123.3	−20.1	125.4
349	December 15, 1973	65/SL4 15	5	105	00 01 00	00 01 50	− 5.8	118.5	− 8.7	120.8

TABLE 7. SKYLAB DATA SUMMARY (Continued)

DOY	DATE	PASS	MODE	MAP	TIME START	TIME STOP	START LAT	START LONG	STOP LAT	STOP LONG
352	December 18, 1973	67/SL4 16	5	106	02 00 20	02 01 50	41.9	293.6	44.7	300.0
352	December 18, 1973	67/SL4 16	2	107						
352	December 18, 1973	68/SL4 17	1	108	11 33 20	11 35 20	44.0	225.7	40.9	232.9
352	December 18, 1973	68/SL4 17	5	109	11 44 50	11 46 50	15.2	263.2	10.3	267.1
352	December 18, 1973	68/SL4 17	5	110	11 48 10	11 50 10	5.8	270.8	− 0.1	275.3
1	January 1, 1974	71/SL4 18	1	111						
1	January 1, 1974	71/SL4 18	5	112						
1	January 1, 1974	71/SL4 18	5	113	13 25 20	13 27 15	−26.0	322.0	−20.5	327.3
1	January 1, 1974	71/SL4 18	5	114	13 29 00	13 31 00	15.3	331.9	− 9.5	336.6
1	January 1, 1974	71/SL4 18	5	115	13 32 35	13 34 35	−5.0	340.0	+ .9	344.4
6	January 6, 1974	74/SL4 21	3	116						
6	January 6, 1974	74/SL4 21	5	117	17 55 40	17 57 25	23.7	268.4	28.2	273.0
6	January 6, 1974	74/SL4 21	5	118	18 00 50	18 02 40	36.8	284.2	40.8	291.2
6	January 6, 1974	74/SL4 21	5	119	18 09 00	18 09 10	49.7	322.3	49.8	323.2
6	January 6, 1974	74/SL4 21	5	120	18 11 20	18 11 40	50.2	335.2	50.1	338.1
6	January 6, 1974	74/SL4 21	5	120A	18 14 25	18 15 00	48.1	353.9	47.8	355.1
7	January 7, 1974	76/SL4 22	1	121	17 13 30	17 14 30	24.5	273.9	27.7	277.2
7	January 7, 1974	76/SL4 22	5	122	17 17 20	17 17 35	34.6	285.7	35.0	286.3
7	January 7, 1974	76/SL4 22	5	123	17 18 40	17 20 30	37.8	290.5	41.4	297.0
7	January 7, 1974	76/SL4 22	5	124	17 24 40	17 25 00	48.1	317.2	48.5	318.9
7	January 7, 1974	76/SL4 22	5	125						
7	January 7, 1974	76/SL4 22	5	126						
8	January 8, 1974	78/SL4 23	1	127	16 31 30	16 33 40	26.0		31.3	286.1
8	January 8, 1974	78/SL4 23	5	128	16 34 05	16 36 00	32.7	287.9	37.1	294.2
8	January 8, 1974	78/SL4 23	5	129	16 44 30	16 46 25	49.9	334.9	50.1	346.4
9	January 9, 1974	79/SL4 24	3	130						
9	January 9, 1974	79/SL4 24	5	131	15 45 55	15 47 25	17.5	276.9	21.7	280.7
9	January 9, 1974	79/SL4 24	5	132	15 49 45	15 50 40	28.1	287.2	33.3	293.4
9	January 9, 1974	79/SL4 24	5	133	15 52 50	15 53 05	35.8	297.0	36.4	297.9
9	January 9, 1974	79/SL4 24	5	134	16 00 45	16 02 40	49.2	332.8	50.2	344.1

TABLE 7. SKYLAB DATA SUMMARY (Continued)

DOY	DATE	PASS	MODE	MAP	TIME START	TIME STOP	START LAT	START LONG	STOP LAT	STOP LONG
11	January 11, 1974	81/SL4 26	3	135	17 29 10	17 29 50	23.1	244.1	24.9	245.9
11	January 11, 1974	81/SL4 26	1	136						
12	January 12, 1974	82/SL4 27	3	137						
12	January 12, 1974	82/SL4 27	3	138						
12	January 12, 1974	82/SL4 27	5	139	17 00 30	17 00 50	49.8	305.4	50.0	307.3
12	January 12, 1974	82/SL4 27	5	140						
12	January 12, 1974	82/SL4 27	5	141						
12	January 12, 1974	82/SL4 27	5	142						
12	January 12, 1974	82/SL4 27	3	143						
12	January 12, 1974	82/SL4 27	3	144						
14	January 14, 1974	83/SL4 29	5	145	15 34 35	15 35 15	49.4	310.8	49.8	314.5
14	January 14, 1974	83/SL4 29	5	145A	15 36 15	15 37 00	50.1	320.2	50.2	324.1
14	January 14, 1974	83/SL4 29	5	146	15 38 25	15 40 20	49.9	332.4	48.5	342.5
14	January 14, 1974	83/SL4 29	5	147	15 41 20	15 41 50	47.2	348.3	46.8	350.0
14	January 14, 1974	83/SL4 29	5	148	16 56 00	16 57 50	26.6	238.2	31.5	243.7
18	January 18, 1974	85/SL4 30	1	149						
18	January 18, 1974	85/SL4 30	1	150						
18	January 18, 1974	85/SL4 30	5	151	20 48 35	20 49 30	20.9	291.6	18.5	293.7
21	January 21, 1974	87/SL4 35	1	152	20 14 40	20 16 45	19.4	283.5	13.2	288.8
22	January 22, 1974	88/SL4 37	5	153						
22	January 22, 1974	88/SL4 37	5	154						
22	January 22, 1974	88/SL4 37	5	155	19 31 30	19 31 45	21.4	286.4	20.5	287.2
22	January 22, 1974	88/SL4 37	5	156	19 33 00	19 33 25	16.9	290.4	16.0	291.2
24	January 24, 1974	89/SL4 40	1	157						
24	January 24, 1974	89/SL4 40	1	158						
24	January 24, 1974	89/SL4 40	1	159						
24	January 24, 1974	89/SL4 40	1	160						
24	January 24, 1974	89/SL4 40	1	161						
24	January 24, 1974	89/SL4 40	1	162						
24	January 24, 1974	89/SL4 40	1	163	18 08 00	18 08 50	17.4	299.4	15.0	301.5
24	January 24, 1974	89/SL4 40	5	164	18 09 10	18 11 10	13.6	302.6	8.2	306.8

TABLE 7. SKYLAB DATA SUMMARY (Continued)

DOY	DATE	PASS	MODE	MAP	TIME START	TIME STOP	START LAT	START LONG	STOP LAT	STOP LONG
25	January 25, 1974	90/SL4 41	1	165						
25	January 25, 1974	90/SI4 41	1	166						
25	January 25, 1974	90/SL4 41	3	167						
25	January 25, 1974	90/SL4 41	5	168	17 19 10	17 21 05	37.1	282.2	32.5	288.6
25	January 25, 1974	90/SL4 41	5	169	17 22 30	17 24 20	25.9	296.2	20.8	301.1
25	January 25, 1974	90/SL4 41	5	170						
25	January 25, 1974	90/SL4 41	5	171						
25	January 25, 1974	90/SL4 41	5	172						
26	January 26, 1974	91/SL4 42	3	173						
26	January 26, 1974	91/SL4 42	3	174						
26	January 26, 1974	91/SL4 42	5	175	19 53 50	19 54 10	4.4	271.8	3.4	272.6
27	January 27, 1974	92/SL4 44	5	176						
27	January 27, 1974	92/SL4 44	5	177						
27	January 27, 1974	92/SL4 44	5	178						
27	January 27, 1974	92/SL4 44	5	179						
27	January 27, 1974	92/SL4 44	5	180						
27	January 27, 1974	92/SL4 44	5	181						
27	January 27, 1974	92/SL4 44	5	182	12 48 45	12 49 05	32.2	345.8	31.4	346.9
27	January 27, 1974	92/SL4 44	5	183						
27	January 27, 1974	92/SL4 44	3	184						
27	January 27, 1974	93/SL4 44	5	185	19 09 20	19 11 15	10.3	272.0	4.4	276.6
28	January 28, 1974	94/SL4 46	5	186						
28	January 28, 1974	94/SL4 46	5	187						
28	January 28, 1974	94/SL4 46	5	188						
28	January 28, 1974	94/SL4 46	2	189						
28	January 28, 1974	94/SL4 46	2	190						
28	January 28, 1974	94/SL4 46	2	191						
29	January 29, 1974	95/SL4 47	NAL	192						
29	January, 29, 1974	95/SL4 47	5	193						
29	January 29, 1974	95/SL4 47	5	194						
29	January 29, 1974	95/SL4 47	5	195						
29	January 29, 1974	95/SL4 47	RESET	196						

TABLE 7. SKYLAB DATA SUMMARY (Continued)

DOY	DATE	PASS	MODE	MAP	TIME START	TIME STOP	START LAT	START LONG	STOP LAT	STOP LONG
30	January 30, 1974	96/SL4 48	5	197						
30	January 30, 1974	96/SL4 48	5	198						
30	January 30, 1974	96/SL4 48	5	199						
31	January 31, 1974	97/SL4 49	1	200						
31	January 31, 1974	97/SL4 49	1	201	14 55 25	14 58 15	–16.8	335.6	–24.8	343.0
31	January 31, 1974	97/SL4 49	1	202	15 00 25	15 03 20	–30.7	349.3	–38.0	359.5
31	January 31, 1974	97/SL4 49	1	203	15 04 20	15 07 15	–39.5	2.9	–45.2	15.2
31	January 31, 1974	97/SL4 49	1	204	15 08 05	15 11 10	–46.7	19.8	–49.5	34.9
31	January 31, 1974	97/SL4 49	1	205	15 11 55	15 14 15	–50.1	41.0	–49.9	54.5
31	January 31, 1974	97/SL4 49	1	206	15 15 40	15 18 35	–49.1	61.9	–45.7	76.6
31	January 31, 1974	97/SL4 49	1	207	15 22 10	15 25 00	–38.5	92.7	–31.7	102.5
31	January 31, 1974	97/SL4 49	1	208	15 25 50	15 28 45	–29.3	105.3	–21.1	113.7
31	January 31, 1974	97/SL4 49	1	209	15 29 45	15 32 30	–18.1	116.4	–11.3	122.0
31	January 31, 1974	97/SL4 49	1	210	15 33 20	15 36 10	– 8.1	124.5	– 0.2	130.5
31	January 31, 1974	97/SL4 49	1	211	15 37 10	15 40 05	3.3	133.1	11.2	139.2
31	January 31, 1974	97/SL4 49	1	212	15 41 00	15 44 00	14.4	141.7	22.5	148.8
31	January 31, 1974	97/SL4 49	1	213	15 44 40	15 47 30	24.5	150.8	32.0	159.2
31	January 31, 1974	97/SL4 49	1	214	15 48 30	15 51 25	34.7	162.8	41.1	173.3
31	January 31, 1974	97/SL4 49	5	215	15 52 35	15 55 30	43.4	178.5	47.7	192.1
31	January 31, 1974	97/SL4 49	5	216	15 56 25	15 58 25	48.8	197.3	50.0	208.5
31	January 31, 1974	97/SL4 49	5	217	15 59 40	16 01 40	50.2	216.4	49.5	226.8
31	January 31, 1974	97/SL4 49	1	218	16 02 55	16 03 15	48.5	233.7	48.1	235.4
31	January 31, 1974	97/SL4 49	1	219						
31	January 31, 1974	97/SL4 49	1	220						
31	January 31, 1974	97/SL4 49	1	221						
31	January 31, 1974	97/SL4 49	5	222	16 12 25	16 13 40	29.4	273.3	25.4	277.7
31	January 31, 1974	97/SL4 49	1	223	16 14 15	16 14 50	24.9	278.1	23.6	279.5
31	January 31, 1974	97/SL4 49	1	224						
31	January 31, 1974	97/SL4 49	1	225	16 16 25	16 17 30	18.9	283.8	16.0	286.3
31	January 31, 1974	97/SL4 49	1	226	16 18 00	16 19 00	14.4	287.7	11.4	290.0
32	February 1, 1974	98/SL4 50	1	227						
32	February 1, 1974	98/SL4 49	1	228						
32	February 1, 1974	98/SL4 50	5	229						
32	February 1, 1974	98/SL4 49	2	230						

TABLE 7. SKYLAB DATA SUMMARY (Continued)

DOY	DATE	PASS	MODE	MAP	TIME START	TIME STOP	START LAT	START LONG	STOP LAT	STOP LONG
20	January 20, 1974	86/SL4 32	5	233	19 18 15	19 20 10	34.7	285.7	30.0	291.7

TABLE 7. SKYLAB DATA SUMMARY (Continued)

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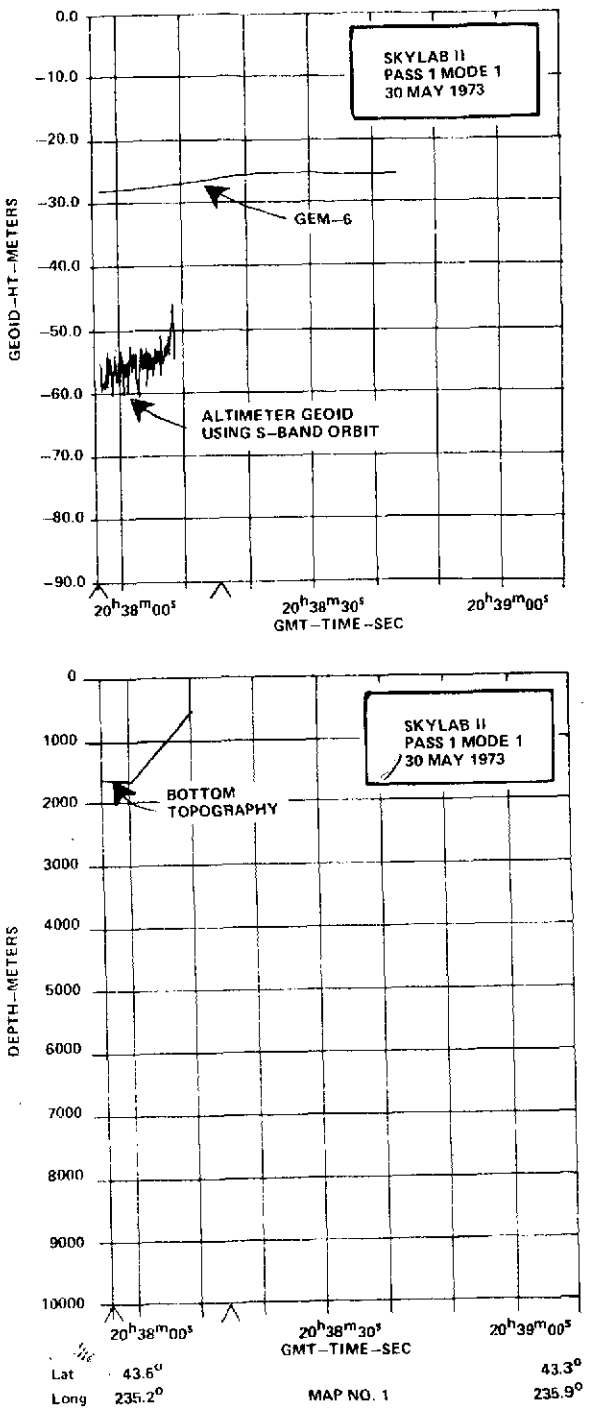
ORIGINAL PAGE IS
OF POOR QUALITY

RESIDUALS AND BOTTOM TOPOGRAPHY

This section contains plots of the residuals (altimeter derived geoid which is computed minus observed height above the referenced ellipsoid) for each SKYLAB pass reduced. These plots represent raw data at the 8 sample per second rate. Also, on the same plot for passes over water, the GEM-6 [8] geoid is supplied for comparison. Finally, a plot of the ocean bottom topography profile is displayed so that one might compare the correlation between the topographic features and the high frequency geoid undulations. The plots were digitized from unclassified ocean bottom contour maps obtained from the Defense Mapping Agency, the Naval Oceanographic Office, and the National Science Foundation. The contours were sampled approximately every 15 km along the subsatellite trace. Where no bottom topography is given one can assume that these are land passes or that ocean bottom contour maps were not available. In the over land cases, the heights are given above mean sea level and are not geoid heights.

It should be noted that latitudes and longitudes are labeled for two specific times on each residual plot. These are denoted with an arrow (Λ) immediately above the time of interest. In reviewing these plots, an occasional drop-out of the altitude residuals will be noted. These are due to loss of track, and on SL-2 and SL-3 usually occur over land areas. During SL-4, these losses were common even over the open ocean for an antenna problem caused the operating signal to noise to be marginal. In addition, when the altitude jitter increases, one should be aware that a pointing problem is the likely cause and therefore the absolute bias and even the trends in these passes will be questionable.



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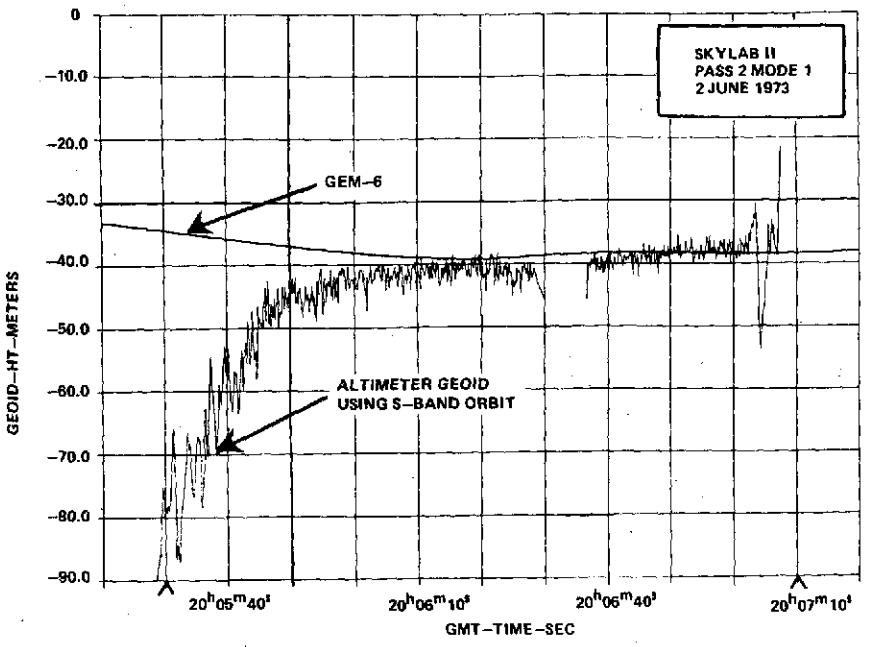
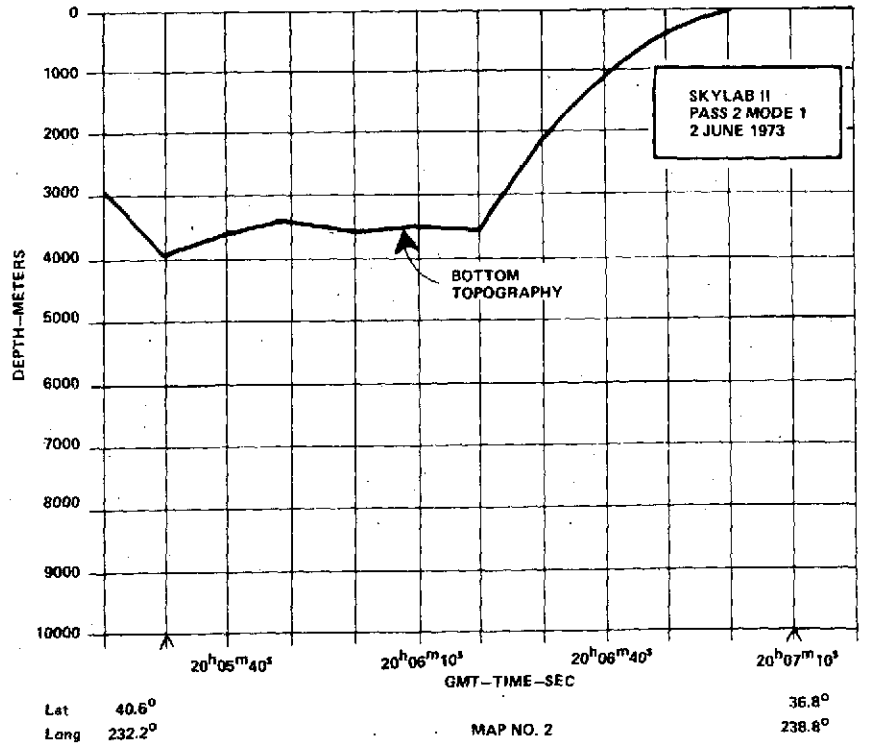
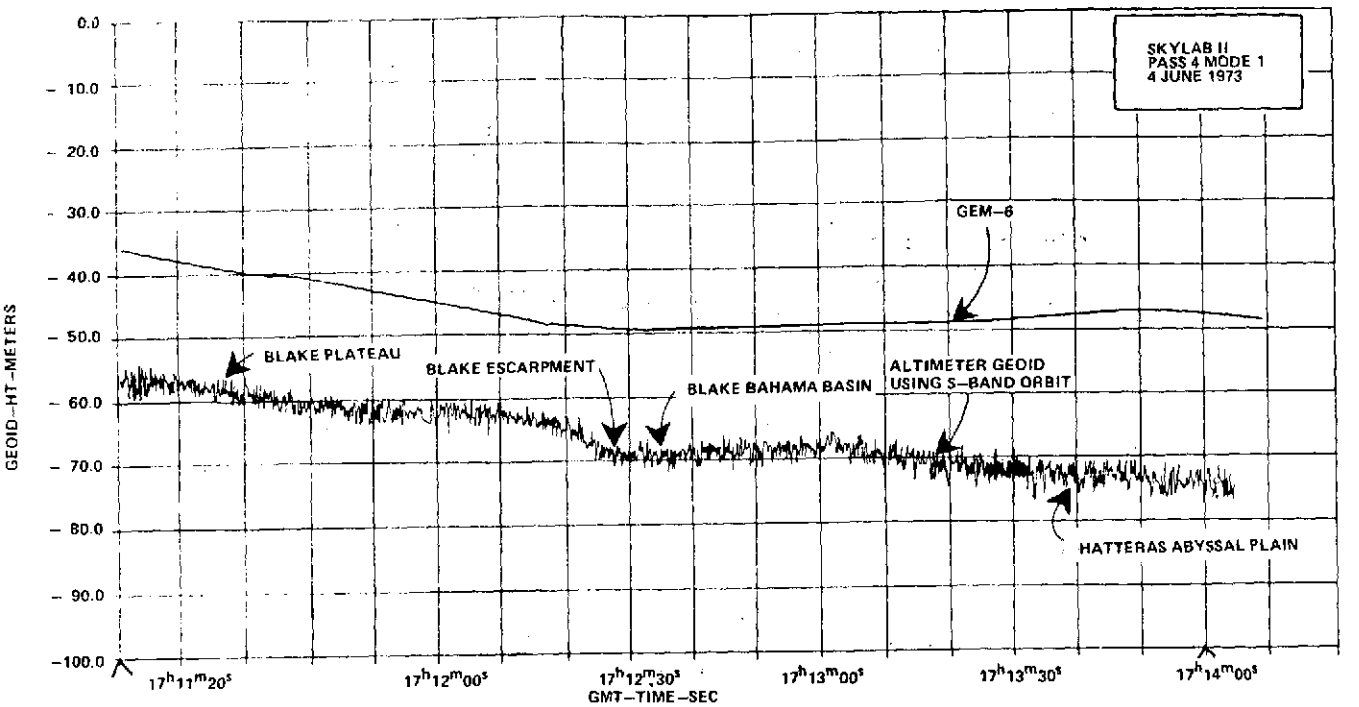
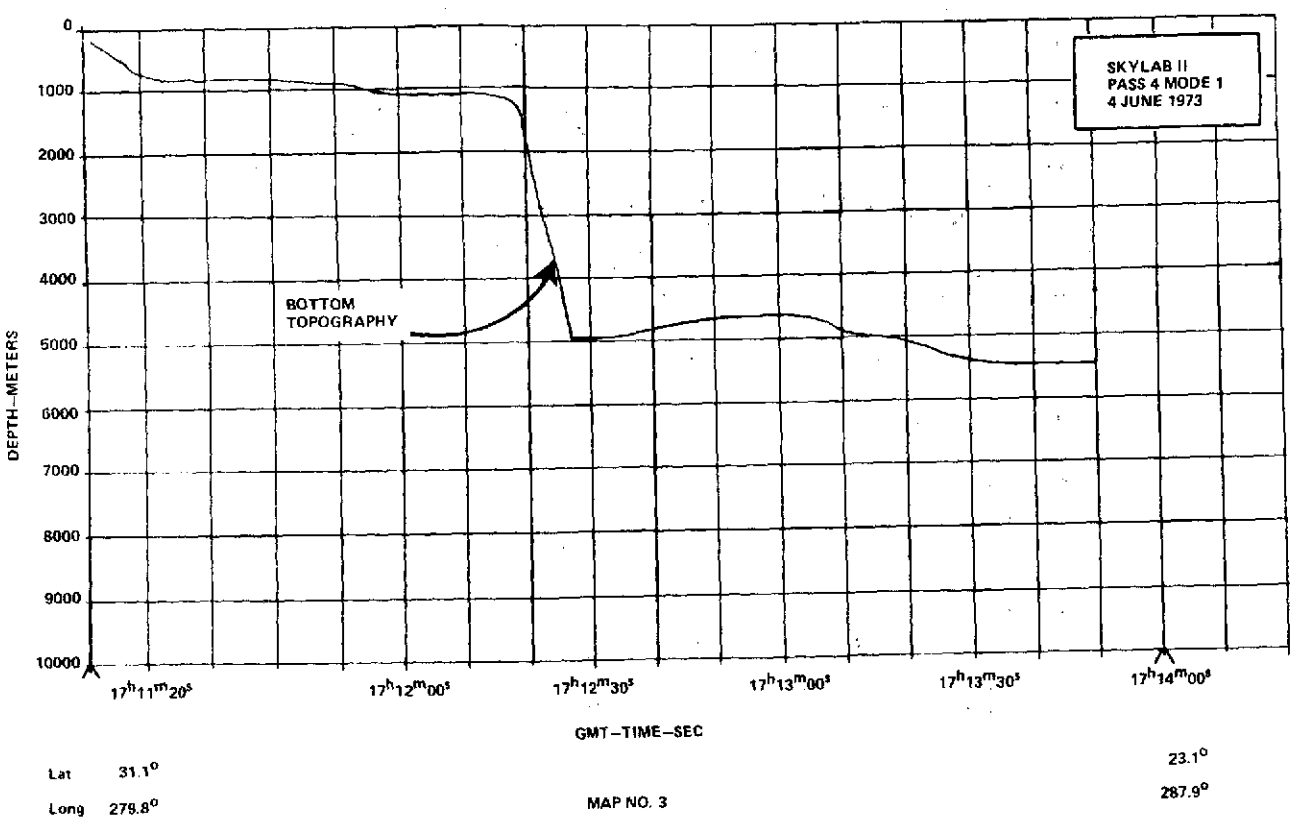




Lat 40.6° 36.8°
Long 232.2° 238.8°

MAP NO. 2





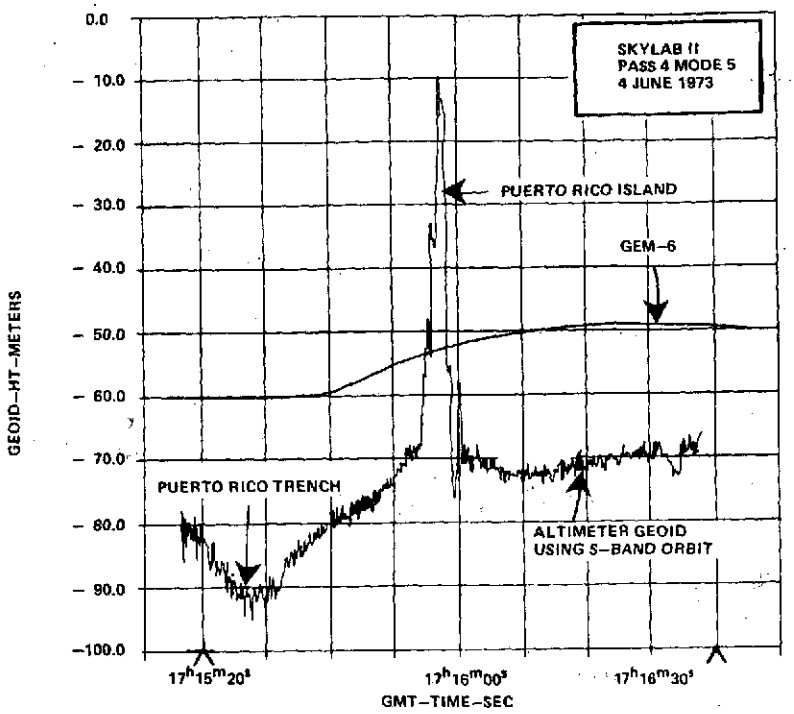
Lat 31.1°

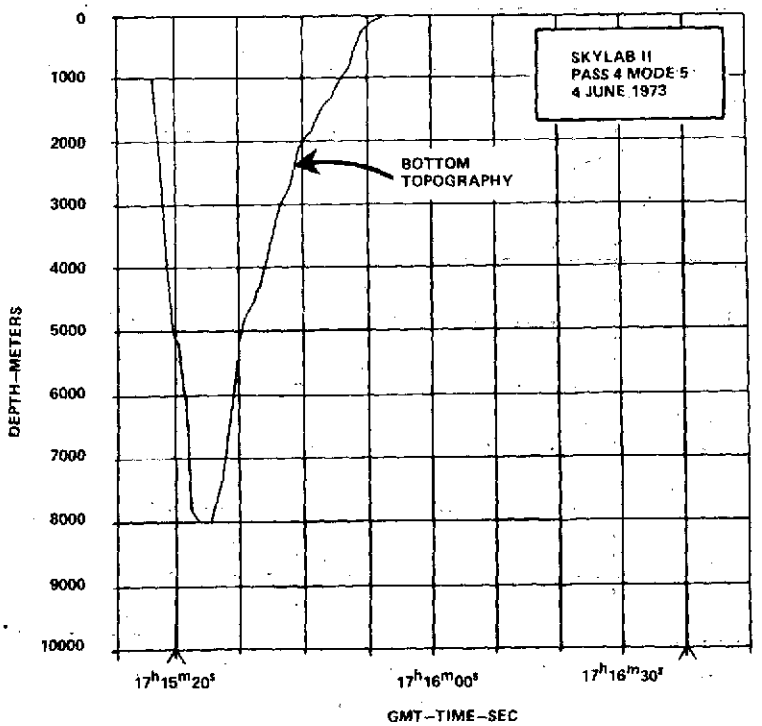
Long 279.8°

MAP NO. 3

23.1°

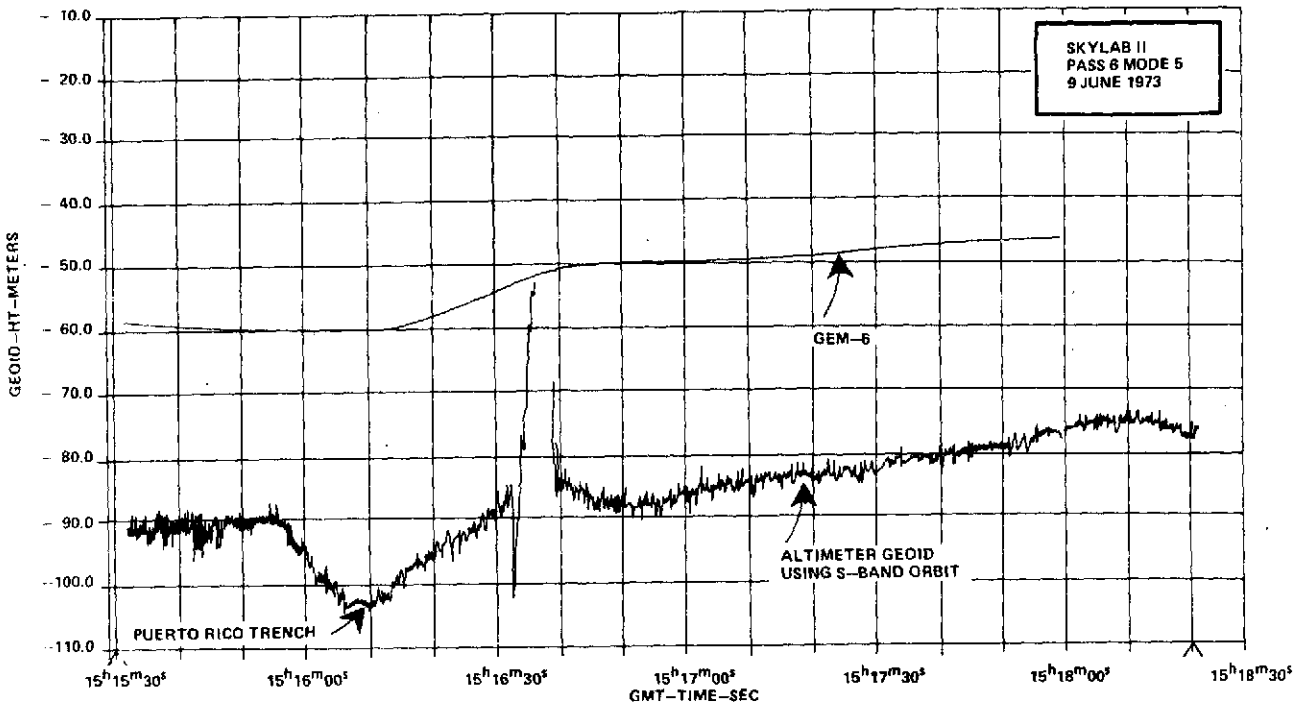
287.9°

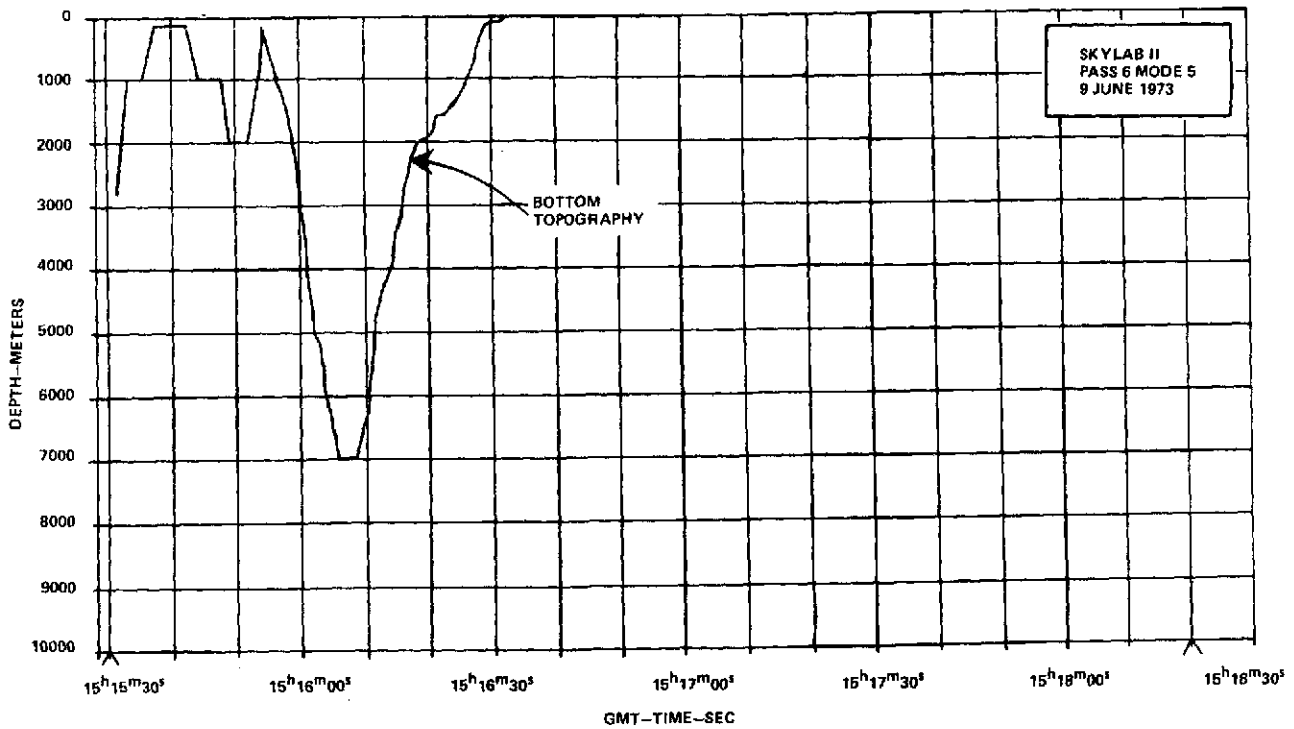




Lat 19.8° 16.0°

Long 291.4° MAP NO. 4 294.7°

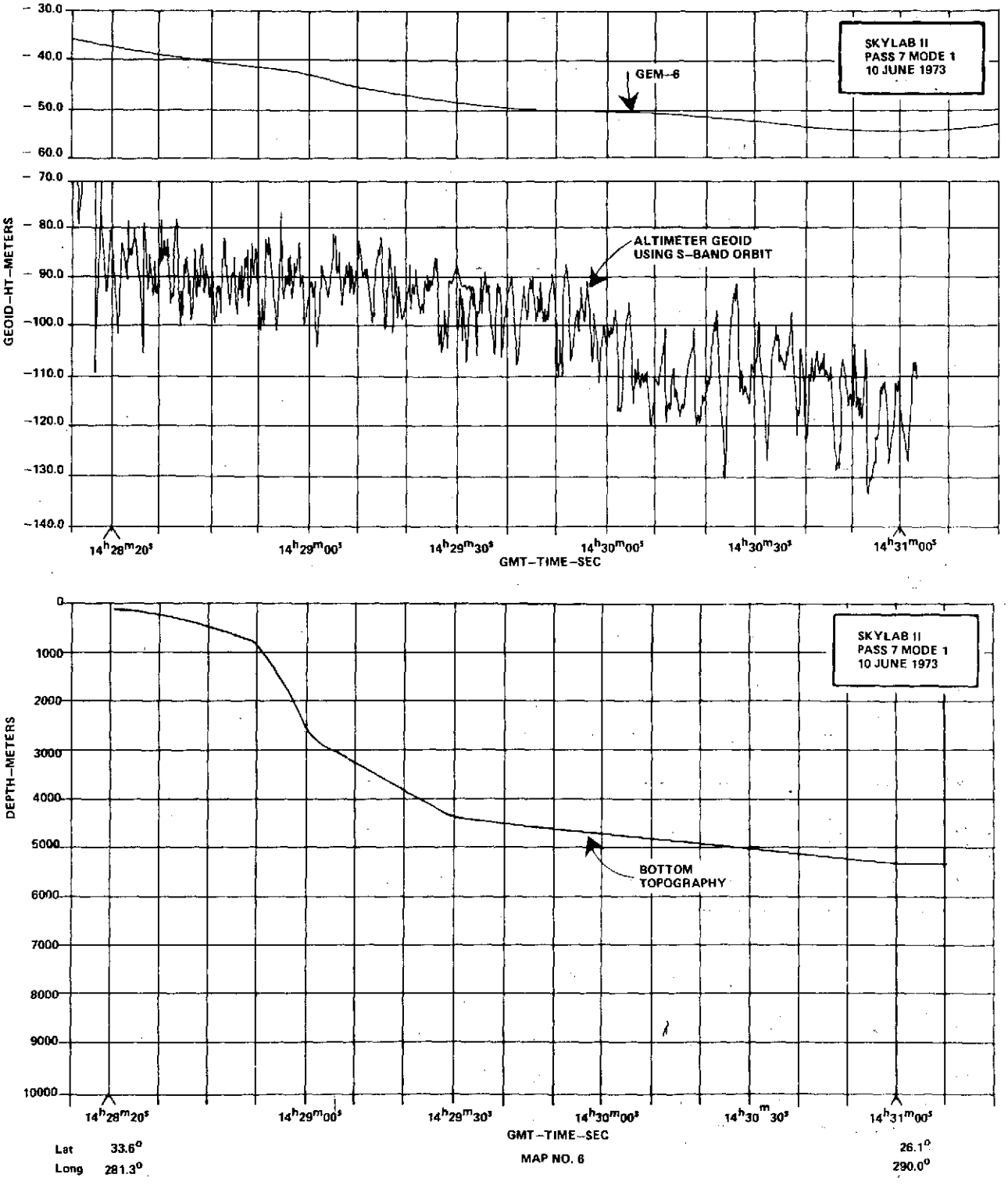


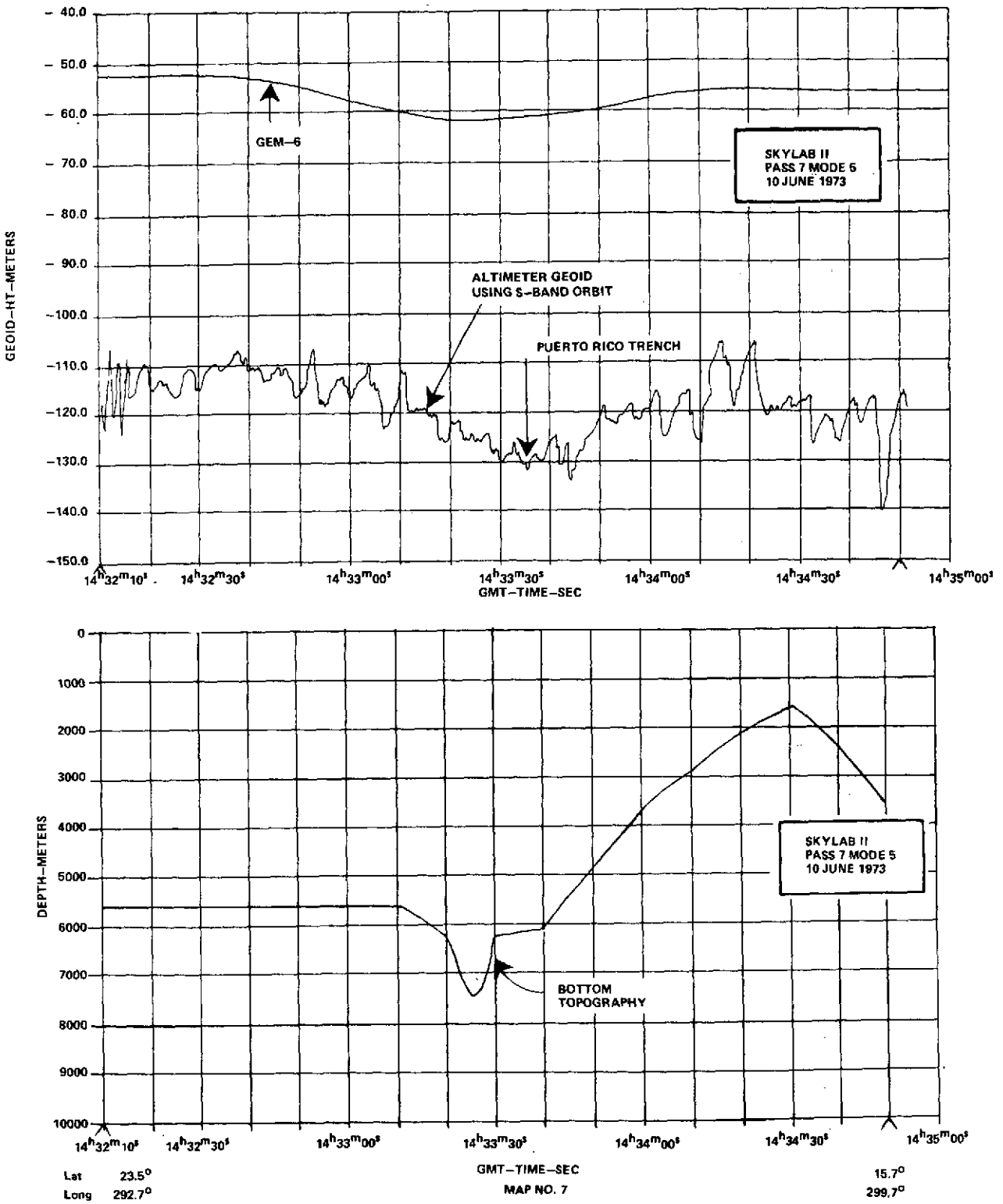


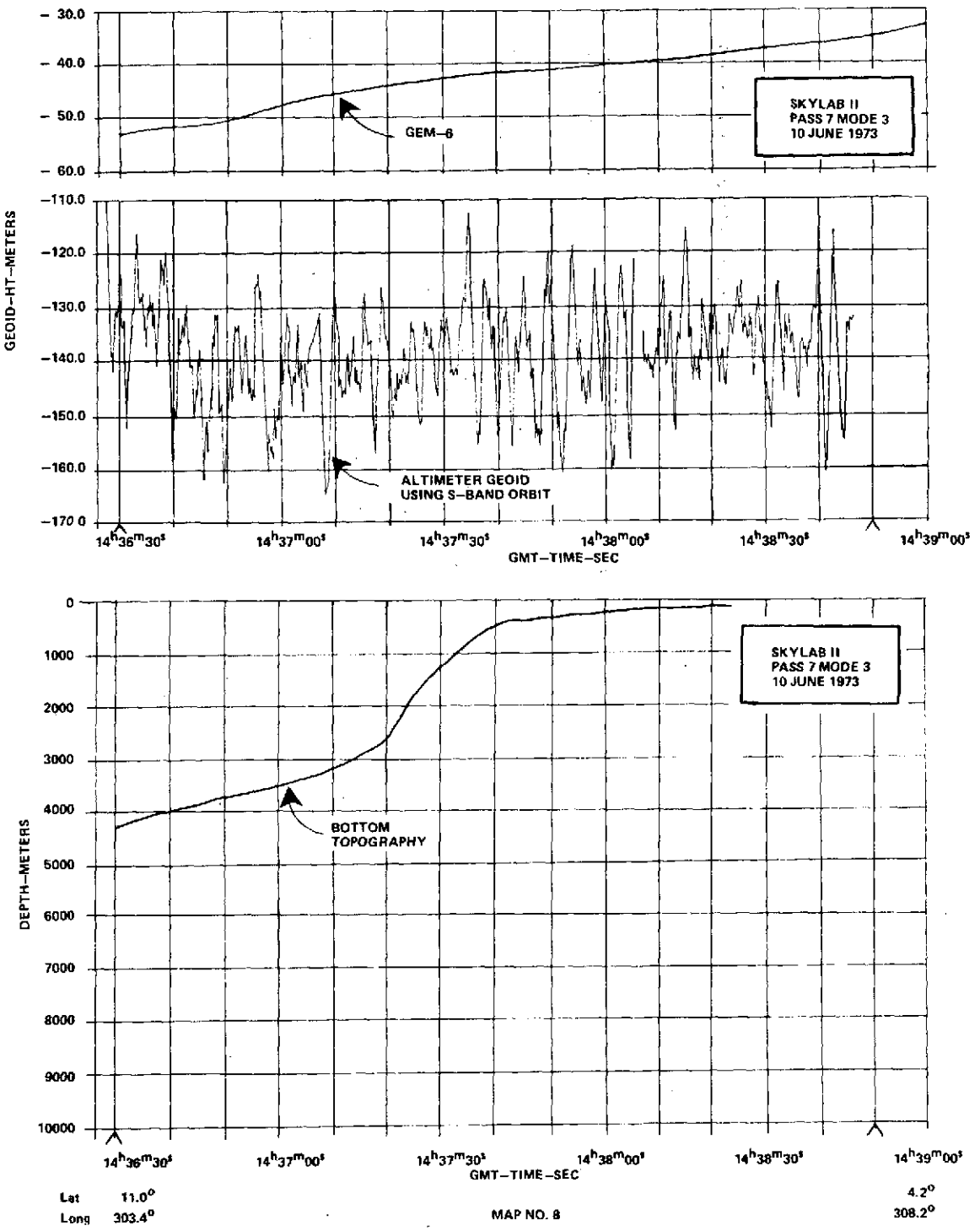
Lat 21.2° 13.6°

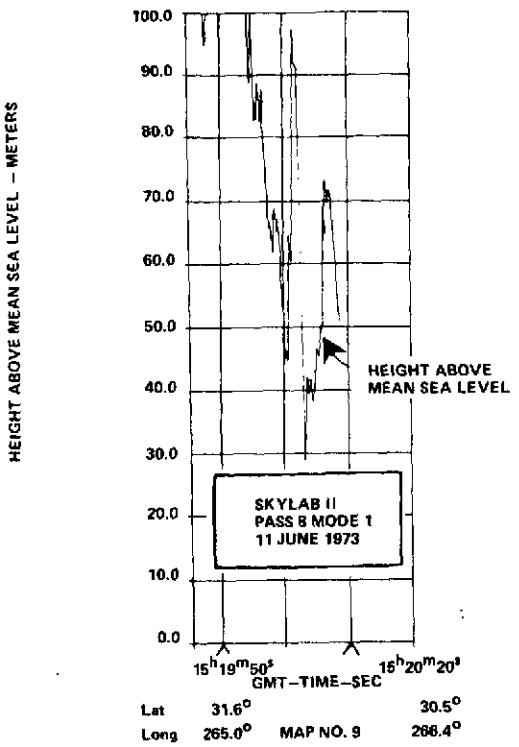
Long 290.2° 297.5°

MAP NO. 5


SKYLAB II
PASS 7 MODE 1
10 JUNE 1973
GEM-6
ALTIMETER GEOID
USING S-BAND ORBIT
GEOID-HT-METERS
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
-120.0
-130.0
-140.0
14h28m20s
14h29m00s
14h29m30s
14h30m00s
14h30m30s
14h31m00s
GMT-TIME-SEC
SKYLAB II
PASS 7 MODE 1
10 JUNE 1973
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
14h28m20s
14h29m00s
14h29m30s
14h30m00s
14h30m30s
14h31m00s
GMT-TIME-SEC
Lat 33.6°
Long 281.3°
MAP NO. 6
26.1°
290.0°


GEOID–HT–METERS
– 40.0
– 50.0
– 60.0
– 70.0
– 80.0
– 90.0
–100.0
–110.0
–120.0
–130.0
–140.0
–150.0
GEM–6
SKYLAB II
PASS 7 MODE 5
10 JUNE 1973
ALTIMETER GEOID
USING S–BAND ORBIT
PUERTO RICO TRENCH
14h32m10s
14h32m30s
14h33m00s
14h33m30s
14h34m00s
14h34m30s
14h35m00s
GMT–TIME–SEC
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
SKYLAB II
PASS 7 MODE 5
10 JUNE 1973
BOTTOM
TOPOGRAPHY
14h32m10s
14h32m30s
14h33m00s
14h33m30s
14h34m00s
14h34m30s
14h35m00s
GMT–TIME–SEC
Lat 23.5°
Long 292.7°
15.7°
299.7°
MAP NO. 7


– 30.0
– 40.0
– 50.0
– 60.0
GEM–6
SKYLAB II
PASS 7 MODE 3
10 JUNE 1973
–110.0
–120.0
–130.0
–140.0
–150.0
–160.0
–170.0
GEOID–HT–METERS
ALTIMETER GEOID
USING S–BAND ORBIT
14h36m30s
14h37m00s
14h37m30s
14h38m00s
14h38m30s
14h39m00s
GMT–TIME–SEC
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
DEPTH–METERS
SKYLAB II
PASS 7 MODE 3
10 JUNE 1973
BOTTOM
TOPOGRAPHY
14h36m30s
14h37m00s
14h37m30s
14h38m00s
14h38m30s
14h39m00s
GMT–TIME–SEC
Lat 11.0°
Long 303.4°
MAP NO. 8
4.2°
308.2°



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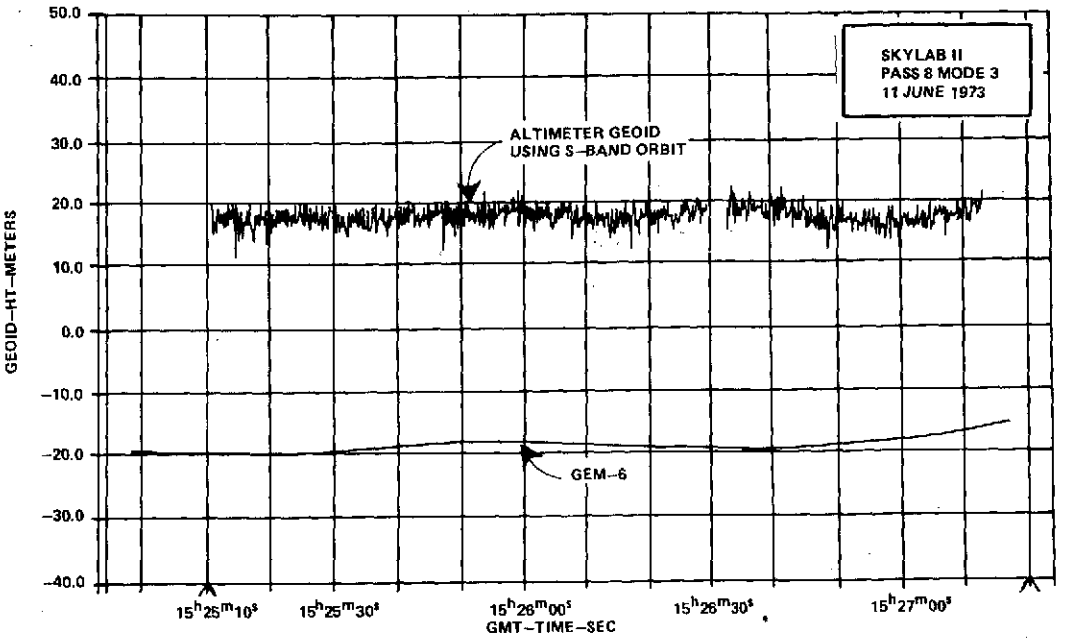
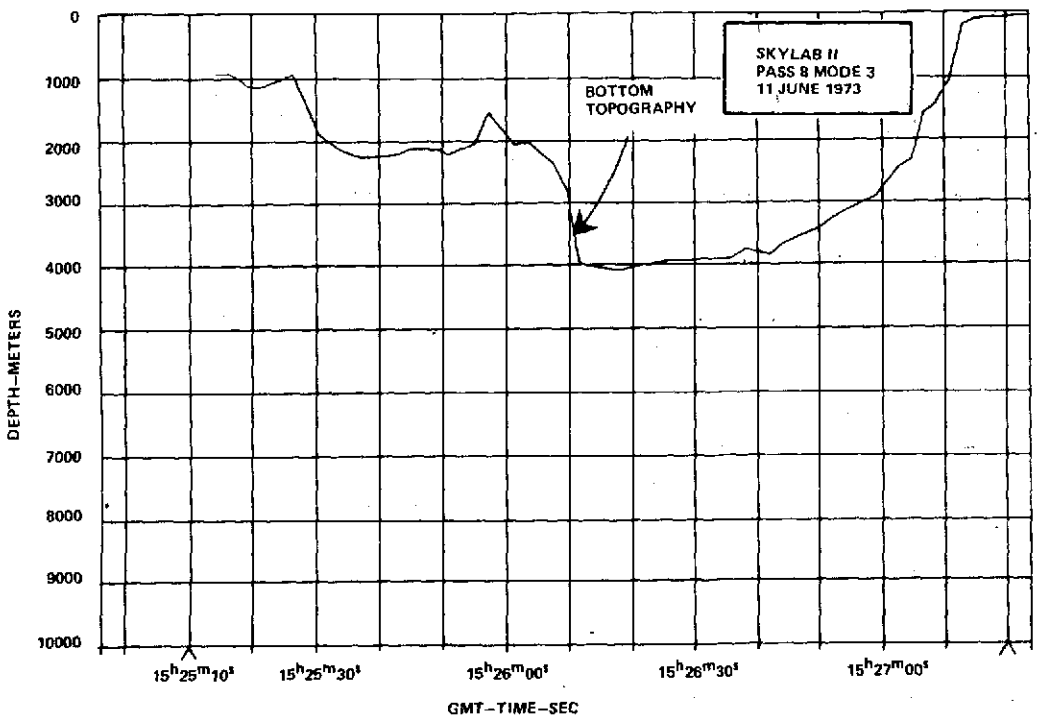
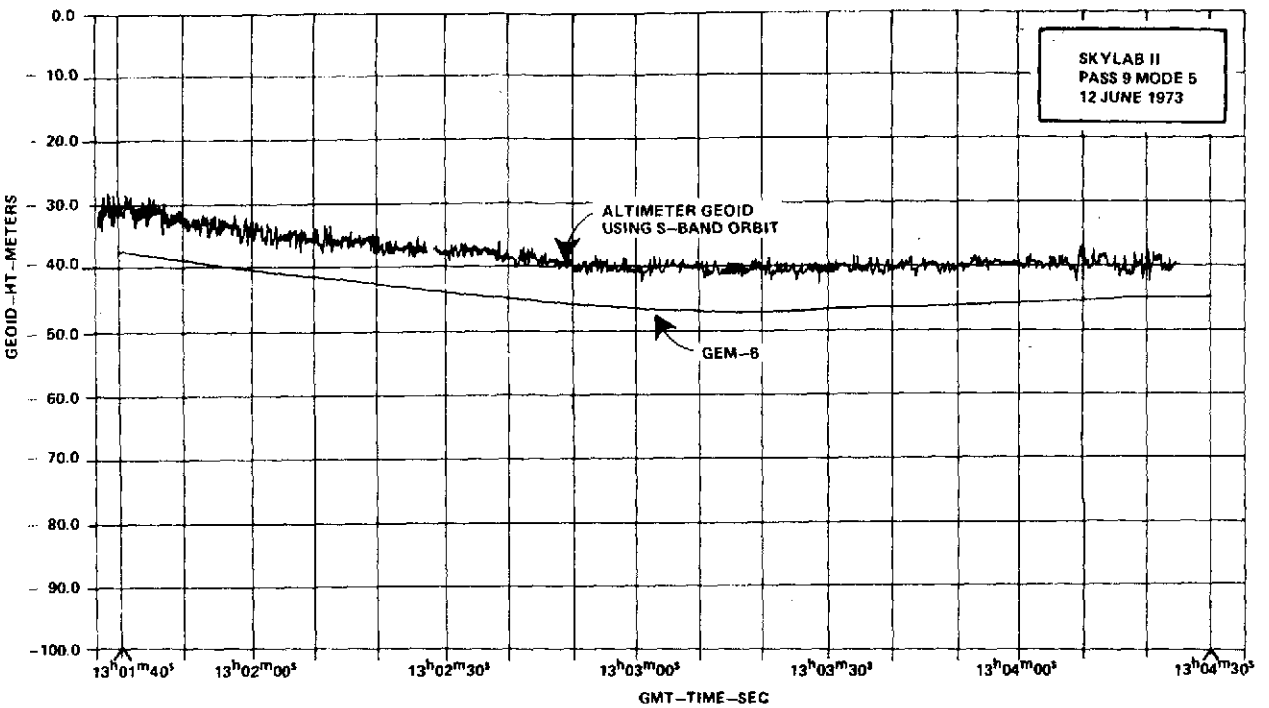
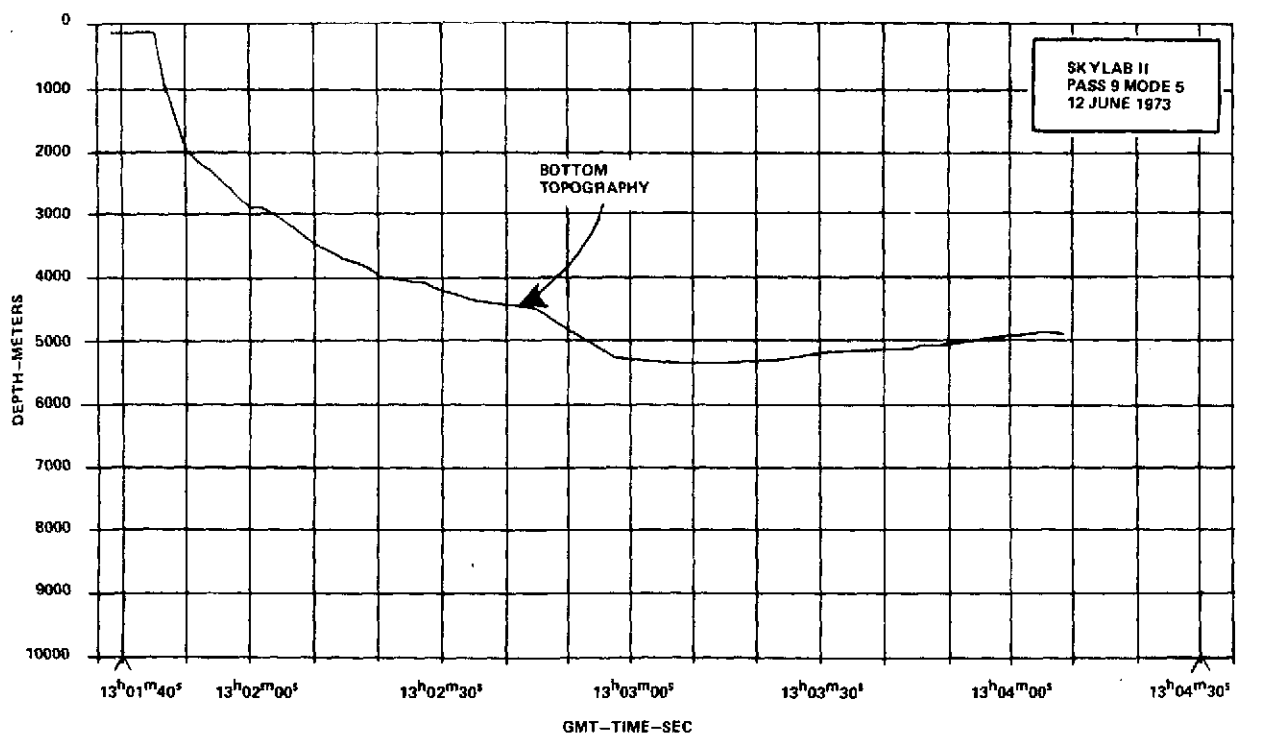




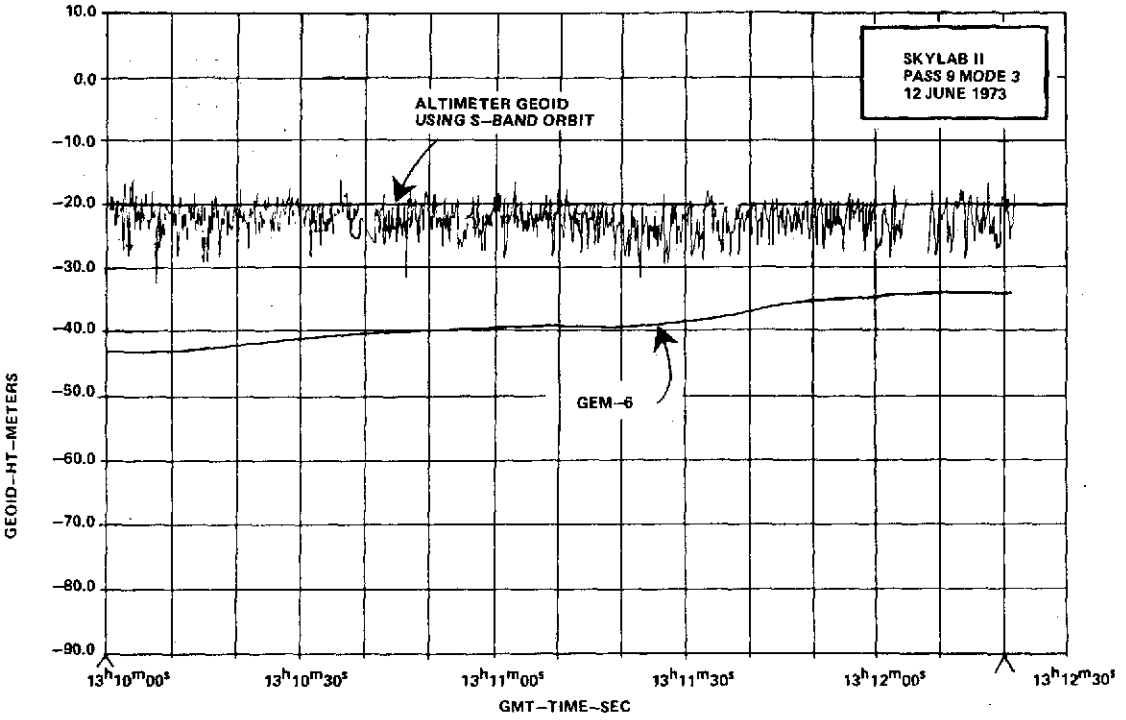
Lat 16.8° 10.5°

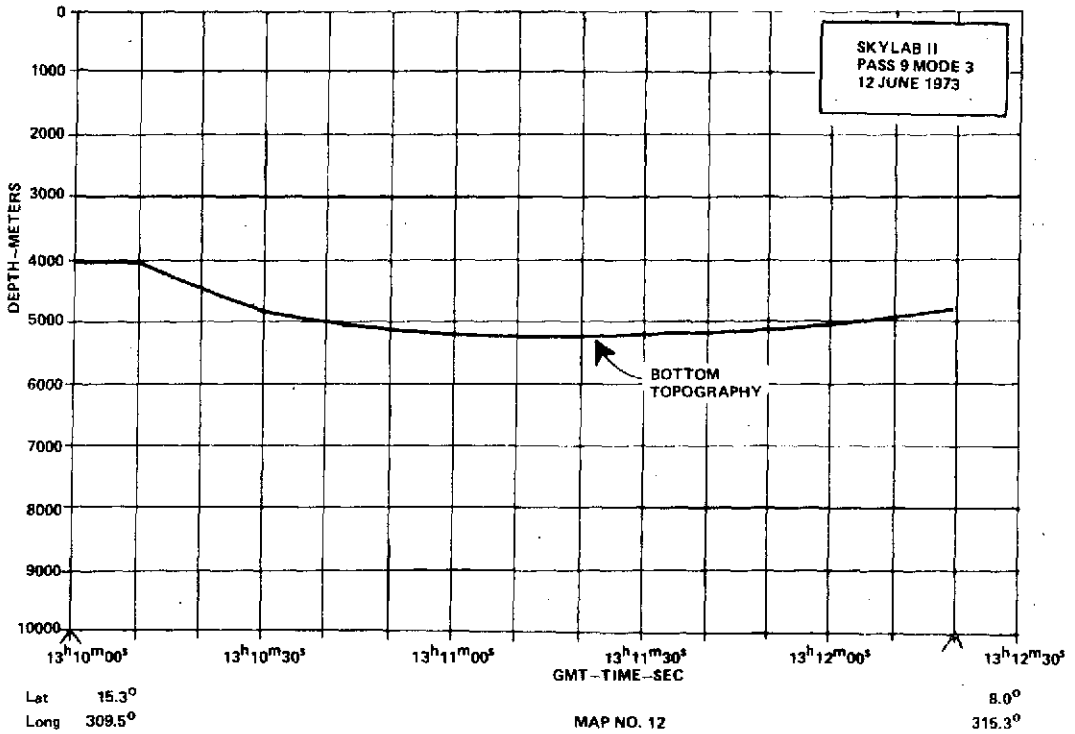
Long 279.8° MAP NO. 10 284.9°

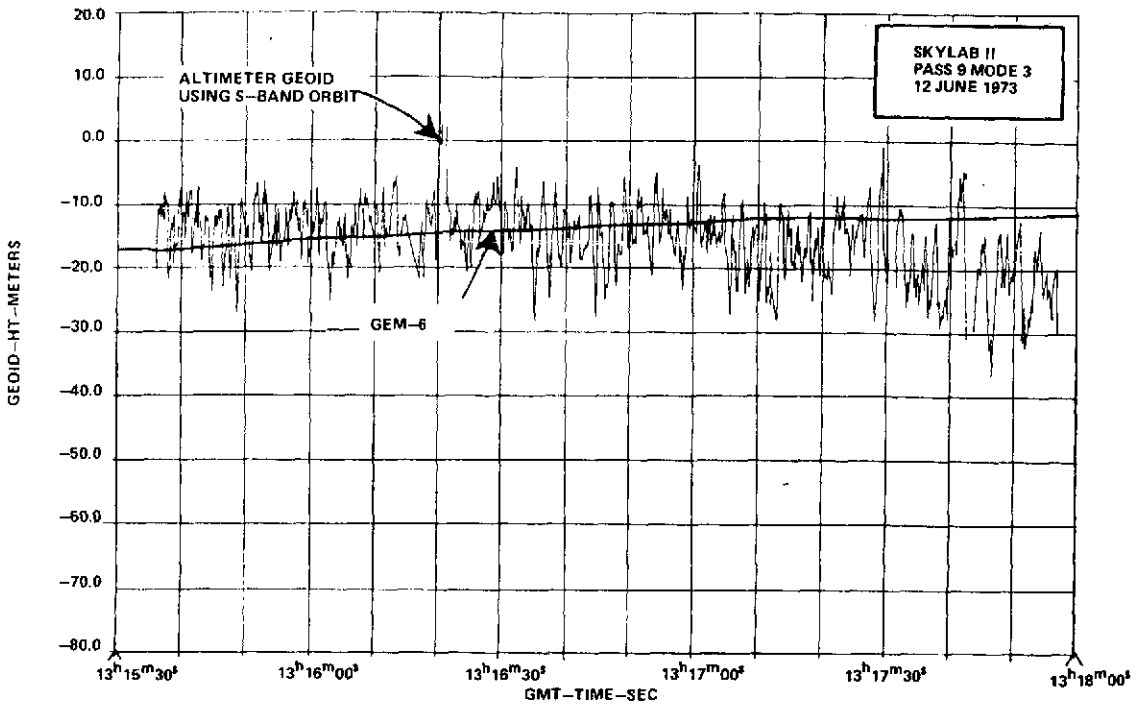


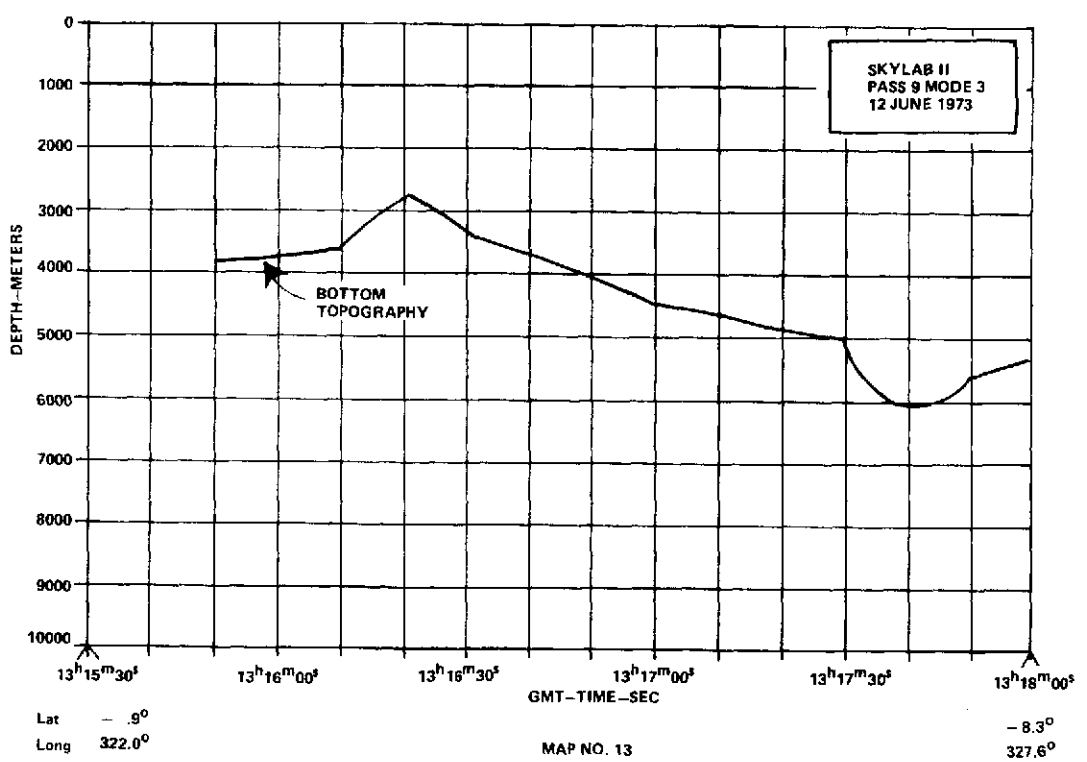


Lat	37.5°		30.5°
Long	285.1°	MAP NO. 11	294.7°


SKYLAB II
PASS 9 MODE 3
12 JUNE 1973
ALTIMETER GEOID
USING S-BAND ORBIT
GEM-6
GEOID-HT-METERS
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
13h10m00s
13h10m30s
13h11m00s
13h11m30s
13h12m00s
13h12m30s
GMT-TIME-SEC

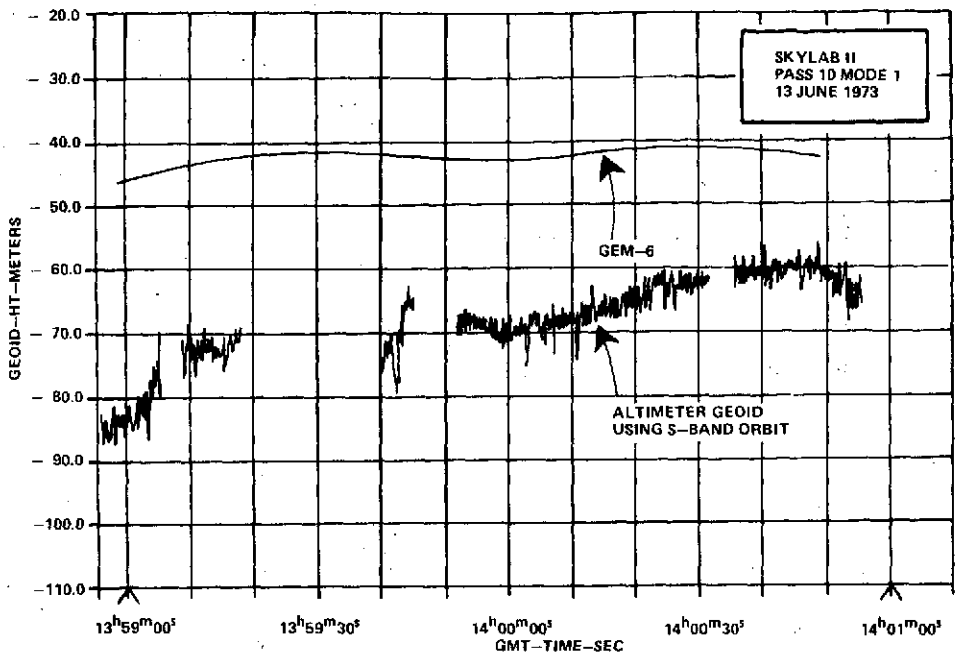

SKYLAB II
PASS 9 MODE 3
12 JUNE 1973
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
13h10m00s
13h10m30s
13h11m00s
13h11m30s
13h12m00s
13h12m30s
GMT-TIME-SEC
Lat 15.3°
Long 309.5°
MAP NO. 12
8.0°
315.3°

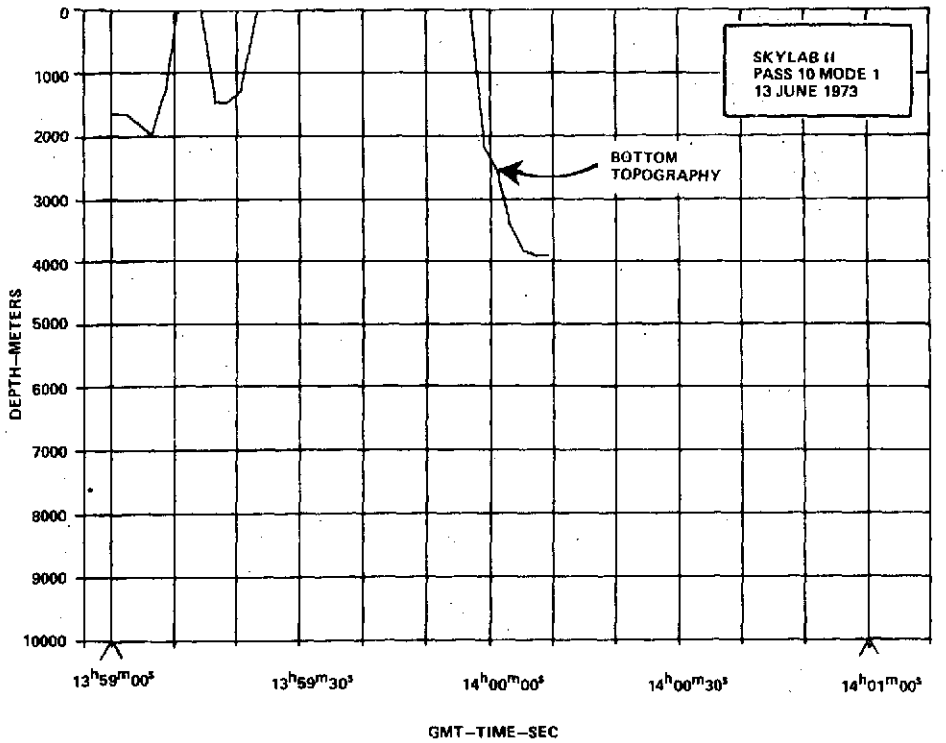

SKYLAB II
PASS 9 MODE 3
12 JUNE 1973
ALTIMETER GEOID
USING S–BAND ORBIT
GEM–6
GEOID–HT–METERS
20.0
10.0
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
–60.0
–70.0
–80.0
13h15m30s
13h16m00s
13h16m30s
13h17m00s
13h17m30s
13h18m00s
GMT–TIME–SEC


SKYLAB II
PASS 9 MODE 3
12 JUNE 1973
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
13h15m30s
13h16m00s
13h16m30s
13h17m00s
13h17m30s
13h18m00s
GMT–TIME–SEC
Lat – .9°
Long 322.0°
– 8.3°
327.6°

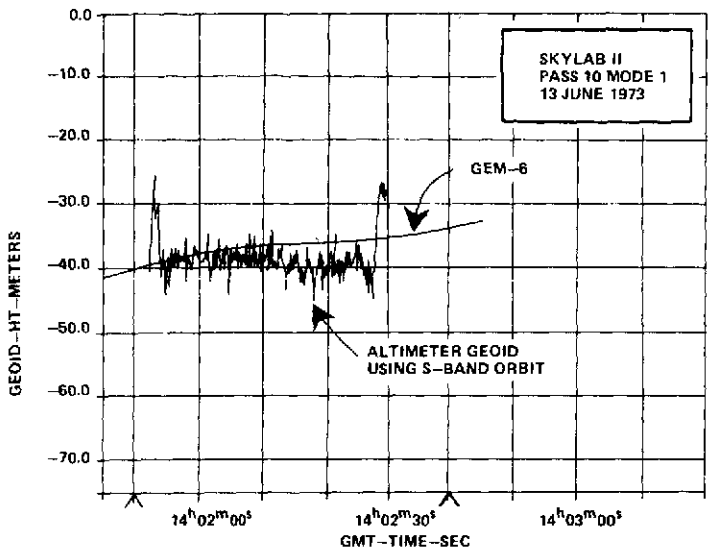
MAP NO. 13

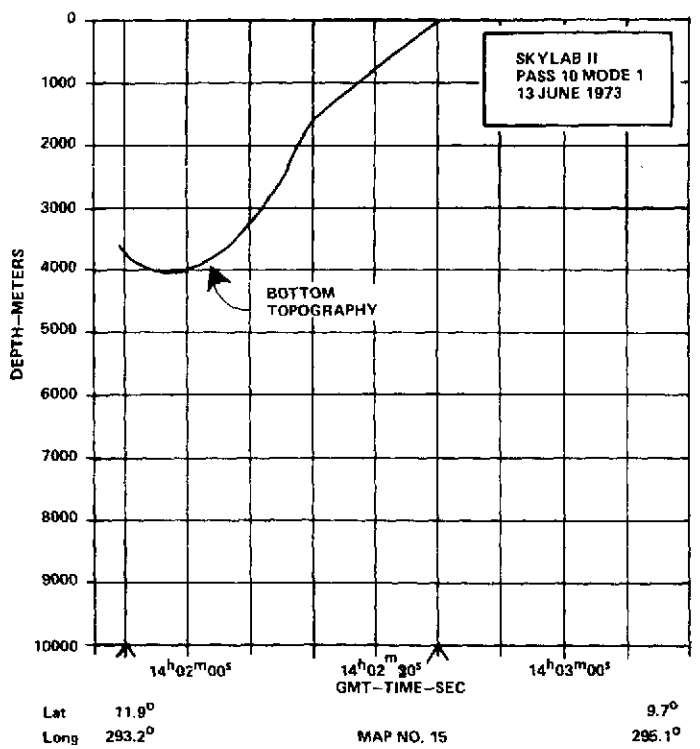
C 12



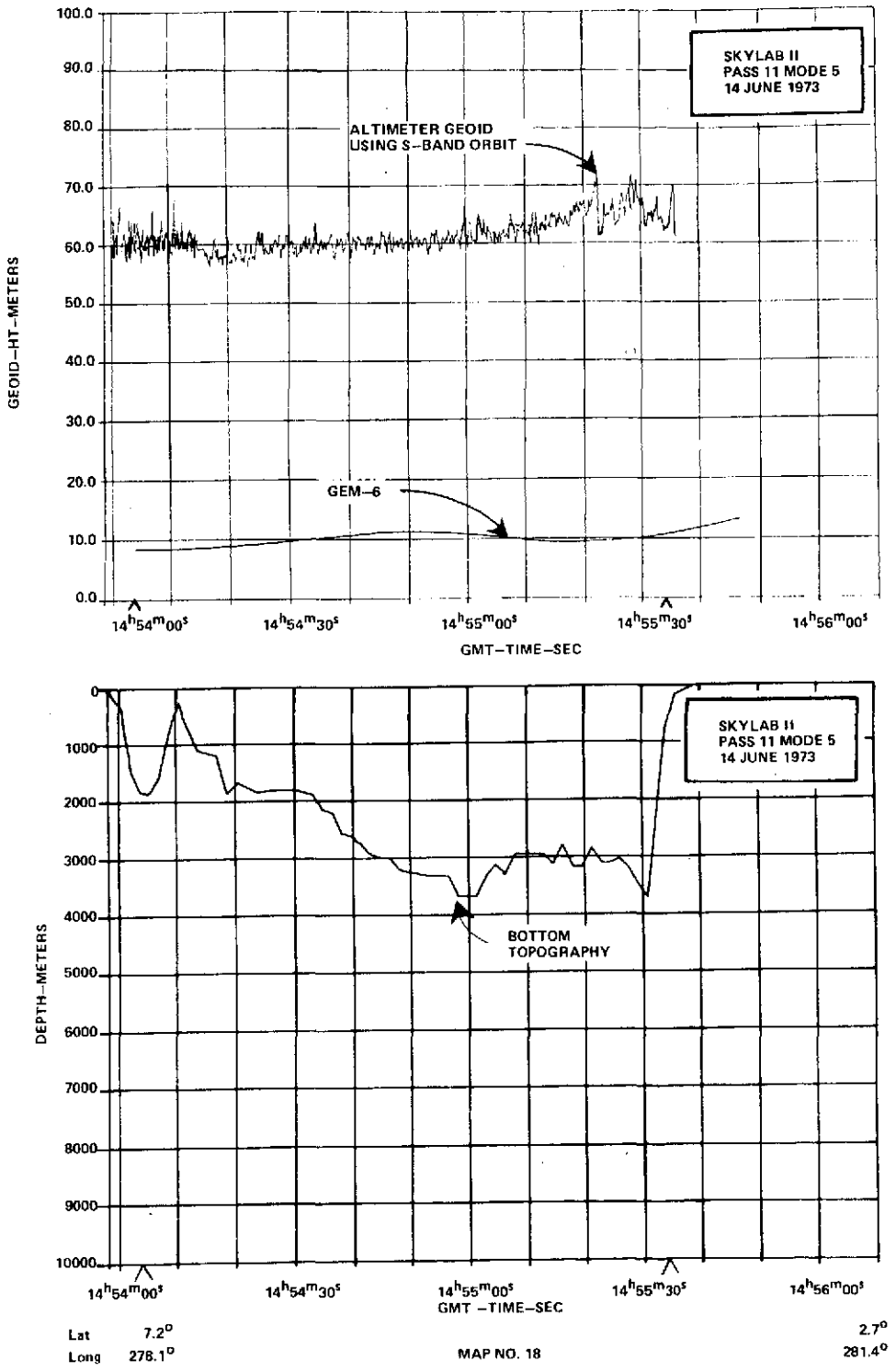


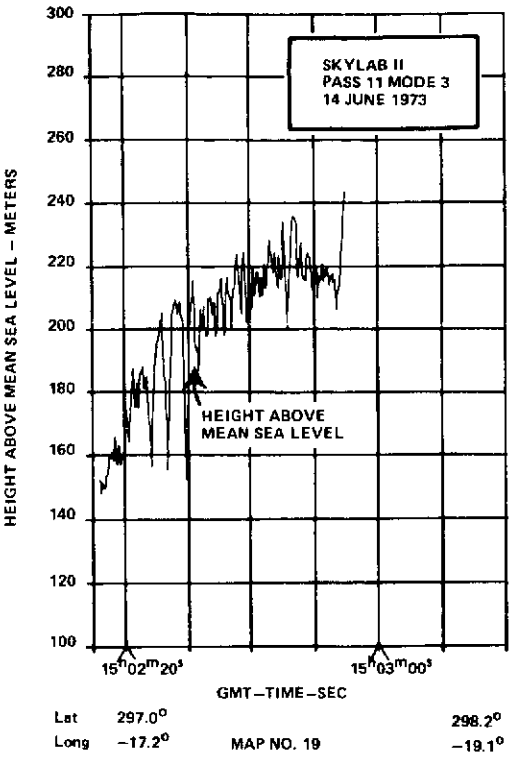
Lat	20.3°		17.2°
Long	286.3°	MAP NO. 14	291.2°

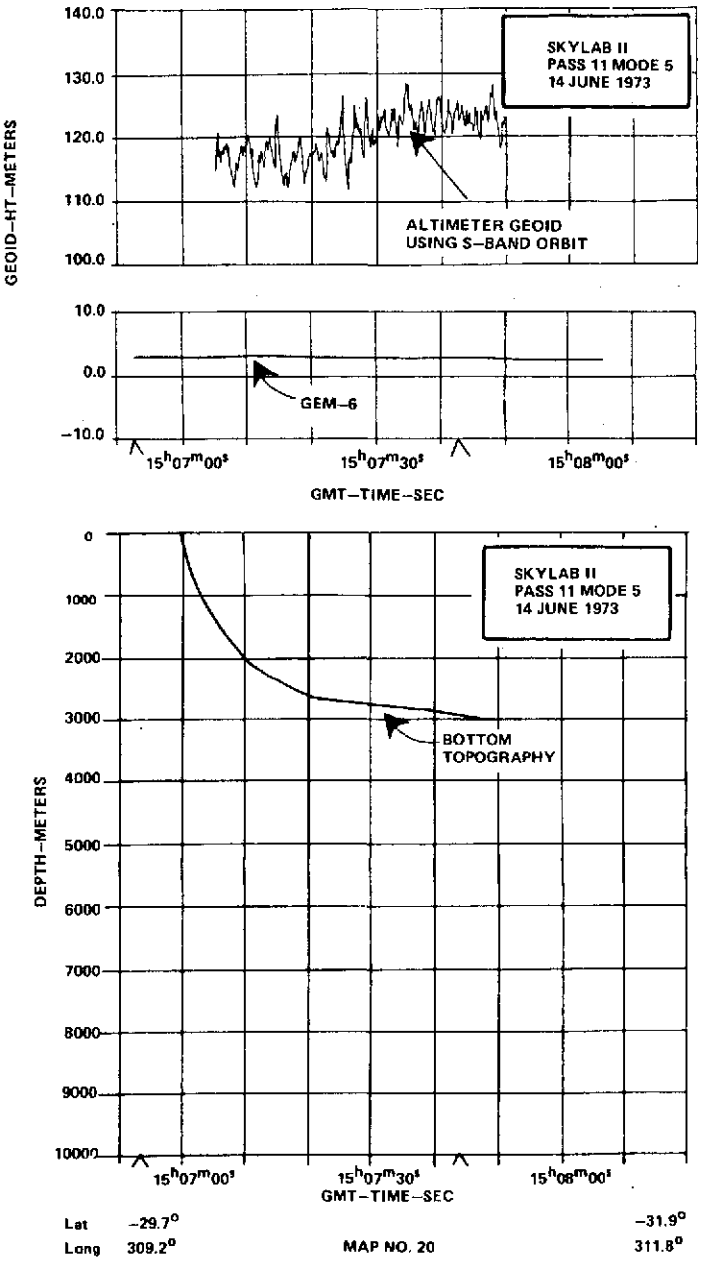


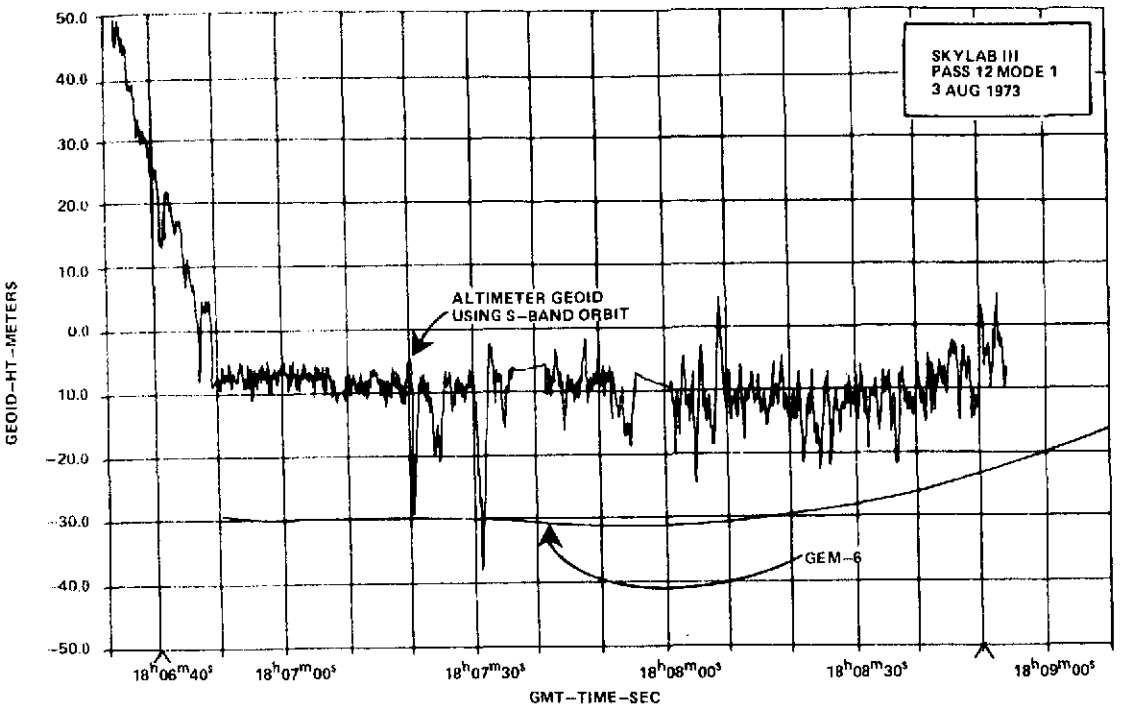


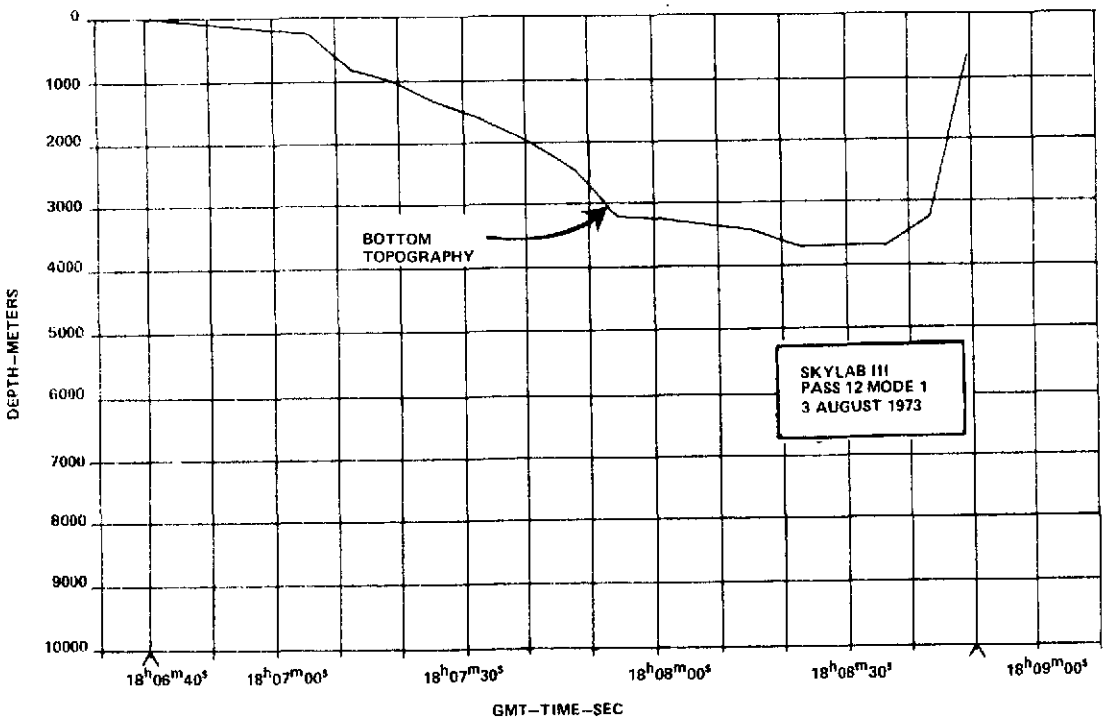
Lat 11.9° 9.7°
Long 293.2° MAP NO. 15 295.1°


SKYLAB II
PASS 11 MODE 5
14 JUNE 1973
ALTIMETER GEOID
USING S-BAND ORBIT
GEM-6
GEOID-HT-METERS
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
14h54m00s
14h54m30s
14h55m00s
14h55m30s
14h56m00s
GMT-TIME-SEC
SKYLAB II
PASS 11 MODE 5
14 JUNE 1973
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
14h54m00s
14h54m30s
14h55m00s
14h55m30s
14h56m00s
GMT -TIME-SEC
Lat 7.2°
Long 278.1°
2.7°
281.4°
MAP NO. 18


SKYLAB II
PASS 11 MODE 3
14 JUNE 1973
HEIGHT ABOVE MEAN SEA LEVEL – METERS
300
280
260
240
220
200
180
160
140
120
100
HEIGHT ABOVE
MEAN SEA LEVEL
15h02m20s
15h03m00s
GMT–TIME–SEC
Lat 297.0° 298.2°
Long –17.2° MAP NO. 19 –19.1°


SKYLAB II
PASS 11 MODE 5
14 JUNE 1973
ALTIMETER GEOID
USING S-BAND ORBIT
GEOID-HT-METERS
140.0
130.0
120.0
110.0
100.0
10.0
0.0
-10.0
GEM-6
15h07m00s
15h07m30s
15h08m00s
GMT-TIME-SEC
SKYLAB II
PASS 11 MODE 5
14 JUNE 1973
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
15h07m00s
15h07m30s
15h08m00s
GMT-TIME-SEC
Lat -29.7°
Long 309.2°
MAP NO. 20
-31.9°
311.8°

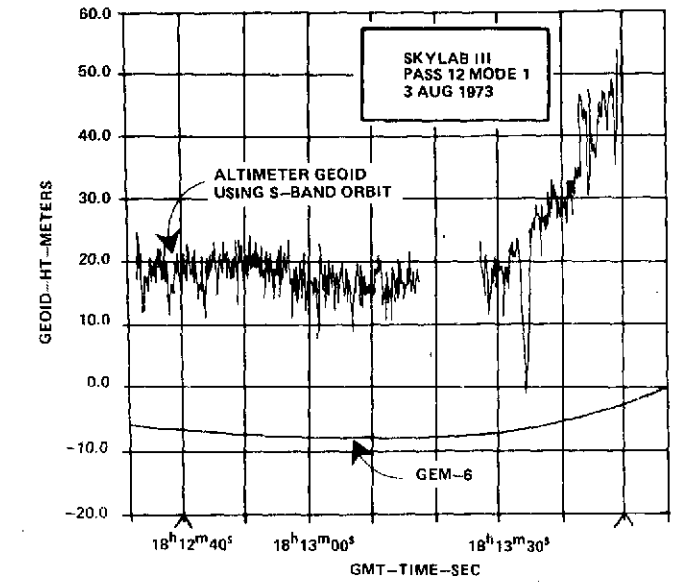


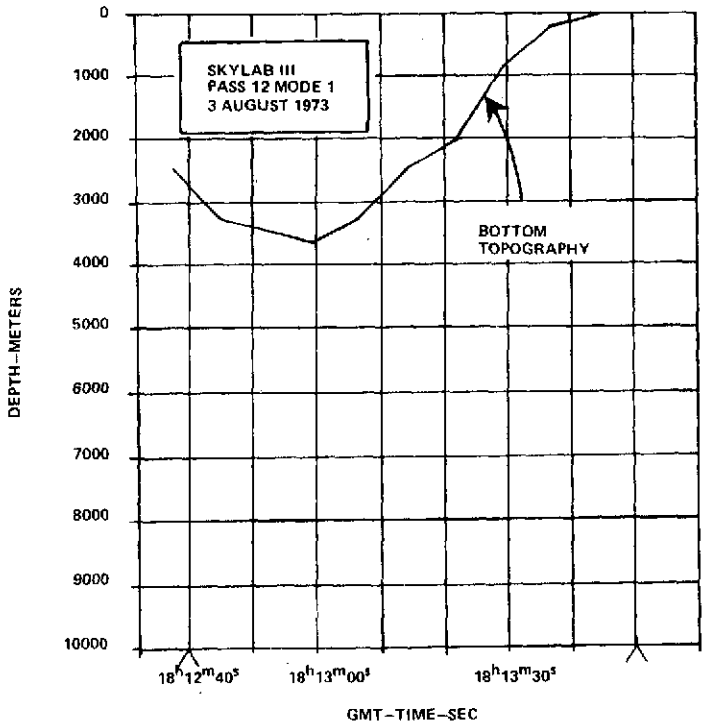


Lat 29.1°
Long 264.0°

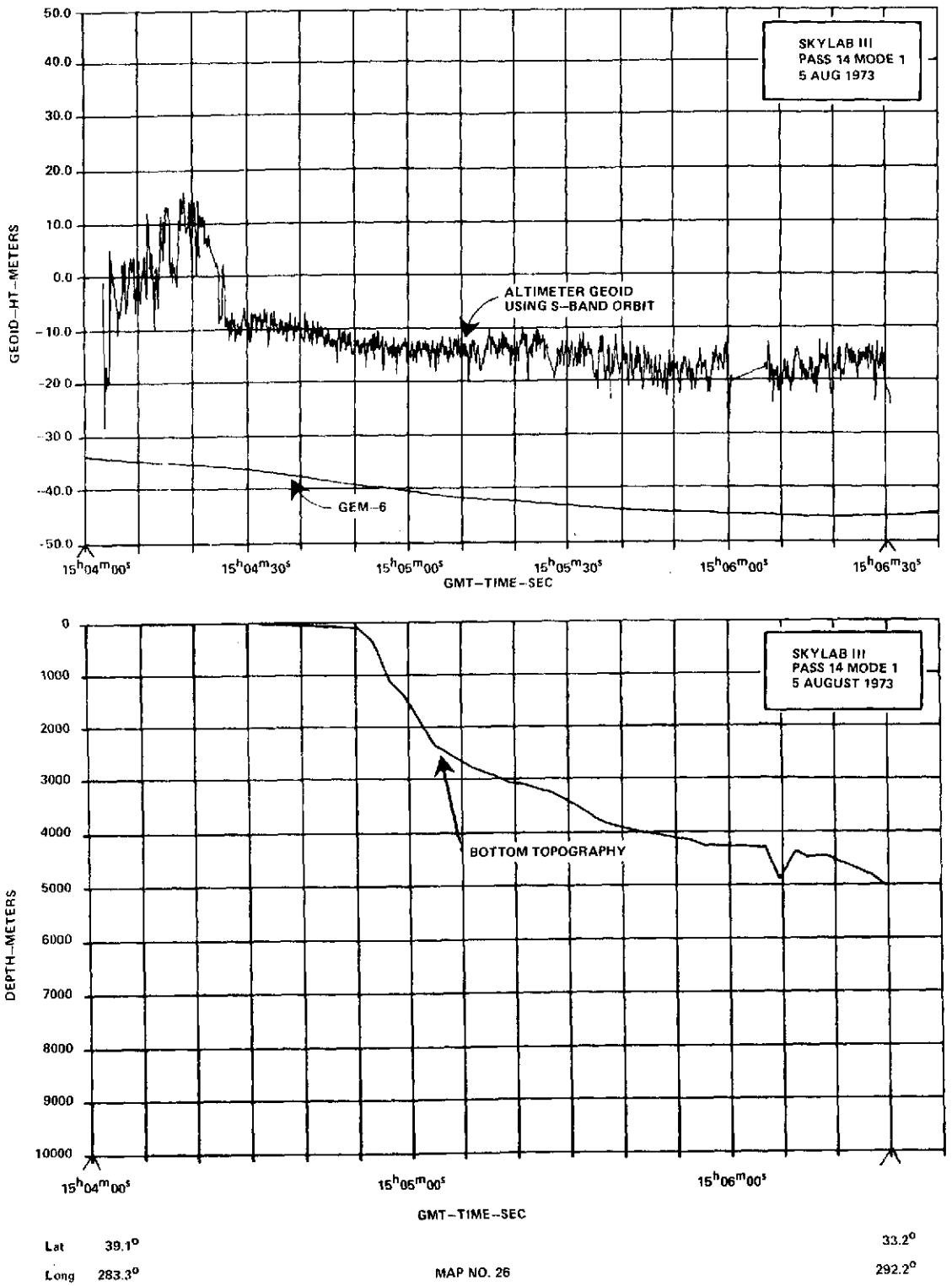
MAP NO. 22

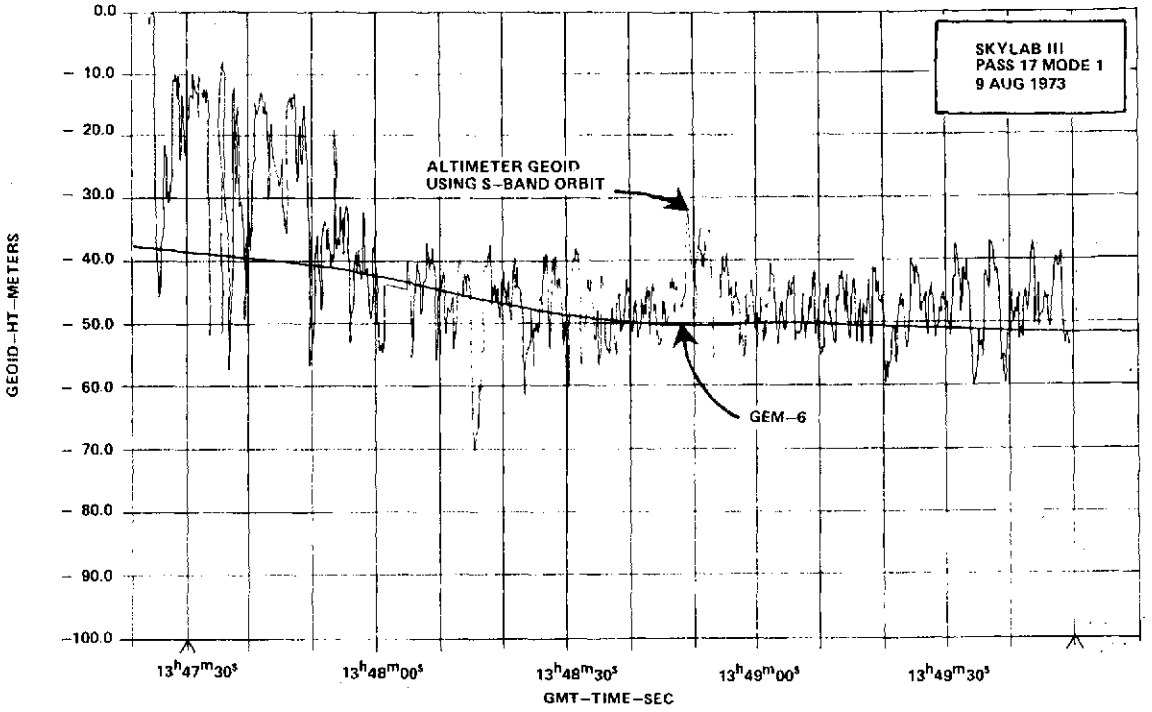
23.2°
270.1°

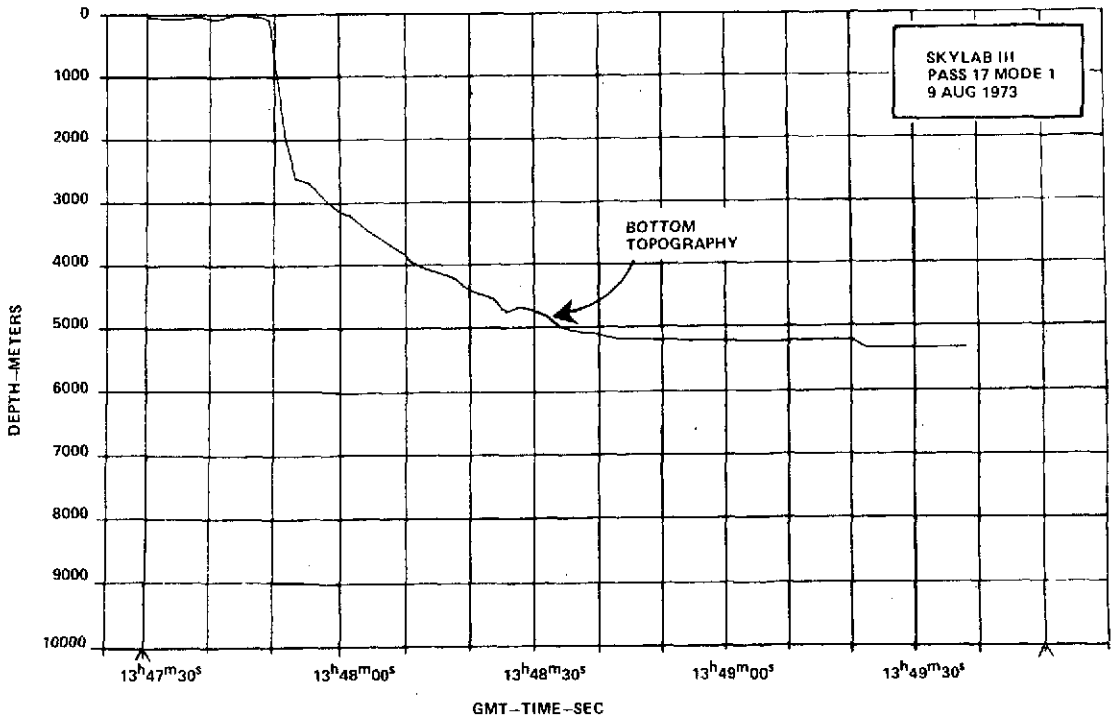




Lat	12.2°		8.8°
Long	279.7°	MAP NO. 23	282.4°

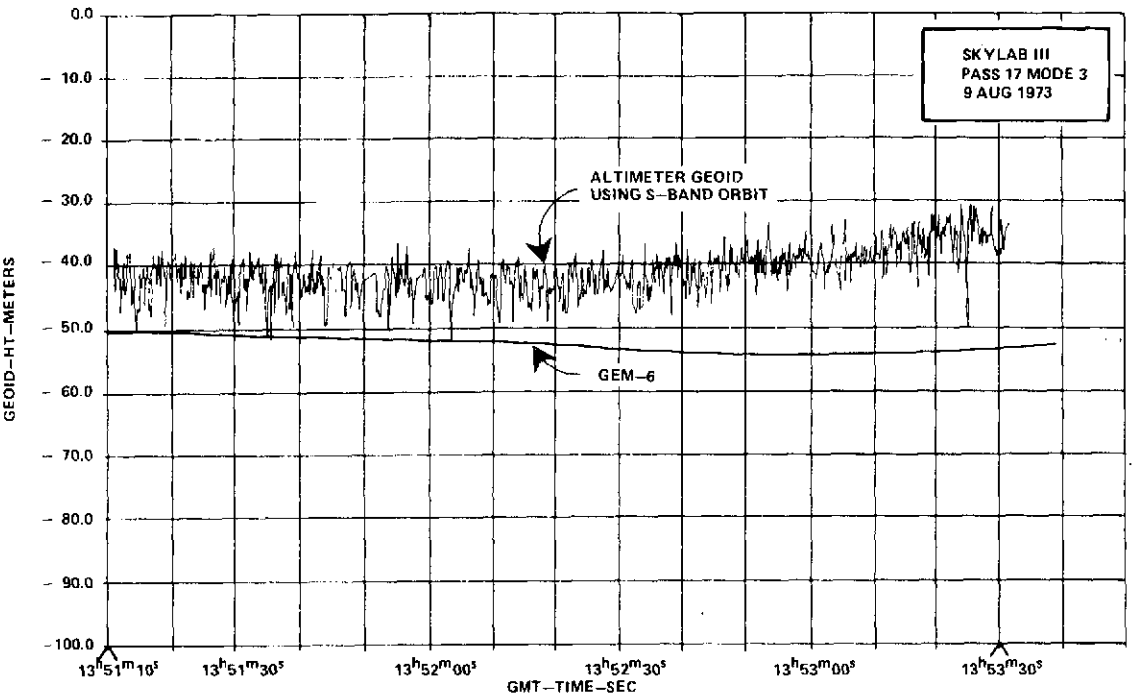

SKYLAB III
PASS 14 MODE 1
5 AUG 1973
GEOID–HT–METERS
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
ALTIMETER GEOID
USING S–BAND ORBIT
GEM–6
15h04m00s
15h04m30s
15h05m00s
15h05m30s
15h06m00s
15h06m30s
GMT–TIME–SEC
SKYLAB III
PASS 14 MODE 1
5 AUGUST 1973
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
BOTTOM TOPOGRAPHY
15h04m00s
15h05m00s
15h06m00s
GMT–TIME–SEC
Lat 39.1°
Long 283.3°
MAP NO. 26
33.2°
292.2°

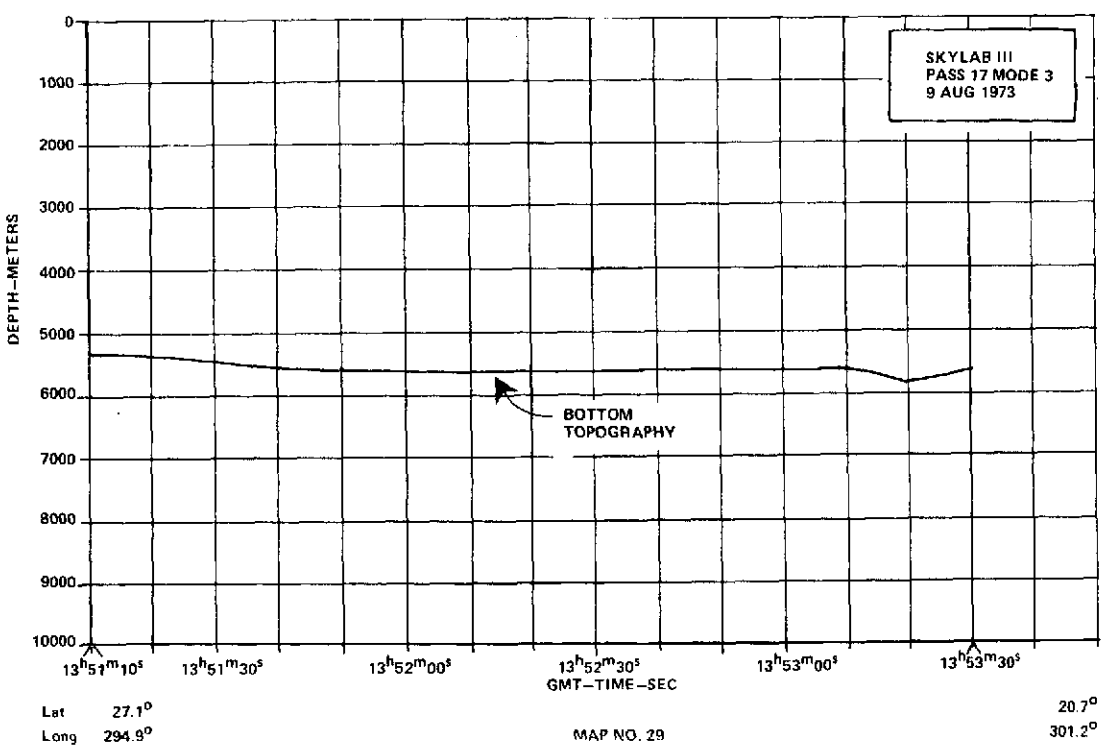




Lat 36.4° 31.0°

Long 283.2° MAP NO. 28 - 290.4°

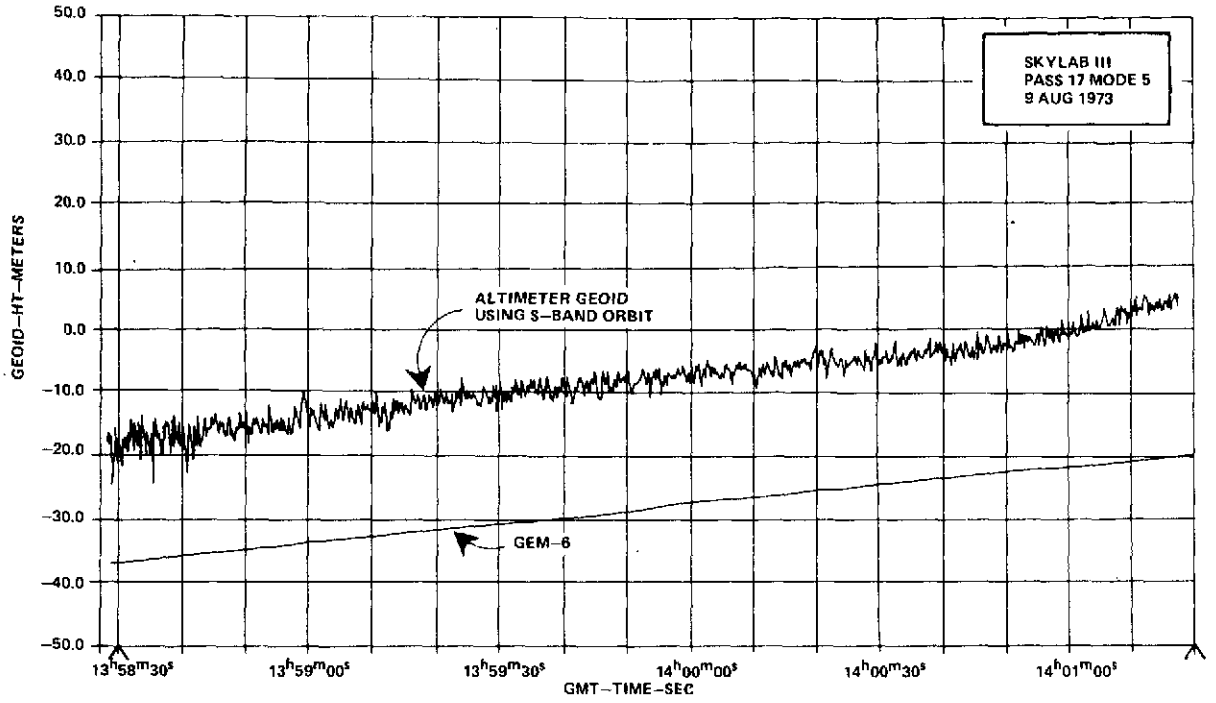


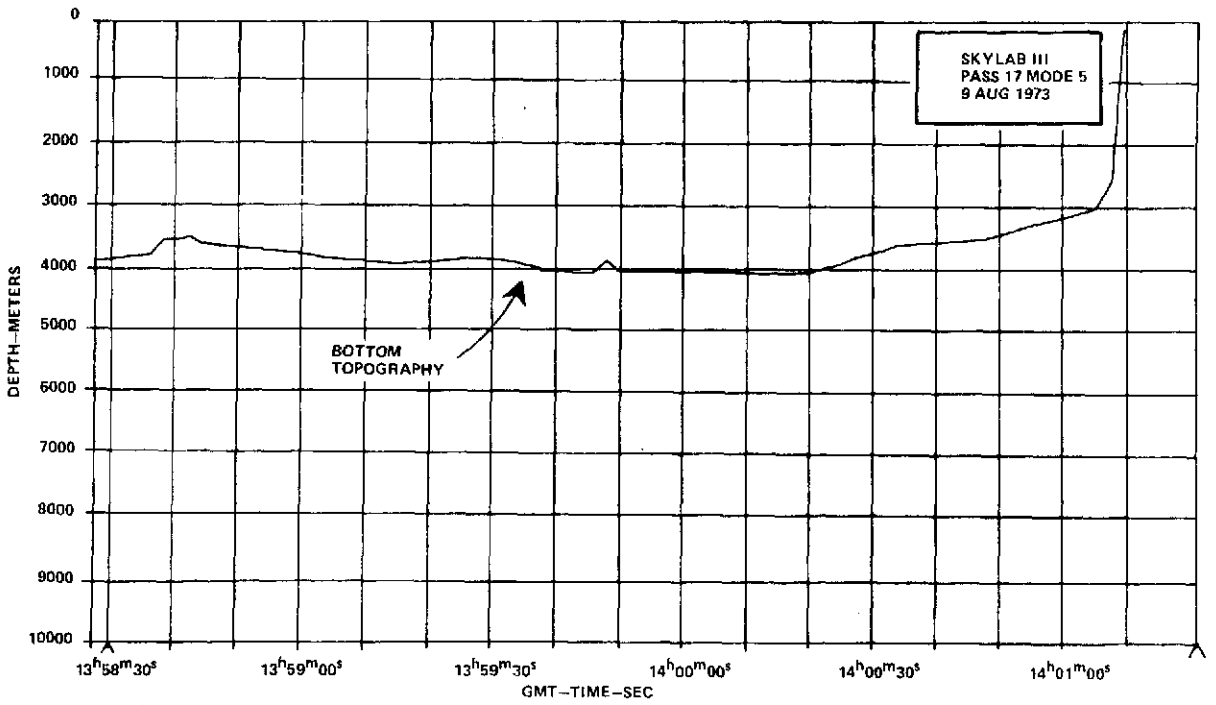


Lat 27.1°
Long 294.9°

MAP NO. 29

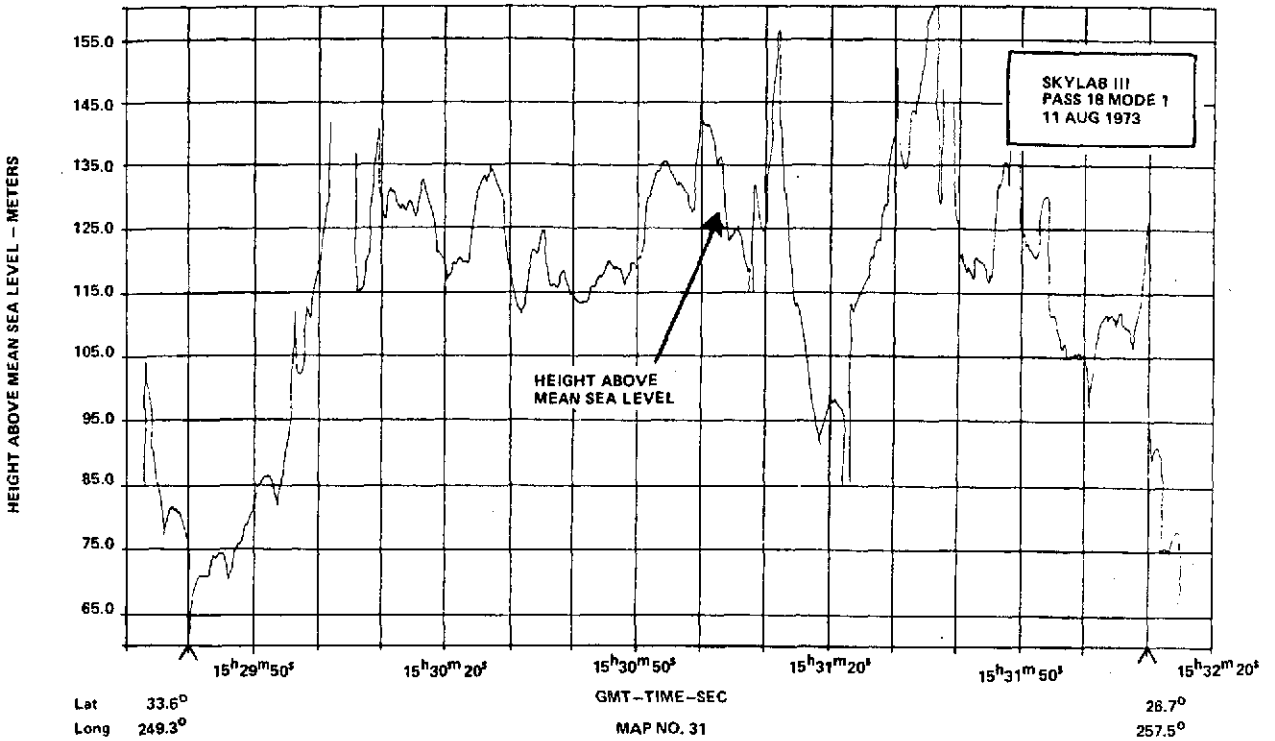
20.7°
301.2°

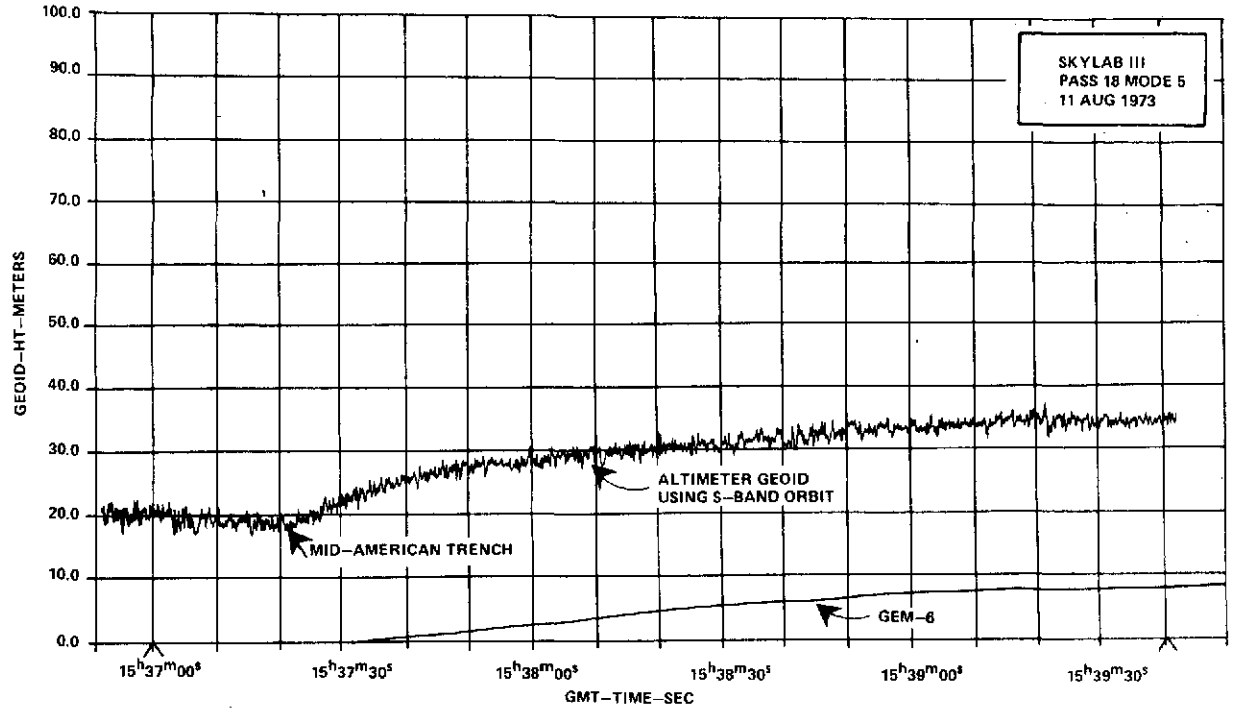


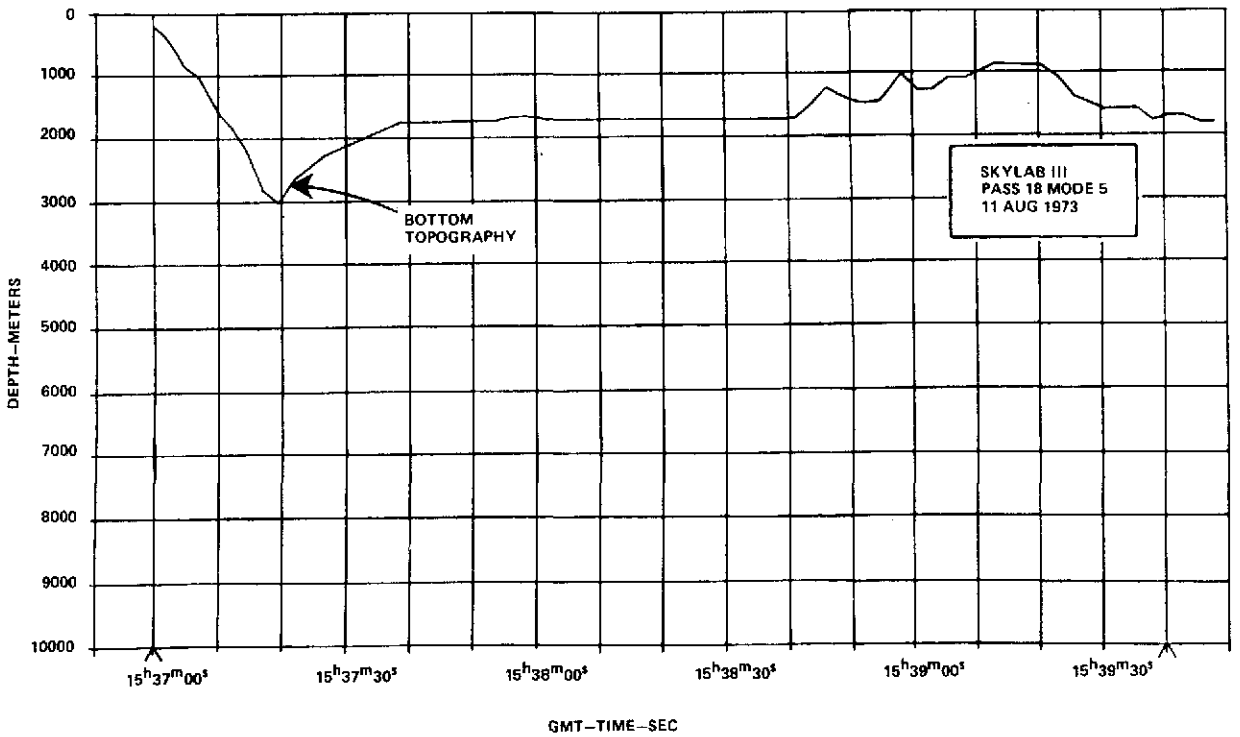


Lat 6.1° − 2.3°
Long 313.1° 319.5°

MAP NO. 30

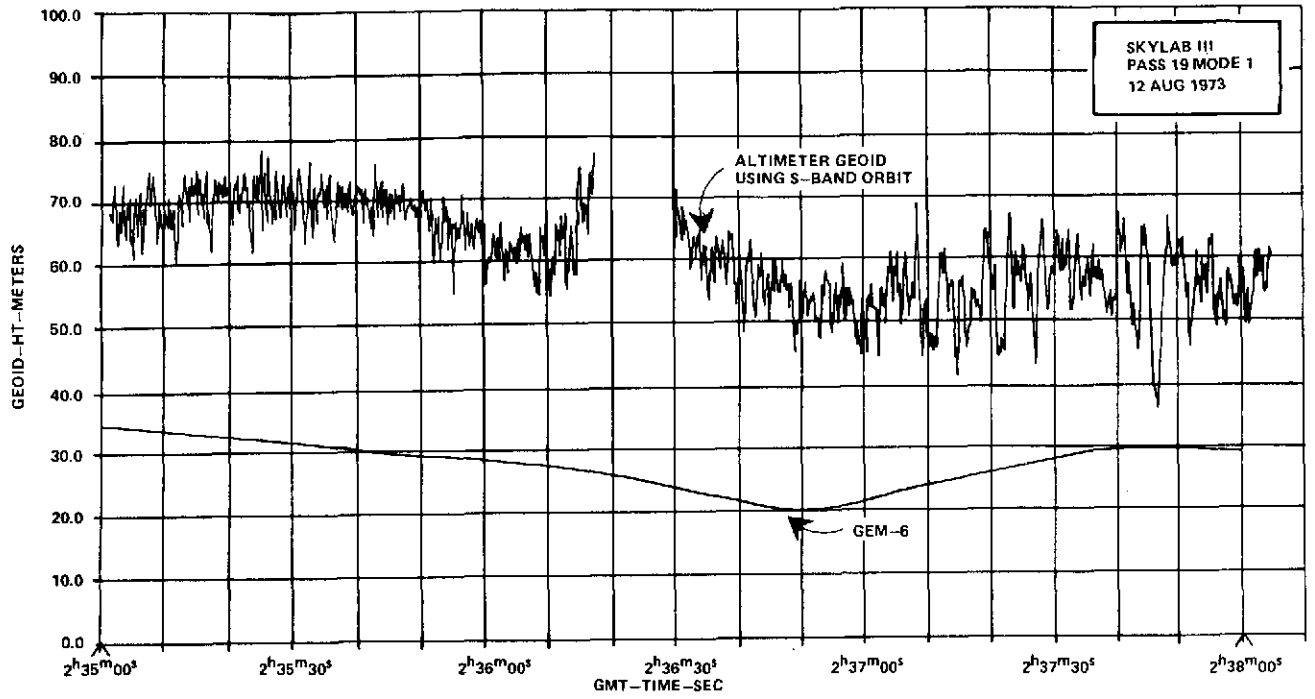

HEIGHT ABOVE MEAN SEA LEVEL – METERS
155.0
145.0
135.0
125.0
115.0
105.0
95.0
85.0
75.0
65.0
SKYLAB III
PASS 18 MODE 1
11 AUG 1973
HEIGHT ABOVE
MEAN SEA LEVEL
15h29m50s
15h30m20s
15h30m50s
15h31m20s
15h31m50s
15h32m20s
GMT–TIME–SEC
Lat 33.6°
Long 249.3°
28.7°
257.5°
MAP NO. 31

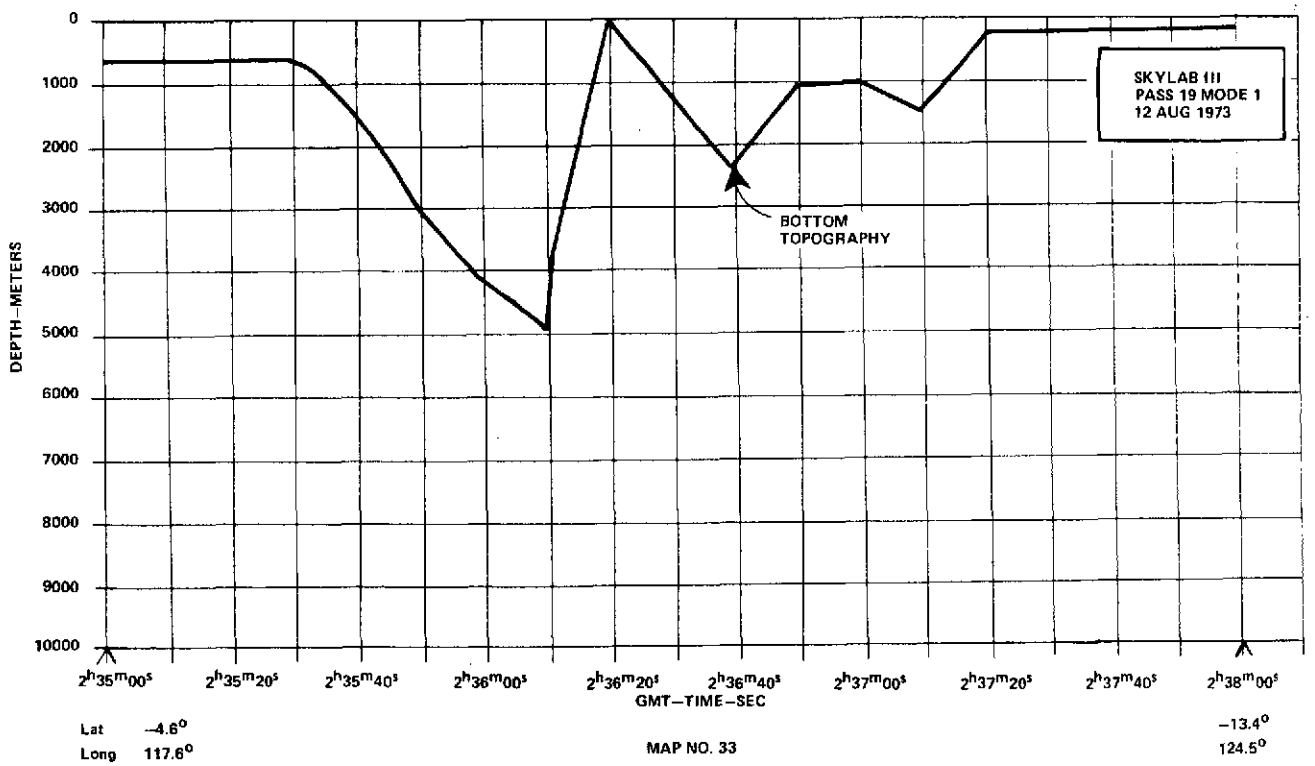




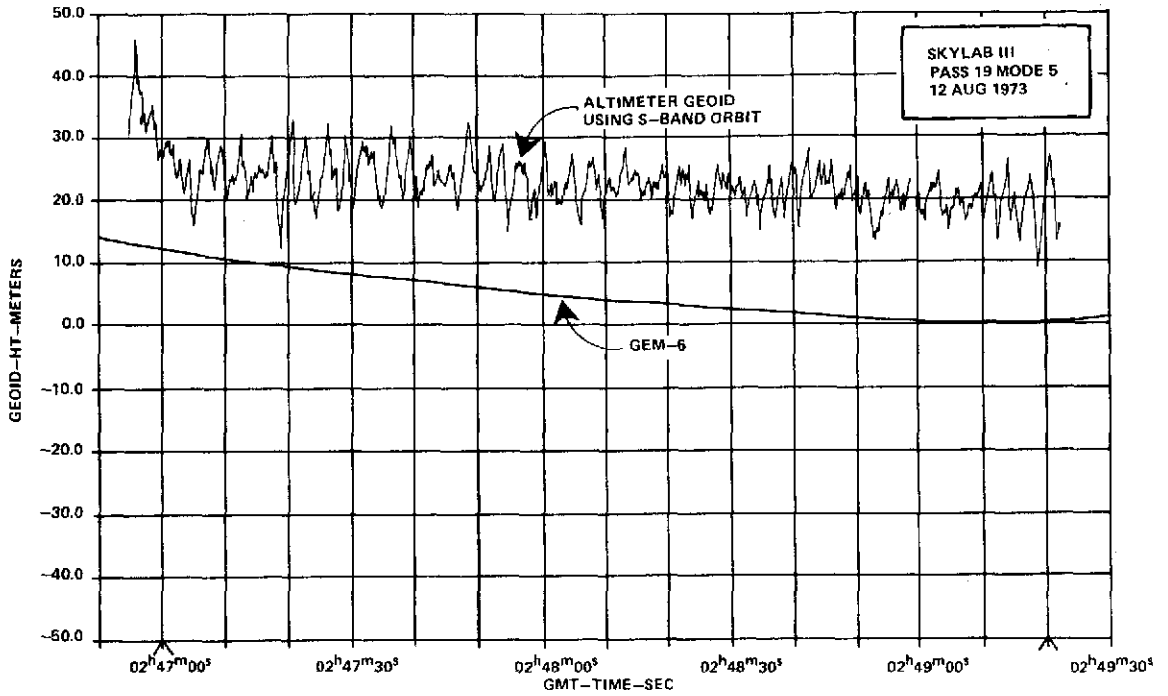
Lat 13.1° 5.2°

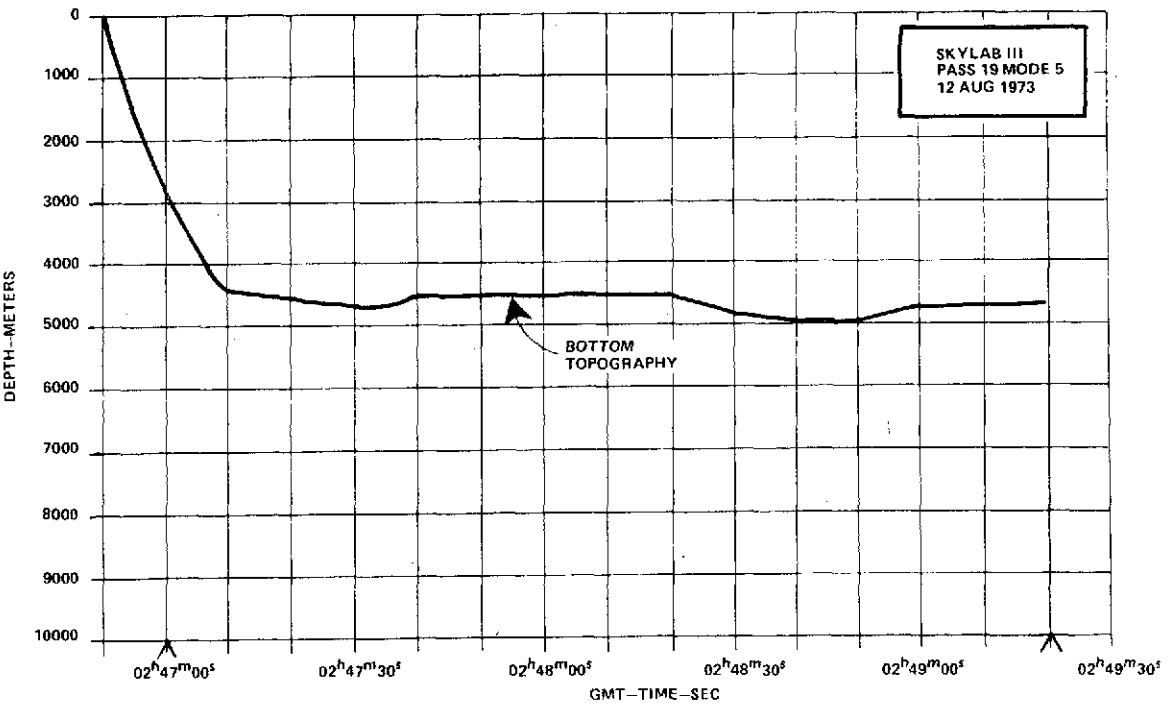
Long 269.9° MAP NO. 32 276.0°





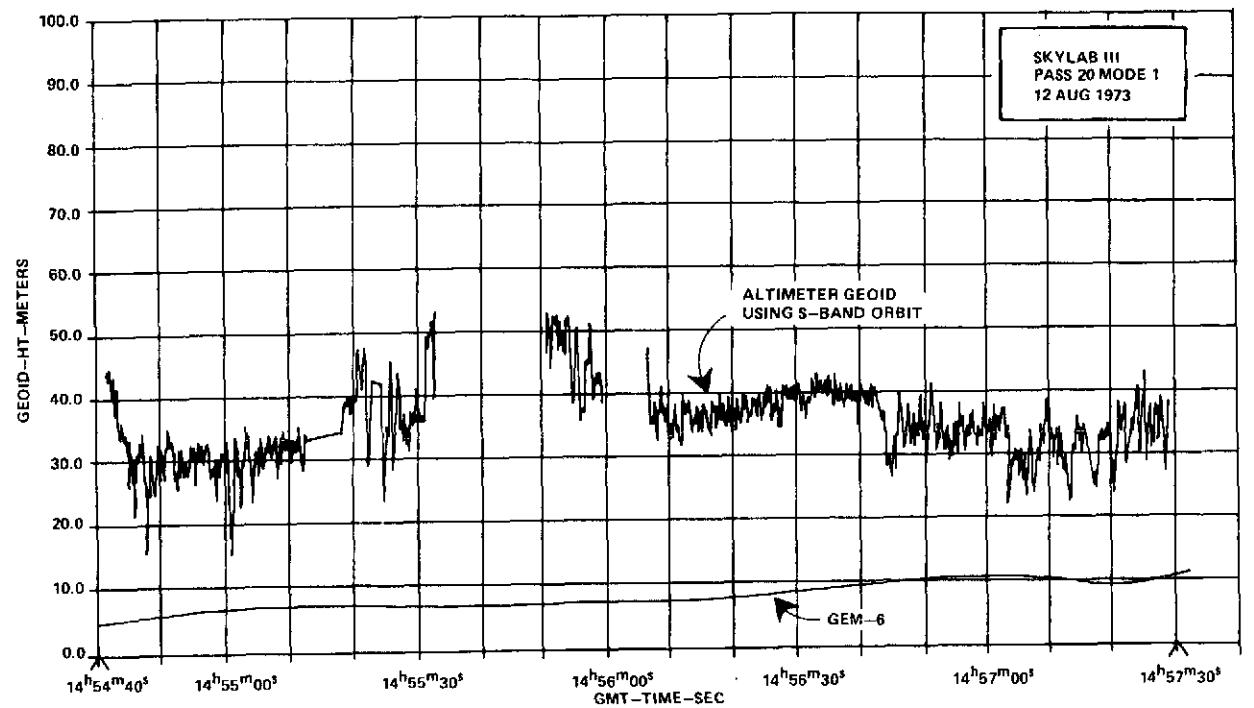
Lat −4.6° MAP NO. 33 −13.4°
Long 117.6° 124.5°

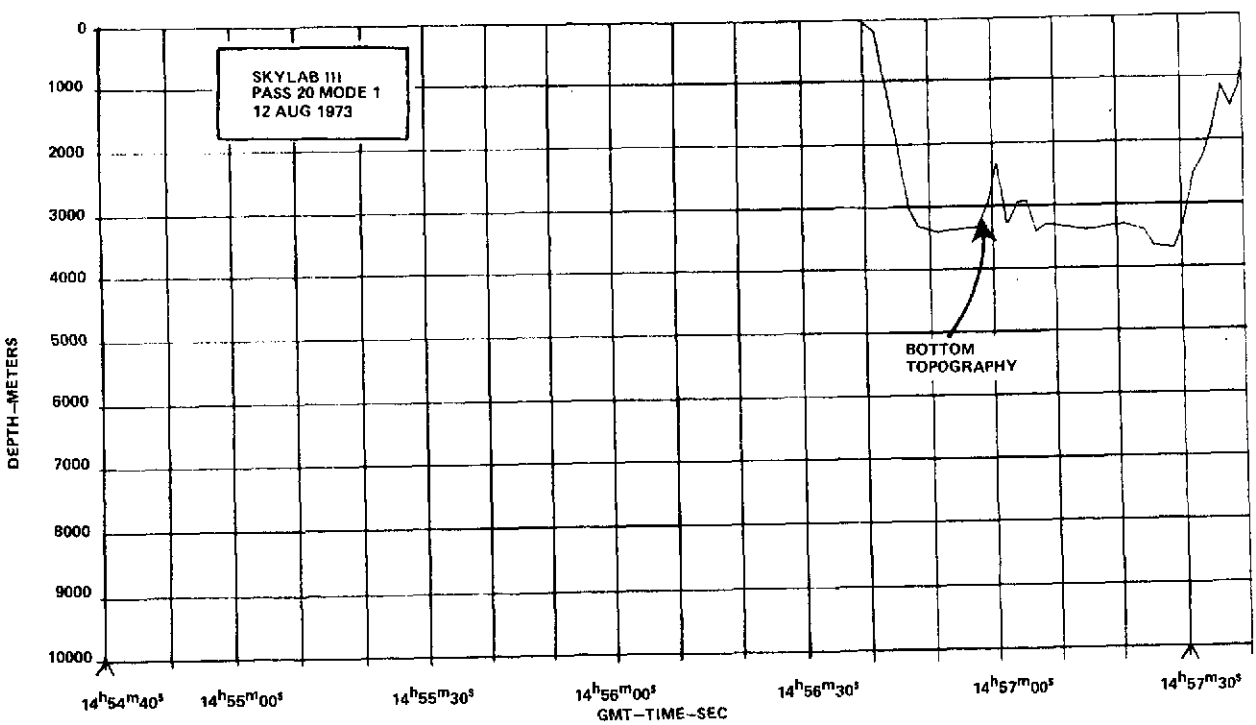




Lat -37.5° -42.4°
Long 150.5° 159.7°

MAP NO. 34





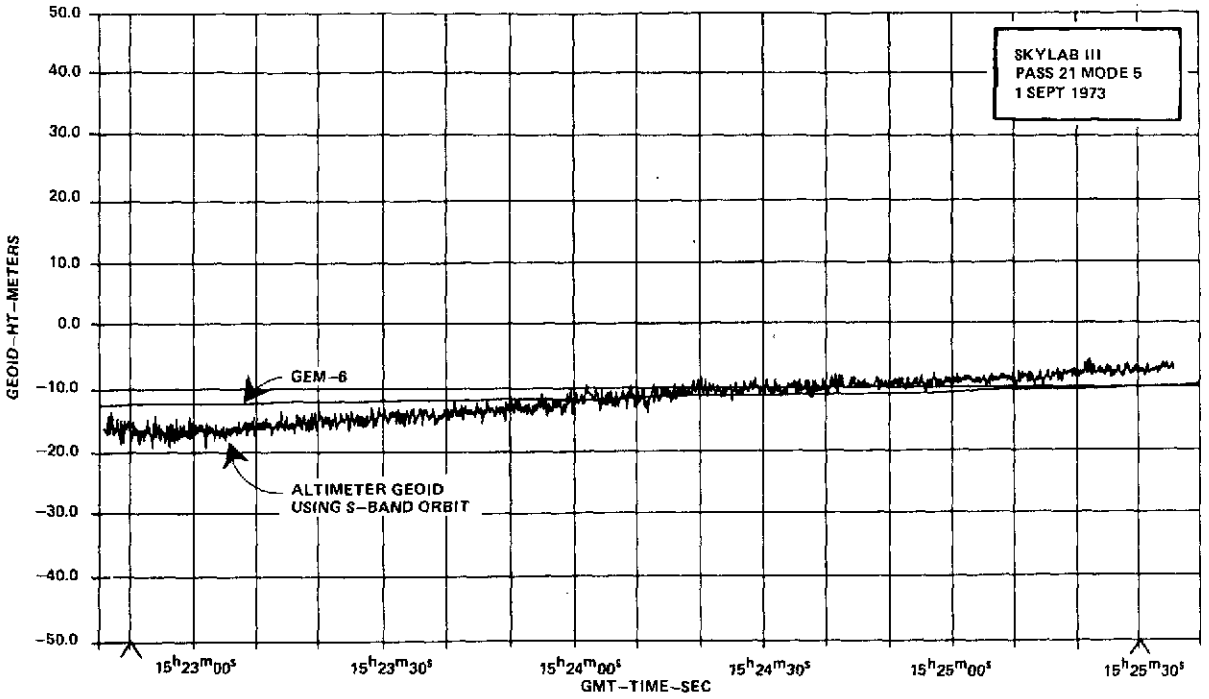
Lat 11.9°

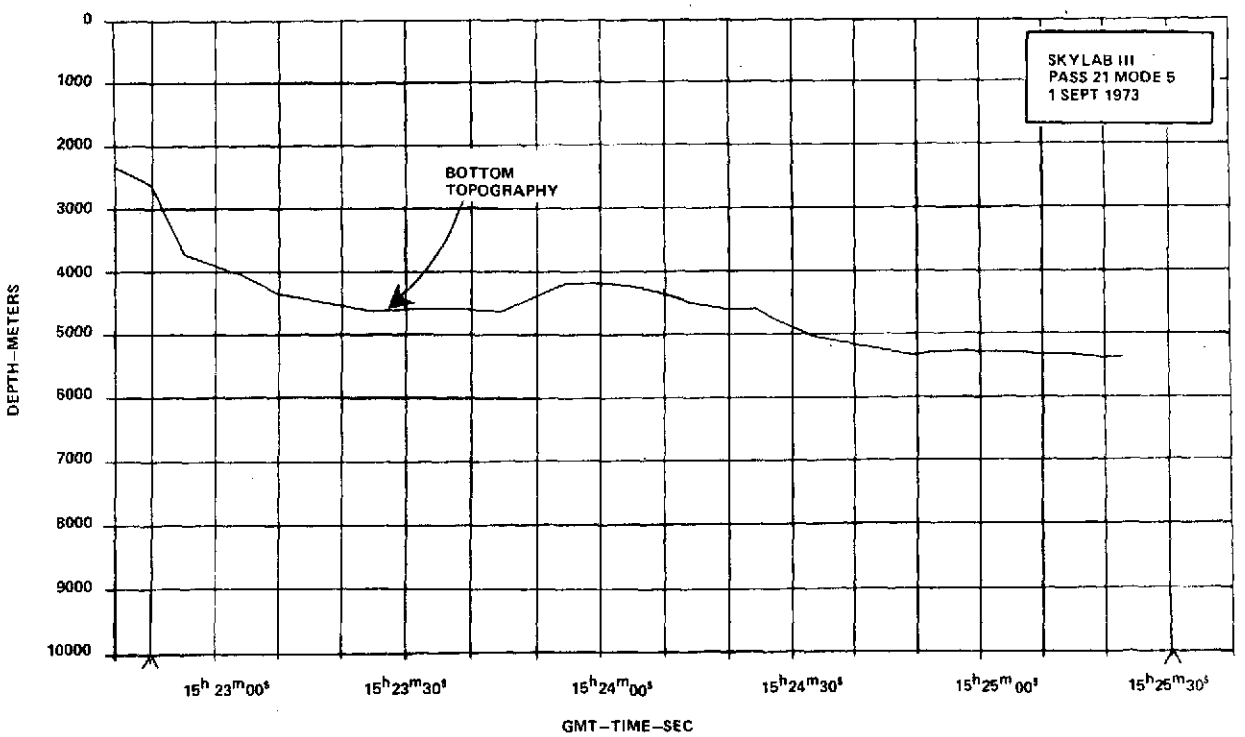
Long 275.6°

MAP NO. 34A

3.5°

282.1°

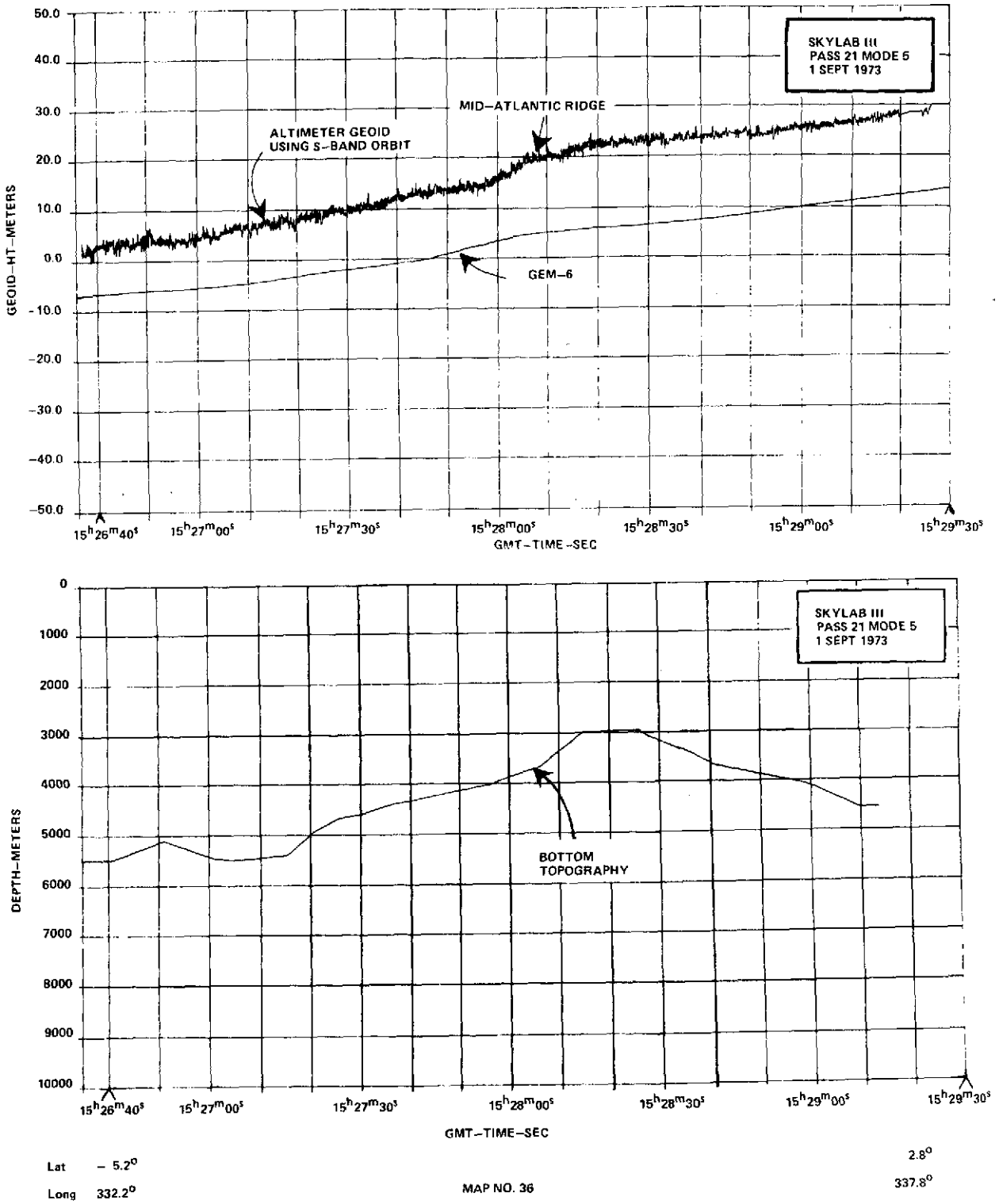


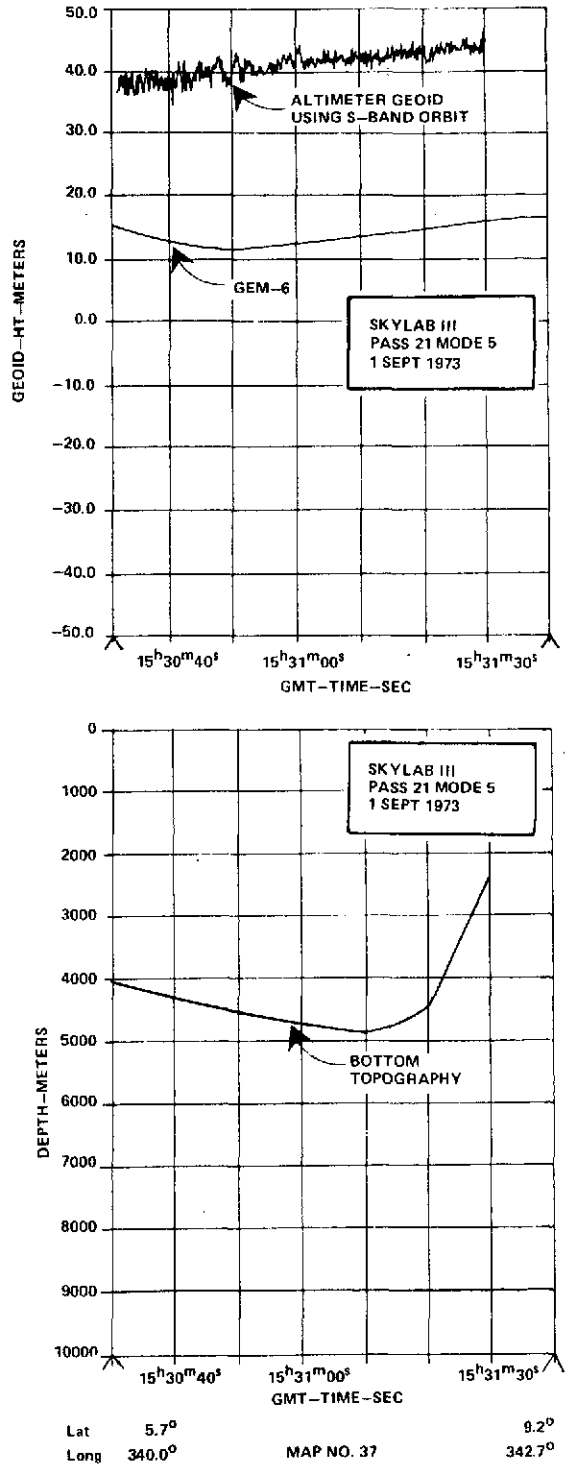


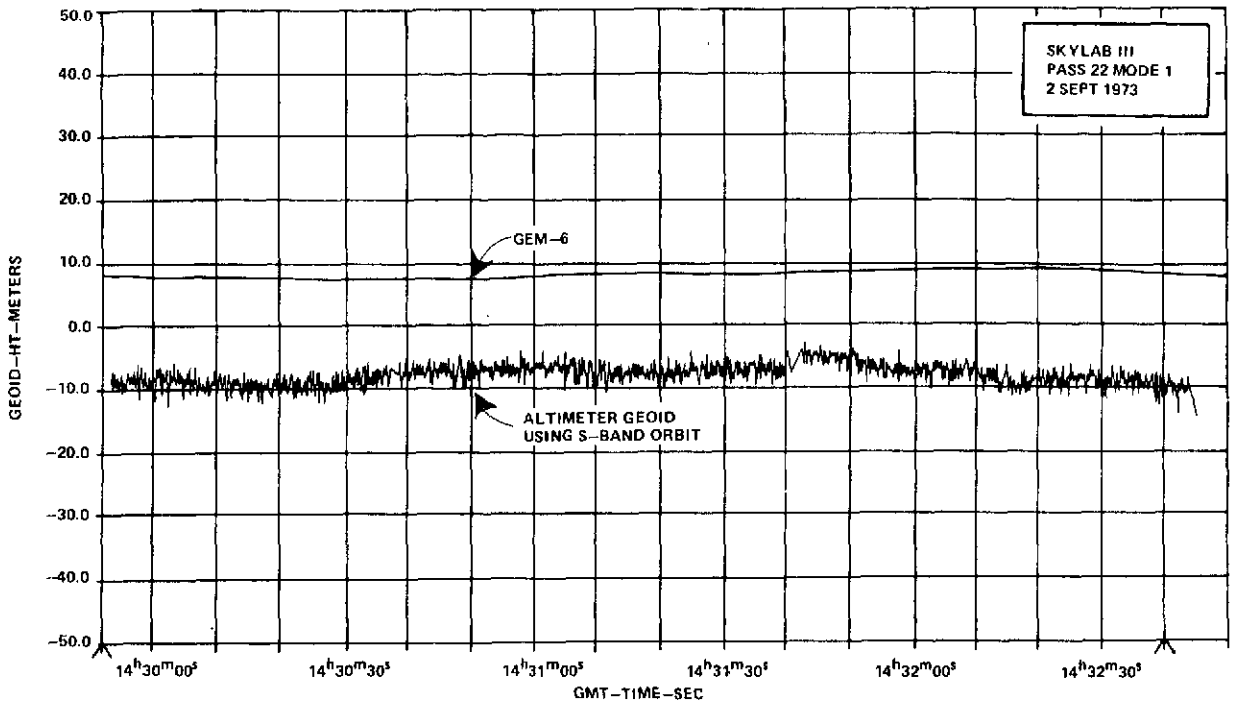
Lat –16.5° –8.7°

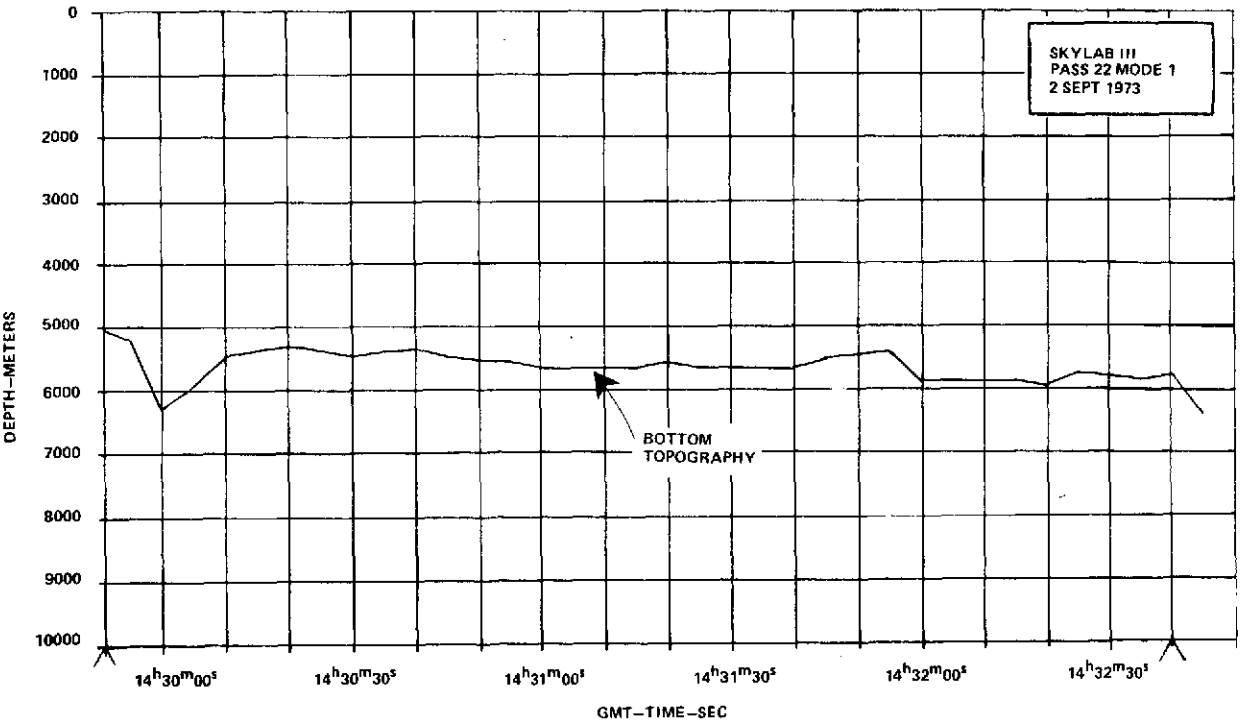
Long 322.9° 329.2°

MAP NO. 35


SKYLAB III
PASS 21 MODE 5
1 SEPT 1973
MID–ATLANTIC RIDGE
ALTIMETER GEOID
USING S–BAND ORBIT
GEM–6
GEOID–HT–METERS
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
15h26m40s
15h27m00s
15h27m30s
15h28m00s
15h28m30s
15h29m00s
15h29m30s
GMT–TIME–SEC
SKYLAB III
PASS 21 MODE 5
1 SEPT 1973
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
15h26m40s
15h27m00s
15h27m30s
15h28m00s
15h28m30s
15h29m00s
15h29m30s
GMT–TIME–SEC
Lat – 5.2°
Long 332.2°
MAP NO. 36
2.8°
337.8°


50.0
40.0
30.0
20.0
10.0
0.0
−10.0
−20.0
−30.0
−40.0
−50.0
GEOID–HT–METERS
ALTIMETER GEOID
USING S–BAND ORBIT
GEM–6
SKYLAB III
PASS 21 MODE 5
1 SEPT 1973
15h30m40s
15h31m00s
15h31m30s
GMT–TIME–SEC
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
DEPTH–METERS
SKYLAB III
PASS 21 MODE 5
1 SEPT 1973
BOTTOM
TOPOGRAPHY
15h30m40s
15h31m00s
15h31m30s
GMT–TIME–SEC
Lat 5.7° 9.2°
Long 340.0° MAP NO. 37 342.7°

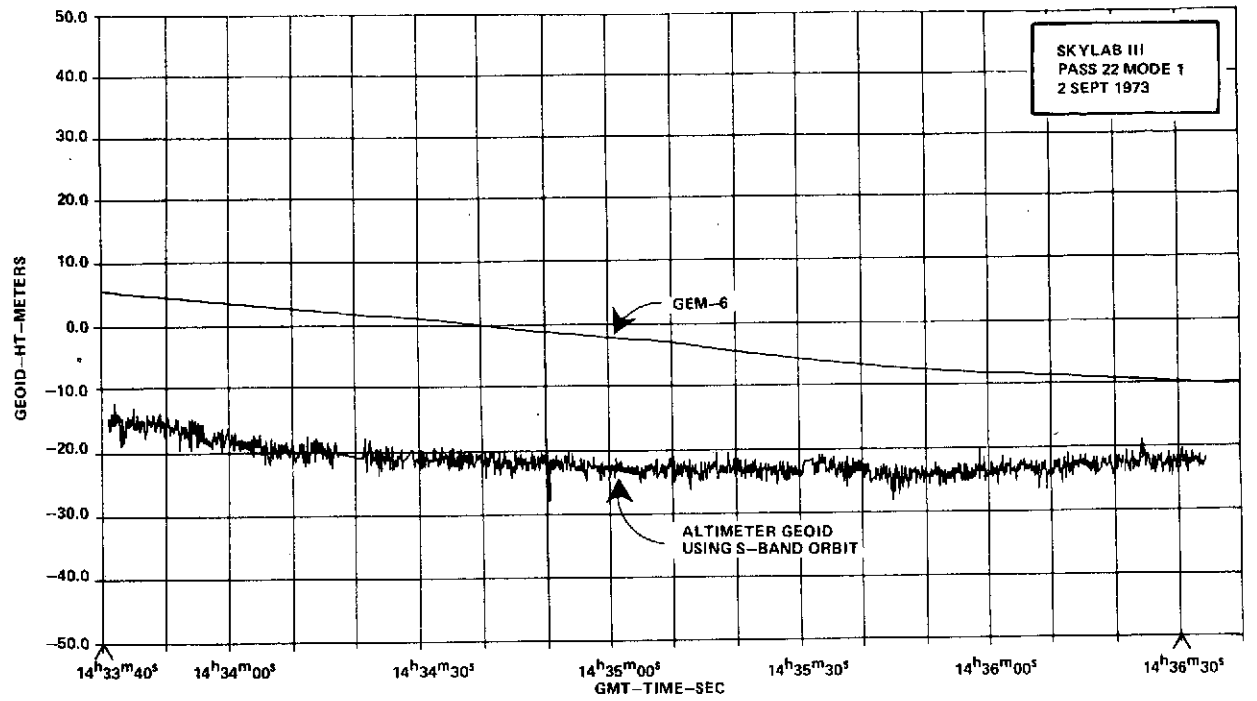


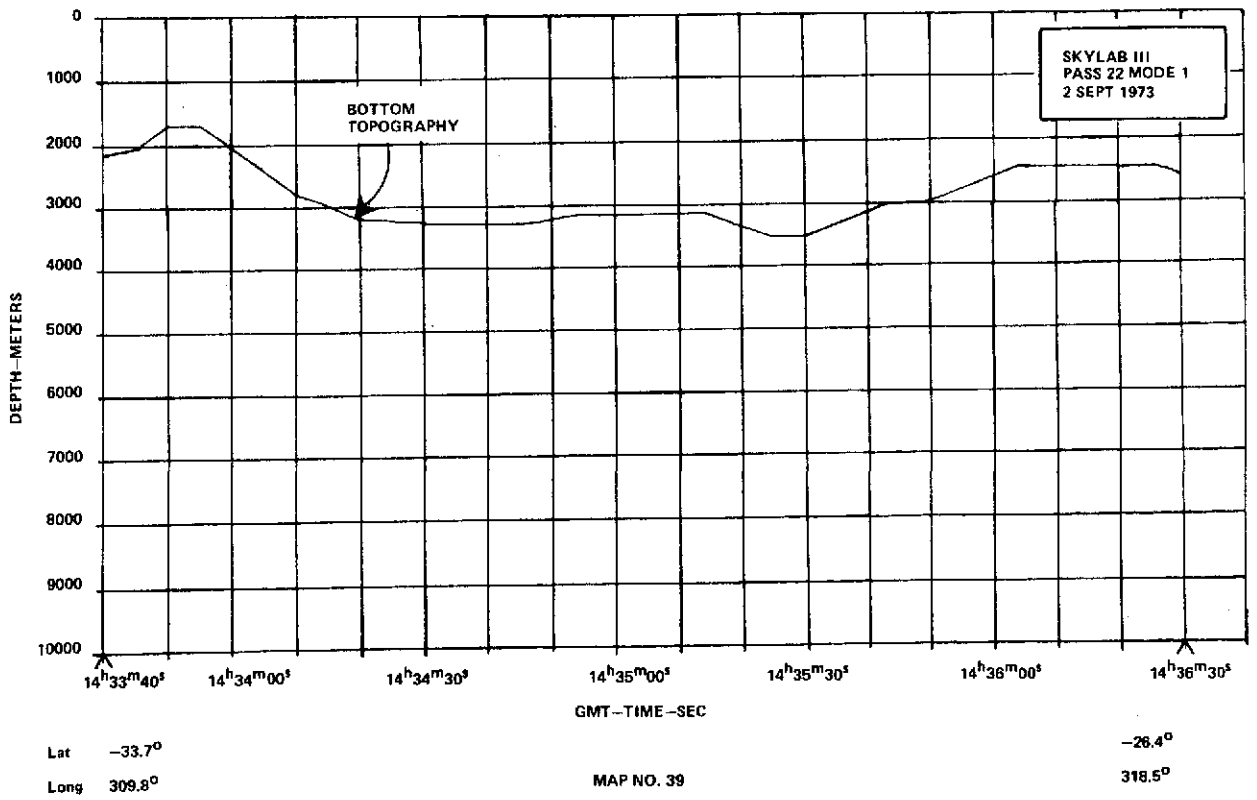


Lat –41.9° –36.1°

Long 296.1° 306.4°

MAP NO. 38

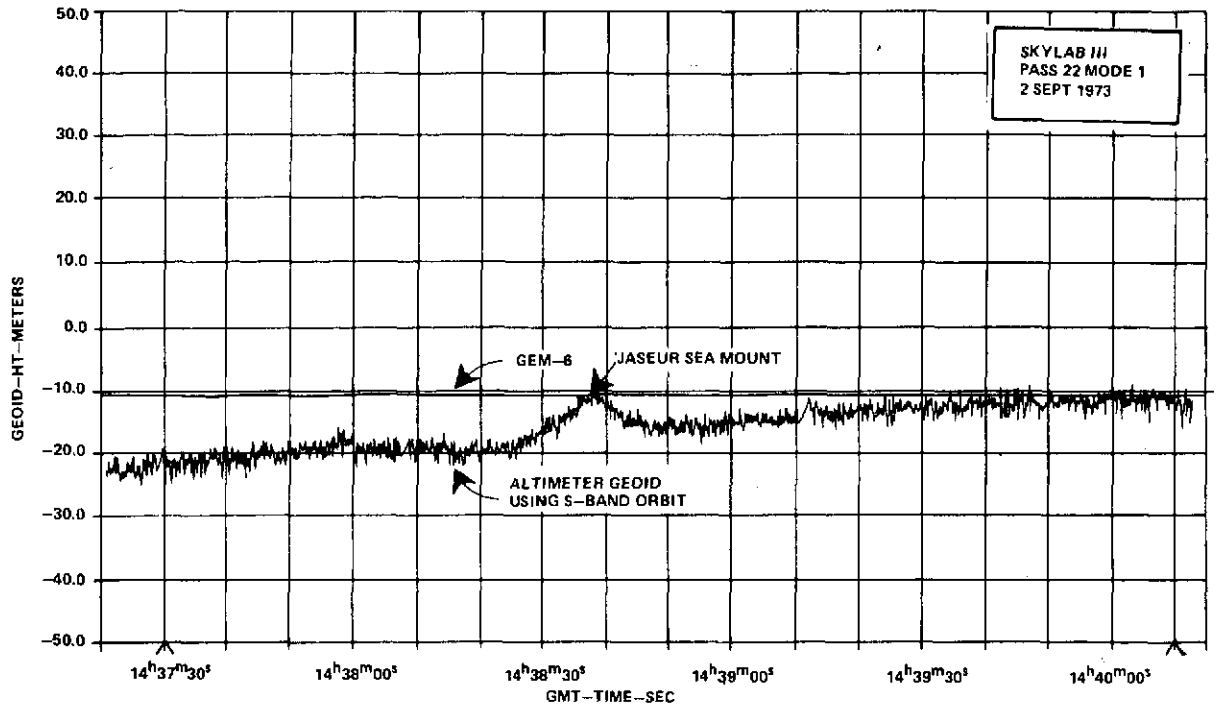


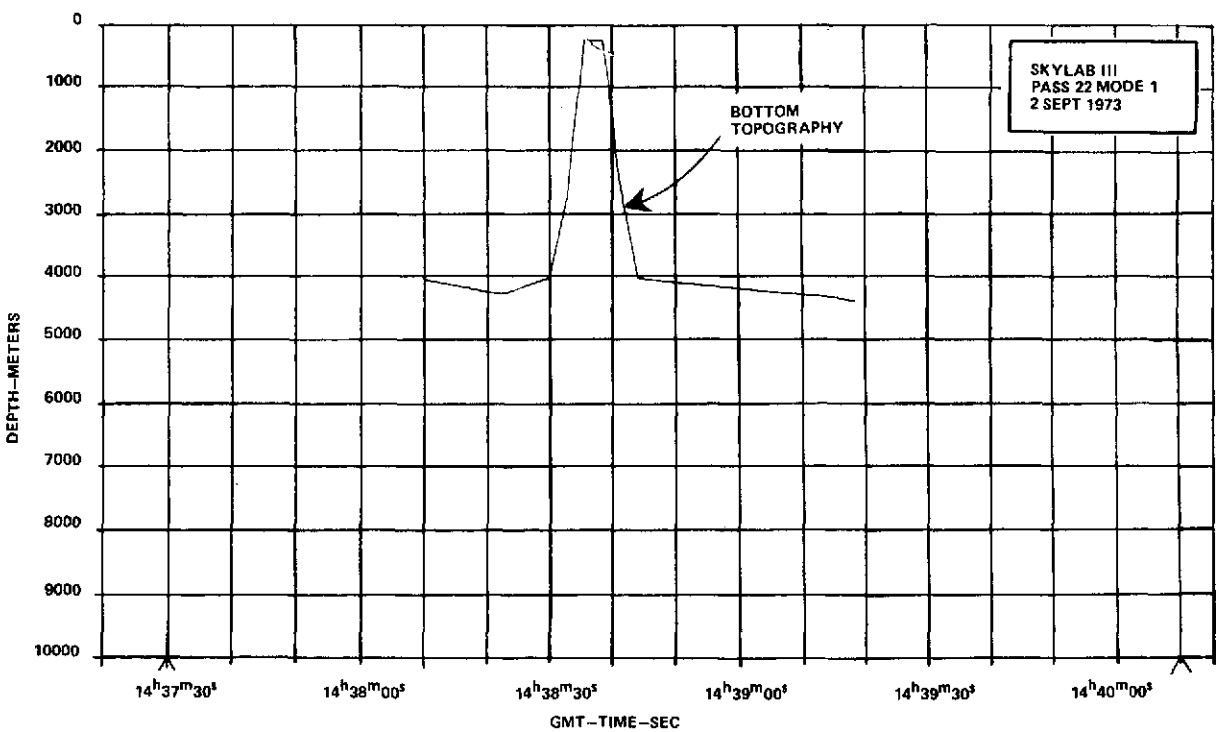


Lat –33.7° –26.4°

Long 309.8° 318.5°

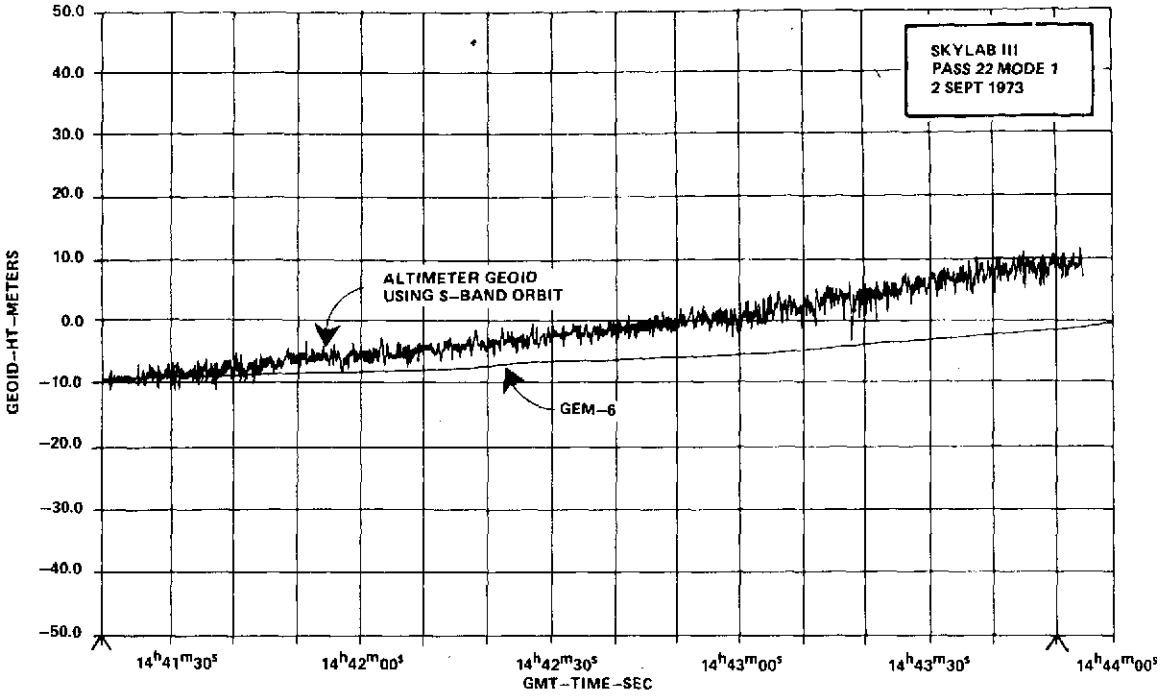
MAP NO. 39

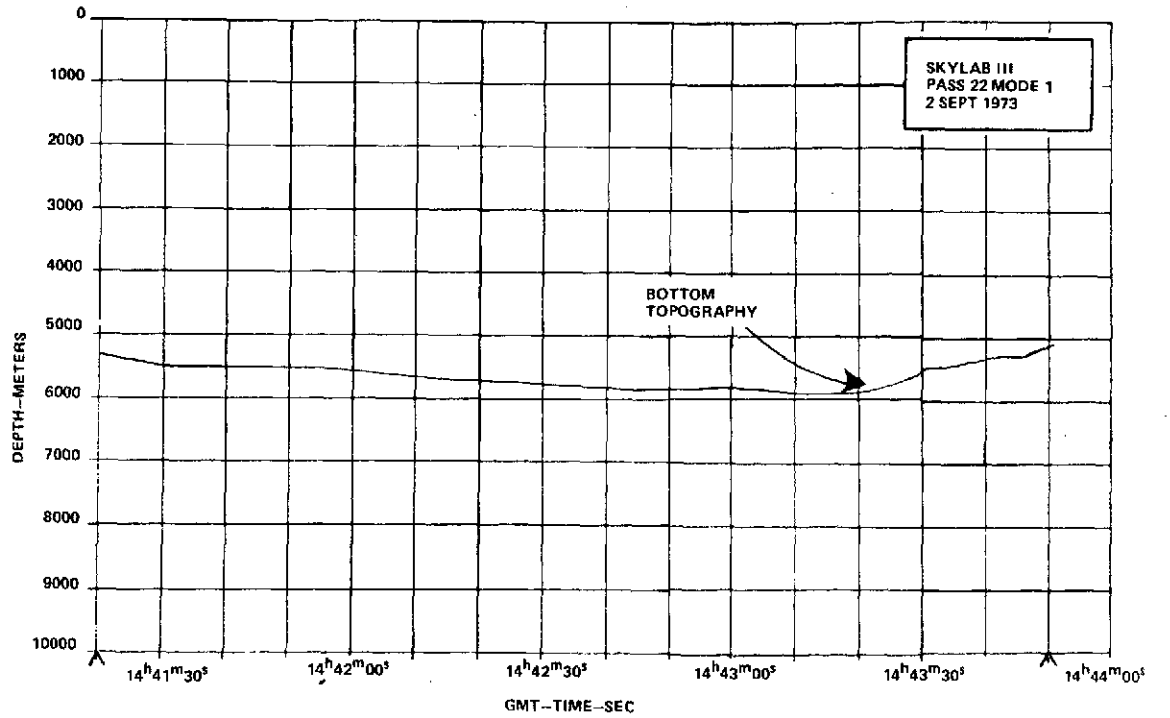




Lat –24.1° –16.1°

Long 320.8° MAP NO. 40 328.1°

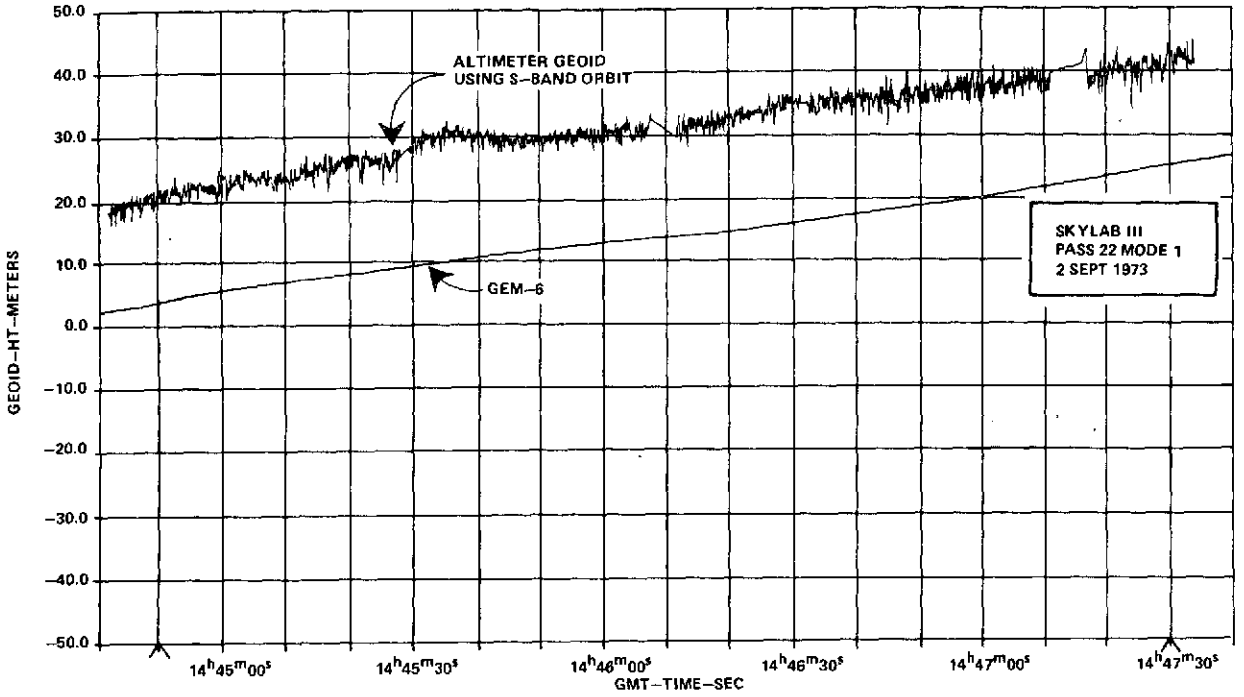


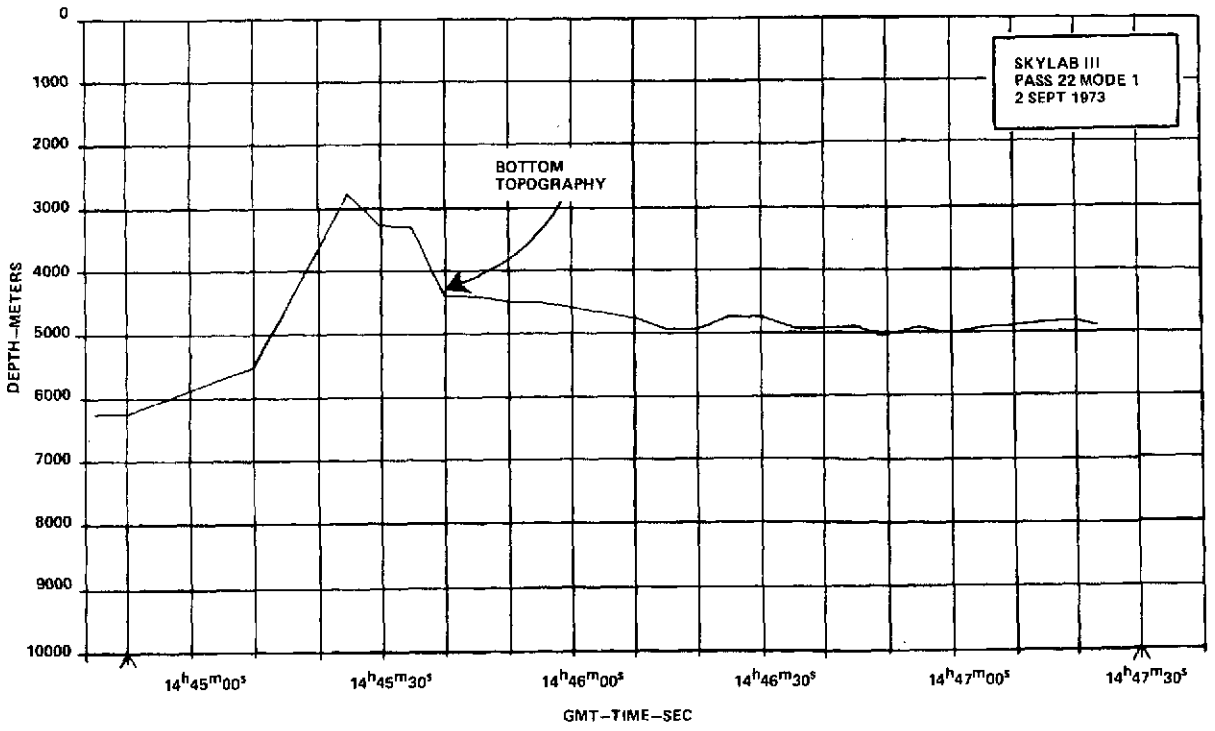


Lat −12.7° −5.3°

Long 330.9° 336.6°

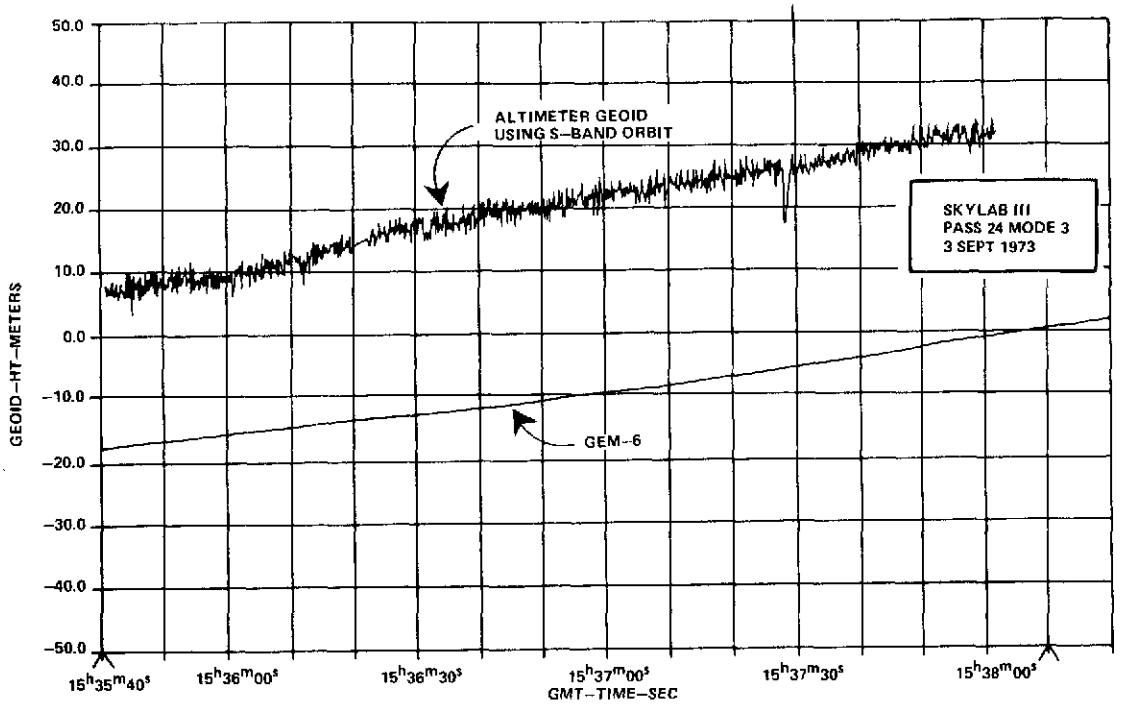
MAP NO. 41

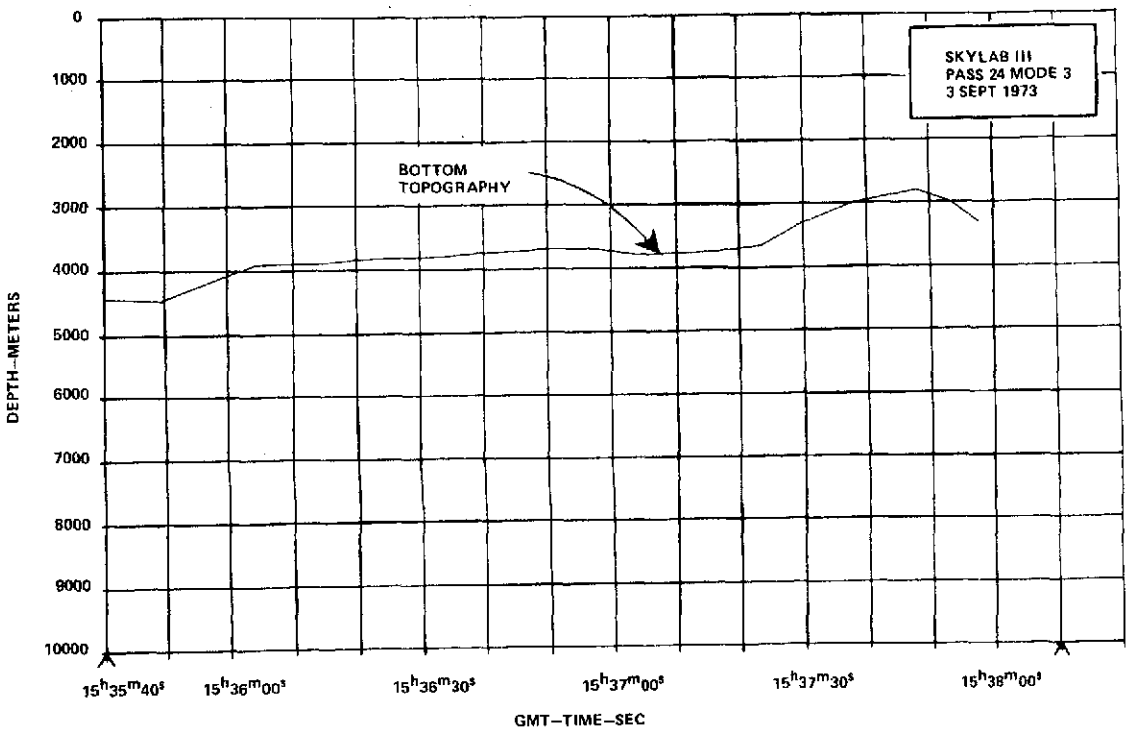




Lat -2.3^o 5.7^o

Long 338.8^o MAP NO. 42 334.8^o

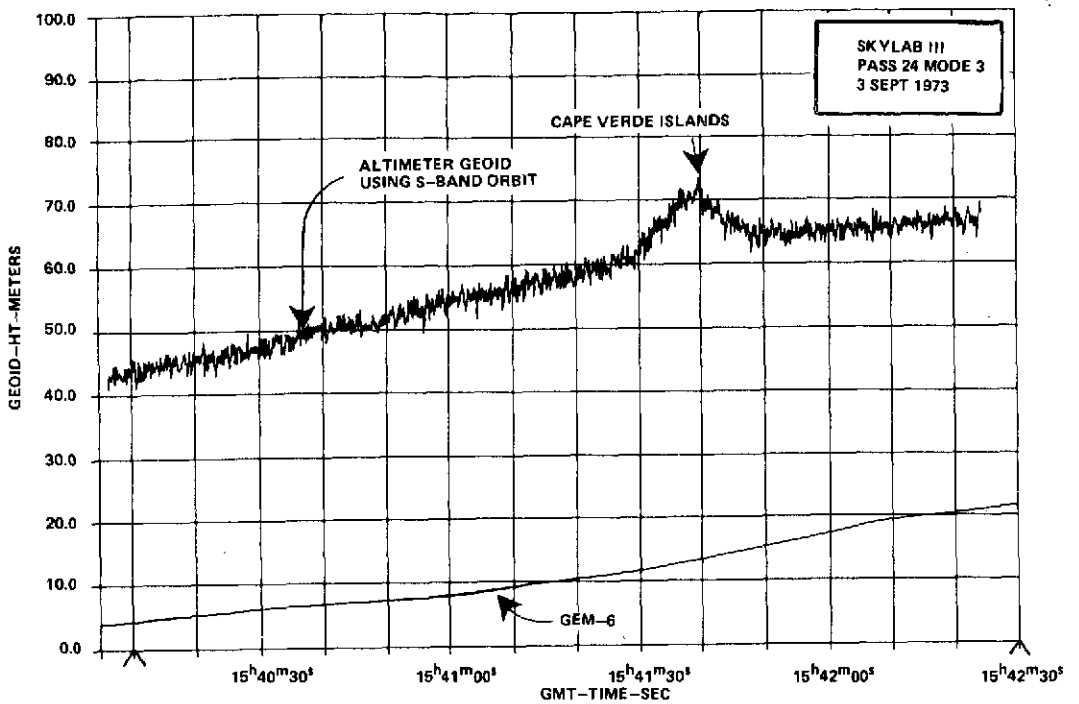


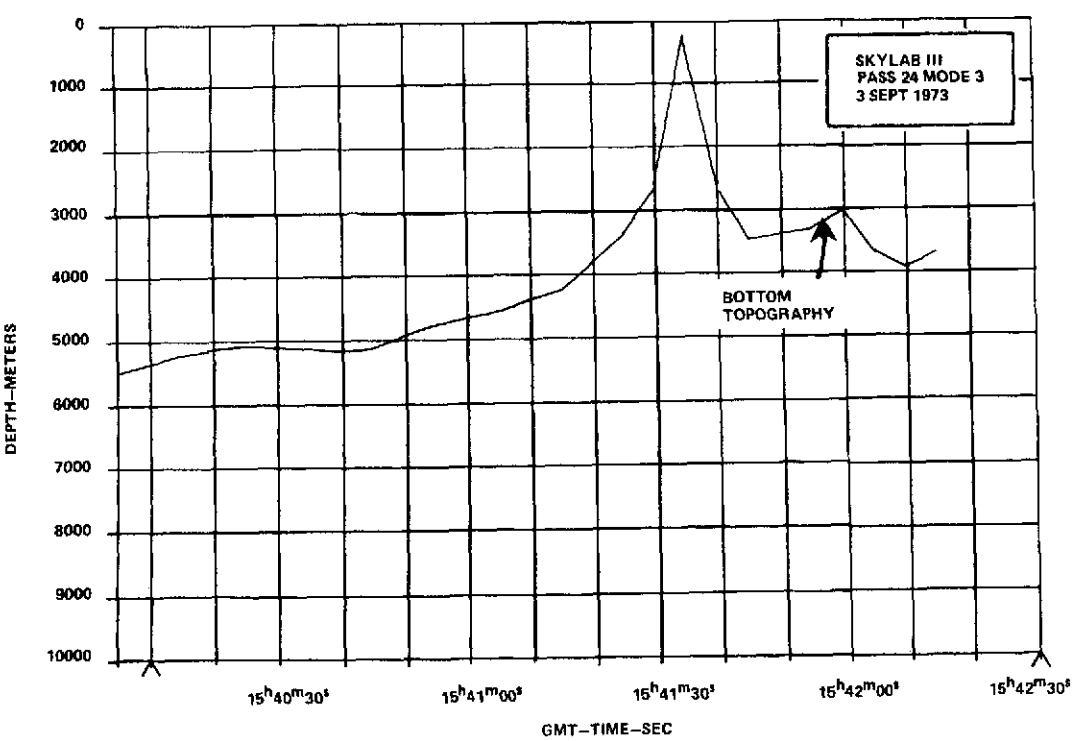


Lat – 0.7° 6.7°

Long 321.4° 326.7°

MAP NO. 43

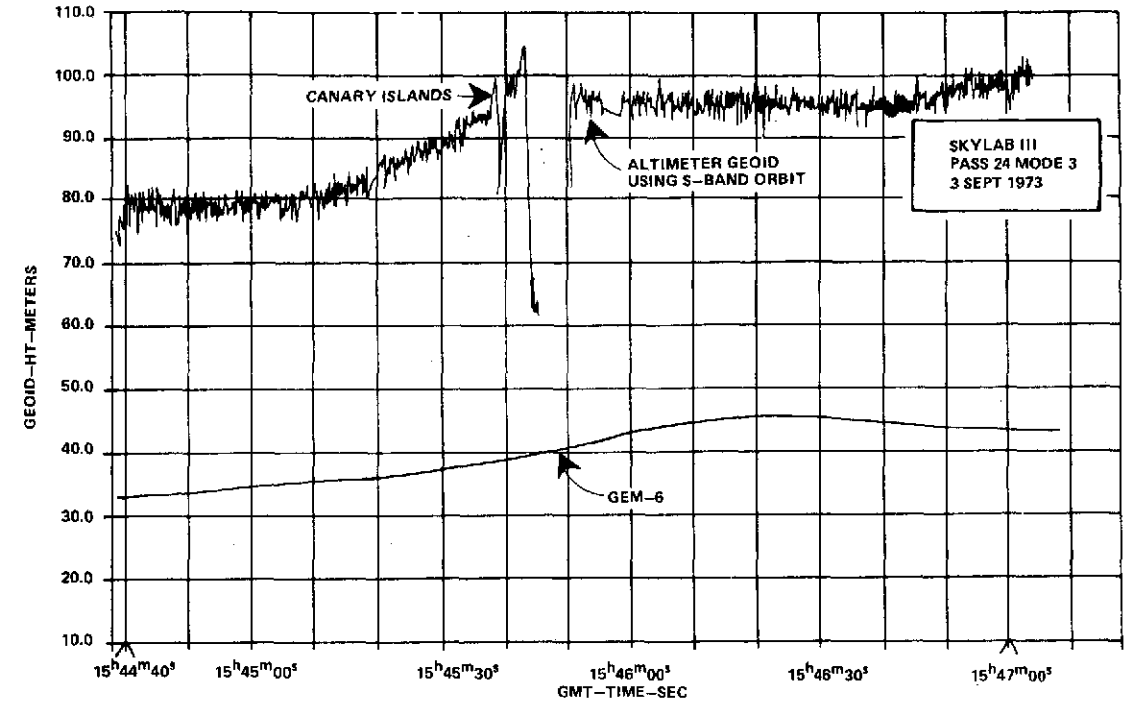


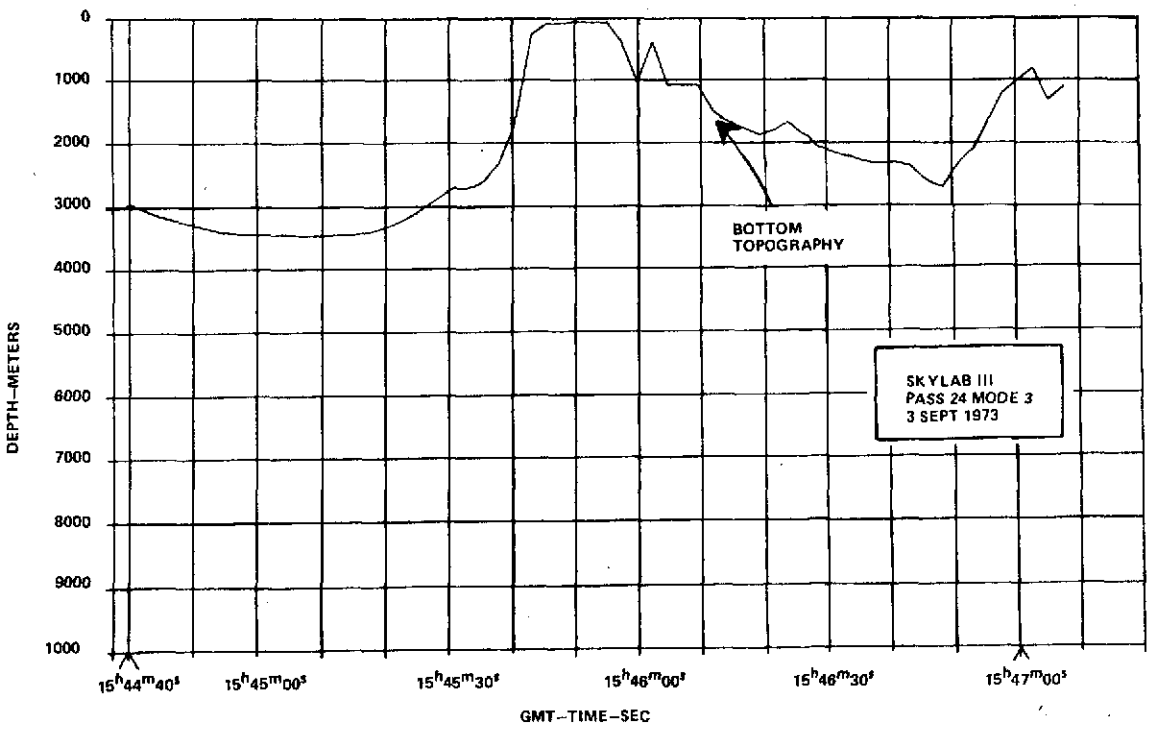


Lat 12.6° 19.4°

Long 331.4° 337.1°

MAP NO. 44

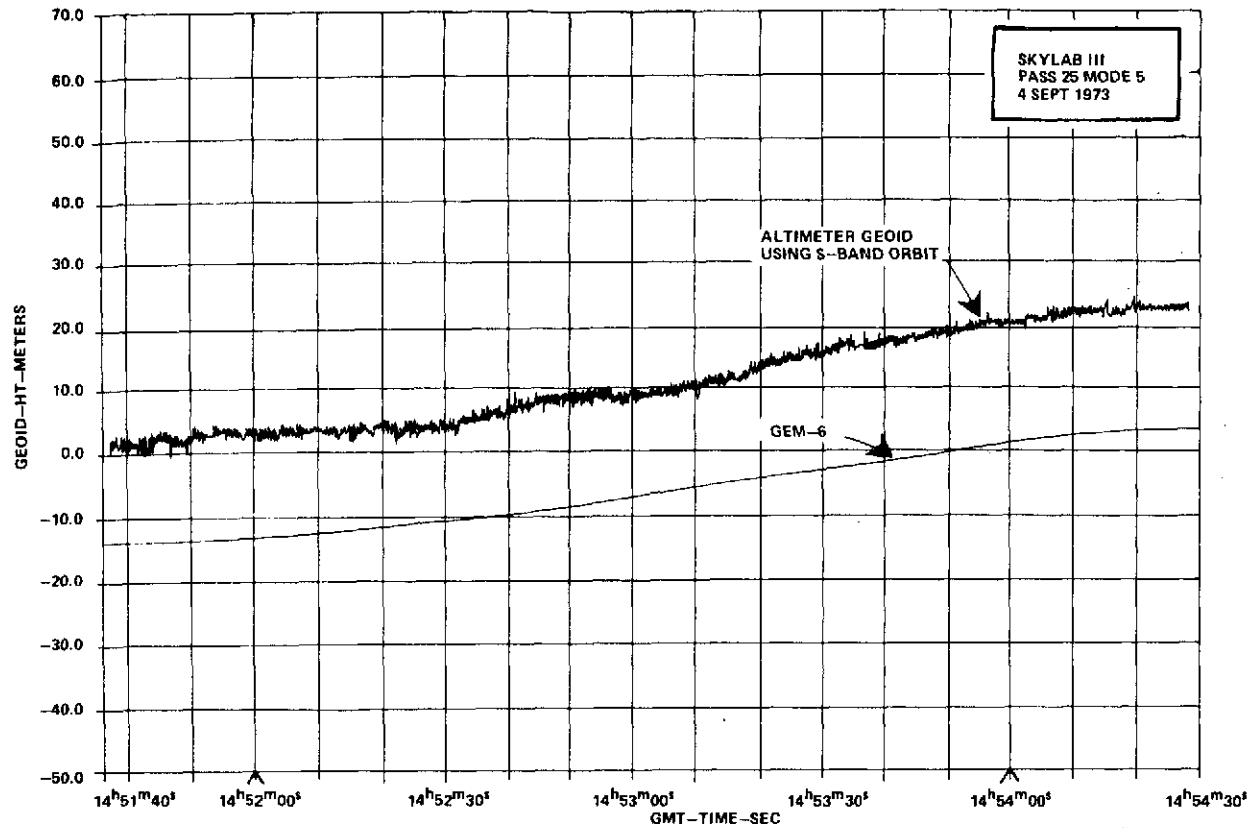


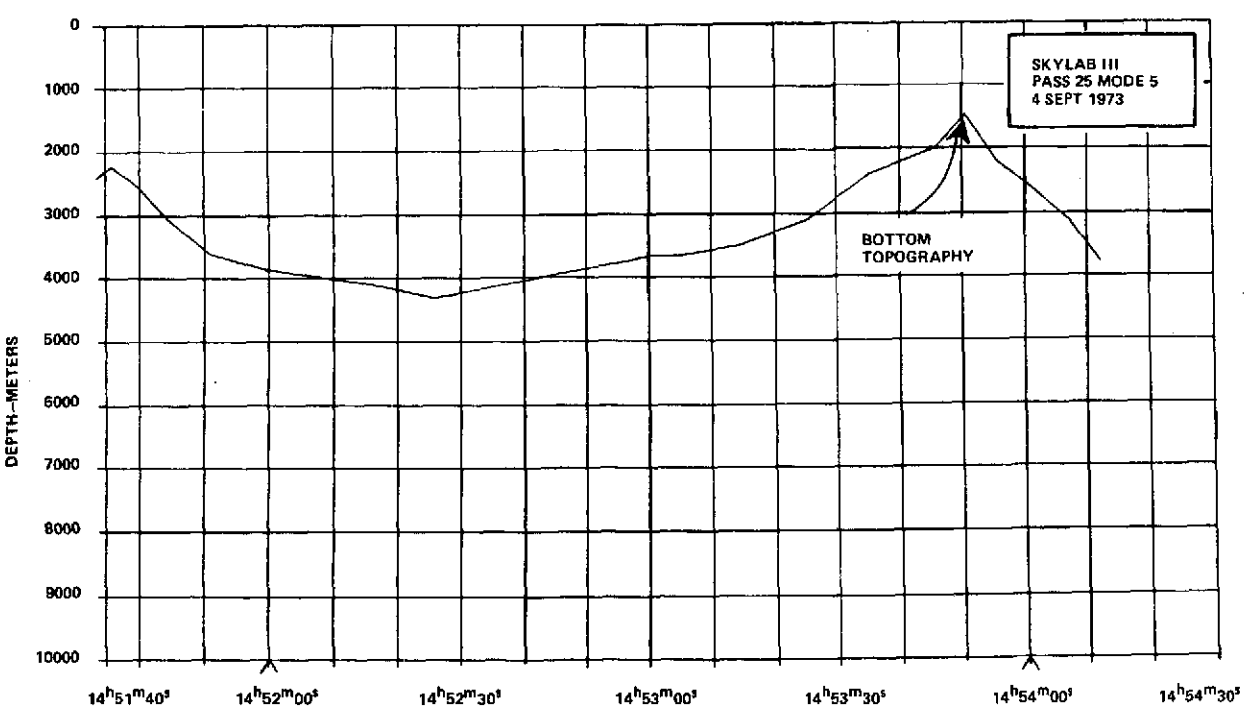


Lat 26.4° 31.7°

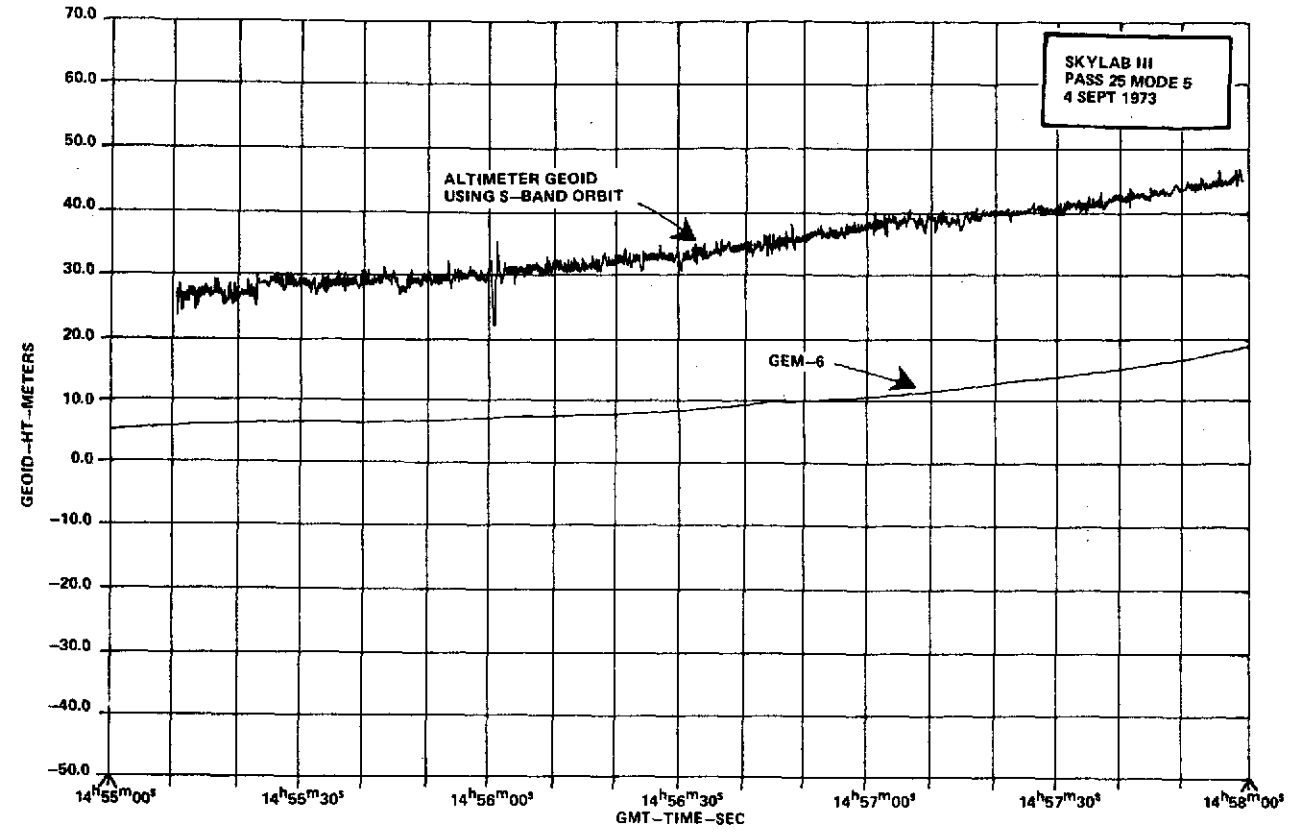
Long 343.8° 349.8°

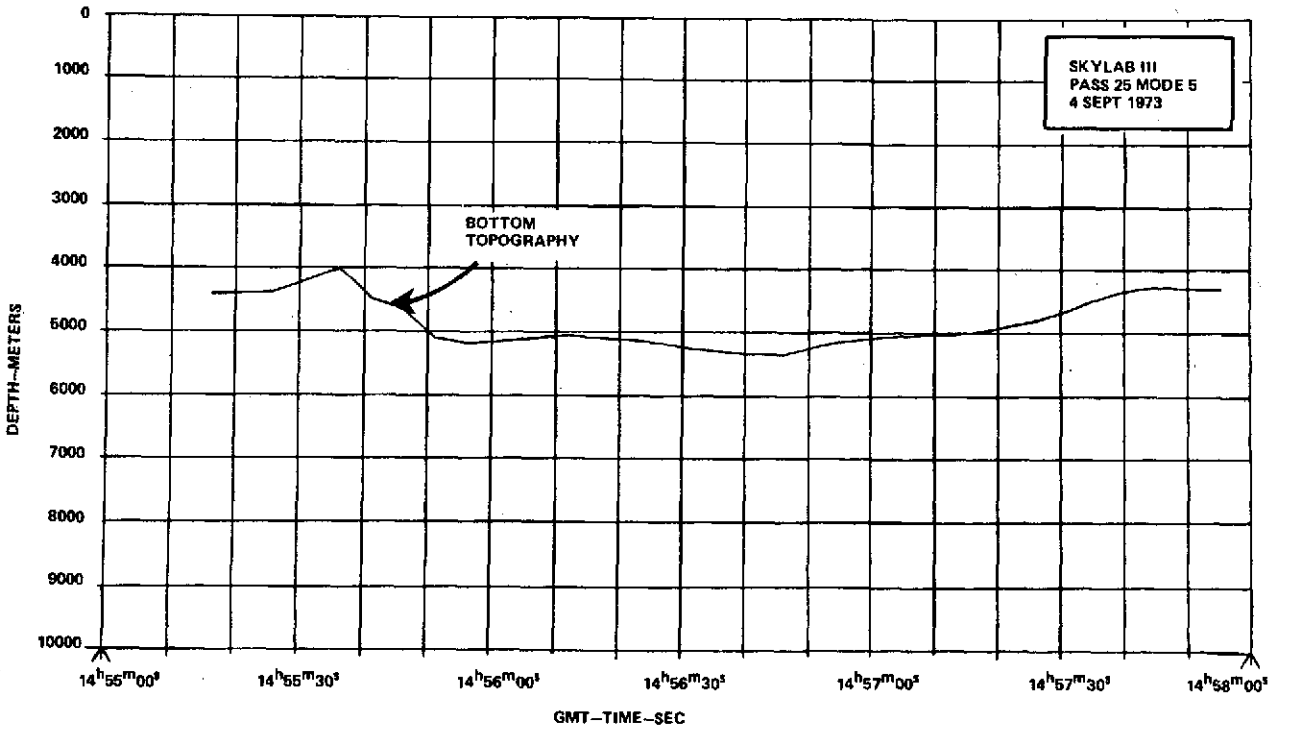
MAP NO. 45





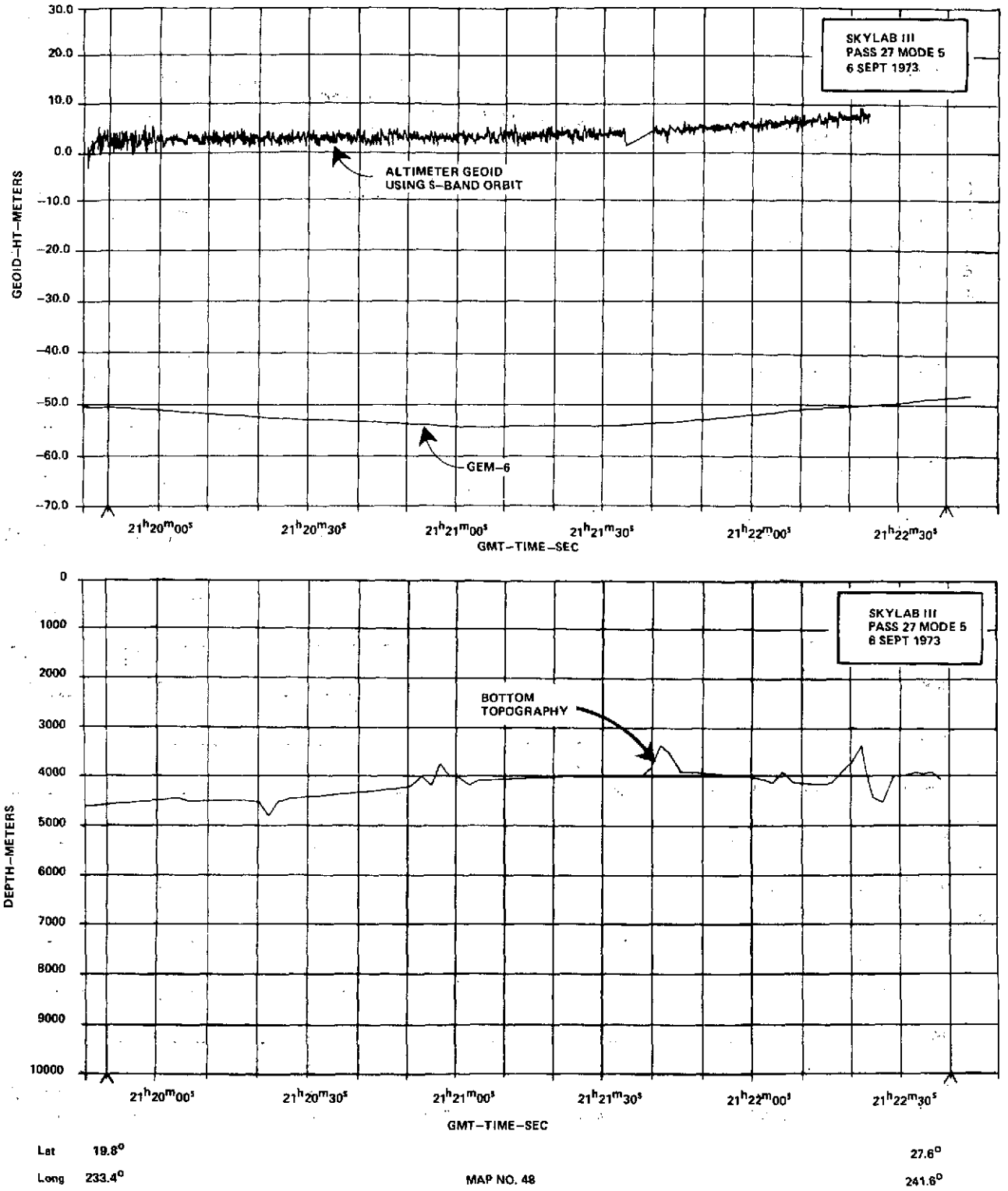
Lat	-4.2°		4.2°
Long	323.3°	MAP NO. 46	329.7°

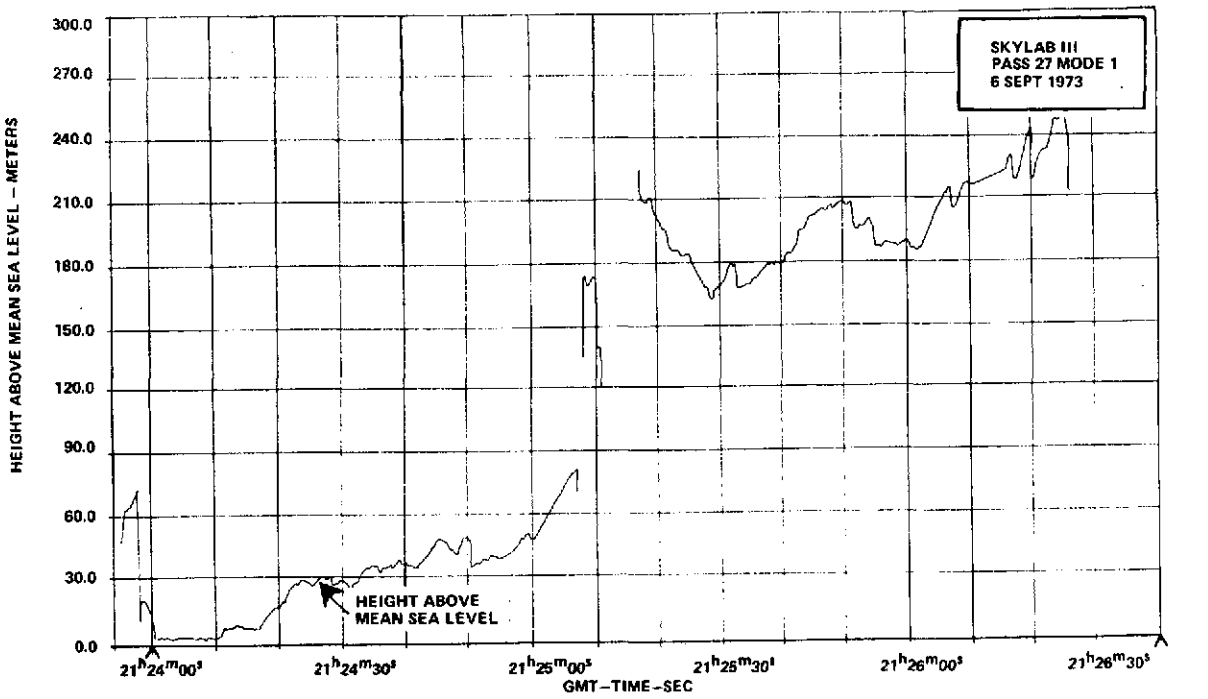




Lat 5.7° 14.6°

Long 330.8° MAP NO. 47 337.7°

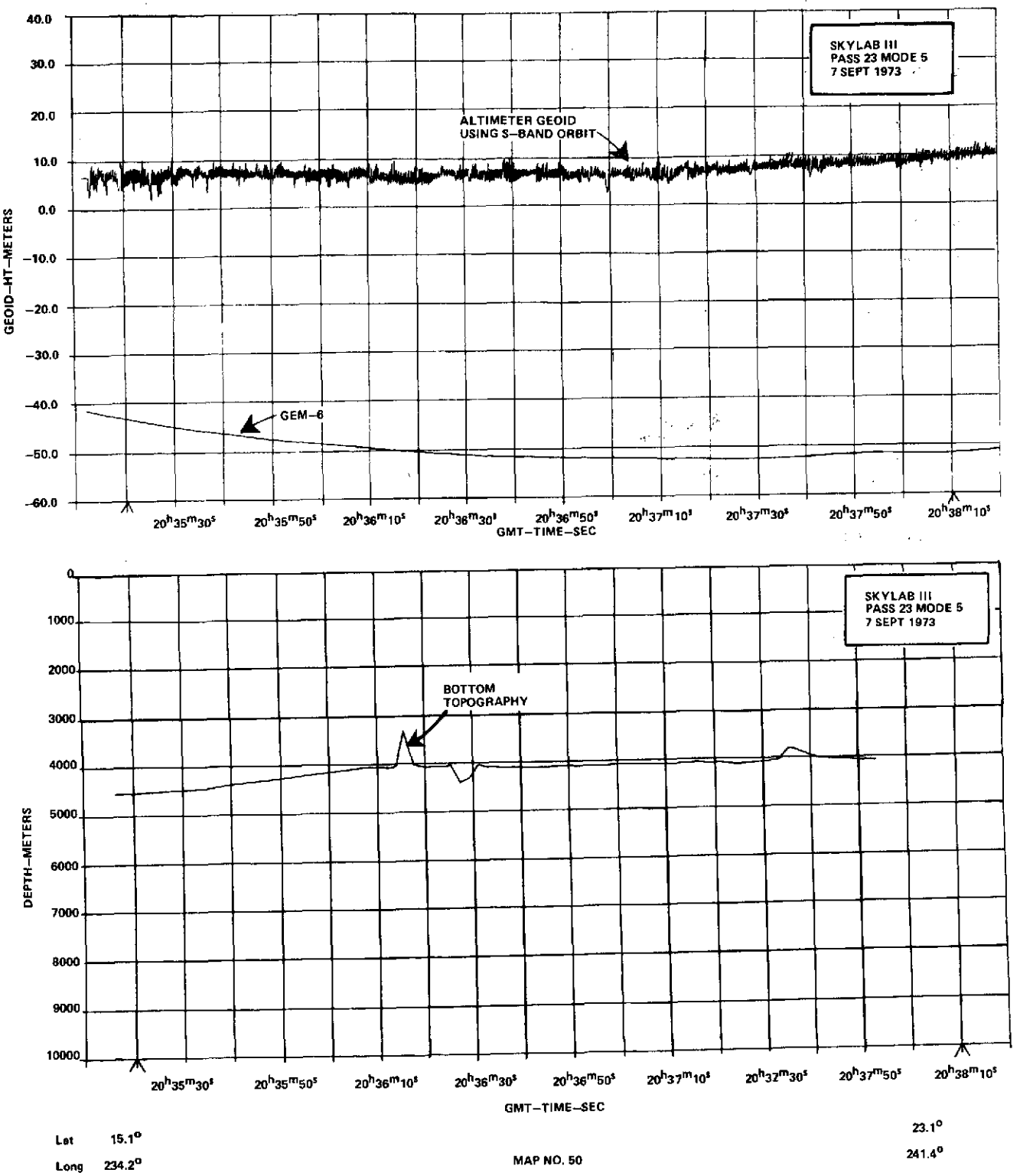

SKYLAB III
PASS 27 MODE 5
6 SEPT 1973
ALTIMETER GEOID
USING S-BAND ORBIT
GEM-6
GEOID-HT-METERS
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
21h20m00s
21h20m30s
21h21m00s
21h21m30s
21h22m00s
21h22m30s
GMT-TIME-SEC
SKYLAB III
PASS 27 MODE 5
6 SEPT 1973
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
21h20m00s
21h20m30s
21h21m00s
21h21m30s
21h22m00s
21h22m30s
GMT-TIME-SEC
Lat 19.8°
Long 233.4°
MAP NO. 48
27.6°
241.6°

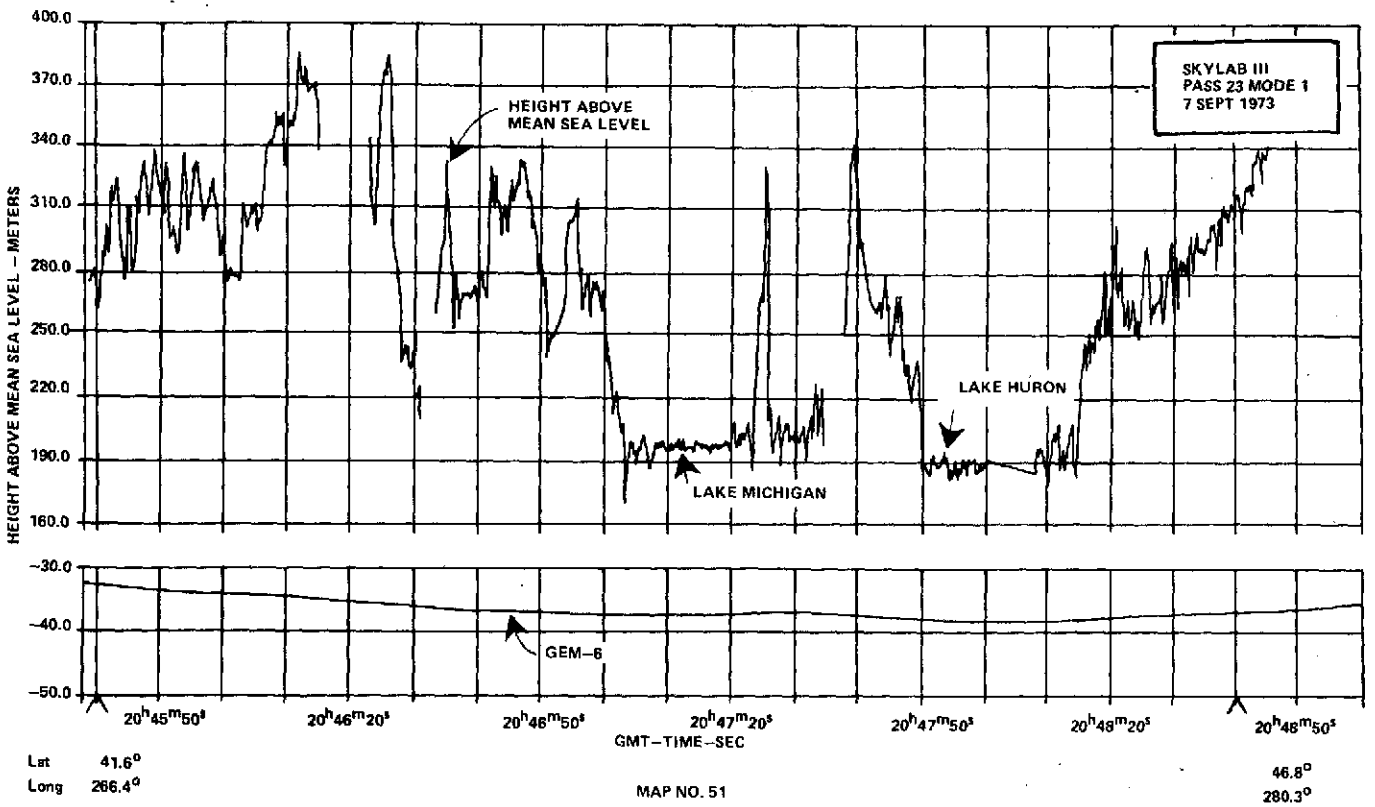


Lat 31.1° 37.6°

Long 245.2° 254.3°

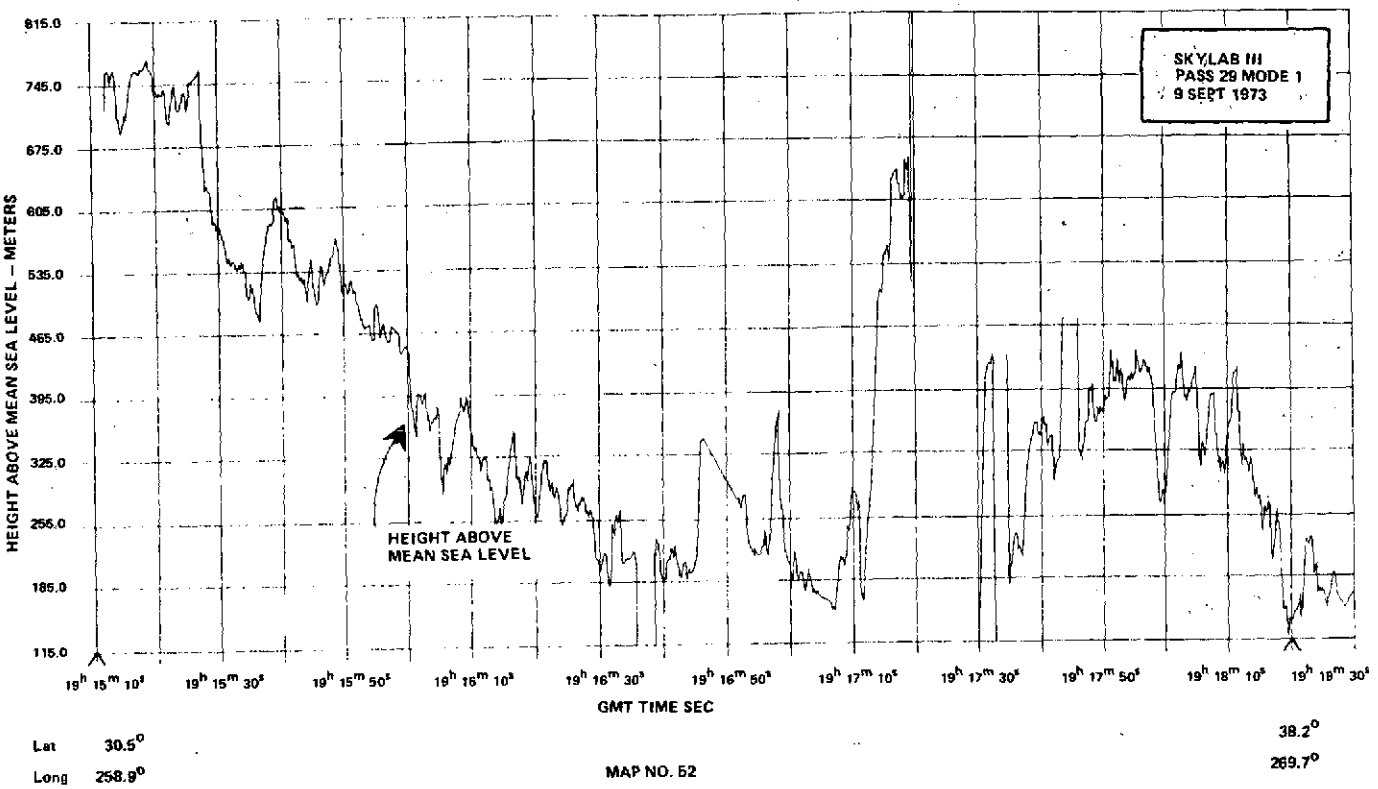
MAP NO. 49


SKYLAB III
PASS 23 MODE 5
7 SEPT 1973
ALTIMETER GEOID
USING S-BAND ORBIT
GEM-6
GEOID-HT-METERS
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
20h35m30s
20h35m50s
20h36m10s
20h36m30s
20h36m50s
20h37m10s
20h37m30s
20h37m50s
20h38m10s
GMT-TIME-SEC
SKYLAB III
PASS 23 MODE 5
7 SEPT 1973
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
20h35m30s
20h35m50s
20h36m10s
20h36m30s
20h36m50s
20h37m10s
20h37m30s
20h37m50s
20h38m10s
GMT-TIME-SEC
Lat 15.1°
Long 234.2°
MAP NO. 50
23.1°
241.4°

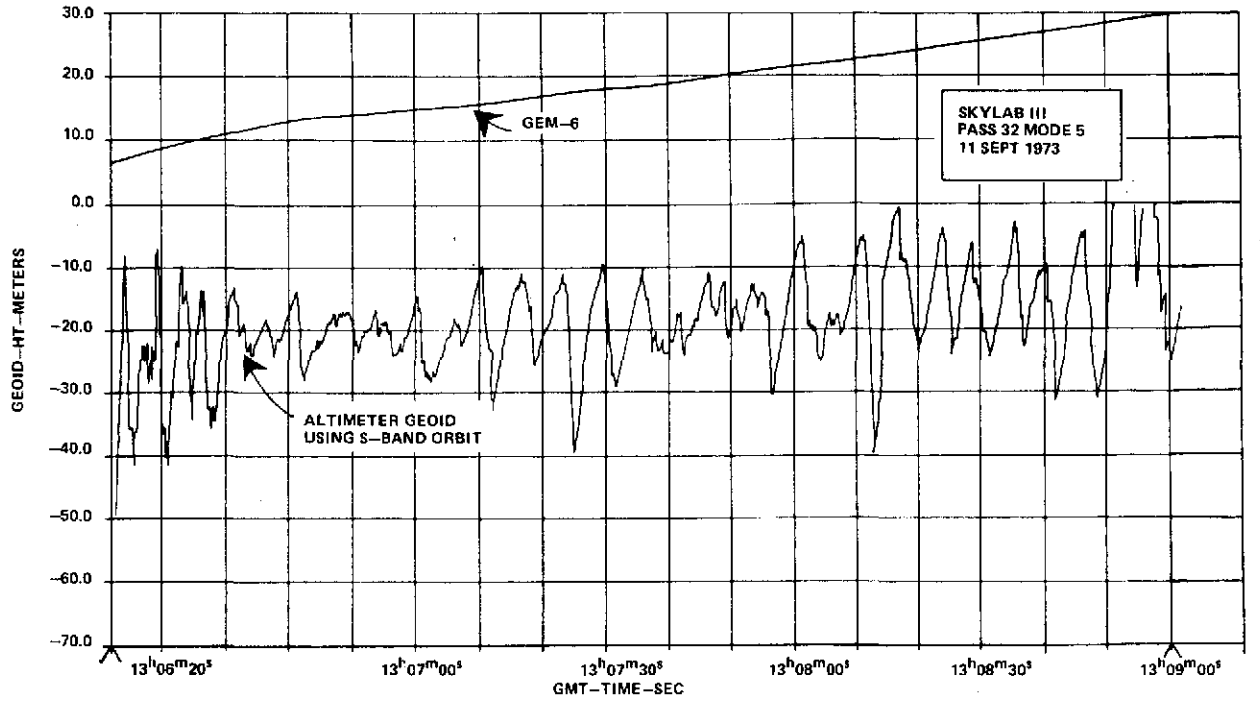


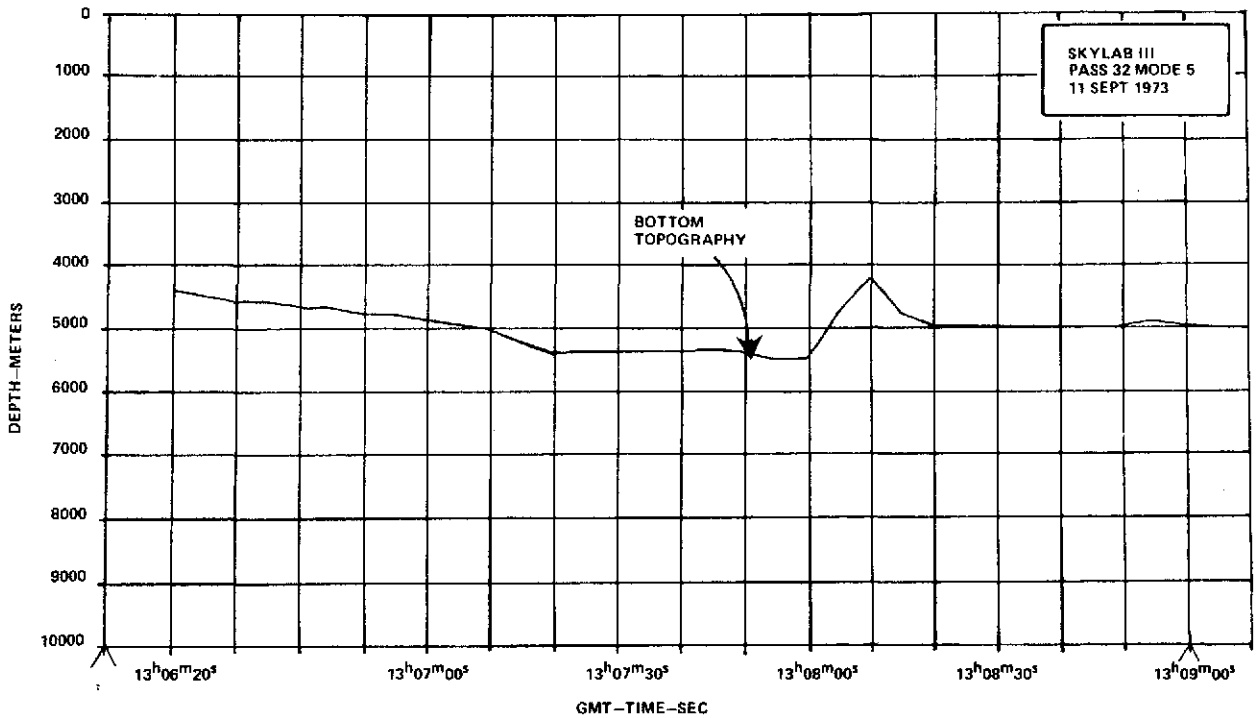
MAP NO. 51

DIFFERENCE IN HEIGHT DETERMINED FOR LAKE HURON AND LAKE MICHIGAN IS DUE TO MODE CHANGE DURING DATA TAKE


SKYLAB III
PASS 29 MODE 1
9 SEPT 1973
HEIGHT ABOVE MEAN SEA LEVEL – METERS
815.0
745.0
675.0
605.0
535.0
465.0
395.0
325.0
255.0
185.0
115.0
HEIGHT ABOVE
MEAN SEA LEVEL
19h 15m 10s
19h 15m 30s
19h 15m 50s
19h 16m 10s
19h 16m 30s
19h 16m 50s
19h 17m 10s
19h 17m 30s
19h 17m 50s
19h 18m 10s
19h 18m 30s
GMT TIME SEC
Lat 30.5°
Long 258.9°
38.2°
269.7°

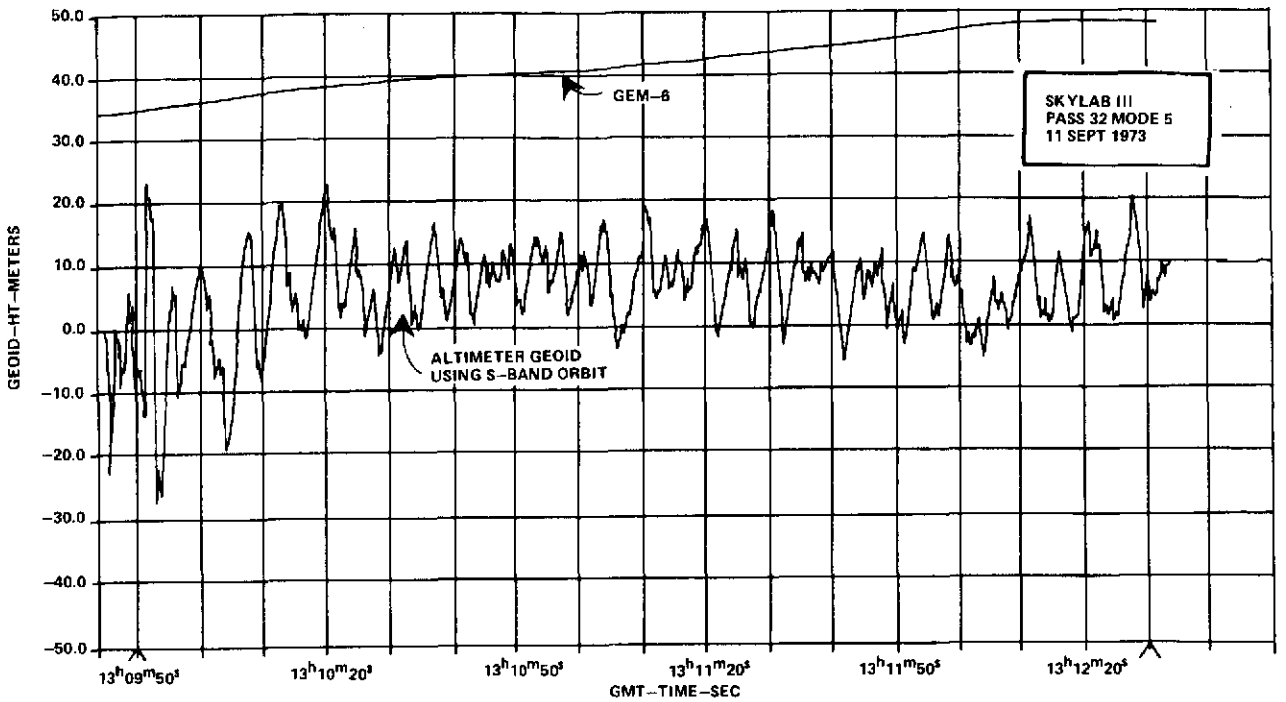
MAP NO. 52

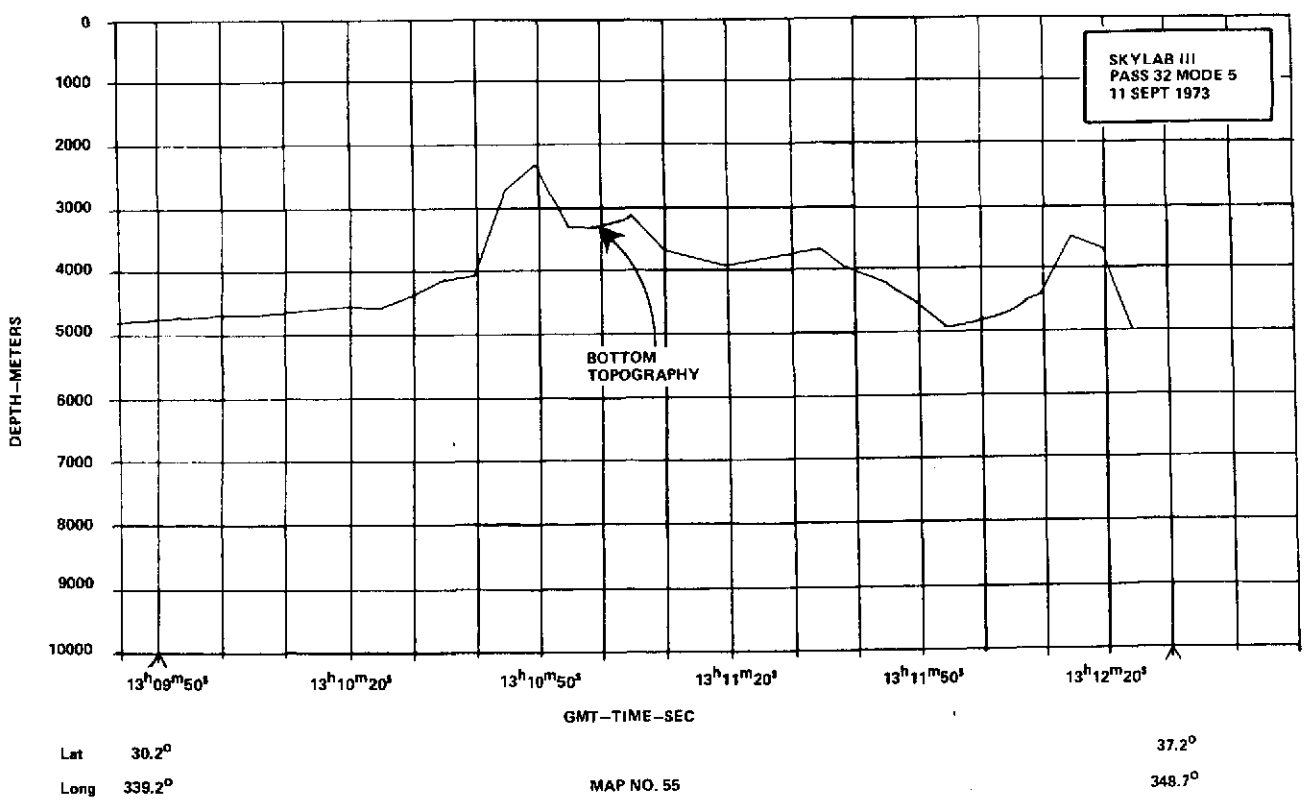




Lat 20.6° 28.0°

Long 329.4° MAP NO. 54 336.7°

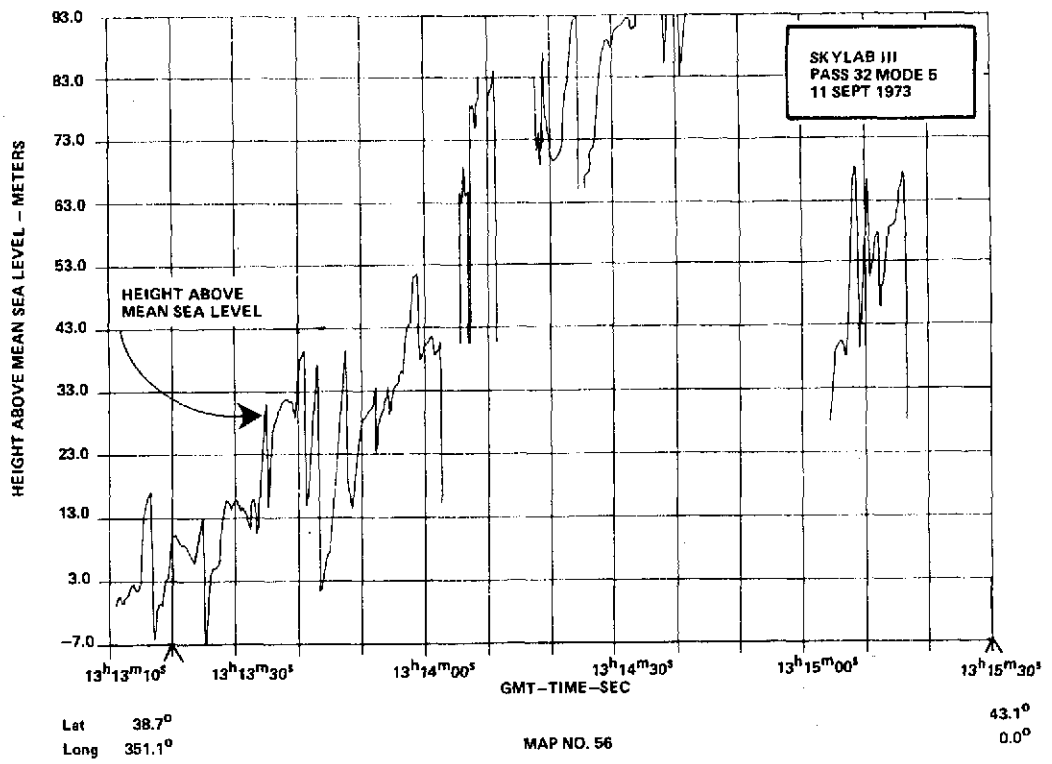


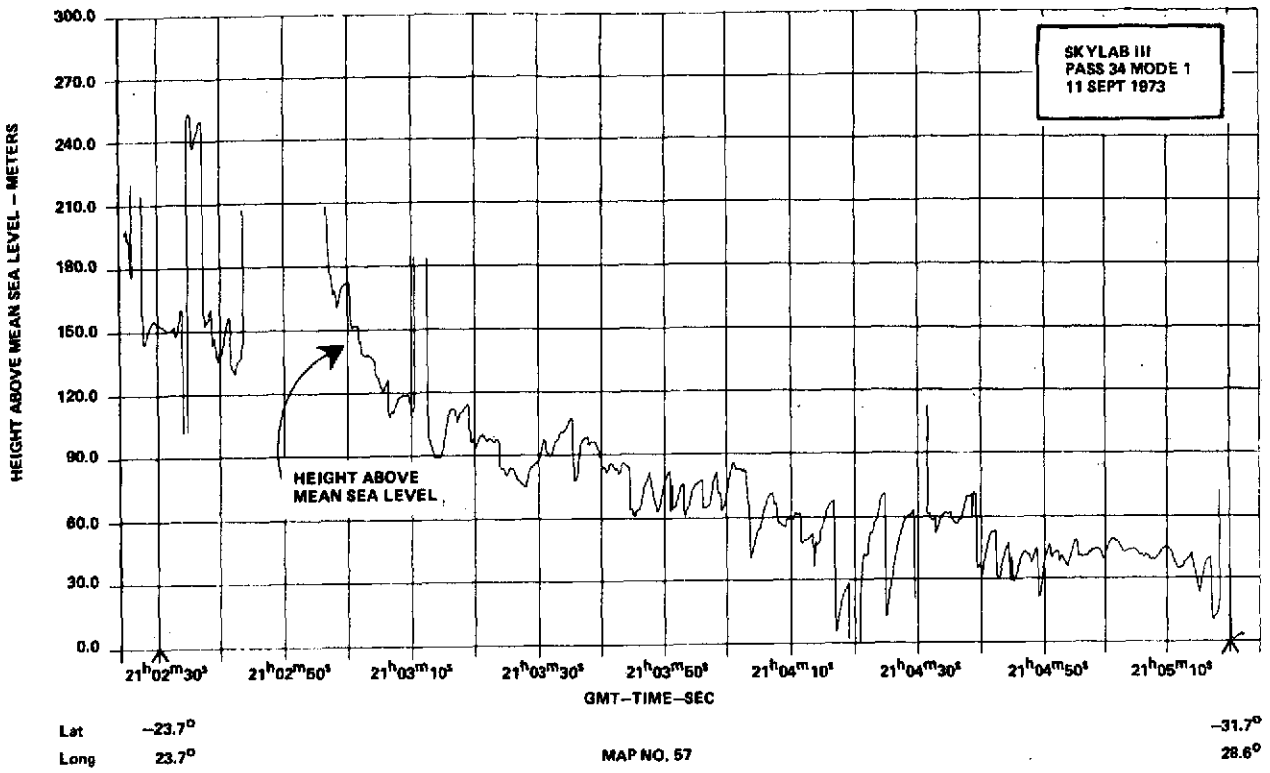


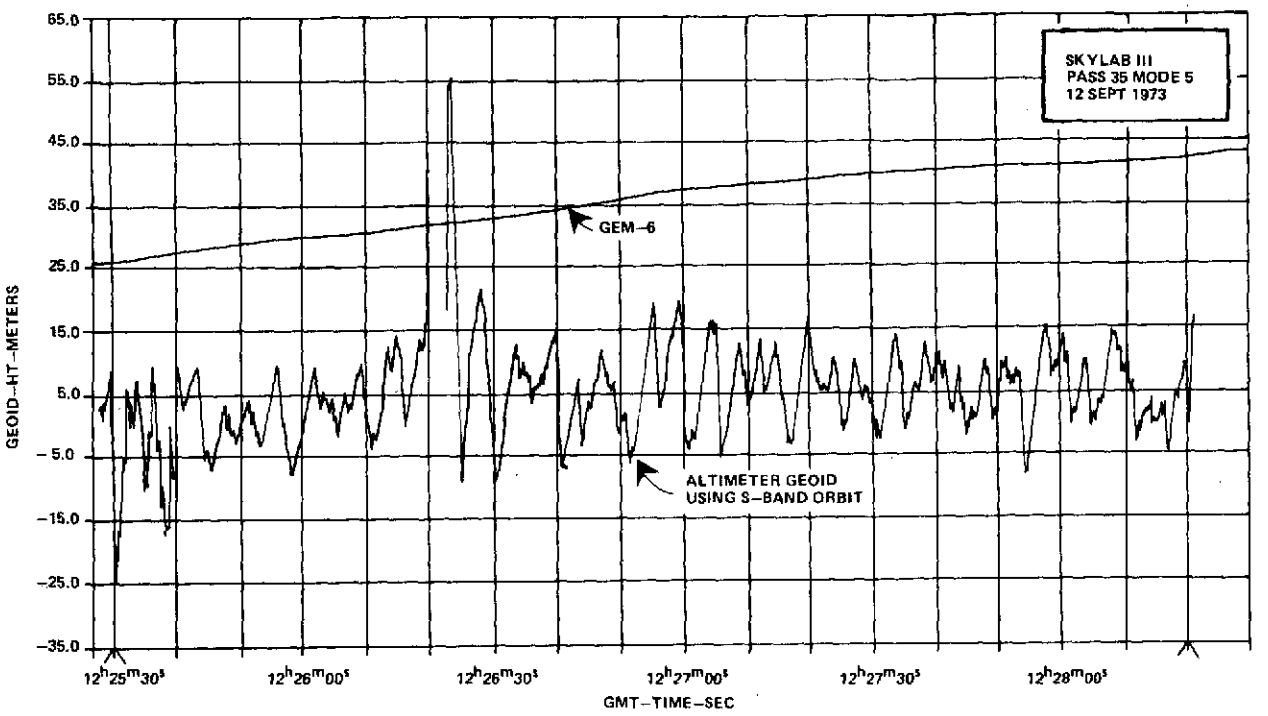
Lat 30.2° 37.2°

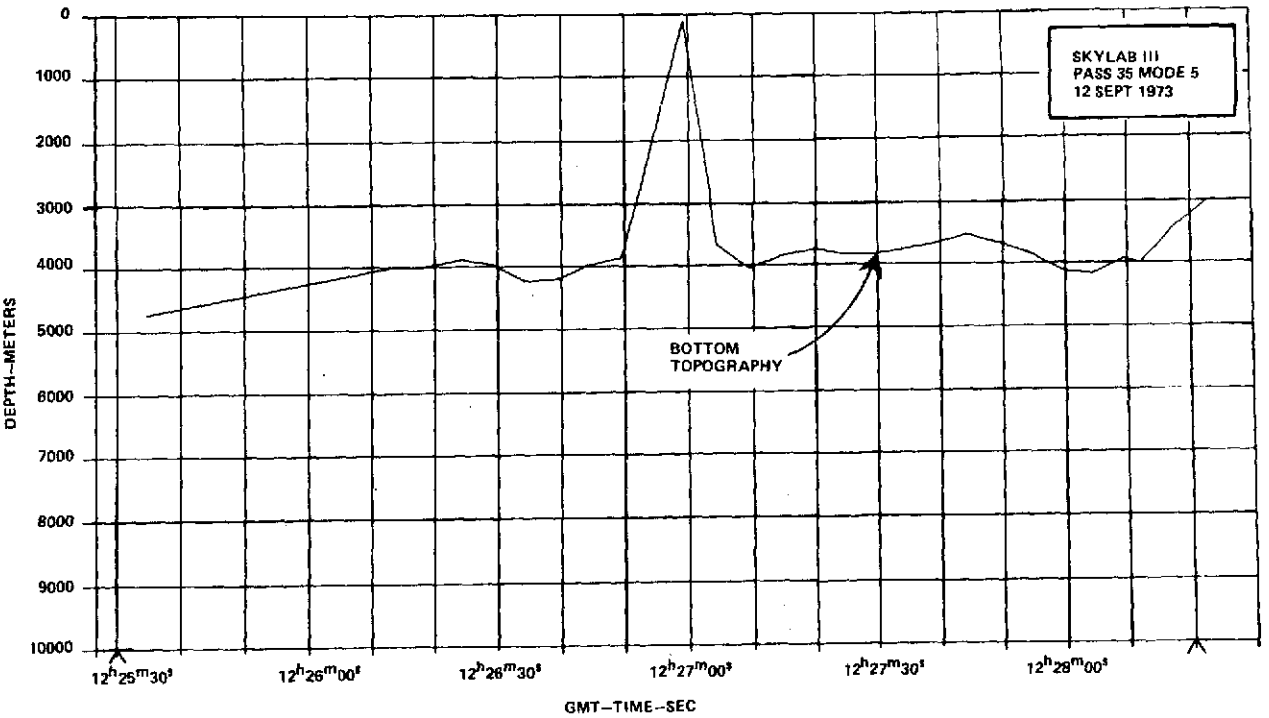
Long 339.2° 348.7°

MAP NO. 55


SKYLAB III
PASS 32 MODE 5
11 SEPT 1973
HEIGHT ABOVE MEAN SEA LEVEL – METERS
93.0
83.0
73.0
63.0
53.0
43.0
33.0
23.0
13.0
3.0
–7.0
HEIGHT ABOVE
MEAN SEA LEVEL
13h13m10s
13h13m30s
13h14m00s
13h14m30s
13h15m00s
13h15m30s
GMT–TIME–SEC
Lat 38.7°
Long 351.1°
43.1°
0.0°
MAP NO. 56


SKYLAB III
PASS 34 MODE 1
11 SEPT 1973
HEIGHT ABOVE MEAN SEA LEVEL – METERS
300.0
270.0
240.0
210.0
180.0
150.0
120.0
90.0
60.0
30.0
0.0
HEIGHT ABOVE MEAN SEA LEVEL
21h02m30s
21h02m50s
21h03m10s
21h03m30s
21h03m50s
21h04m10s
21h04m30s
21h04m50s
21h05m10s
GMT–TIME–SEC
Lat –23.7° –31.7°
Long 23.7° 28.6°
MAP NO. 57

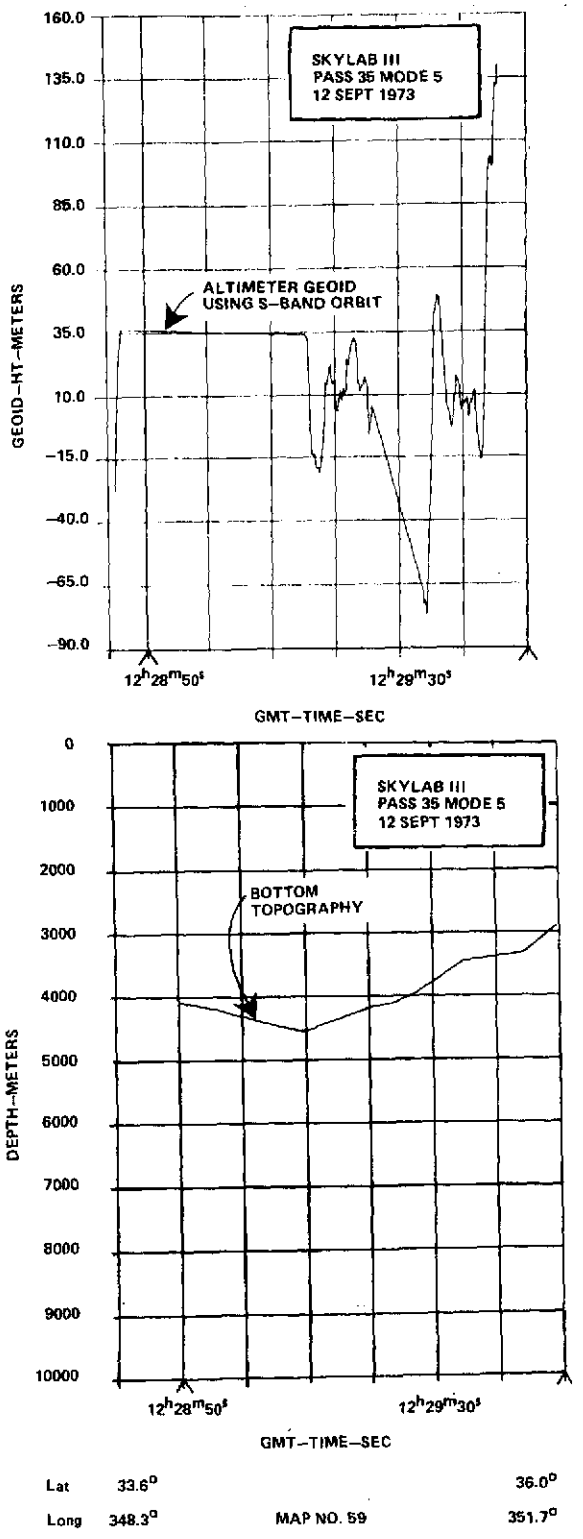


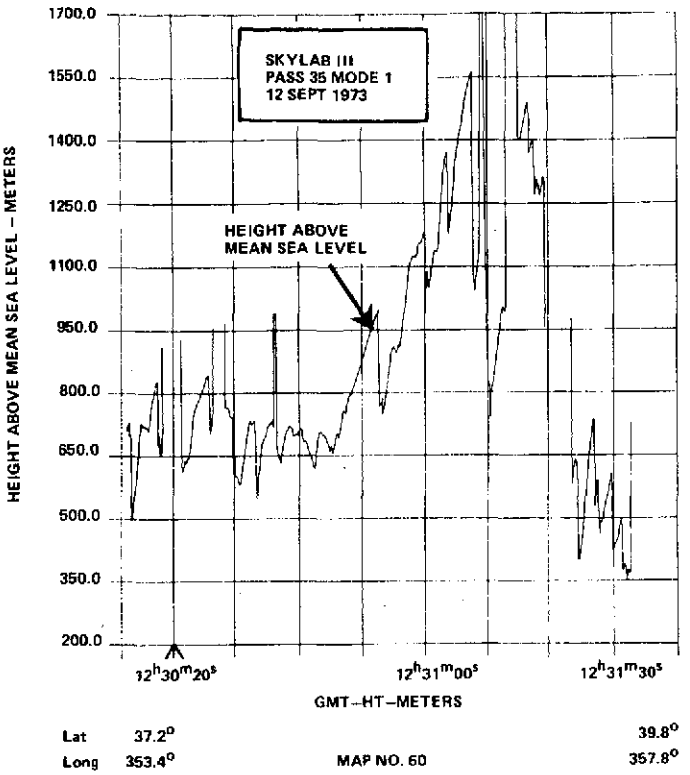


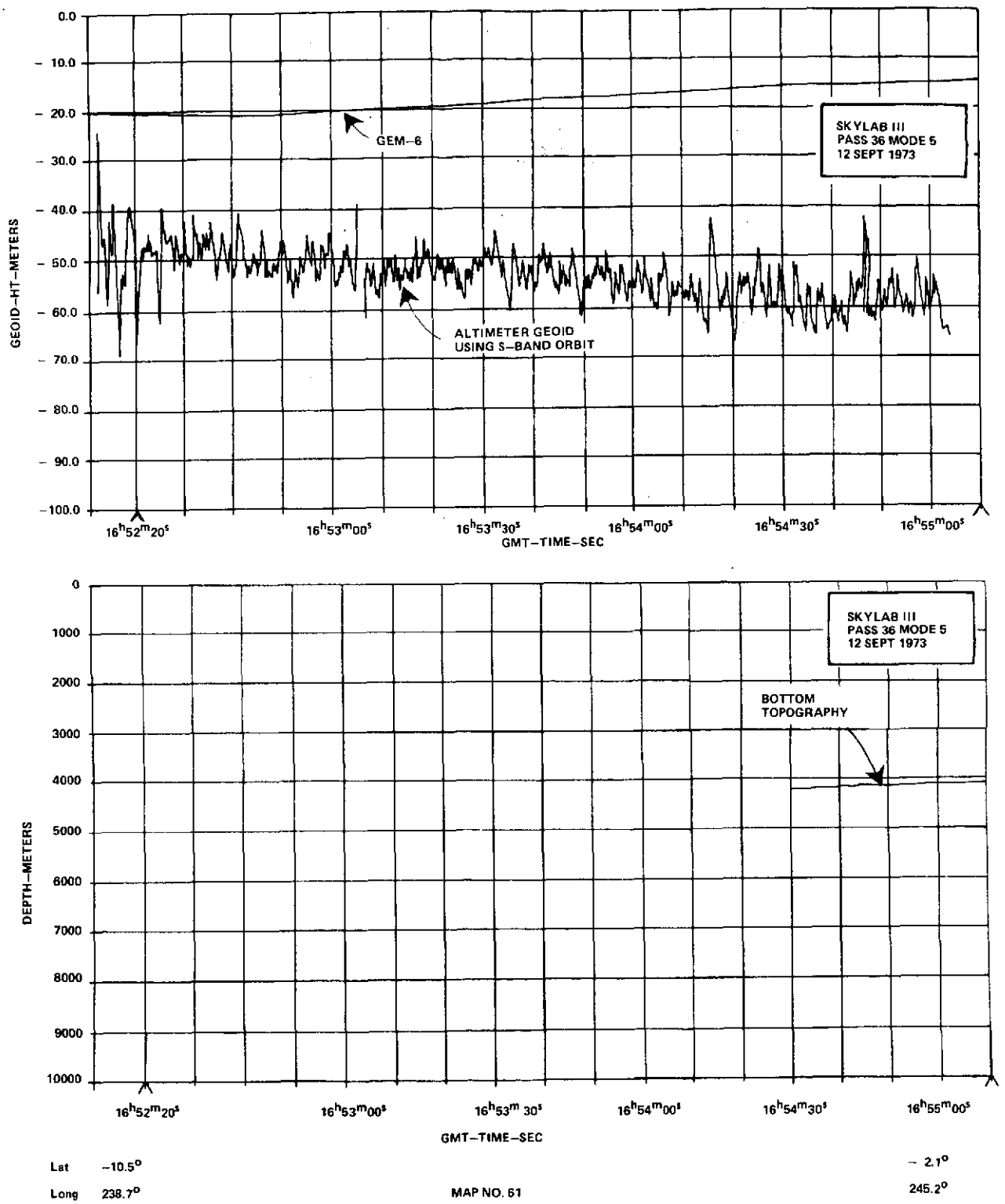
Lat 24.9° 32.4°

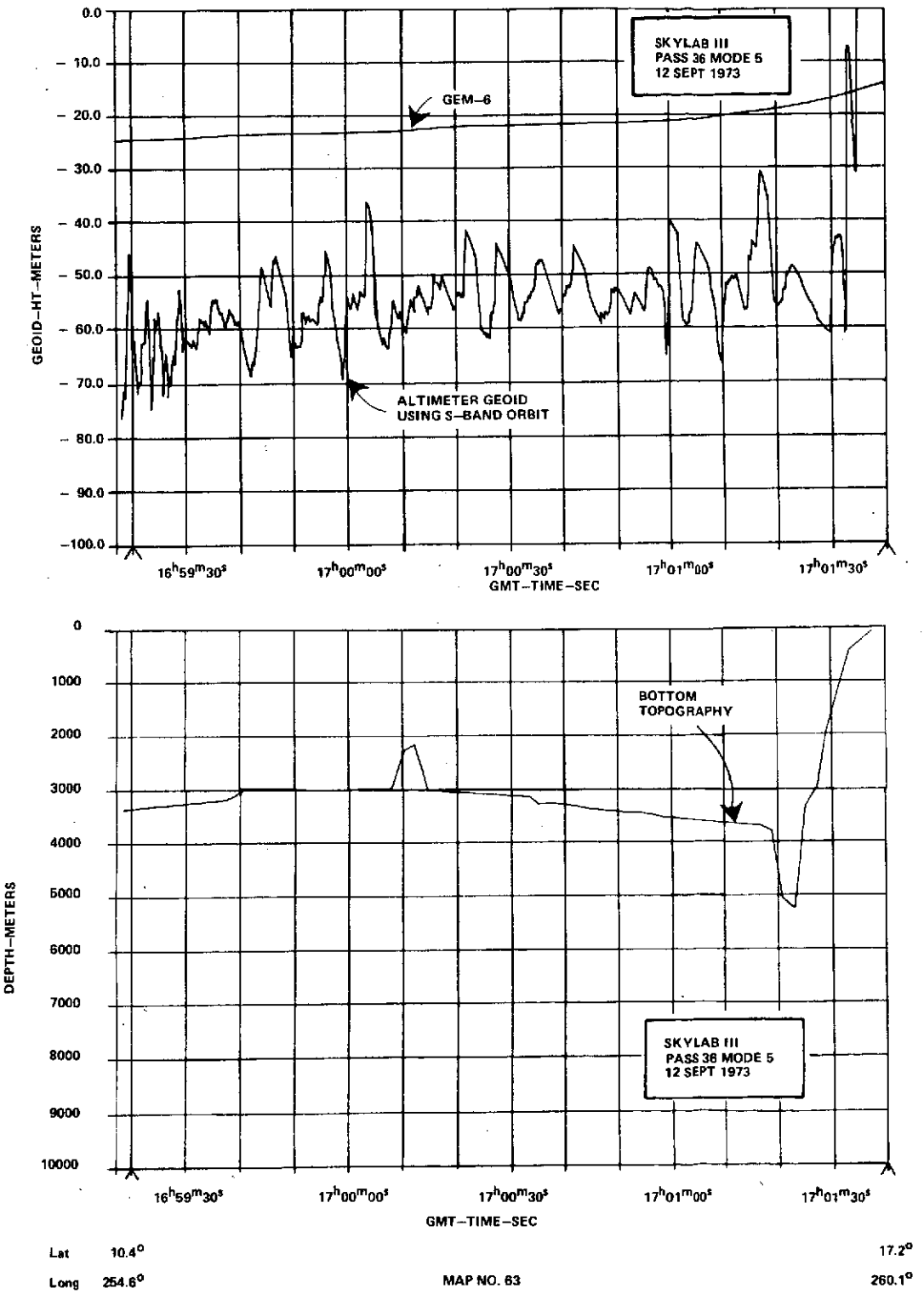
Long 338.2° 346.6°

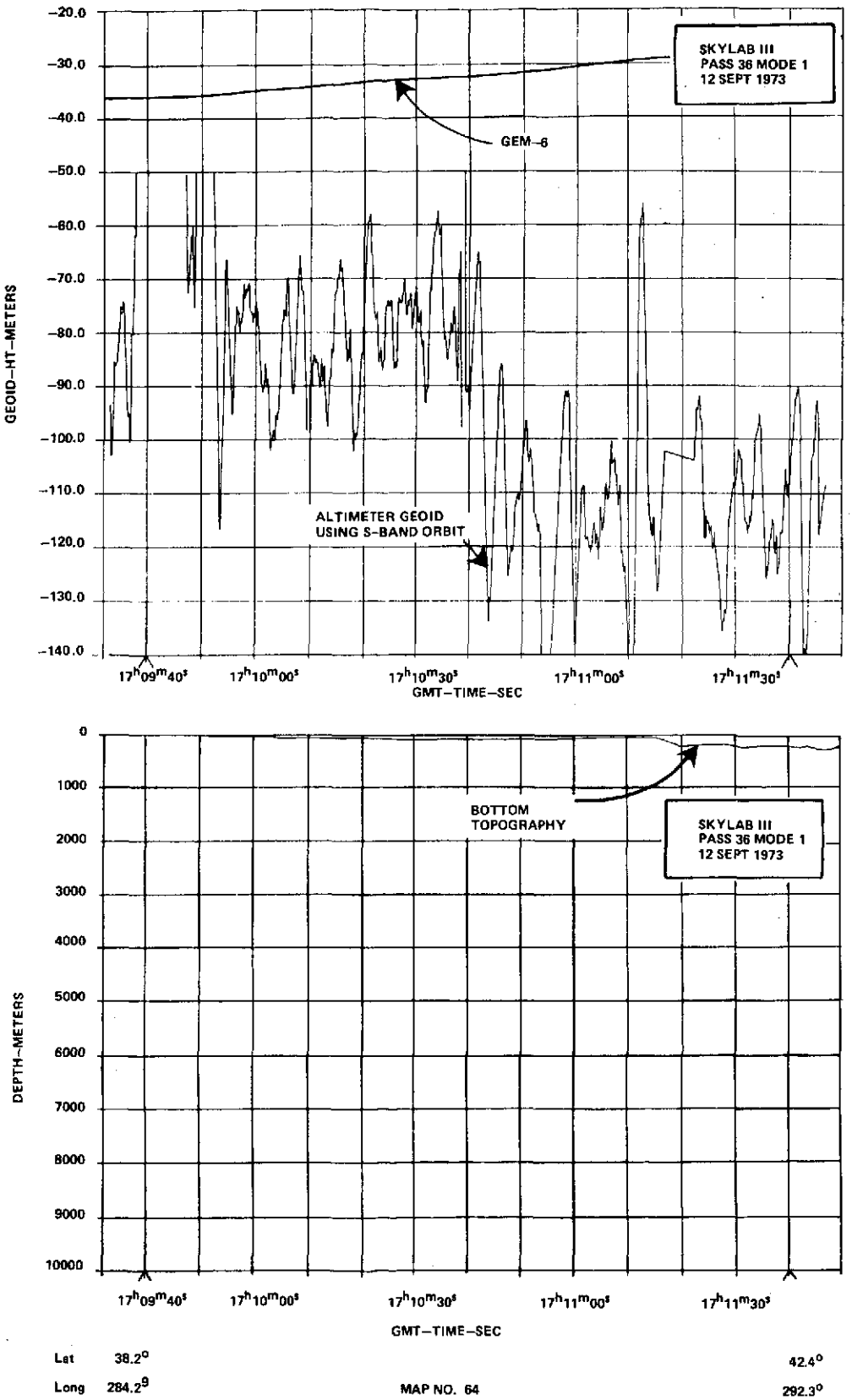
MAP NO. 58

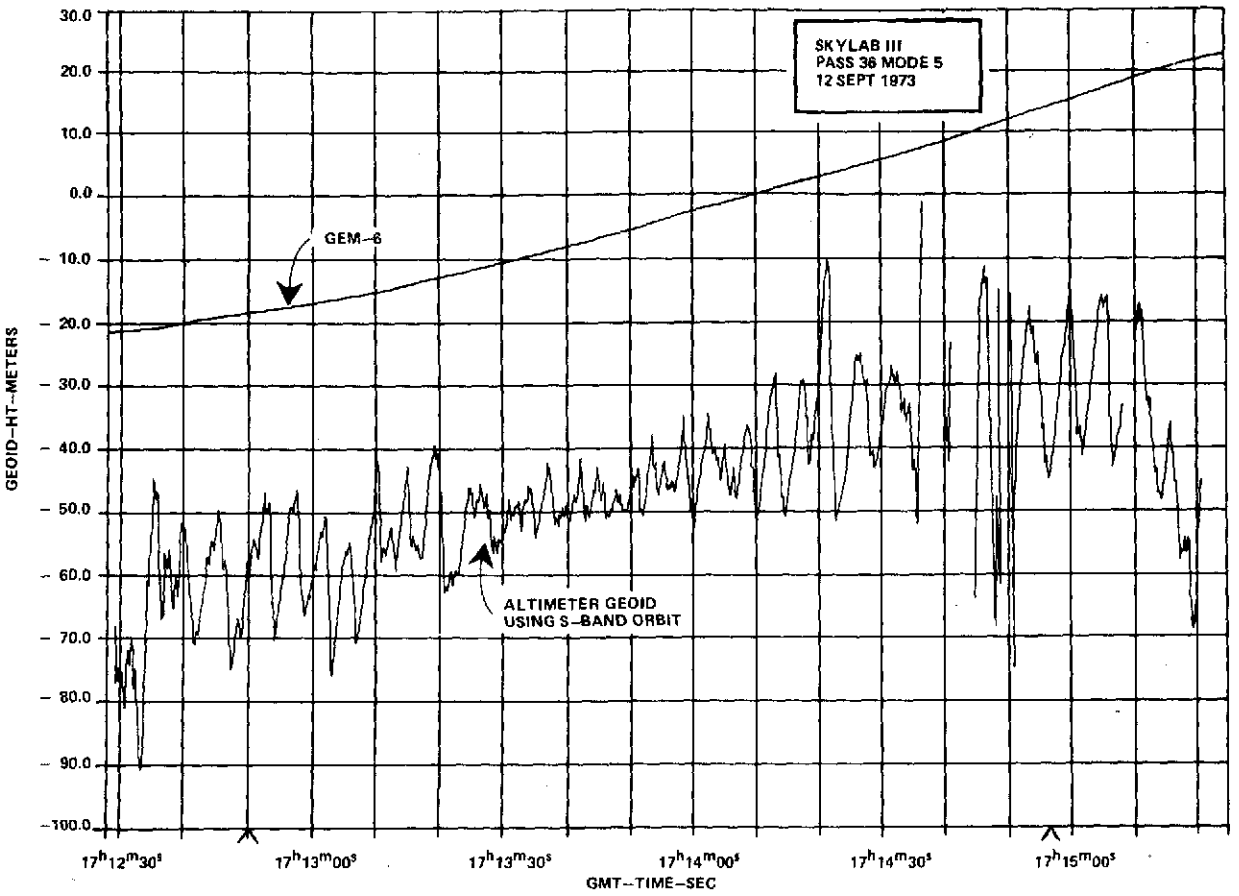

SKYLAB III
PASS 35 MODE 5
12 SEPT 1973
ALTIMETER GEOID
USING S-BAND ORBIT
GEOID-HT-METERS
160.0
135.0
110.0
85.0
60.0
35.0
10.0
-15.0
-40.0
-65.0
-90.0
12h28m50s
12h29m30s
GMT-TIME-SEC
SKYLAB III
PASS 35 MODE 5
12 SEPT 1973
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
12h28m50s
12h29m30s
GMT-TIME-SEC
Lat 33.6° 36.0°
Long 348.3° MAP NO. 59 351.7°

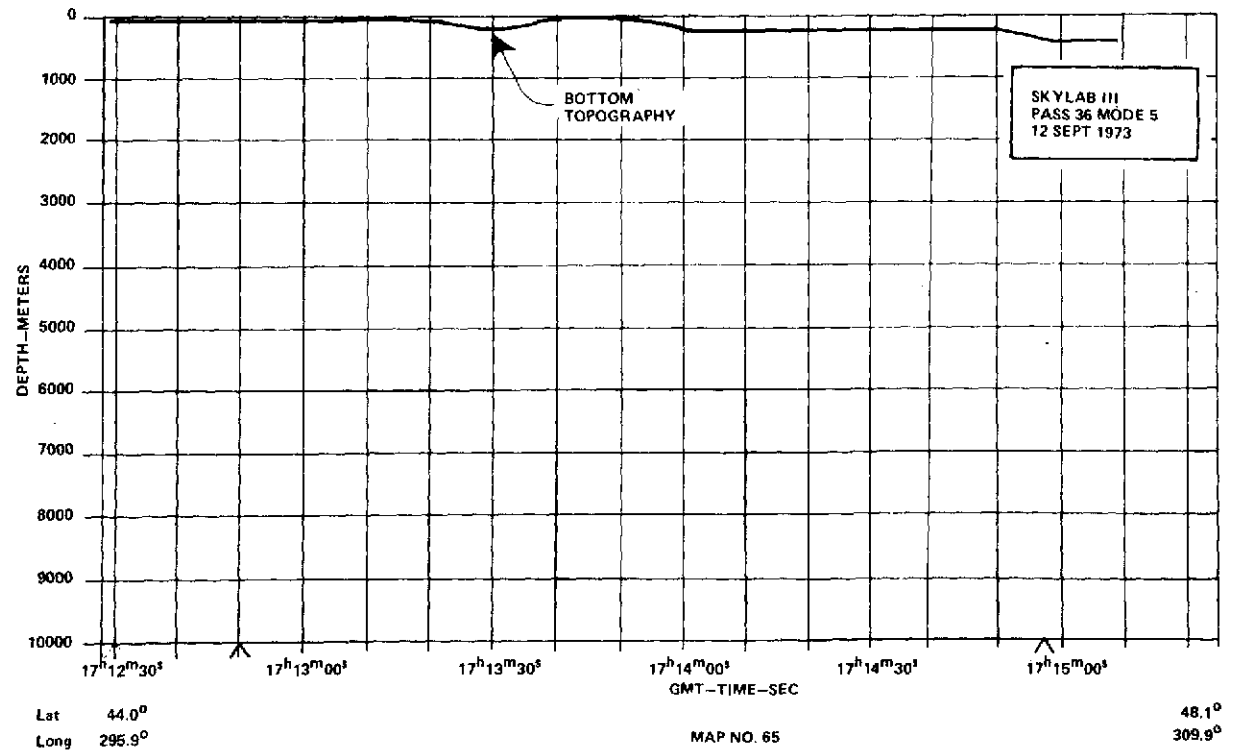

SKYLAB III
PASS 35 MODE 1
12 SEPT 1973
HEIGHT ABOVE
MEAN SEA LEVEL
HEIGHT ABOVE MEAN SEA LEVEL – METERS
1700.0
1550.0
1400.0
1250.0
1100.0
950.0
800.0
650.0
500.0
350.0
200.0
12h30m20s
12h31m00s
12h31m30s
GMT–HT–METERS
Lat 37.2° 39.8°
Long 353.4° MAP NO. 60 357.8°


0.0
– 10.0
– 20.0
– 30.0
– 40.0
– 50.0
– 60.0
– 70.0
– 80.0
– 90.0
–100.0
GEOID–HT–METERS
GEM–6
SKYLAB III
PASS 36 MODE 5
12 SEPT 1973
ALTIMETER GEOID
USING S–BAND ORBIT
16h52m20s
16h53m00s
16h53m30s
16h54m00s
16h54m30s
16h55m00s
GMT–TIME–SEC
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
DEPTH–METERS
SKYLAB III
PASS 36 MODE 5
12 SEPT 1973
BOTTOM
TOPOGRAPHY
16h52m20s
16h53m00s
16h53m 30s
16h54m00s
16h54m30s
16h55m00s
GMT–TIME–SEC
Lat –10.5°
Long 238.7°
MAP NO. 61
– 2.1°
245.2°


SKYLAB III
PASS 36 MODE 5
12 SEPT 1973
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
0.0
– 10.0
– 20.0
– 30.0
– 40.0
– 50.0
– 60.0
– 70.0
– 80.0
– 90.0
–100.0
16h59m30s
17h00m00s
17h00m30s
17h01m00s
17h01m30s
GMT–TIME–SEC
BOTTOM
TOPOGRAPHY
SKYLAB III
PASS 36 MODE 5
12 SEPT 1973
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
16h59m30s
17h00m00s
17h00m30s
17h01m00s
17h01m30s
GMT–TIME–SEC
Lat 10.4°
17.2°
Long 254.6°
MAP NO. 63
260.1°

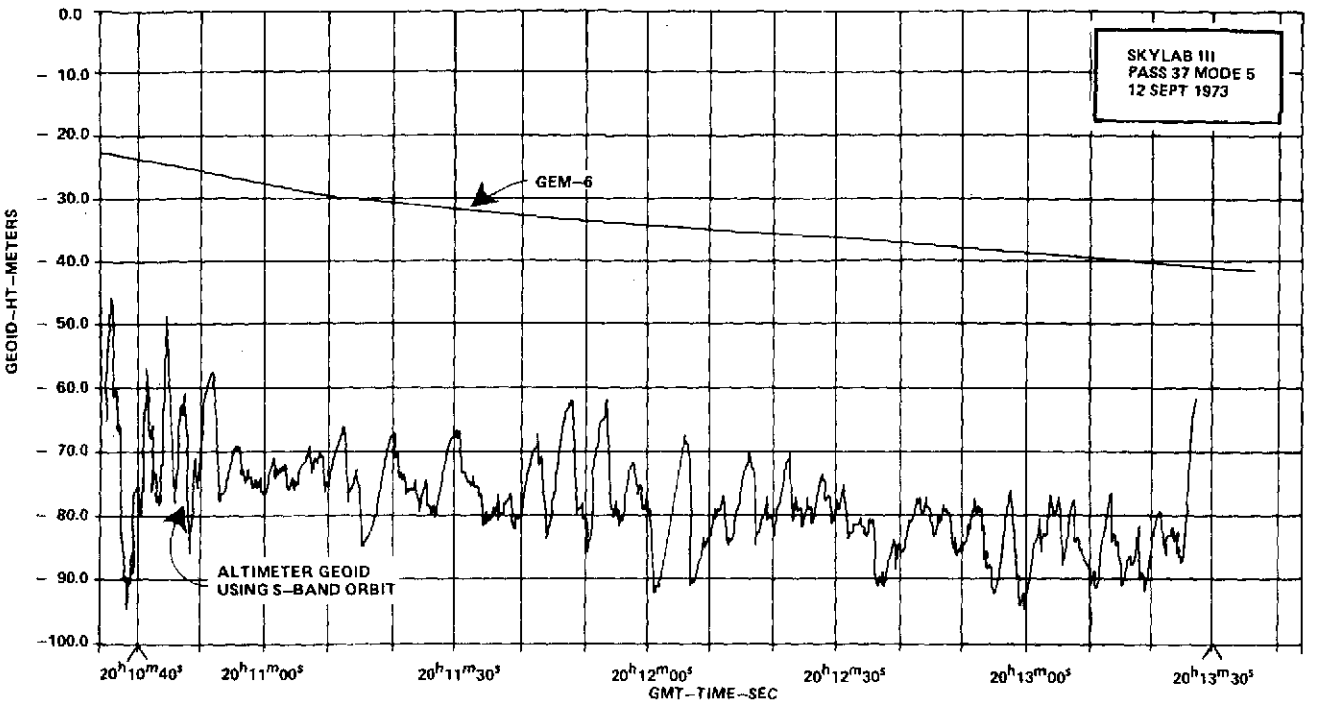

SKYLAB III
PASS 36 MODE 1
12 SEPT 1973
GEM-6
ALTIMETER GEOID
USING S-BAND ORBIT
GEOID-HT-METERS
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
-120.0
-130.0
-140.0
17h09m40s
17h10m00s
17h10m30s
17h11m00s
17h11m30s
GMT-TIME-SEC
BOTTOM
TOPOGRAPHY
SKYLAB III
PASS 36 MODE 1
12 SEPT 1973
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
17h09m40s
17h10m00s
17h10m30s
17h11m00s
17h11m30s
GMT-TIME-SEC
Lat 38.2°
42.4°
Long 284.2°
292.3°
MAP NO. 64

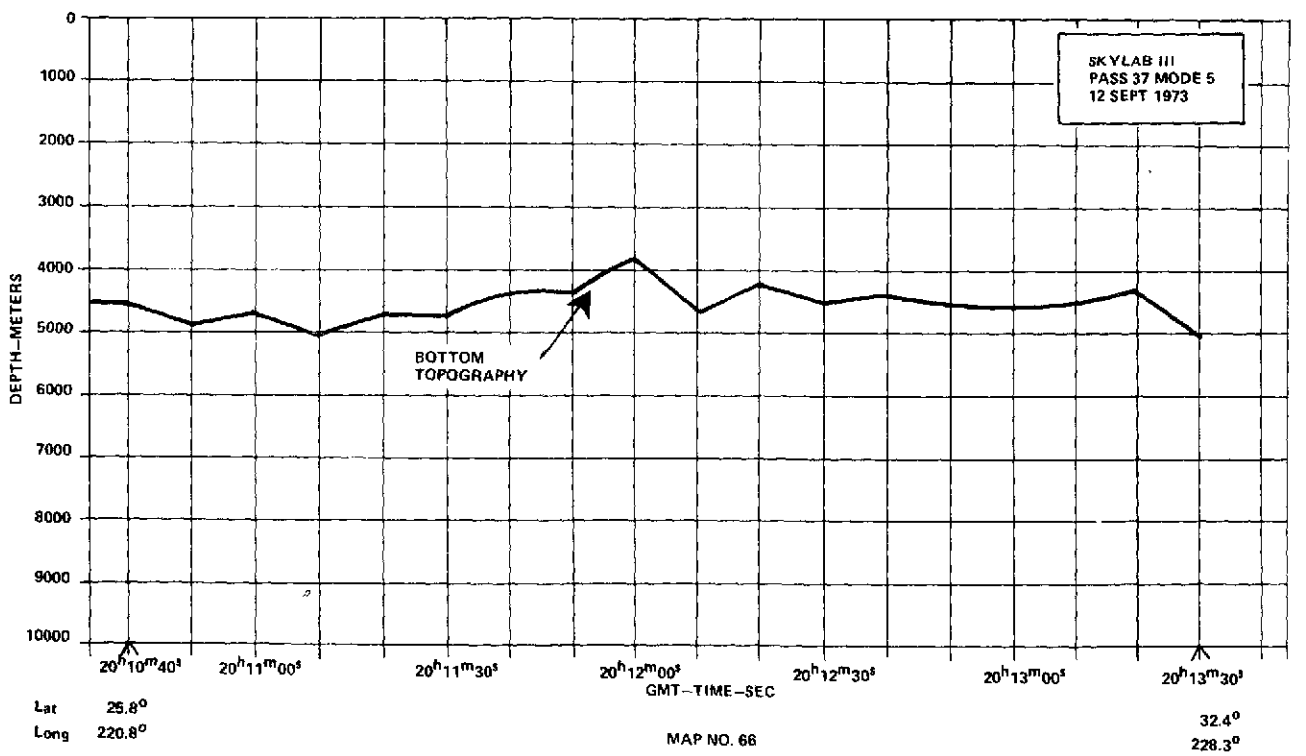




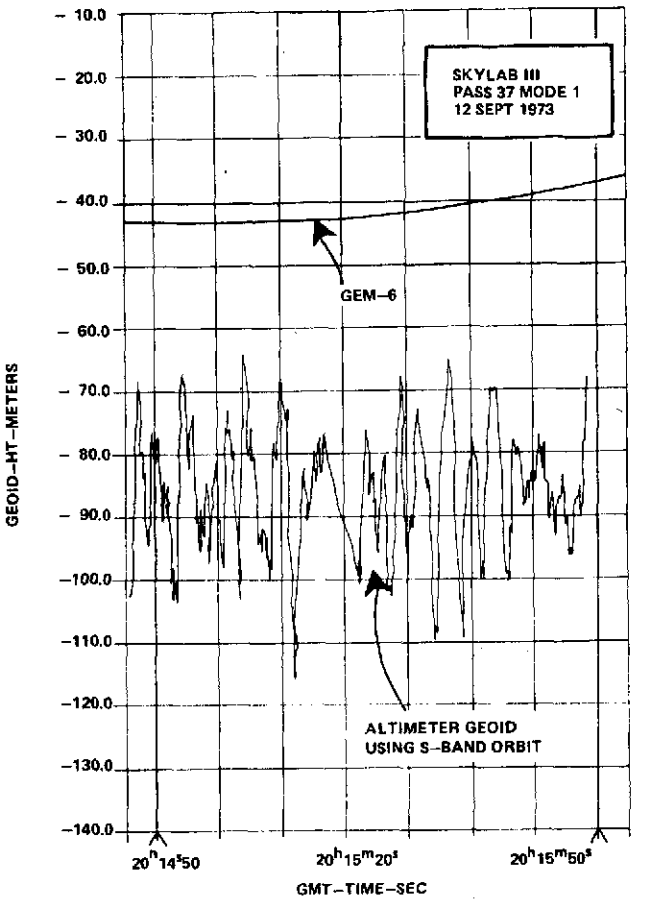
Lat 44.0° 48.1°
Long 295.9° 309.9°

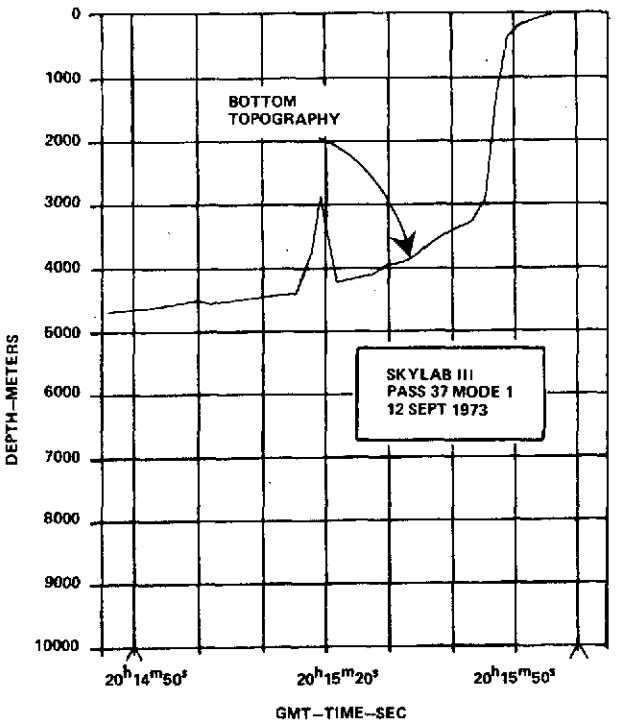
MAP NO. 65


SKYLAB III
PASS 37 MODE 5
12 SEPT 1973
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
0.0
– 10.0
– 20.0
– 30.0
– 40.0
– 50.0
– 60.0
– 70.0
– 80.0
– 90.0
–100.0
20h10m40s
20h11m00s
20h11m30s
20h12m00s
20h12m30s
20h13m00s
20h13m30s
GMT–TIME–SEC

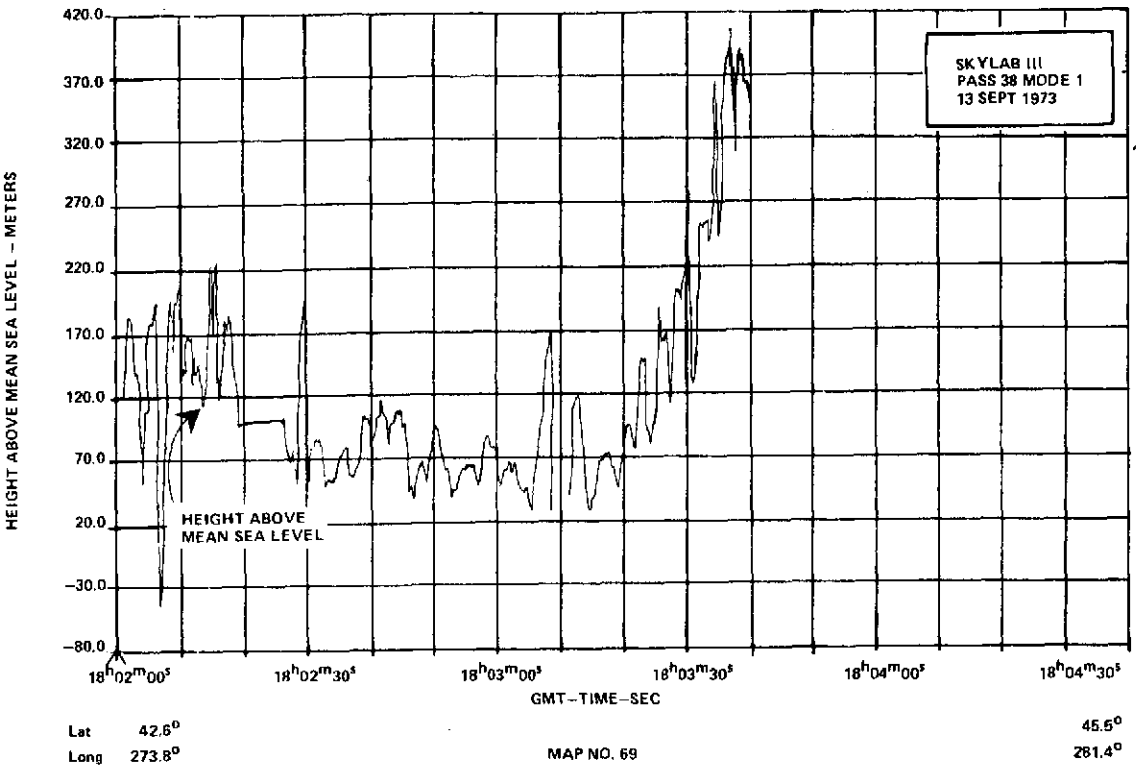

SKYLAB III
PASS 37 MODE 5
12 SEPT 1973
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
20h10m40s
20h11m00s
20h11m30s
20h12m00s
20h12m30s
20h13m00s
20h13m30s
GMT–TIME–SEC
Lat 25.8°
Long 220.8°
32.4°
228.3°

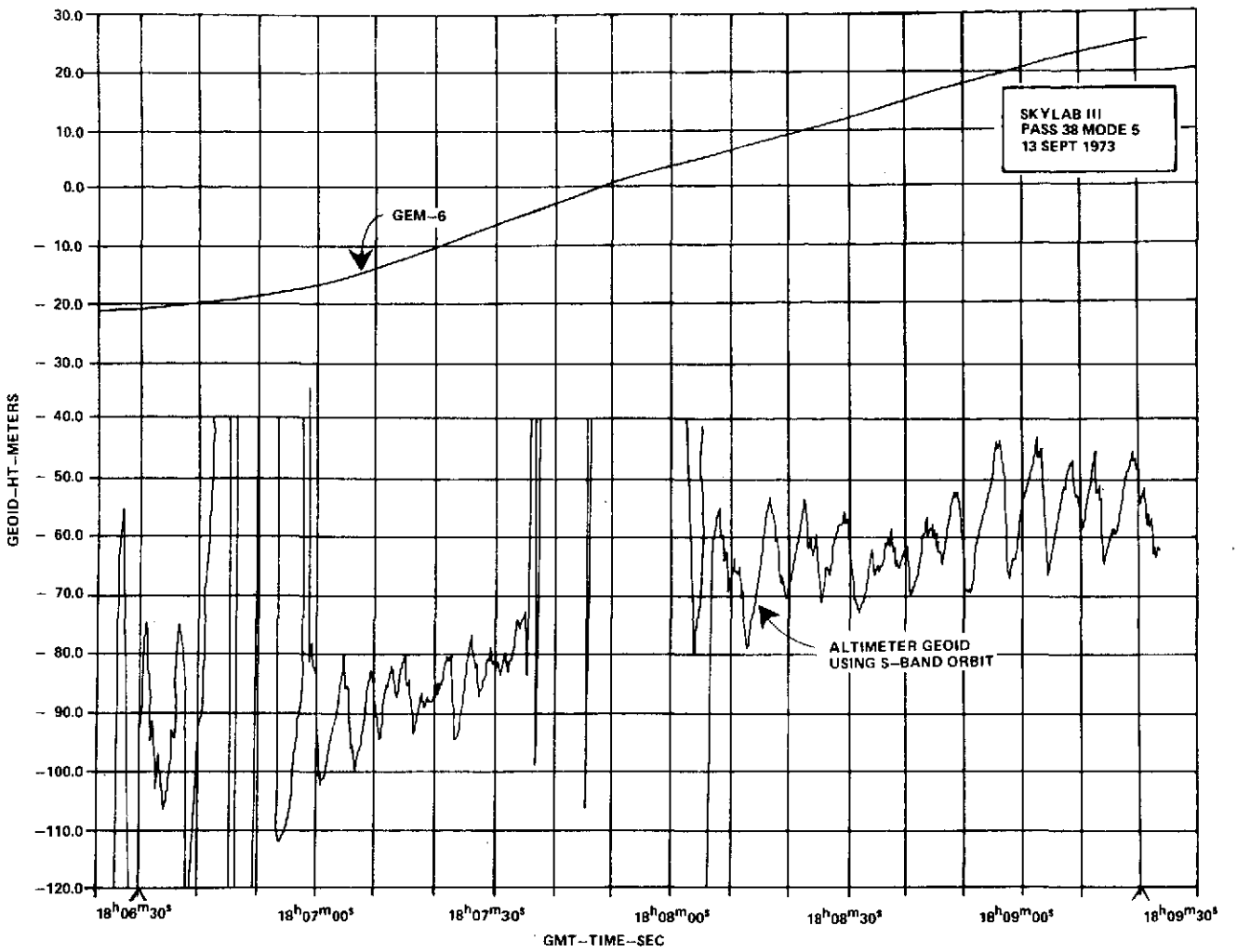
MAP NO. 66

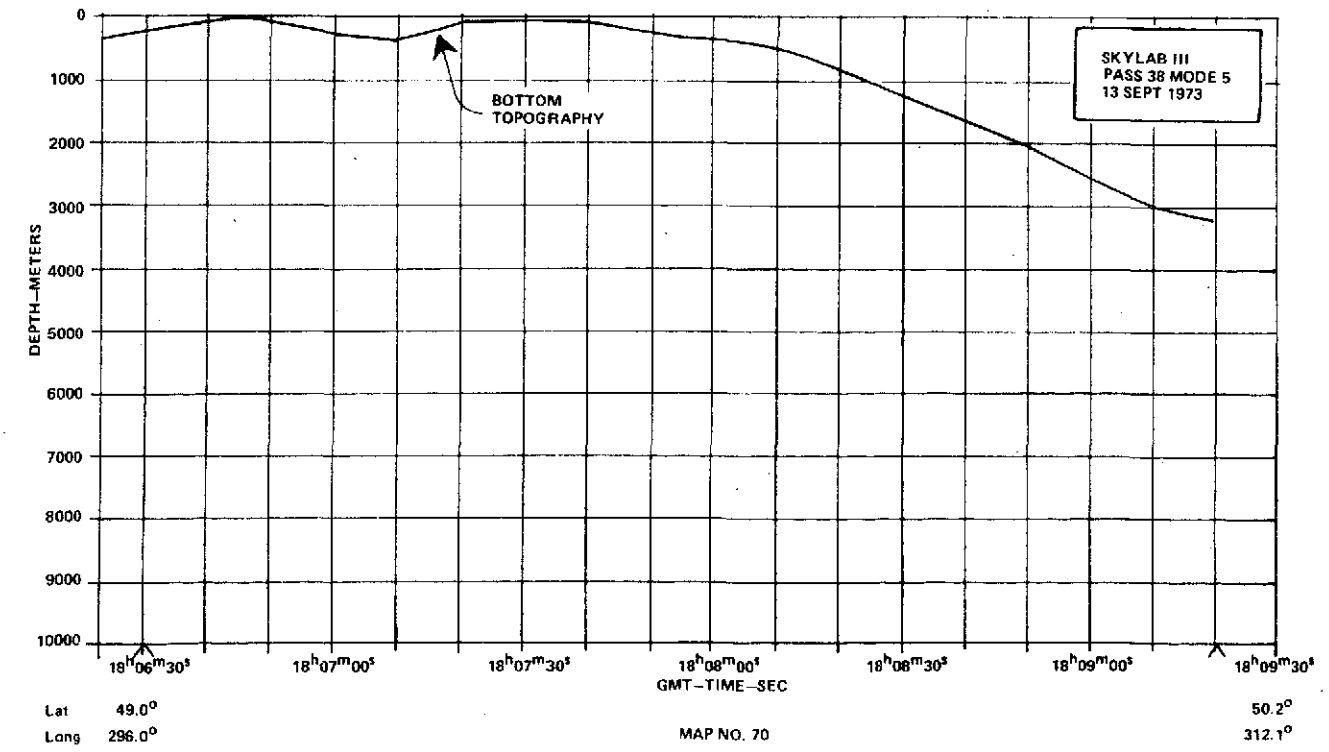




Lat	35.7°		38.4°
Long	232.8°	MAP NO. 67	237.0°

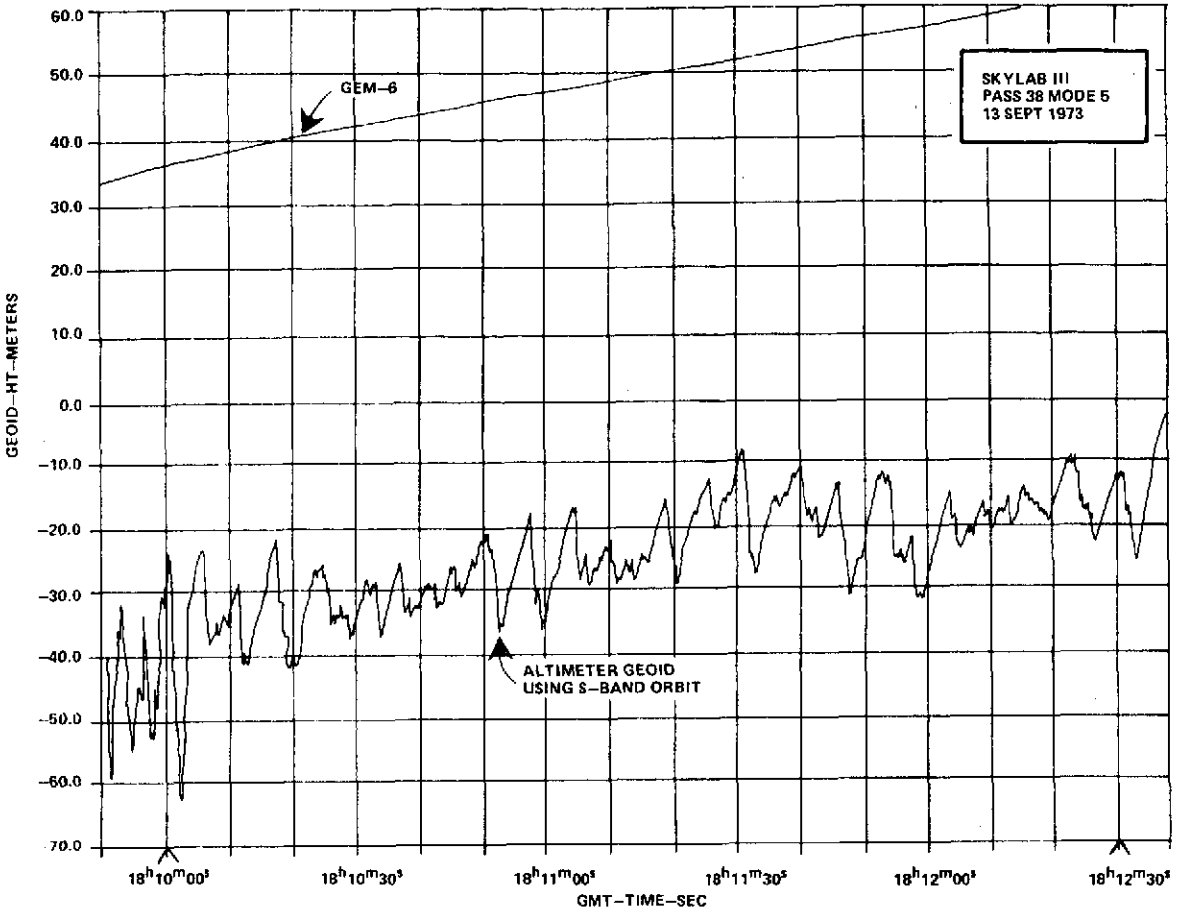

SKYLAB III
PASS 38 MODE 1
13 SEPT 1973
HEIGHT ABOVE MEAN SEA LEVEL – METERS
420.0
370.0
320.0
270.0
220.0
170.0
120.0
70.0
20.0
–30.0
–80.0
HEIGHT ABOVE
MEAN SEA LEVEL
18h02m00s
18h02m30s
18h03m00s
18h03m30s
18h04m00s
18h04m30s
GMT–TIME–SEC
Lat 42.6°
Long 273.8°
45.6°
281.4°
MAP NO. 69

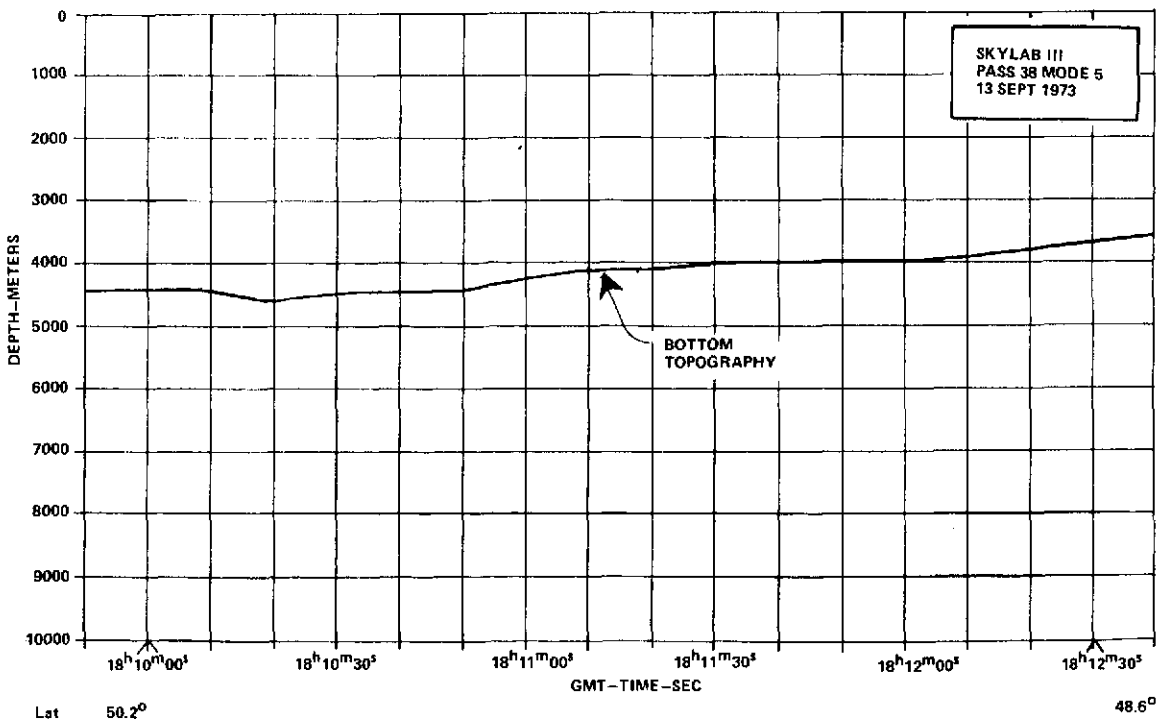




Lat 49.0° 50.2°
Long 296.0° 312.1°

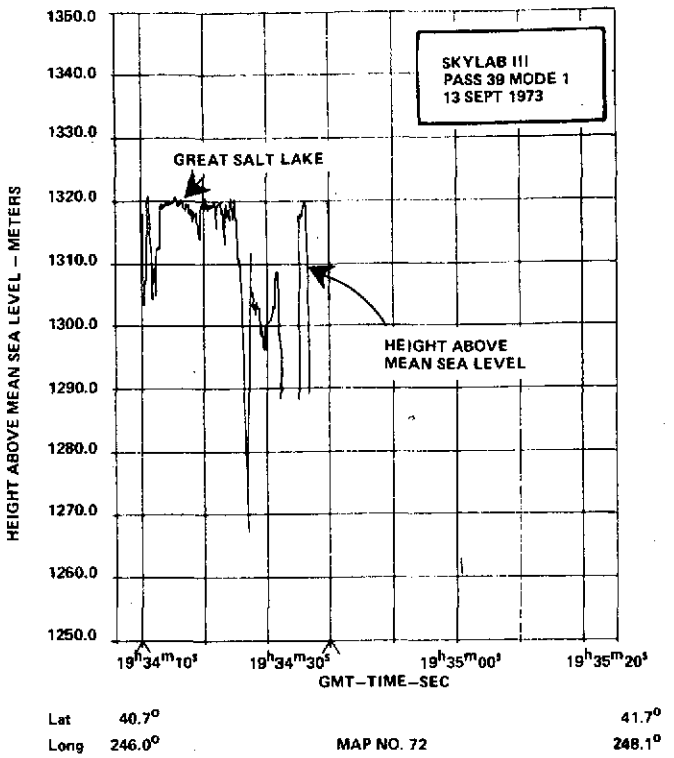
MAP NO. 70

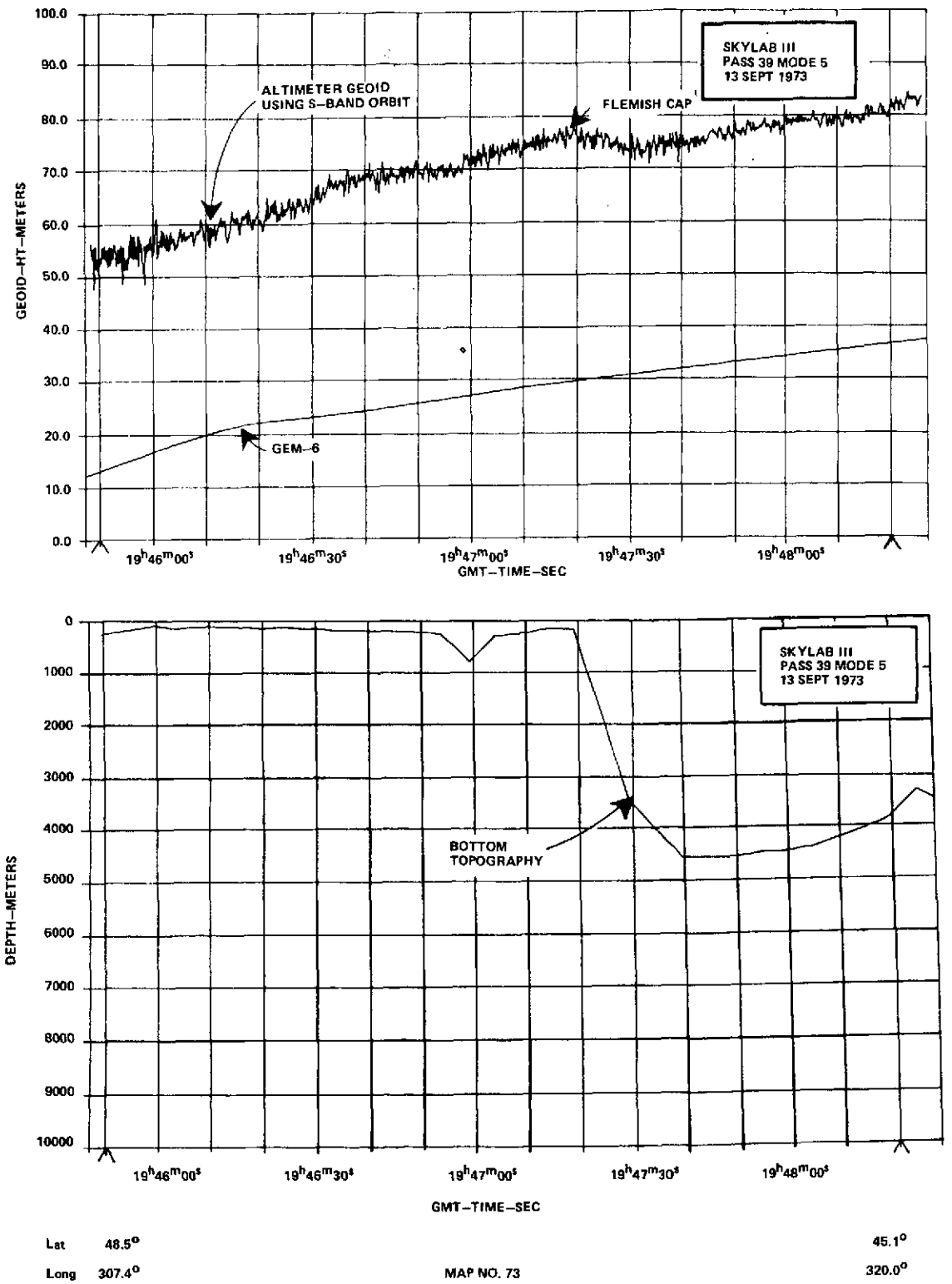


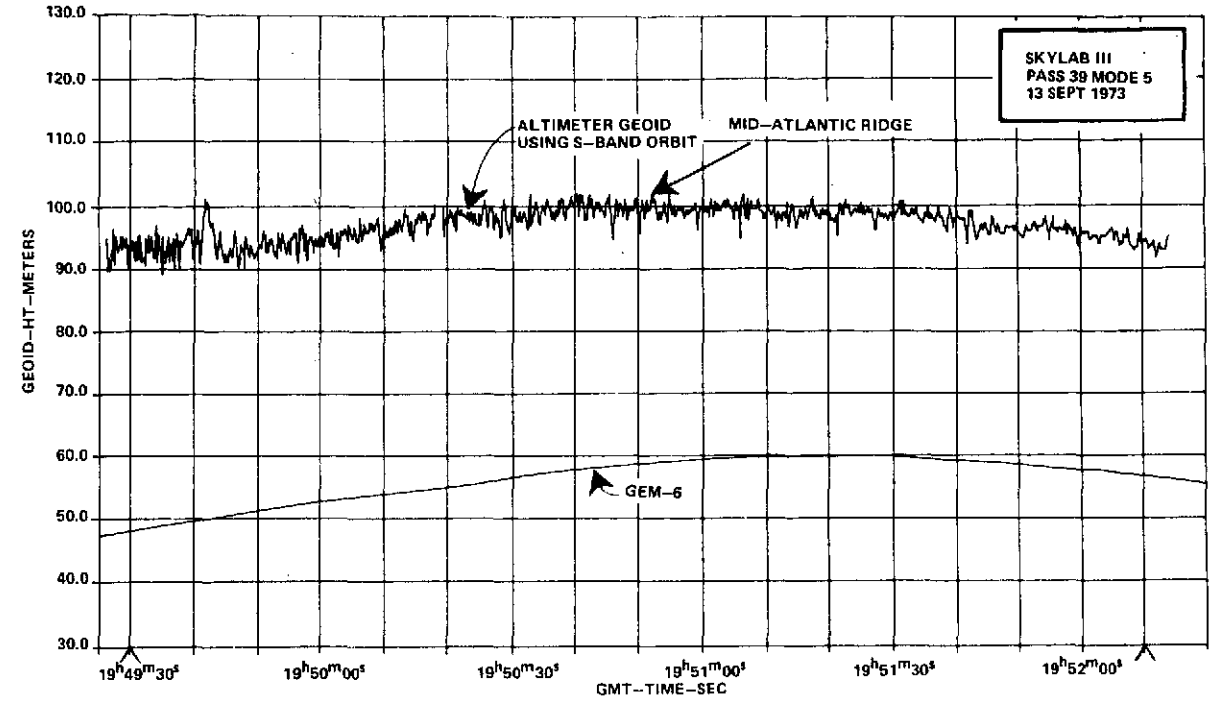


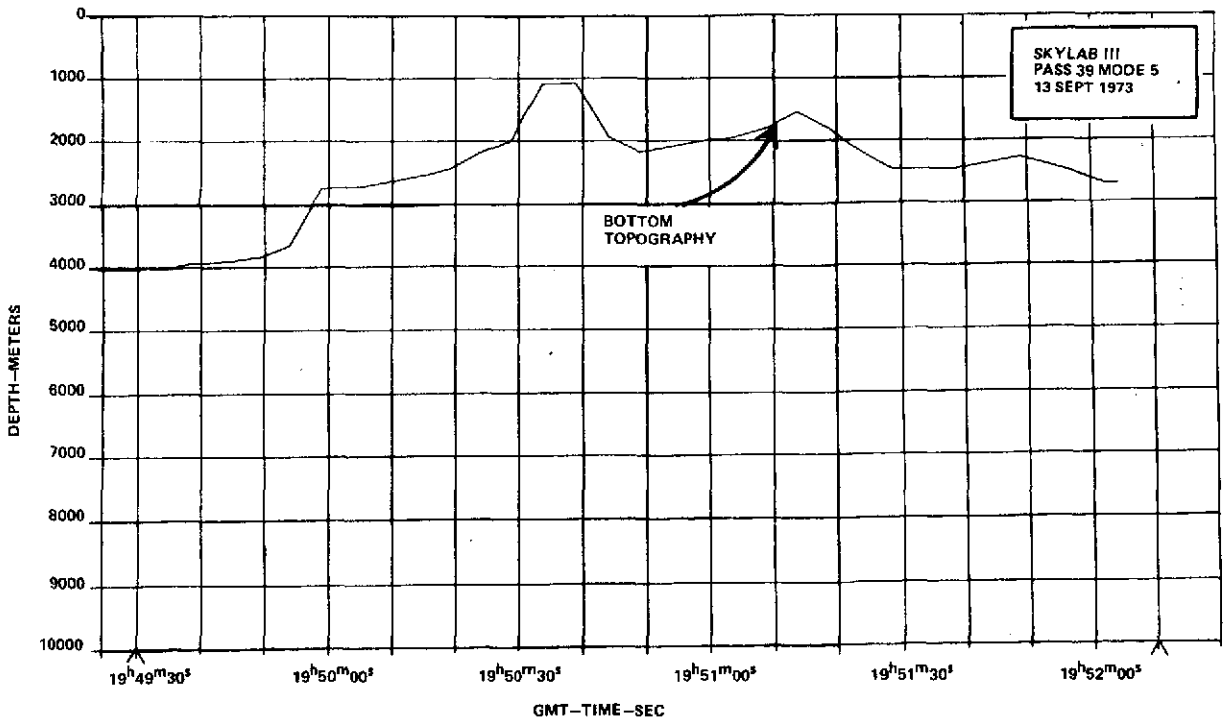
Lat 50.2° 48.6°
Long 315.0° 330.0°

MAP NO. 71


SKYLAB III
PASS 39 MODE 1
13 SEPT 1973
GREAT SALT LAKE
HEIGHT ABOVE
MEAN SEA LEVEL
HEIGHT ABOVE MEAN SEA LEVEL – METERS
1350.0
1340.0
1330.0
1320.0
1310.0
1300.0
1290.0
1280.0
1270.0
1260.0
1250.0
19h34m10s
19h34m30s
19h35m00s
19h35m20s
GMT–TIME–SEC
Lat 40.7° 41.7°
Long 246.0° 248.1°
MAP NO. 72

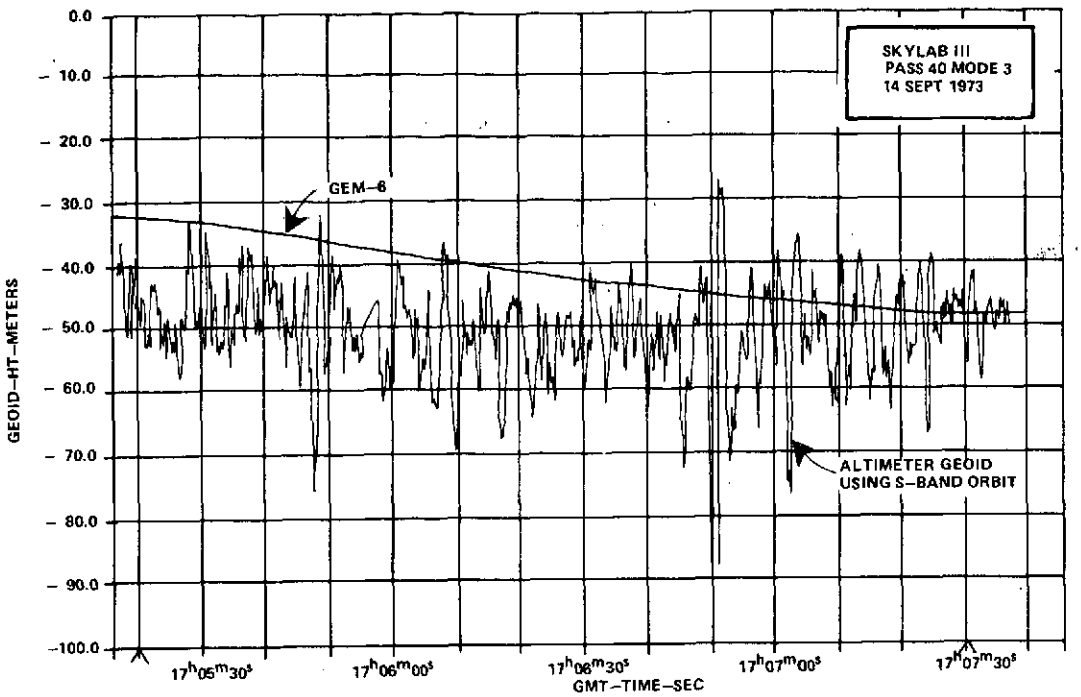

SKYLAB III
PASS 39 MODE 5
13 SEPT 1973
ALTIMETER GEOID
USING S-BAND ORBIT
FLEMISH CAP
GEM-6
GEOID-HT-METERS
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
19h46m00s
19h46m30s
19h47m00s
19h47m30s
19h48m00s
GMT-TIME-SEC
SKYLAB III
PASS 39 MODE 5
13 SEPT 1973
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
19h46m00s
19h46m30s
19h47m00s
19h47m30s
19h48m00s
GMT-TIME-SEC
Lat 48.5°
Long 307.4°
MAP NO. 73
45.1°
320.0°

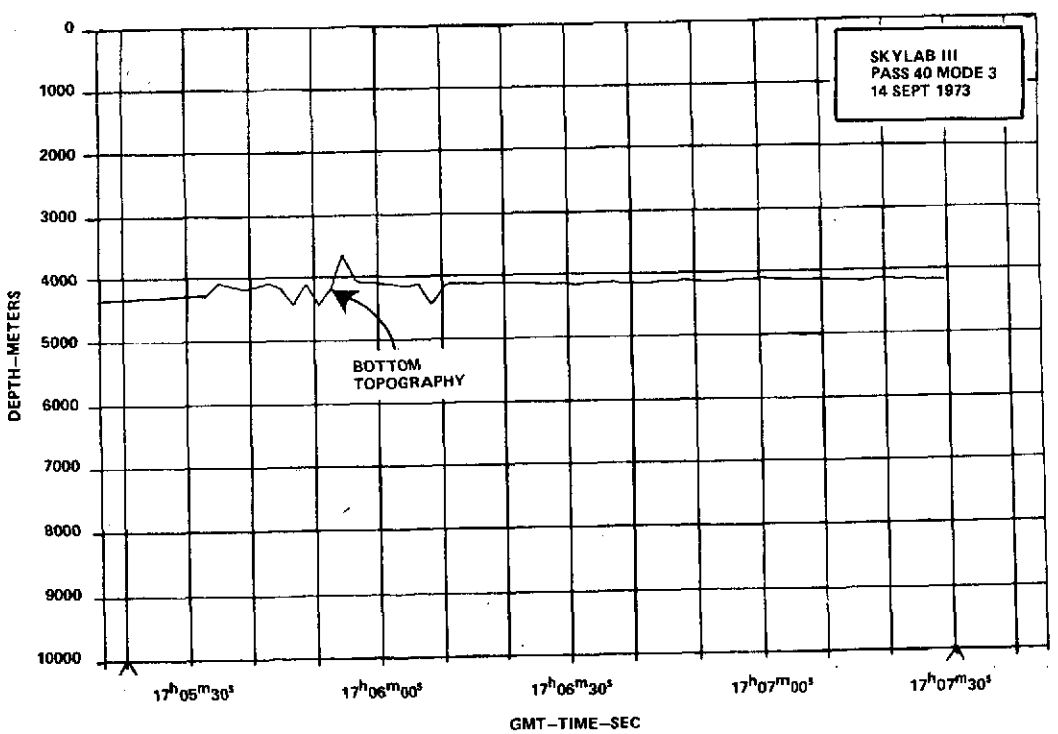




Lat 43.4° 37.5°

Long 324.6° MAP NO. 74 336.0°

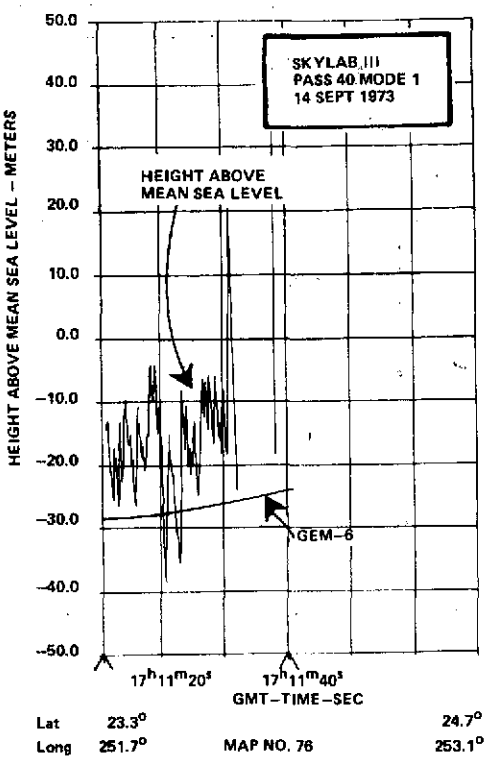




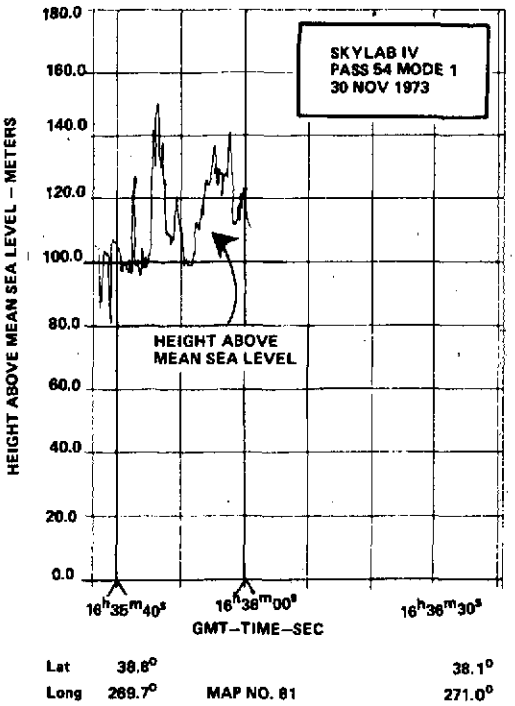
Lat 6.4° 12.8°

Long 237.5° 242.5°

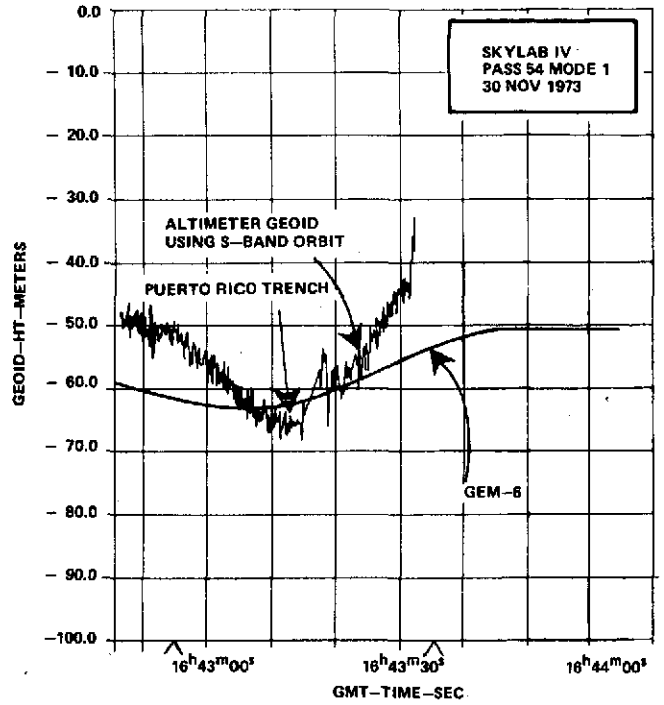
MAP NO. 75

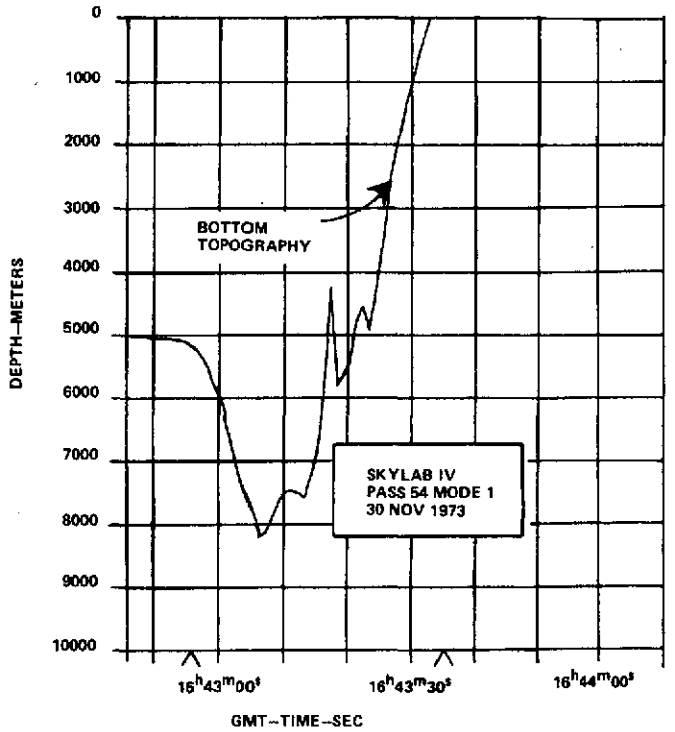


ORIGINAL PAGE IS
OF POOR QUALITY

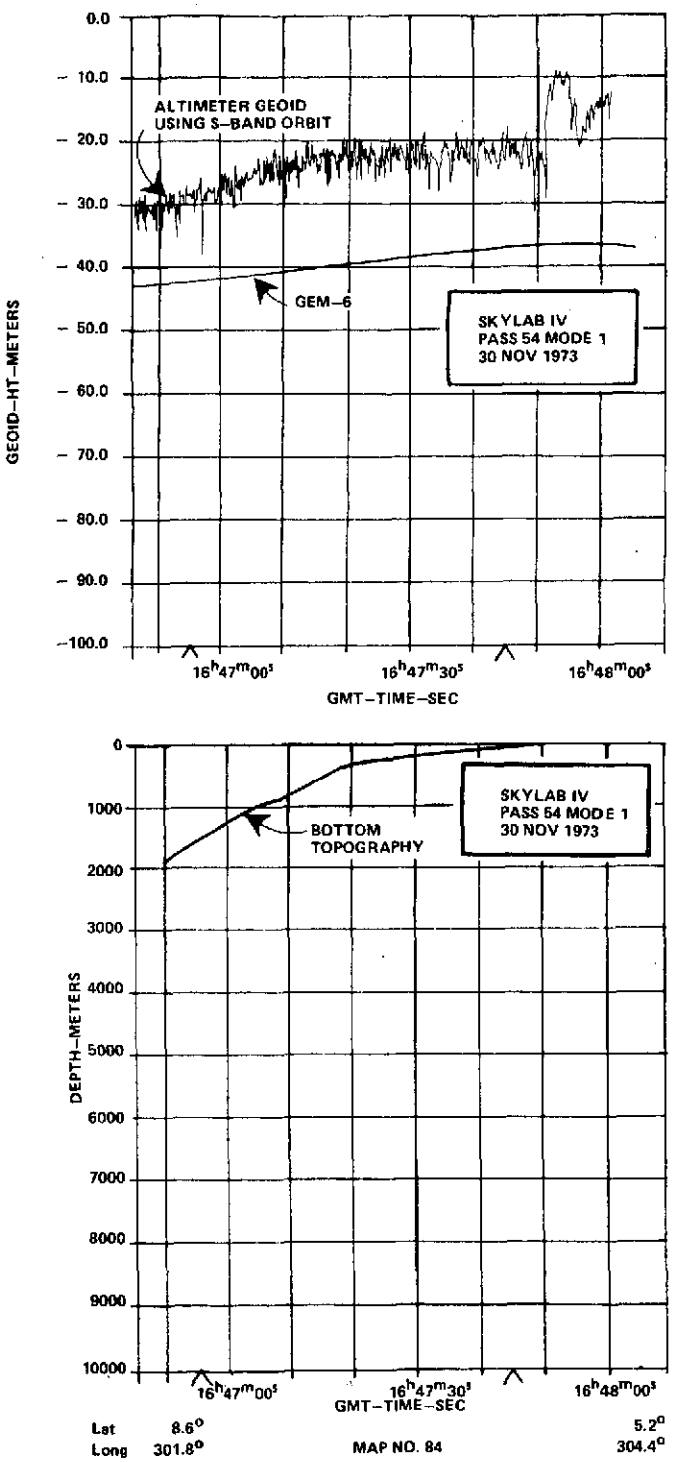


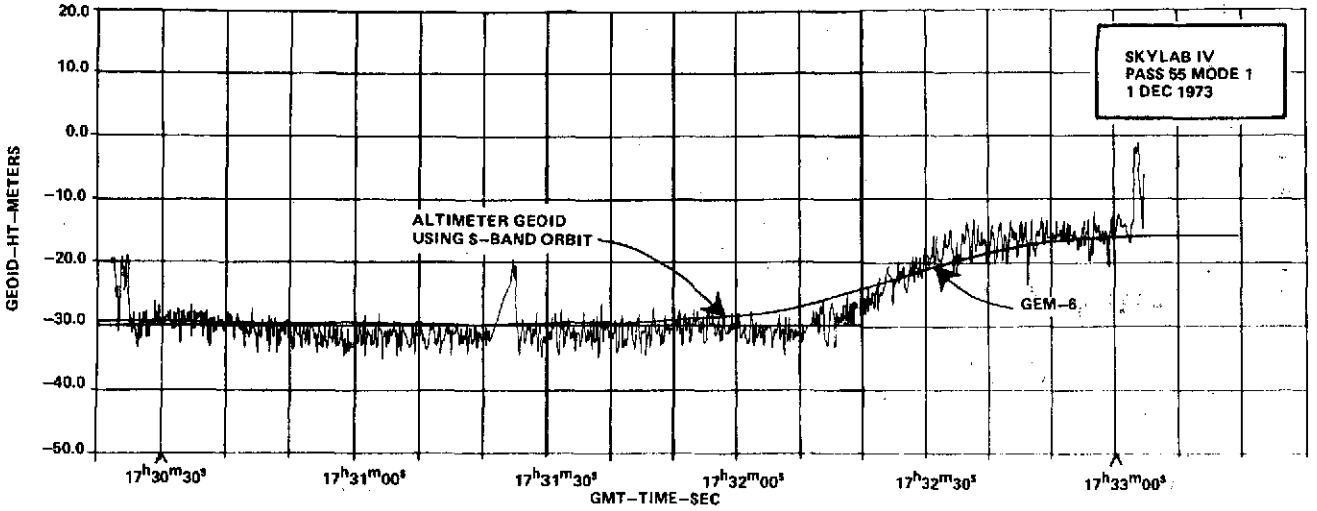
Lat	38.6°		38.1°
Long	269.7°	MAP NO. 81	271.0°

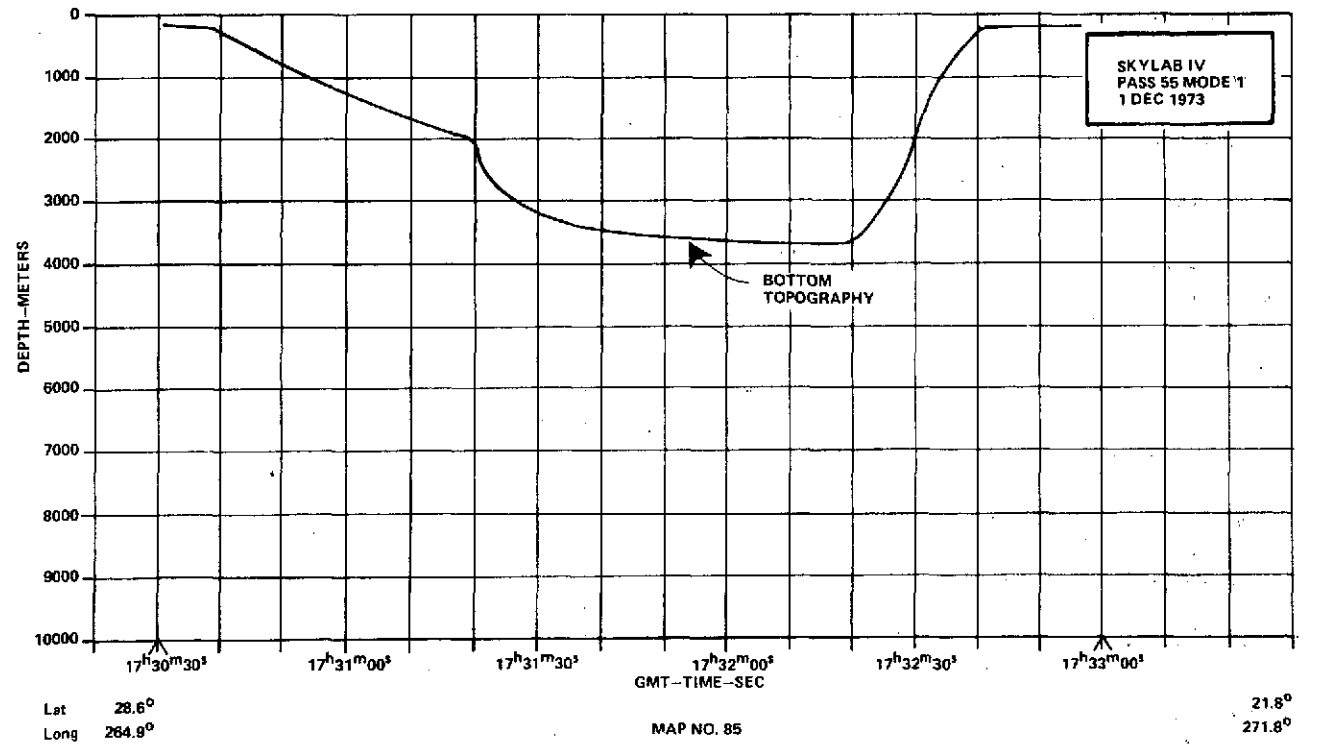




Lat	20.2°		18.3°
Long	292.2°	MAP NO. 83	293.8°

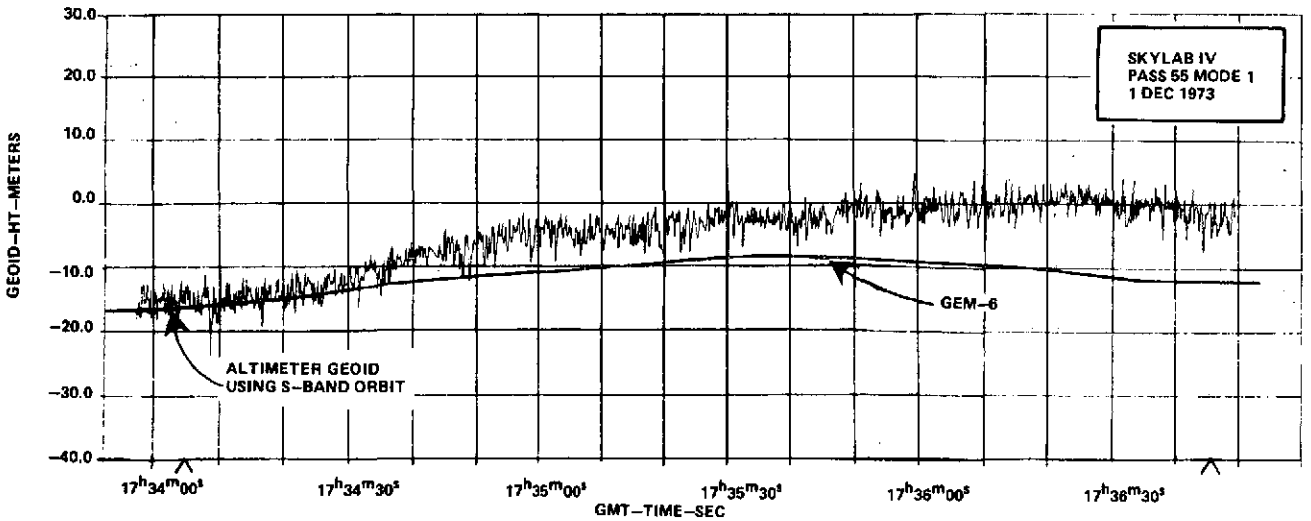

0.0
– 10.0
– 20.0
– 30.0
– 40.0
– 50.0
– 60.0
– 70.0
– 80.0
– 90.0
–100.0
GEOID–HT–METERS
ALTIMETER GEOID
USING S–BAND ORBIT
GEM–6
SKYLAB IV
PASS 54 MODE 1
30 NOV 1973
16h47m00s
16h47m30s
16h48m00s
GMT–TIME–SEC
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
DEPTH–METERS
BOTTOM
TOPOGRAPHY
SKYLAB IV
PASS 54 MODE 1
30 NOV 1973
16h47m00s
16h47m30s
16h48m00s
GMT–TIME–SEC
Lat 8.6°
Long 301.8°
MAP NO. 84
5.2°
304.4°

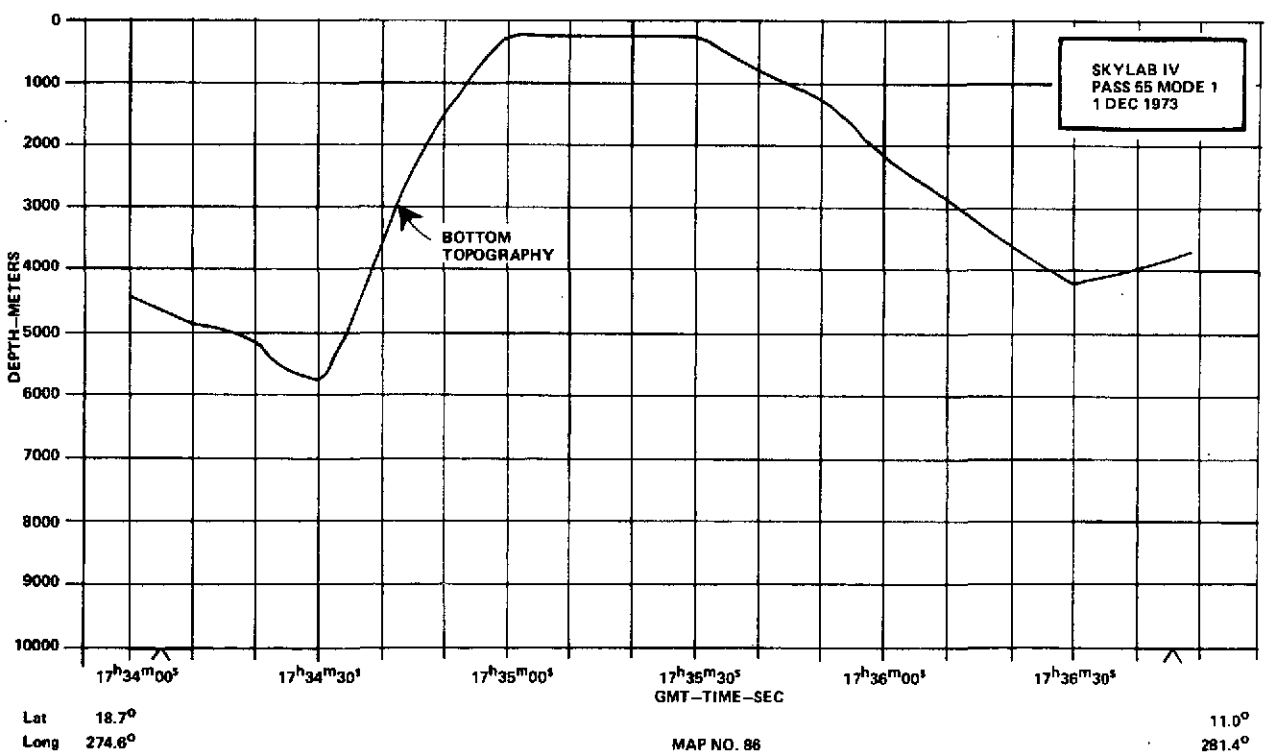




Lat 28.6° 21.8°
Long 264.9° 271.8°

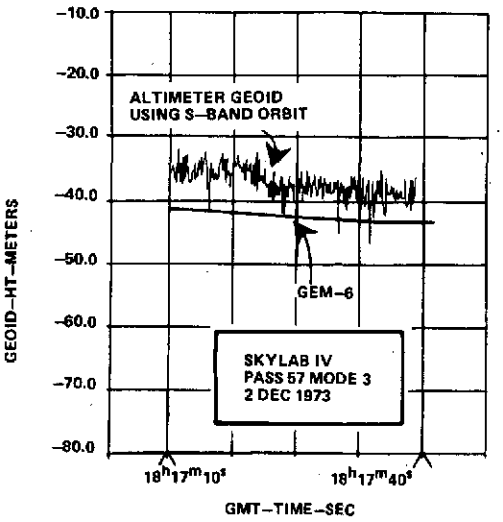
MAP NO. 85

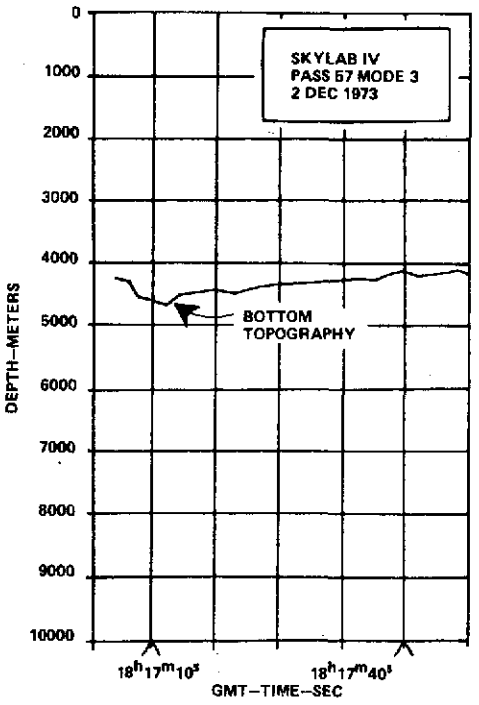




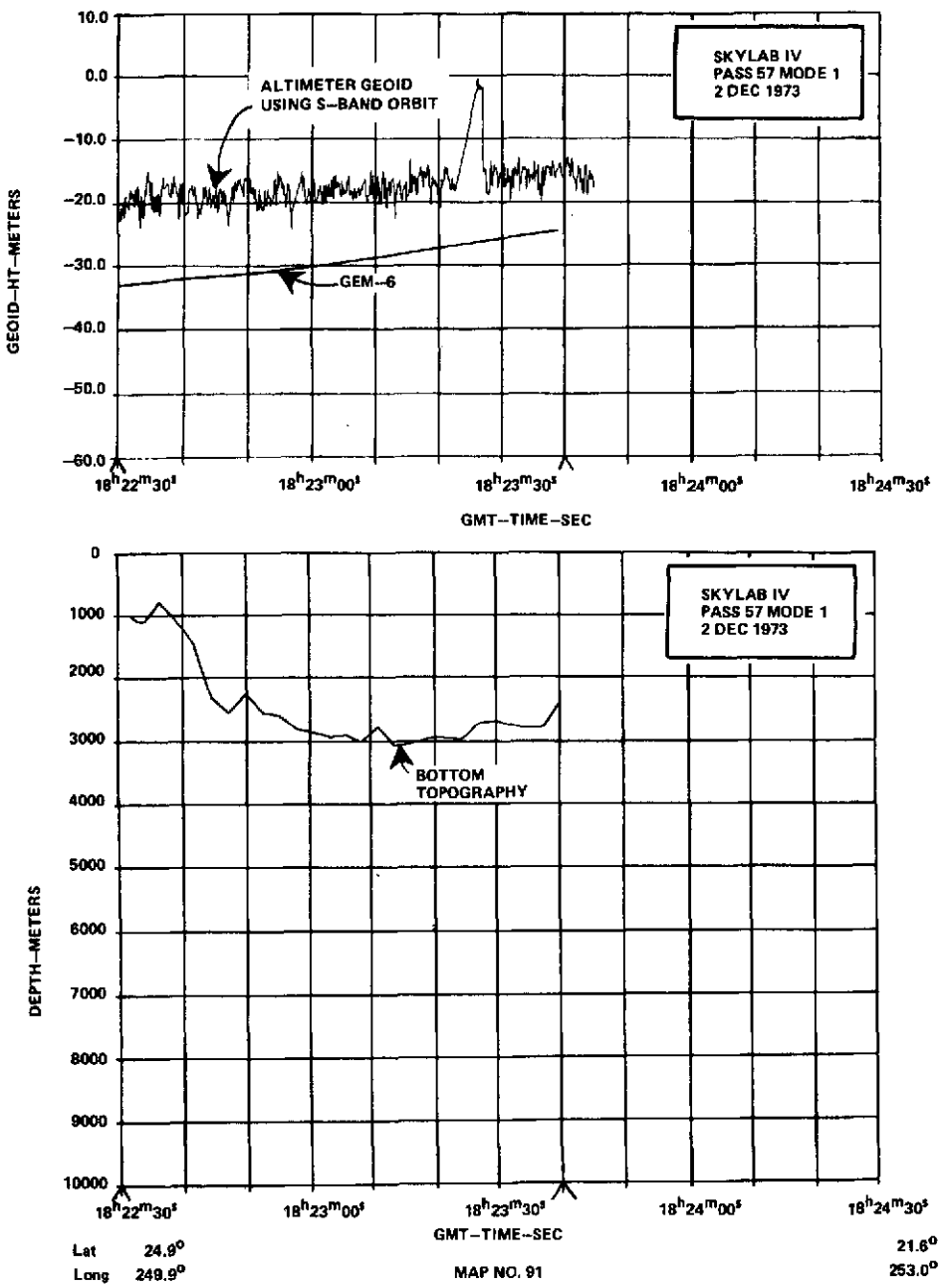
Lat 18.7° 11.0°
Long 274.6° 281.4°

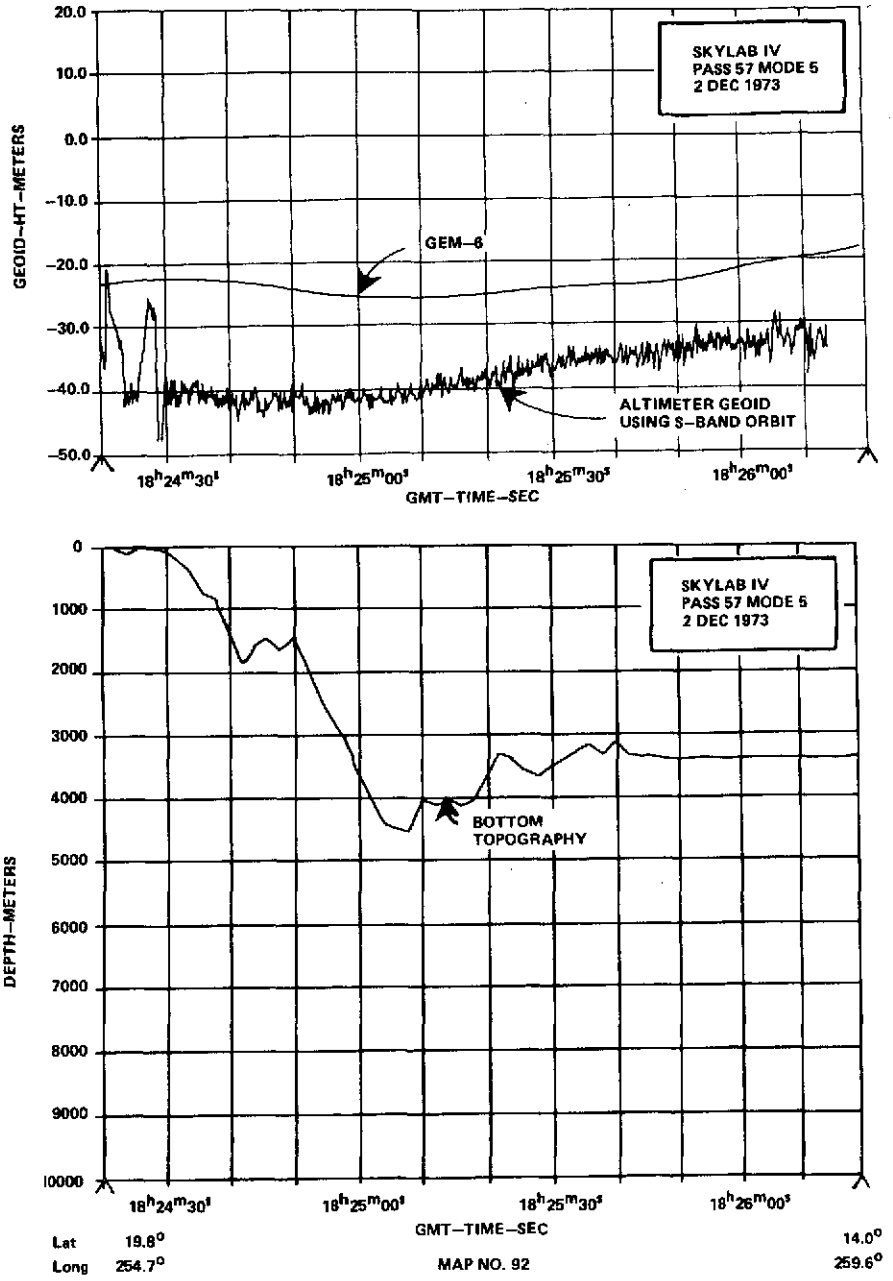
MAP NO. 86

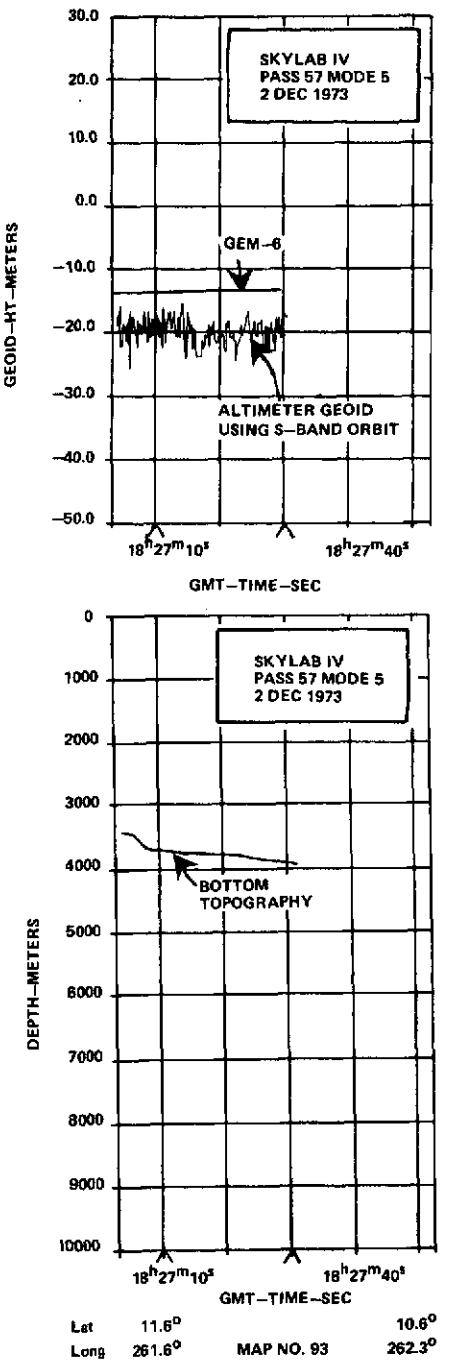


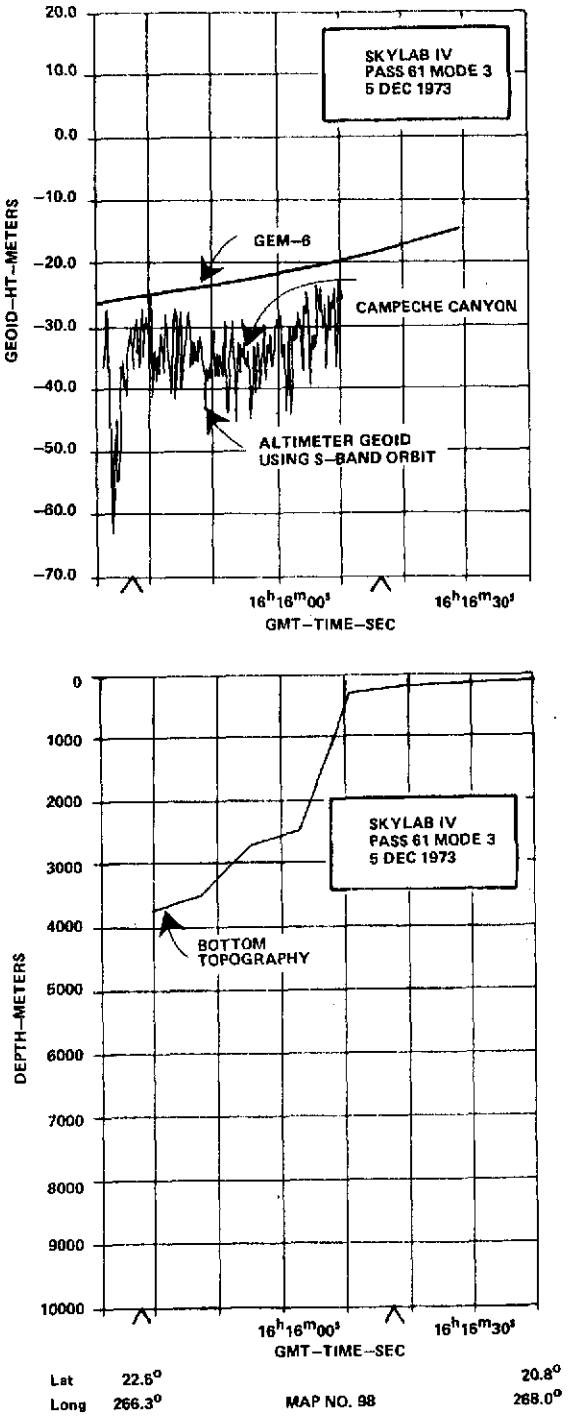


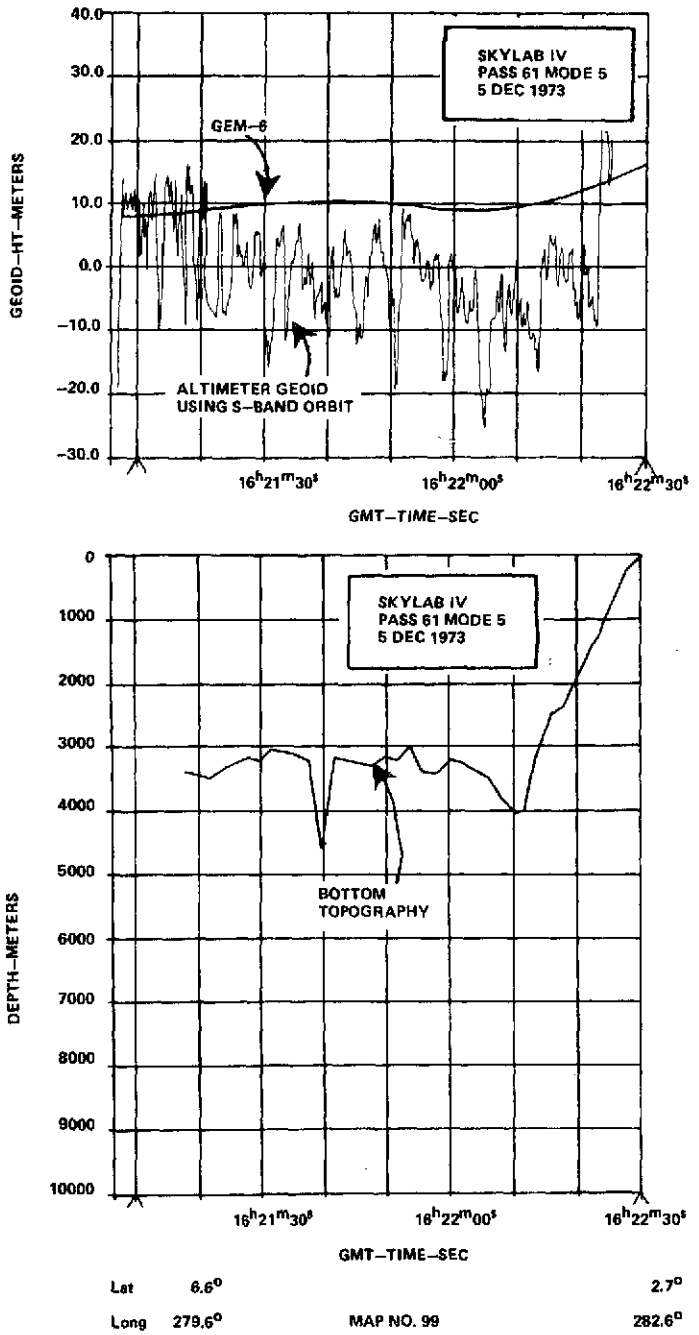
Lat	38.3°		36.8°
Long	232.8°	MAP NO. 89	235.2°

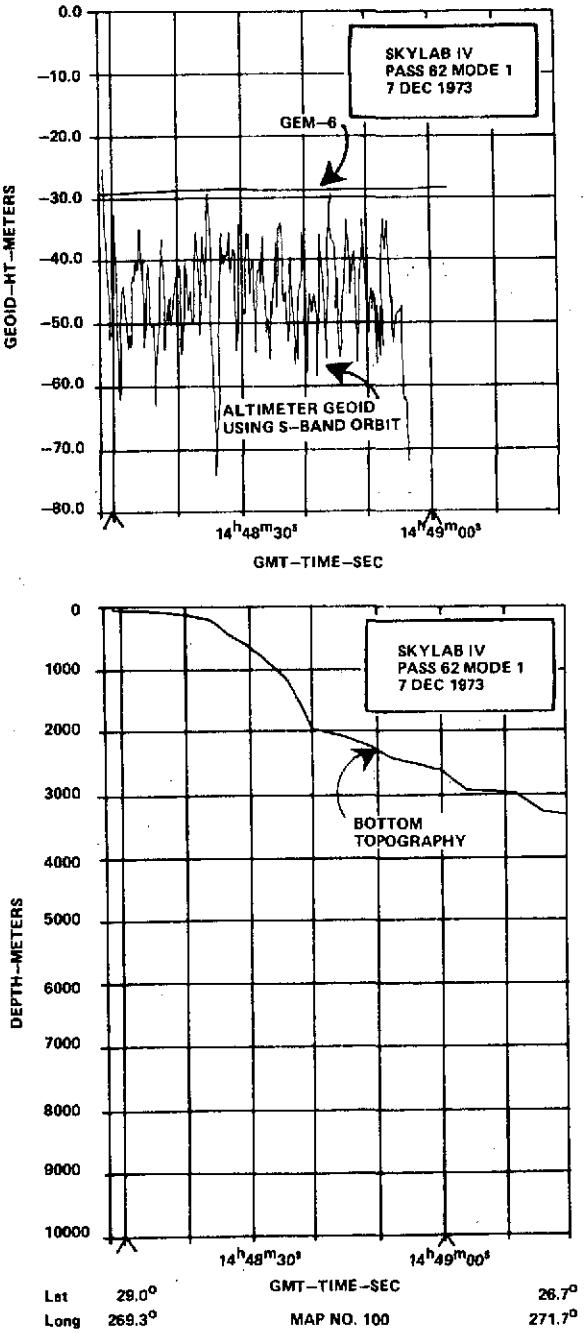

SKYLAB IV
PASS 57 MODE 1
2 DEC 1973
ALTIMETER GEOID
USING S–BAND ORBIT
GEM–6
GEOID–HT–METERS
10.0
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
–60.0
18h22m30s
18h23m00s
18h23m30s
18h24m00s
18h24m30s
GMT–TIME–SEC
SKYLAB IV
PASS 57 MODE 1
2 DEC 1973
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
18h22m30s
18h23m00s
18h23m30s
18h24m00s
18h24m30s
GMT–TIME–SEC
Lat 24.9°
Long 249.9°
MAP NO. 91
21.6°
253.0°

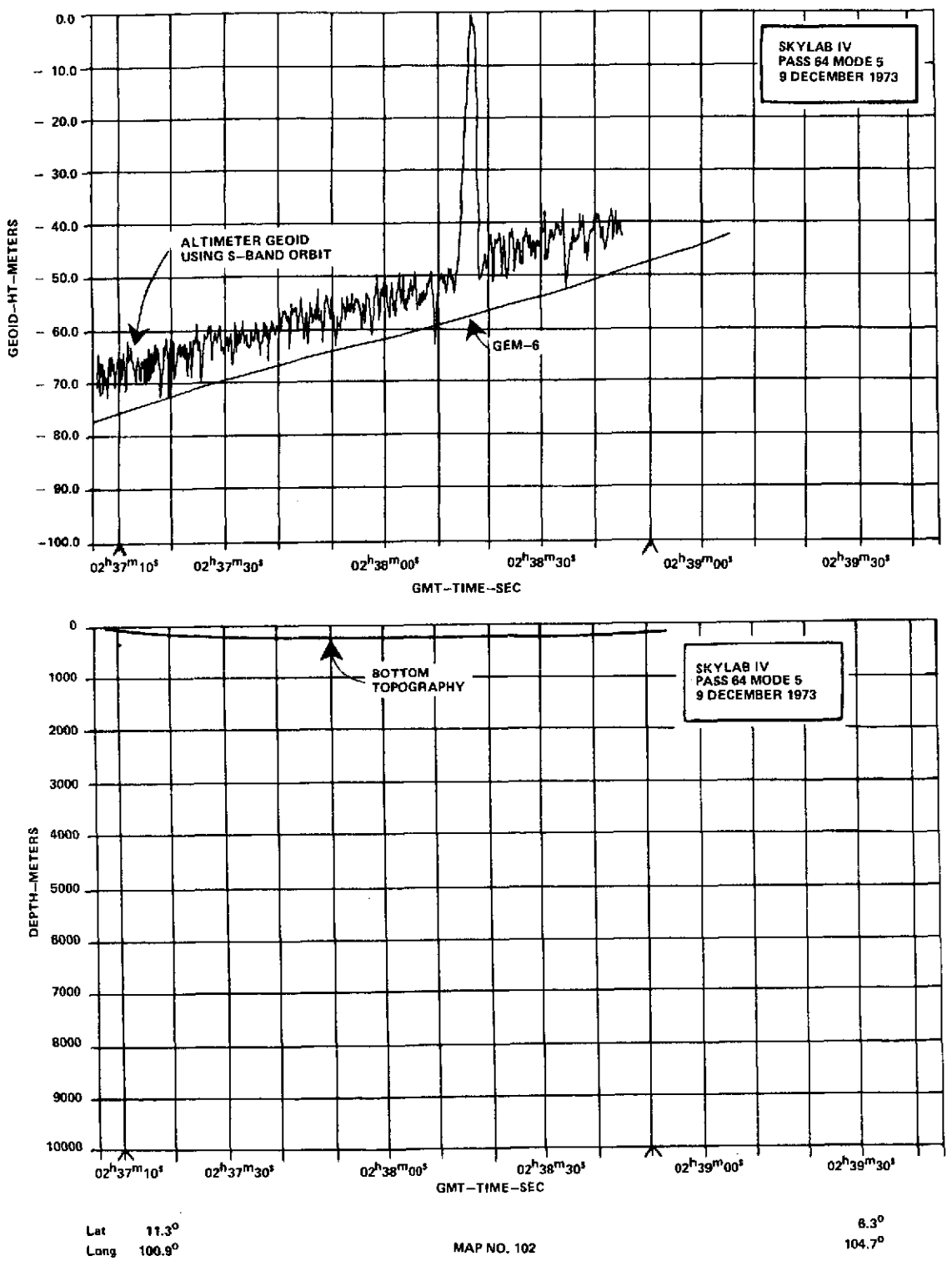

SKYLAB IV
PASS 57 MODE 5
2 DEC 1973
GEOID–HT–METERS
20.0
10.0
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
18h24m30s
18h25m00s
18h25m30s
18h26m00s
GMT–TIME–SEC
SKYLAB IV
PASS 57 MODE 5
2 DEC 1973
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
BOTTOM
TOPOGRAPHY
18h24m30s
18h25m00s
18h25m30s
18h26m00s
GMT–TIME–SEC
Lat 19.8° 14.0°
Long 254.7° 259.6°
MAP NO. 92

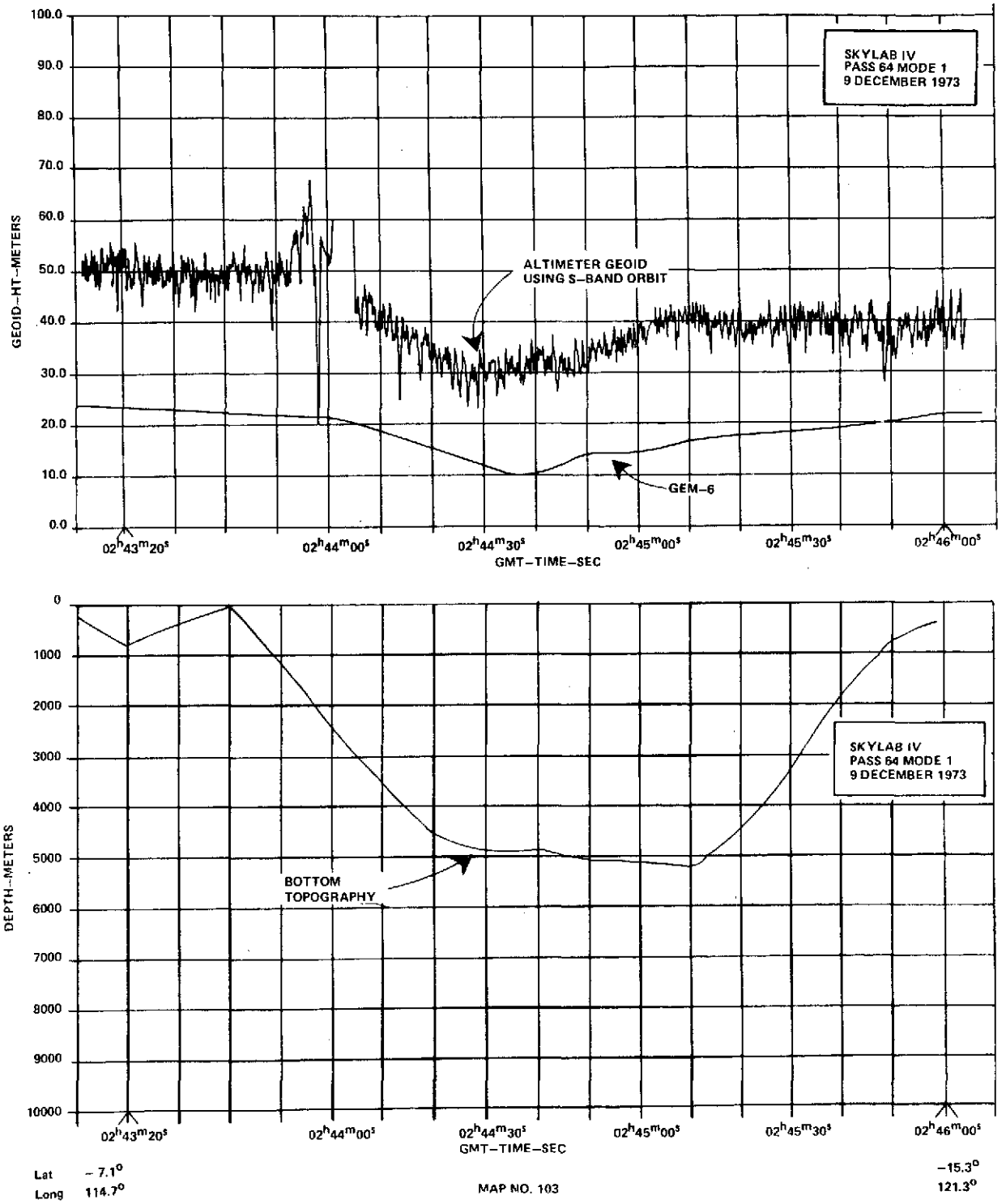

SKYLAB IV
PASS 57 MODE 5
2 DEC 1973
GEM-6
ALTIMETER GEOID
USING S-BAND ORBIT
GEOID-HT-METERS
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
18h27m10s
18h27m40s
GMT-TIME-SEC
SKYLAB IV
PASS 57 MODE 5
2 DEC 1973
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
18h27m10s
18h27m40s
GMT-TIME-SEC
Lat 11.6° 10.6°
Long 261.6° MAP NO. 93 262.3°

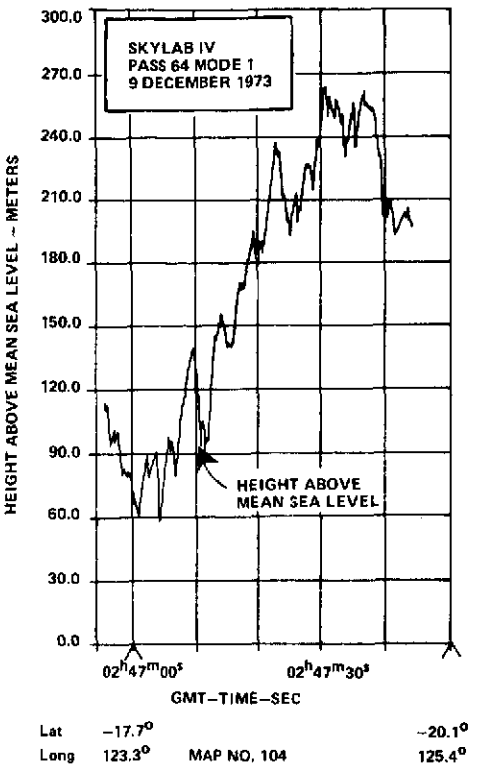

SKYLAB IV
PASS 61 MODE 3
5 DEC 1973
GEM–6
CAMPECHE CANYON
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
20.0
10.0
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
–60.0
–70.0
16h16m00s
16h16m30s
GMT–TIME–SEC
SKYLAB IV
PASS 61 MODE 3
5 DEC 1973
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
16h16m00s
16h16m30s
GMT–TIME–SEC
Lat 22.6° 20.8°
Long 266.3° MAP NO. 98 268.0°

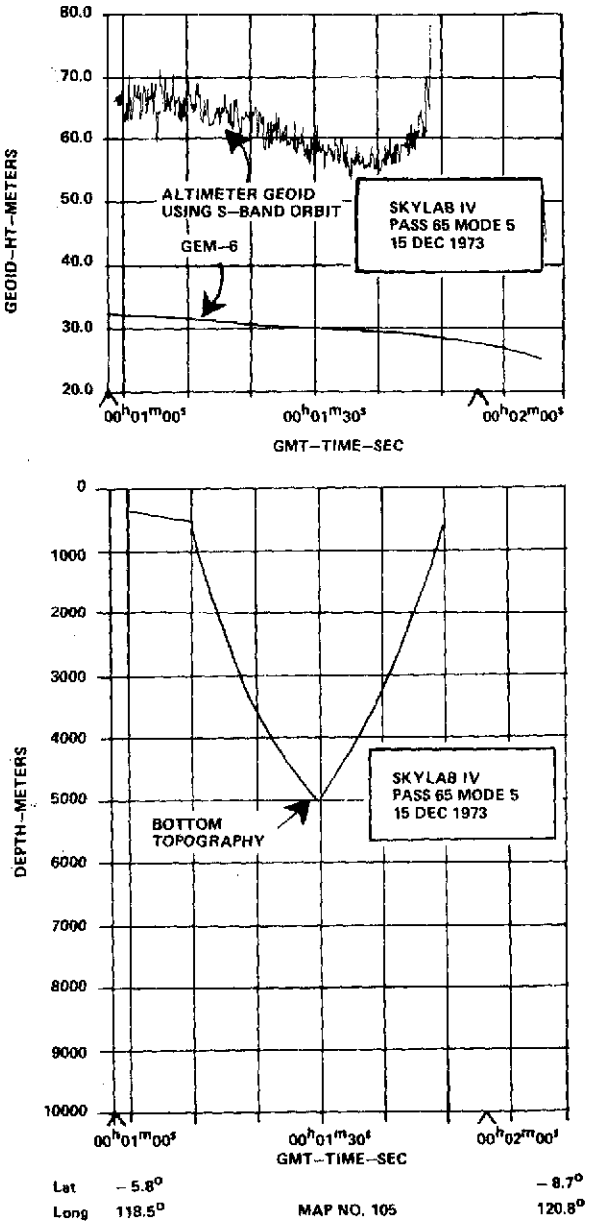

SKYLAB IV
PASS 61 MODE 5
5 DEC 1973
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
40.0
30.0
20.0
10.0
0.0
–10.0
–20.0
–30.0
16h21m30s
16h22m00s
16h22m30s
GMT–TIME–SEC
SKYLAB IV
PASS 61 MODE 5
5 DEC 1973
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
16h21m30s
16h22m00s
16h22m30s
GMT–TIME–SEC
Lat 6.6° 2.7°
Long 279.6° MAP NO. 99 282.6°

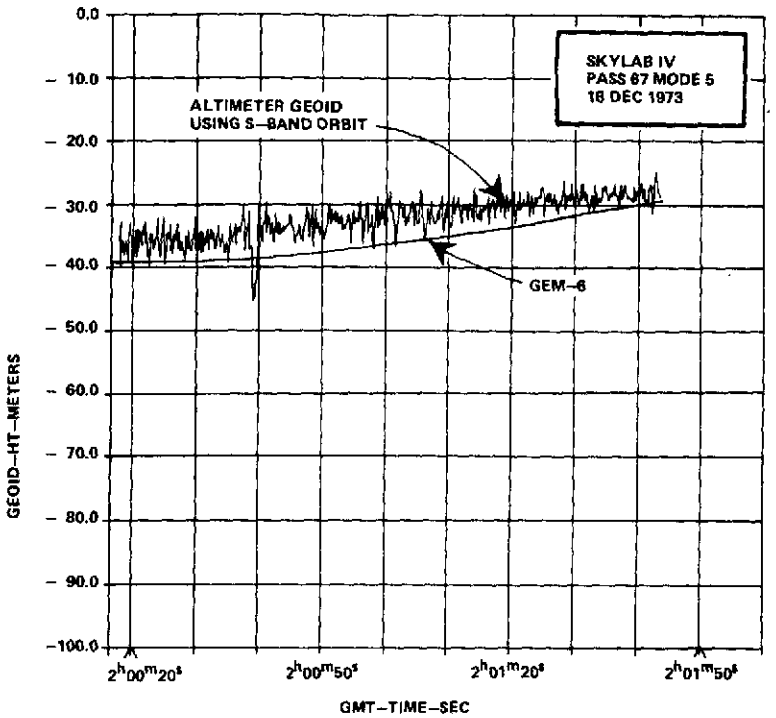

SKYLAB IV
PASS 62 MODE 1
7 DEC 1973
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
–60.0
–70.0
–80.0
14h48m30s
14h49m00s
GMT–TIME–SEC
SKYLAB IV
PASS 62 MODE 1
7 DEC 1973
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
14h48m30s
14h49m00s
GMT–TIME–SEC
Lat 29.0° 26.7°
Long 269.3° MAP NO. 100 271.7°

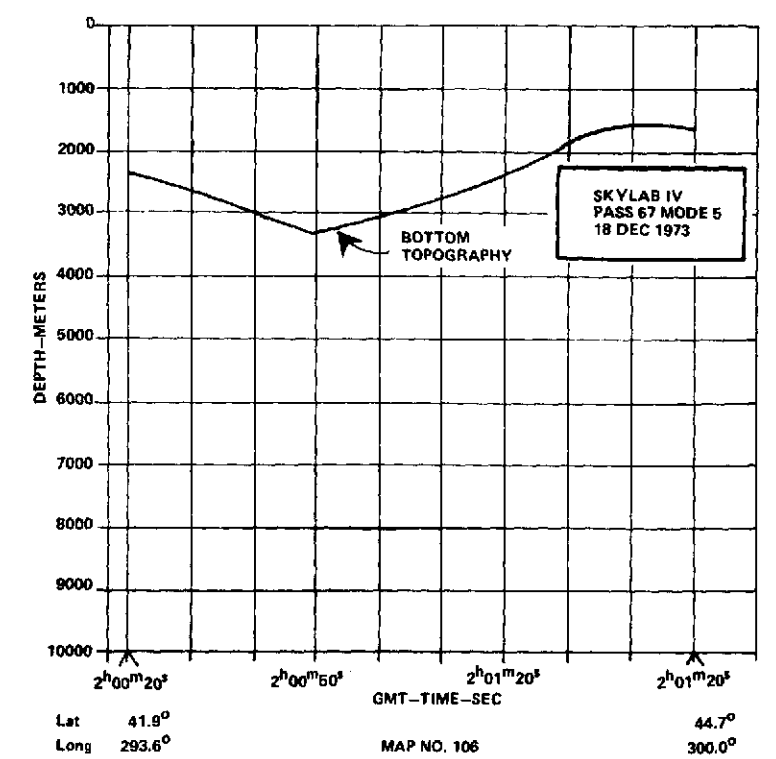

SKYLAB IV
PASS 64 MODE 5
9 DECEMBER 1973
ALTIMETER GEOID
USING S-BAND ORBIT
GEM-6
GEOID-HT-METERS
0.0
- 10.0
- 20.0
- 30.0
- 40.0
- 50.0
- 60.0
- 70.0
- 80.0
- 90.0
-100.0
02h37m10s
02h37m30s
02h38m00s
02h38m30s
02h39m00s
02h39m30s
GMT-TIME-SEC
SKYLAB IV
PASS 64 MODE 5
9 DECEMBER 1973
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
02h37m10s
02h37m30s
02h38m00s
02h38m30s
02h39m00s
02h39m30s
GMT-TIME-SEC
Lat 11.3°
Long 100.9°
MAP NO. 102
6.3°
104.7°


SKYLAB IV
PASS 64 MODE 1
9 DECEMBER 1973
GEOID–HT–METERS
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
ALTIMETER GEOID
USING S–BAND ORBIT
GEM–6
02h43m20s
02h44m00s
02h44m30s
02h45m00s
02h45m30s
02h46m00s
GMT–TIME–SEC
SKYLAB IV
PASS 64 MODE 1
9 DECEMBER 1973
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
BOTTOM
TOPOGRAPHY
02h43m20s
02h44m00s
02h44m30s
02h45m00s
02h45m30s
02h46m00s
GMT–TIME–SEC
Lat – 7.1°
Long 114.7°
MAP NO. 103
–15.3°
121.3°


SKYLAB IV
PASS 64 MODE 1
9 DECEMBER 1973
HEIGHT ABOVE MEAN SEA LEVEL – METERS
300.0
270.0
240.0
210.0
180.0
150.0
120.0
90.0
60.0
30.0
0.0
HEIGHT ABOVE MEAN SEA LEVEL
02h47m00s
02h47m30s
GMT–TIME–SEC
Lat –17.7° –20.1°
Long 123.3° MAP NO. 104 125.4°

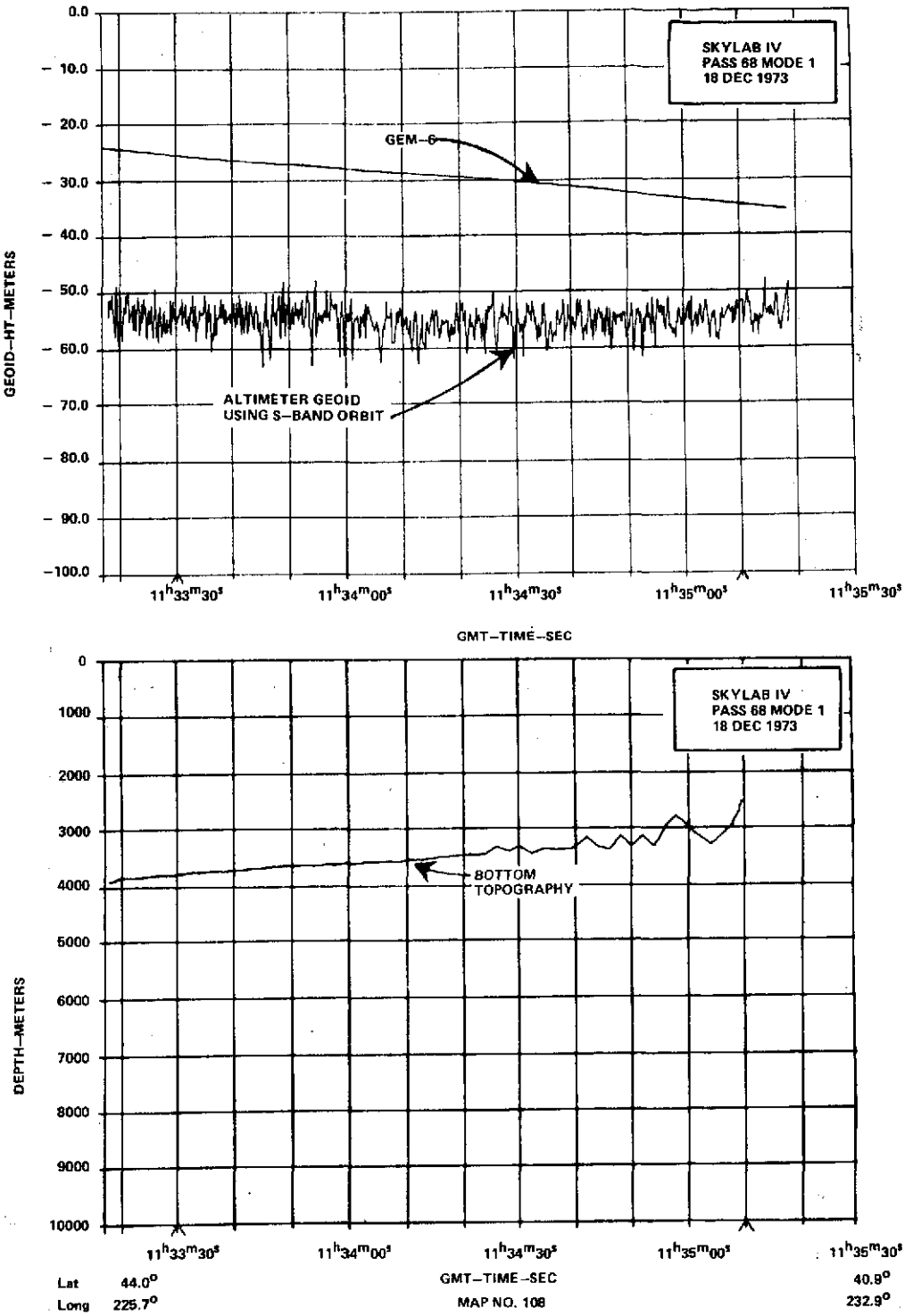

80.0
70.0
60.0
50.0
40.0
30.0
20.0
GEOID–HT–METERS
ALTIMETER GEOID
USING S–BAND ORBIT
GEM–6
SKYLAB IV
PASS 65 MODE 5
15 DEC 1973
00h01m00s
00h01m30s
00h02m00s
GMT–TIME–SEC
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
DEPTH–METERS
BOTTOM
TOPOGRAPHY
SKYLAB IV
PASS 65 MODE 5
15 DEC 1973
00h01m00s
00h01m30s
00h02m00s
GMT–TIME–SEC
Lat – 5.8° – 8.7°
Long 118.5° MAP NO. 105 120.8°

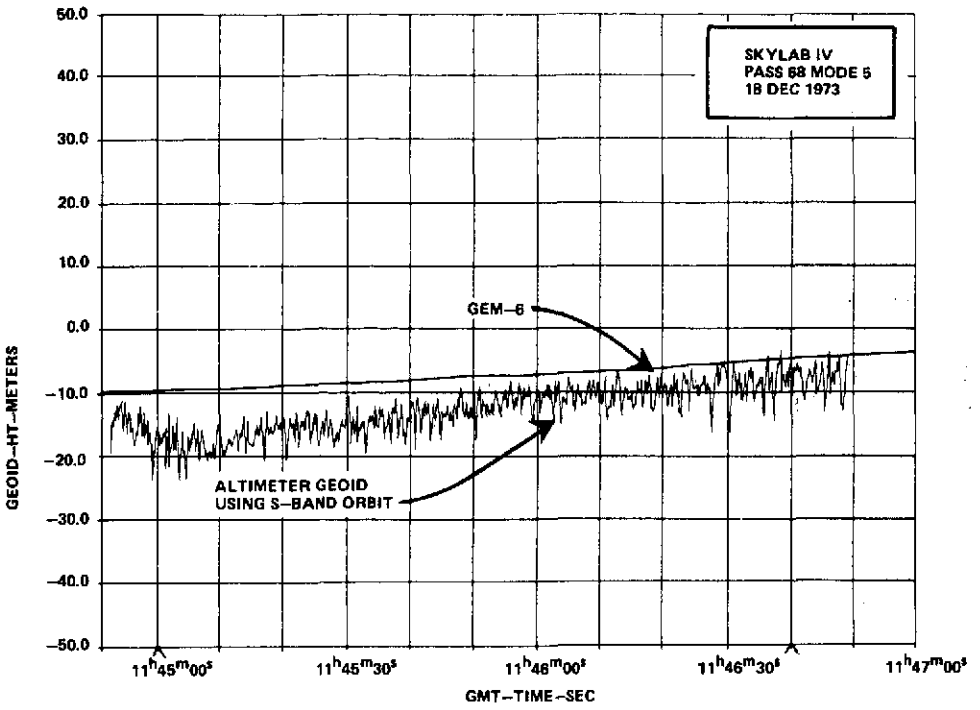


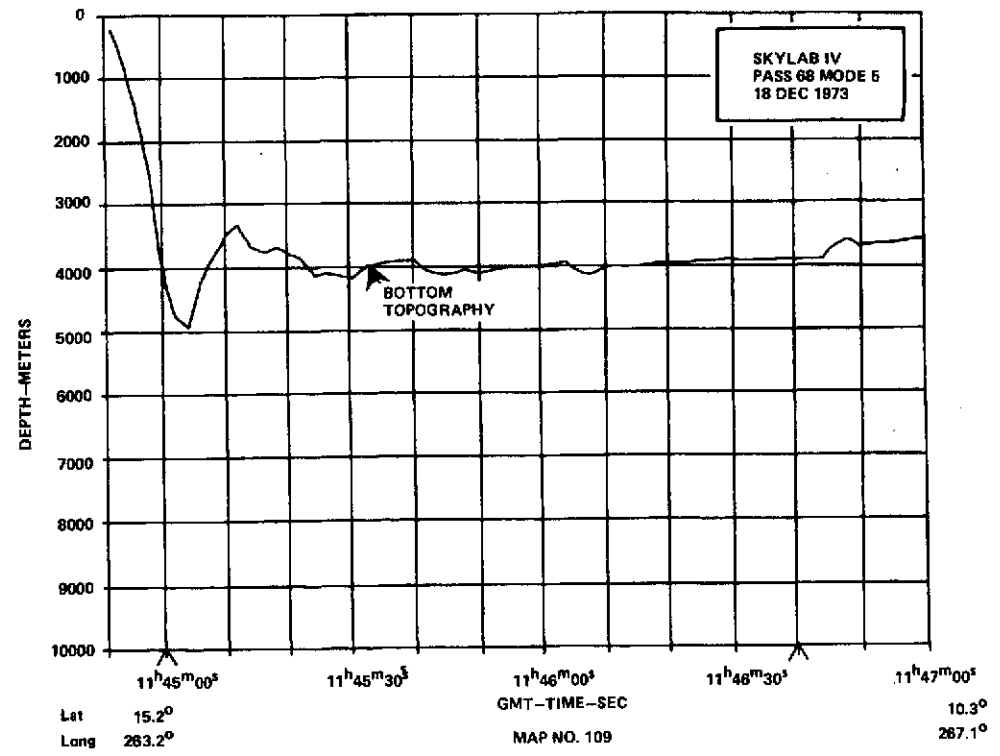


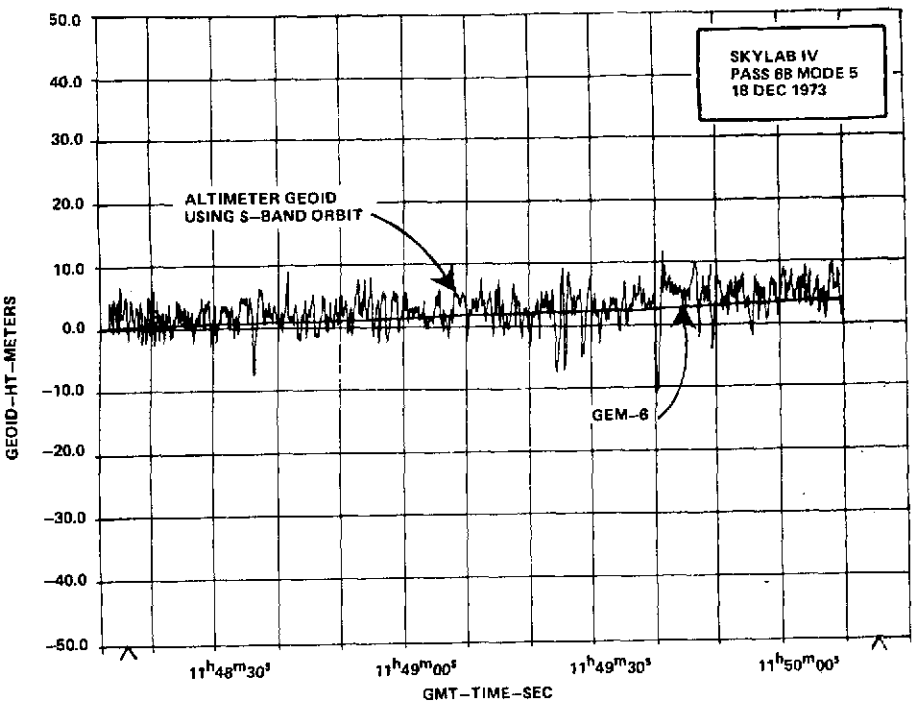
Lat 41.9° 44.7°
Long 293.6° 300.0°

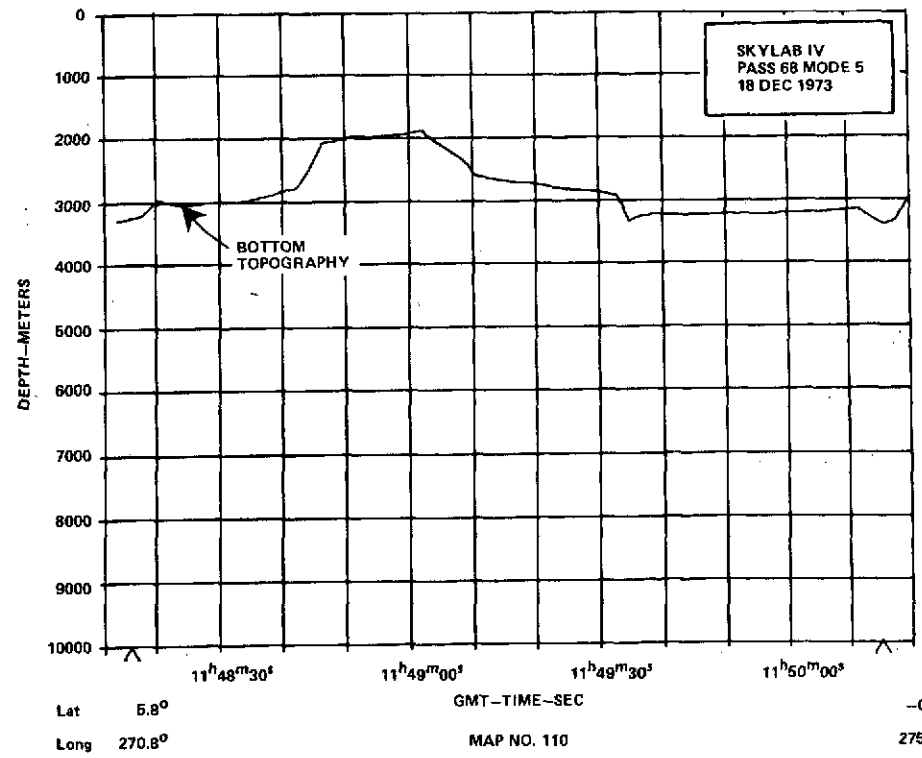
MAP NO. 106

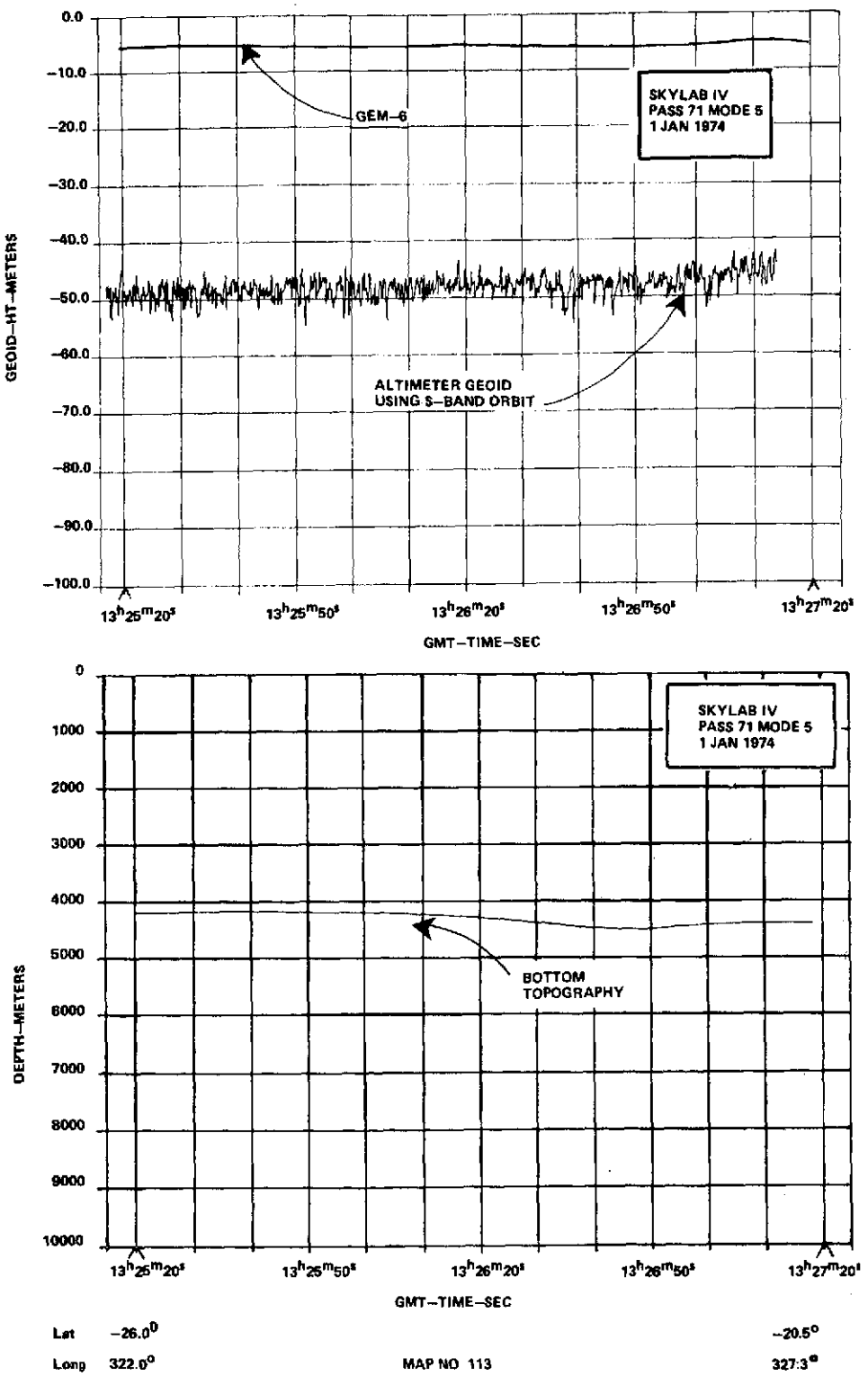

SKYLAB IV
PASS 68 MODE 1
18 DEC 1973
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
0.0
– 10.0
– 20.0
– 30.0
– 40.0
– 50.0
– 60.0
– 70.0
– 80.0
– 90.0
–100.0
11h33m30s
11h34m00s
11h34m30s
11h35m00s
11h35m30s
GMT–TIME–SEC
SKYLAB IV
PASS 68 MODE 1
18 DEC 1973
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11h33m30s
11h34m00s
11h34m30s
11h35m00s
11h35m30s
Lat 44.0°
Long 225.7°
GMT–TIME–SEC
MAP NO. 108
40.9°
232.9°

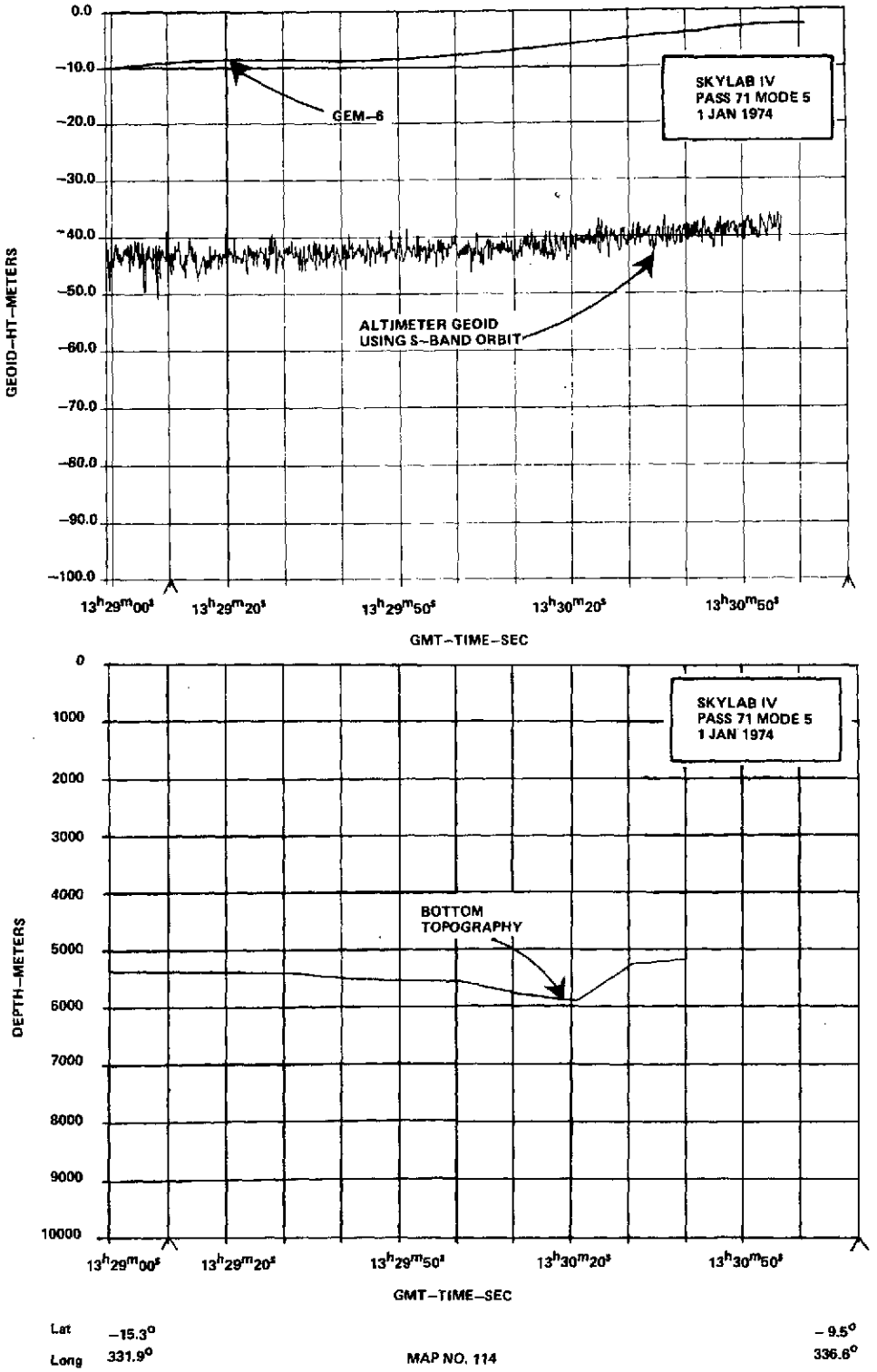

SKYLAB IV
PASS 68 MODE 5
18 DEC 1973
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
50.0
40.0
30.0
20.0
10.0
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
11h45m00s
11h45m30s
11h46m00s
11h46m30s
11h47m00s
GMT–TIME–SEC

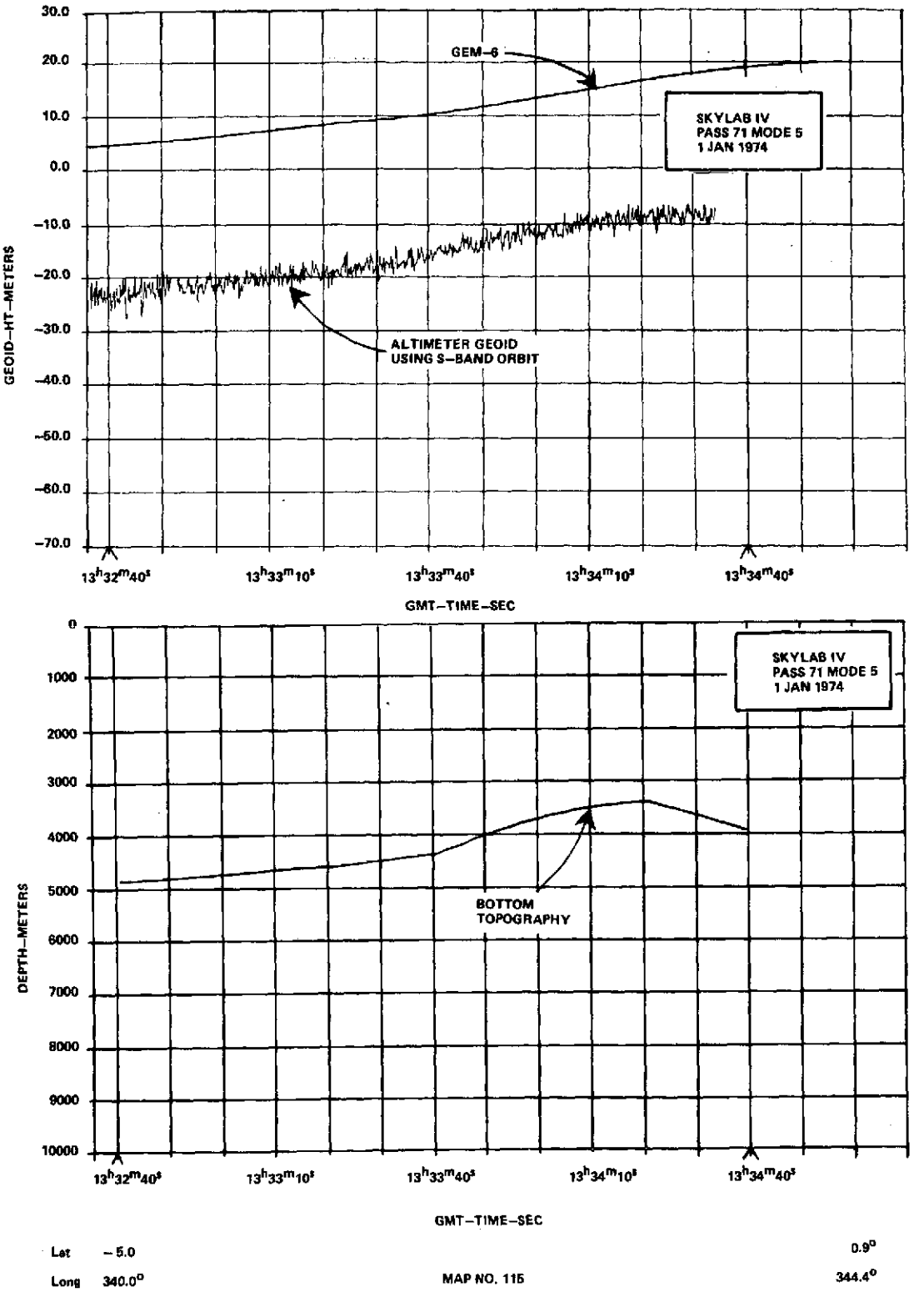

SKYLAB IV
PASS 68 MODE 5
18 DEC 1973
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11h45m00s
11h45m30s
11h46m00s
11h46m30s
11h47m00s
GMT–TIME–SEC
Lat 15.2°
Long 263.2°
MAP NO. 109
10.3°
267.1°

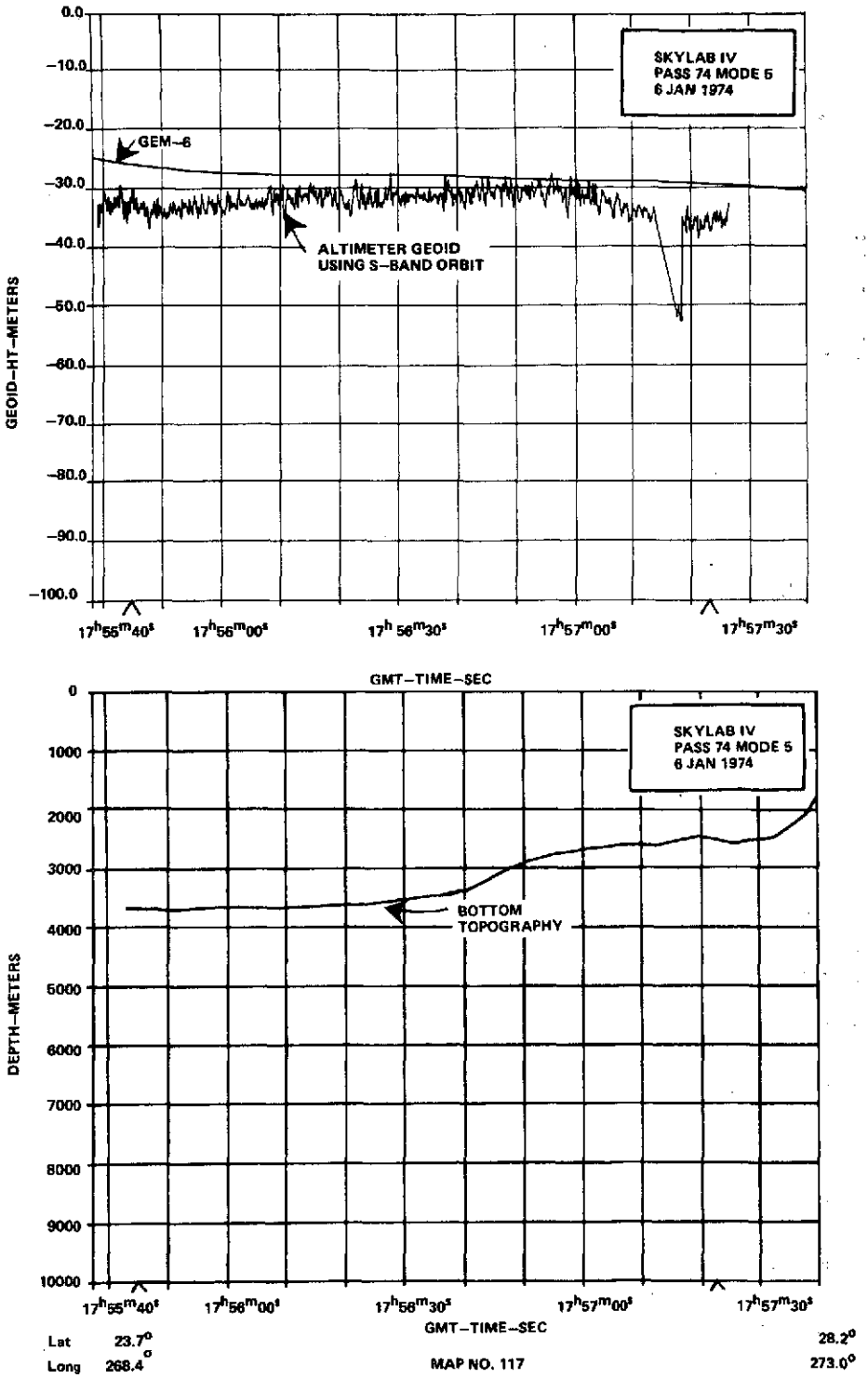

SKYLAB IV
PASS 68 MODE 5
18 DEC 1973
ALTIMETER GEOID
USING S-BAND ORBIT
GEM-6
GEOID-HT-METERS
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
11h48m30s
11h49m00s
11h49m30s
11h50m00s
GMT-TIME-SEC

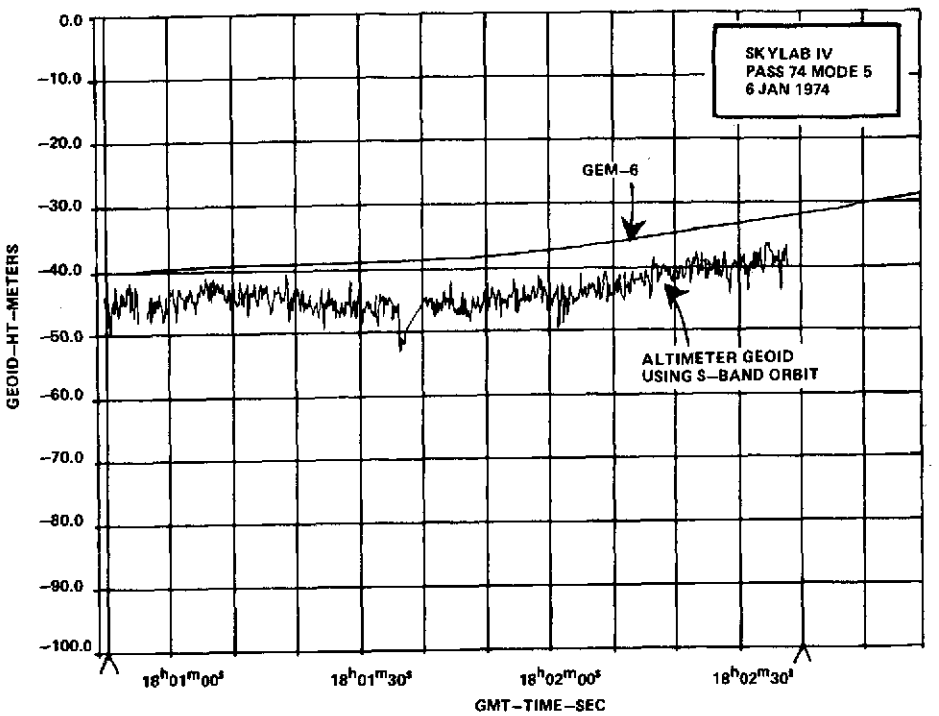

SKYLAB IV
PASS 68 MODE 5
18 DEC 1973
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11h48m30s
11h49m00s
11h49m30s
11h50m00s
GMT-TIME-SEC
Lat 5.8°
Long 270.8°
MAP NO. 110
-0.1°
275.3°

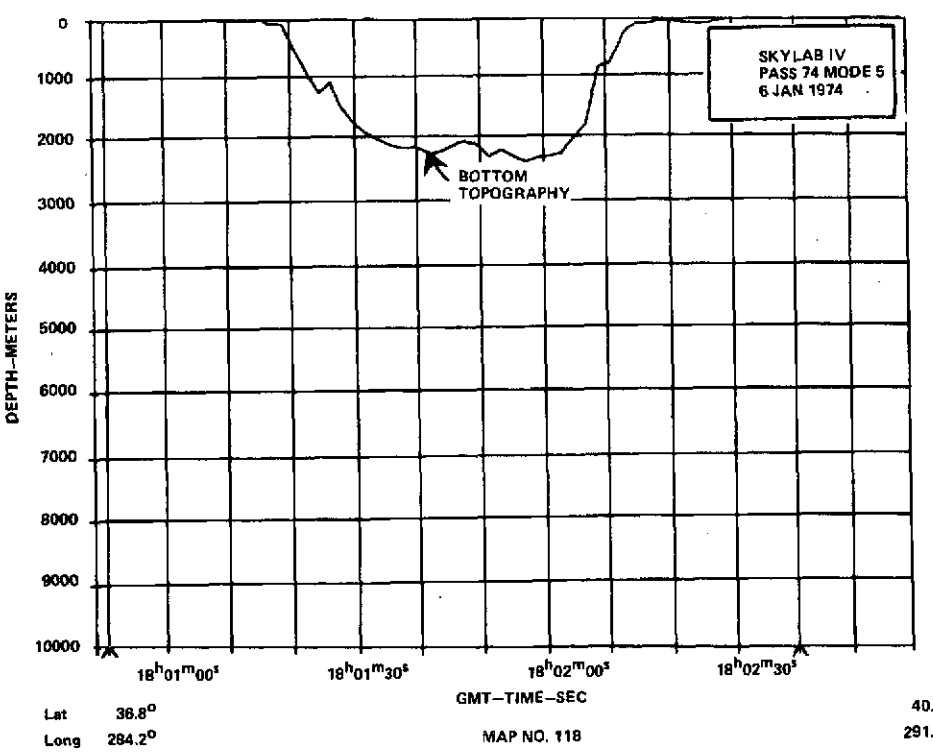

0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
GEOID–HT–METERS
GEM–6
SKYLAB IV
PASS 71 MODE 5
1 JAN 1974
ALTIMETER GEOID
USING S–BAND ORBIT
13h25m20s
13h25m50s
13h26m20s
13h26m50s
13h27m20s
GMT–TIME–SEC
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
DEPTH–METERS
SKYLAB IV
PASS 71 MODE 5
1 JAN 1974
BOTTOM
TOPOGRAPHY
13h25m20s
13h25m50s
13h26m20s
13h26m50s
13h27m20s
GMT–TIME–SEC
Lat -26.0°
Long 322.0°
MAP NO 113
-20.5°
327.3°

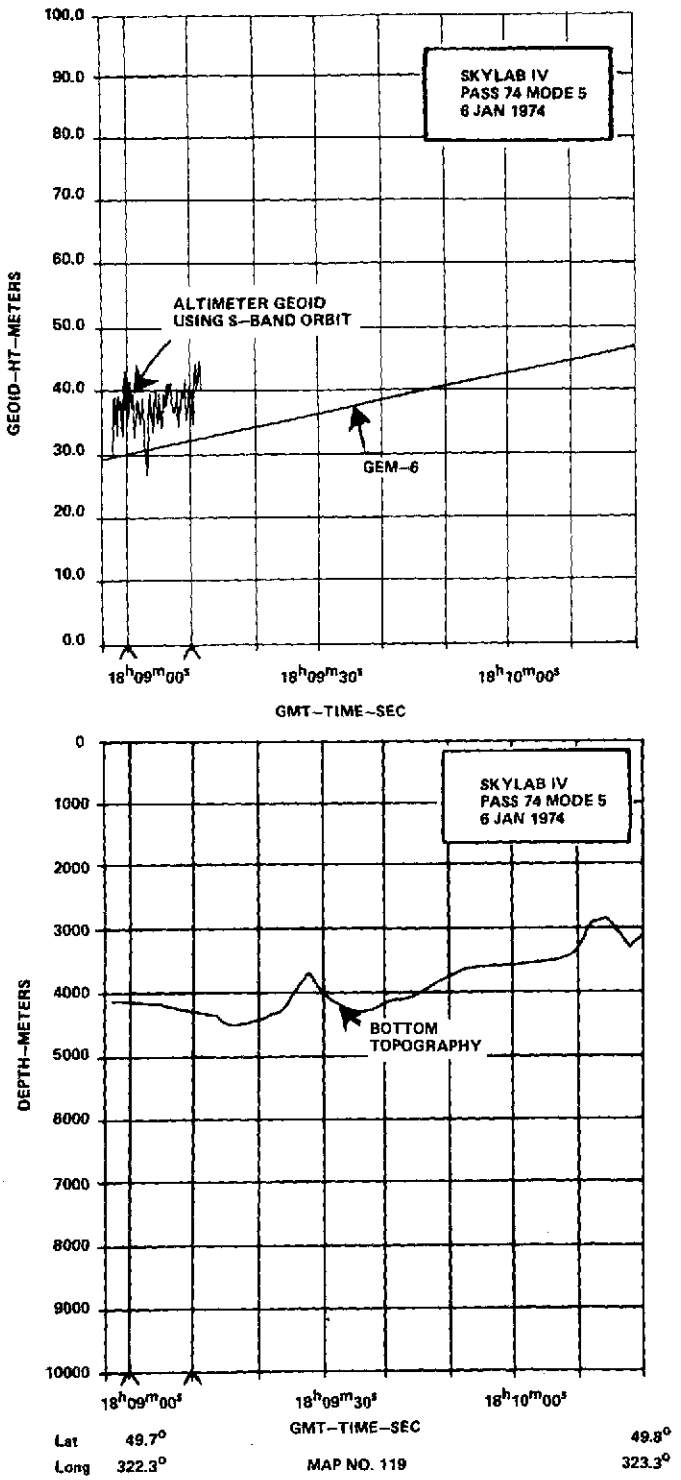

0.0
−10.0
−20.0
−30.0
−40.0
−50.0
−60.0
−70.0
−80.0
−90.0
−100.0
GEOID−HT−METERS
GEM−6
SKYLAB IV
PASS 71 MODE 5
1 JAN 1974
ALTIMETER GEOID
USING S−BAND ORBIT
13h29m00s
13h29m20s
13h29m50s
13h30m20s
13h30m50s
GMT−TIME−SEC
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
DEPTH−METERS
SKYLAB IV
PASS 71 MODE 5
1 JAN 1974
BOTTOM
TOPOGRAPHY
13h29m00s
13h29m20s
13h29m50s
13h30m20s
13h30m50s
GMT−TIME−SEC
Lat −15.3° −9.5°
Long 331.9° 336.6°
MAP NO. 114

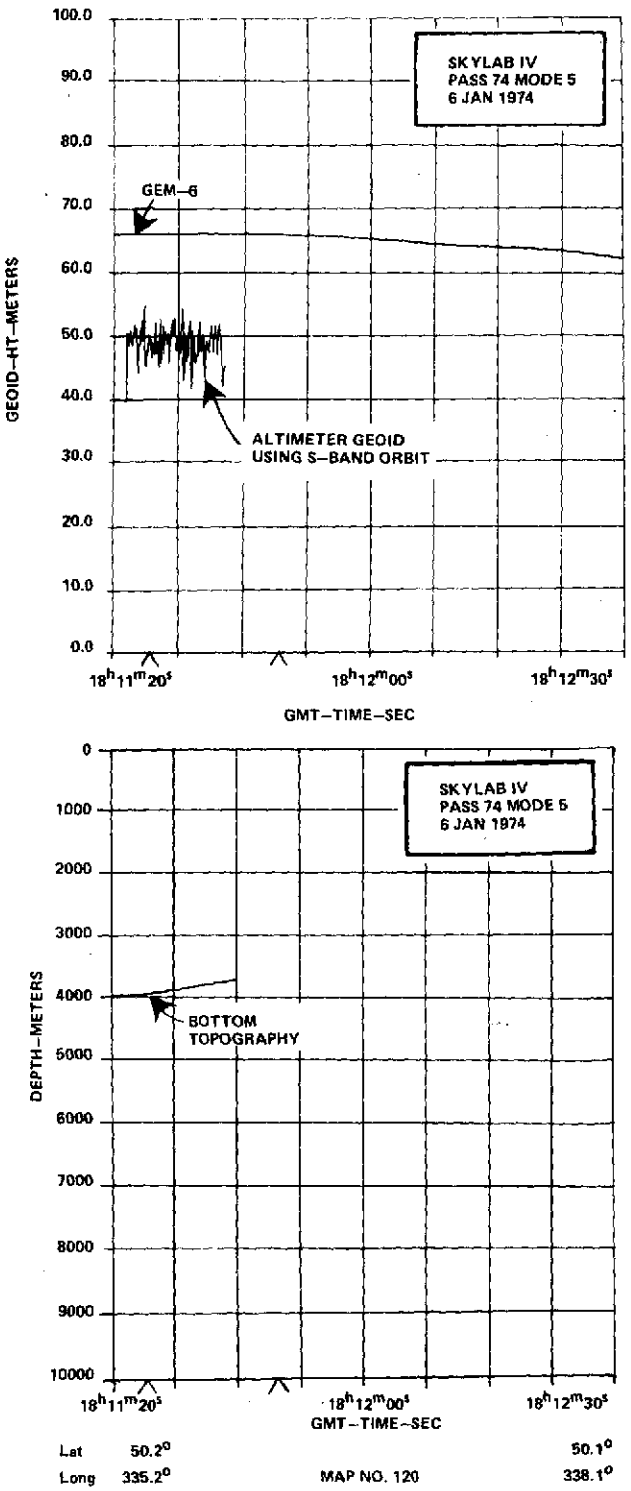

30.0
20.0
10.0
0.0
−10.0
−20.0
−30.0
−40.0
−50.0
−60.0
−70.0
GEOID–HT–METERS
GEM–6
SKYLAB IV
PASS 71 MODE 5
1 JAN 1974
ALTIMETER GEOID
USING S–BAND ORBIT
13h32m40s
13h33m10s
13h33m40s
13h34m10s
13h34m40s
GMT–TIME–SEC
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
DEPTH–METERS
SKYLAB IV
PASS 71 MODE 5
1 JAN 1974
BOTTOM
TOPOGRAPHY
13h32m40s
13h33m10s
13h33m40s
13h34m10s
13h34m40s
GMT–TIME–SEC
Lat −5.0
Long 340.0°
MAP NO. 115
0.9°
344.4°

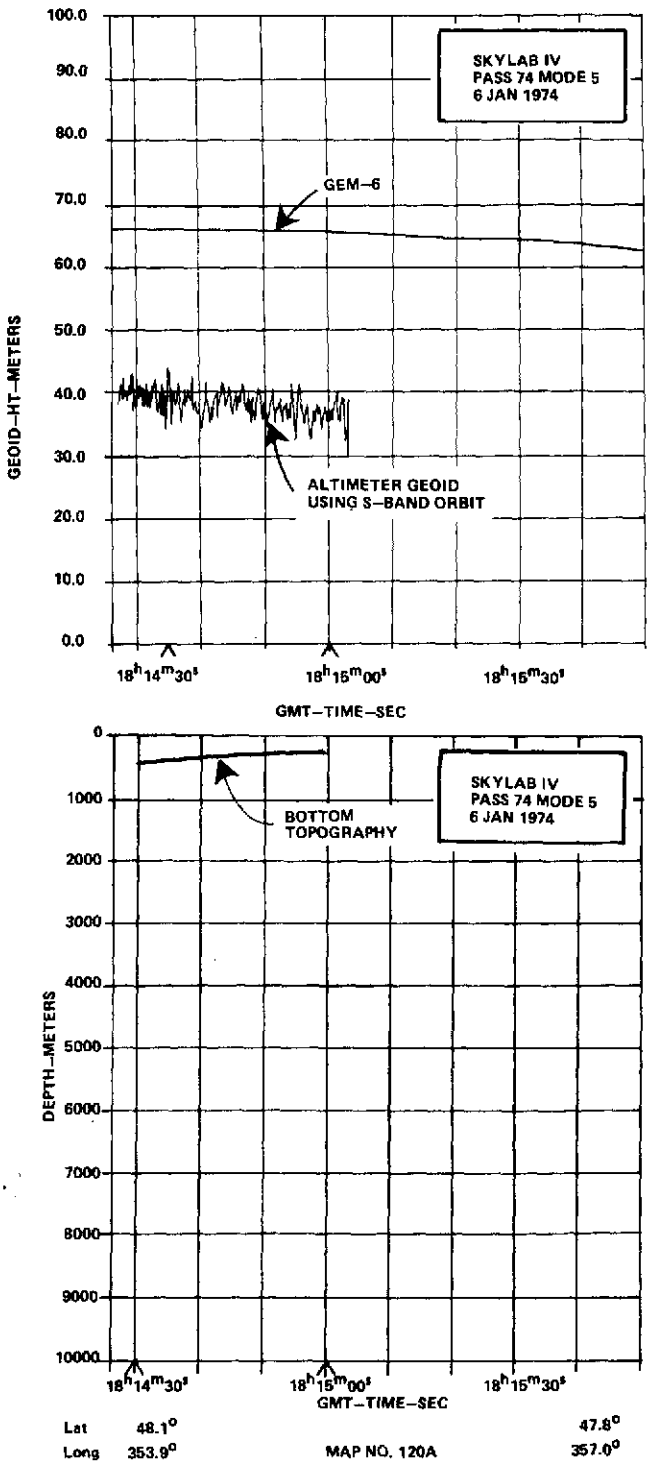

SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
–60.0
–70.0
–80.0
–90.0
–100.0
17h55m40s
17h56m00s
17h 56m30s
17h57m00s
17h57m30s
GMT–TIME–SEC
SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
17h55m40s
17h56m00s
17h58m30s
17h57m00s
17h57m30s
GMT–TIME–SEC
Lat 23.7°
Long 268.4°
MAP NO. 117
28.2°
273.0°

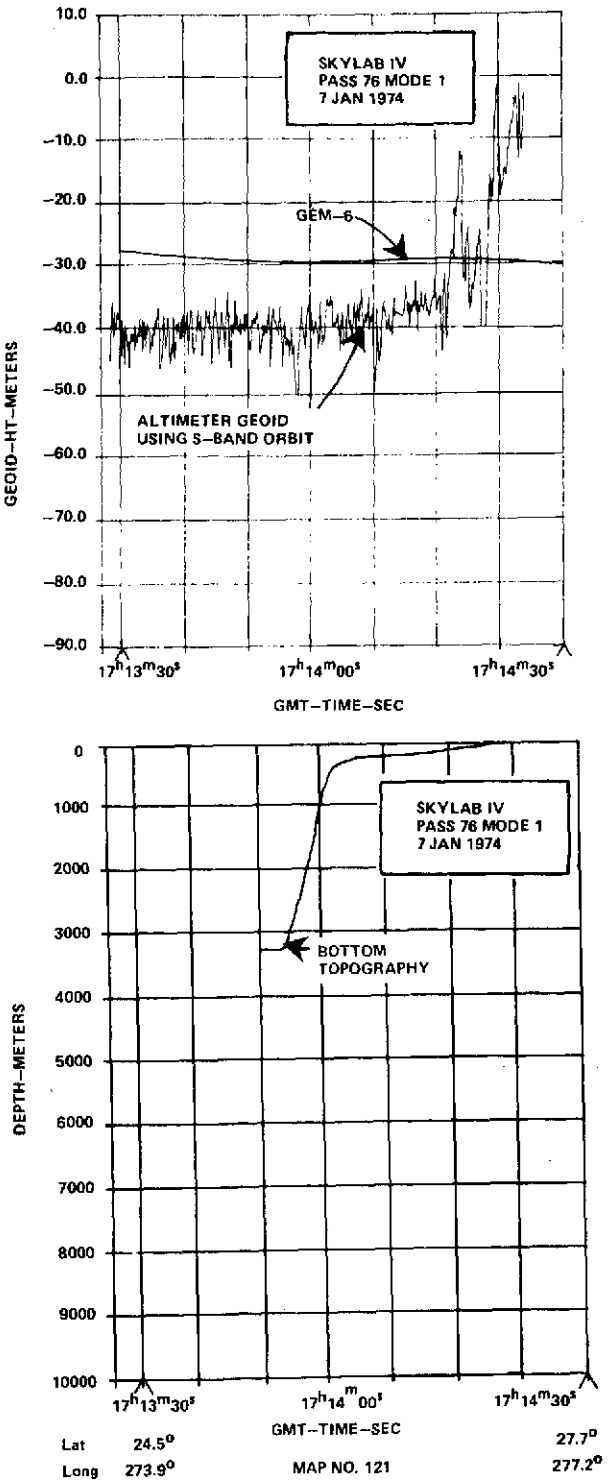

SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
–60.0
–70.0
–80.0
–90.0
–100.0
18h01m00s
18h01m30s
18h02m00s
18h02m30s
GMT–TIME–SEC

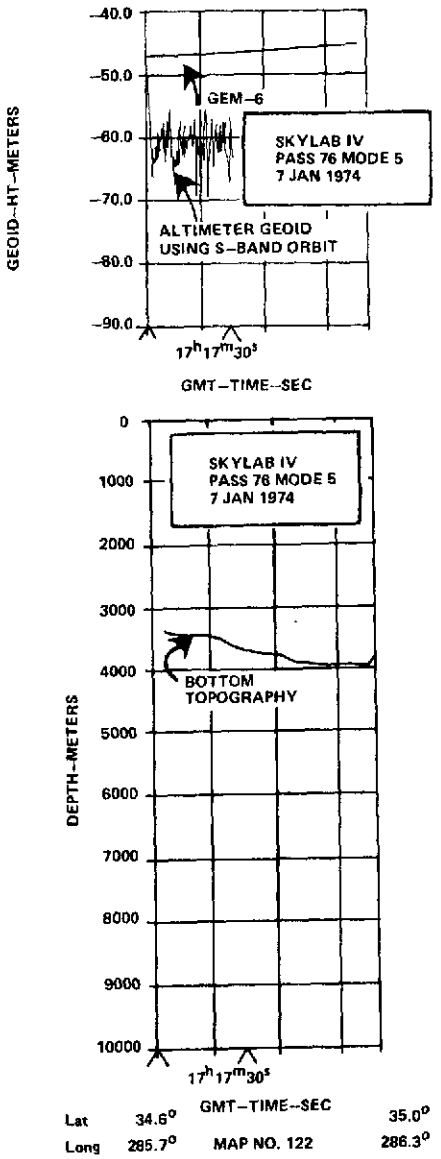

SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
18h01m00s
18h01m30s
18h02m00s
18h02m30s
GMT–TIME–SEC
Lat 36.8°
Long 284.2°
MAP NO. 118
40.8°
291.2°

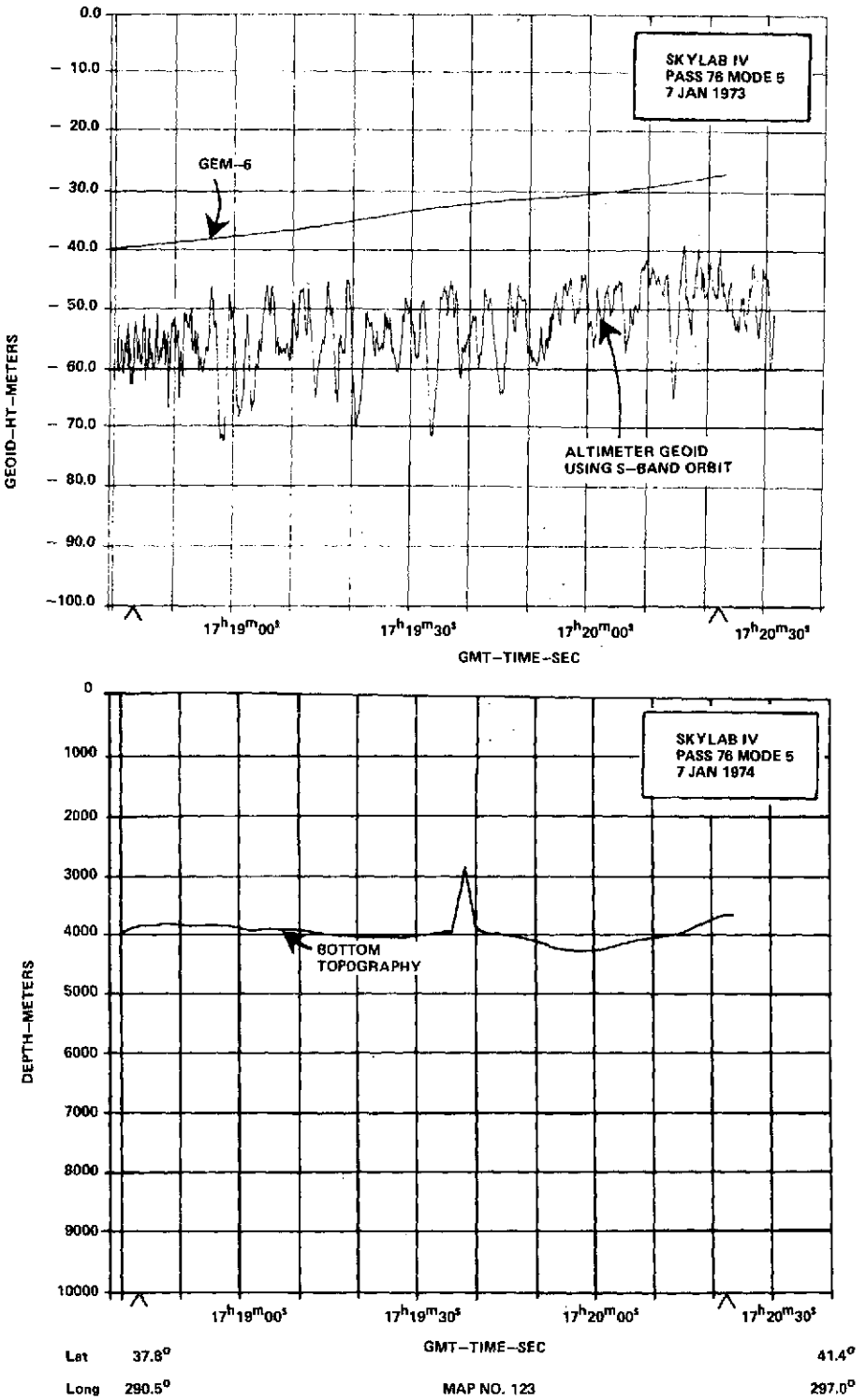

SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
ALTIMETER GEOID
USING S-BAND ORBIT
GEM-6
GEOID-HT-METERS
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
18h09m00s
18h09m30s
18h10m00s
GMT-TIME-SEC
SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
18h09m00s
18h09m30s
18h10m00s
GMT-TIME-SEC
Lat 49.7°
Long 322.3°
MAP NO. 119
49.8°
323.3°

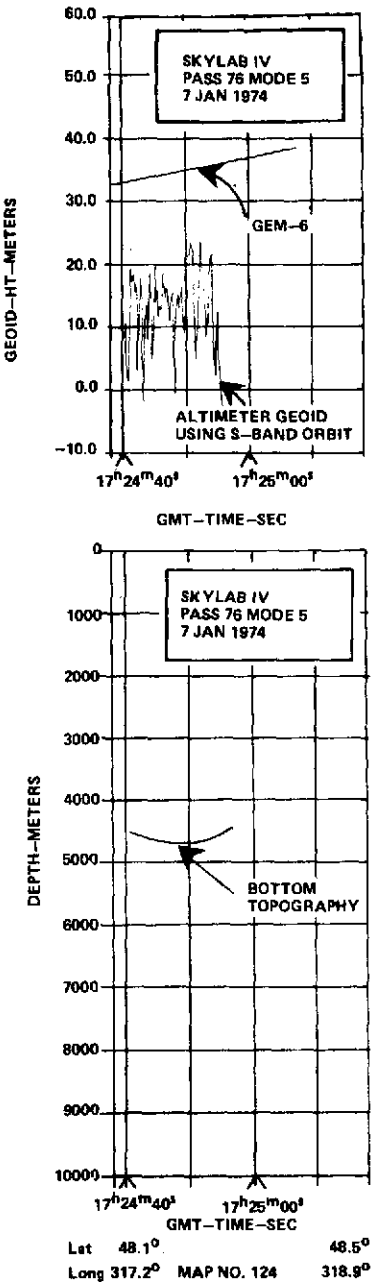

SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
18h11m20s
18h12m00s
18h12m30s
GMT–TIME–SEC
SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
18h11m20s
18h12m00s
18h12m30s
GMT–TIME–SEC
Lat 50.2°
Long 335.2°
MAP NO. 120
50.1°
338.1°

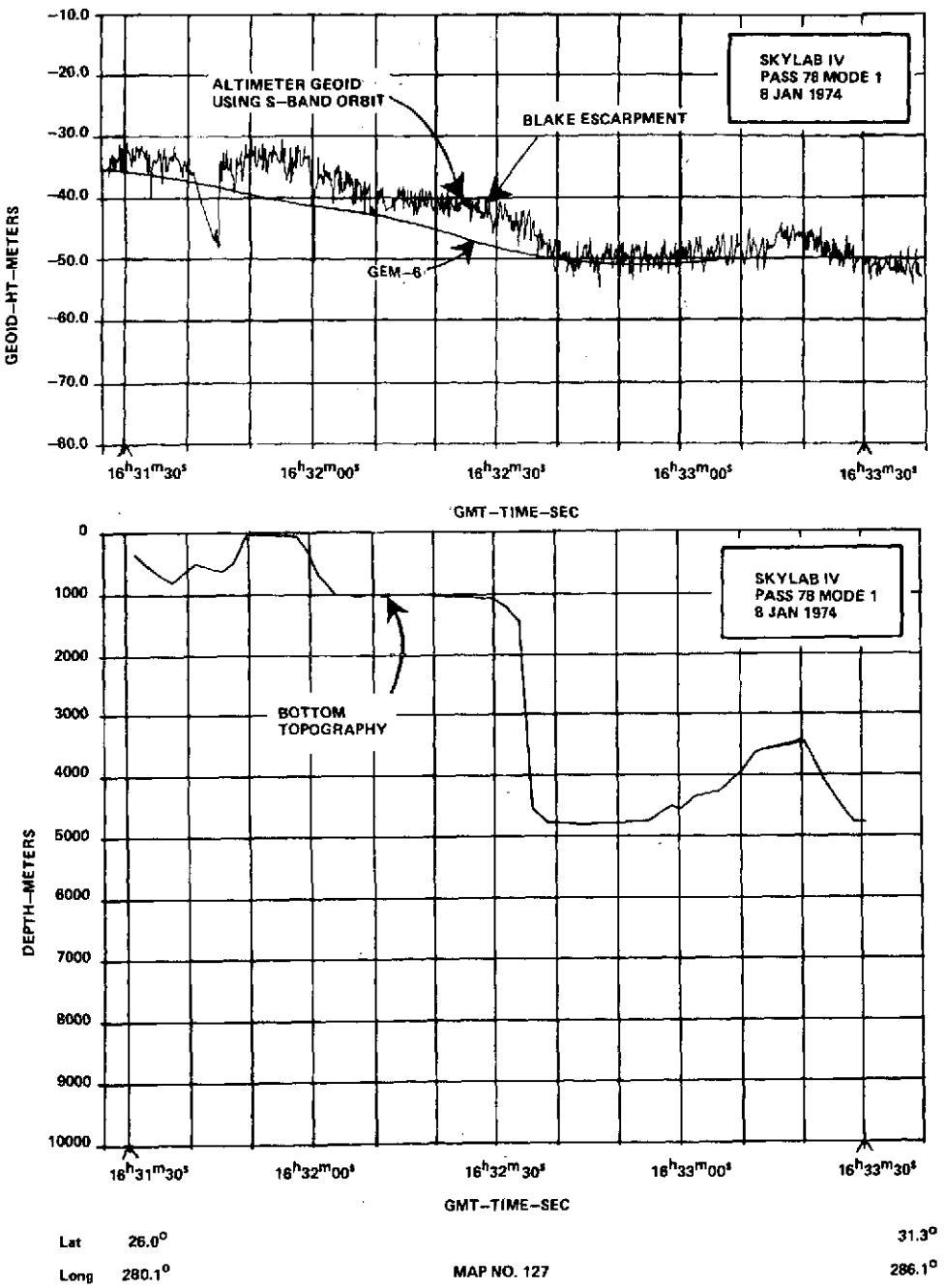

SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
18h14m30s
18h15m00s
18h15m30s
GMT–TIME–SEC
SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
18h14m30s
18h15m00s
18h15m30s
GMT–TIME–SEC
Lat 48.1° 47.8°
Long 353.9° 357.0°
MAP NO. 120A

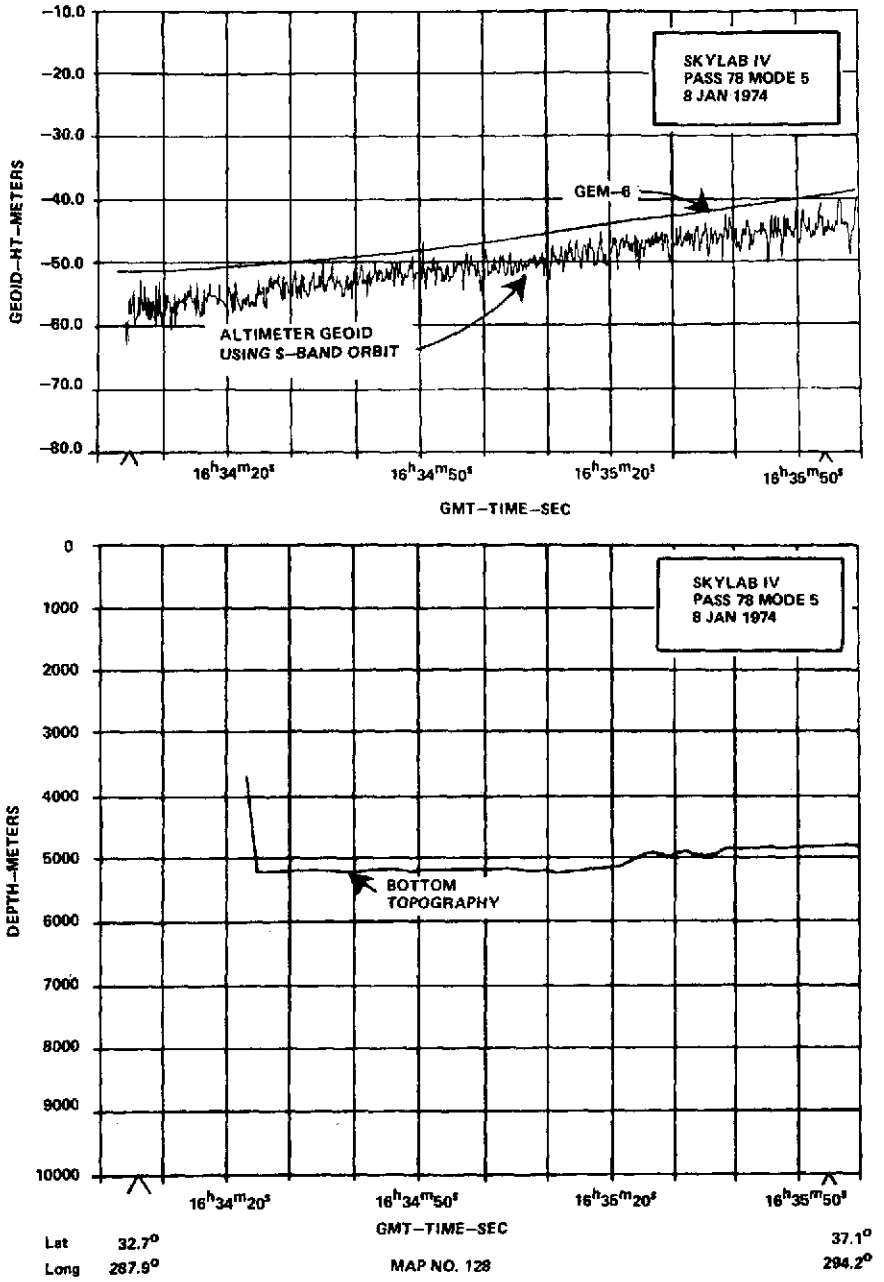

SKYLAB IV
PASS 76 MODE 1
7 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
10.0
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
–60.0
–70.0
–80.0
–90.0
17h13m30s
17h14m00s
17h14m30s
GMT–TIME–SEC
SKYLAB IV
PASS 76 MODE 1
7 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
17h13m30s
17h14m00s
17h14m30s
GMT–TIME–SEC
Lat 24.5° 27.7°
Long 273.9° 277.2°
MAP NO. 121

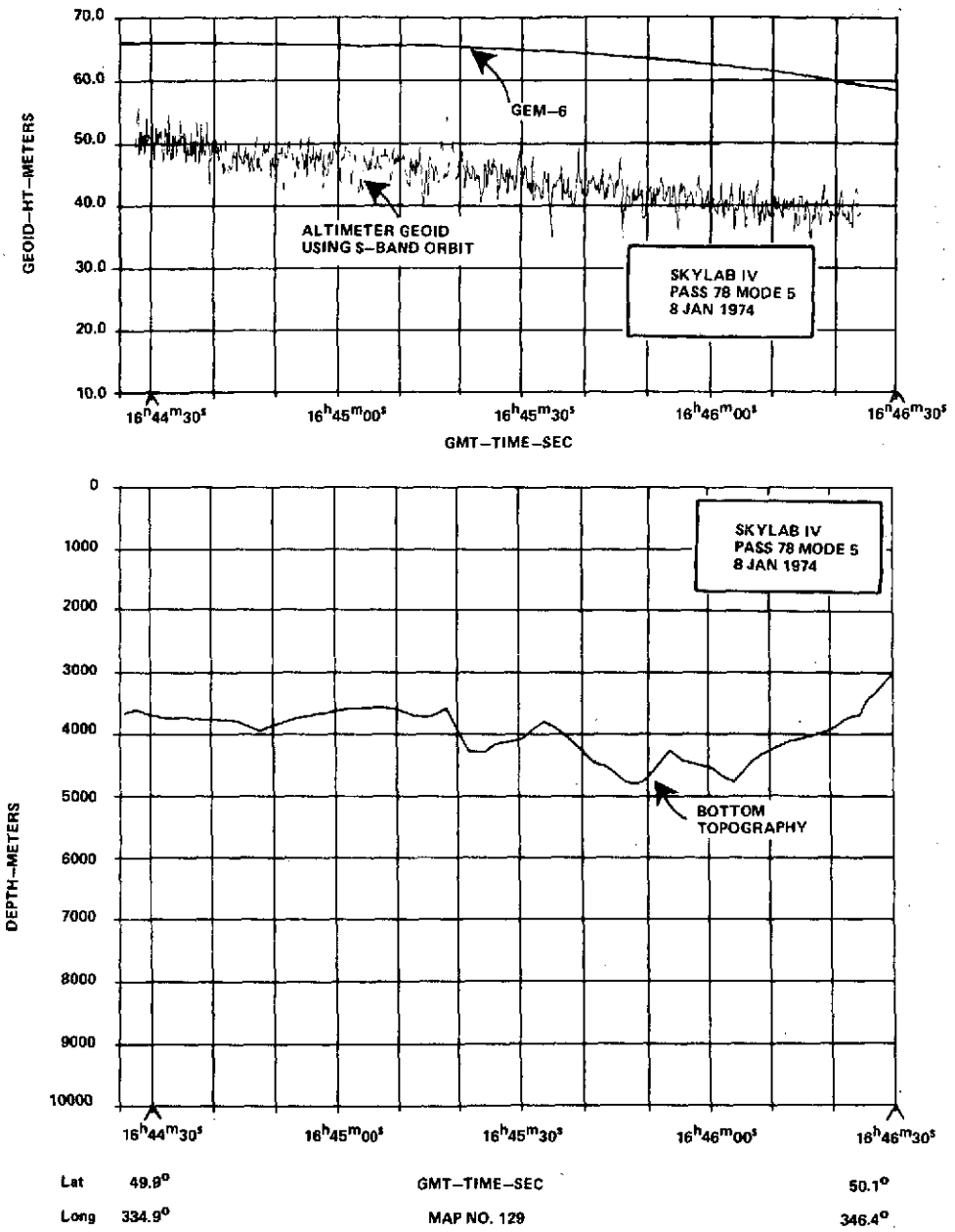

GEOID--HT--METERS
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
GEM-6
SKYLAB IV
PASS 76 MODE 5
7 JAN 1974
ALTIMETER GEOID
USING S-BAND ORBIT
17h17m30s
GMT-TIME--SEC
DEPTH--METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
SKYLAB IV
PASS 76 MODE 5
7 JAN 1974
BOTTOM
TOPOGRAPHY
17h17m30s
GMT-TIME--SEC
Lat 34.6° 35.0°
Long 285.7° MAP NO. 122 286.3°

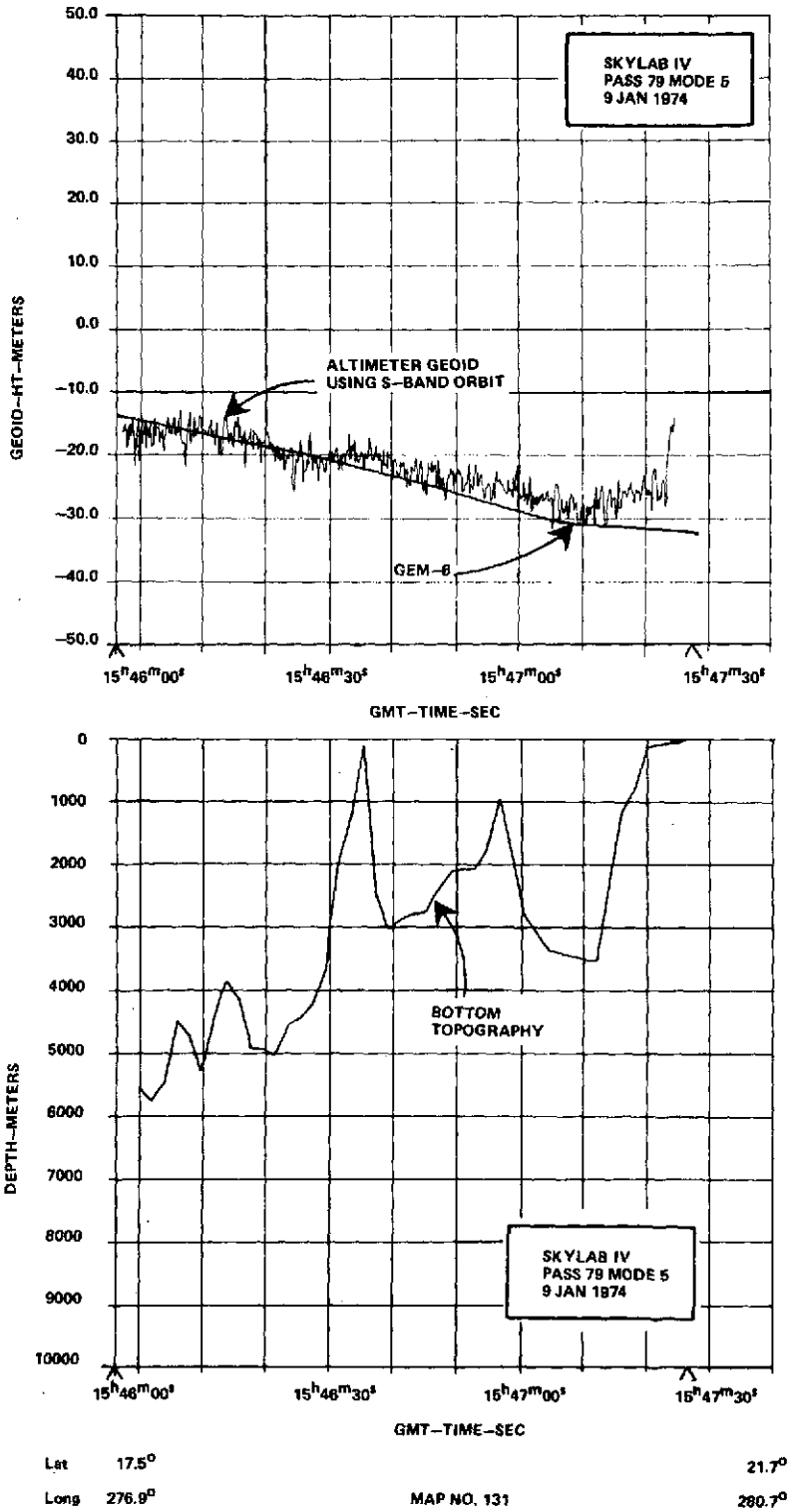

SKYLAB IV
PASS 76 MODE 5
7 JAN 1973
GEM-6
ALTIMETER GEOID
USING S-BAND ORBIT
GEOID-HT-METERS
0.0
- 10.0
- 20.0
- 30.0
- 40.0
- 50.0
- 60.0
- 70.0
- 80.0
- 90.0
-100.0
17h19m00s
17h19m30s
17h20m00s
17h20m30s
GMT-TIME-SEC
SKYLAB IV
PASS 76 MODE 5
7 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
17h19m00s
17h19m30s
17h20m00s
17h20m30s
GMT-TIME-SEC
Lat 37.8°
41.4°
Long 290.5°
MAP NO. 123
297.0°

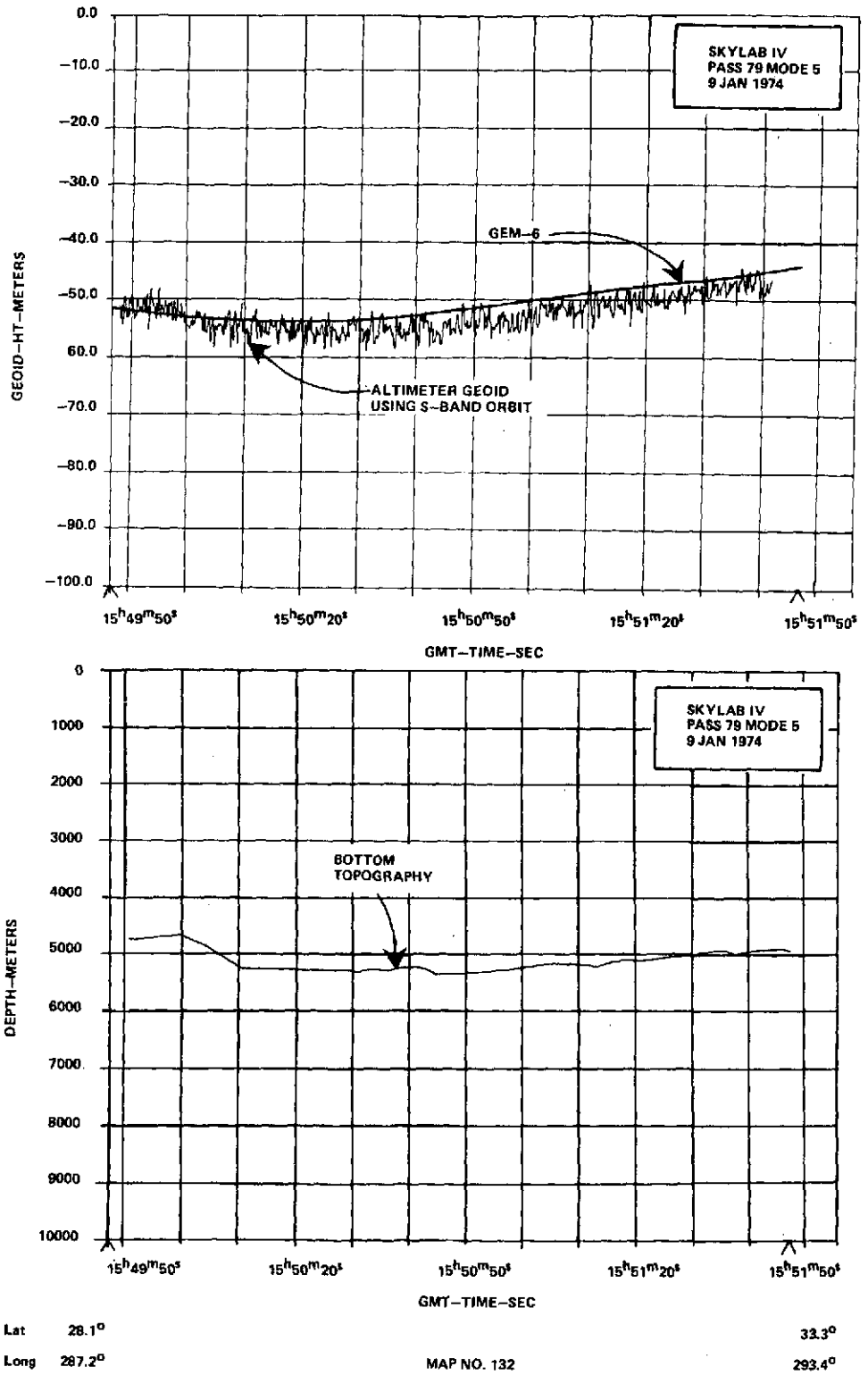

SKYLAB IV
PASS 76 MODE 5
7 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
60.0
50.0
40.0
30.0
20.0
10.0
0.0
–10.0
17h24m40s
17h25m00s
GMT–TIME–SEC
SKYLAB IV
PASS 76 MODE 5
7 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
17h24m40s
17h25m00s
GMT–TIME–SEC
Lat 48.1°
48.5°
Long 317.2°
MAP NO. 124
318.9°

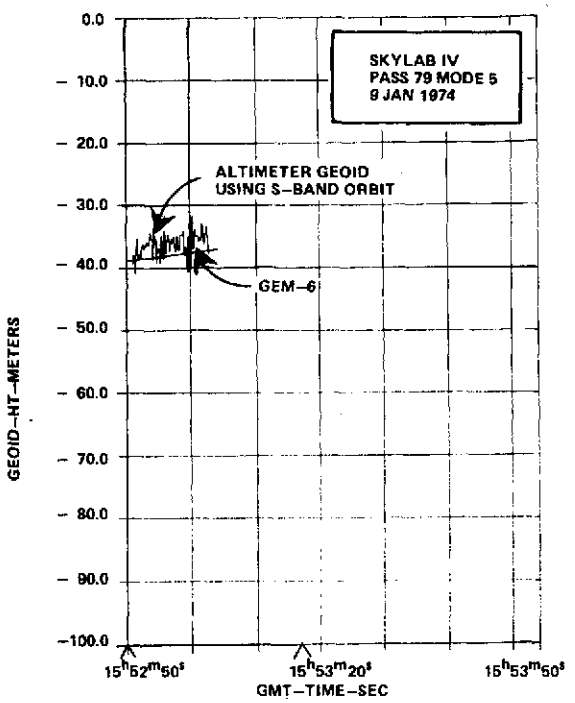

SKYLAB IV
PASS 78 MODE 1
8 JAN 1974
ALTIMETER GEOID
USING S-BAND ORBIT
BLAKE ESCARPMENT
GEM-6
GEOID-HT-METERS
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
16h31m30s
16h32m00s
16h32m30s
16h33m00s
16h33m30s
GMT-TIME-SEC
SKYLAB IV
PASS 78 MODE 1
8 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
16h31m30s
16h32m00s
16h32m30s
16h33m00s
16h33m30s
GMT-TIME-SEC
Lat 26.0°
31.3°
Long 280.1°
286.1°
MAP NO. 127

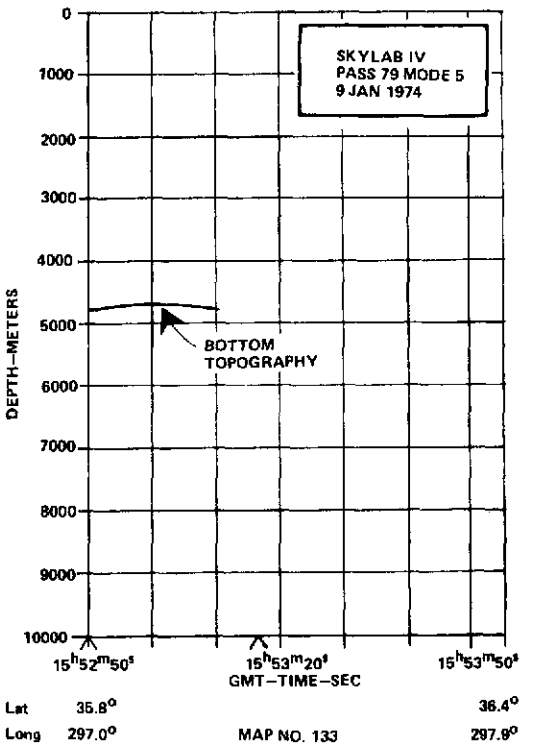

SKYLAB IV
PASS 78 MODE 5
8 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
–10.0
–20.0
–30.0
–40.0
–50.0
–60.0
–70.0
–80.0
16h34m20s
16h34m50s
16h35m20s
16h35m50s
GMT–TIME–SEC
SKYLAB IV
PASS 78 MODE 5
8 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
16h34m20s
16h34m50s
16h35m20s
16h35m50s
GMT–TIME–SEC
Lat 32.7°
Long 287.9°
MAP NO. 128
37.1°
294.2°


GEOID–HT–METERS
70.0
60.0
50.0
40.0
30.0
20.0
10.0
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
SKYLAB IV
PASS 78 MODE 5
8 JAN 1974
16h44m30s
16h45m00s
16h45m30s
16h46m00s
16h46m30s
GMT–TIME–SEC
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
SKYLAB IV
PASS 78 MODE 5
8 JAN 1974
BOTTOM
TOPOGRAPHY
16h44m30s
16h45m00s
16h45m30s
16h46m00s
16h46m30s
Lat 49.9°
Long 334.9°
GMT–TIME–SEC
MAP NO. 129
50.1°
346.4°


SKYLAB IV
PASS 79 MODE 5
9 JAN 1974
ALTIMETER GEOID
USING S-BAND ORBIT
GEM-6
GEOID-HT-METERS
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
15h46m00s
15h46m30s
15h47m00s
15h47m30s
GMT-TIME-SEC
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
SKYLAB IV
PASS 79 MODE 5
9 JAN 1974
GMT-TIME-SEC
Lat 17.5°
21.7°
Long 276.9°
MAP NO. 131
280.7°

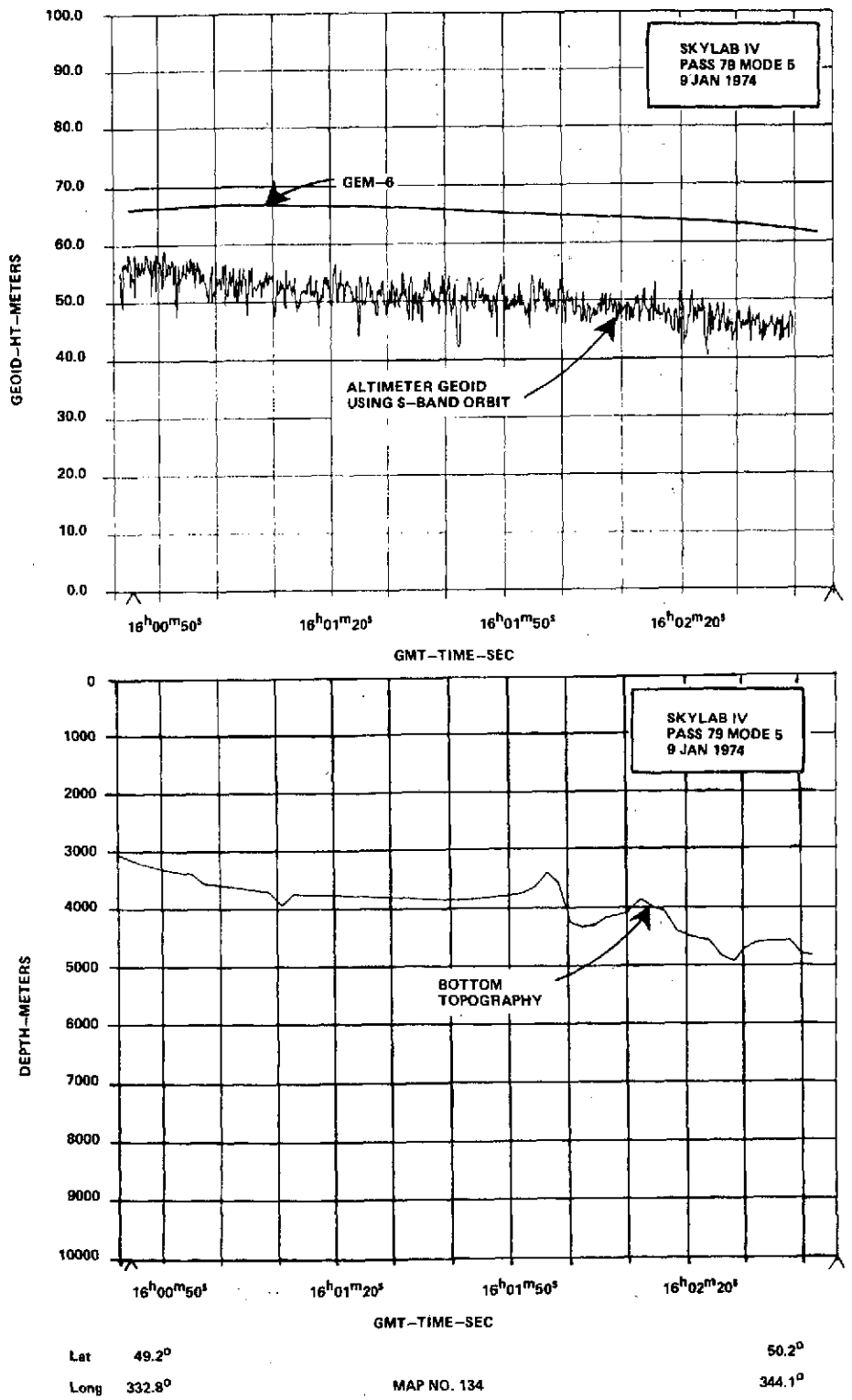

SKYLAB IV
PASS 79 MODE 5
9 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
60.0
–70.0
–80.0
–90.0
–100.0
15h49m50s
15h50m20s
15h50m50s
15h51m20s
15h51m50s
GMT–TIME–SEC
SKYLAB IV
PASS 79 MODE 5
9 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
15h49m50s
15h50m20s
15h50m50s
15h51m20s
15h51m50s
GMT–TIME–SEC
Lat 28.1°
33.3°
Long 287.2°
MAP NO. 132
293.4°

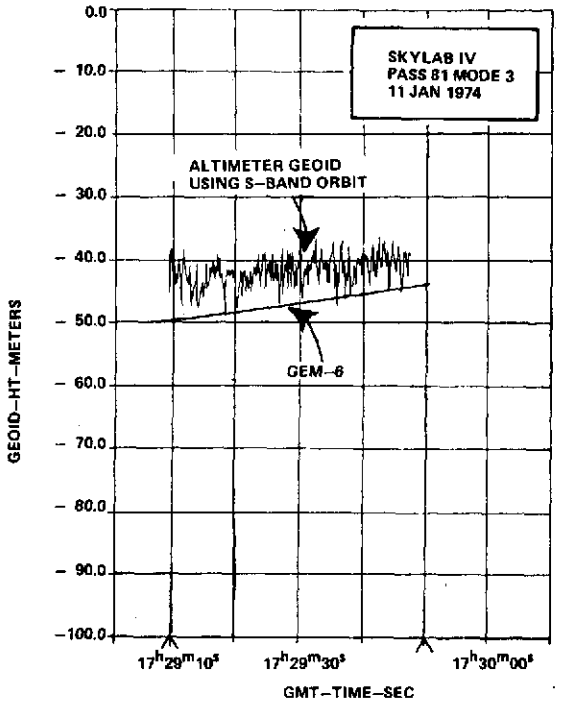


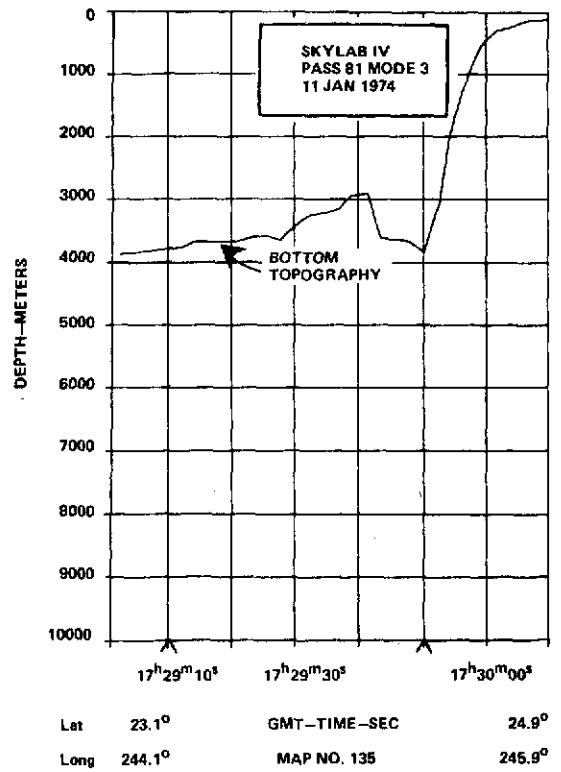


Lat 35.8° 36.4°

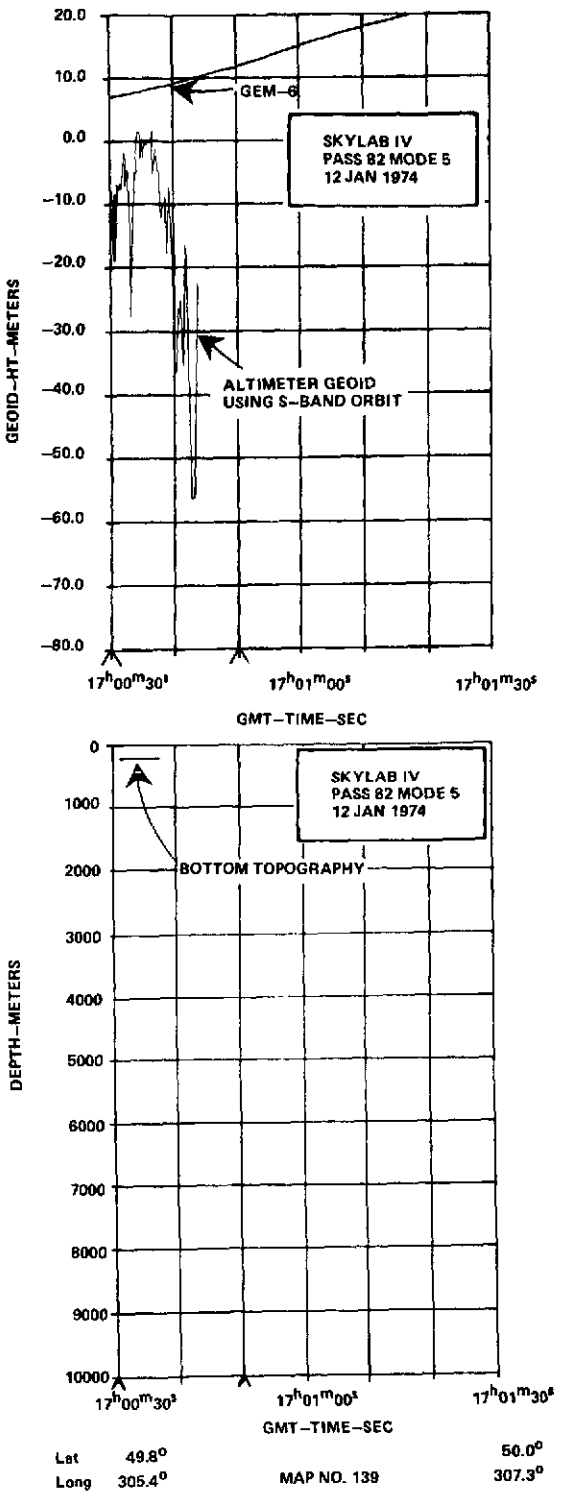
Long 297.0° MAP NO. 133 297.8°

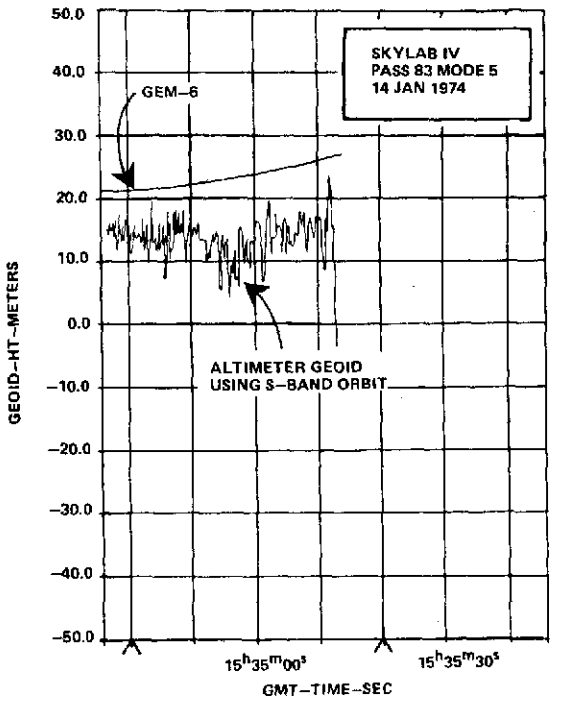

SKYLAB IV
PASS 78 MODE 5
9 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
16h00m50s
16h01m20s
16h01m50s
16h02m20s
GMT–TIME–SEC
SKYLAB IV
PASS 79 MODE 5
9 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
16h00m50s
16h01m20s
16h01m50s
16h02m20s
GMT–TIME–SEC
Lat 49.2°
Long 332.8°
MAP NO. 134
50.2°
344.1°

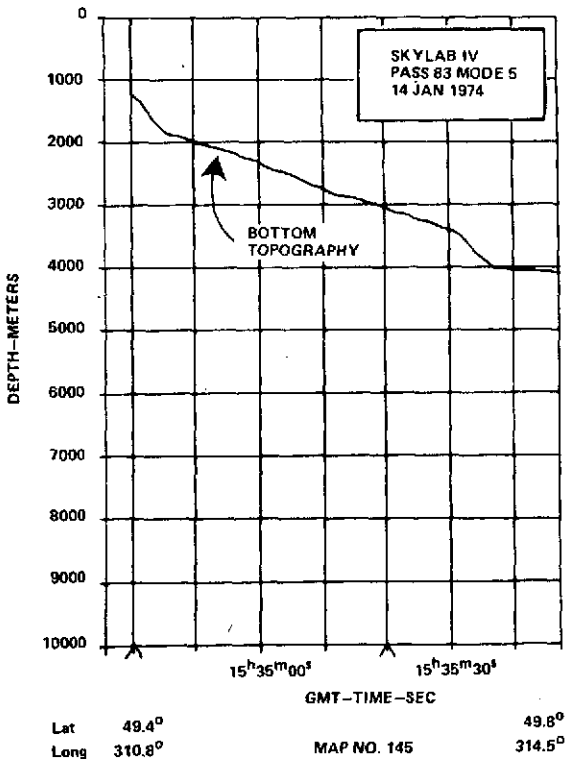




Lat	23.1°	GMT-TIME-SEC	24.9°
Long	244.1°	MAP NO. 135	245.9°

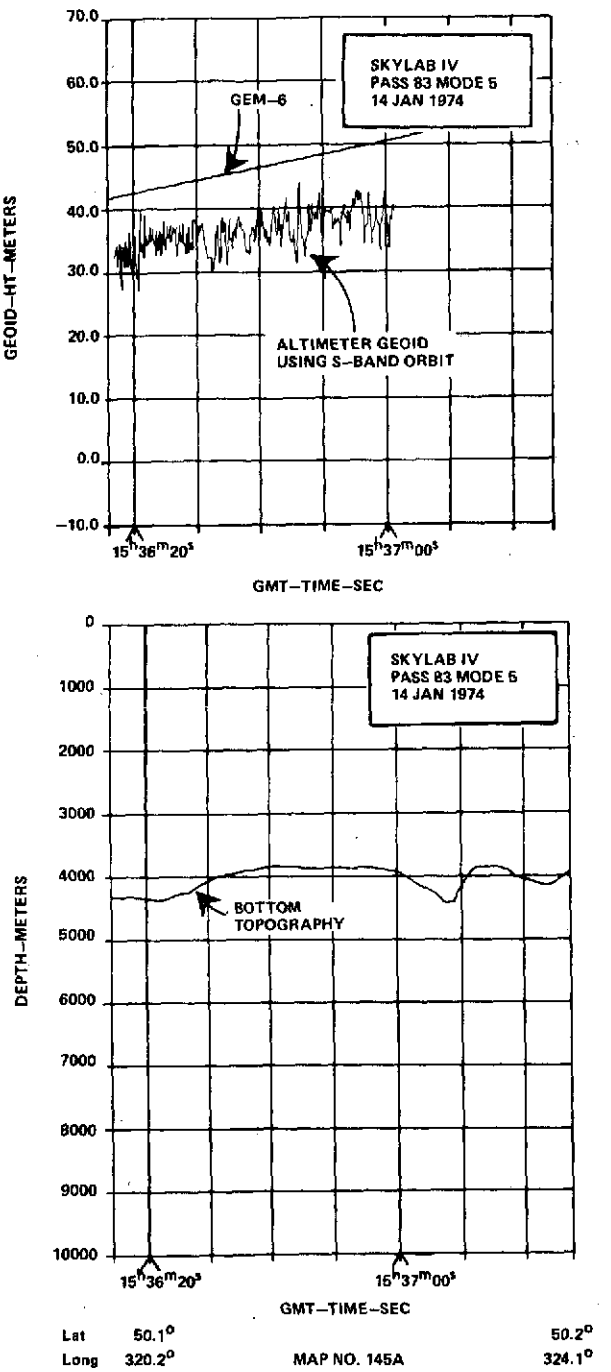

20.0
10.0
0.0
−10.0
−20.0
−30.0
−40.0
−50.0
−60.0
−70.0
−80.0
GEOID−HT−METERS
GEM−6
SKYLAB IV
PASS 82 MODE 5
12 JAN 1974
ALTIMETER GEOID
USING S−BAND ORBIT
17h00m30s
17h01m00s
17h01m30s
GMT−TIME−SEC
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
DEPTH−METERS
SKYLAB IV
PASS 82 MODE 5
12 JAN 1974
BOTTOM TOPOGRAPHY
17h00m30s
17h01m00s
17h01m30s
GMT−TIME−SEC
Lat 49.8°
Long 305.4°
MAP NO. 139
50.0°
307.3°

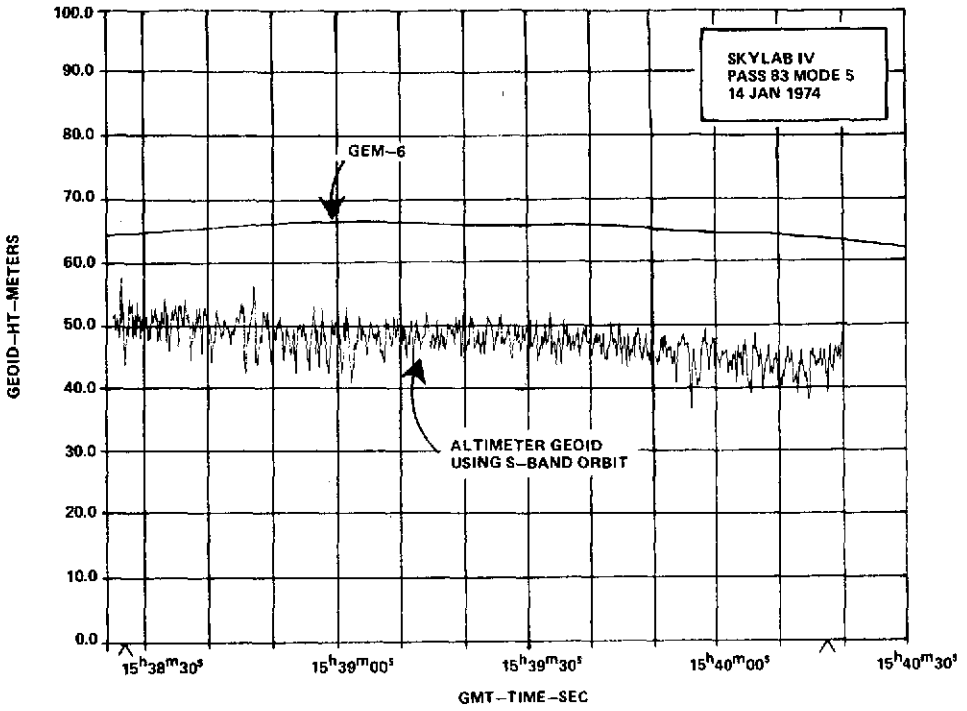


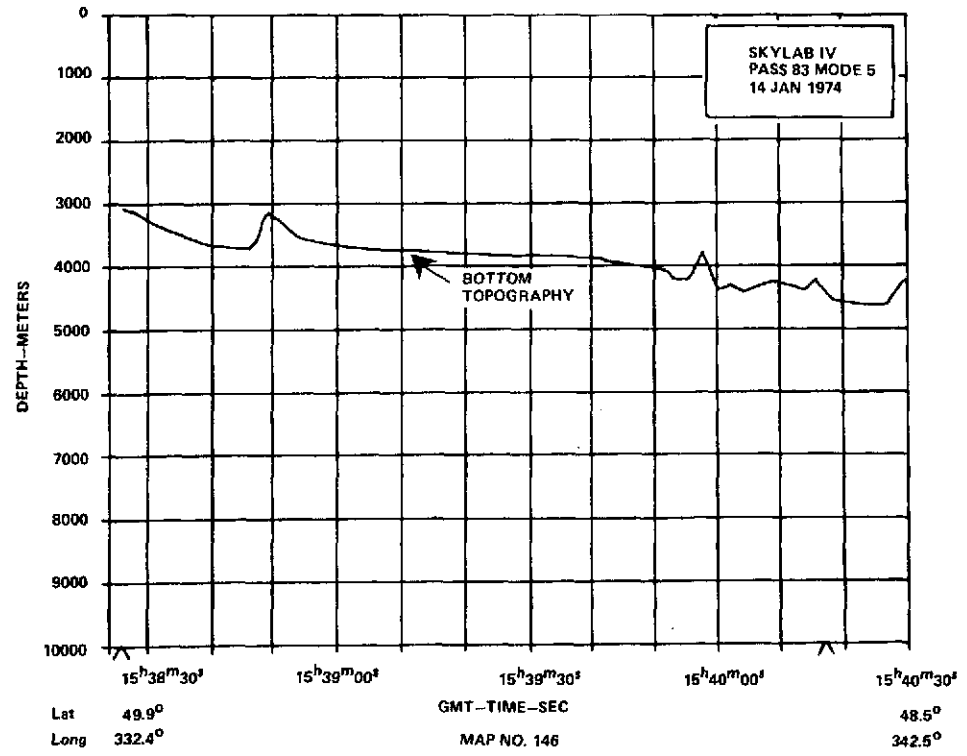


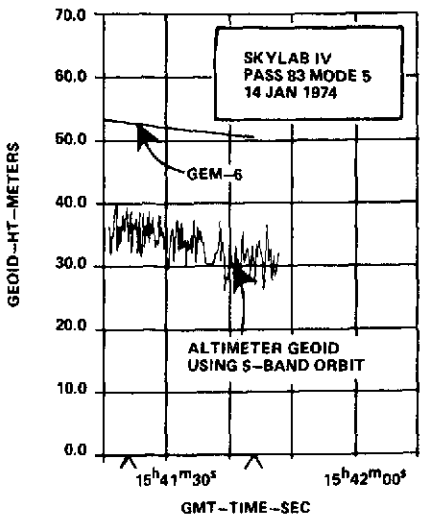
Lat	49.4°		49.8°
Long	310.8°	MAP NO. 145	314.5°

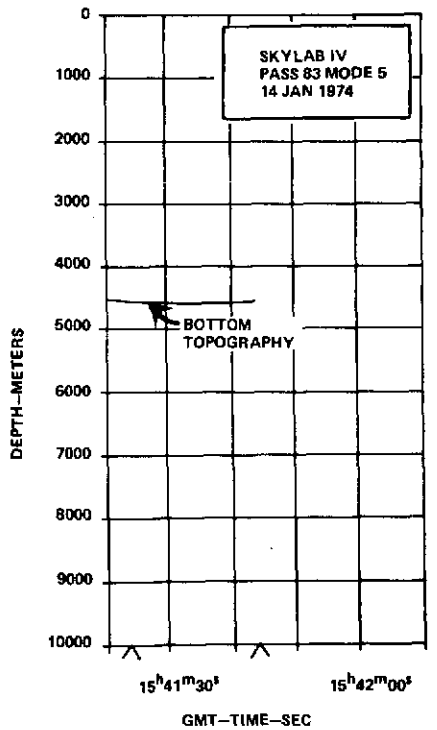
C-3


SKYLAB IV
PASS 83 MODE 5
14 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
–10.0
15h36m20s
15h37m00s
GMT–TIME–SEC
SKYLAB IV
PASS 83 MODE 5
14 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
15h36m20s
15h37m00s
GMT–TIME–SEC
Lat 50.1° 50.2°
Long 320.2° MAP NO. 145A 324.1°

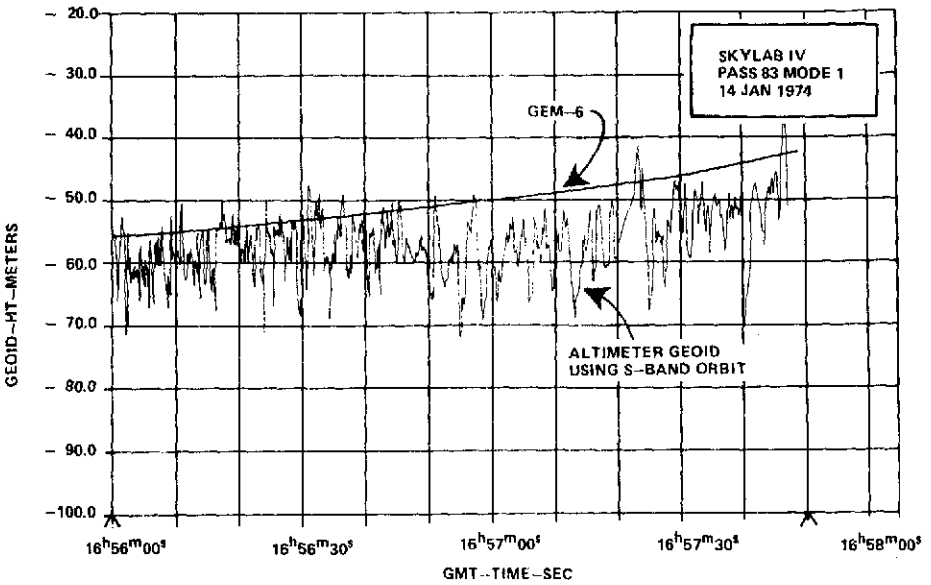

SKYLAB IV
PASS 83 MODE 5
14 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
15h38m30s
15h39m00s
15h39m30s
15h40m00s
15h40m30s
GMT–TIME–SEC

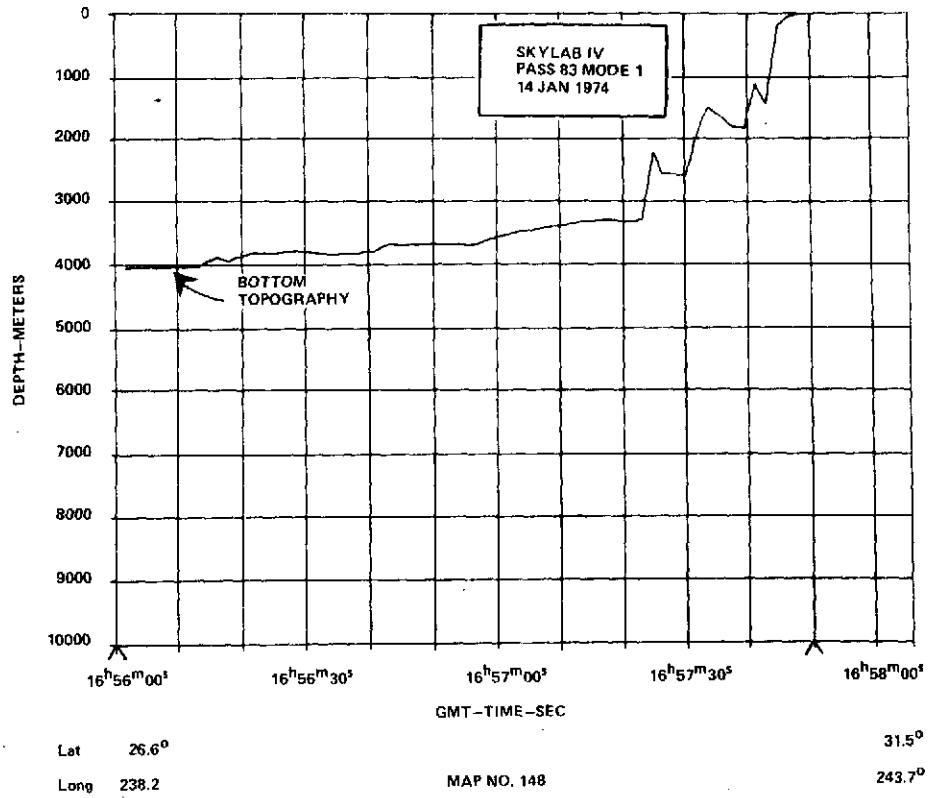

SKYLAB IV
PASS 83 MODE 5
14 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
15h38m30s
15h39m00s
15h39m30s
15h40m00s
15h40m30s
GMT–TIME–SEC
Lat 49.9° 48.5°
Long 332.4° 342.5°
MAP NO. 146





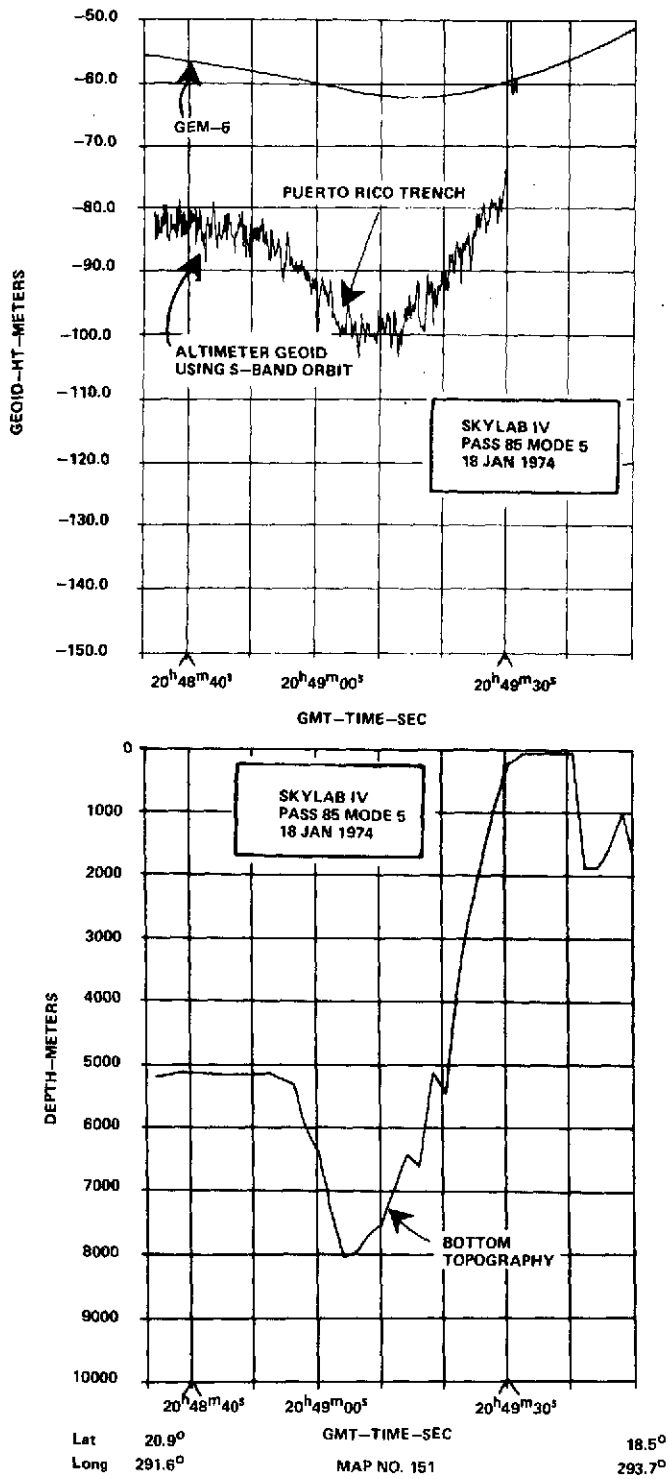
Lat	47.2°		46.8°
Long	348.3°	MAP NO. 147	350.0°

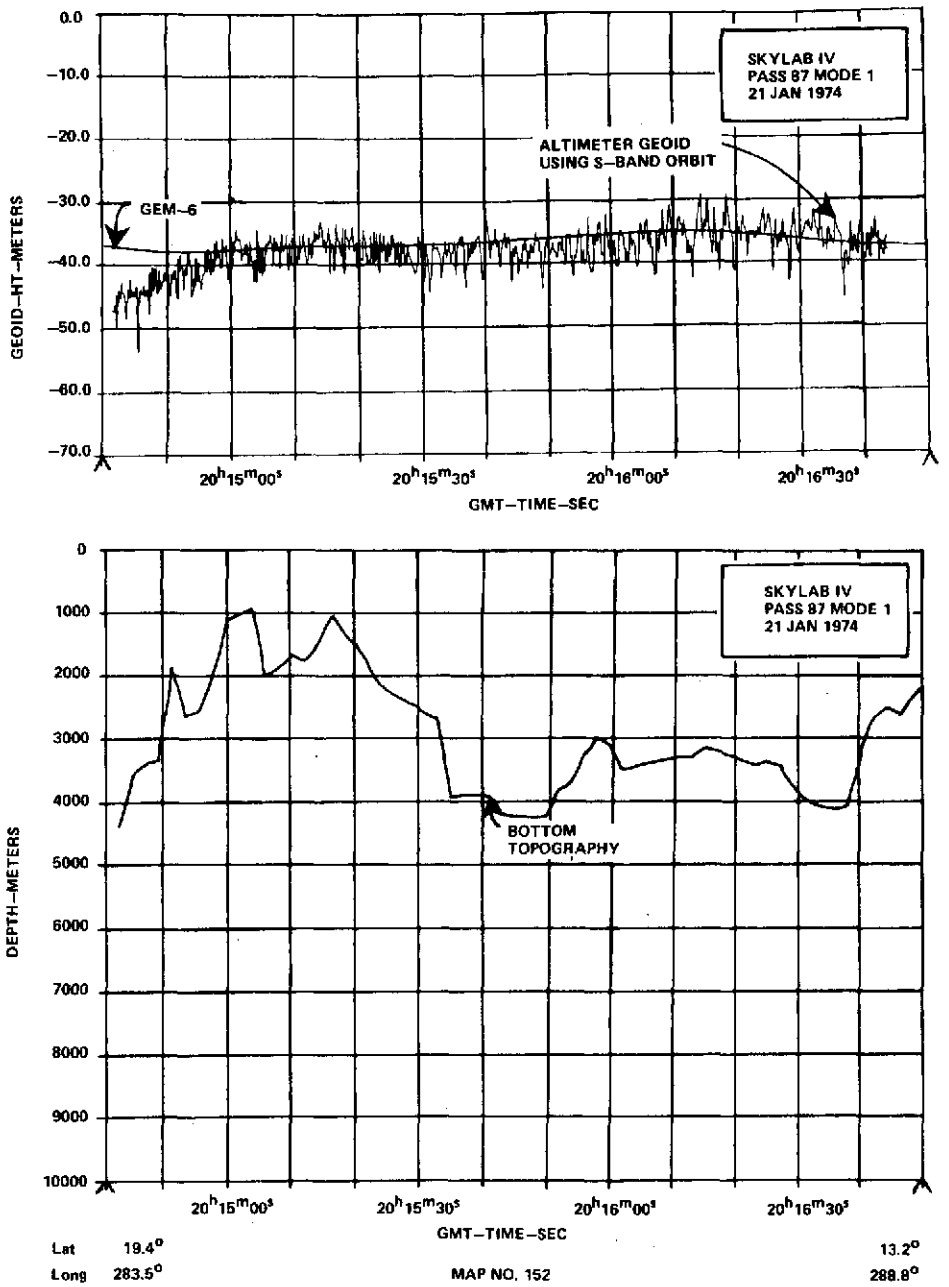


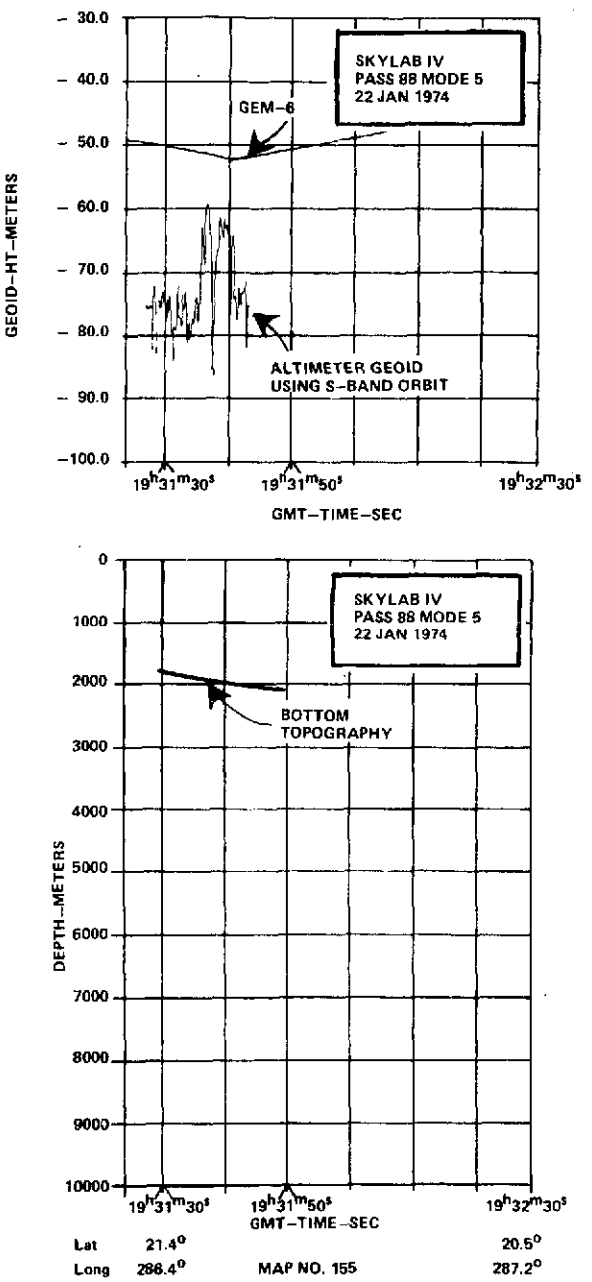


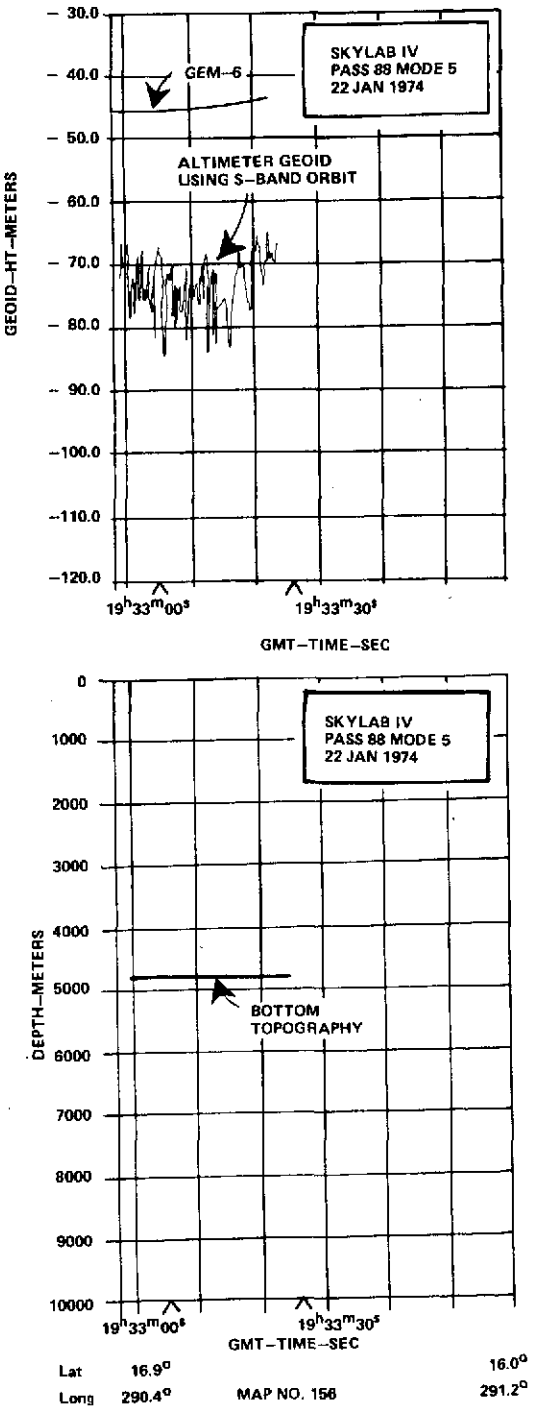
Lat 26.6° 31.5°

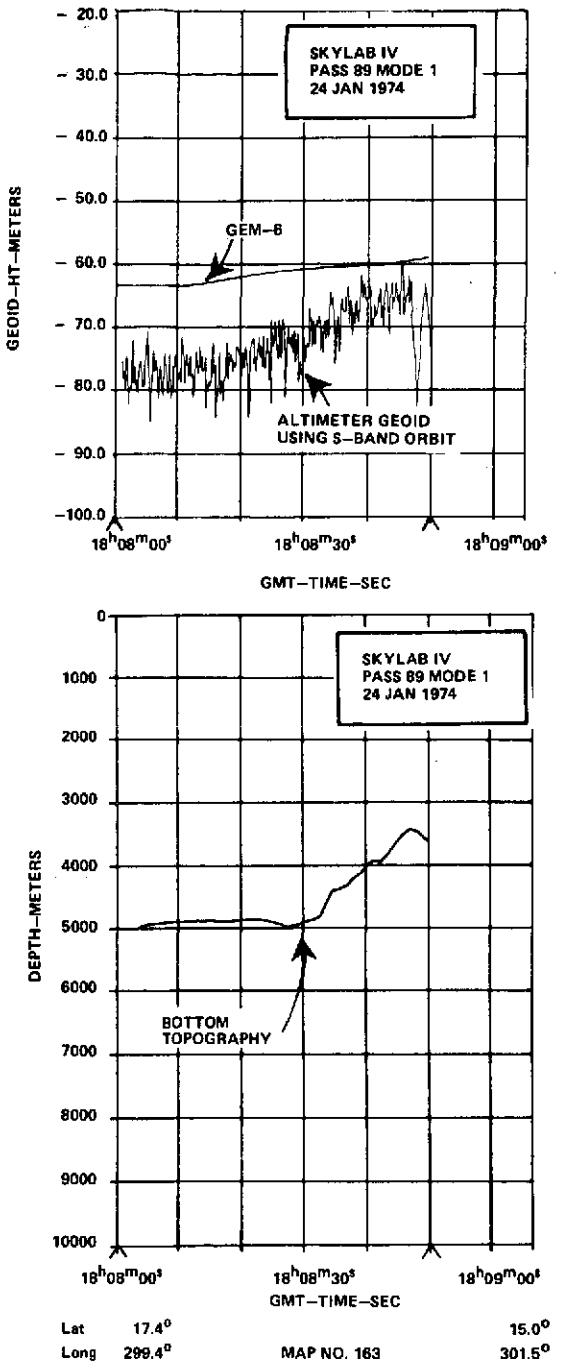
Long 238.2 MAP NO. 148 243.7°

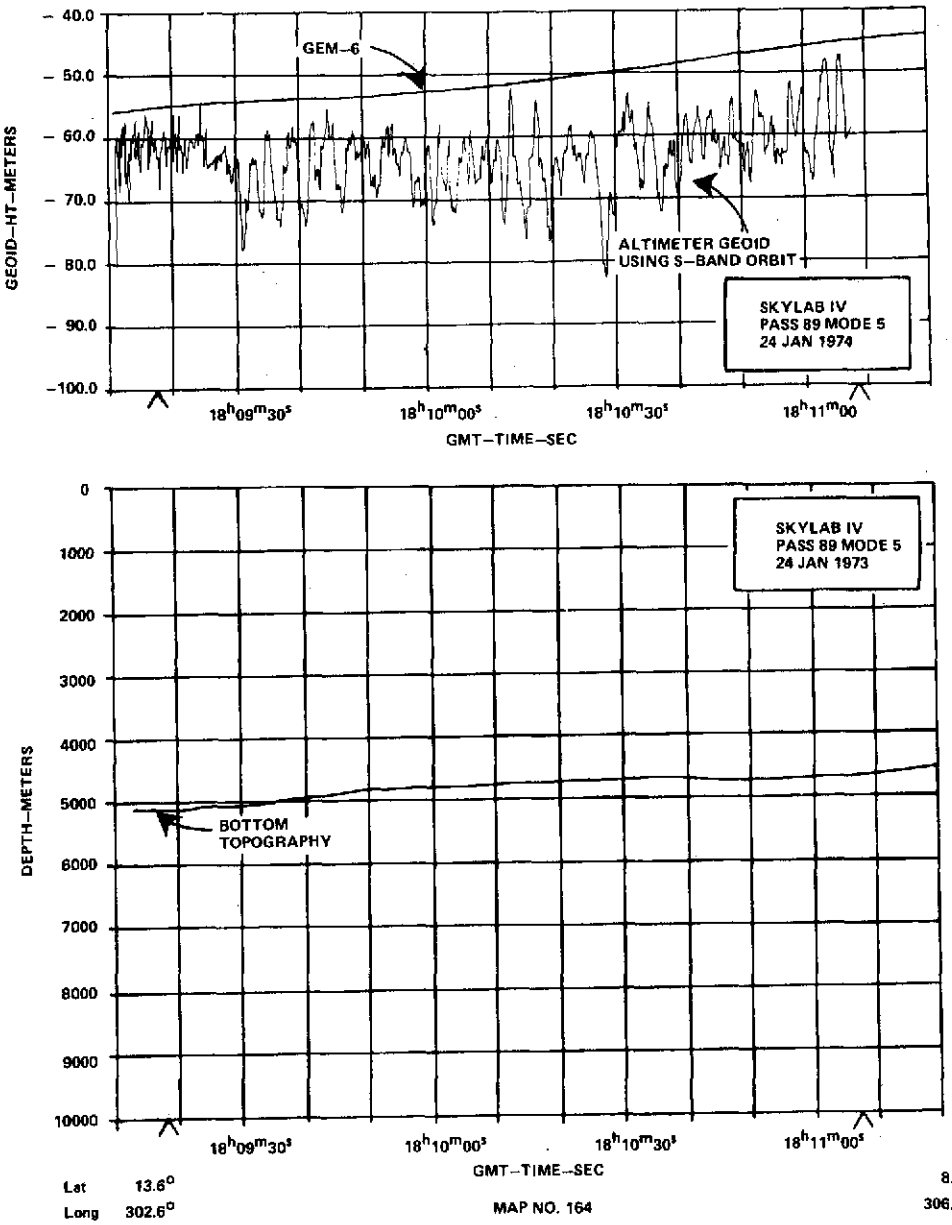

-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
-120.0
-130.0
-140.0
-150.0
GEOID-HT-METERS
GEM-6
PUERTO RICO TRENCH
ALTIMETER GEOID
USING S-BAND ORBIT
SKYLAB IV
PASS 85 MODE 5
18 JAN 1974
20h48m40s
20h49m00s
20h49m30s
GMT-TIME-SEC
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
DEPTH-METERS
SKYLAB IV
PASS 85 MODE 5
18 JAN 1974
BOTTOM
TOPOGRAPHY
20h48m40s
20h49m00s
20h49m30s
GMT-TIME-SEC
Lat 20.9° 18.5°
Long 291.6° 293.7°
MAP NO. 151

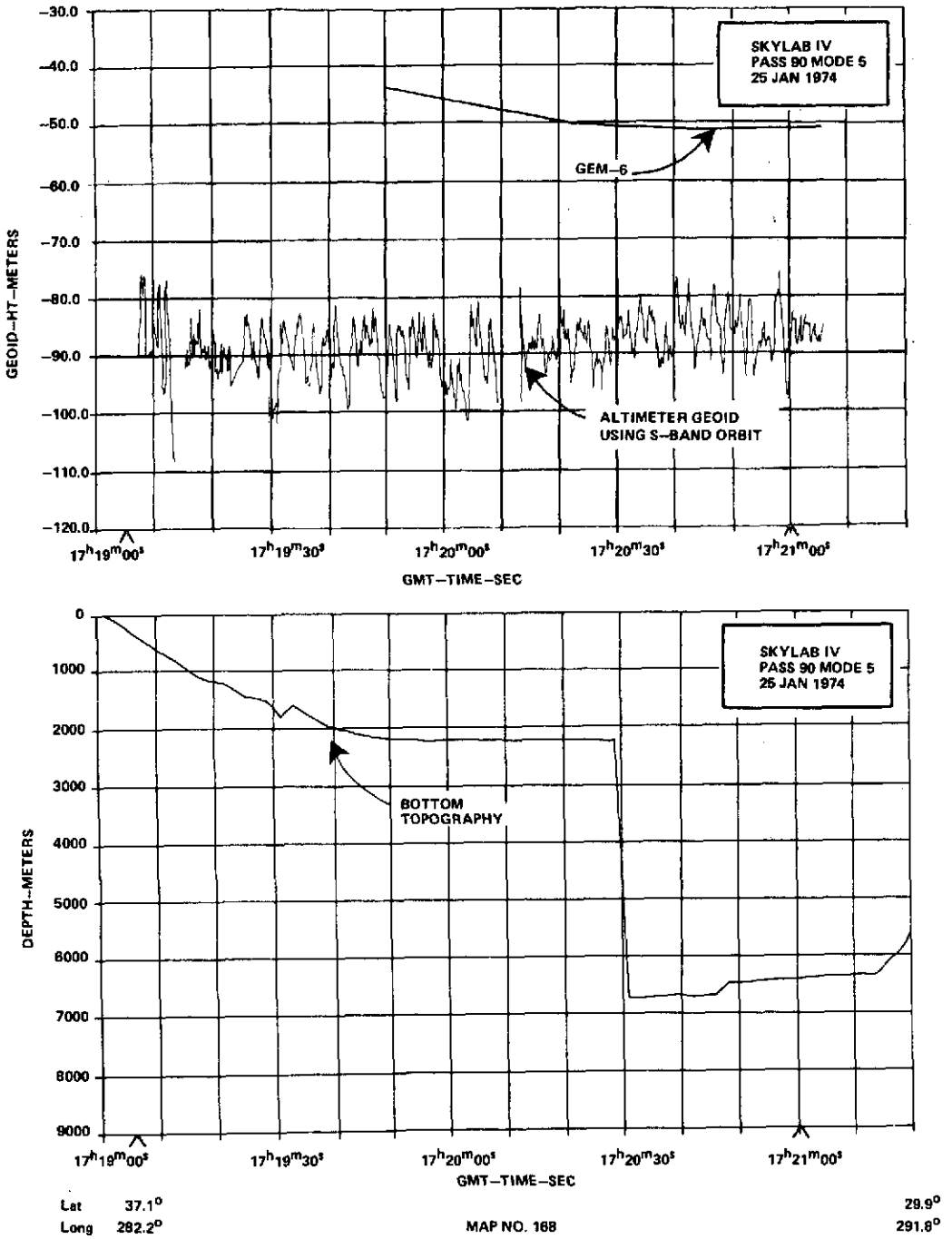

SKYLAB IV
PASS 87 MODE 1
21 JAN 1974
ALTIMETER GEOID
USING S–BAND ORBIT
GEM–6
GEOID–HT–METERS
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
–60.0
–70.0
20h15m00s
20h15m30s
20h16m00s
20h16m30s
GMT–TIME–SEC
SKYLAB IV
PASS 87 MODE 1
21 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
20h15m00s
20h15m30s
20h16m00s
20h16m30s
GMT–TIME–SEC
Lat 19.4°
Long 283.5°
MAP NO. 152
13.2°
288.8°

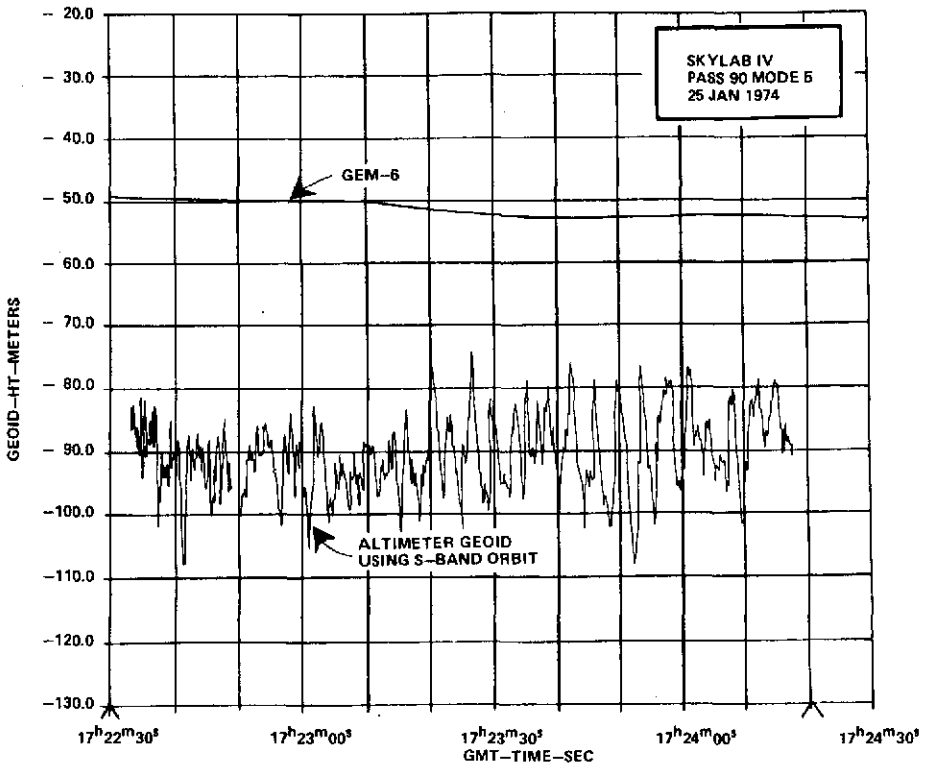

SKYLAB IV
PASS 88 MODE 5
22 JAN 1974
GEM-6
ALTIMETER GEOID
USING S-BAND ORBIT
GEOID-HT-METERS
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
19h31m30s
19h31m50s
19h32m30s
GMT-TIME-SEC
SKYLAB IV
PASS 88 MODE 5
22 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
19h31m30s
19h31m50s
19h32m30s
GMT-TIME-SEC
Lat 21.4° 20.5°
Long 288.4° MAP NO. 155 287.2°

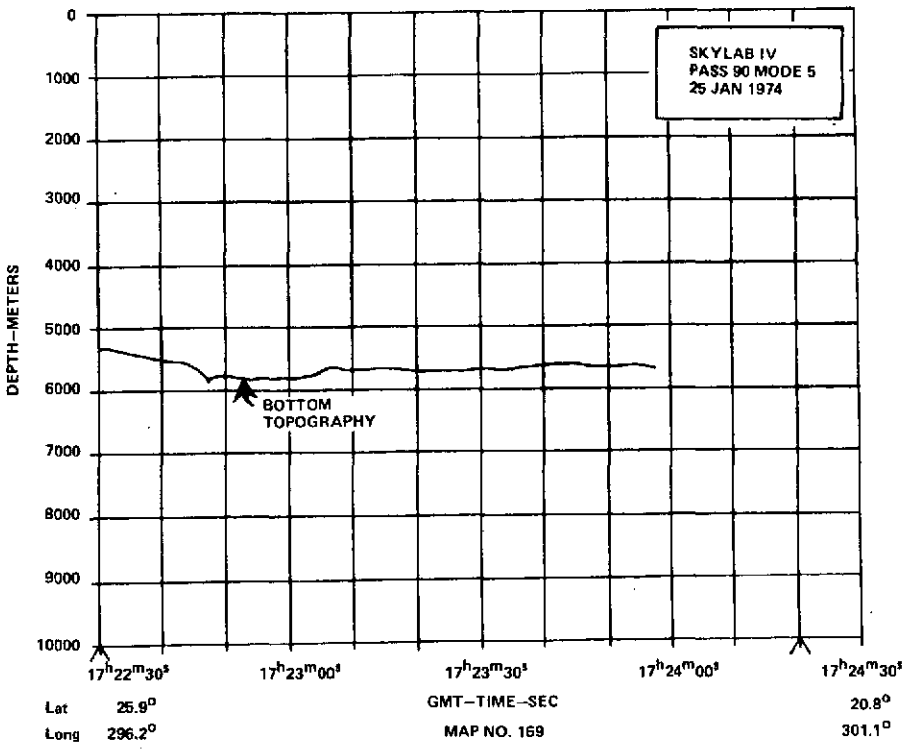

SKYLAB IV
PASS 88 MODE 5
22 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
– 30.0
– 40.0
– 50.0
– 60.0
– 70.0
– 80.0
– 90.0
–100.0
–110.0
–120.0
19h33m00s
19h33m30s
GMT–TIME–SEC
SKYLAB IV
PASS 88 MODE 5
22 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
19h33m00s
19h33m30s
GMT–TIME–SEC
Lat 16.9°
Long 290.4°
MAP NO. 156
16.0°
291.2°

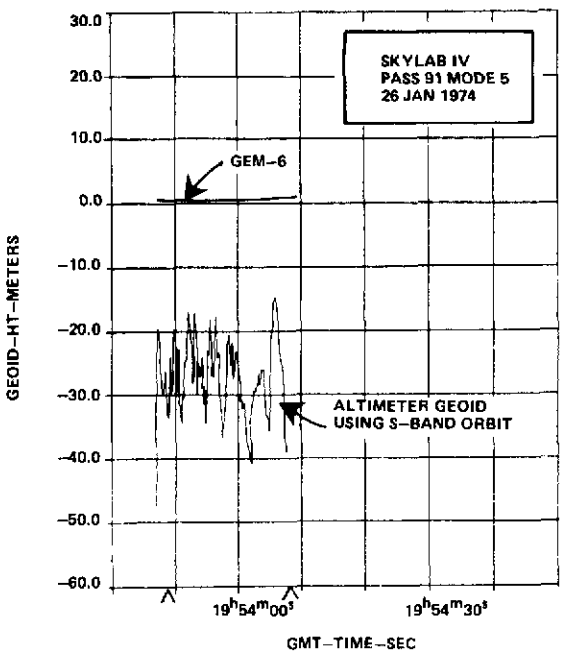

SKYLAB IV
PASS 89 MODE 1
24 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
– 20.0
– 30.0
– 40.0
– 50.0
– 60.0
– 70.0
– 80.0
– 90.0
–100.0
18h08m00s
18h08m30s
18h09m00s
GMT–TIME–SEC
SKYLAB IV
PASS 89 MODE 1
24 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
18h08m00s
18h08m30s
18h09m00s
GMT–TIME–SEC
Lat 17.4° 15.0°
Long 299.4° MAP NO. 163 301.5°

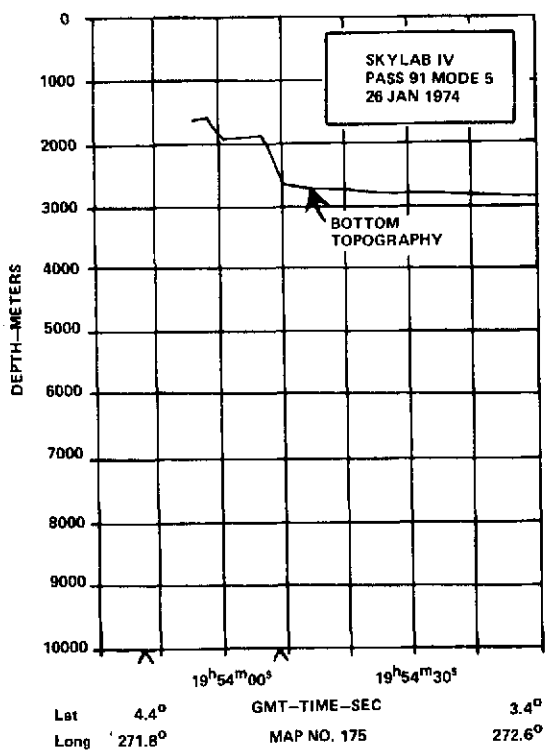

GEOID–HT–METERS
– 40.0
– 50.0
– 60.0
– 70.0
– 80.0
– 90.0
–100.0
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
SKYLAB IV
PASS 89 MODE 5
24 JAN 1974
18h09m30s
18h10m00s
18h10m30s
18h11m00
GMT–TIME–SEC
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
SKYLAB IV
PASS 89 MODE 5
24 JAN 1973
BOTTOM
TOPOGRAPHY
18h09m30s
18h10m00s
18h10m30s
18h11m00s
GMT–TIME–SEC
Lat 13.6°
Long 302.6°
MAP NO. 164
8.2°
306.8°

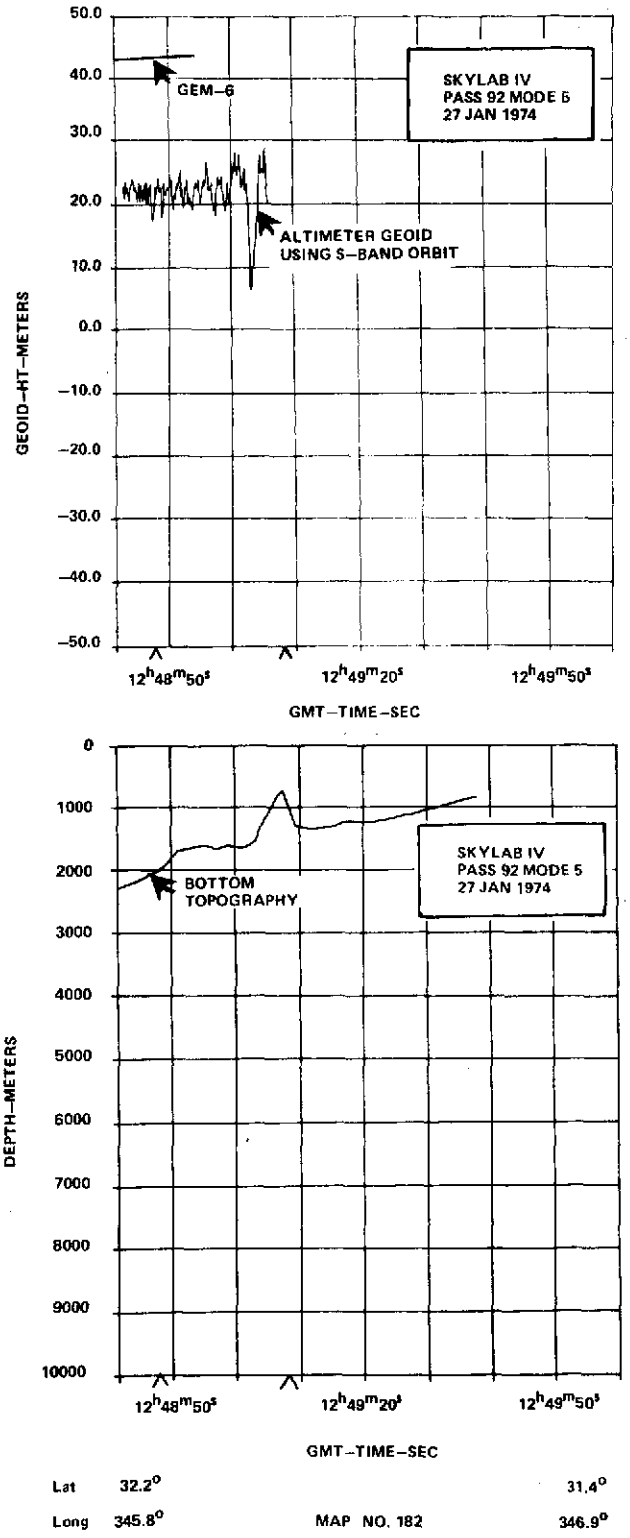

SKYLAB IV
PASS 90 MODE 5
25 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
–30.0
–40.0
–50.0
–60.0
–70.0
–80.0
–90.0
–100.0
–110.0
–120.0
17h19m00s
17h19m30s
17h20m00s
17h20m30s
17h21m00s
GMT–TIME–SEC
SKYLAB IV
PASS 90 MODE 5
25 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
17h19m00s
17h19m30s
17h20m00s
17h20m30s
17h21m00s
GMT–TIME–SEC
Lat 37.1°
Long 282.2°
MAP NO. 168
29.9°
291.8°

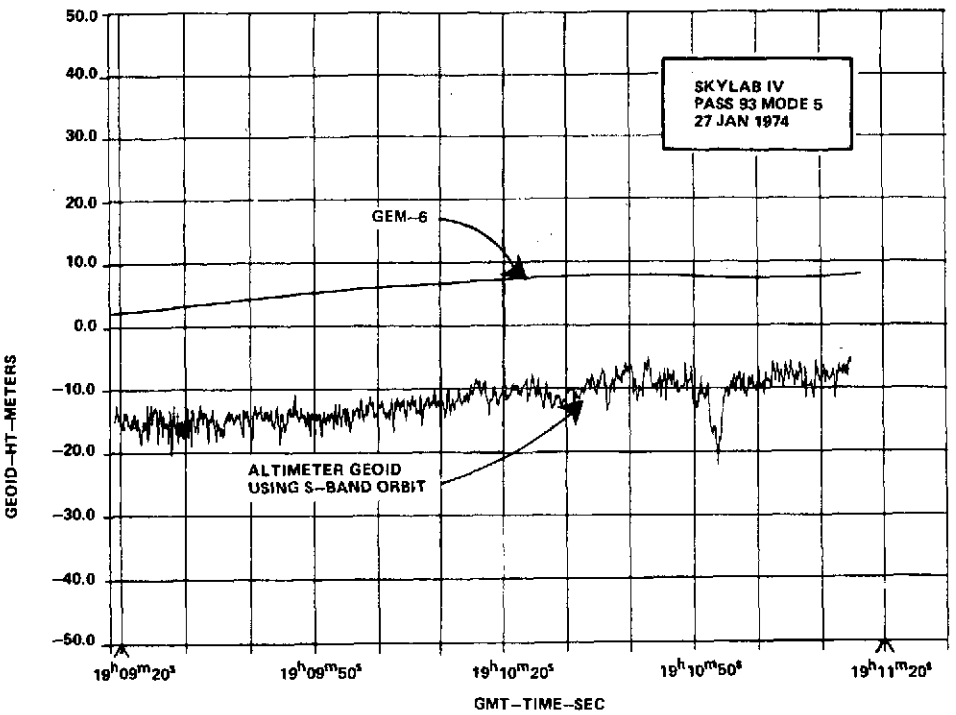

SKYLAB IV
PASS 90 MODE 5
25 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
– 20.0
– 30.0
– 40.0
– 50.0
– 60.0
– 70.0
– 80.0
– 90.0
–100.0
–110.0
–120.0
–130.0
17h22m30s
17h23m00s
17h23m30s
17h24m00s
17h24m30s
GMT–TIME–SEC

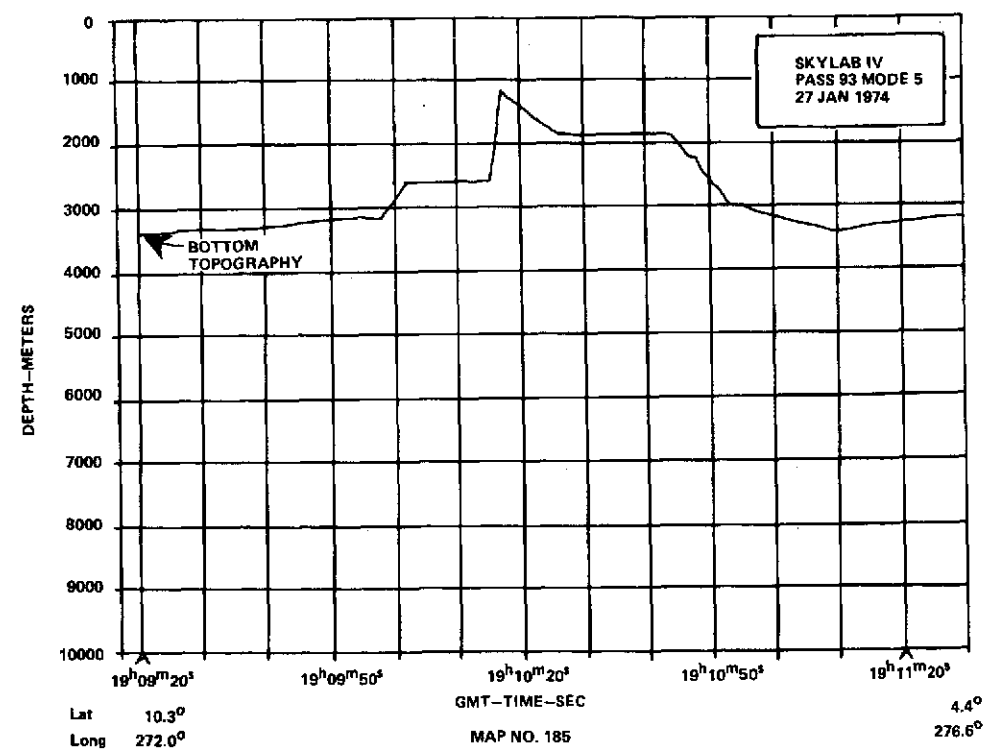

SKYLAB IV
PASS 90 MODE 5
25 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
17h22m30s
17h23m00s
17h23m30s
17h24m00s
17h24m30s
Lat 25.9°
Long 296.2°
GMT–TIME–SEC
MAP NO. 169
20.8°
301.1°

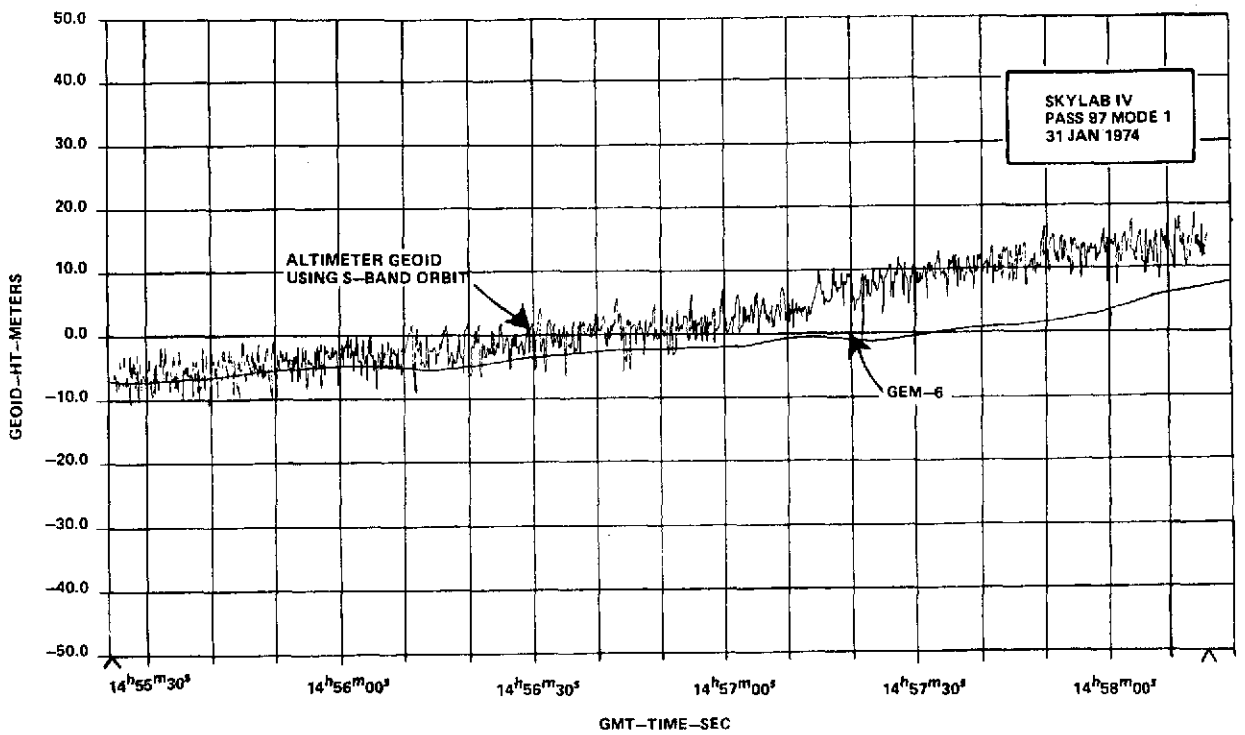

SKYLAB IV
PASS 91 MODE 5
26 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
30.0
20.0
10.0
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
–60.0
19h54m00s
19h54m30s
GMT–TIME–SEC

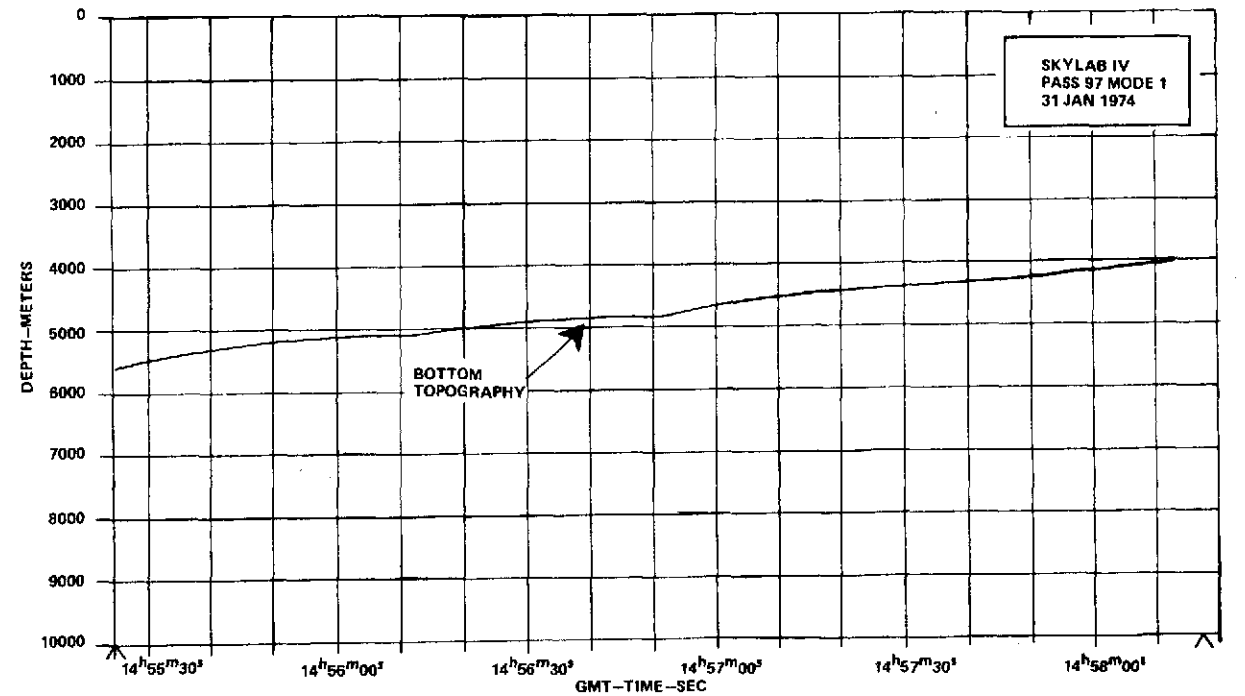

SKYLAB IV
PASS 91 MODE 5
26 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
19h54m00s
19h54m30s
GMT–TIME–SEC
Lat 4.4° 3.4°
Long 271.8° 272.6°
MAP NO. 175


50.0
40.0
30.0
20.0
10.0
0.0
−10.0
−20.0
−30.0
−40.0
−50.0
GEOID−HT−METERS
GEM−6
SKYLAB IV
PASS 92 MODE 5
27 JAN 1974
ALTIMETER GEOID
USING S−BAND ORBIT
12h48m50s
12h49m20s
12h49m50s
GMT−TIME−SEC
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
DEPTH−METERS
BOTTOM
TOPOGRAPHY
SKYLAB IV
PASS 92 MODE 5
27 JAN 1974
12h48m50s
12h49m20s
12h49m50s
GMT−TIME−SEC
Lat 32.2° 31.4°
Long 345.8° MAP NO. 182 346.9°


SKYLAB IV
PASS 93 MODE 5
27 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
50.0
40.0
30.0
20.0
10.0
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
19h09m20s
19h09m50s
19h10m20s
19h10m50s
19h11m20s
GMT–TIME–SEC

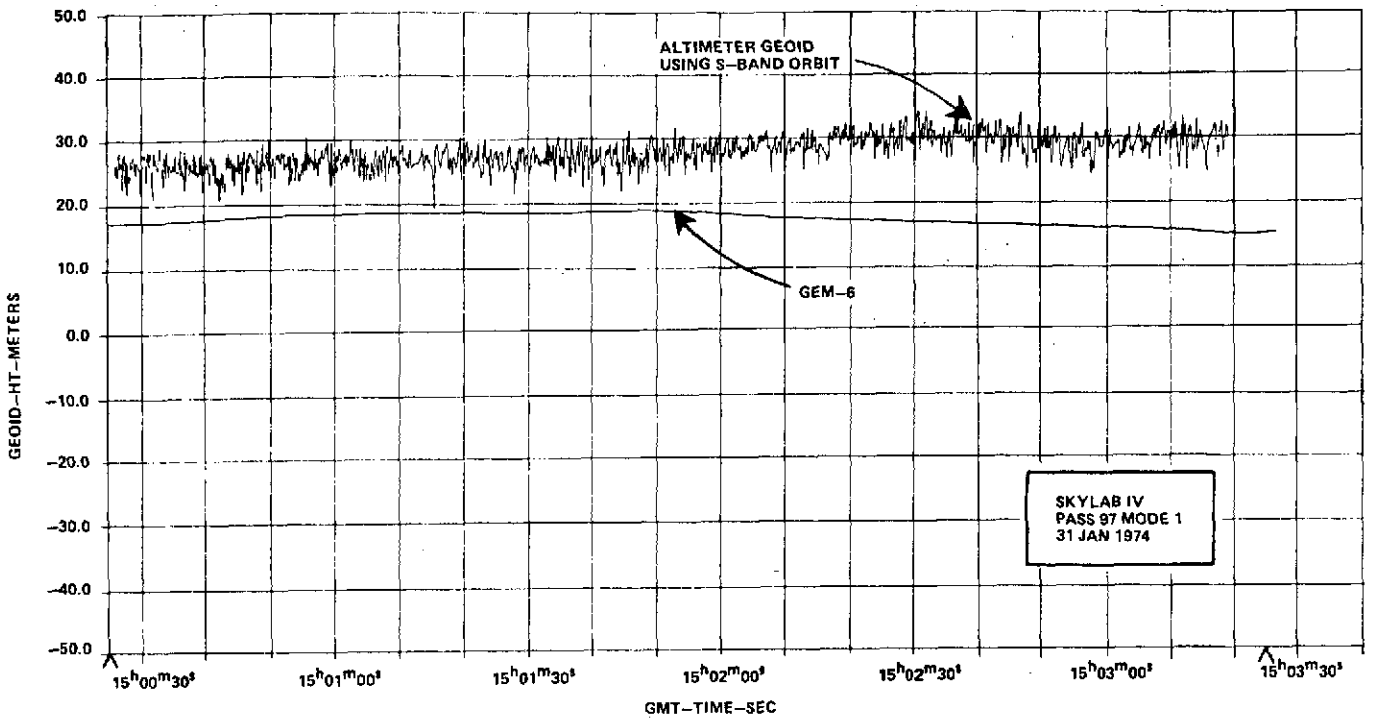

SKYLAB IV
PASS 93 MODE 5
27 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
19h09m20s
19h09m50s
19h10m20s
19h10m50s
19h11m20s
GMT–TIME–SEC
Lat 10.3°
Long 272.0°
4.4°
276.6°
MAP NO. 185

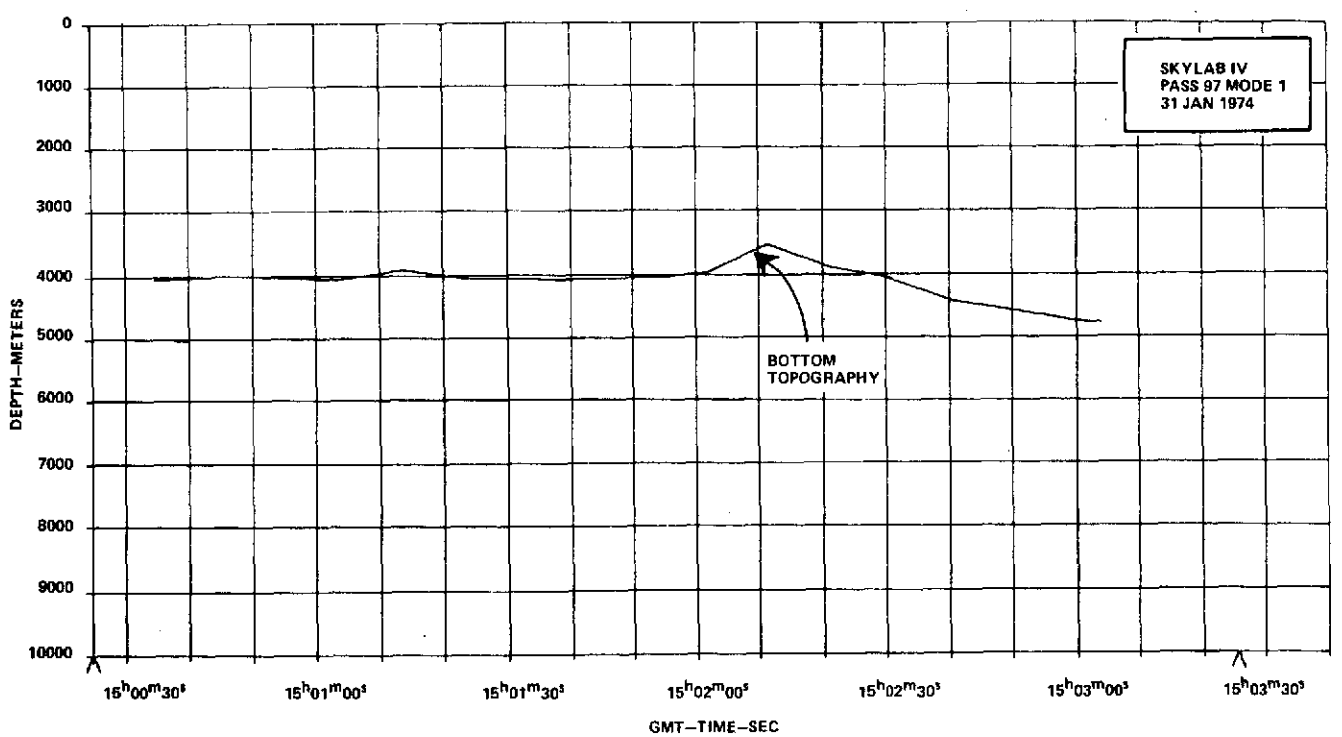




Lat –16.8° –24.8°
Long 335.6° 343.0°

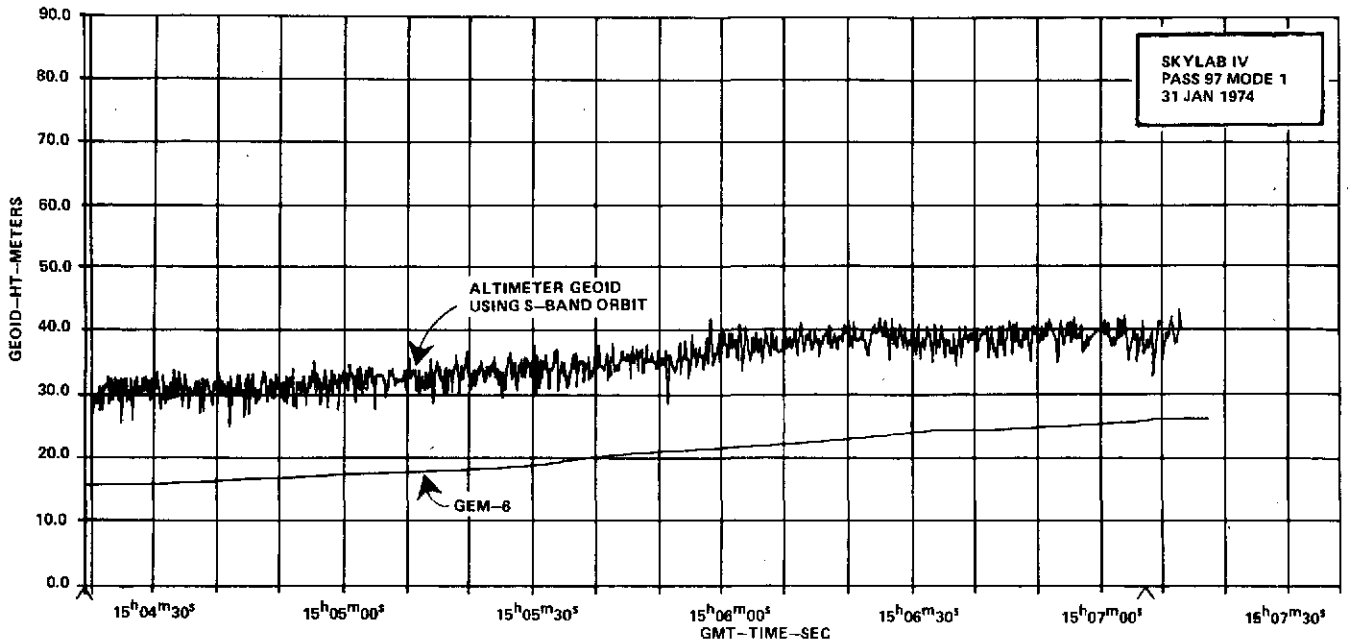
MAP NO. 201

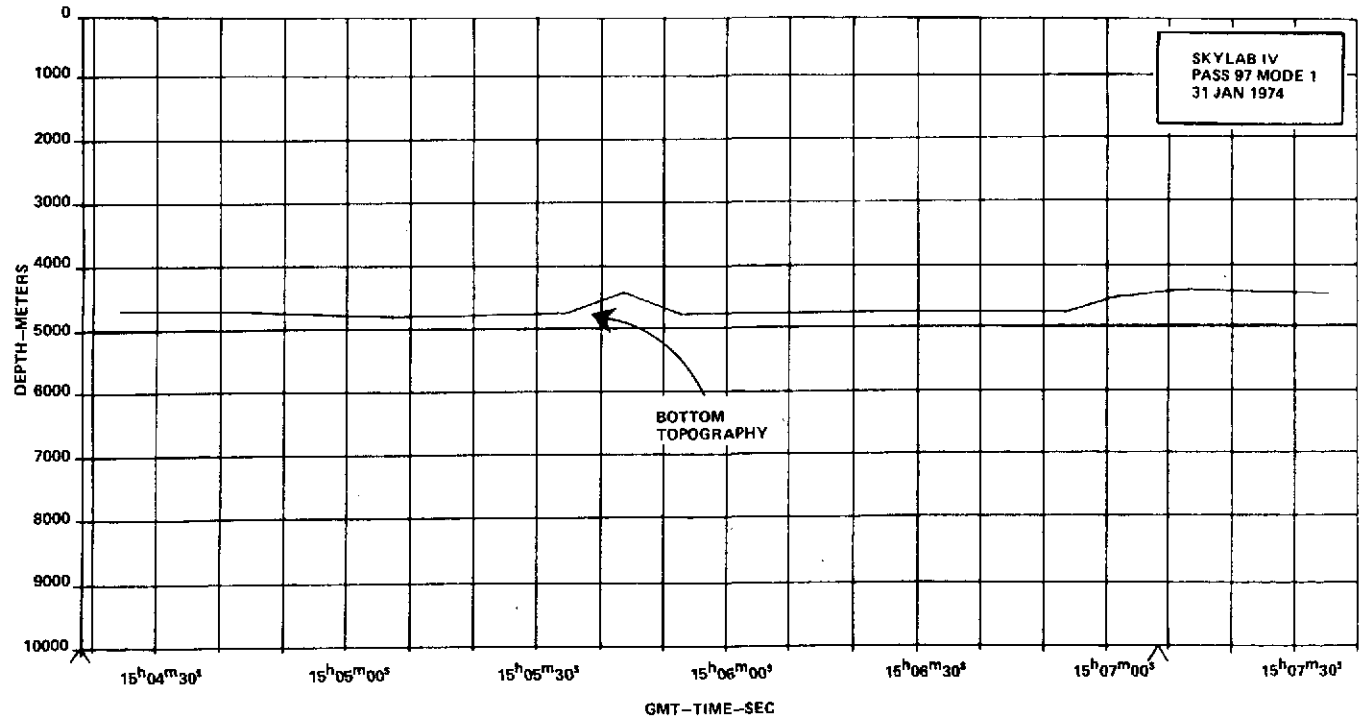




Lat –30.7° –38.0°

Long –349.3° MAP NO. 202 359.5°

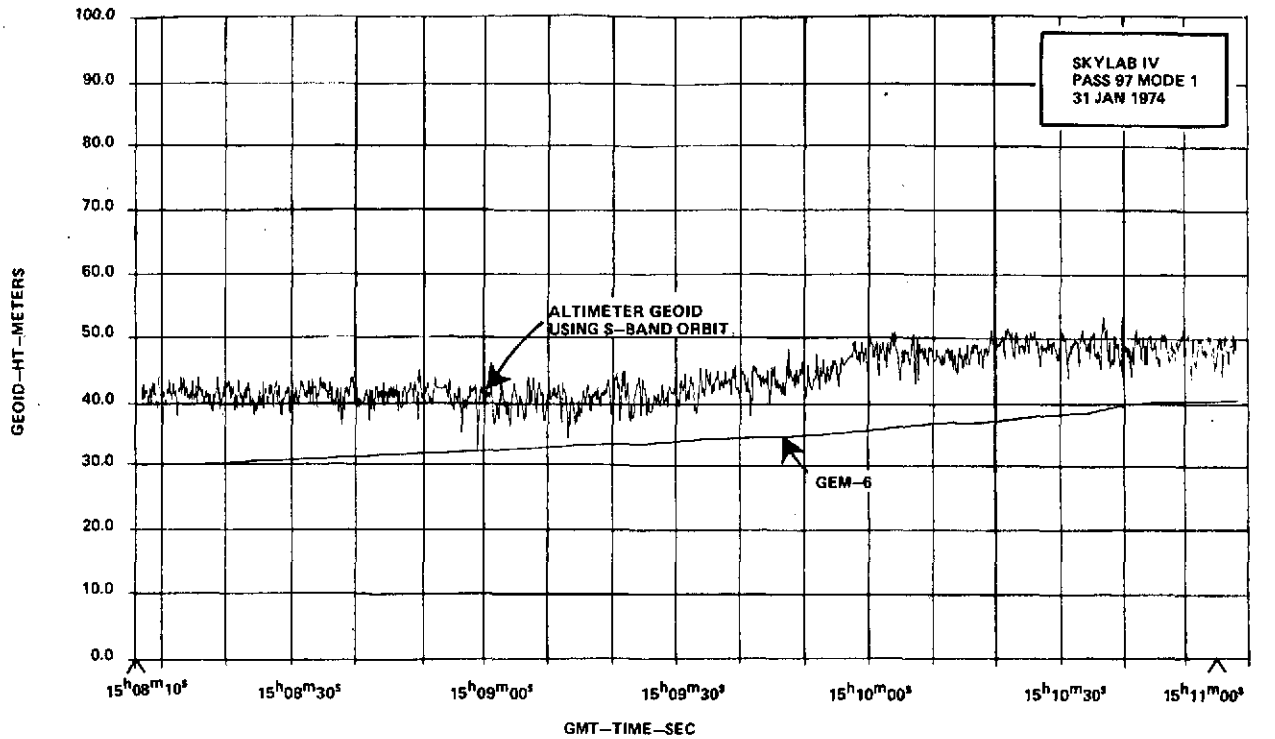


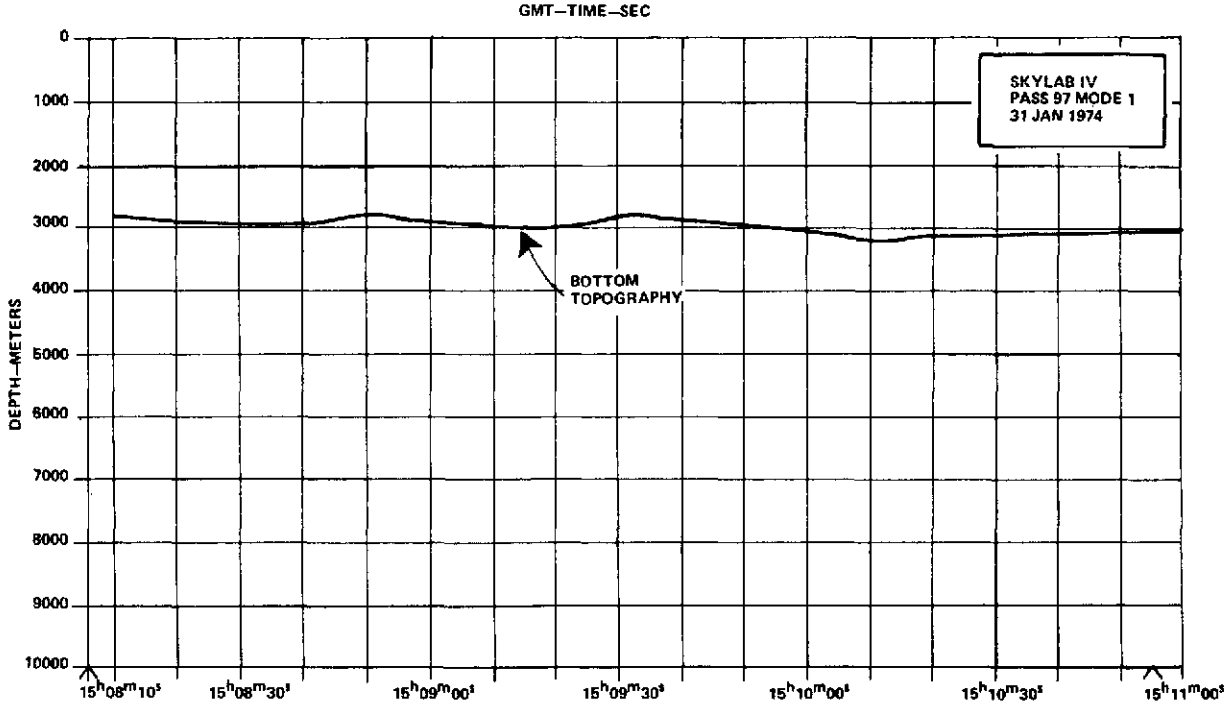


Lat −39.9° −45.2°

Long 2.9° 15.2°

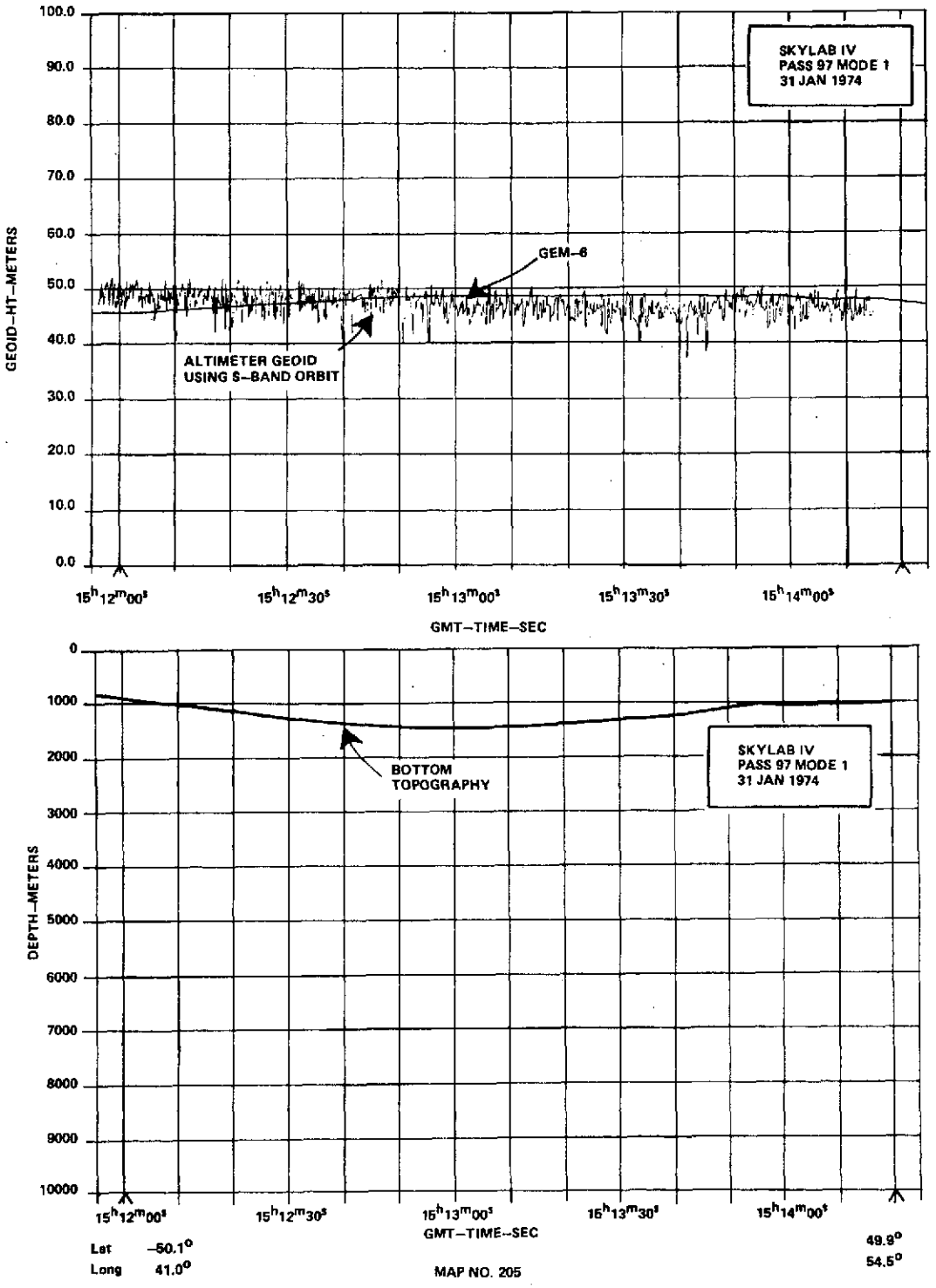
MAP NO. 203

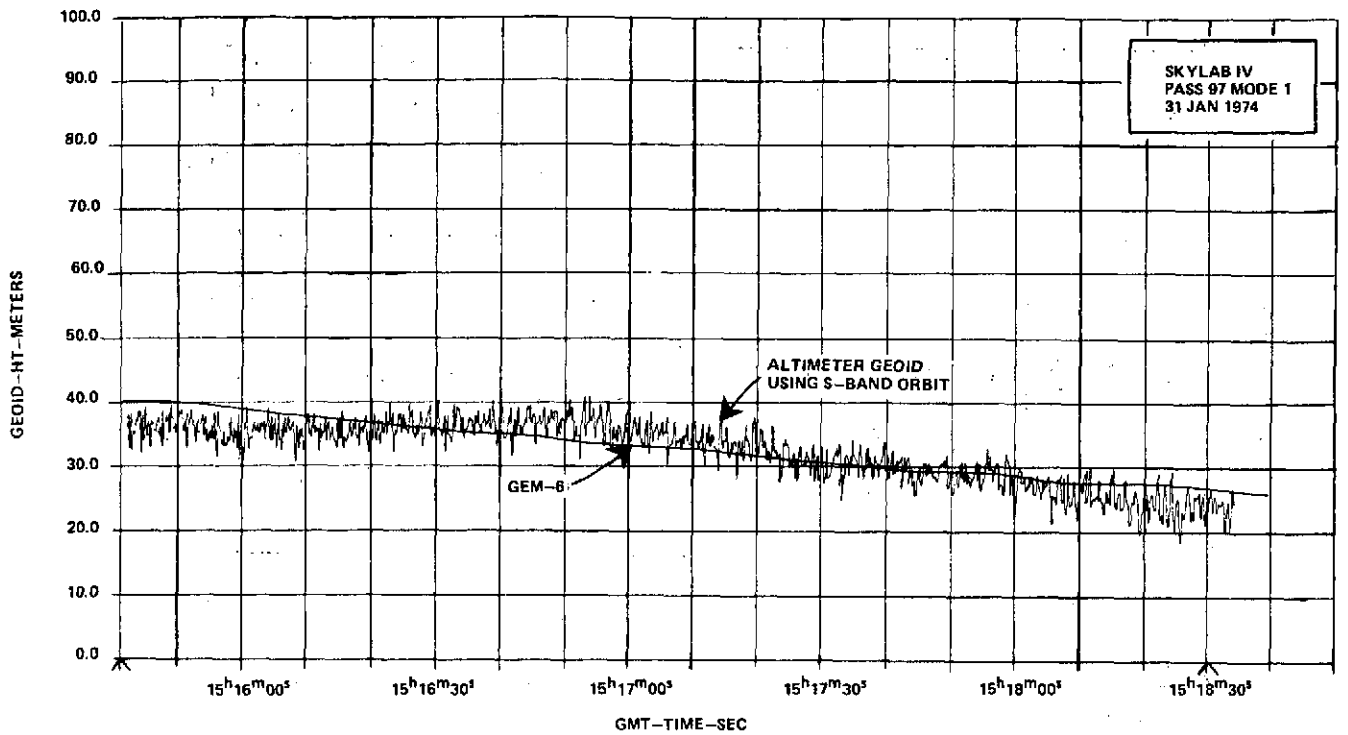


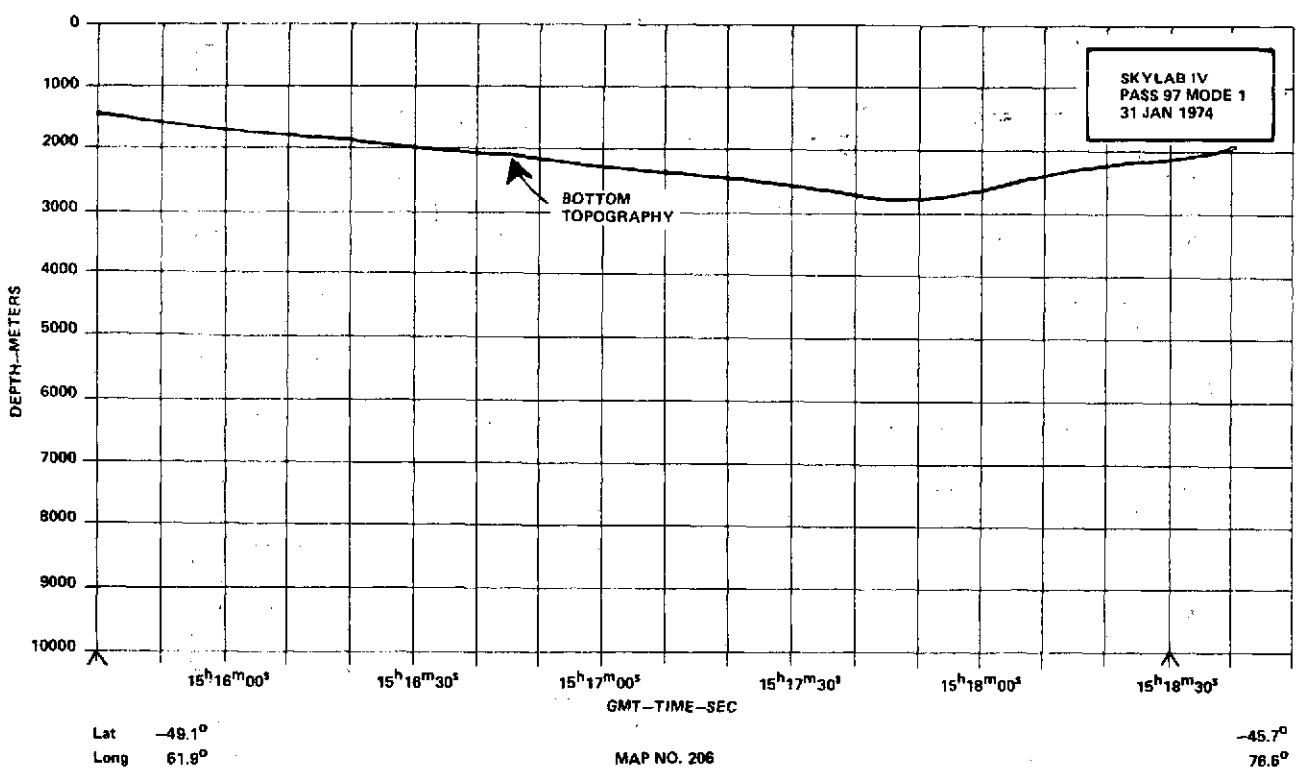


Lat -46.7° 49.5°
Long 19.8° 34.9°

MAP NO. 204

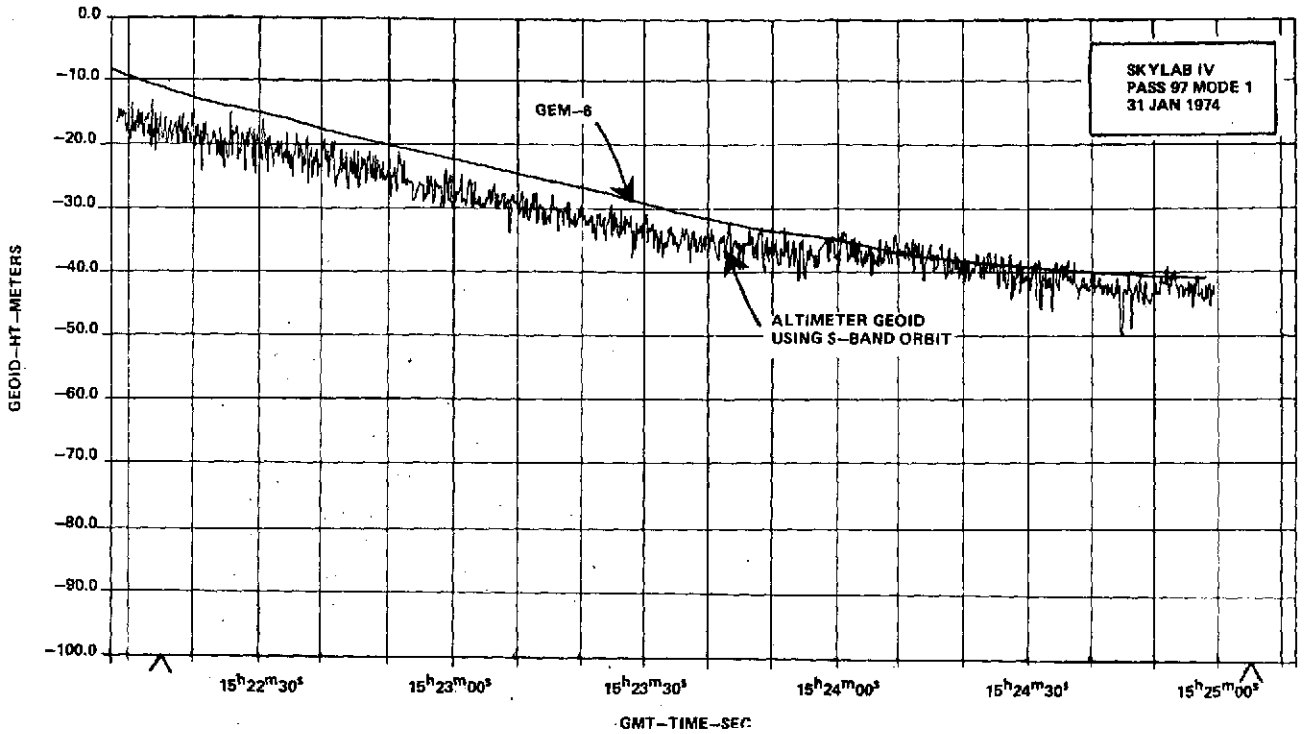

SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
GEM-6
ALTIMETER GEOID
USING S-BAND ORBIT
GEOID-HT-METERS
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
15h12m00s
15h12m30s
15h13m00s
15h13m30s
15h14m00s
GMT-TIME-SEC
SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
15h12m00s
15h12m30s
15h13m00s
15h13m30s
15h14m00s
GMT-TIME-SEC
Lat -50.1°
Long 41.0°
MAP NO. 205
49.9°
54.5°

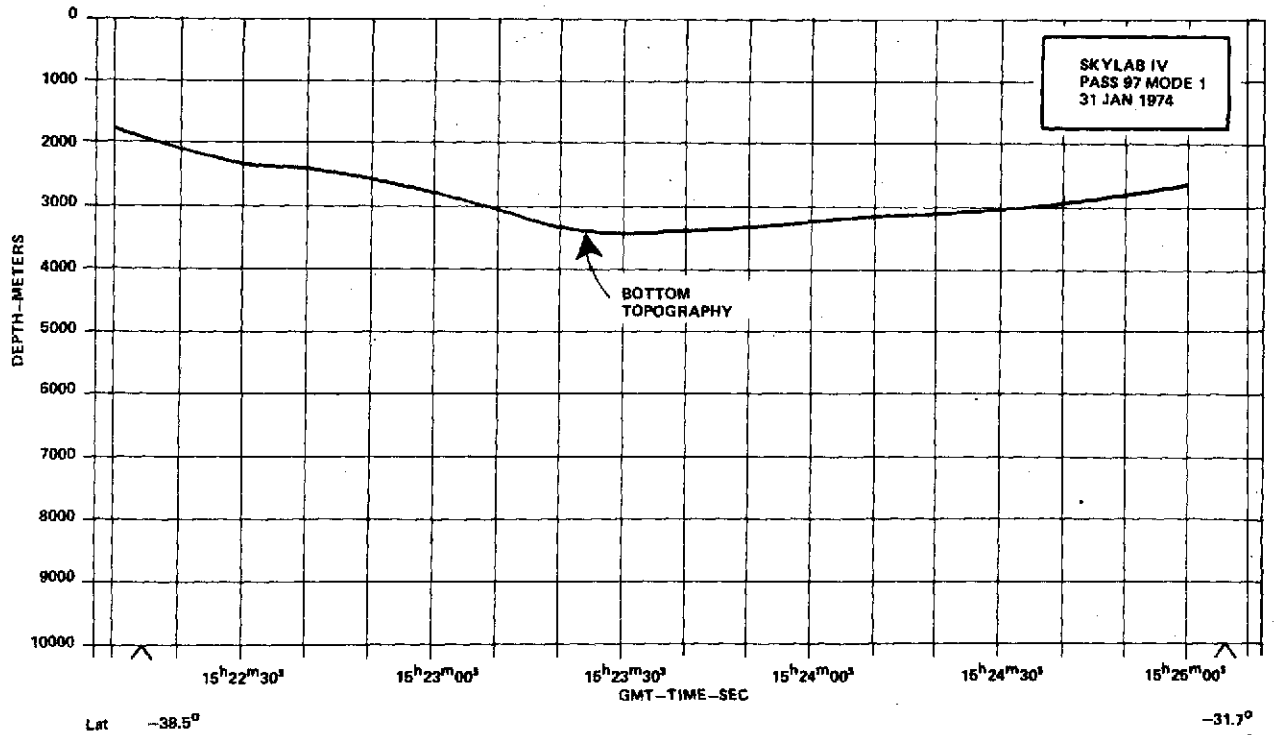




Lat -49.1° -45.7°
Long 61.9° 76.6°

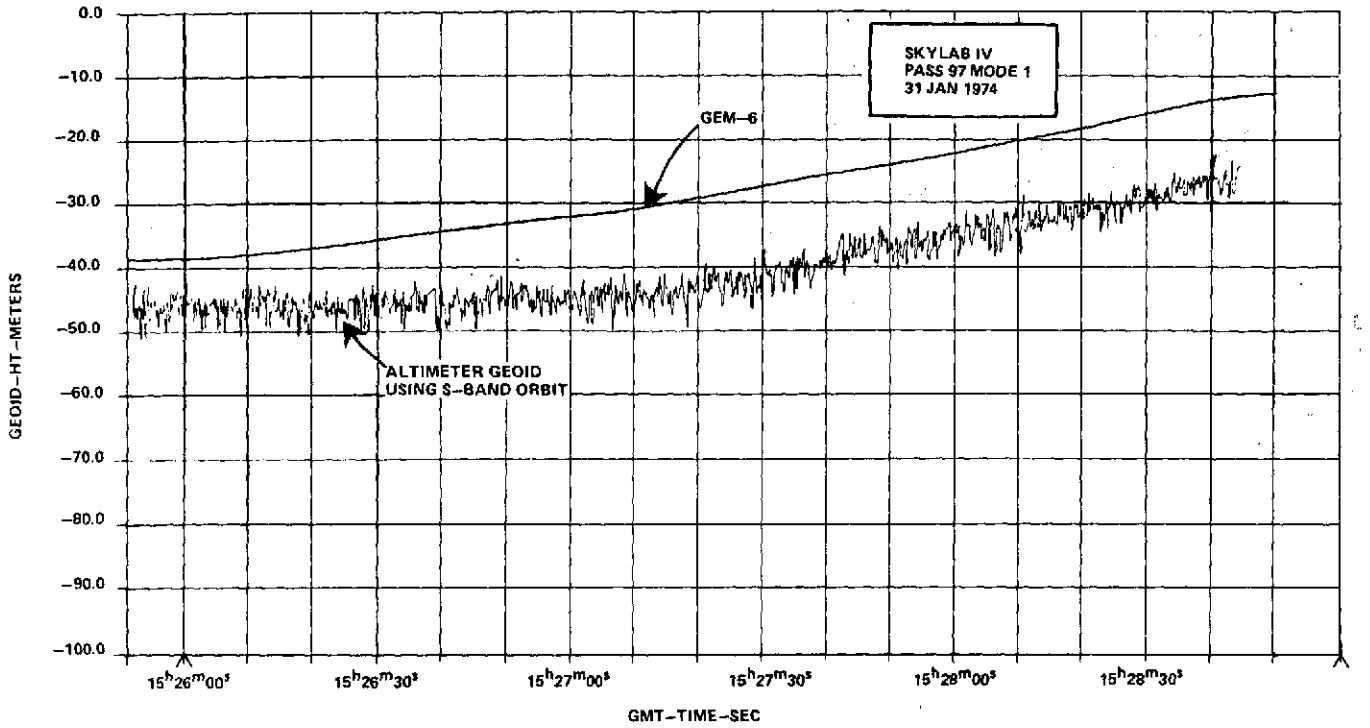
MAP NO. 206

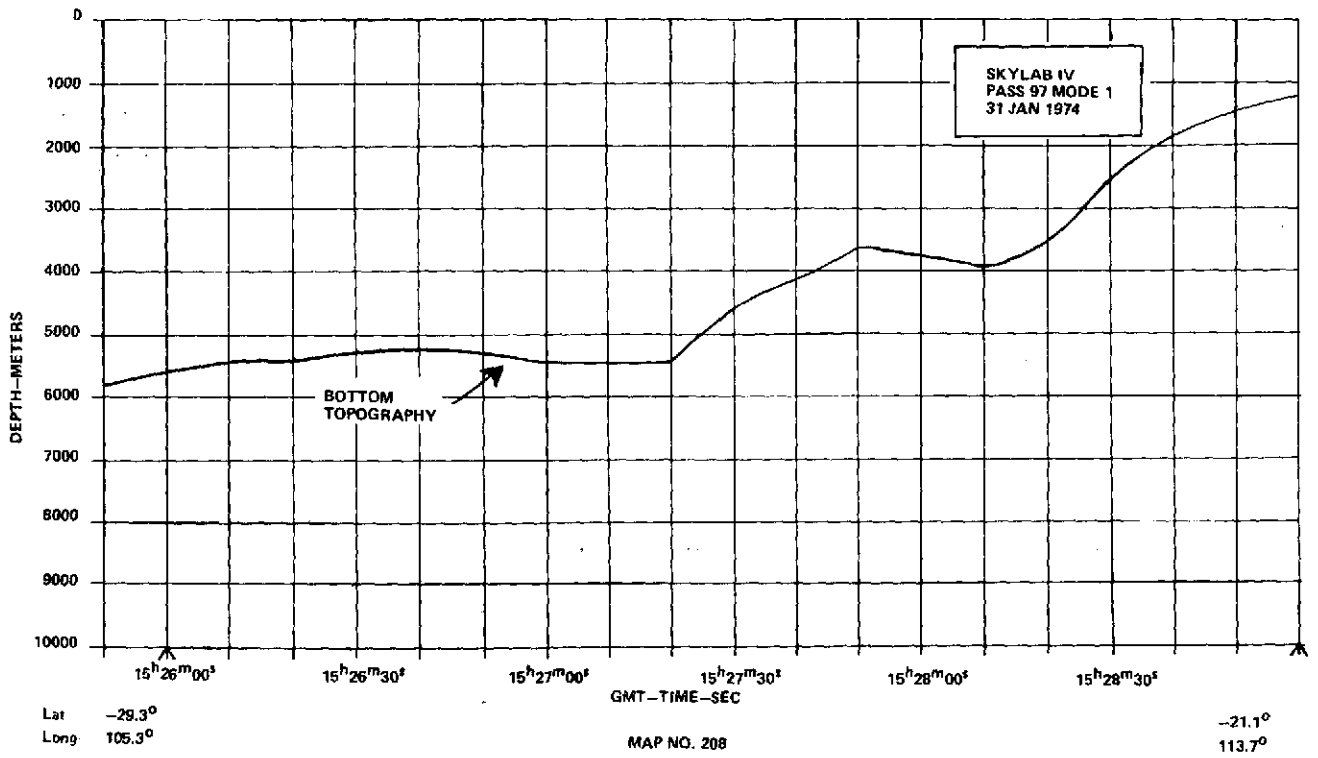


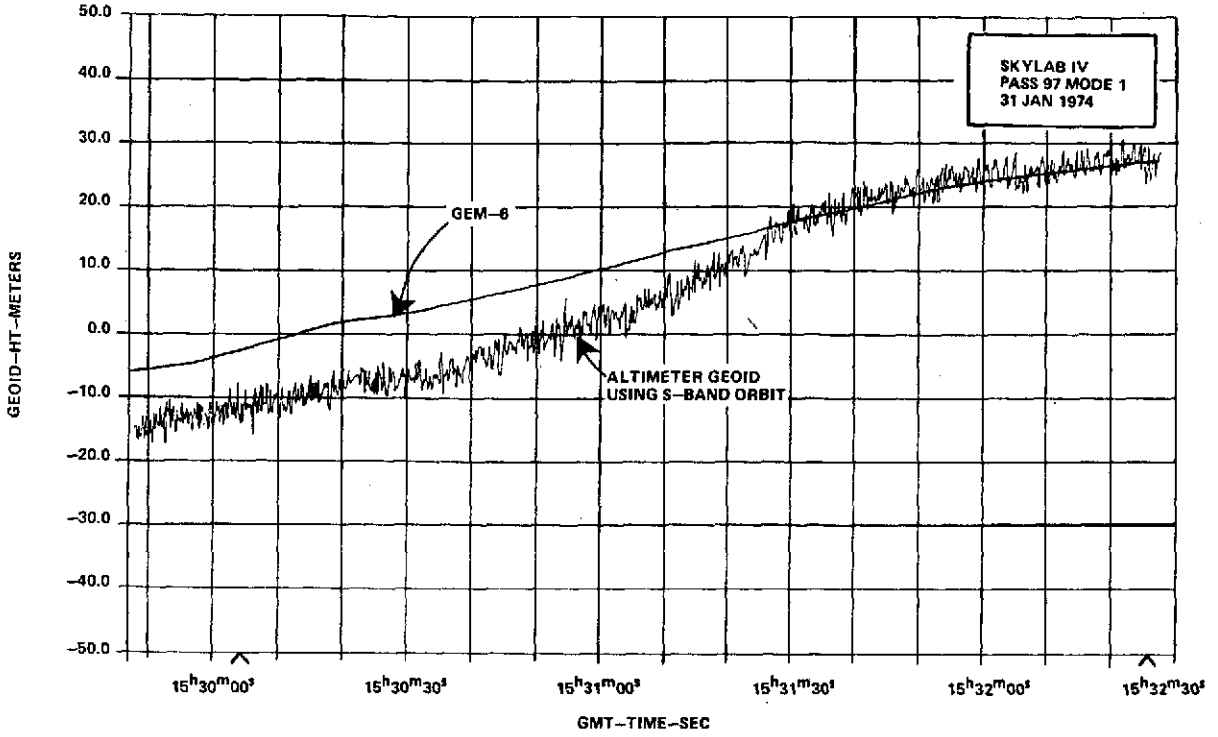


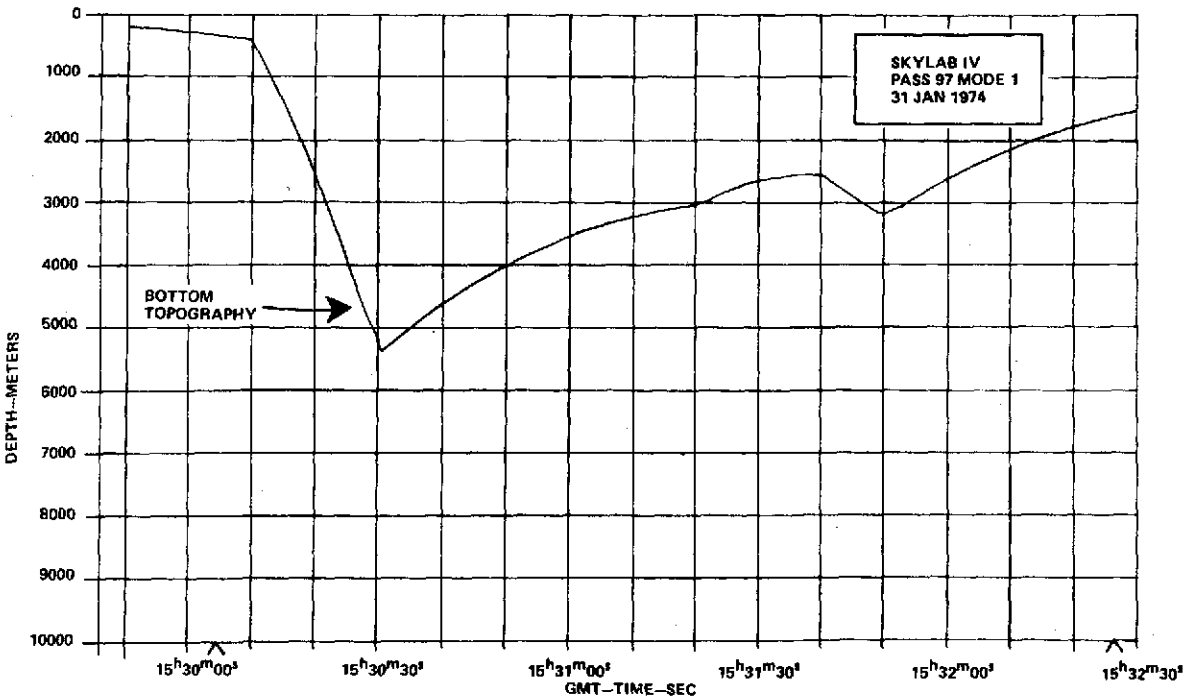
Lat –38.5° –31.7°
Long 92.7° 102.5°

MAP NO. 207


SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
–60.0
–70.0
–80.0
–90.0
–100.0
15h26m00s
15h26m30s
15h27m00s
15h27m30s
15h28m00s
15h28m30s
GMT–TIME–SEC

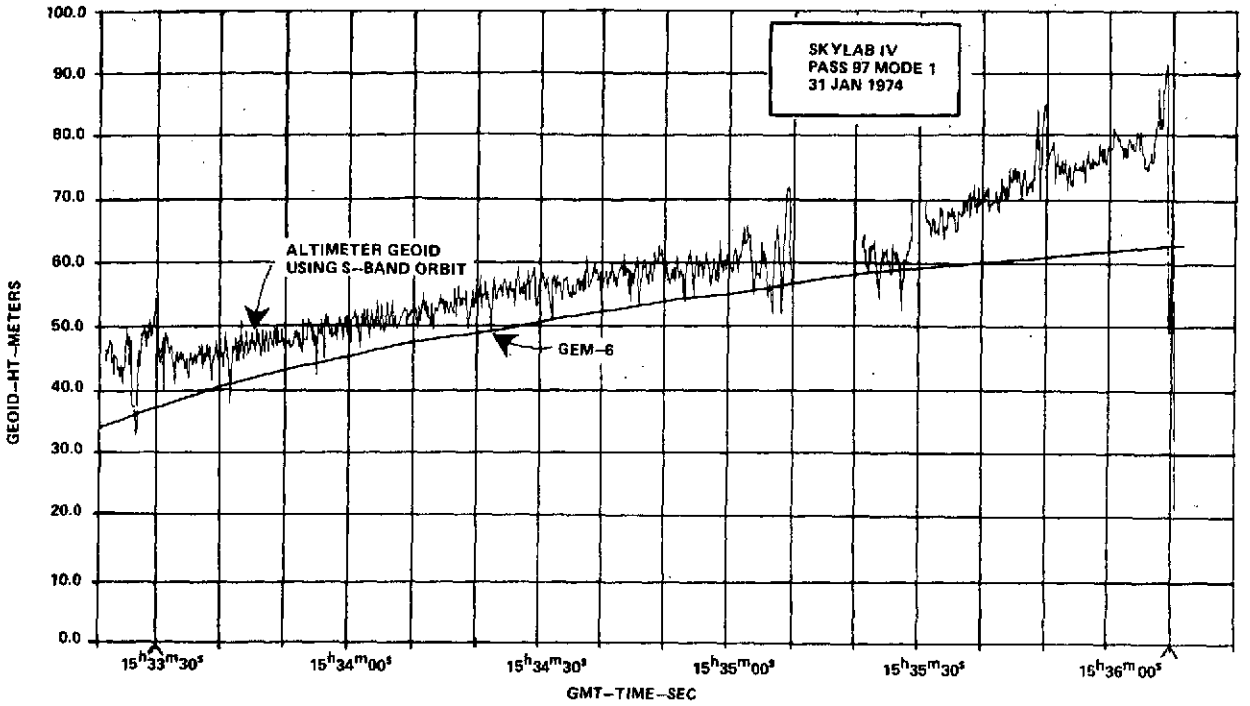

SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
15h26m00s
15h26m30s
15h27m00s
15h27m30s
15h28m00s
15h28m30s
GMT–TIME–SEC
Lat –29.3°
Long 105.3°
MAP NO. 208
–21.1°
113.7°

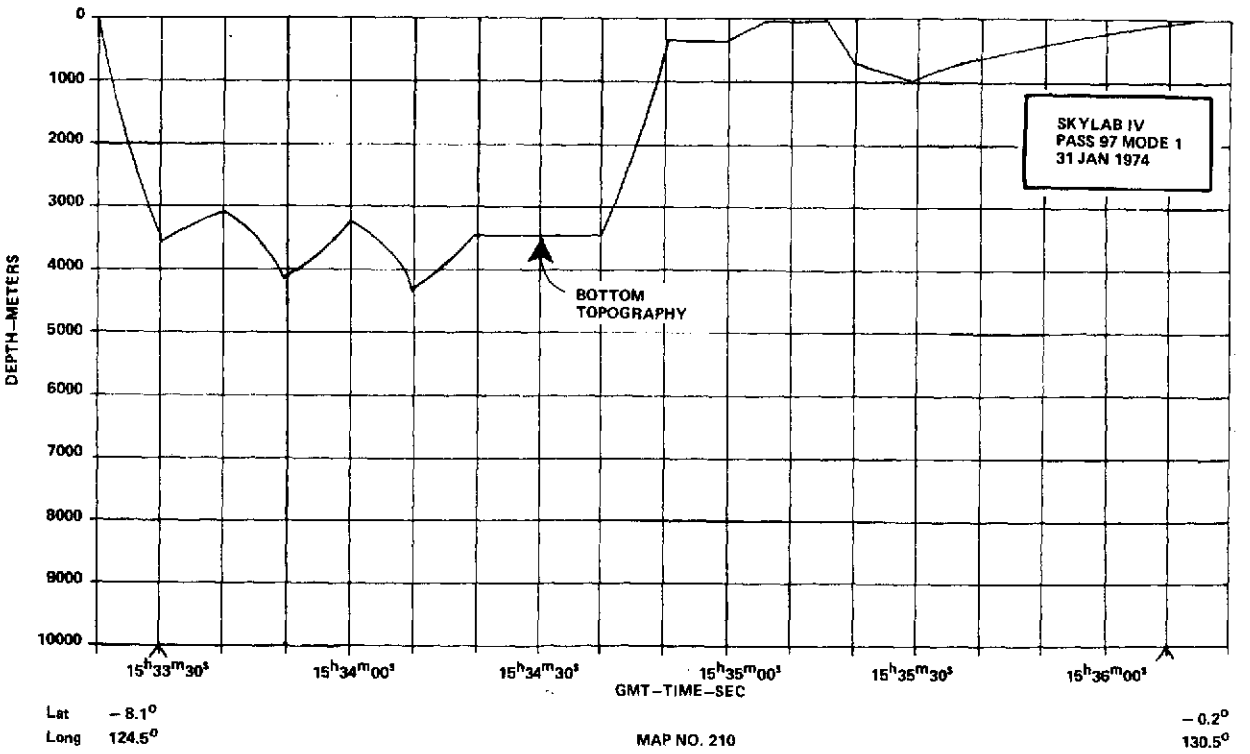




Lat –18.1° –11.3°
Long 116.4° 122.0°

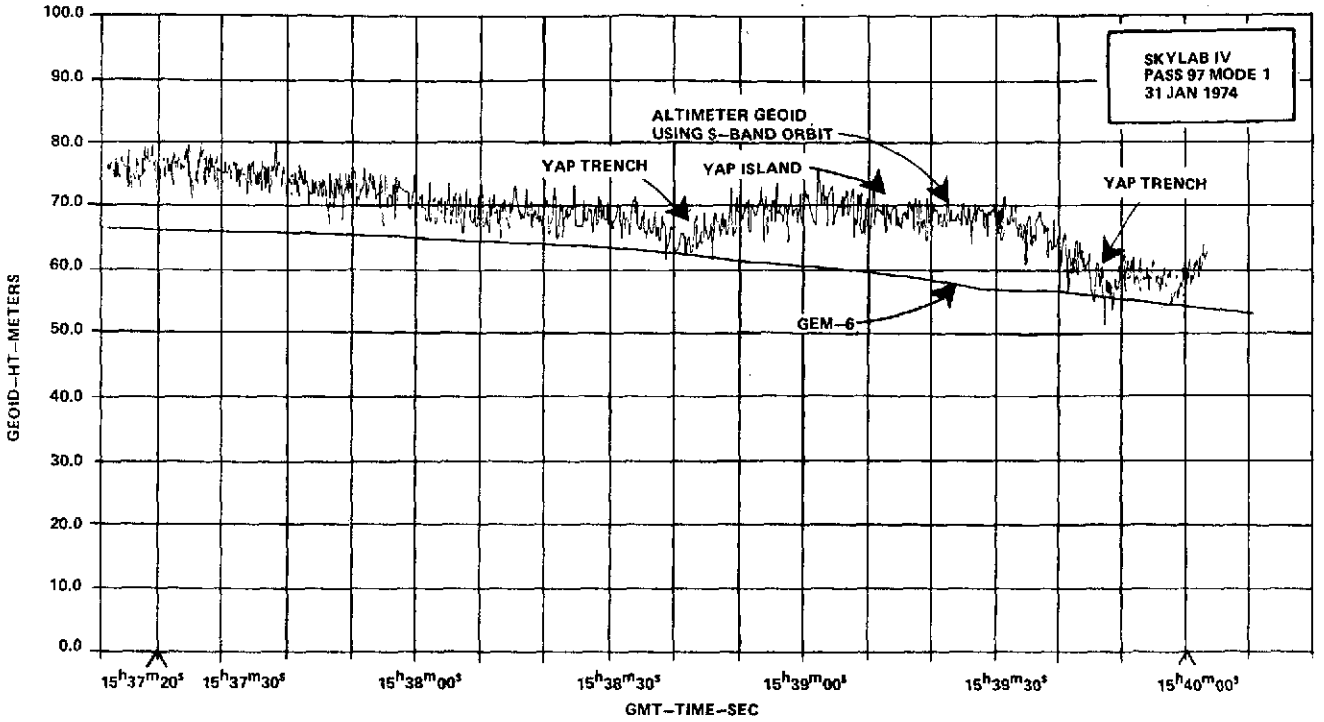
MAP NO. 209

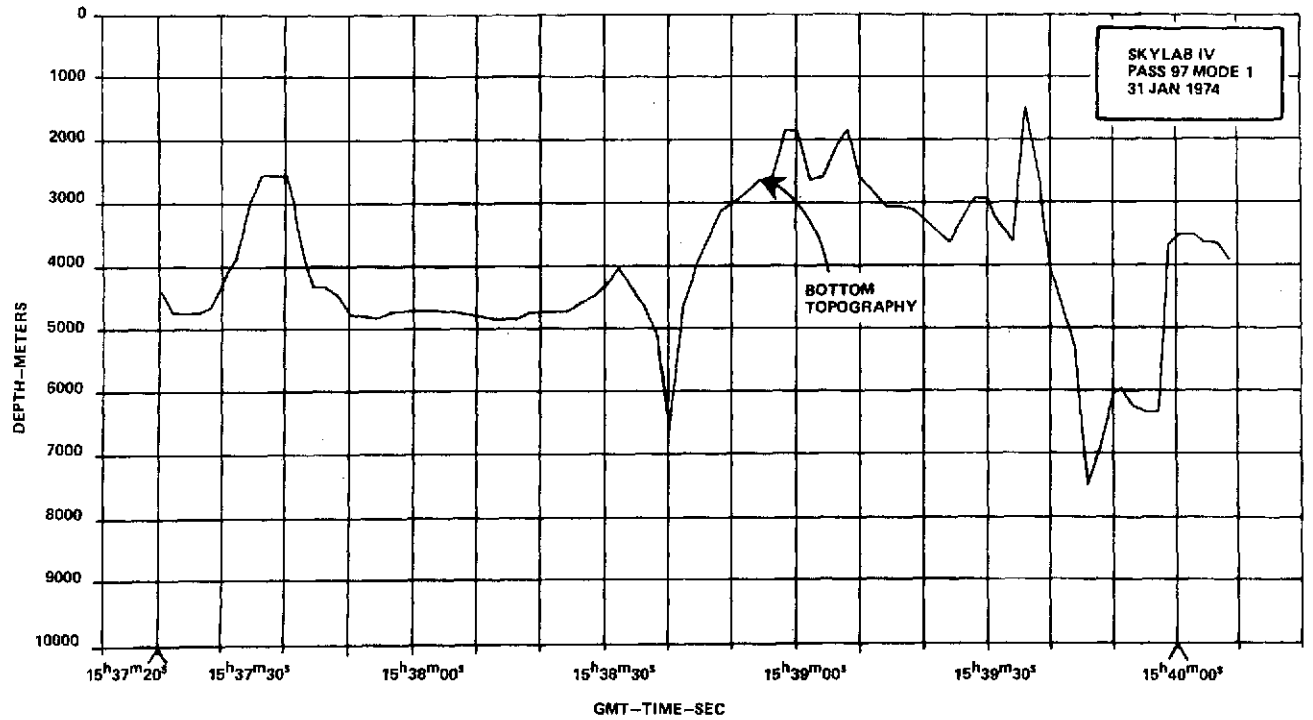




Lat -8.1^{o} -0.2^{o}
Long 124.5^{o} 130.5^{o}

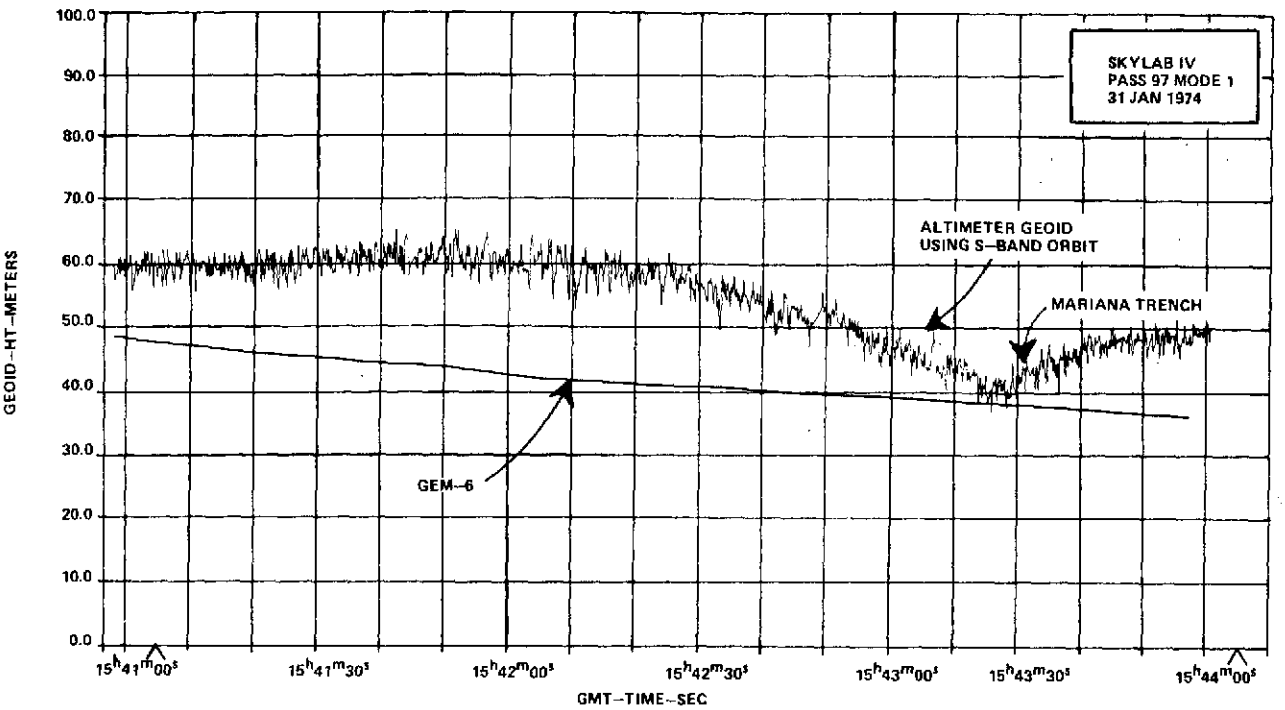
MAP NO. 210

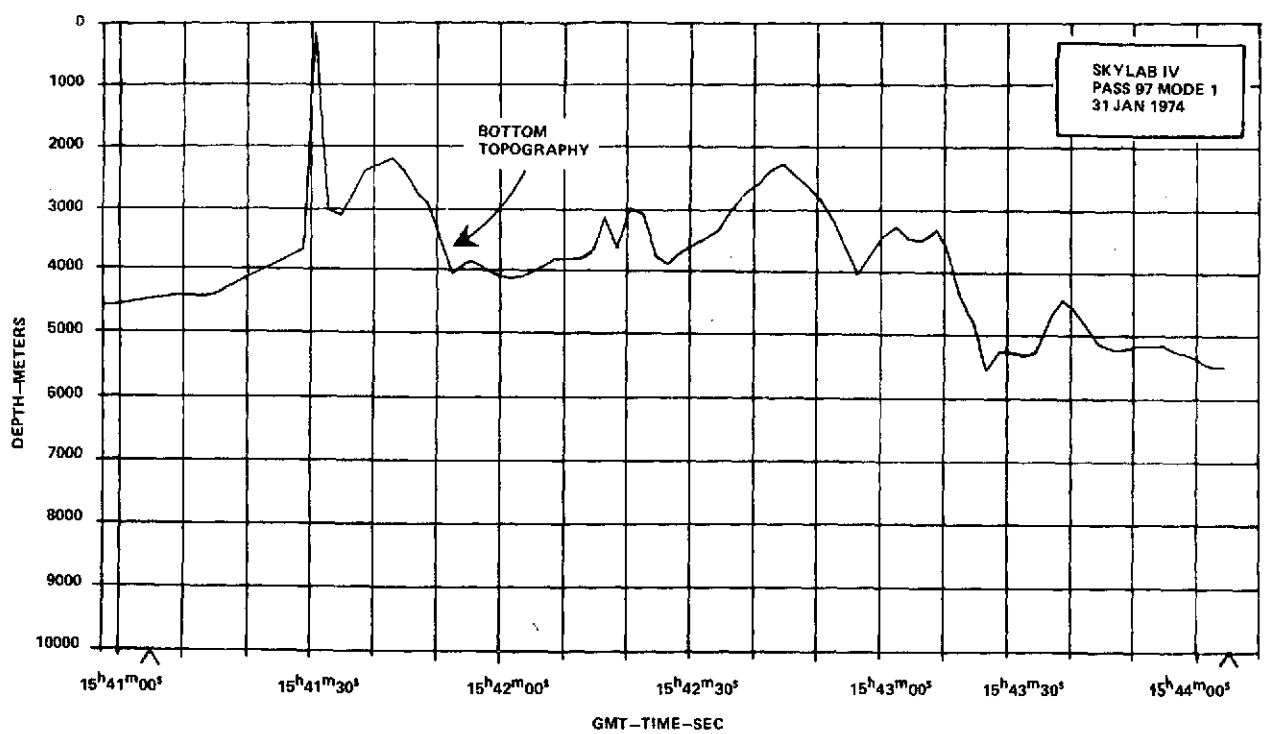




Lat 3.3° 11.2°

Long 133.1° MAP NO. 211 139.2°

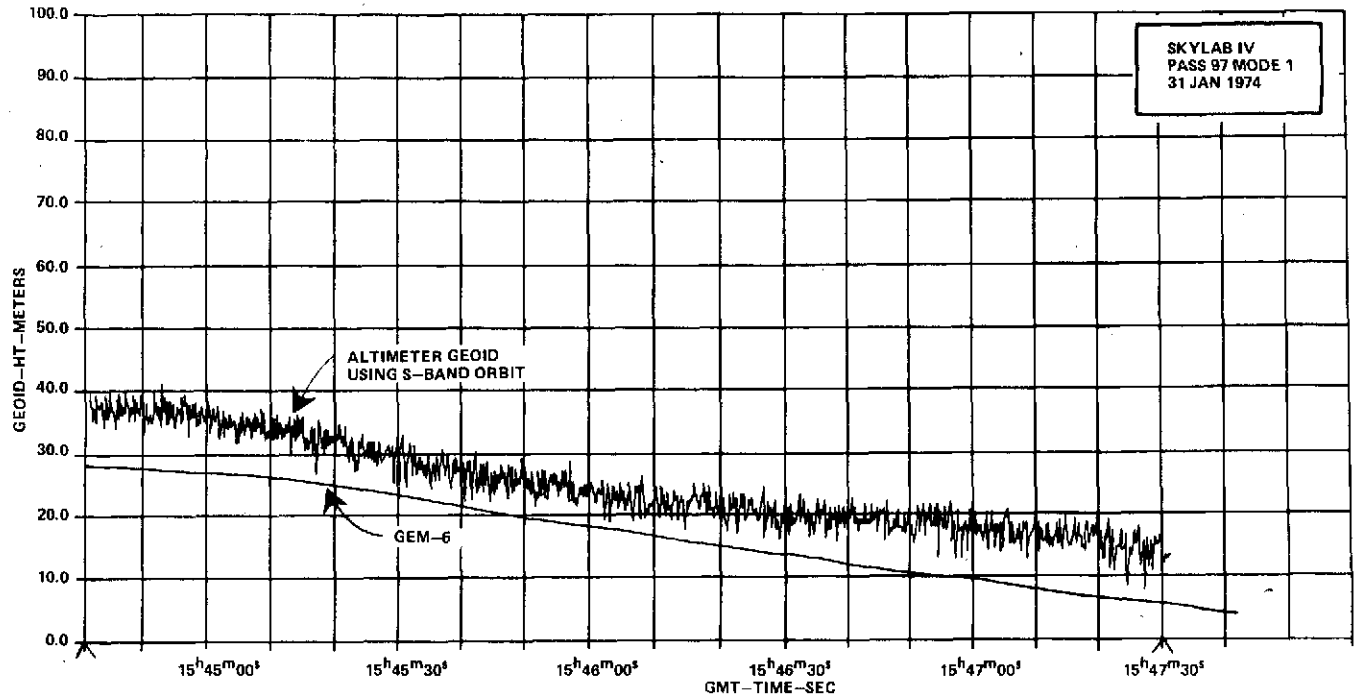


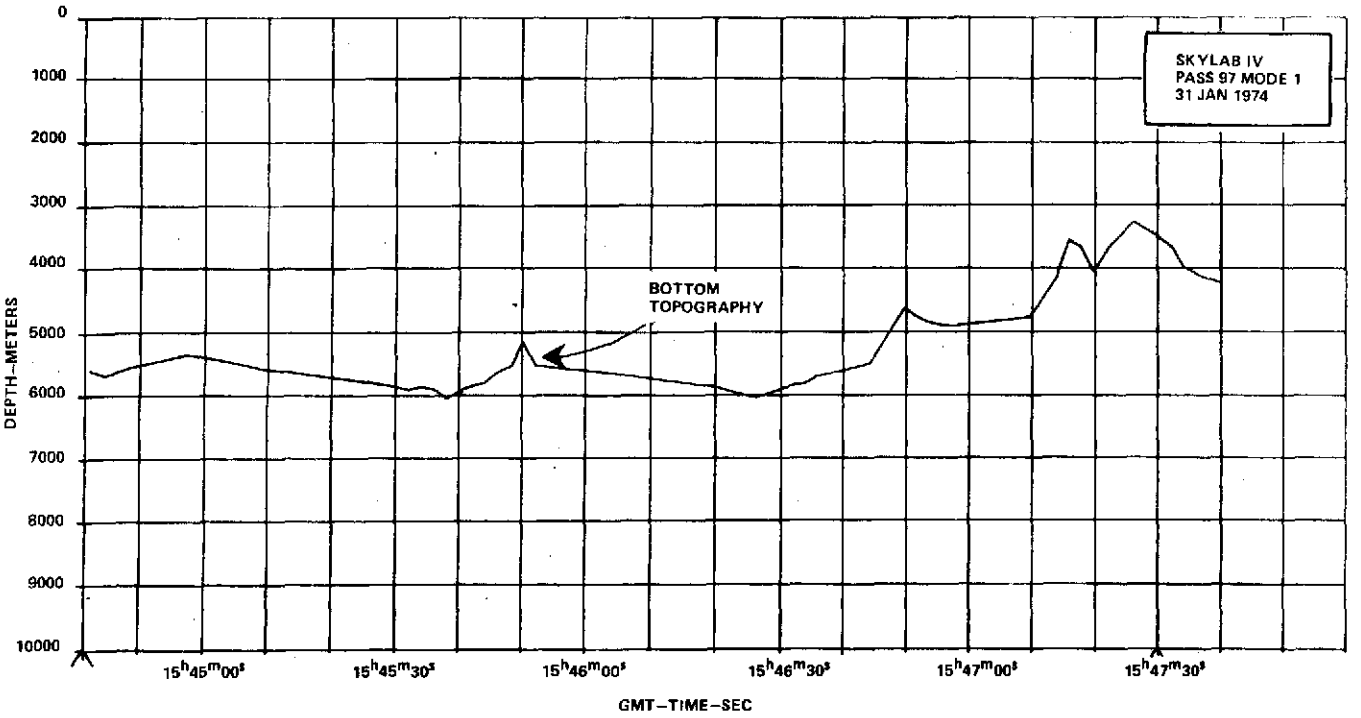


Lat 14.4° 22.5°

Long 141.7° 148.8°

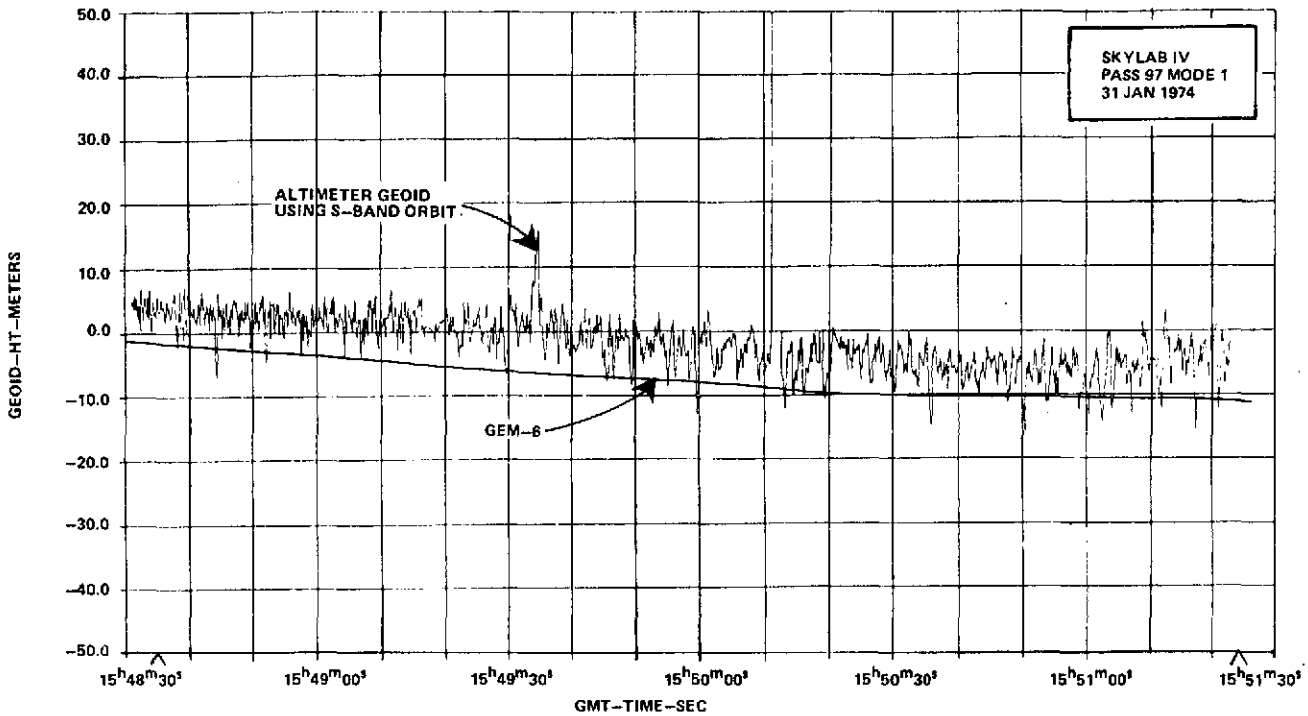
MAP NO. 212

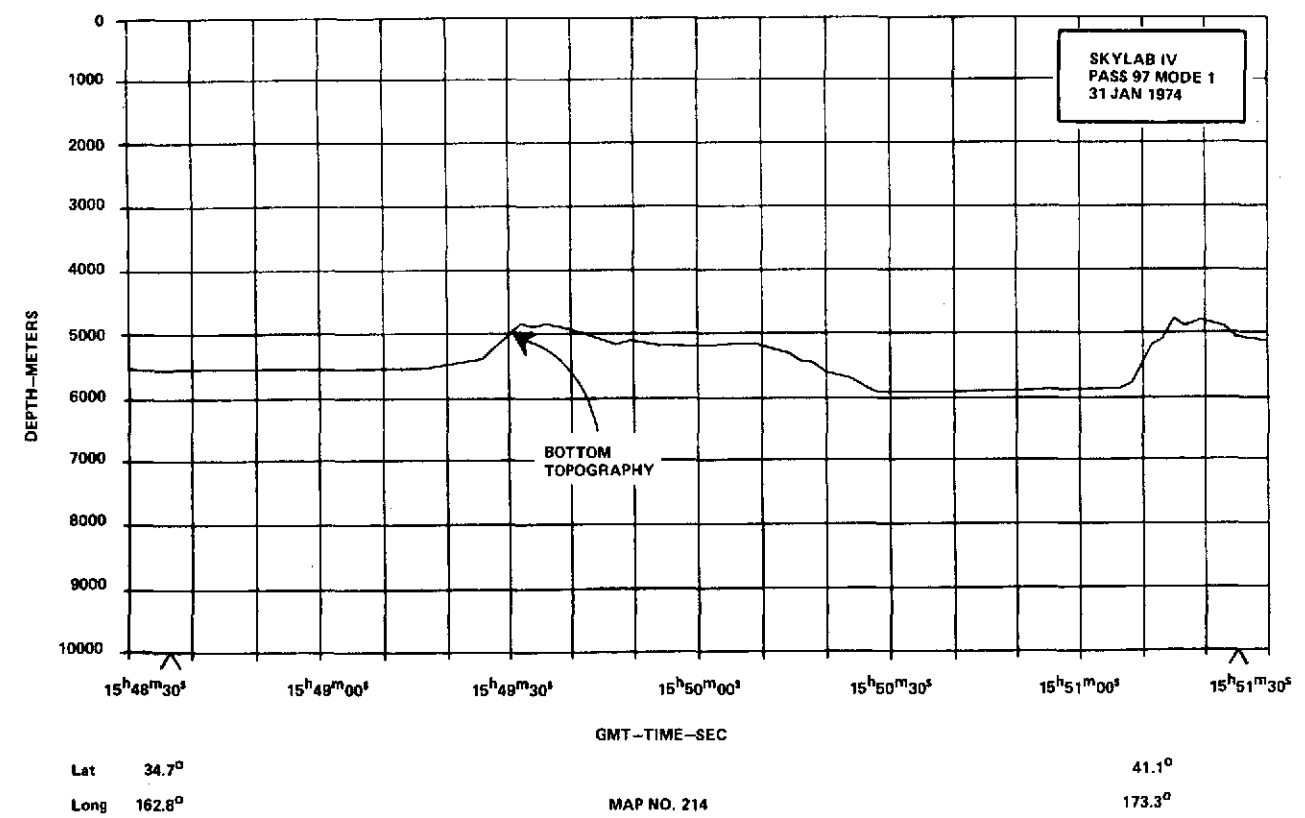




Lat Lat 34.5° 32.0°

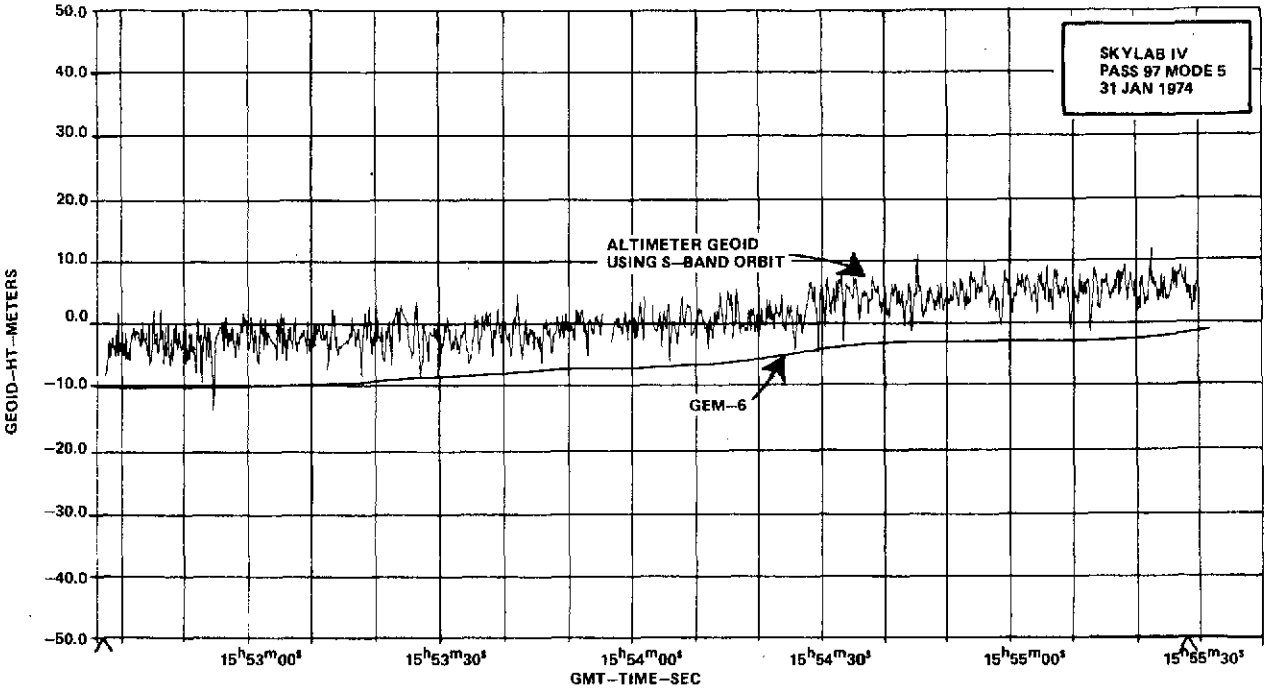
Long 150.8° MAP NO. 213 159.2°

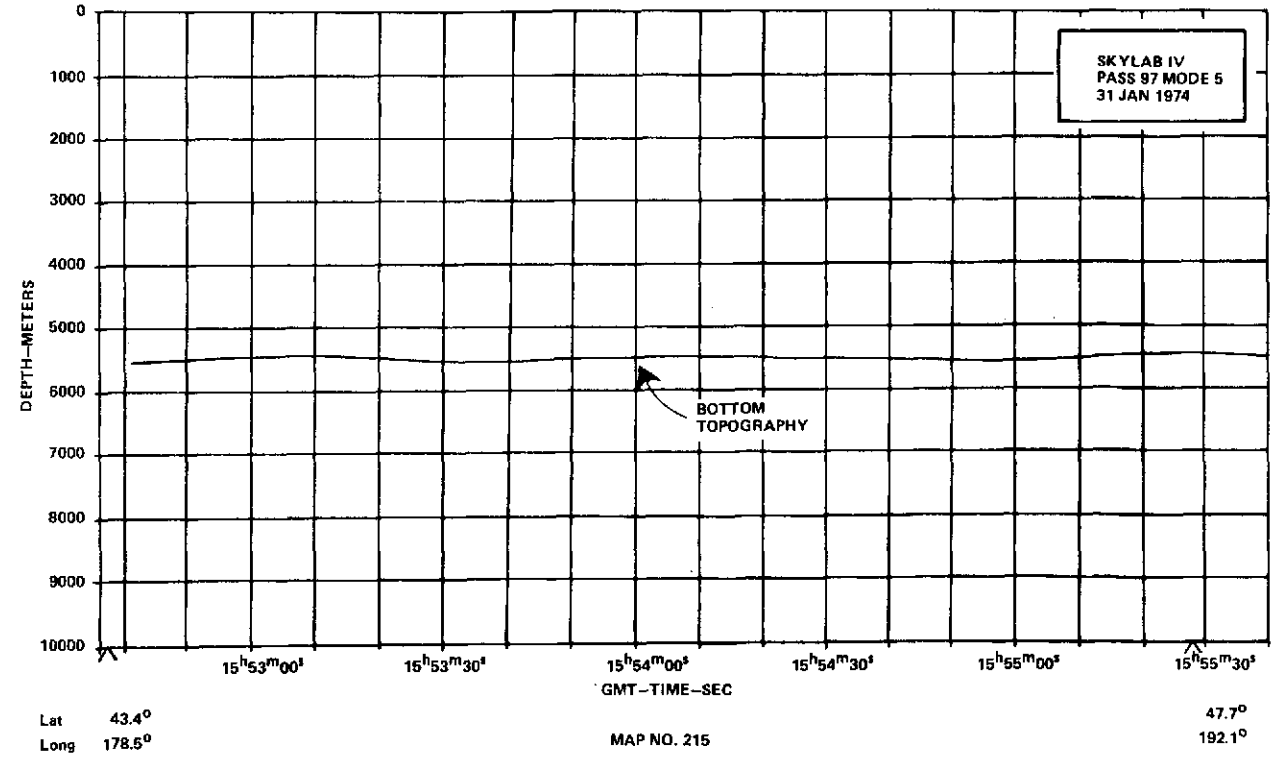




Lat 34.7° 41.1°

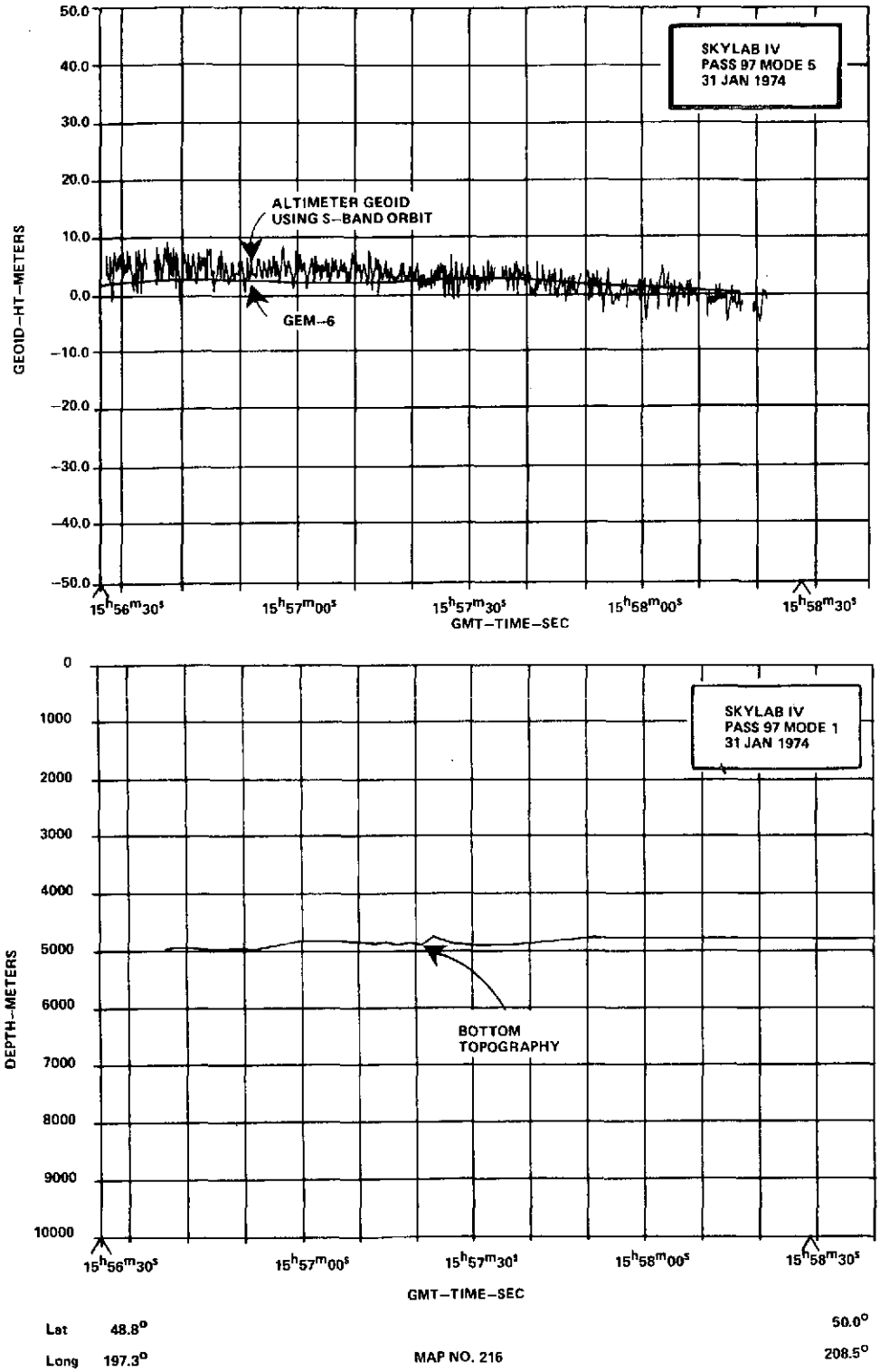
Long 162.8° MAP NO. 214 173.3°

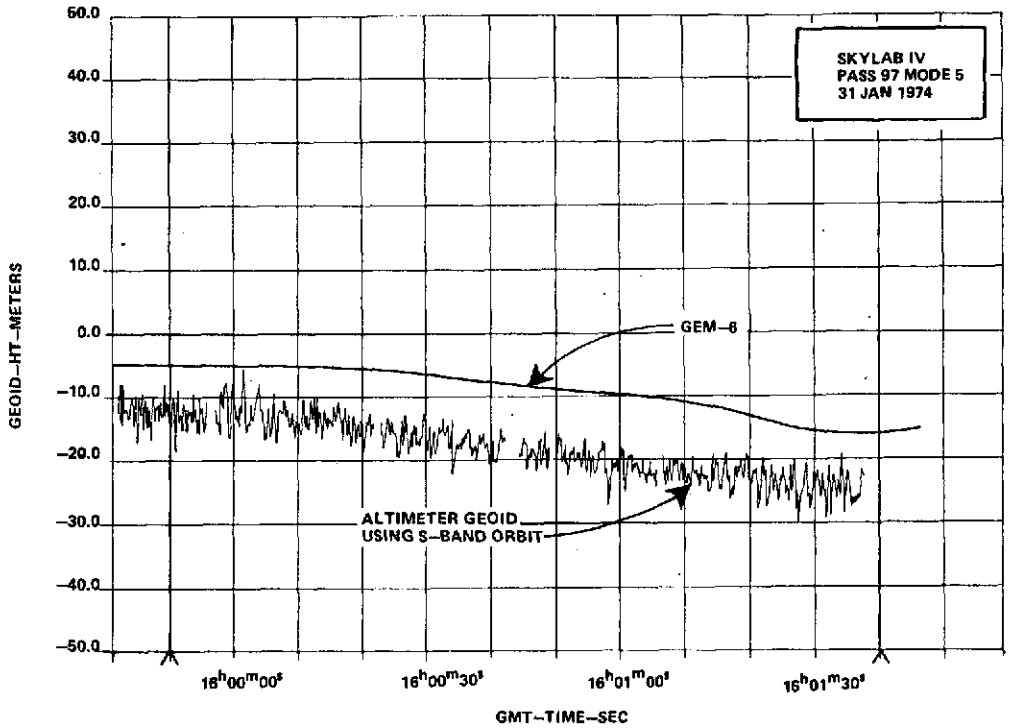


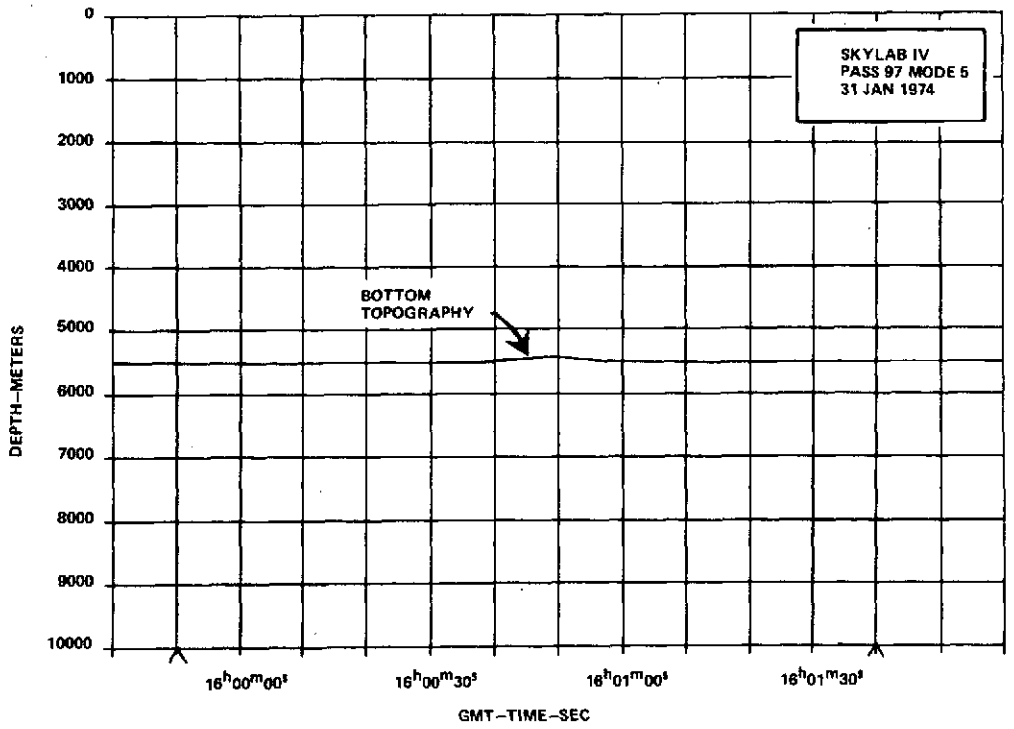


Lat 43.4° 47.7°
Long 178.5° 192.1°

MAP NO. 215


SKYLAB IV
PASS 97 MODE 5
31 JAN 1974
ALTIMETER GEOID
USING S-BAND ORBIT
GEM-6
GEOID-HT-METERS
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
15h56m30s
15h57m00s
15h57m30s
15h58m00s
15h58m30s
GMT-TIME-SEC
SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH-METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
15h56m30s
15h57m00s
15h57m30s
15h58m00s
15h58m30s
GMT-TIME-SEC
Lat 48.8°
Long 197.3°
MAP NO. 216
50.0°
208.5°

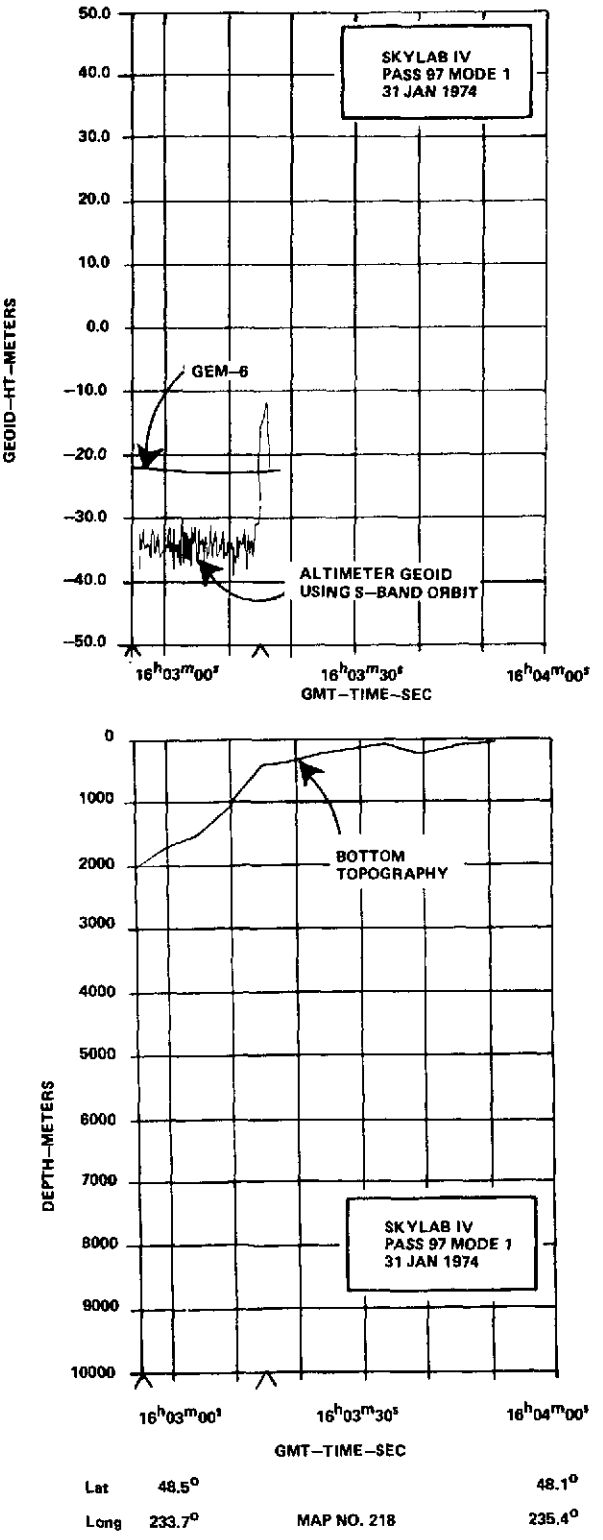


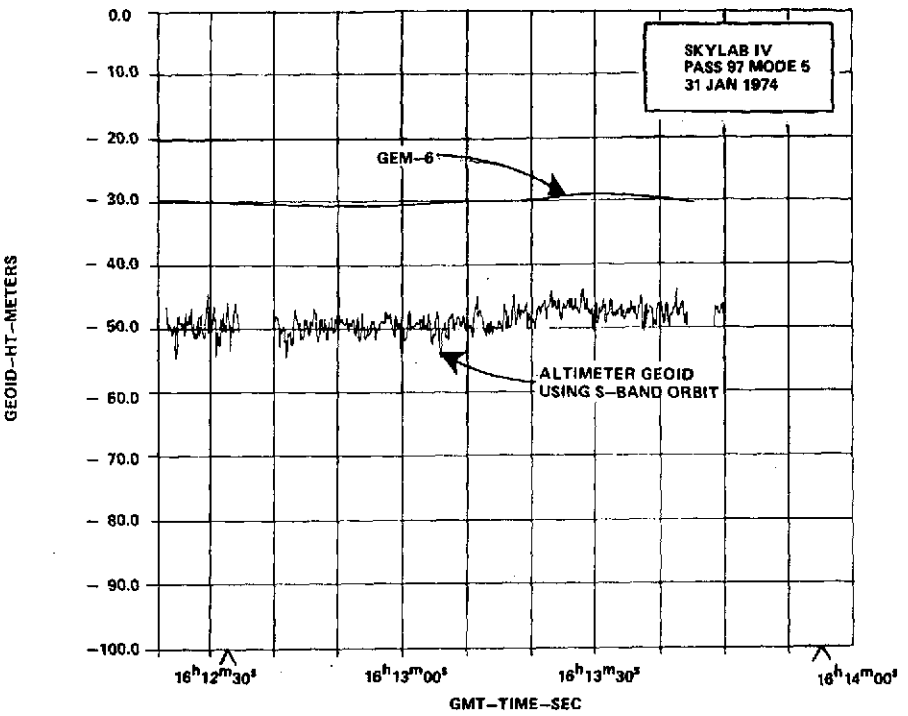


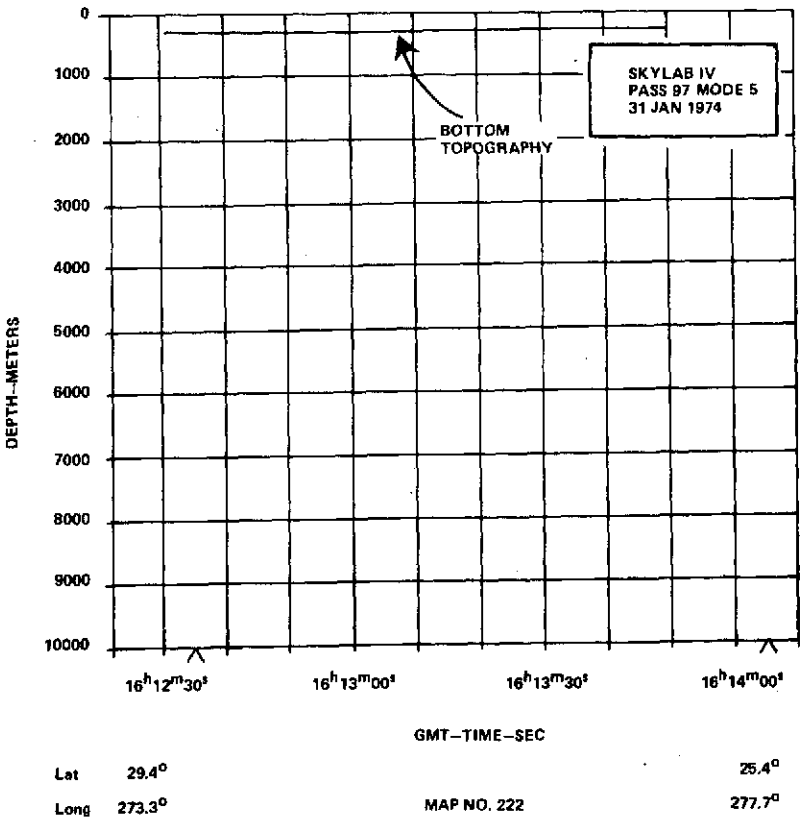
Lat 50.2° 49.5°

Long 216.4° 226.8°

MAP NO. 217

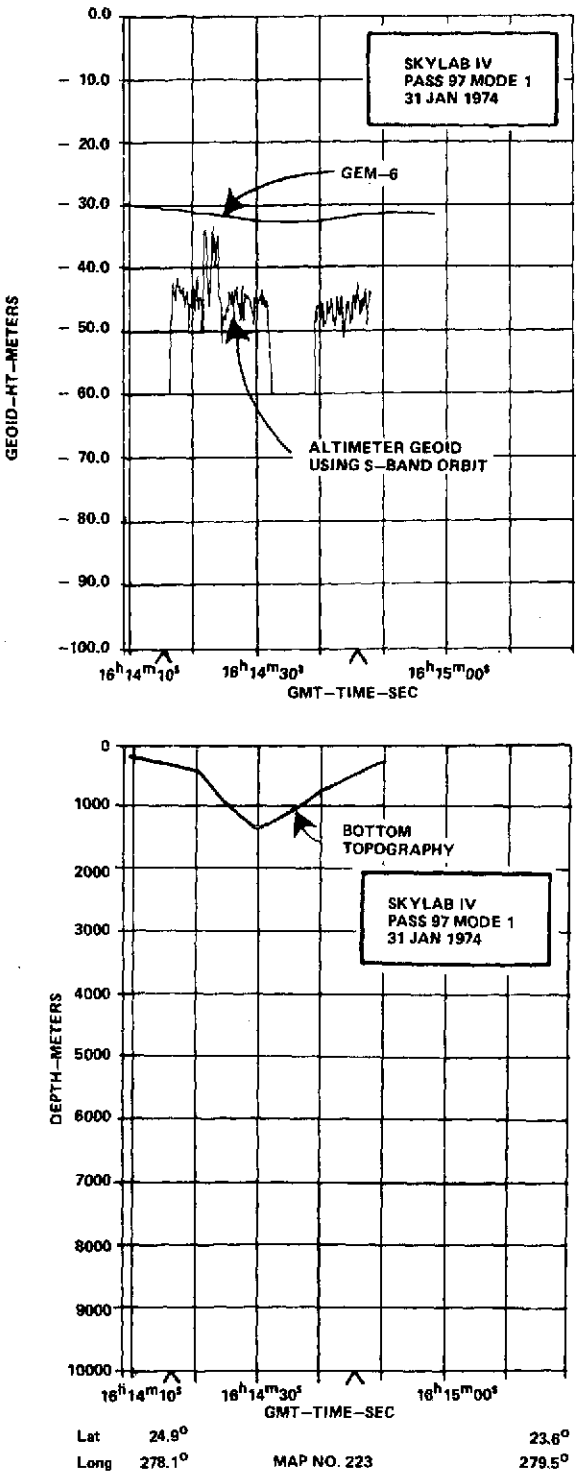

SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
GEOID–HT–METERS
50.0
40.0
30.0
20.0
10.0
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
16h03m00s
16h03m30s
16h04m00s
GMT–TIME–SEC
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
BOTTOM
TOPOGRAPHY
SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
16h03m00s
16h03m30s
16h04m00s
GMT–TIME–SEC
Lat 48.5° 48.1°
Long 233.7° MAP NO. 218 235.4°

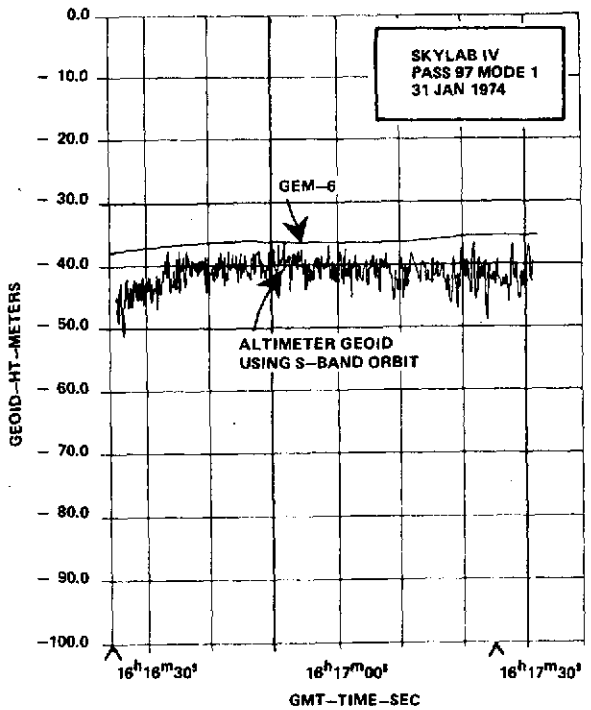


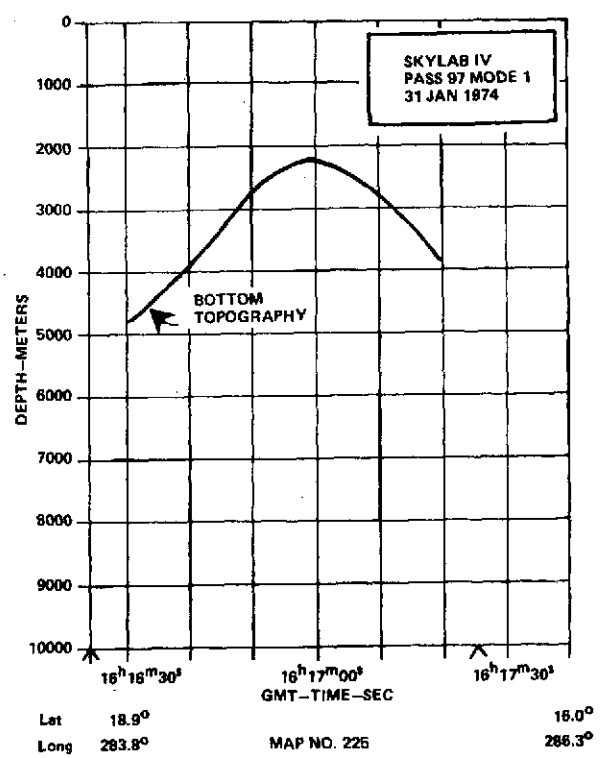


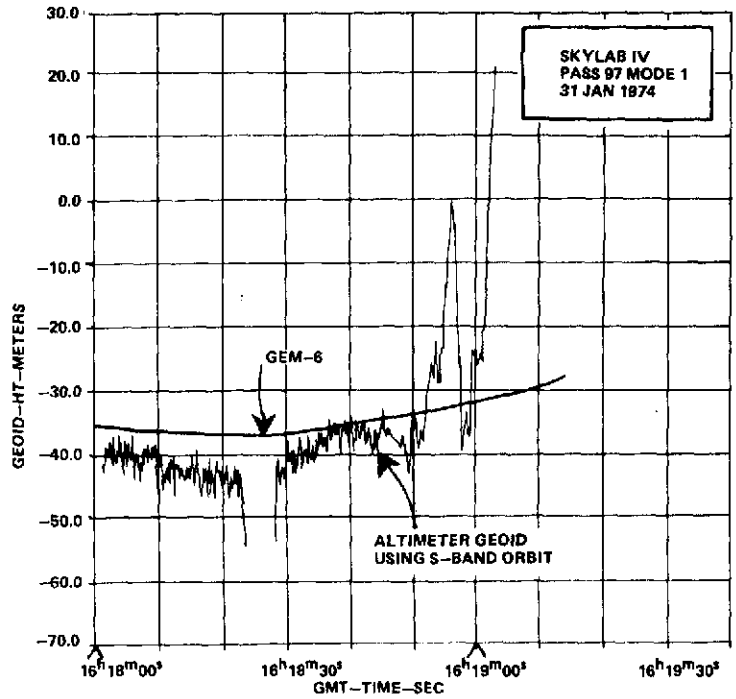
Lat 29.4° 25.4°

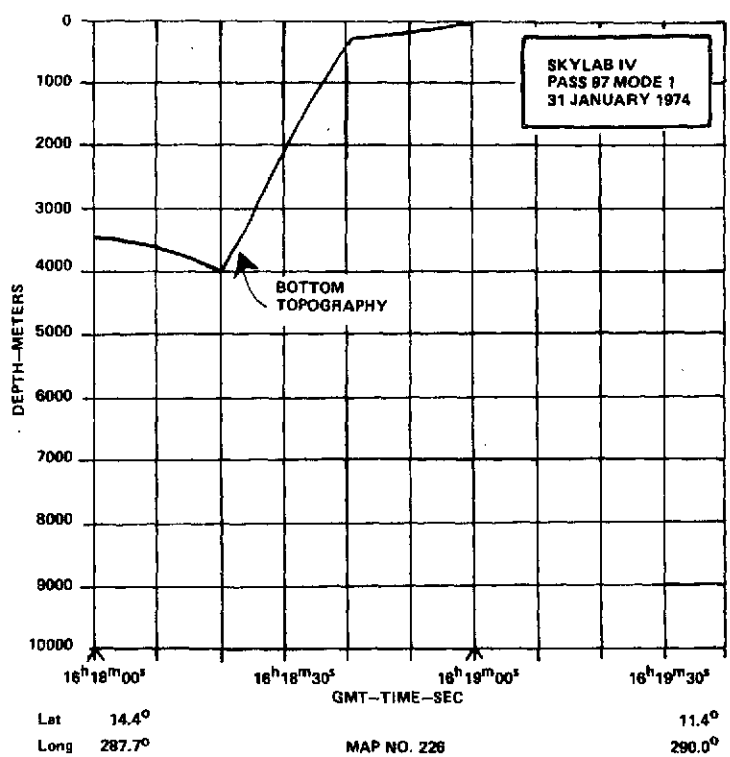
Long 273.3° MAP NO. 222 277.7°

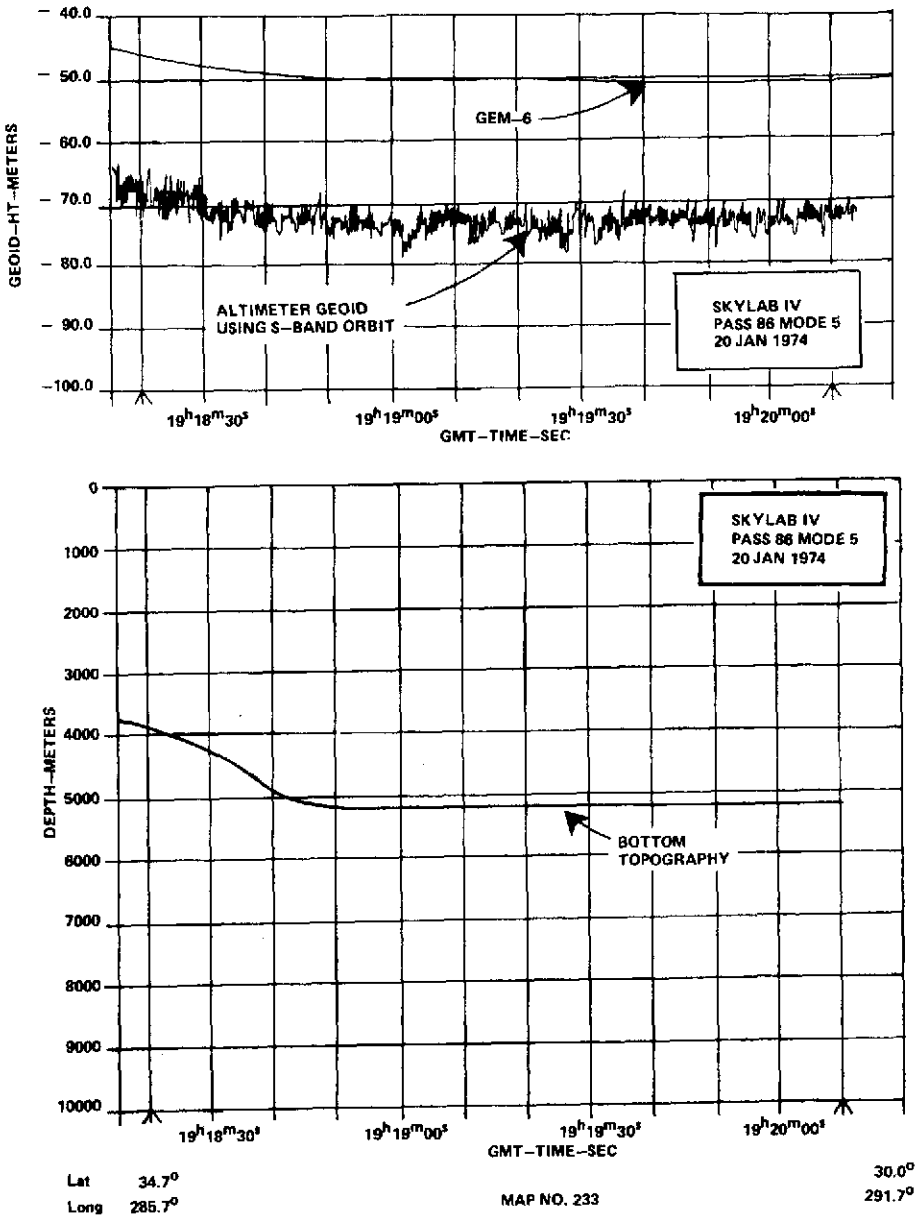

SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
0.0
– 10.0
– 20.0
– 30.0
– 40.0
– 50.0
– 60.0
– 70.0
– 80.0
– 90.0
–100.0
16h14m10s
16h14m30s
16h15m00s
GMT–TIME–SEC
BOTTOM
TOPOGRAPHY
SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
16h14m10s
16h14m30s
16h15m00s
GMT–TIME–SEC
Lat 24.9° 23.6°
Long 278.1° MAP NO. 223 279.5°


SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
GEOID–HT–METERS
0.0
– 10.0
– 20.0
– 30.0
– 40.0
– 50.0
– 60.0
– 70.0
– 80.0
– 90.0
–100.0
16h16m30s
16h17m00s
16h17m30s
GMT–TIME–SEC


SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
BOTTOM
TOPOGRAPHY
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
16h16m30s
16h17m00s
16h17m30s
GMT–TIME–SEC
Lat 18.9° 16.0°
Long 283.8° 286.3°
MAP NO. 225


SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
GEOID–HT–METERS
30.0
20.0
10.0
0.0
–10.0
–20.0
–30.0
–40.0
–50.0
–60.0
–70.0
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
16h18m00s
16h18m30s
16h19m00s
16h19m30s
GMT–TIME–SEC


SKYLAB IV
PASS 97 MODE 1
31 JANUARY 1974
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
BOTTOM
TOPOGRAPHY
16h18m00s
16h18m30s
16h19m00s
16h19m30s
GMT–TIME–SEC
Lat 14.4°
Long 287.7°
MAP NO. 226
11.4°
290.0°


GEOID–HT–METERS
40.0
50.0
60.0
70.0
80.0
90.0
100.0
GEM–6
ALTIMETER GEOID
USING S–BAND ORBIT
SKYLAB IV
PASS 86 MODE 5
20 JAN 1974
19h18m30s
19h19m00s
19h19m30s
19h20m00s
GMT–TIME–SEC
DEPTH–METERS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
SKYLAB IV
PASS 86 MODE 5
20 JAN 1974
BOTTOM
TOPOGRAPHY
19h18m30s
19h19m00s
19h19m30s
19h20m00s
GMT–TIME–SEC
Lat 34.7°
Long 285.7°
MAP NO. 233
30.0°
291.7°

AUTOMATIC GAIN CONTROL

The Automatic Gain Control (AGC) of the altimeter is a good indicator of the relative signal strength of the return signals. Unfortunately, in the conversion of counts to volts that can be related to signal level, the wrong calibration curve was mistakenly utilized in the ground processing. The effort required to reprocess the AGC to correct this error was not felt to be justified, for the relative values of signal strength would still be significant even if the absolute calibration was lost. In addition, it was thought that those whose interest centered on the use of the altitude measurements for topography or geoid studies would primarily use AGC as a relative signal quality indicator.

In using the plots supplied in this document, it should be remembered that a -30 db AGC level, when operating with the 100 ns pulsewidth and 10 MHz bandwidth, is the strongest expected signal. If the returns get stronger, chances are the surface has become specular. At this -30 db level the system is operating with a signal-to-noise of approximately 30 db. As operating parameters are changed, the signal level will change in discrete steps; therefore, these steps can help establish exact times of sub-mode changes. By comparing signal levels of good pointing passes to those where pointing was not good, the direct effects of pointing on AGC can be appreciated.

Sharp spikes (less than 10 sec in duration) in the altitude residuals can often be related to the AGC plots as sudden loss of signal (deep fades) or sudden increases in signal (specular returns). These can cause the altitude tracker momentarily to lose track which in turn creates both the positive and negative sharp spikes seen.

Changes in AGC are primarily due to the changes in the ocean surface roughness. Therefore, the subsurface topography, currents, surface winds, etc. are parameters being sensed by the altimeter AGC. In addition, rain may attenuate the signal causing the AGC to show a loss of signal up to 5 db.

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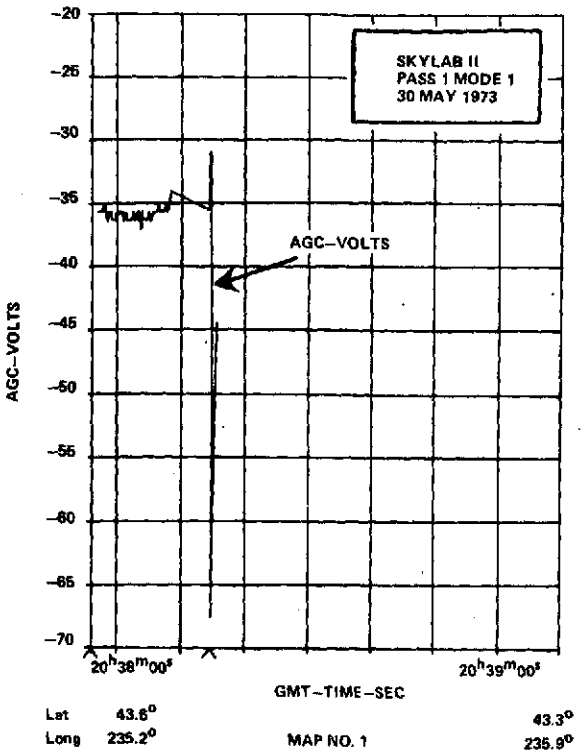
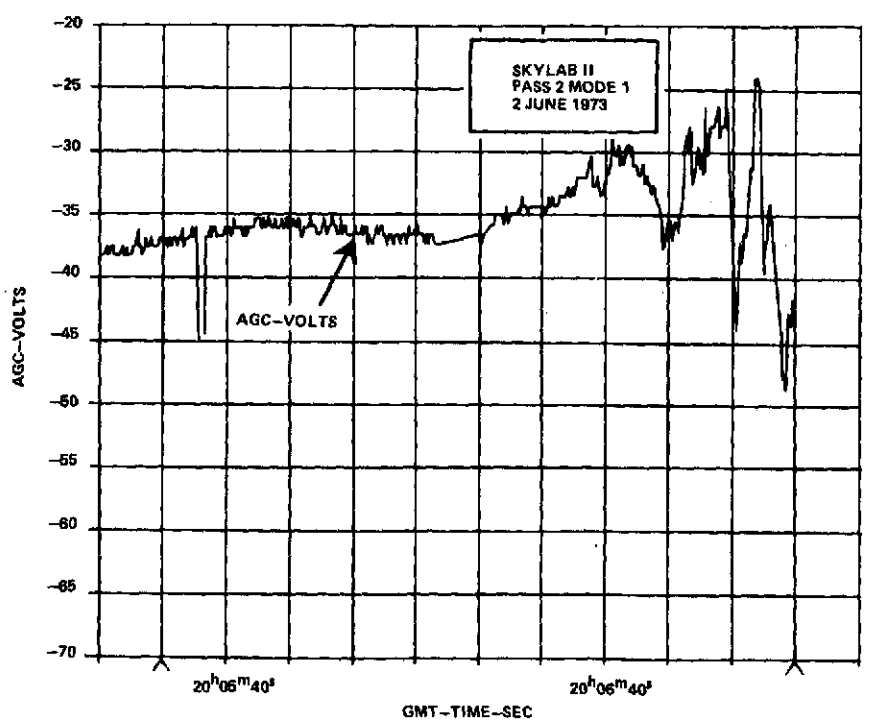
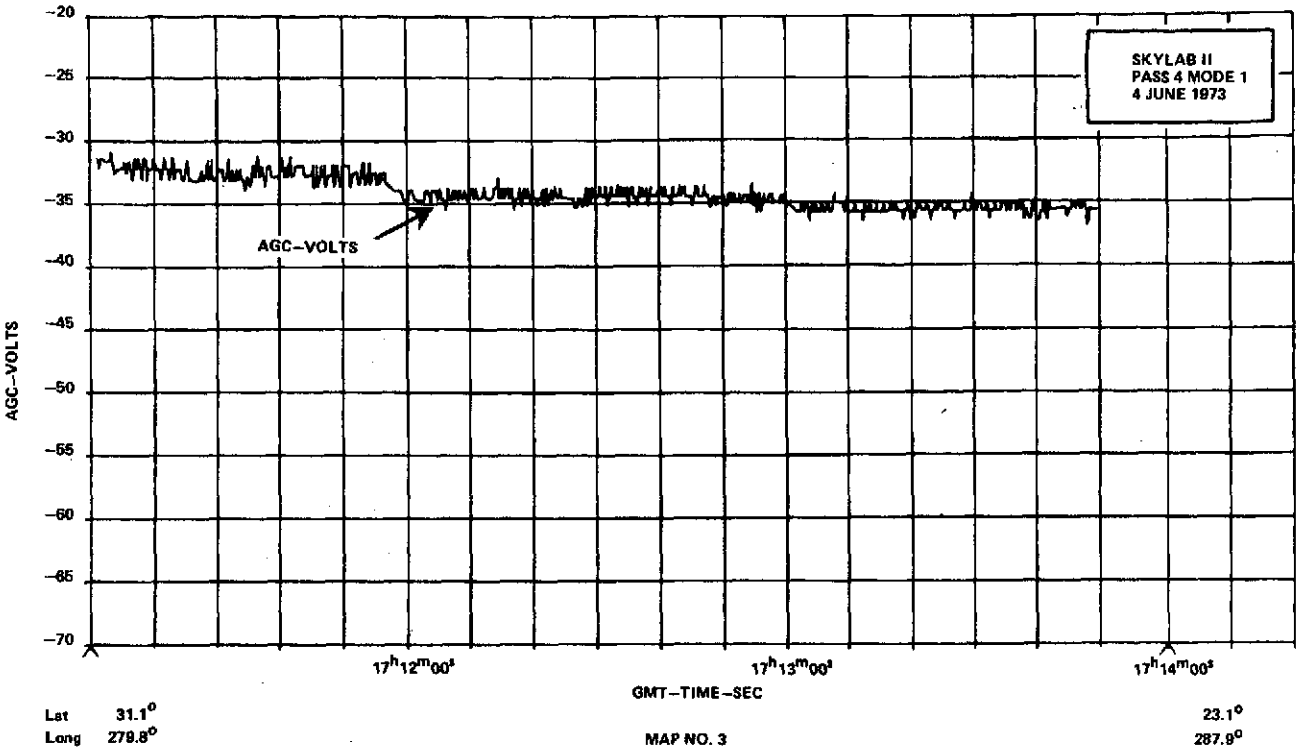


Lat 43.6° 43.3°
Long 235.2° MAP NO. 1 235.9°



Lat 40.6° 36.8°
Long 232.2° MAP NO. 2 238.8°



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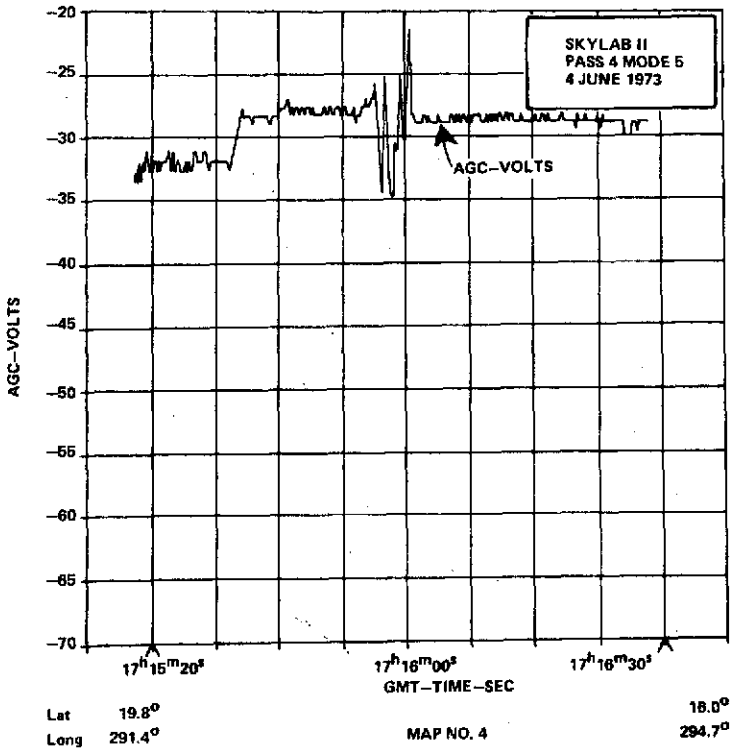

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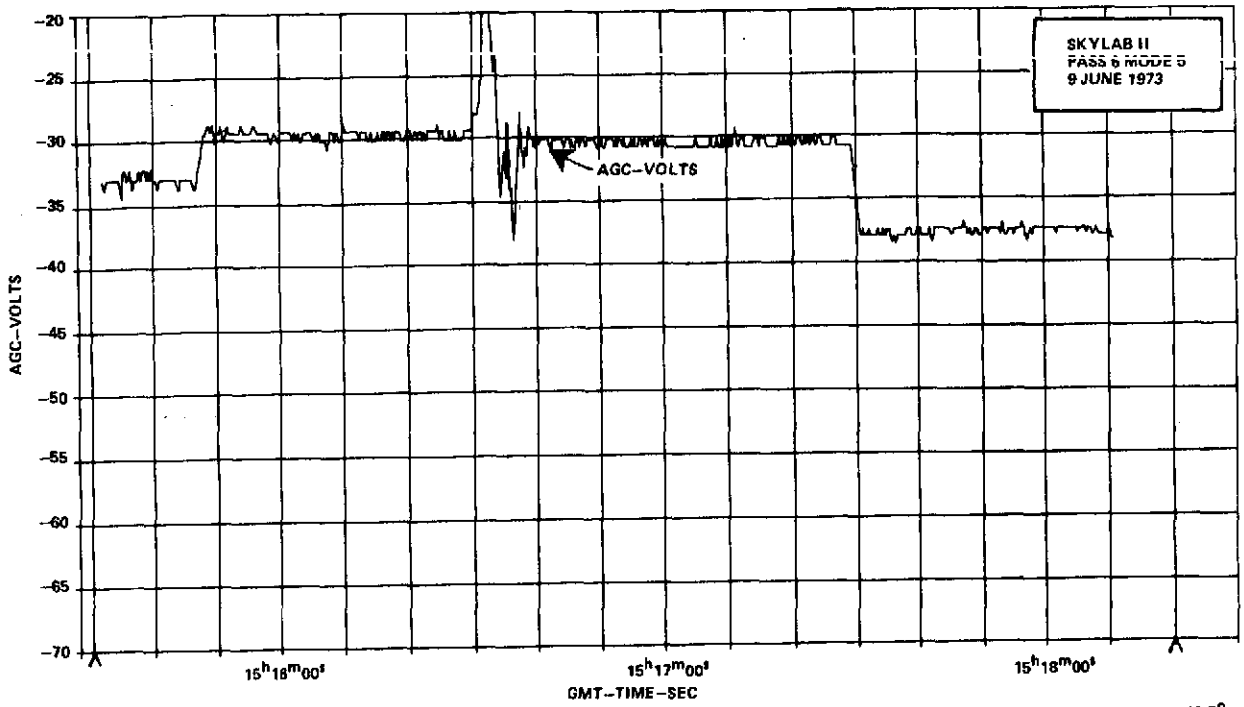
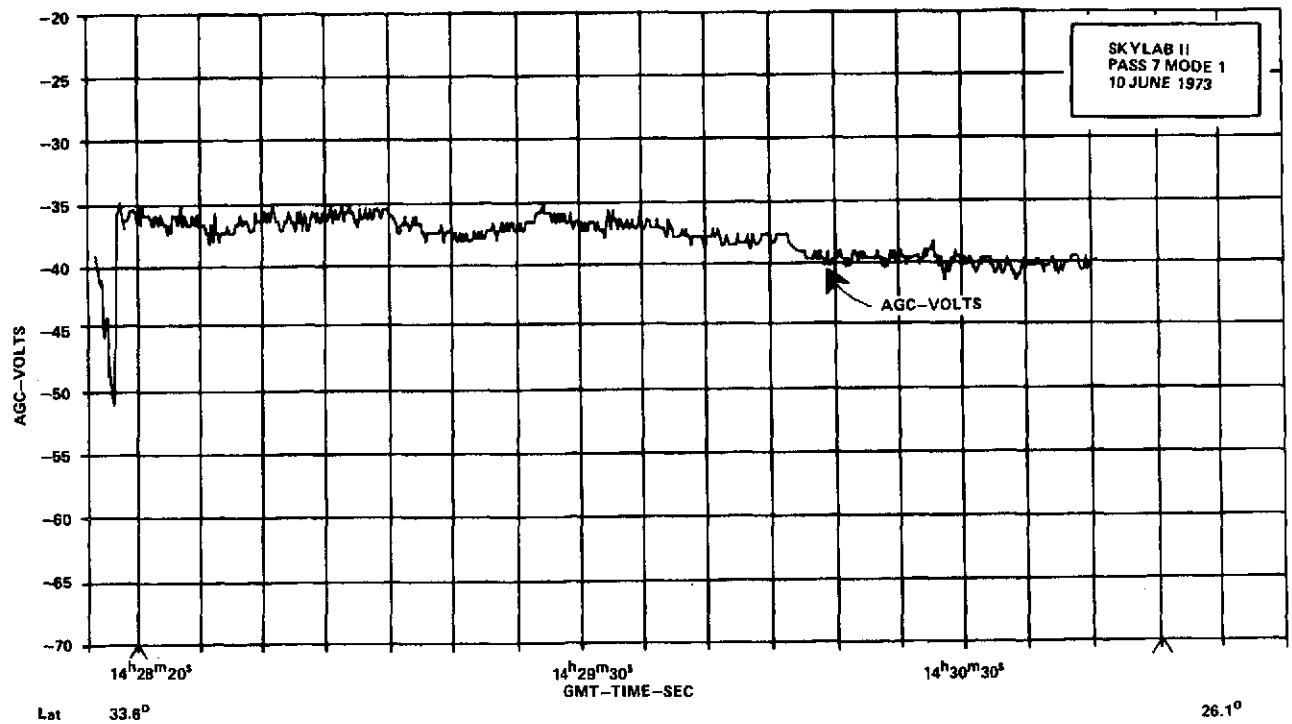


Lat 21.2°
Long 290.2°

MAP NO. 5

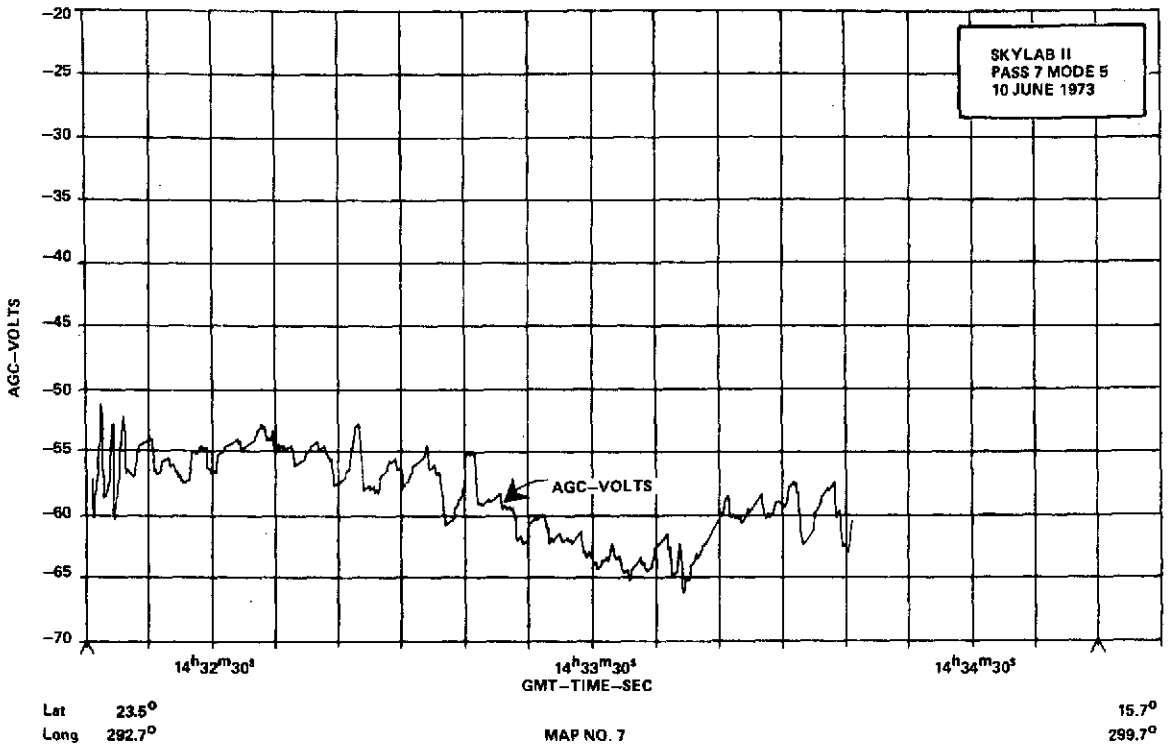
13.5°
297.5°

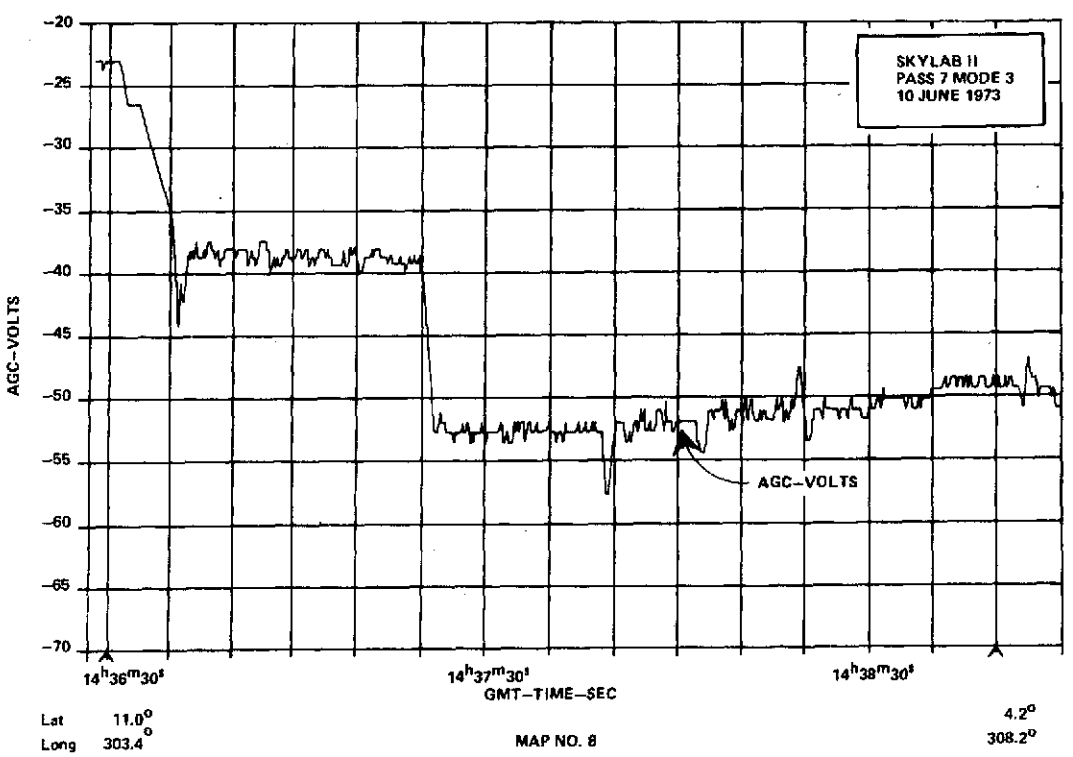


Lat 33.6°
Long 281.3°

MAP NO. 6

26.1°
290.0°


SKYLAB II
PASS 7 MODE 5
10 JUNE 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
AGC–VOLTS
14h32m30s
14h33m30s
14h34m30s
GMT–TIME–SEC
Lat 23.5°
Long 292.7°
15.7°
299.7°
MAP NO. 7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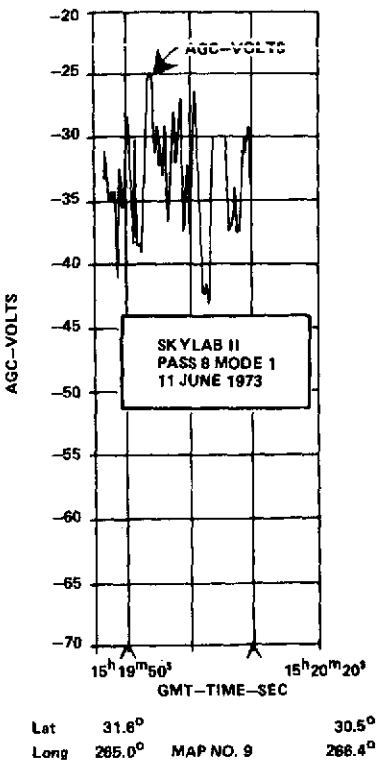
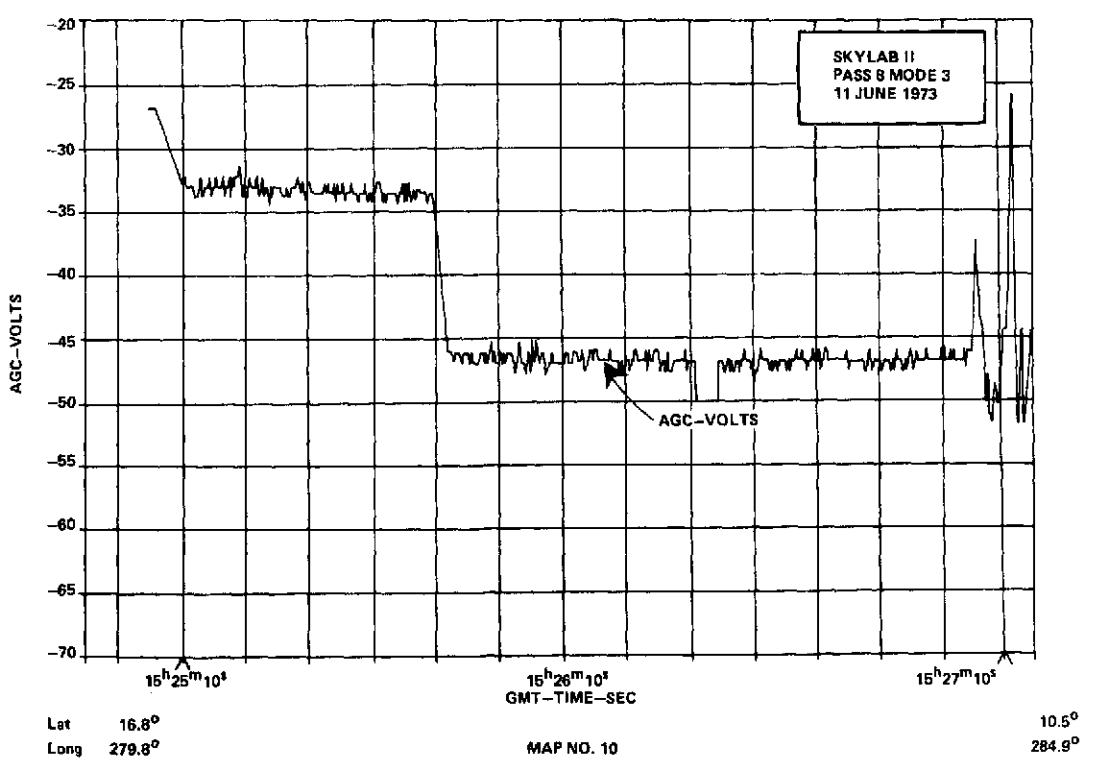
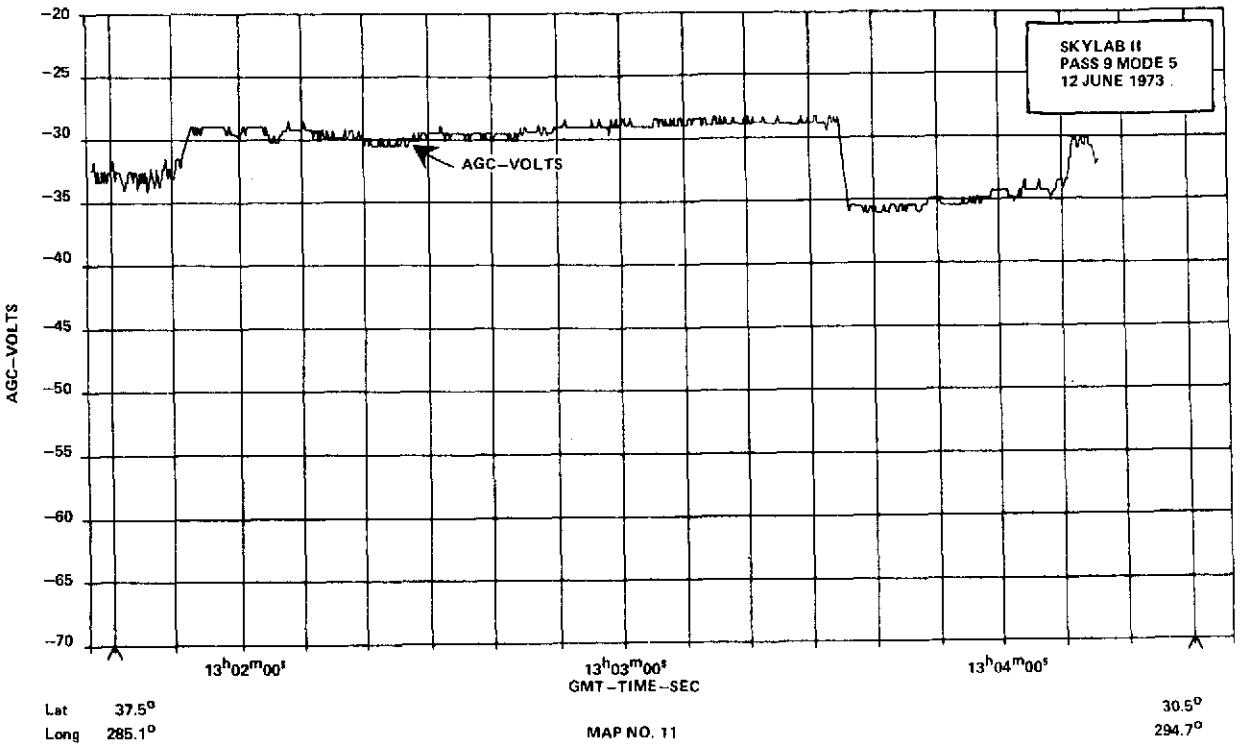
PASS 7 MODE 3
10 JUNE 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
AGC–VOLTS
14h36m30s
14h37m30s
14h38m30s
GMT–TIME–SEC
Lat 11.0°
Long 303.4°
4.2°
308.2°
MAP NO. 8


AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
SKYLAB II
PASS 8 MODE 1
11 JUNE 1973
15h19m50s
15h20m20s
GMT–TIME–SEC
Lat 31.6°
30.5°
Long 265.0°
MAP NO. 9
266.4°


AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
SKYLAB II
PASS 8 MODE 3
11 JUNE 1973
AGC–VOLTS
15h25m10s
15h26m10s
15h27m10s
GMT–TIME–SEC
Lat 16.8°
10.5°
Long 279.8°
MAP NO. 10
284.9°



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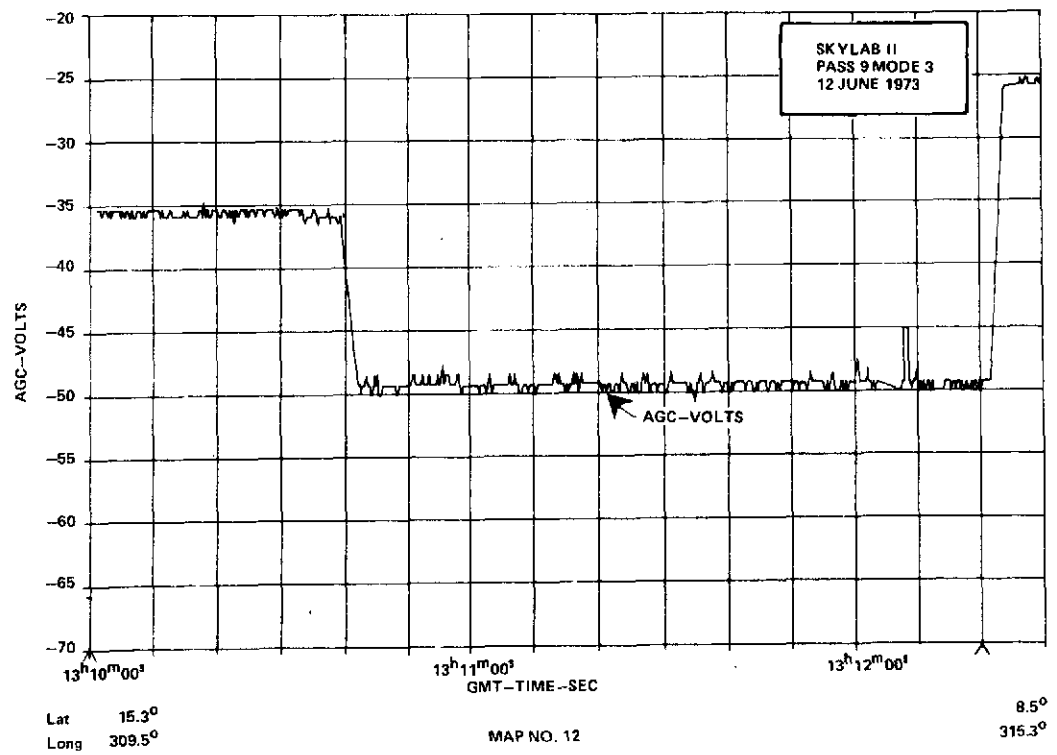

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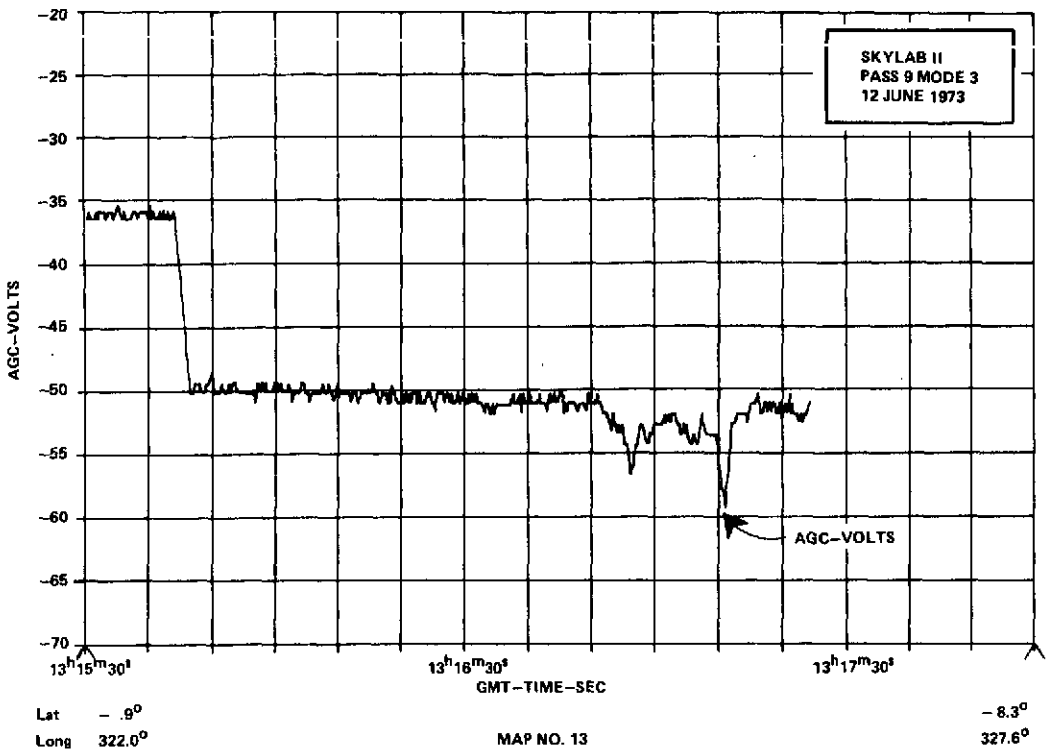
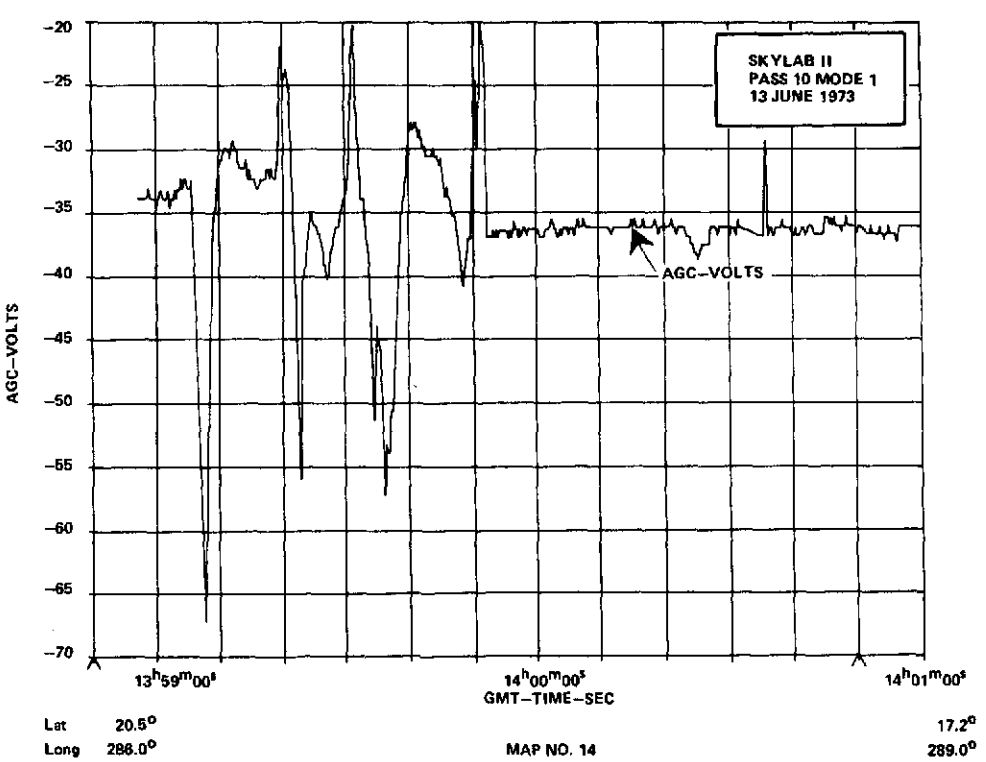

SKYLAB II
PASS 9 MODE 3
12 JUNE 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
AGC–VOLTS
$13^h15^m30^s$
$13^h16^m30^s$
$13^h17^m30^s$
GMT–TIME–SEC
Lat – .9°
Long 322.0°
MAP NO. 13
– 8.3°
327.6°


SKYLAB II
PASS 10 MODE 1
13 JUNE 1973
AGC–VOLTS
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–40
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–60
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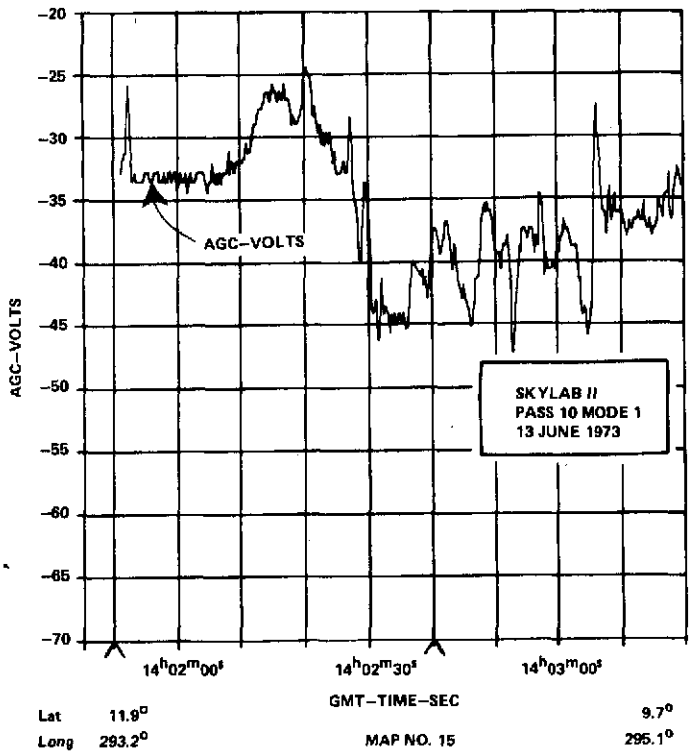
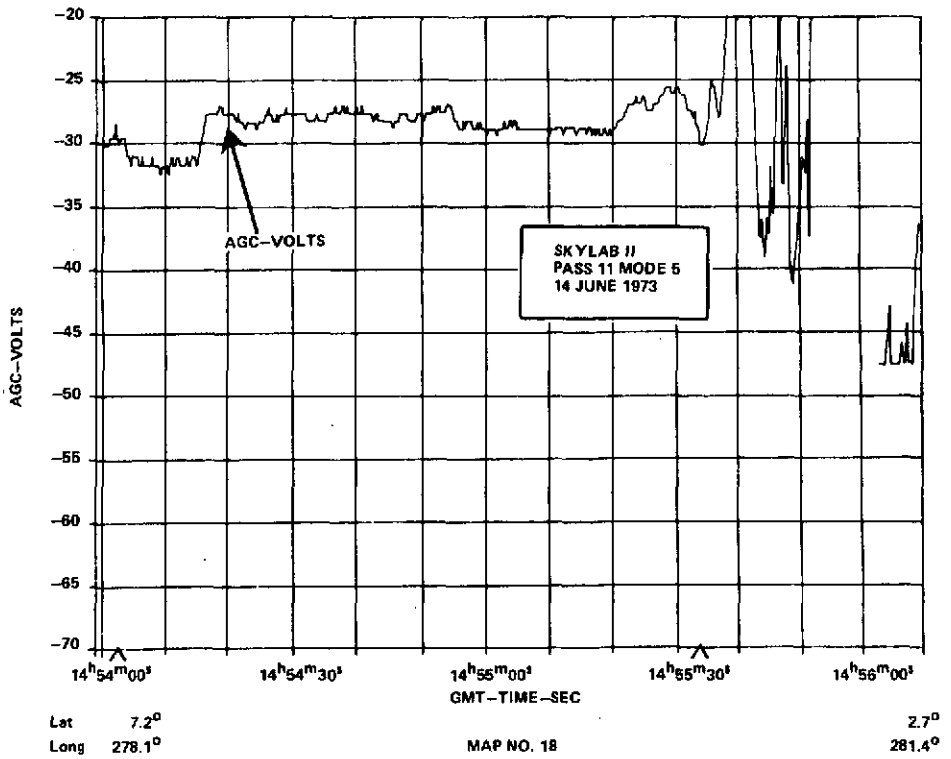
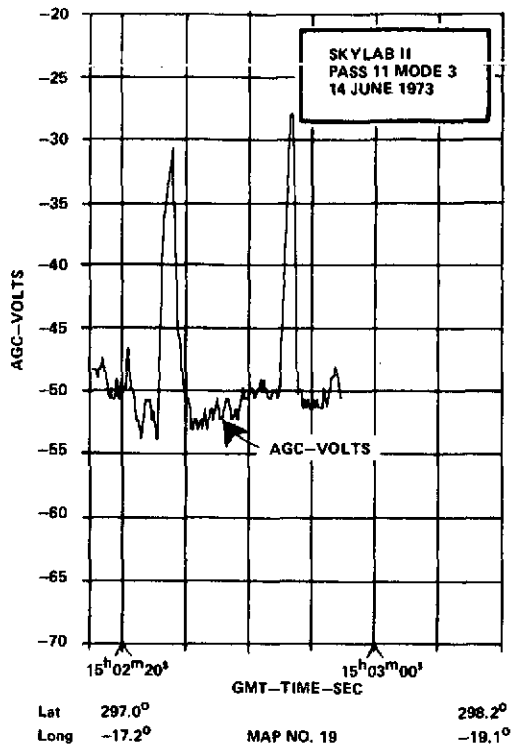
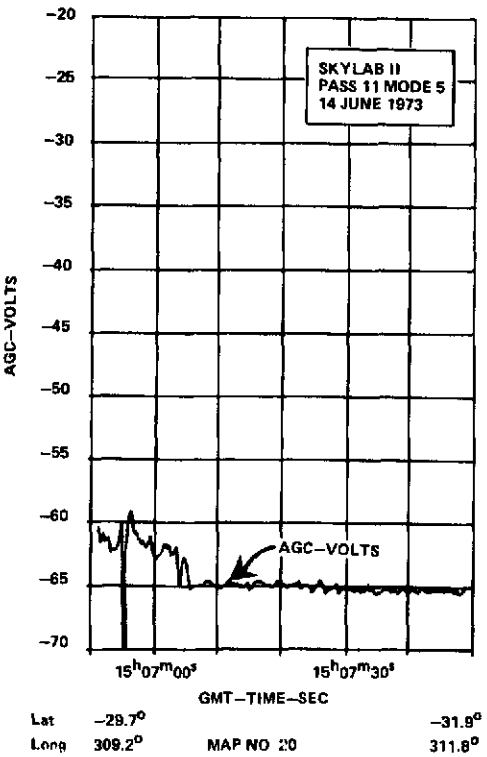
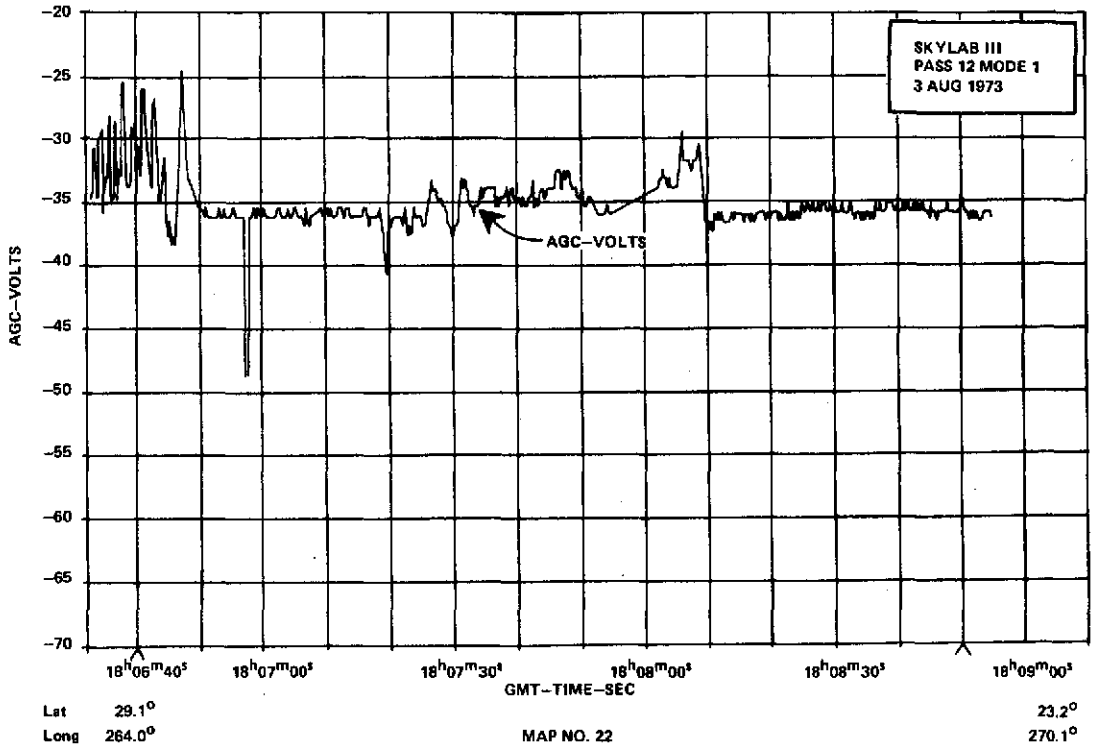
–70
AGC–VOLTS
AGC–VOLTS
$13^h59^m00^s$
$14^h00^m00^s$
$14^h01^m00^s$
GMT–TIME–SEC
Lat 20.5°
Long 286.0°
MAP NO. 14
17.2°
289.0°


-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
AGC-VOLTS
AGC-VOLTS
SKYLAB II
PASS 10 MODE 1
13 JUNE 1973
14h02m00s
14h02m30s
14h03m00s
GMT-TIME-SEC
Lat 11.9°
Long 293.2°
9.7°
295.1°
MAP NO. 15


-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
AGC-VOLTS
AGC-VOLTS
SKYLAB II
PASS 11 MODE 5
14 JUNE 1973
14h54m00s
14h54m30s
14h55m00s
14h55m30s
14h56m00s
GMT-TIME-SEC
Lat 7.2°
Long 278.1°
2.7°
281.4°
MAP NO. 18

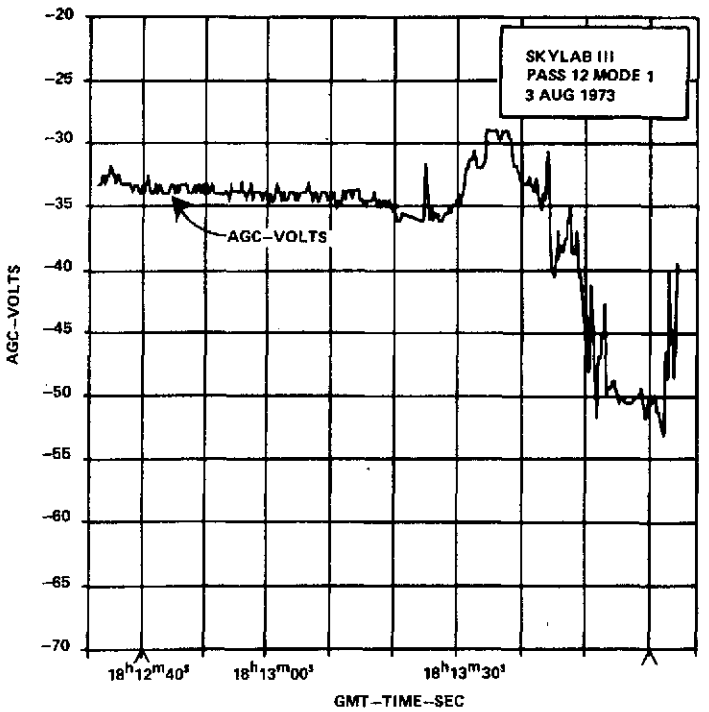

SKYLAB II
PASS 11 MODE 3
14 JUNE 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
15h02m20s
15h03m00s
GMT–TIME–SEC
Lat 297.0° 298.2°
Long –17.2° MAP NO. 19 –19.1°


SKYLAB II
PASS 11 MODE 5
14 JUNE 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
15h07m00s
15h07m30s
GMT–TIME–SEC
Lat –29.7° –31.9°
Long 309.2° MAP NO 20 311.8°



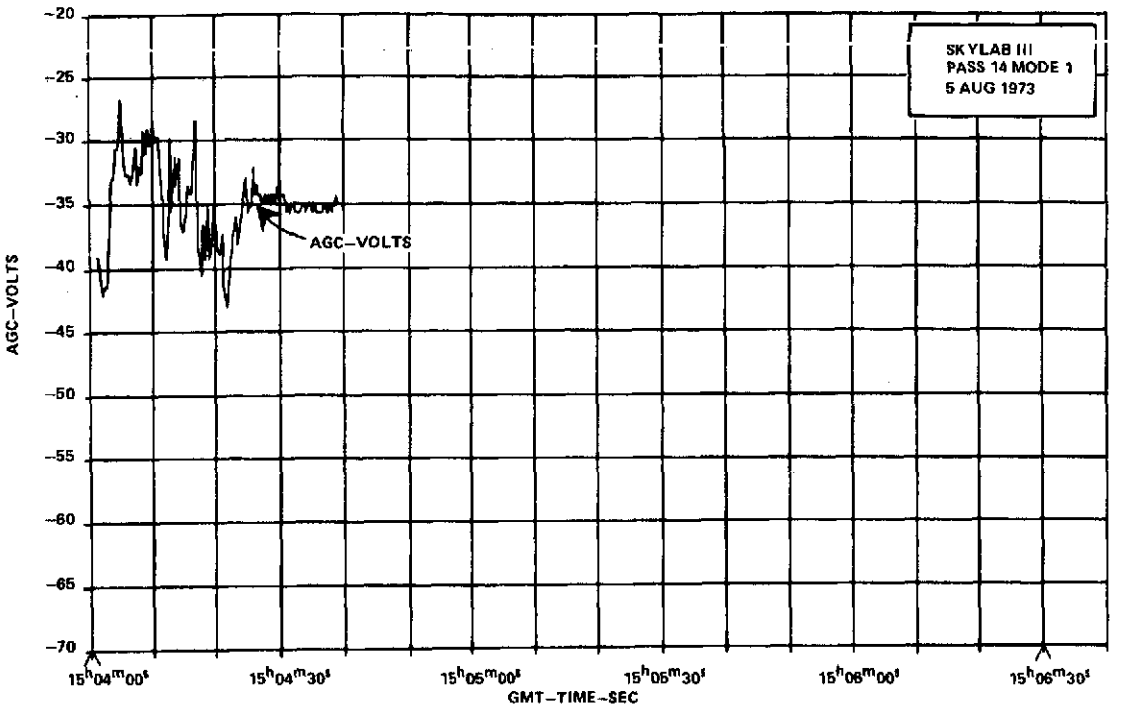
Lat 29.1° 23.2°
Long 264.0° 270.1°

MAP NO. 22



Lat 12.2° 8.8°
Long 279.7° 282.4°

MAP NO. 23



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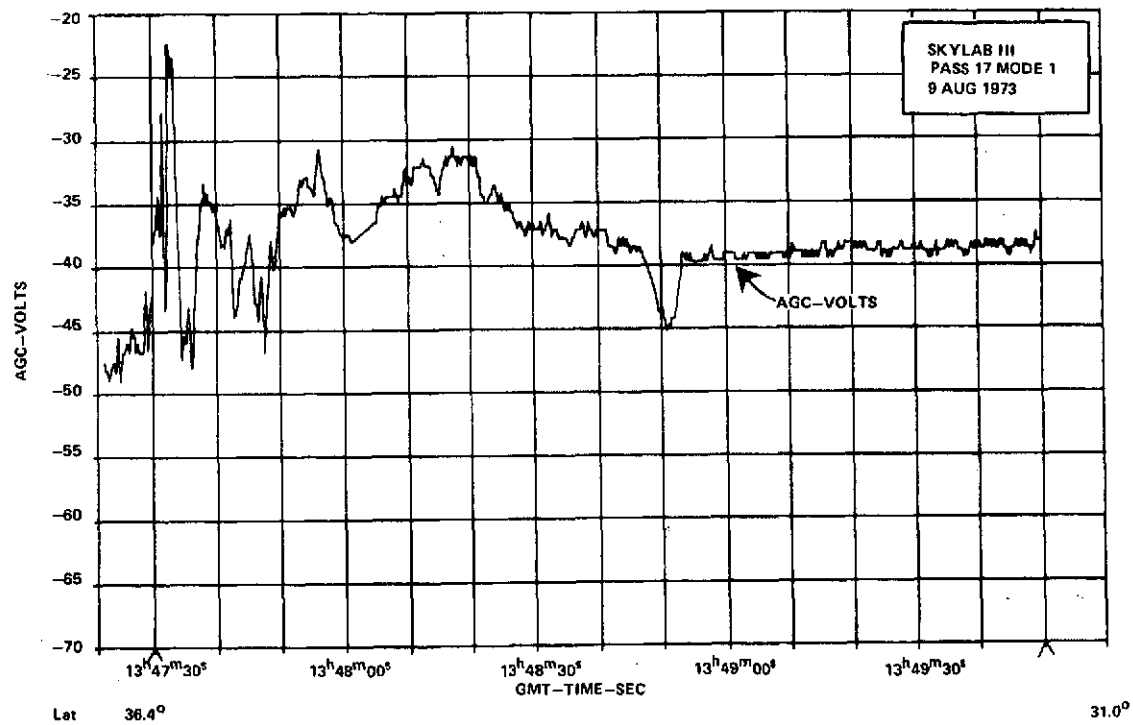

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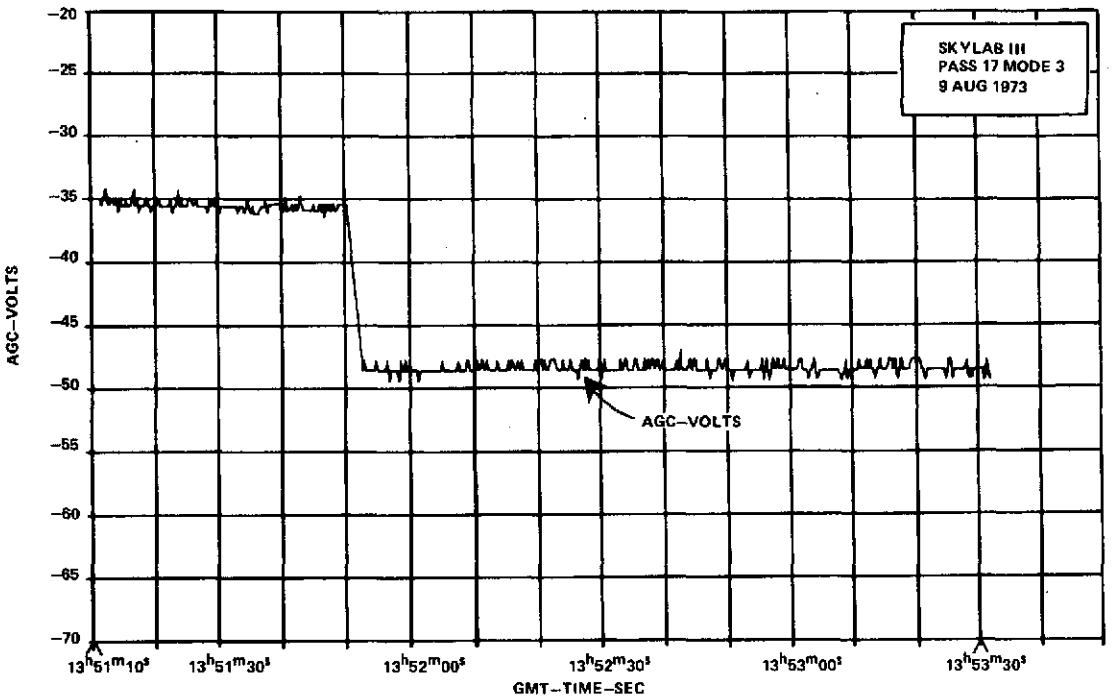
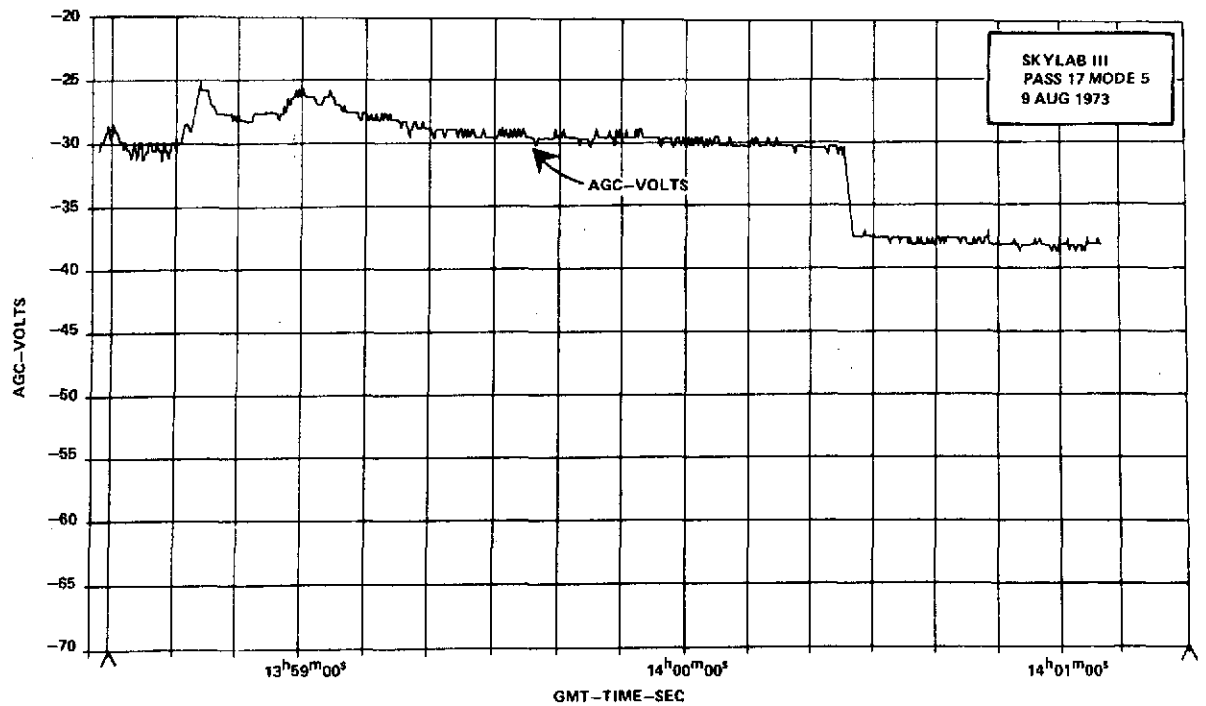


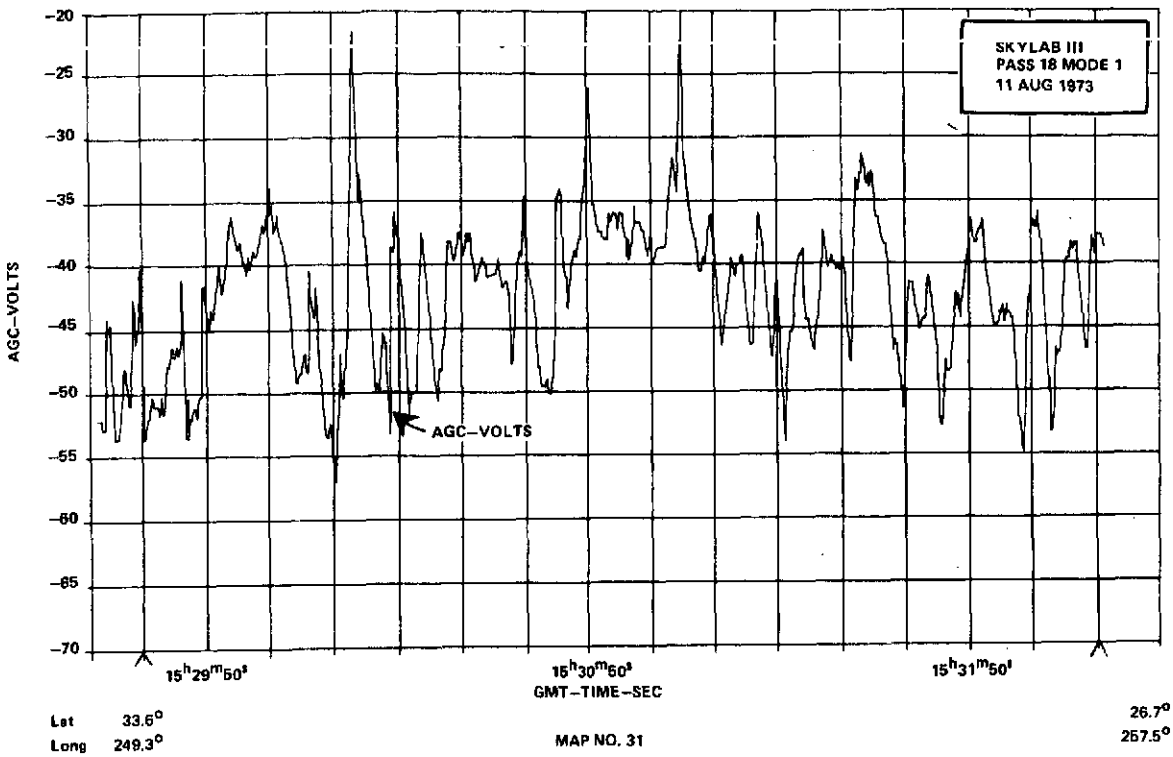
Lat 27.1° 20.7°
Long 294.8° 301.2°

MAP NO. 29



Lat 6.1° – 2.3°
Long 313.1° 319.5°

MAP NO. 30



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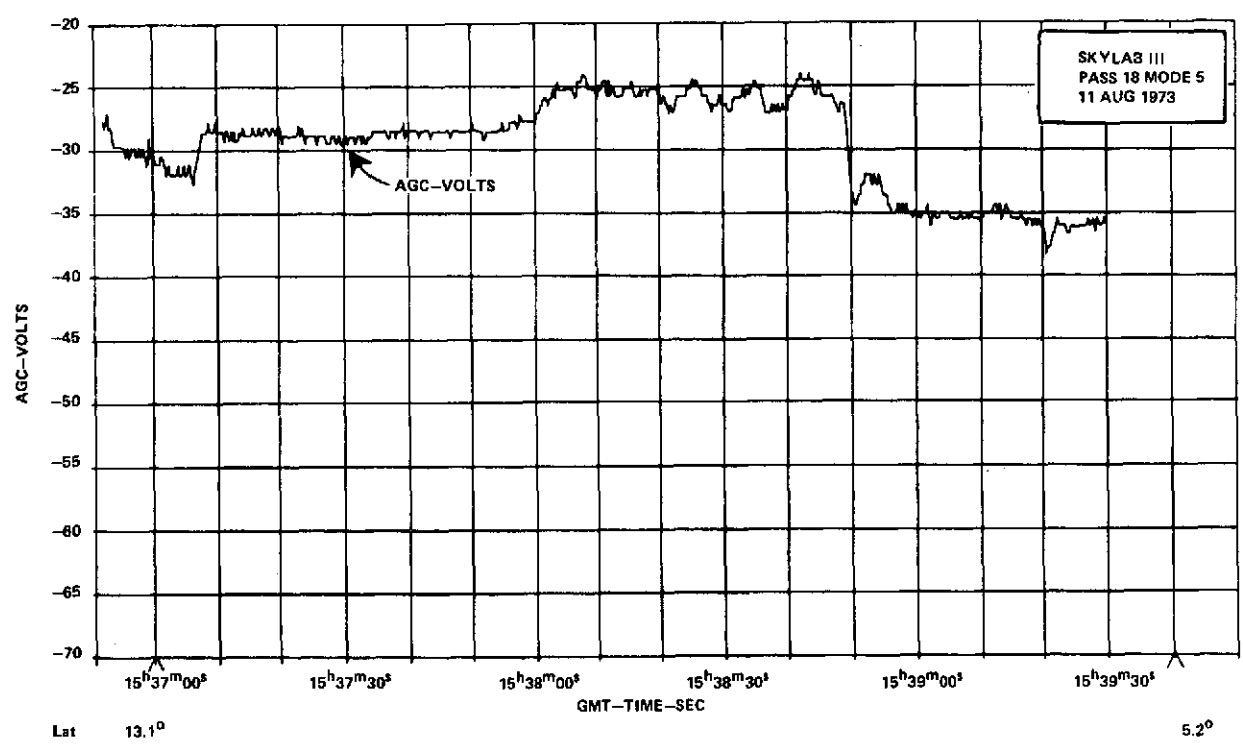

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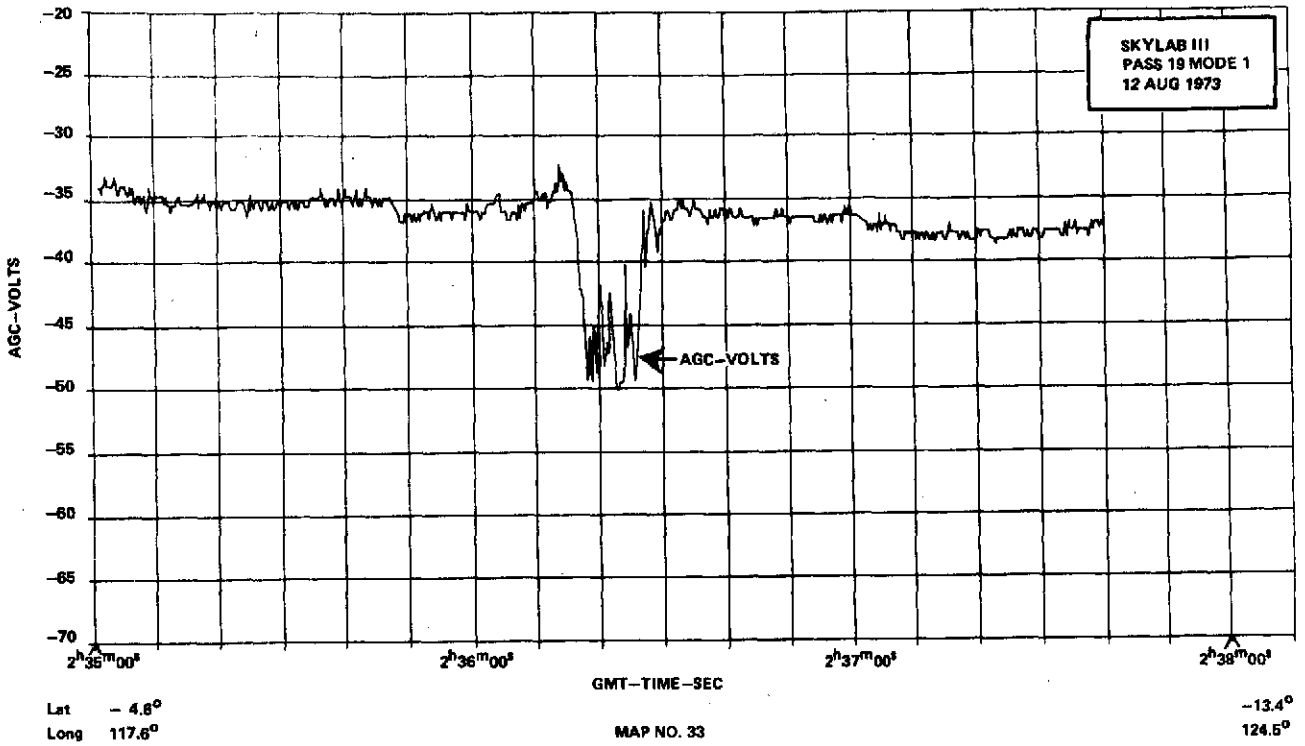
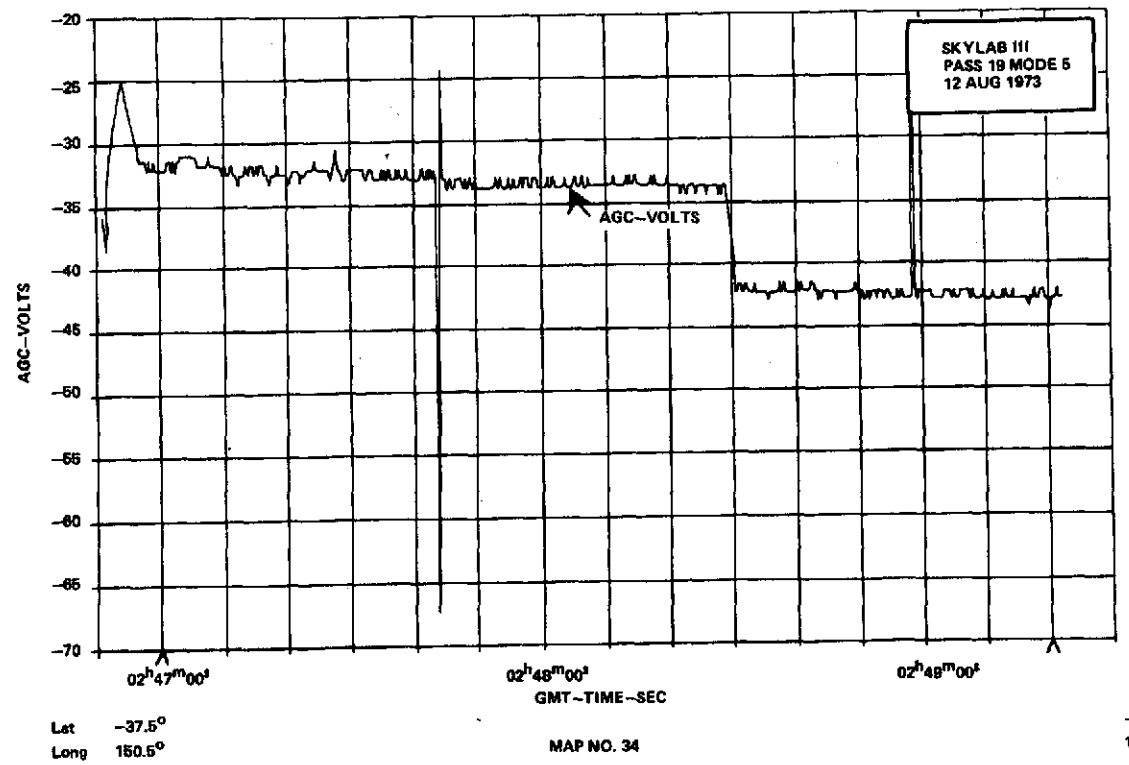


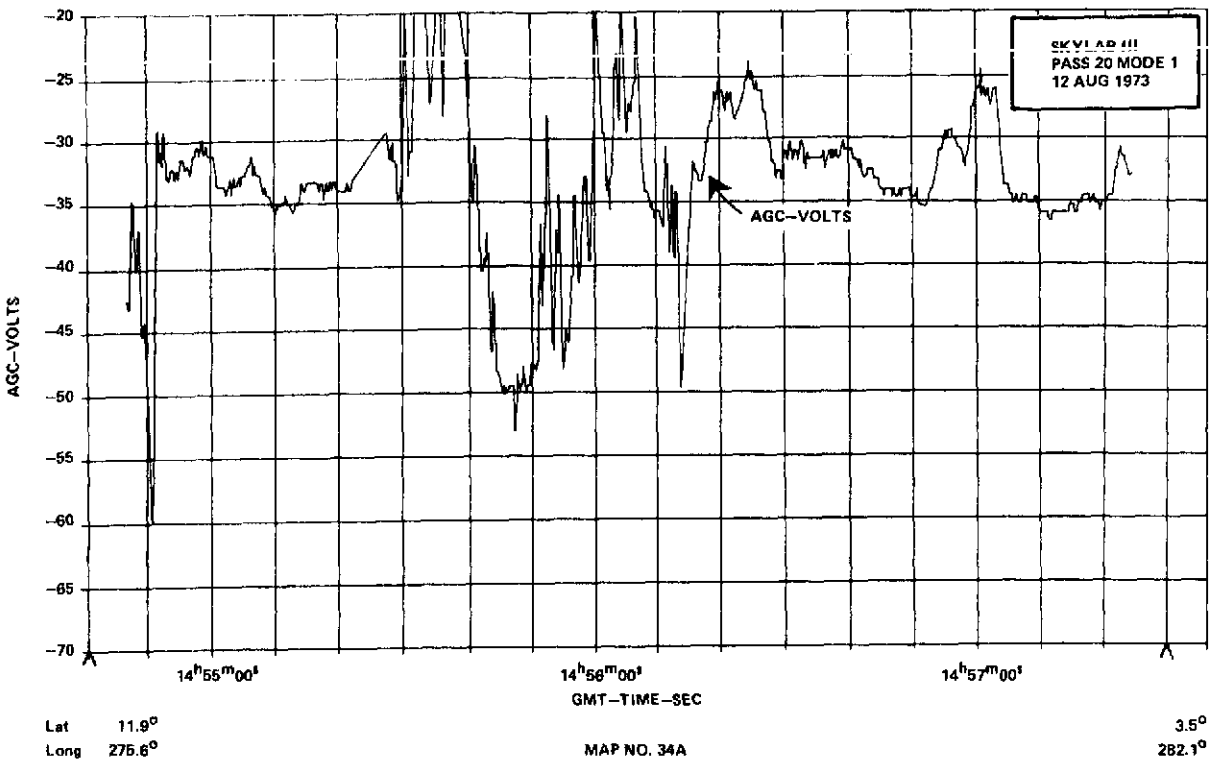
Lat – 4.6° –13.4°
Long 117.6° 124.5°

MAP NO. 33



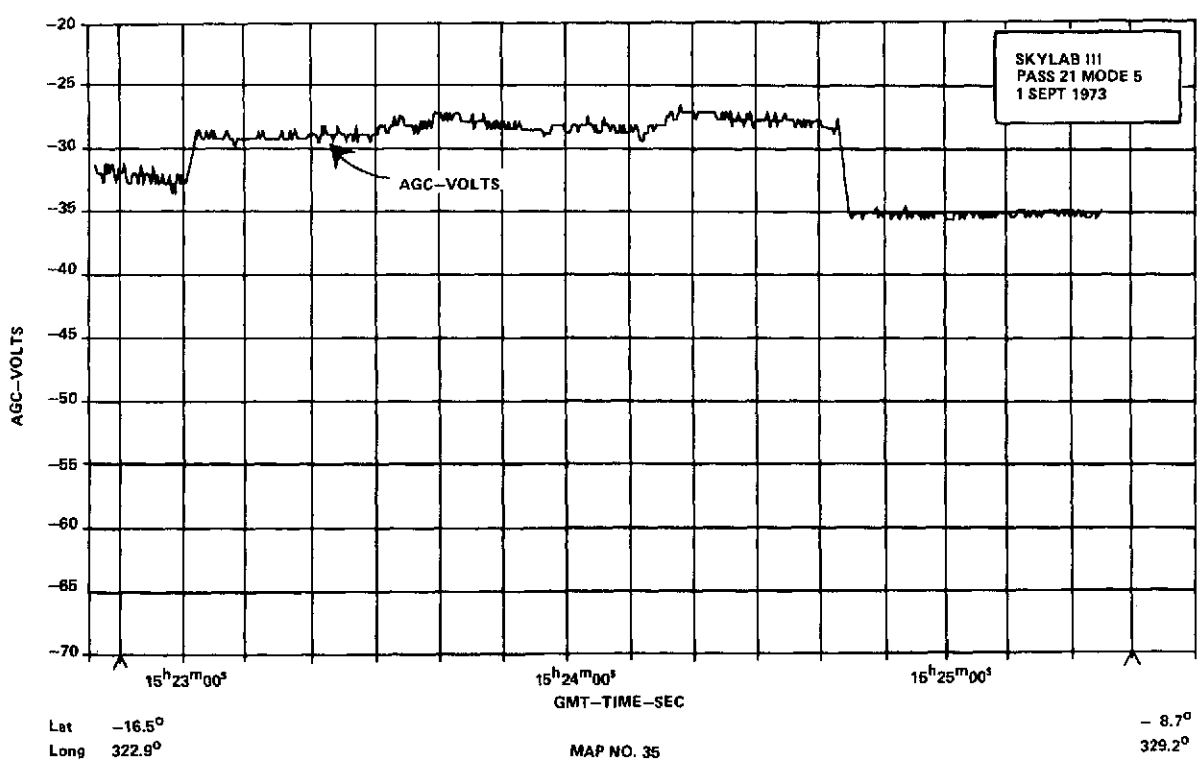
Lat –37.5° –42.4°
Long 150.5° 159.7°

MAP NO. 34



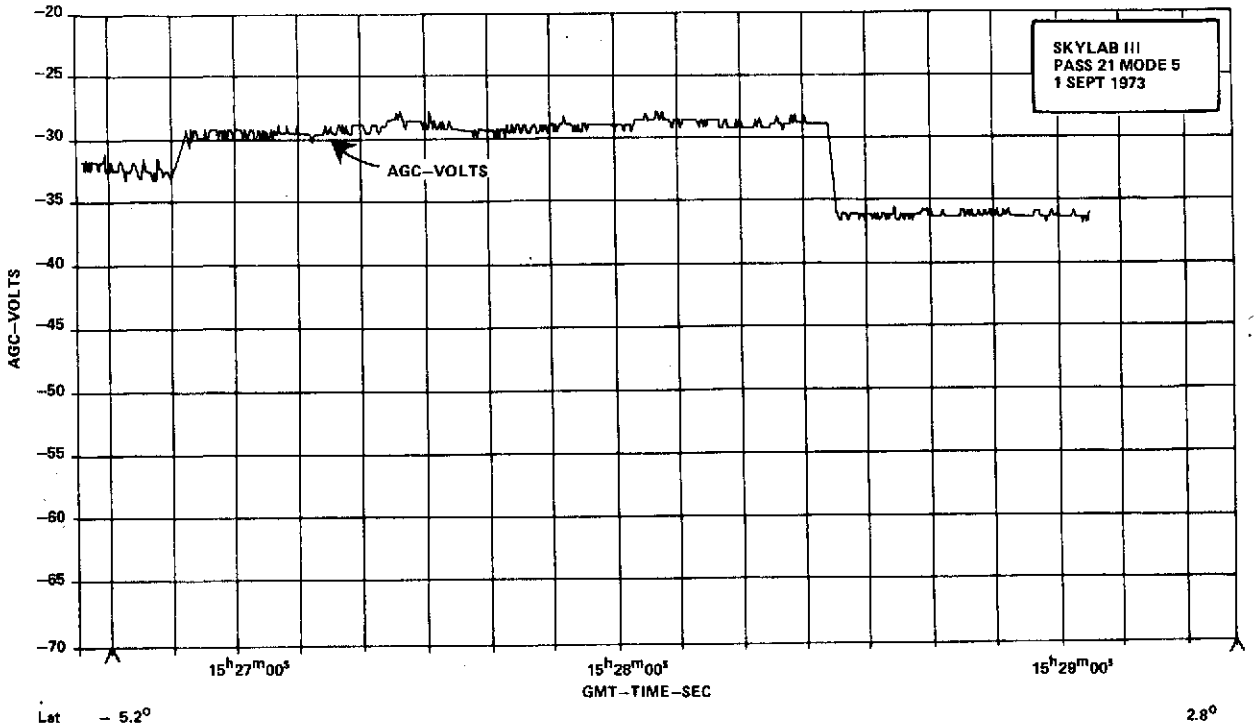
Lat 11.9° 3.5°
Long 275.6° 282.1°

MAP NO. 34A



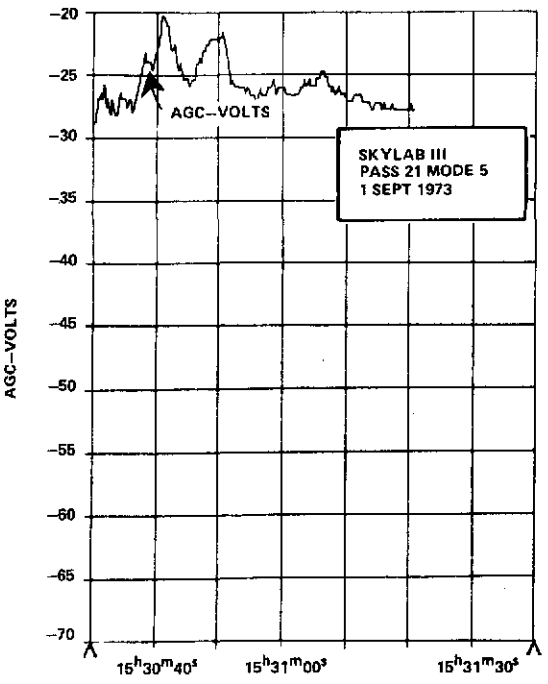
Lat –16.5° – 8.7°
Long 322.9° 329.2°

MAP NO. 35



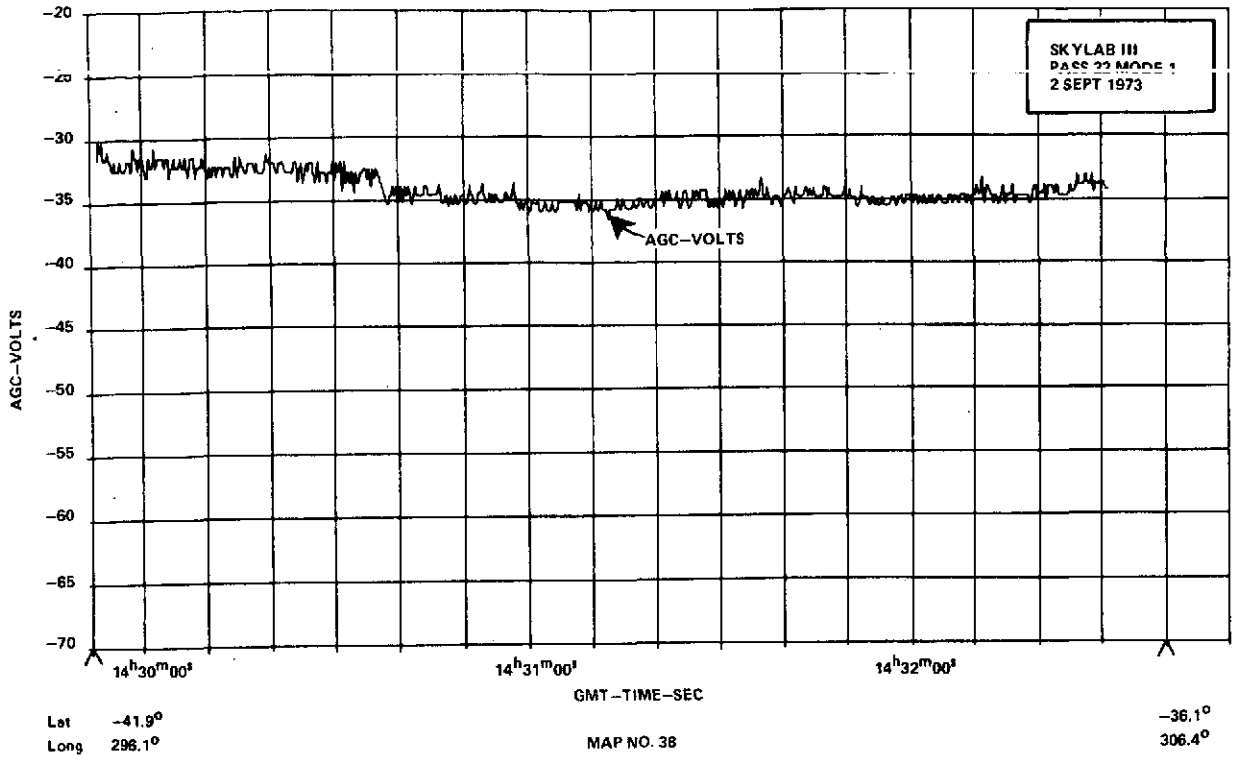
Lat – 5.2° 2.8°
Long 332.2° 337.8°

MAP NO. 36



Lat 5.7° 9.2°
Long 340.0° 342.7°

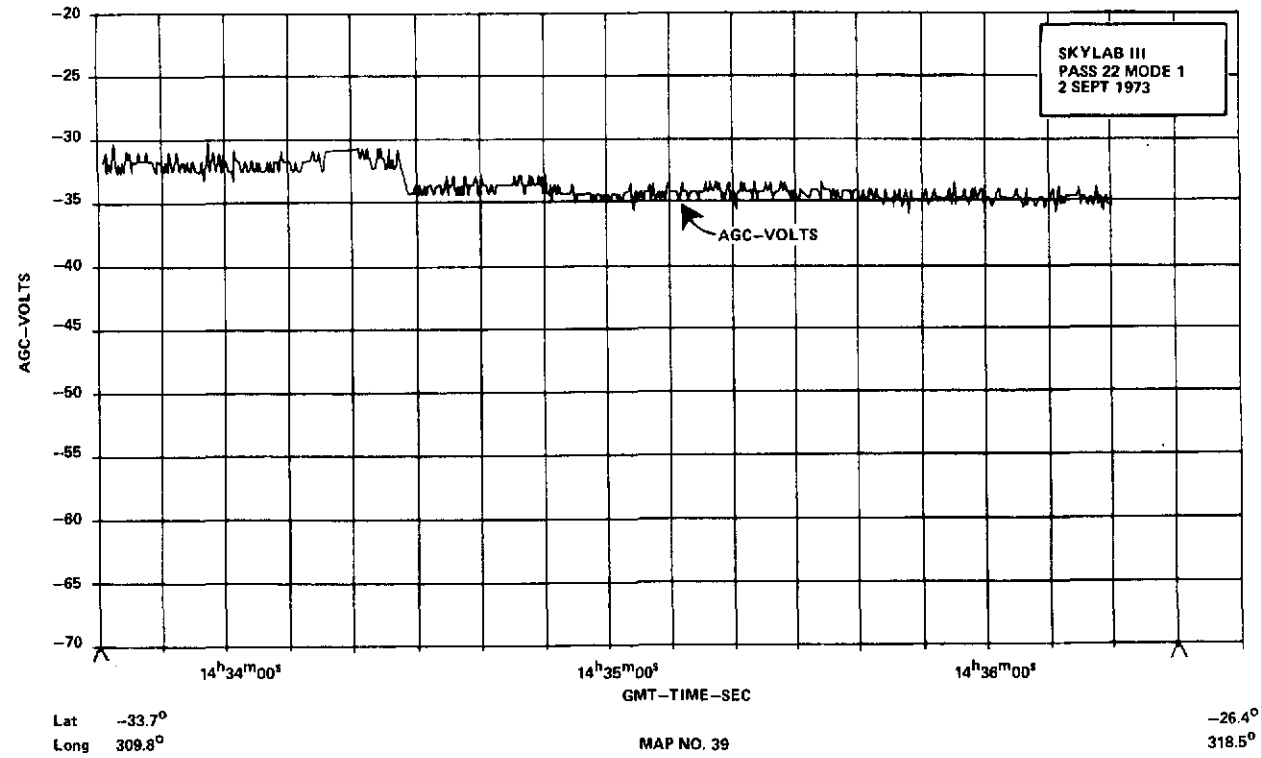
MAP NO. 37



Lat –41.9°
Long 296.1°

MAP NO. 38

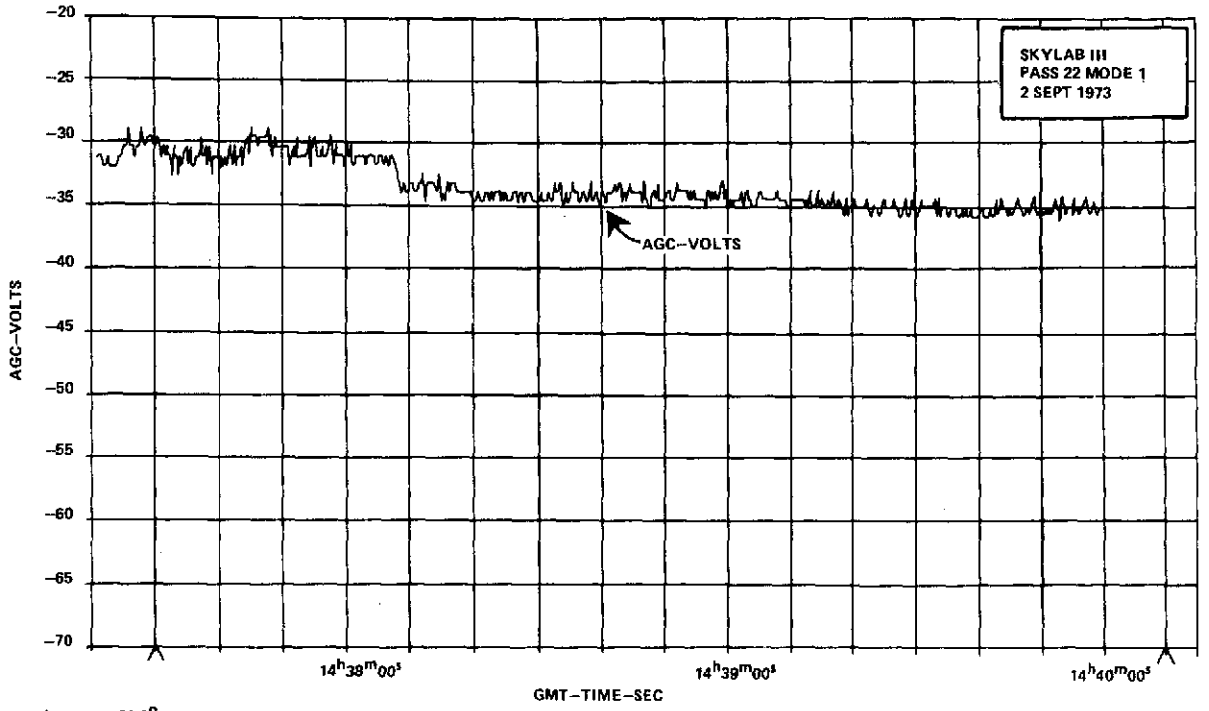
–36.1°
306.4°



Lat –33.7°
Long 309.8°

MAP NO. 39

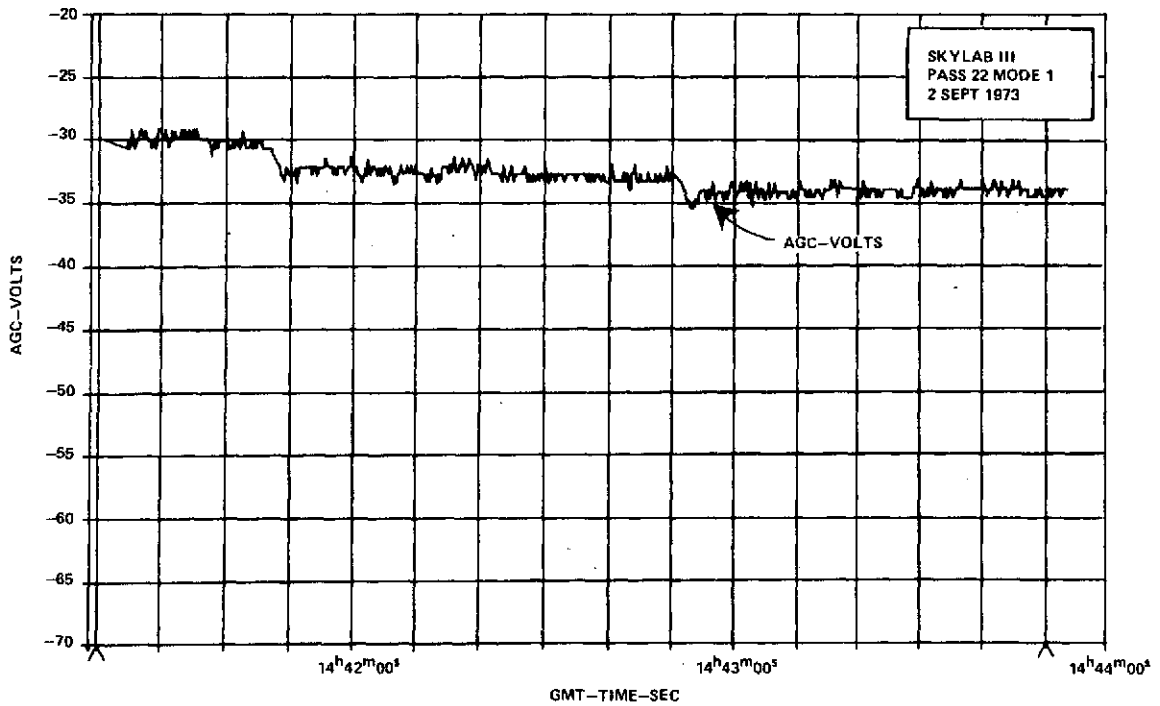
–26.4°
318.5°



Lat −24.1° Long 320.8°

MAP NO. 40

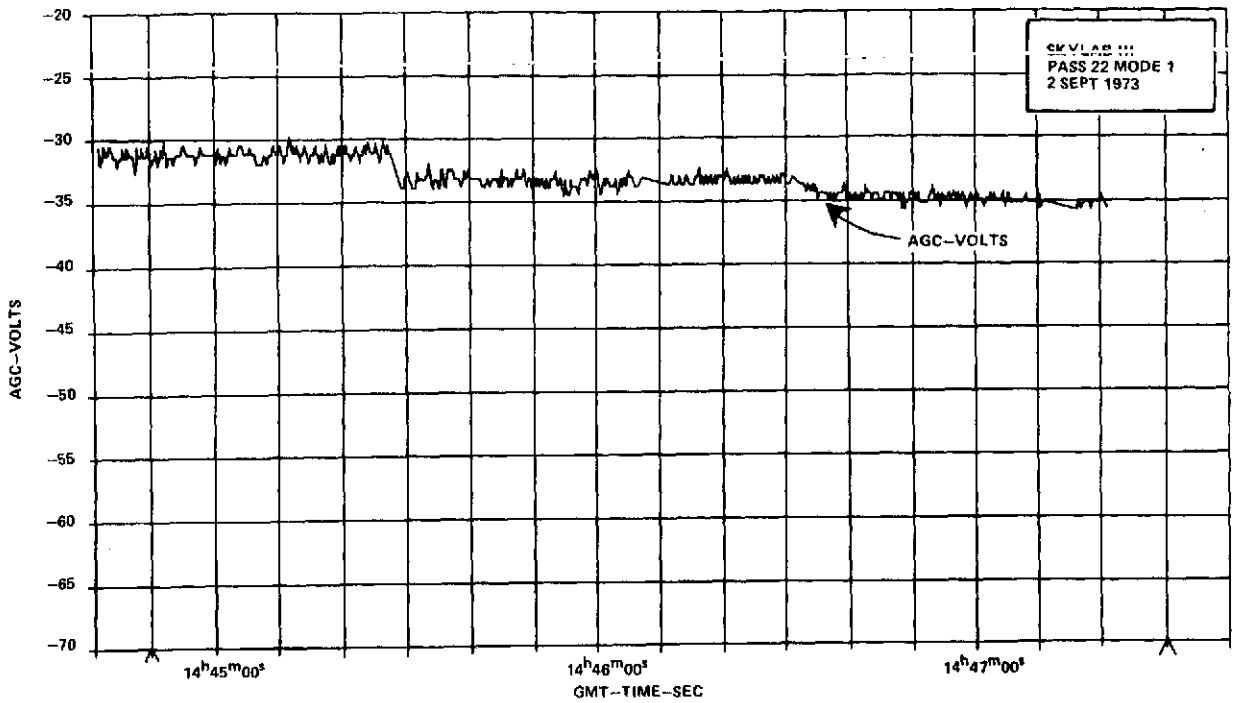
Lat −16.1° Long 328.1°



Lat −12.7° Long 330.9°

MAP NO. 41

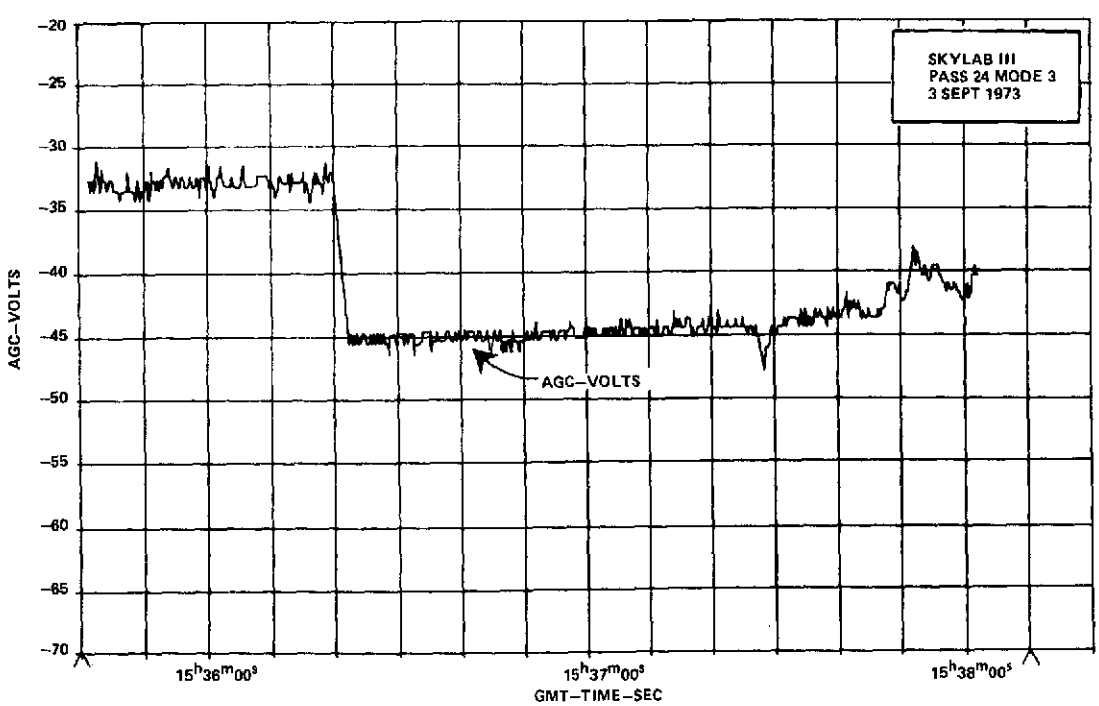
Lat −5.3° Long 336.6°



Lat – 2.3°
Long 338.8°

MAP NO. 42

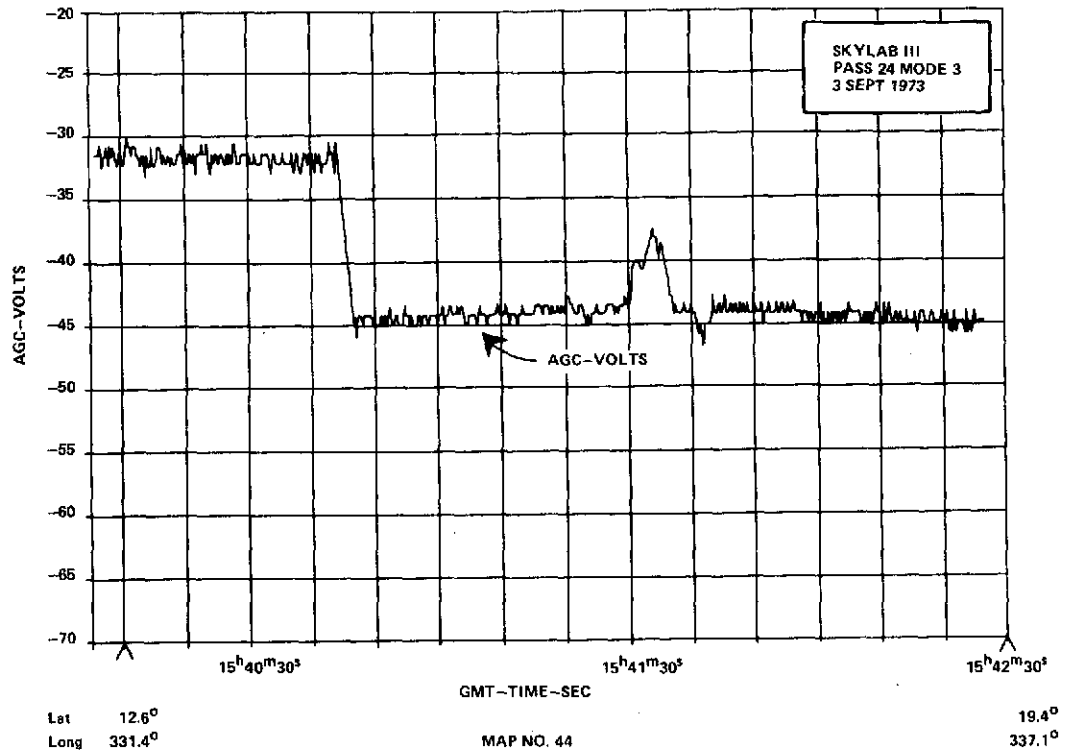
5.7°
334.8°



Lat – 0.7°
Long 321.4°

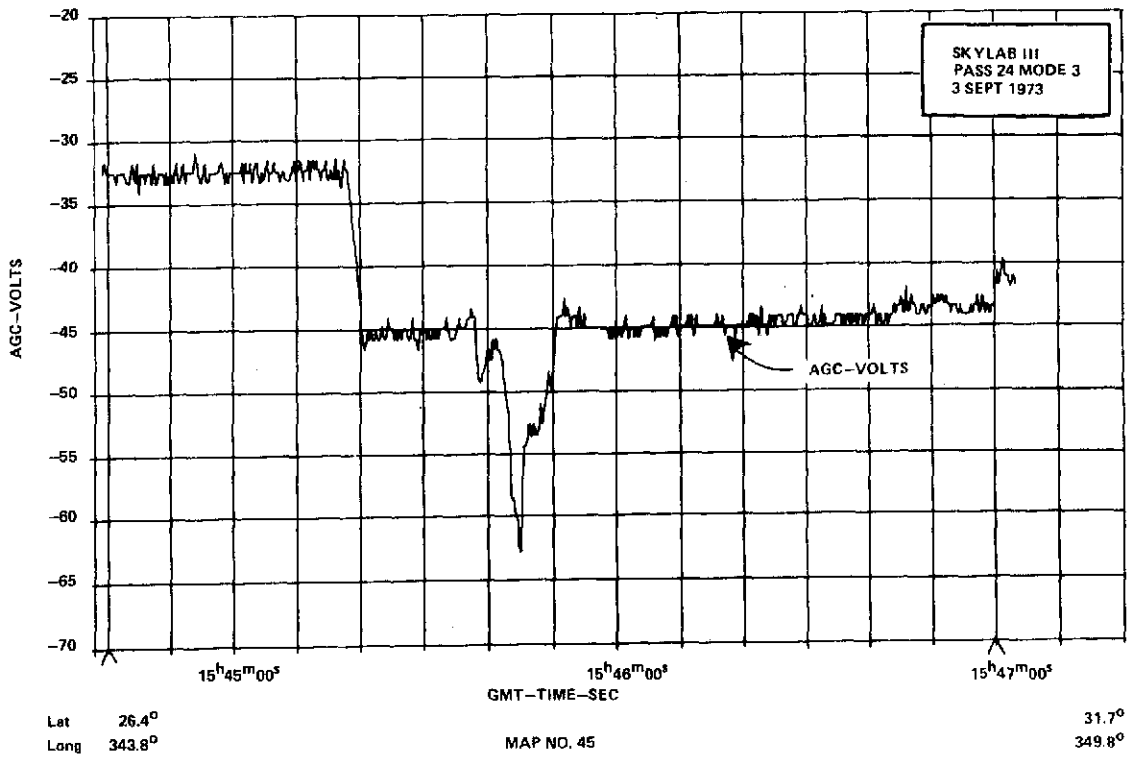
MAP NO. 43

6.7°
326.7°



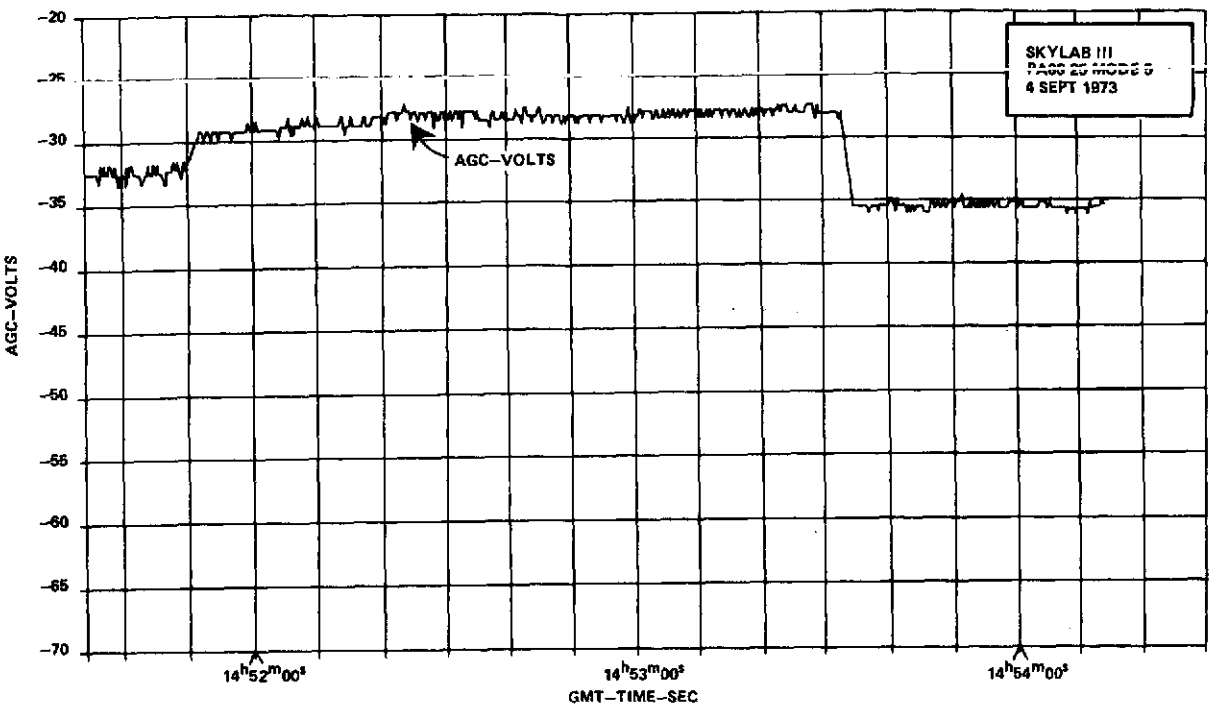
Lat 12.6° 19.4°
Long 331.4° 337.1°

MAP NO. 44



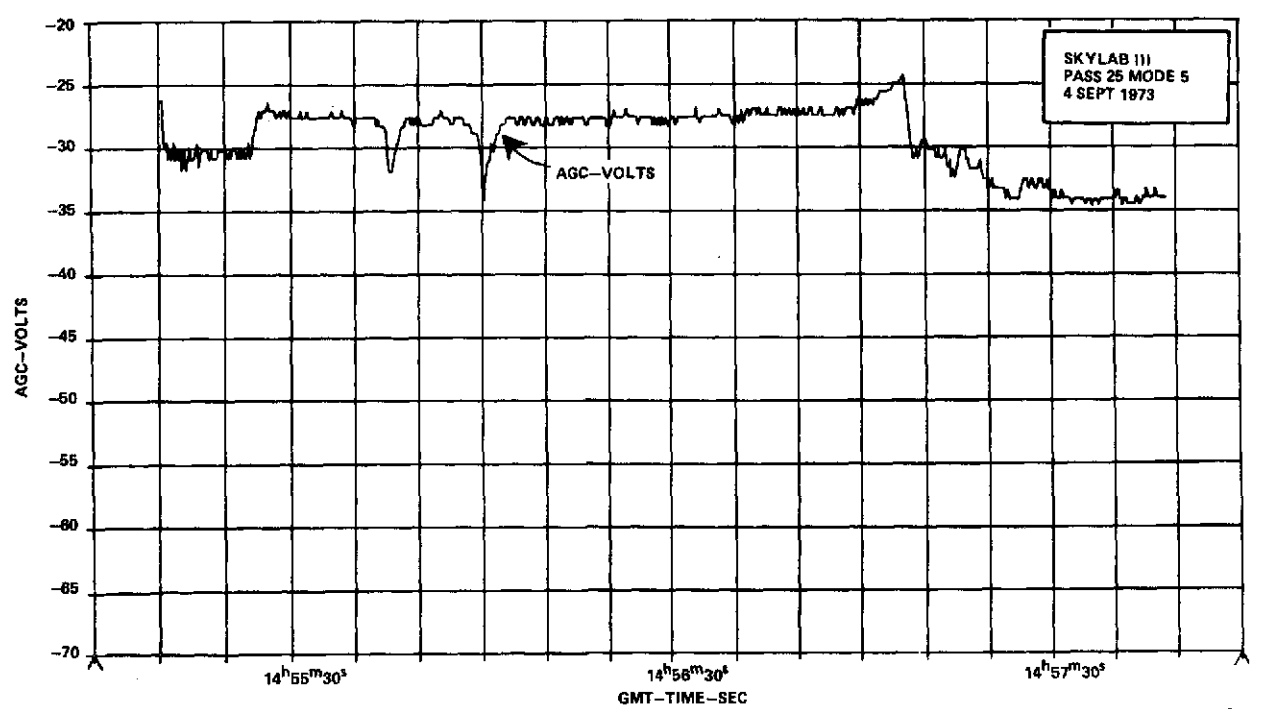
Lat 26.4° 31.7°
Long 343.8° 349.8°

MAP NO. 45



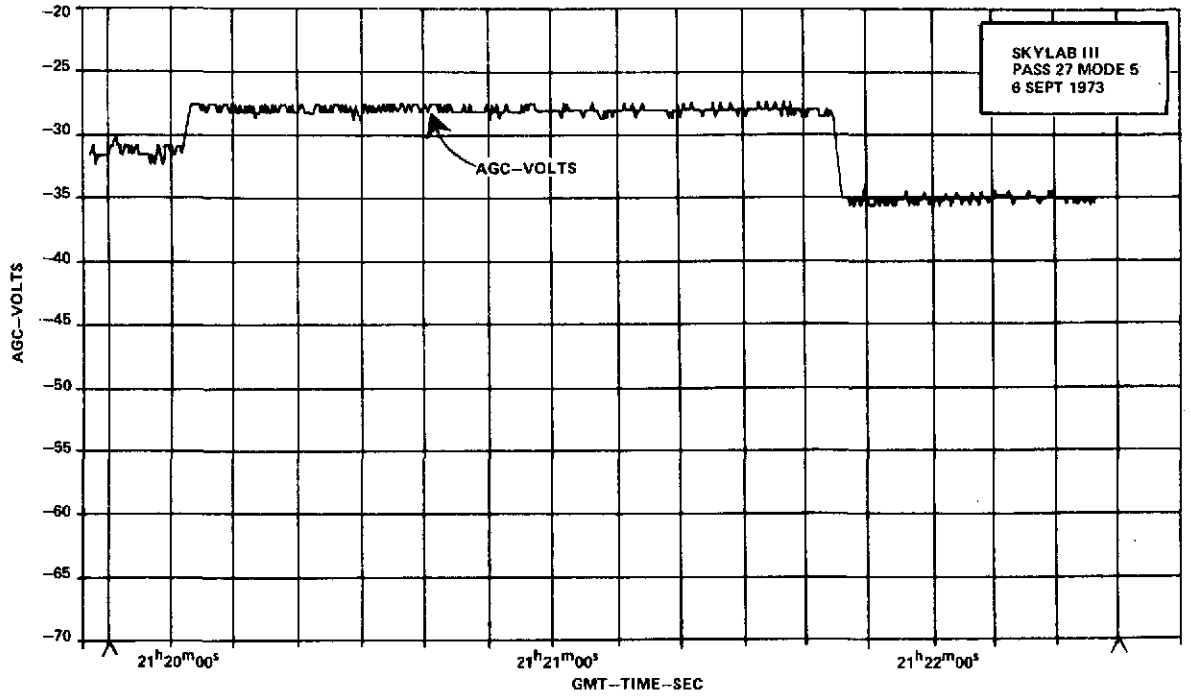
Lat -4.2^{o} 4.2^{o}
Long 323.3^{o} 329.7^{o}

MAP NO. 48



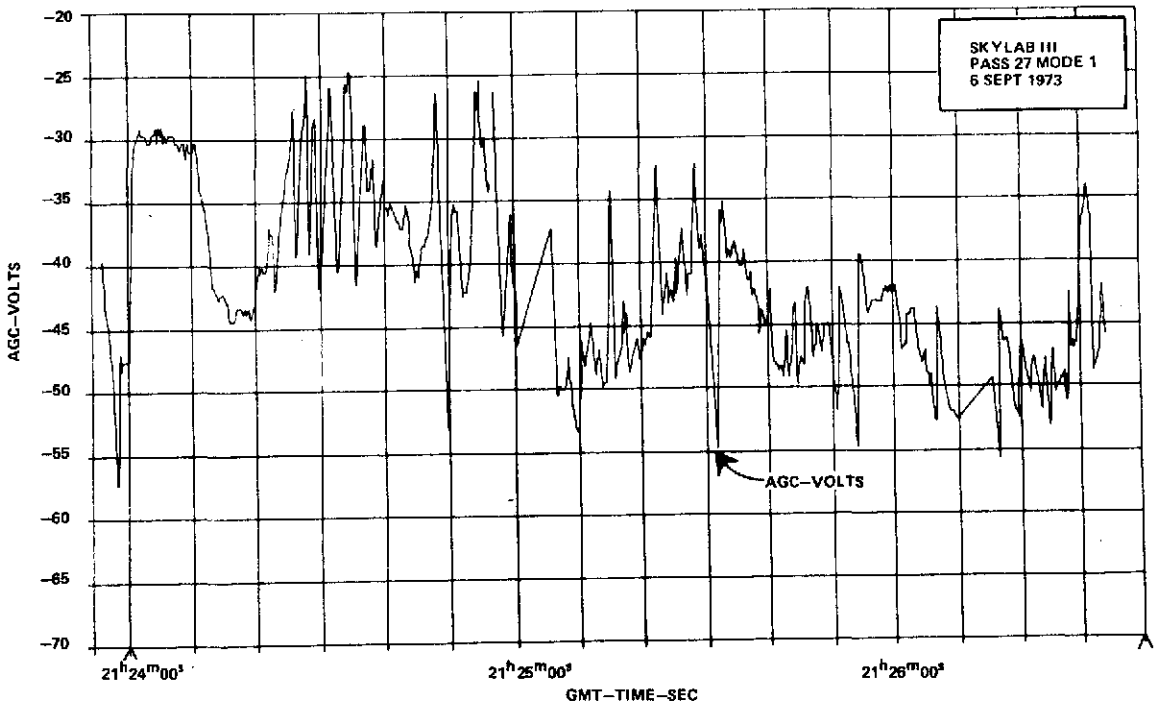
Lat 5.7^{o} 14.6^{o}
Long 330.8^{o} 337.7^{o}

MAP NO. 47



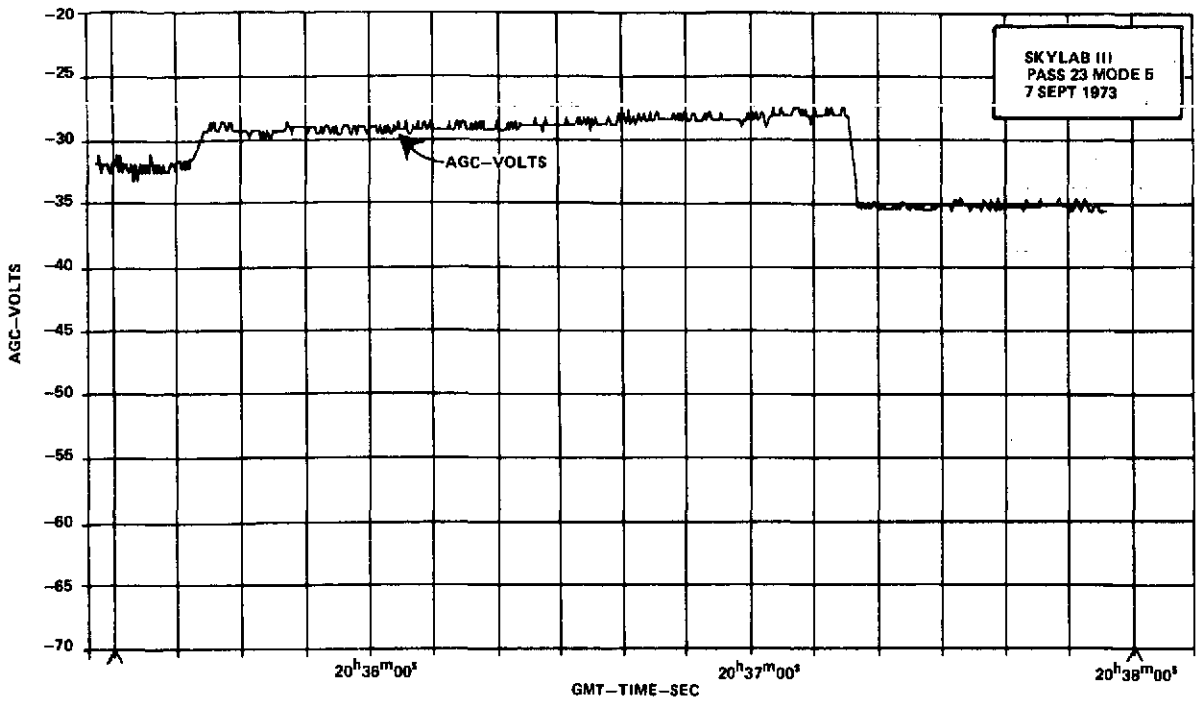
Lat 19.8° 27.6°
Long 233.4° 241.6°

MAP NO. 48



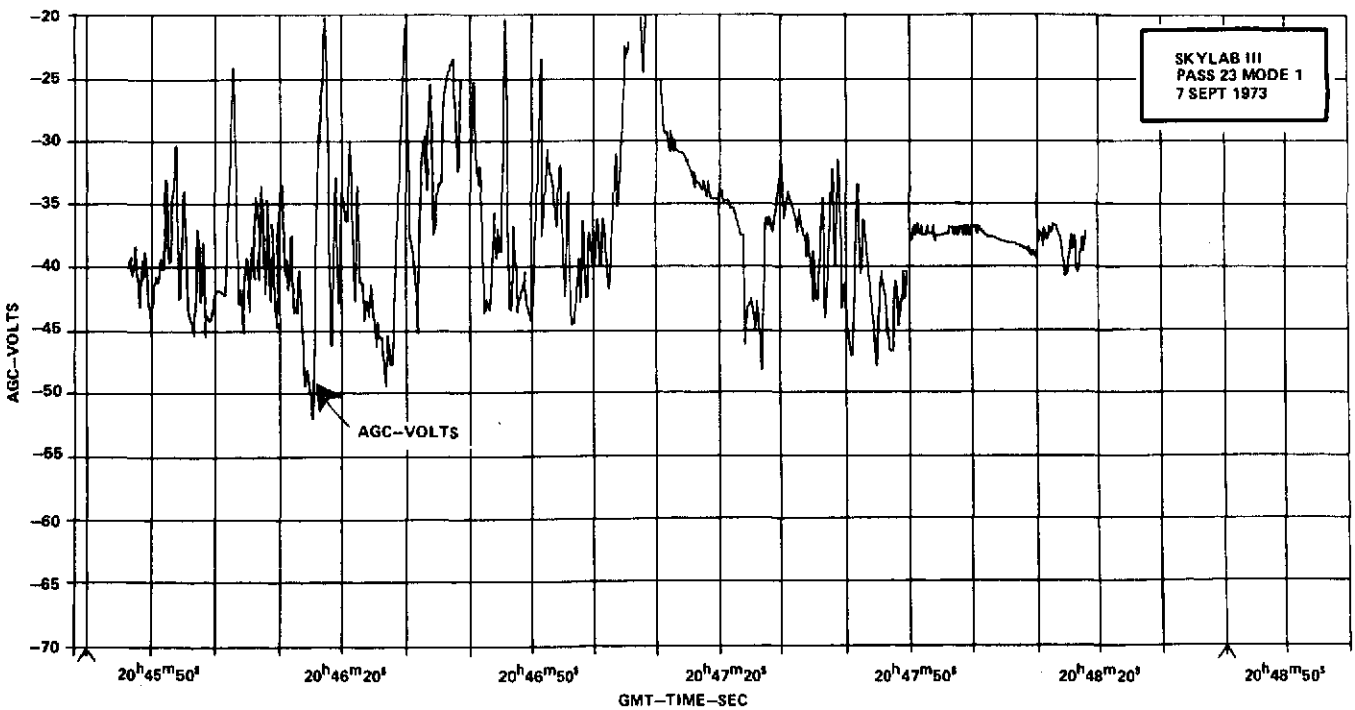
Lat 31.1° 37.6°
Long 245.2° 254.3°

MAP NO. 49



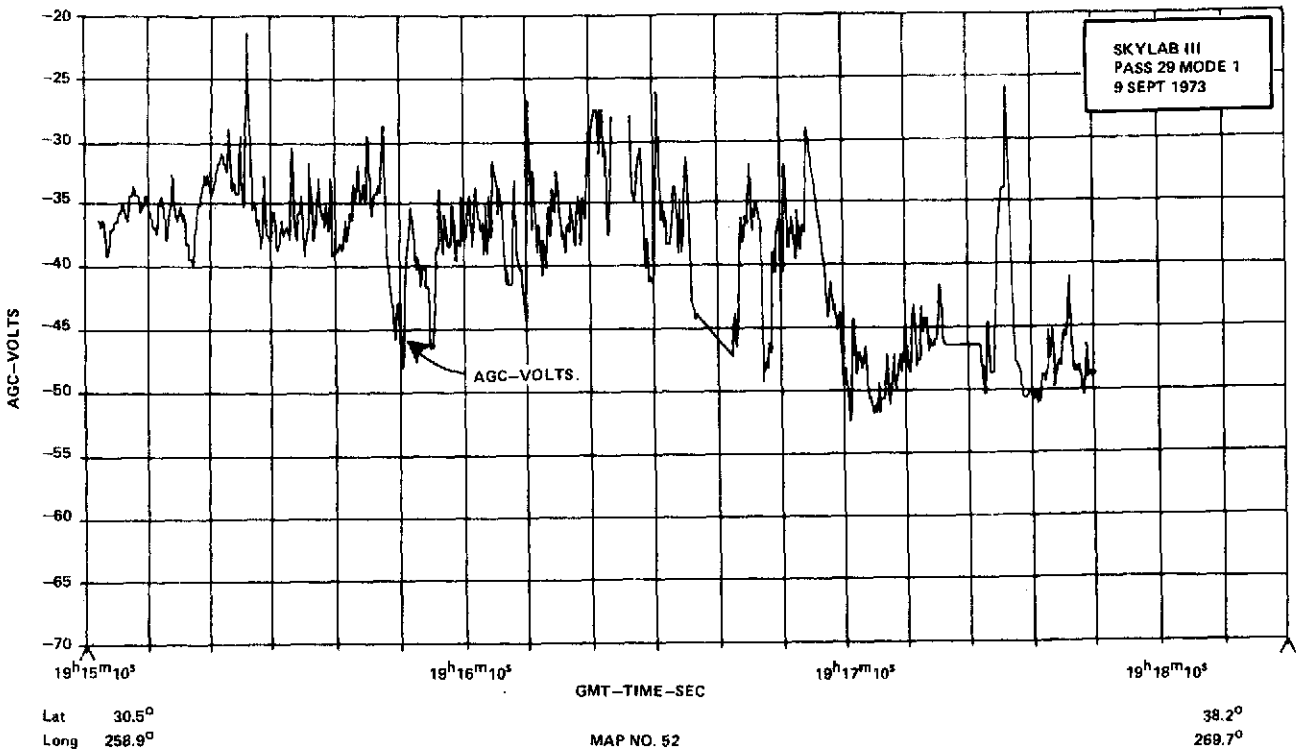
Lat 15.1° 23.1°
Long 234.2° 241.4°

MAP NO. 50

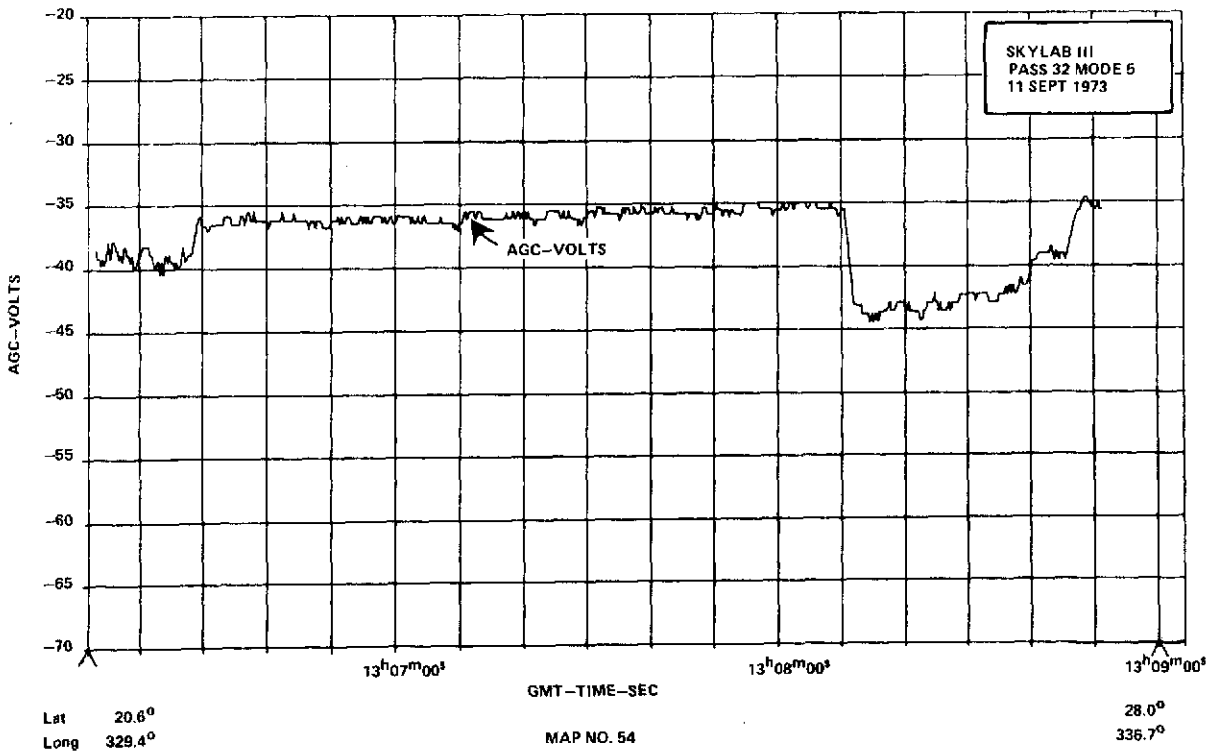


Lat 41.6° 46.8°
Long 266.4° 280.3°

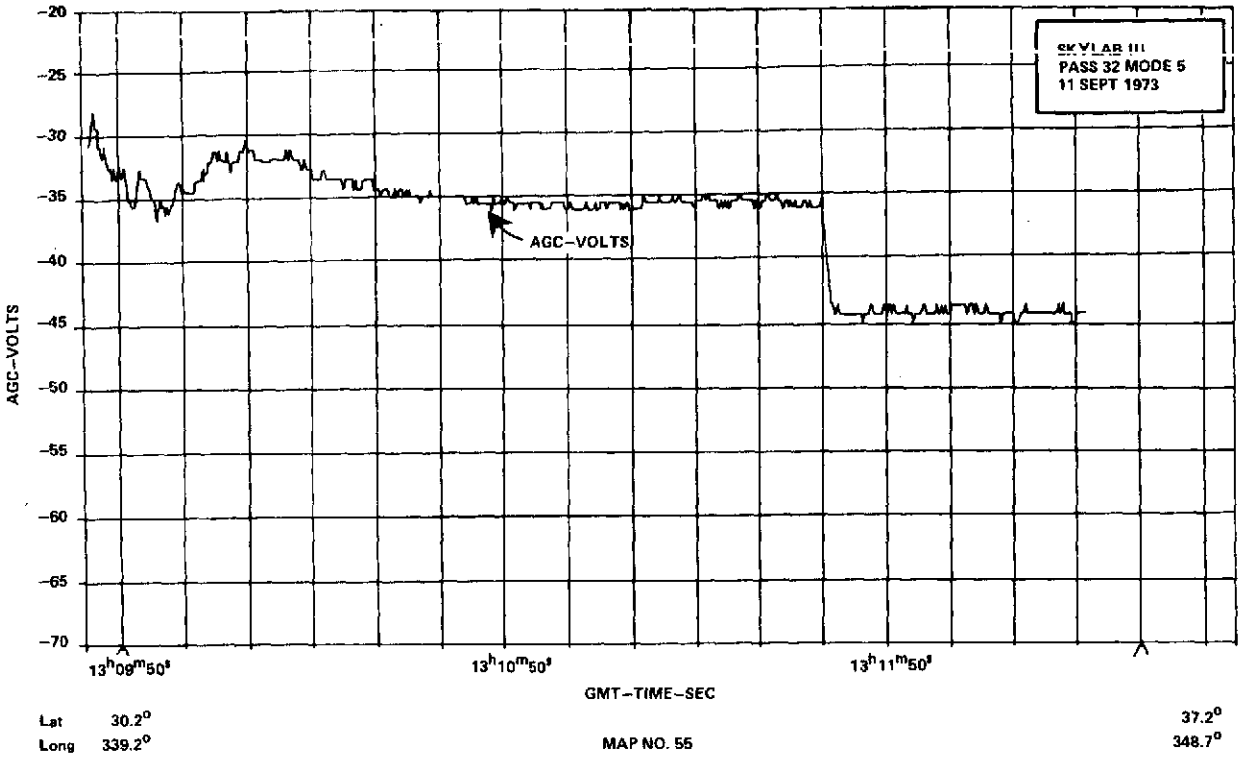
MAP NO. 51

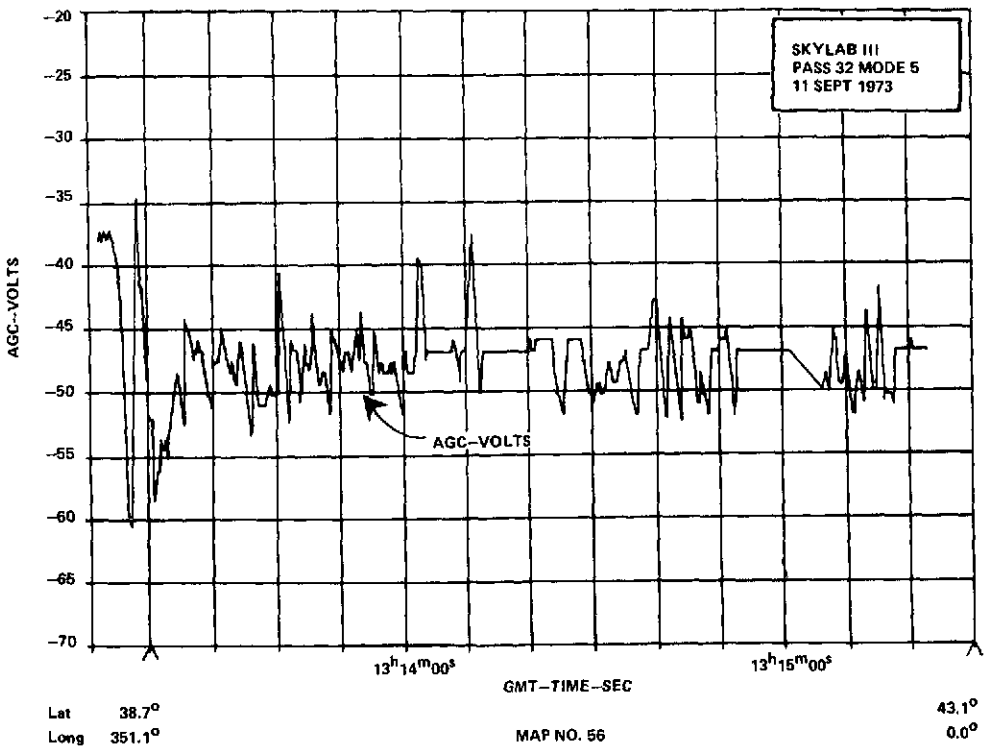


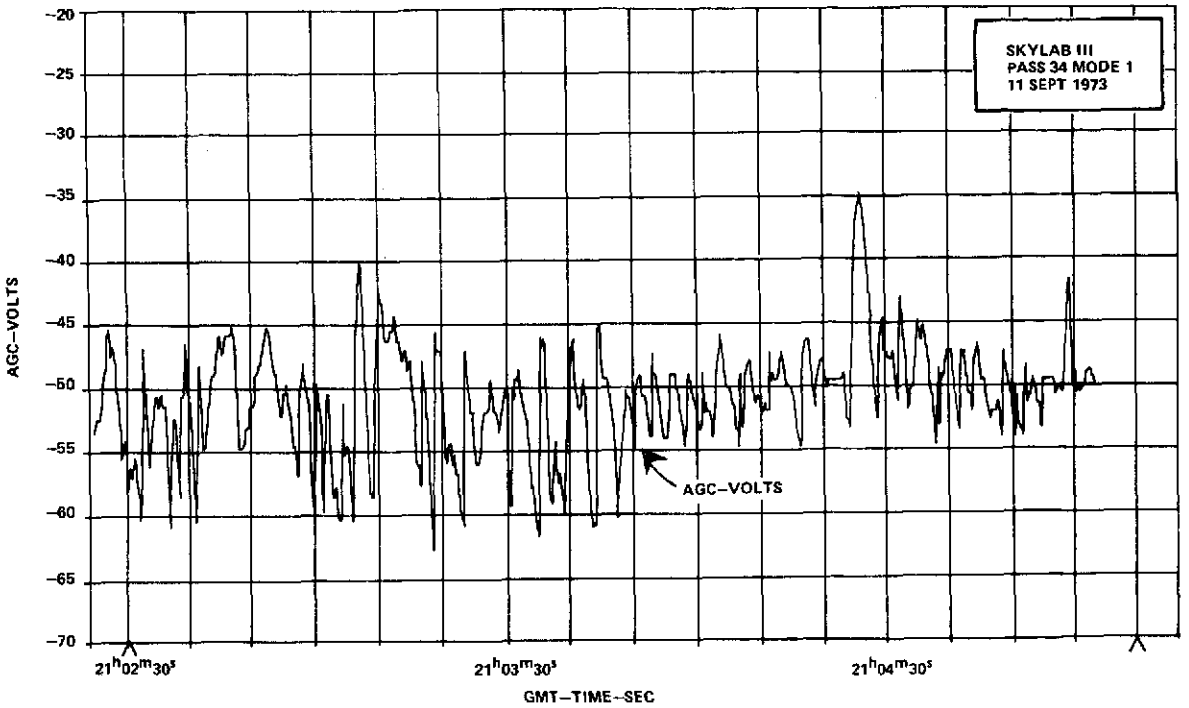
Lat 30.5° 38.2°
Long 258.9° MAP NO. 52 269.7°



Lat 20.6° 28.0°
Long 329.4° MAP NO. 54 336.7°

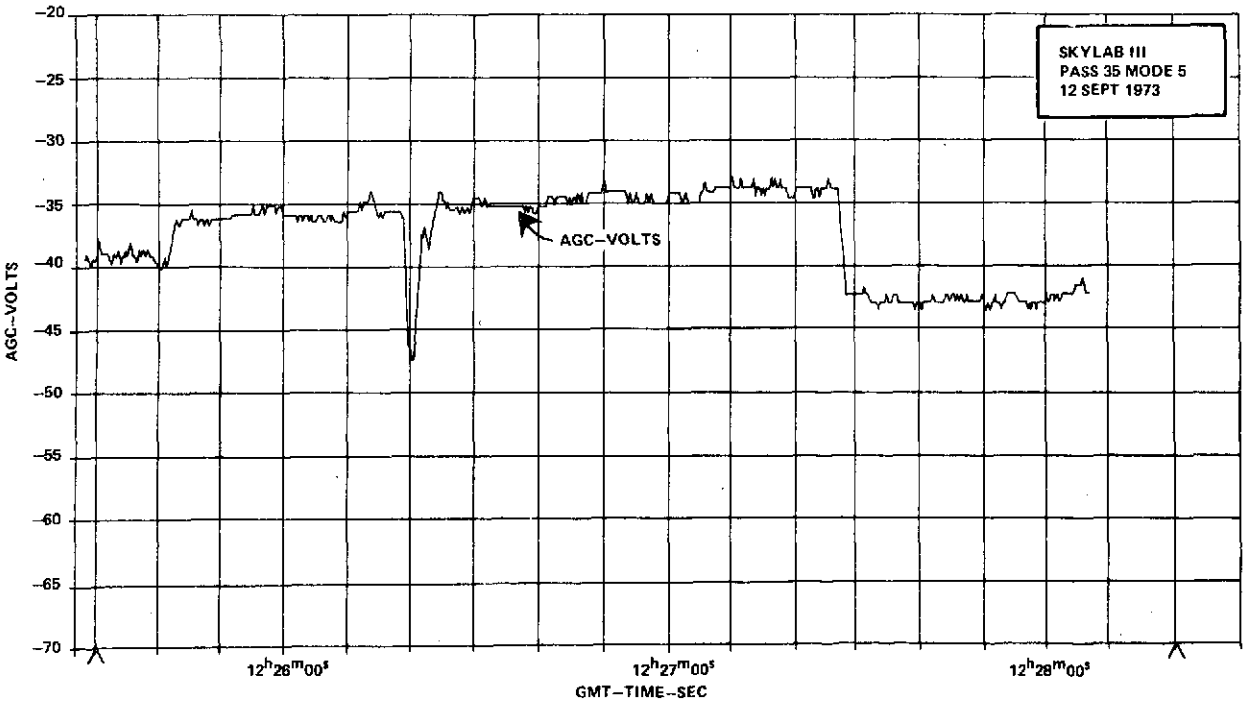

SKYLAB III
PASS 32 MODE 5
11 SEPT 1973
AGC-VOLTS
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
AGC-VOLTS
13h09m50s
13h10m50s
13h11m50s
GMT-TIME-SEC
Lat 30.2°
Long 339.2°
MAP NO. 55
37.2°
348.7°


SKYLAB III
PASS 32 MODE 5
11 SEPT 1973
AGC-VOLTS
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
AGC-VOLTS
13h14m00s
13h15m00s
GMT-TIME-SEC
Lat 38.7°
Long 351.1°
MAP NO. 56
43.1°
0.0°



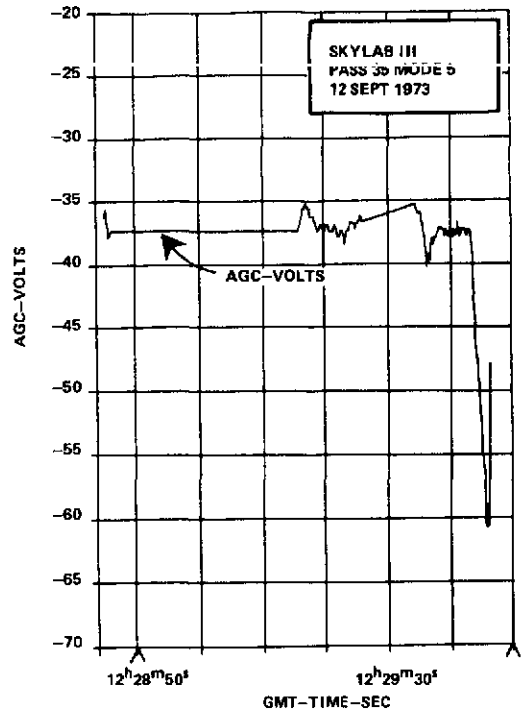
Lat −23.7° −31.7°
Long 23.7° 28.6°

MAP NO. 57

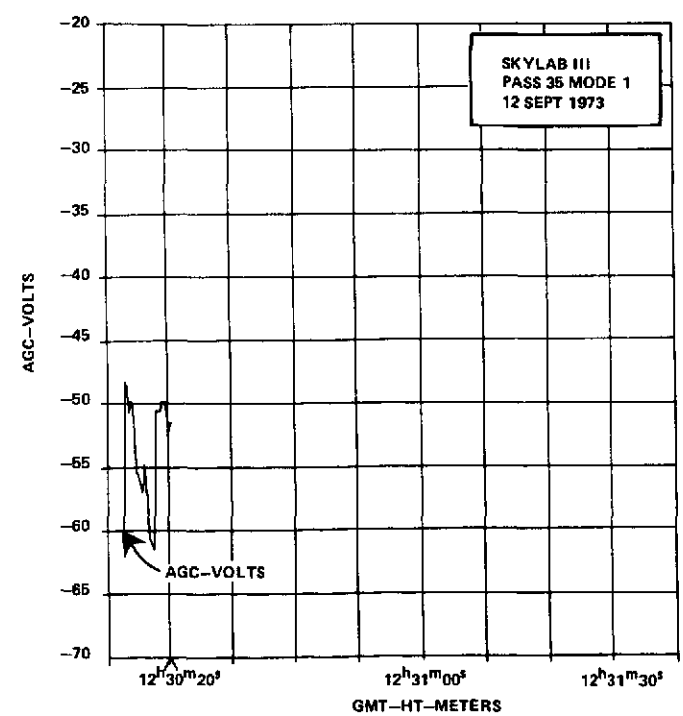


Lat 24.9° 32.4°
Long 338.2° 346.6°

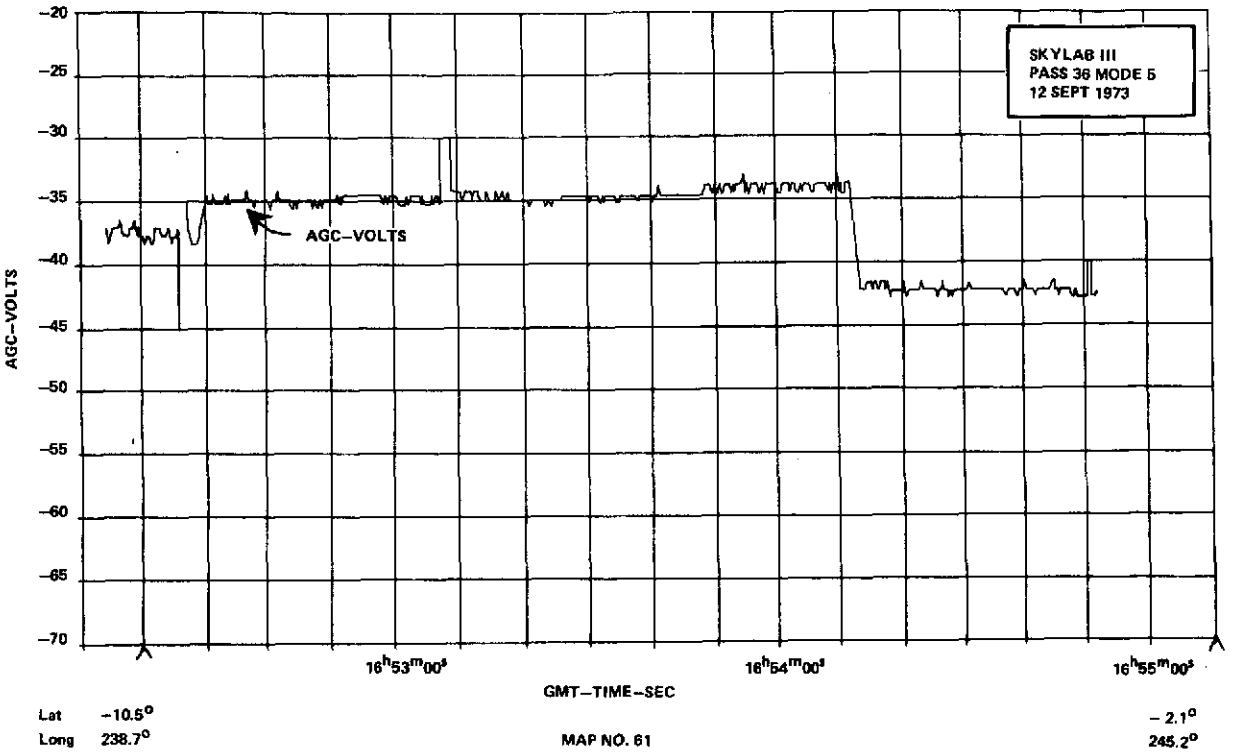
MAP NO. 58



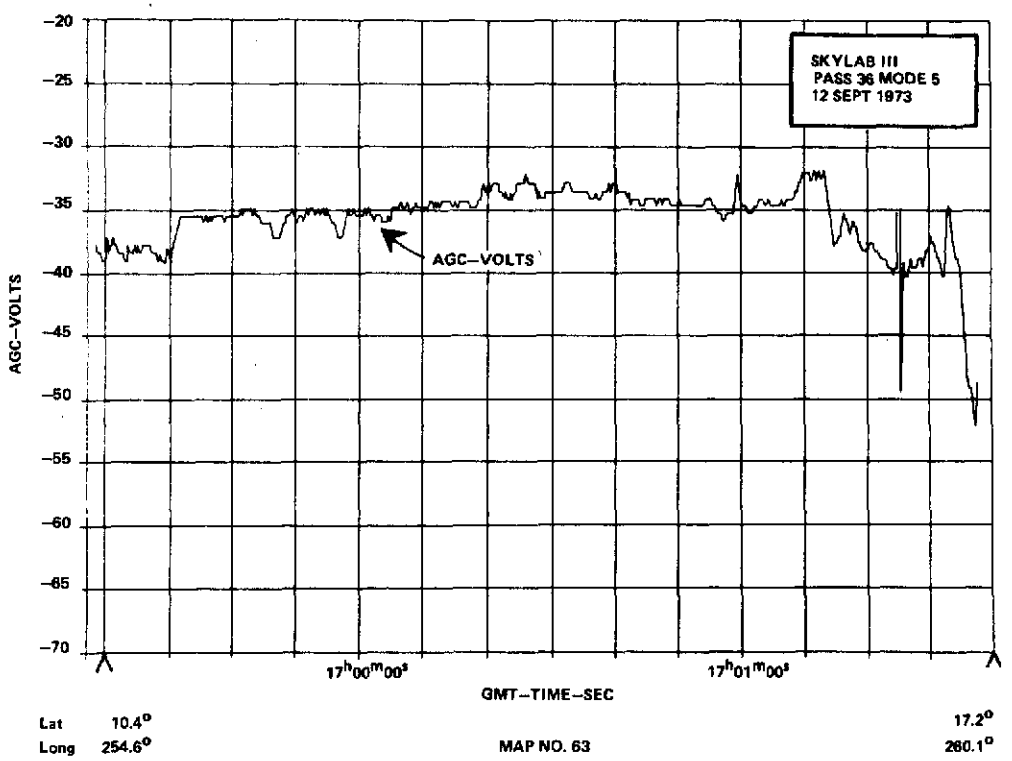
Lat 33.6° 36.0°
Long 348.3° MAP NO. 59 351.7°



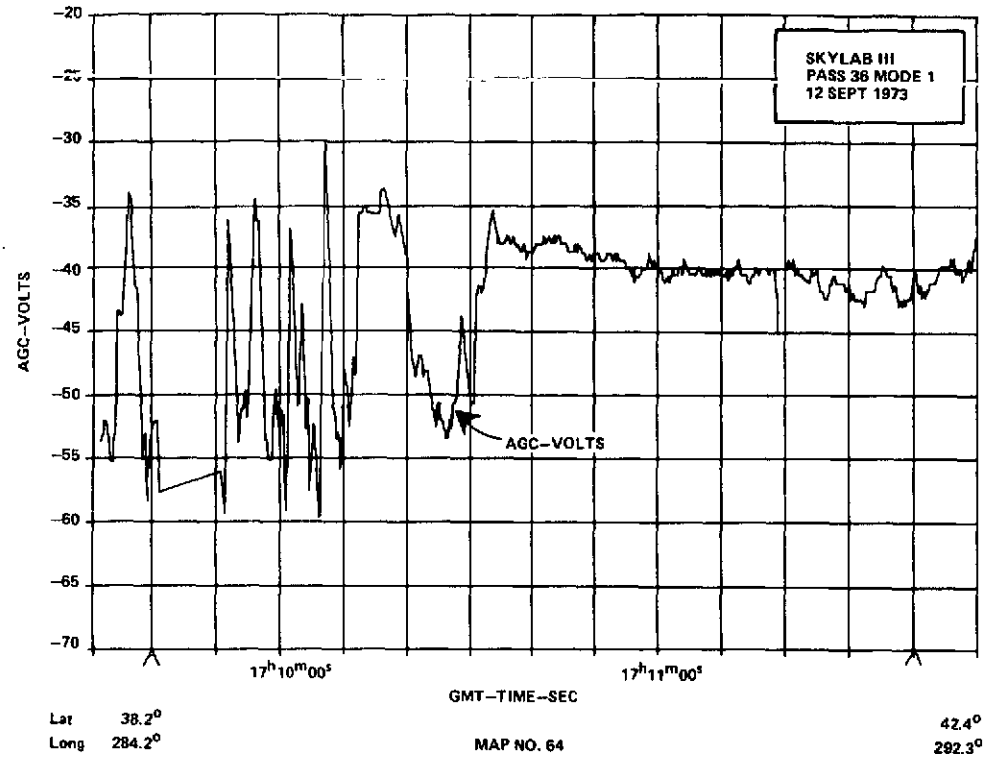
Lat 37.2° 38.8°
Long 353.4° MAP NO. 60 357.8°



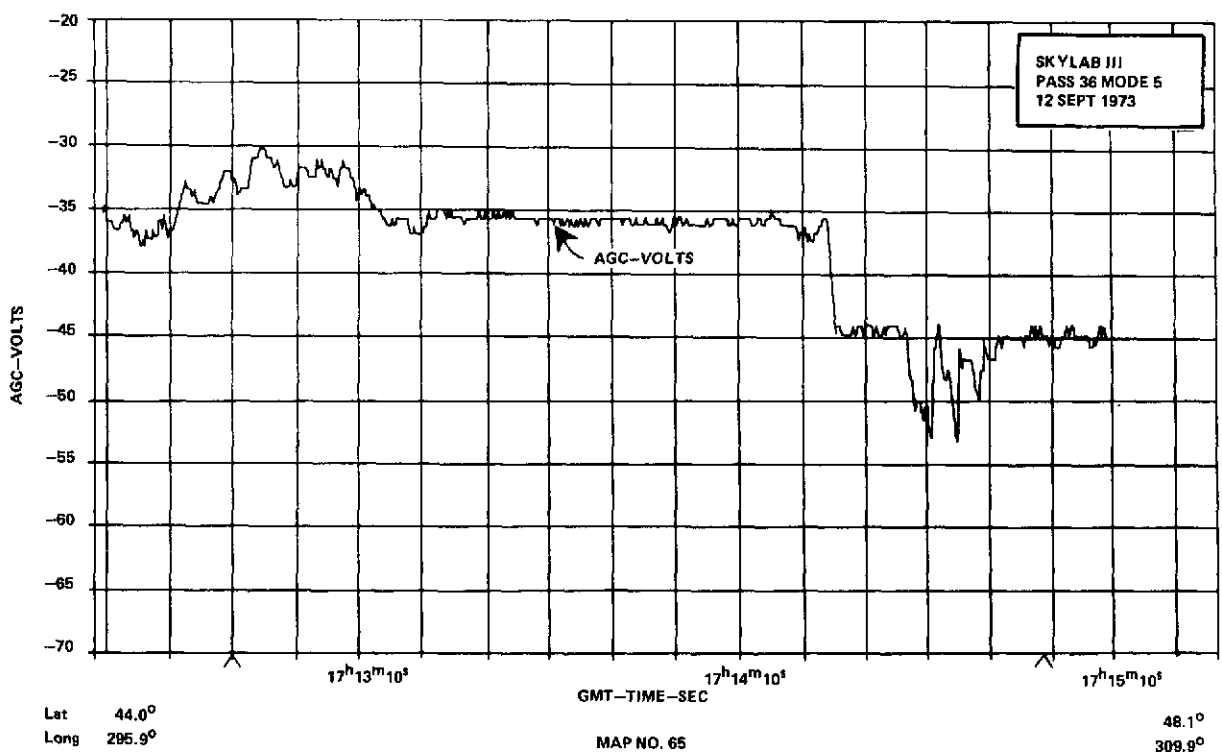
MAP NO. 61



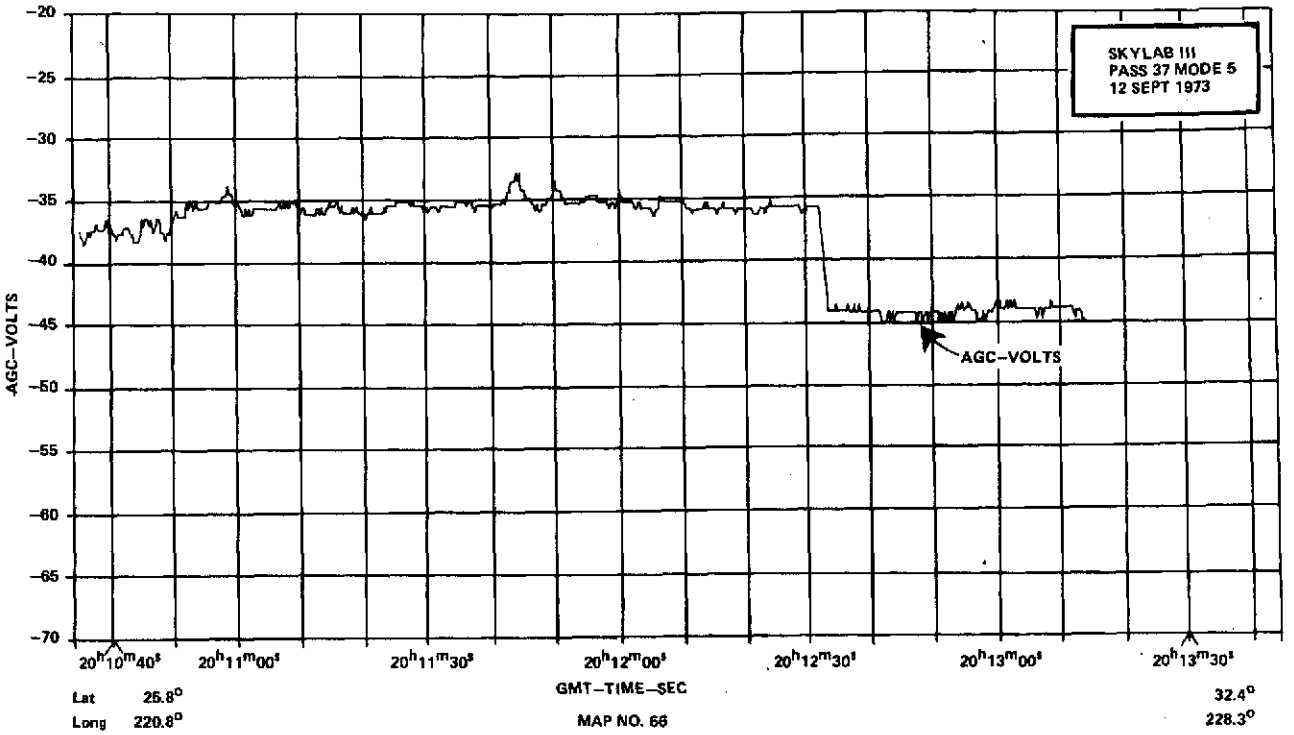
MAP NO. 63



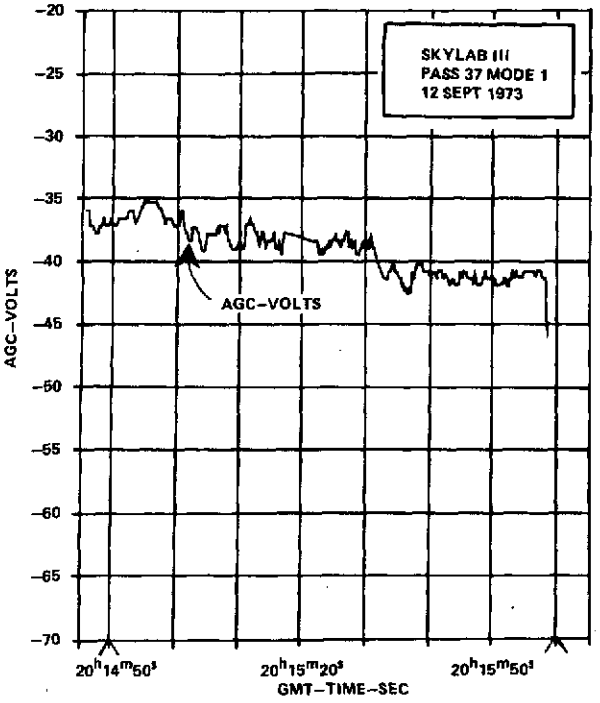
MAP NO. 64



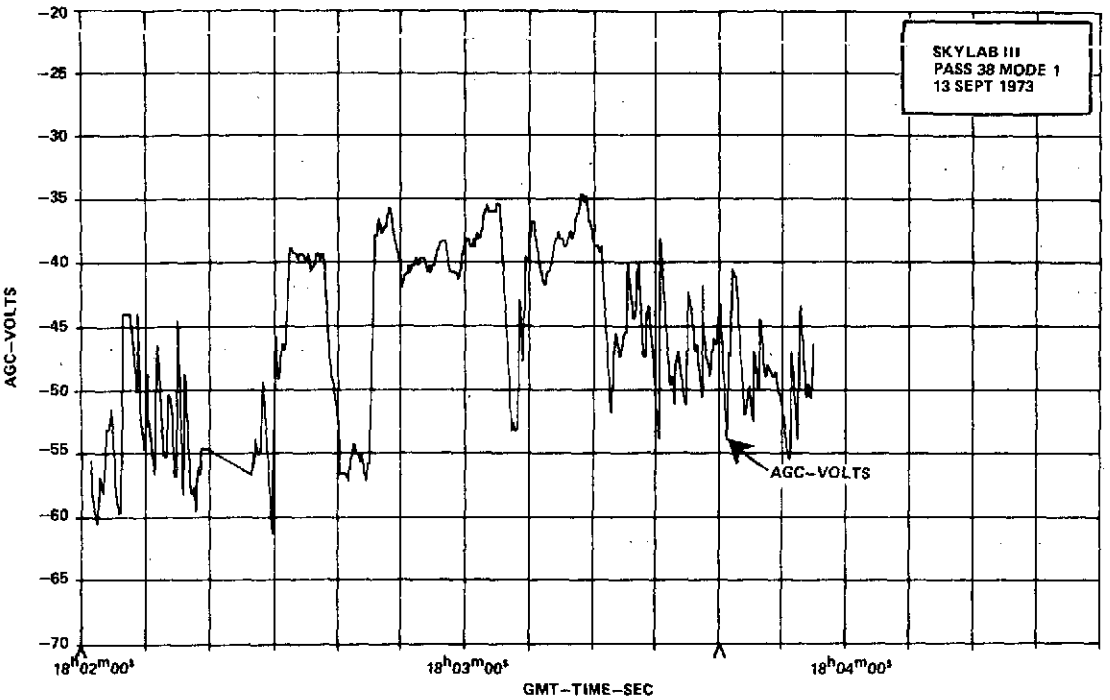
MAP NO. 65



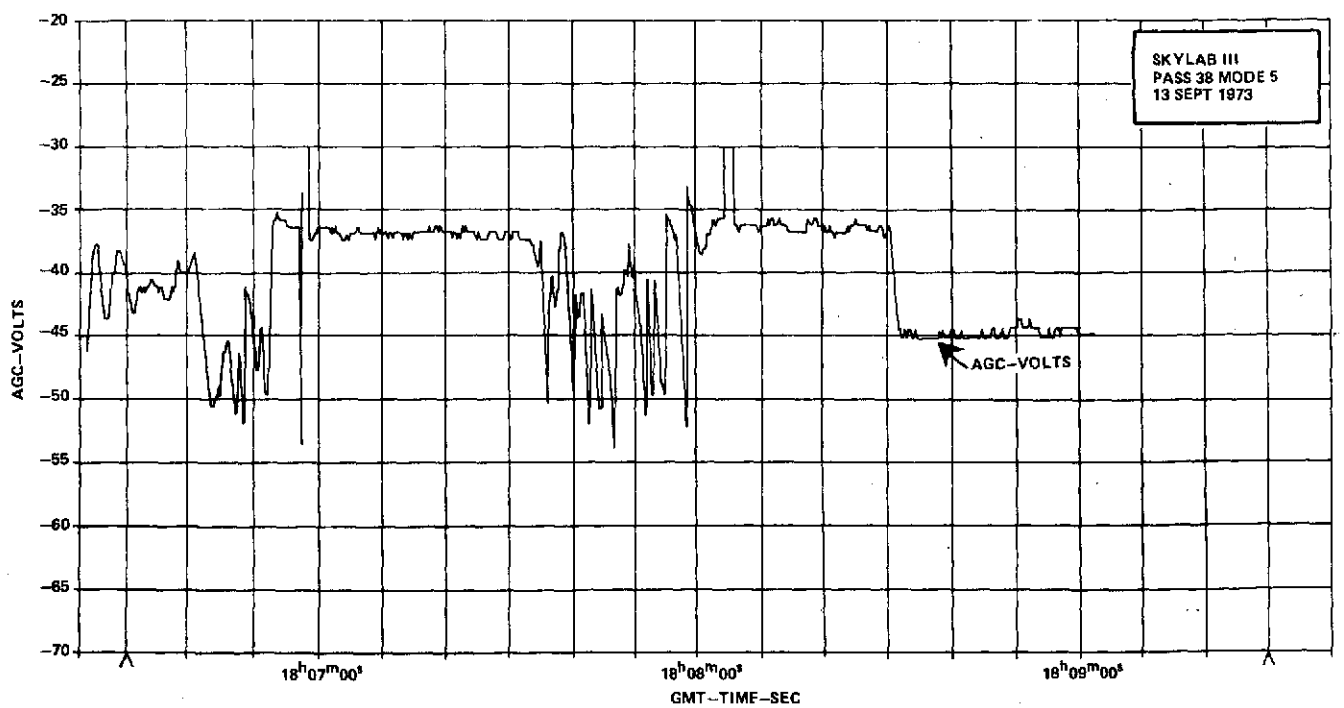
MAP NO. 66



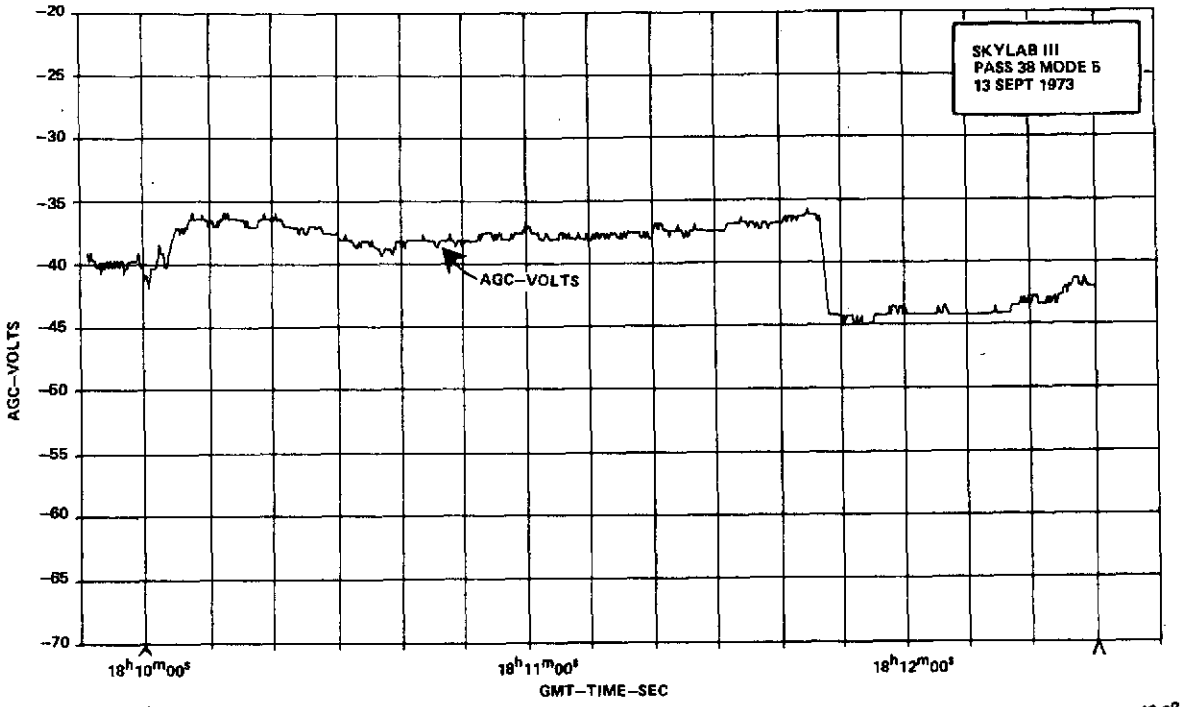
MAP NO. 67



Lat 42.6° 45.5°
Long 273.8° MAP NO. 69 281.4°

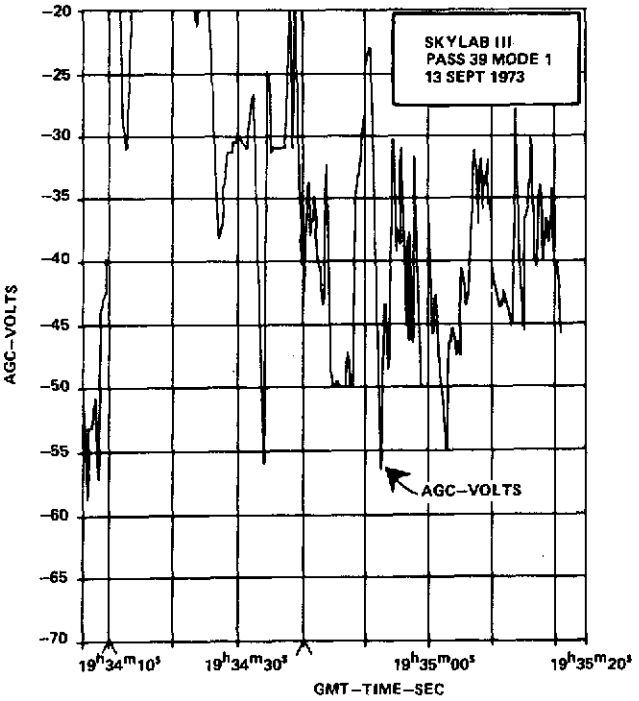


Lat 49.0° 50.2°
Long 296.0° MAP NO. 70 312.1°



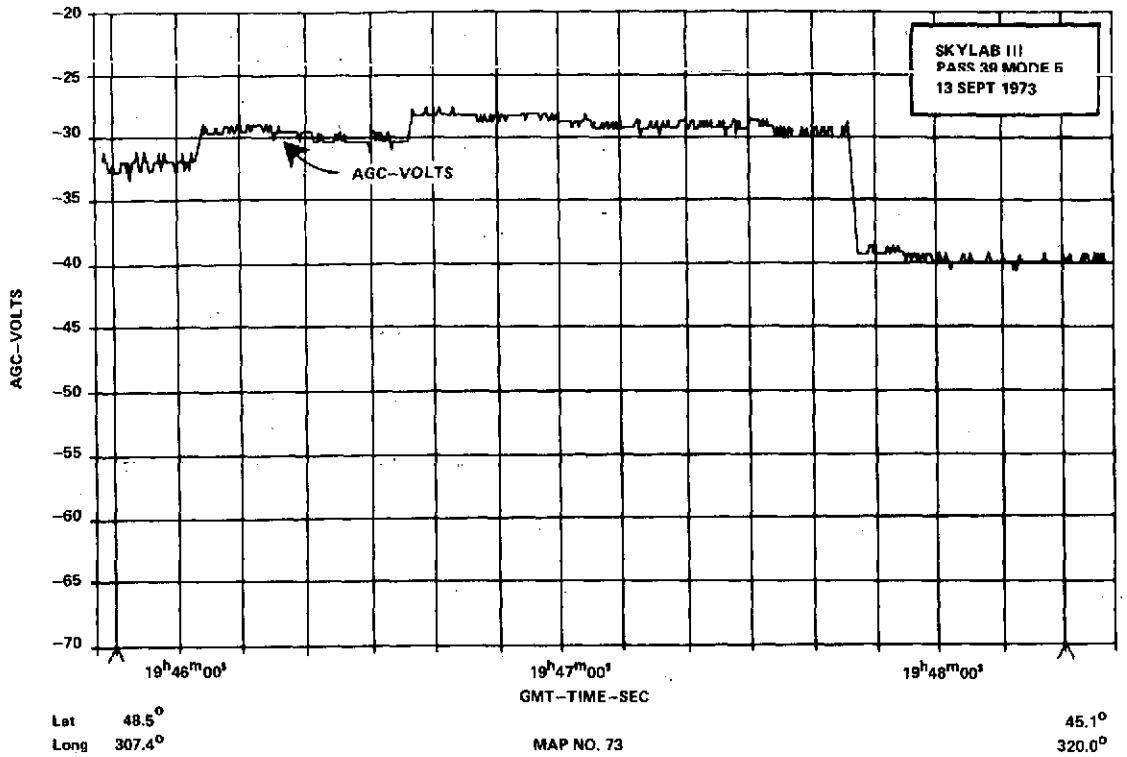
Lat 50.2° 48.6°
Long 315.0° 330.0°

MAP NO. 71



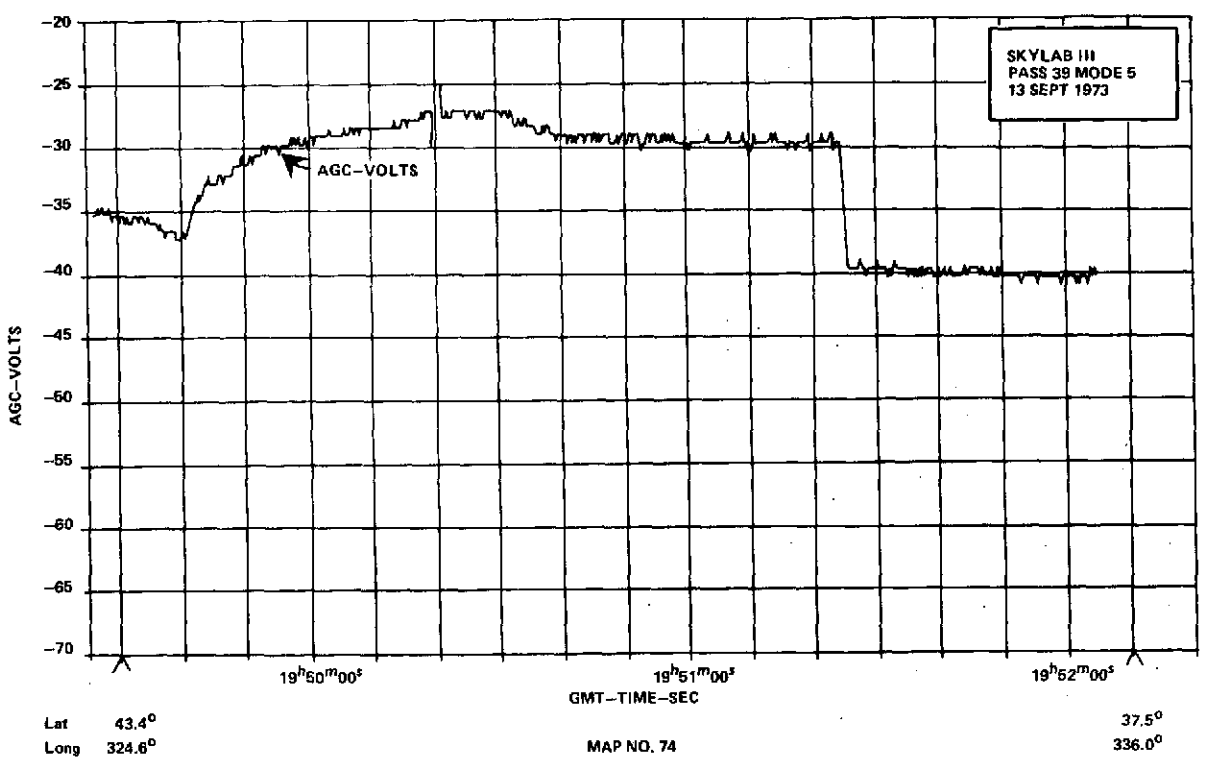
Lat 40.7° 41.7°
Long 246.0° 248.1°

MAP NO. 72



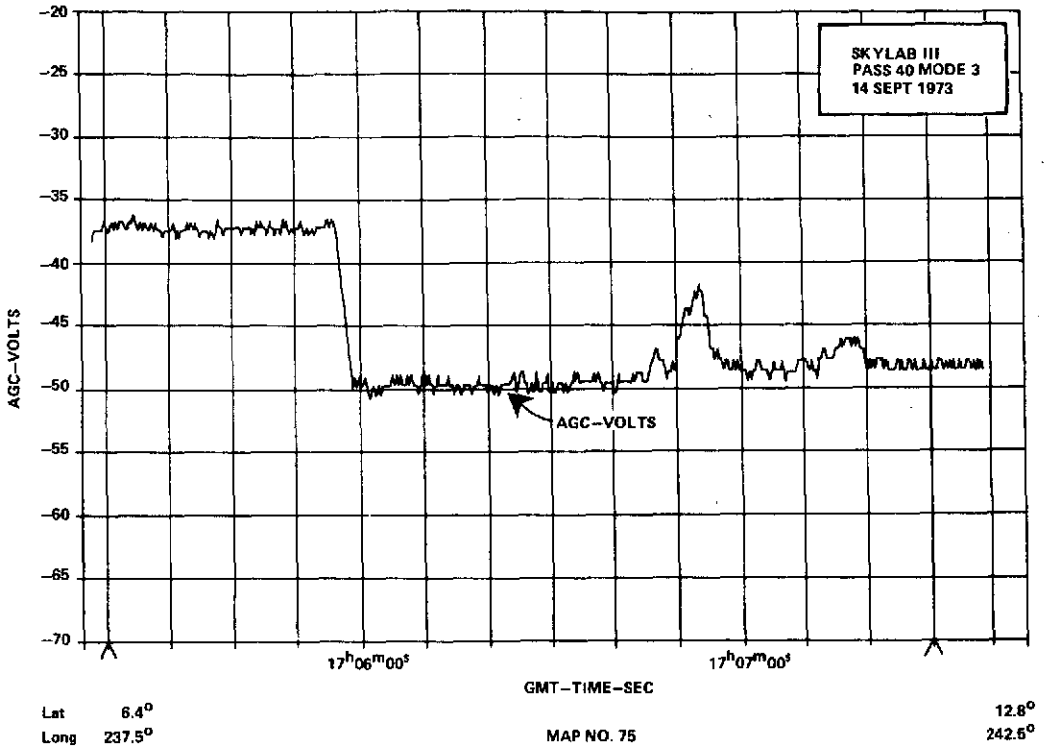
Lat 48.5° 45.1°
Long 307.4° 320.0°

MAP NO. 73



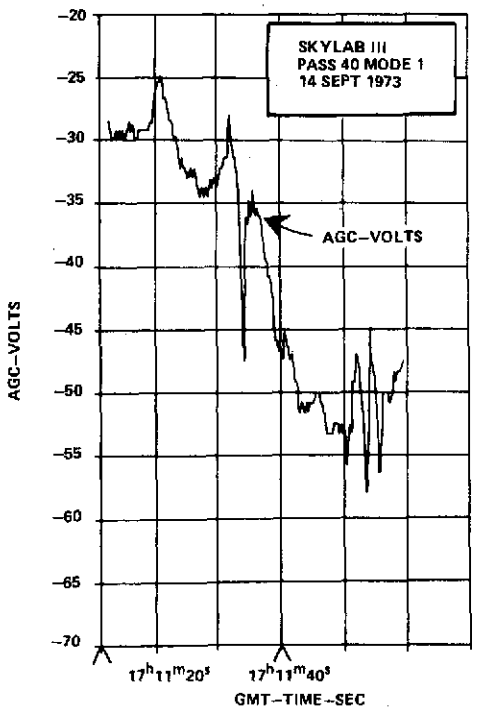
Lat 43.4° 37.5°
Long 324.6° 336.0°

MAP NO. 74



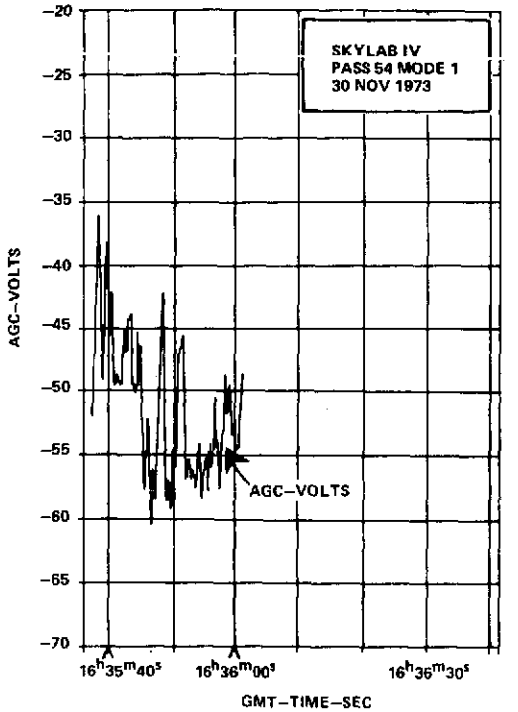
Lat 6.4° 12.8°
Long 237.5° 242.6°

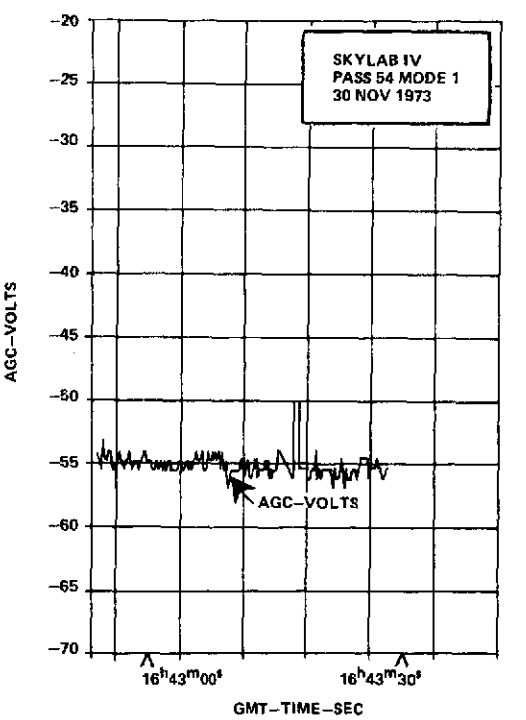
MAP NO. 75

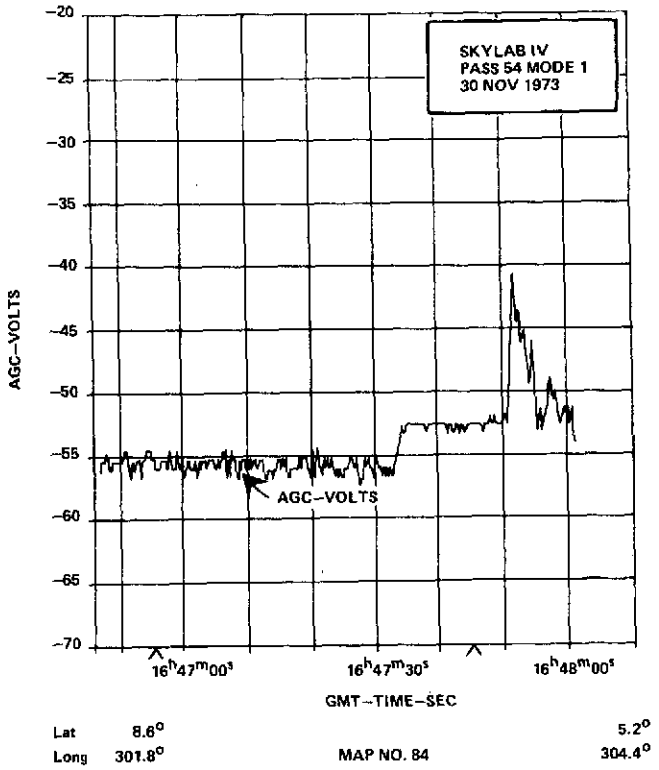


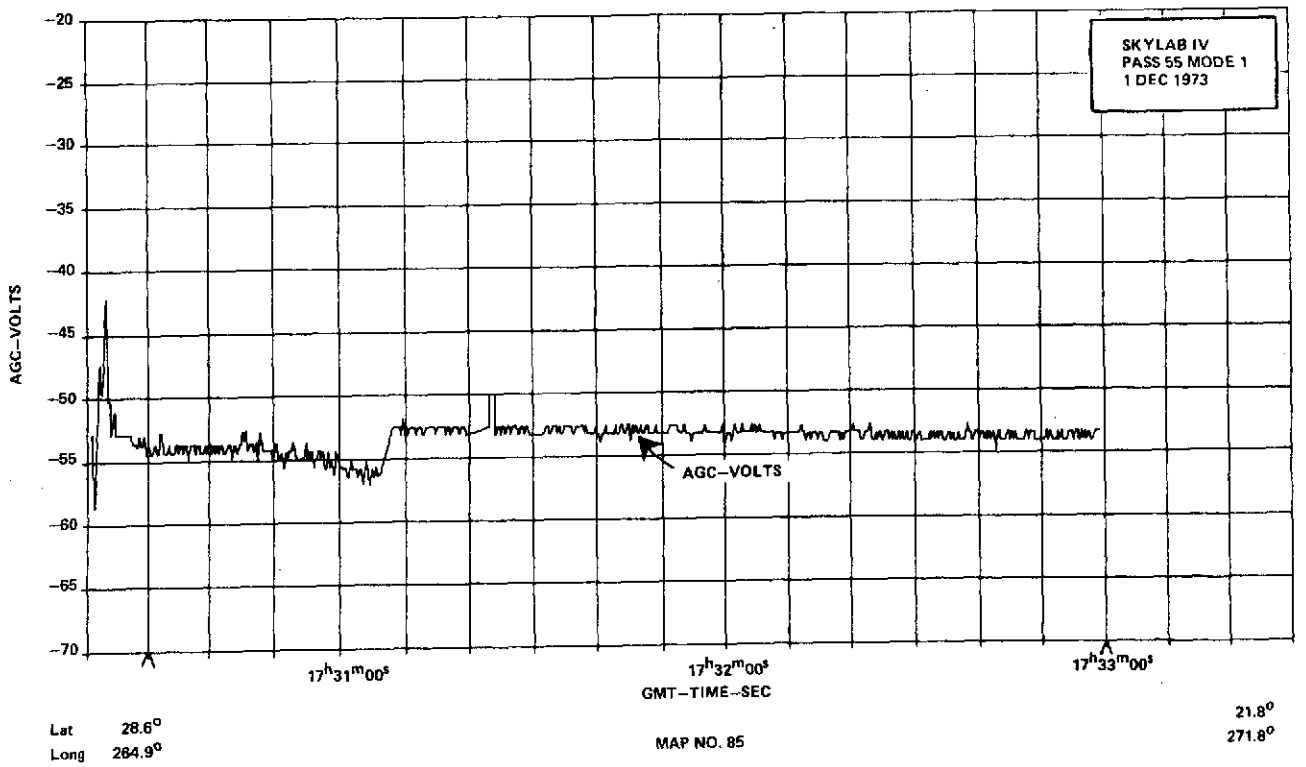
Lat 23.3° 24.7°
Long 251.7° 253.1°

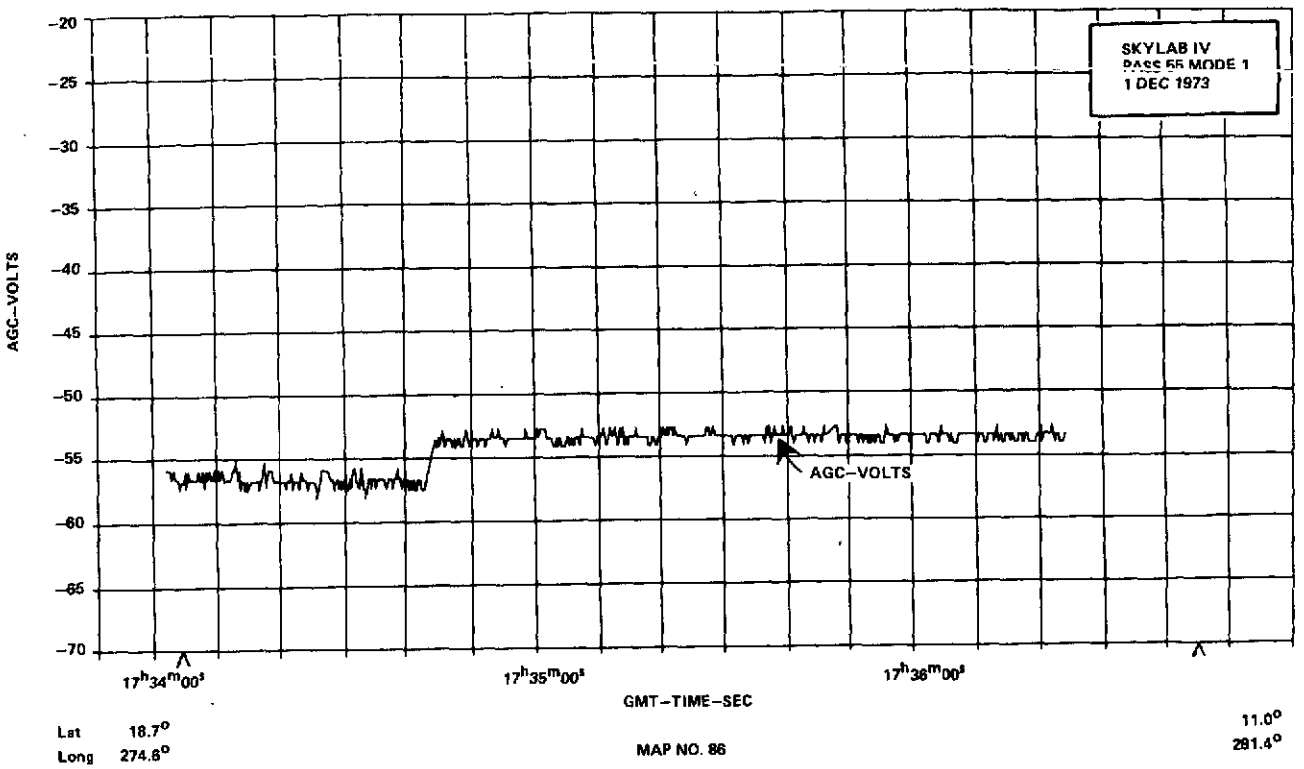
MAP NO. 76

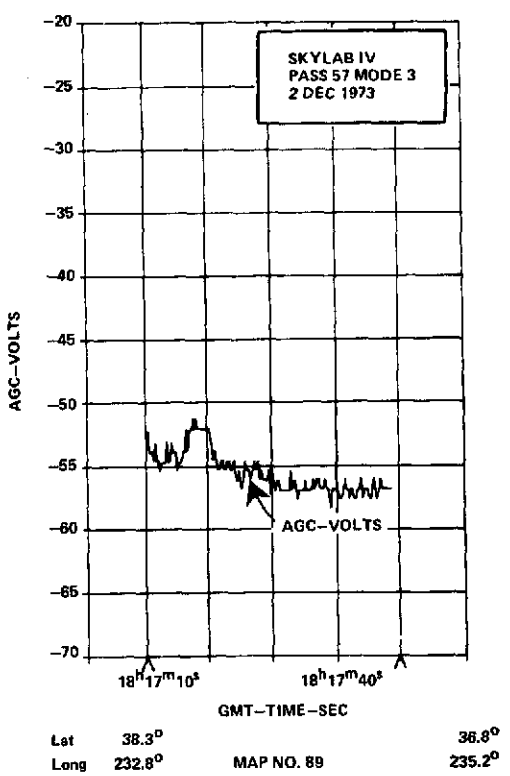

SKYLAB IV
PASS 54 MODE 1
30 NOV 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
16h35m40s
16h36m00s
16h36m30s
GMT–TIME–SEC
Lat 38.8°
Long 269.7°
MAP NO. 81
38.1°
271.0°

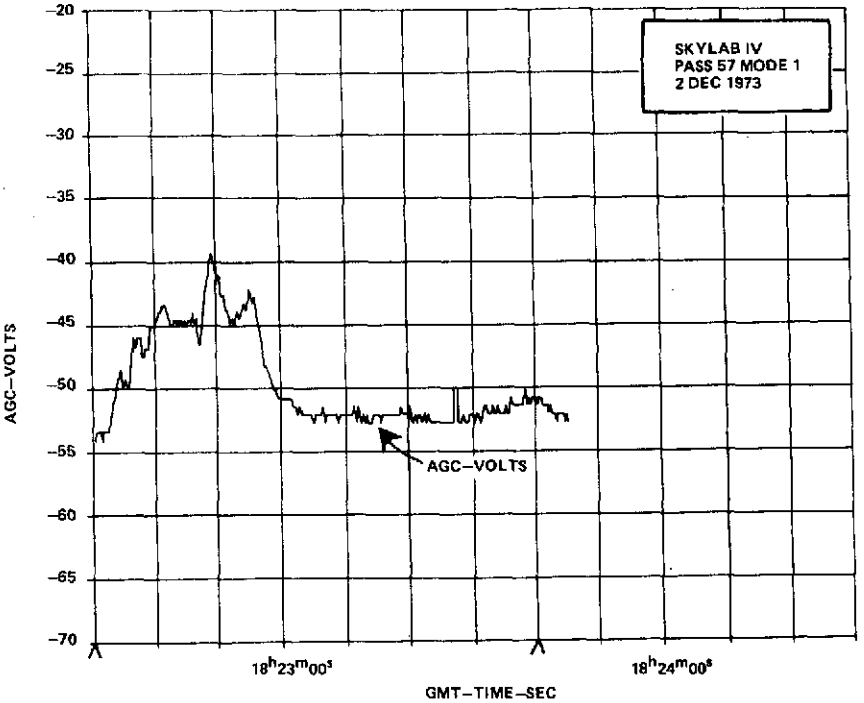

SKYLAB IV
PASS 54 MODE 1
30 NOV 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
16h43m00s
16h43m30s
GMT–TIME–SEC
Lat 20.2°
Long 292.2°
MAP NO. 83
18.3°
293.8°


SKYLAB IV
PASS 54 MODE 1
30 NOV 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
16h47m00s
16h47m30s
16h48m00s
GMT–TIME–SEC
Lat 8.6°
Long 301.8°
MAP NO. 84
5.2°
304.4°


SKYLAB IV
PASS 55 MODE 1
1 DEC 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
17h31m00s
17h32m00s
17h33m00s
GMT–TIME–SEC
Lat 28.6°
Long 264.9°
MAP NO. 85
21.8°
271.8°

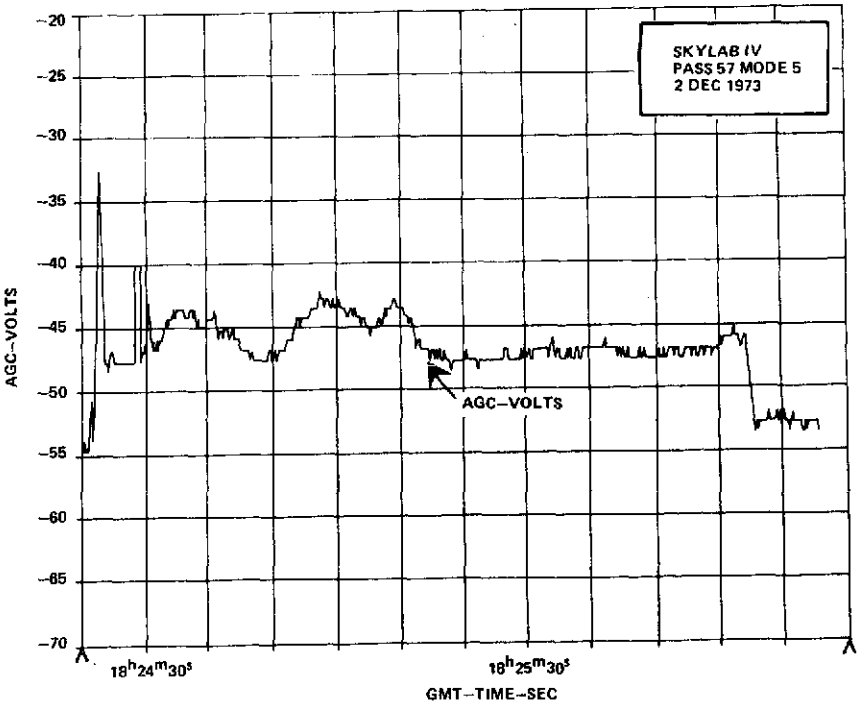

SKYLAB IV
PASS 55 MODE 1
1 DEC 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
17h34m00s
17h35m00s
17h36m00s
GMT–TIME–SEC
Lat 18.7°
Long 274.6°
11.0°
281.4°
MAP NO. 86


SKYLAB IV
PASS 57 MODE 3
2 DEC 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
18h17m10s
18h17m40s
GMT–TIME–SEC
Lat 38.3°
Long 232.8°
36.8°
235.2°
MAP NO. 89



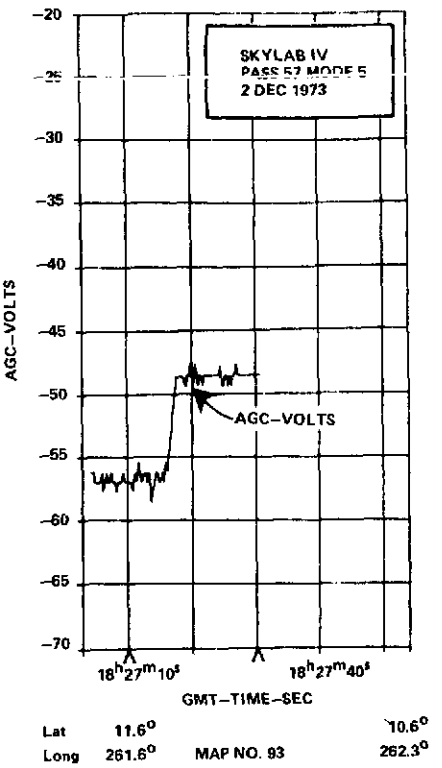
Lat 24.9° 21.6°

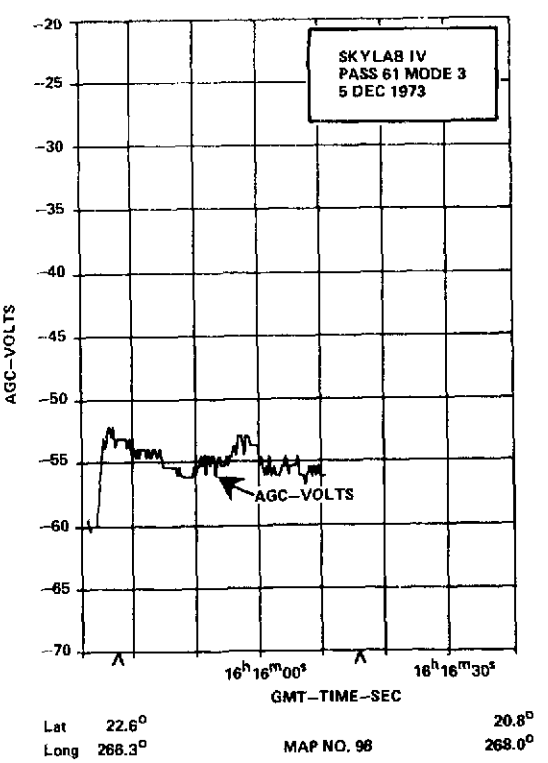
Long 249.9° MAP NO. 91 253.0°

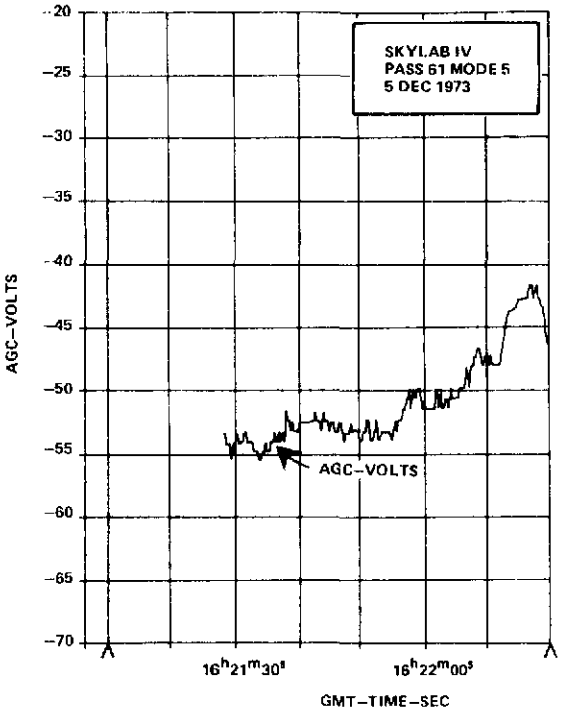


Lat 19.8° 14.0°

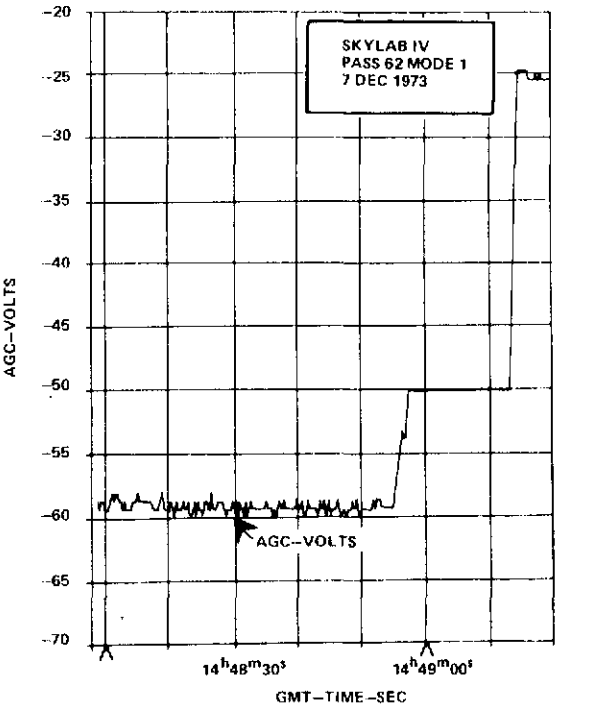
Long 254.7° MAP NO. 92 259.6°


SKYLAB IV
PASS 57 MODE 5
2 DEC 1973
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
AGC-VOLTS
AGC-VOLTS
18h27m10s
18h27m40s
GMT-TIME-SEC
Lat 11.6°
10.6°
Long 261.6°
MAP NO. 93
262.3°

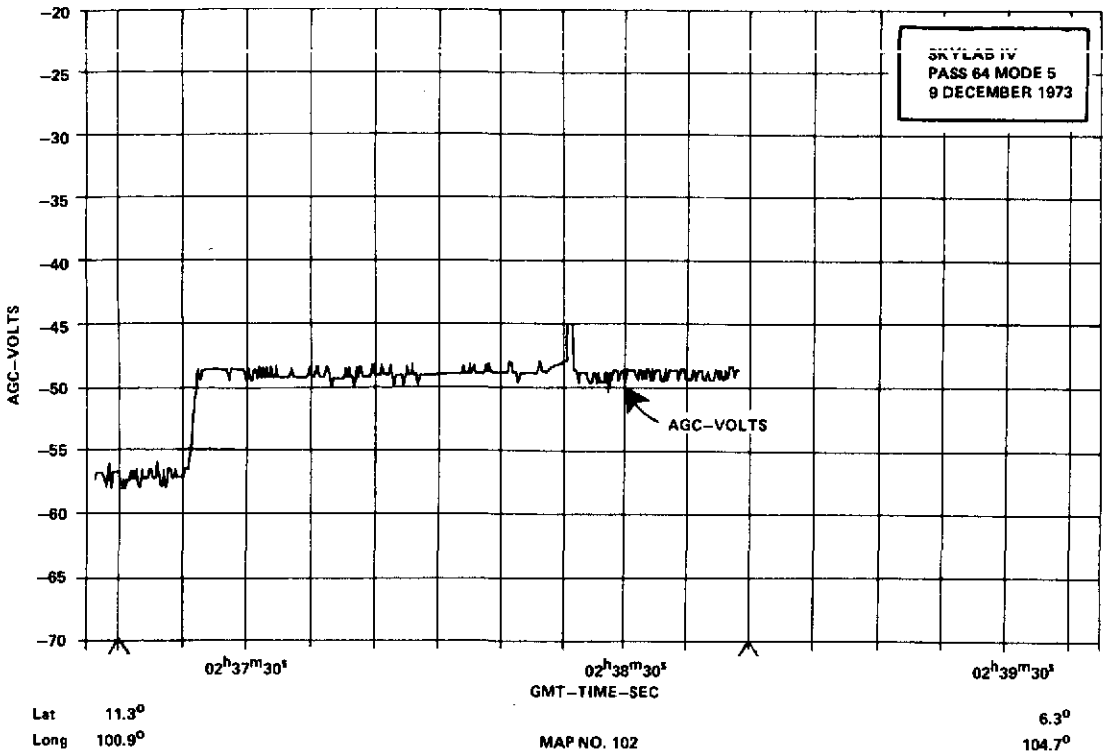

SKYLAB IV
PASS 61 MODE 3
5 DEC 1973
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
AGC-VOLTS
AGC-VOLTS
16h16m00s
16h16m30s
GMT-TIME-SEC
Lat 22.6°
20.8°
Long 266.3°
MAP NO. 98
268.0°



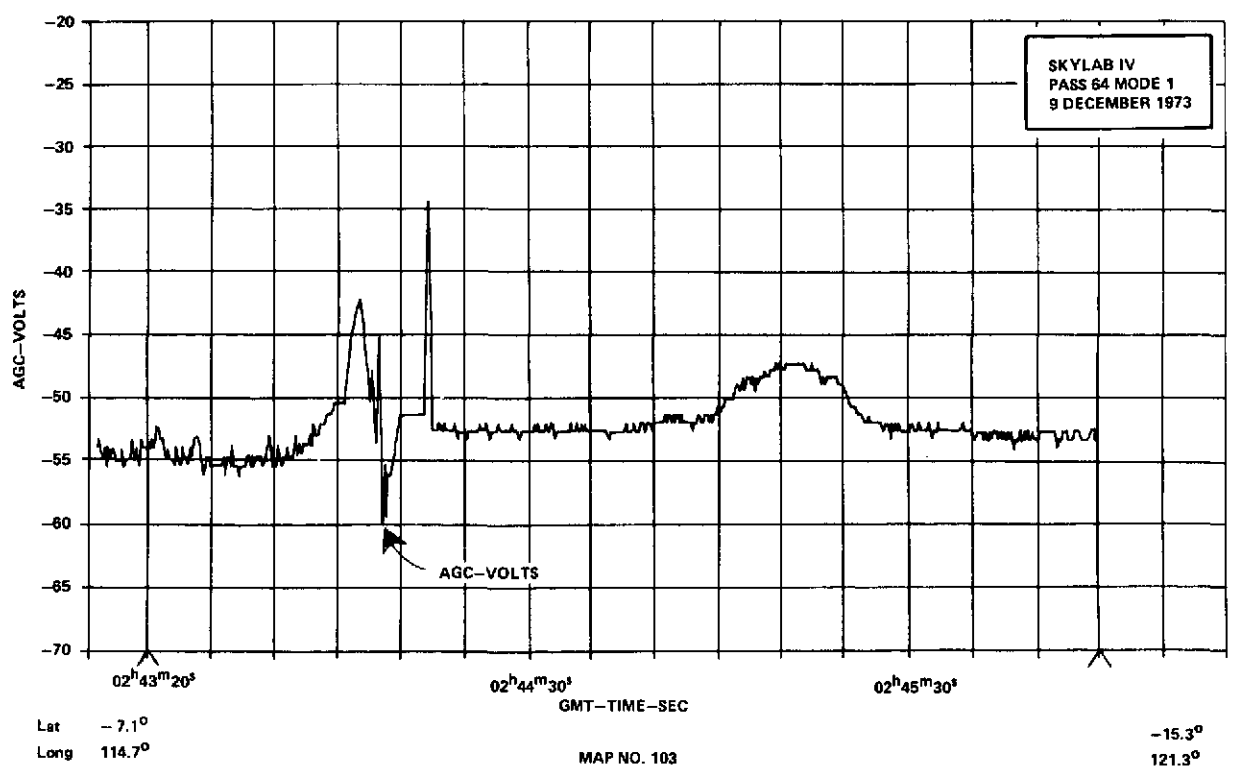
Lat 6.6° 2.7°
Long 279.6° MAP NO. 99 282.6°



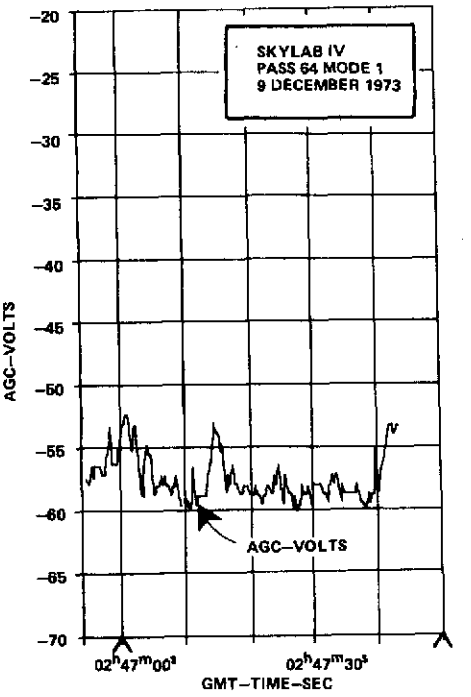
Lat 29.0° 26.7°
Long 269.3° MAP NO. 100 271.7°

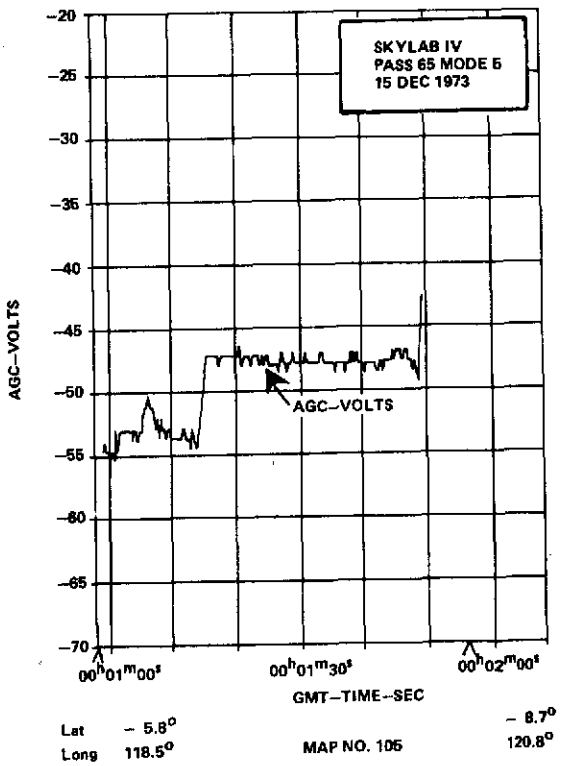


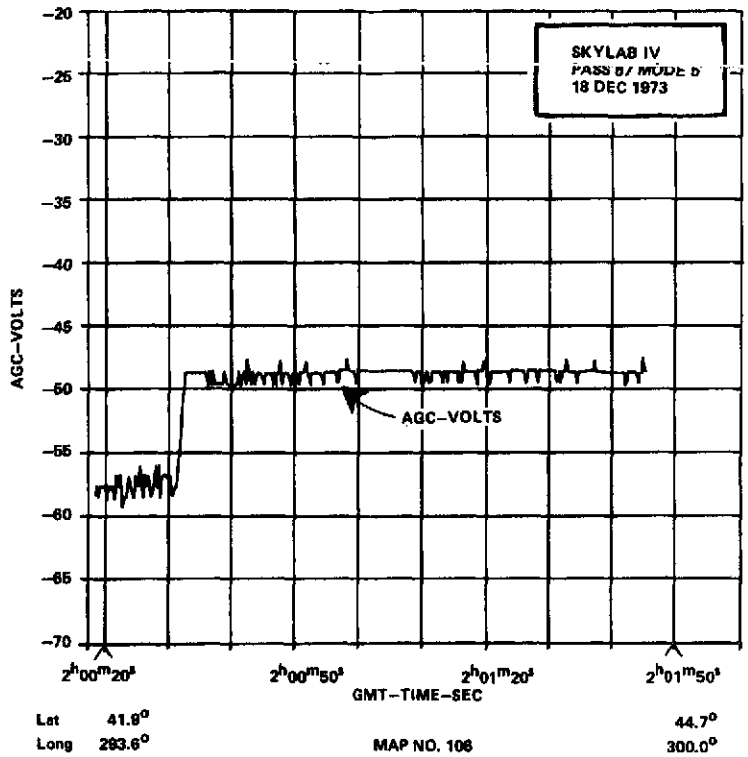
MAP NO. 102

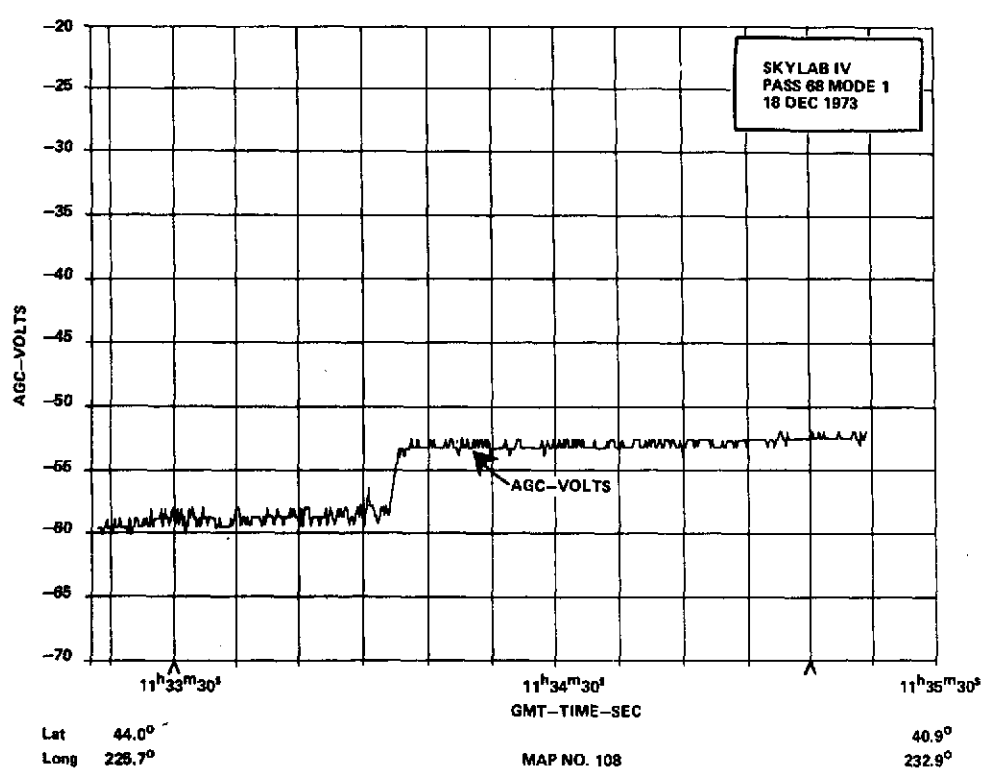


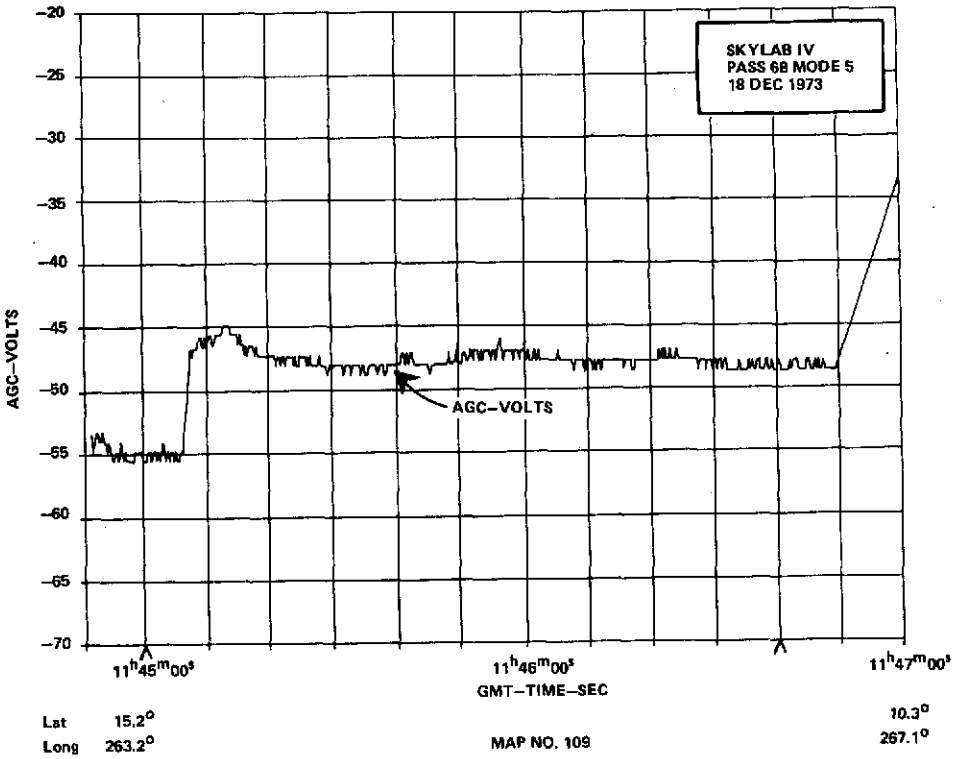
MAP NO. 103


SKYLAB IV
PASS 64 MODE 1
9 DECEMBER 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
02h47m00s
02h47m30s
GMT–TIME–SEC
Lat –17.7° –20.1°
Long 123.3° MAP NO. 104 125.4°

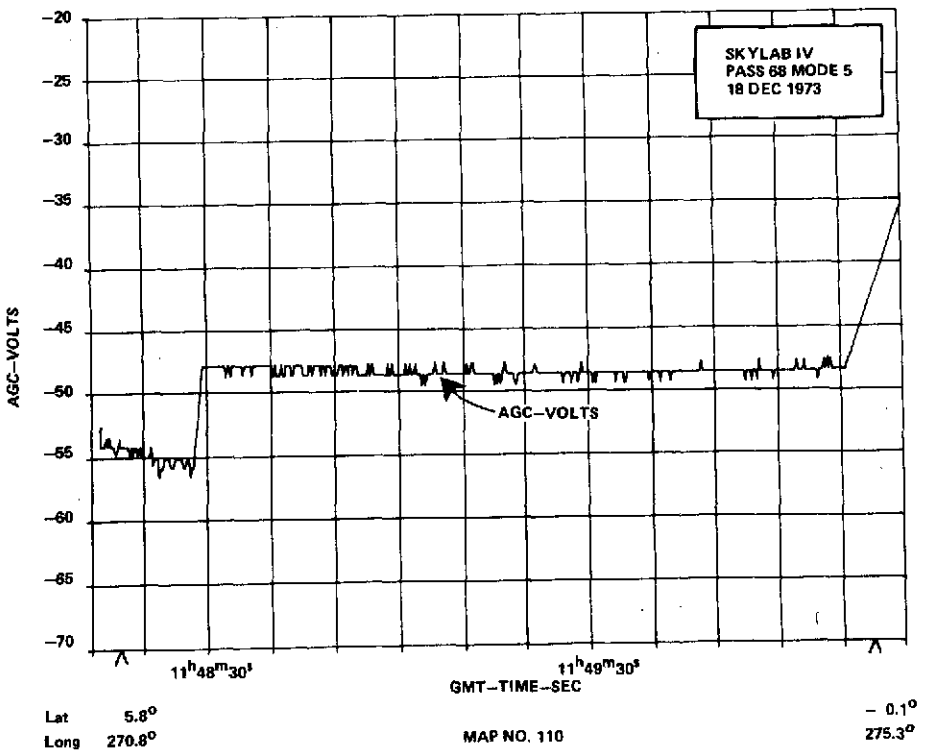

SKYLAB IV
PASS 65 MODE 5
15 DEC 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
00h01m00s
00h01m30s
00h02m00s
GMT–TIME–SEC
Lat – 5.8° – 8.7°
Long 118.5° MAP NO. 105 120.8°


SKYLAB IV
PASS 67 MODE 5
18 DEC 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
2h00m20s
2h00m50s
2h01m20s
2h01m50s
GMT–TIME–SEC
Lat 41.9°
Long 293.6°
MAP NO. 106
44.7°
300.0°

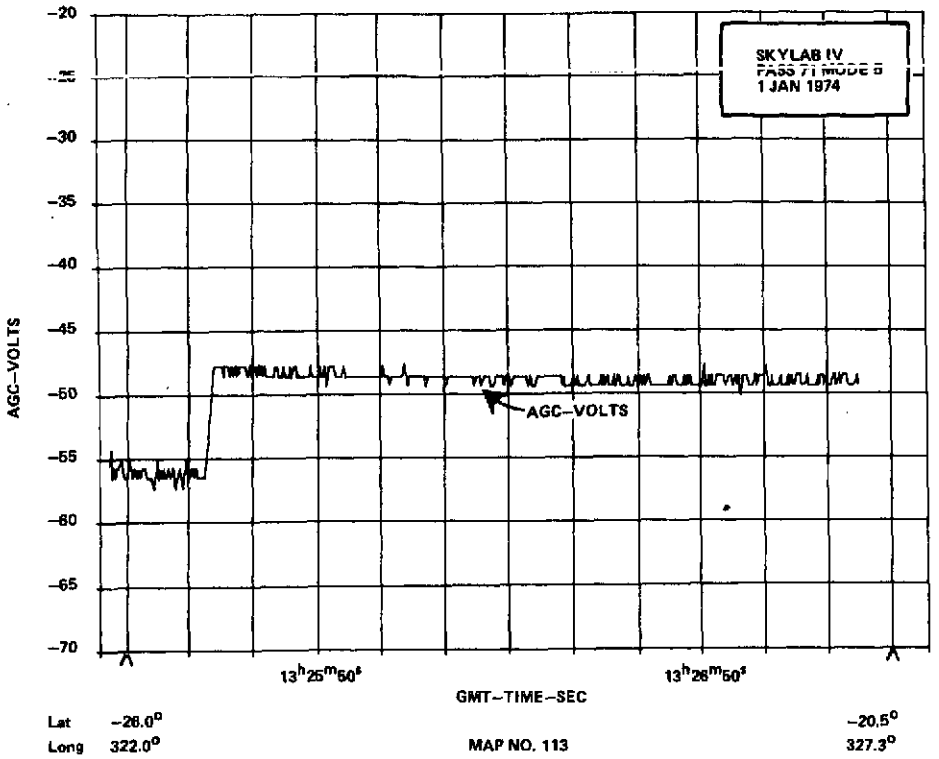

SKYLAB IV
PASS 68 MODE 1
18 DEC 1973
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
11h33m30s
11h34m30s
11h35m30s
GMT–TIME–SEC
Lat 44.0°
Long 225.7°
MAP NO. 108
40.9°
232.9°



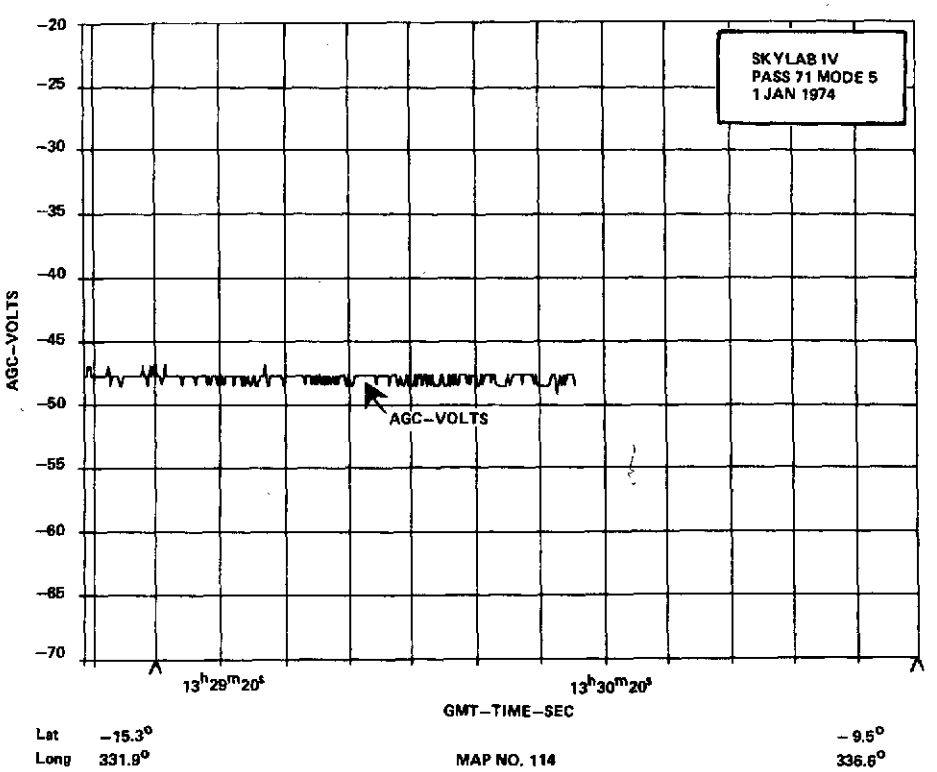
MAP NO. 109



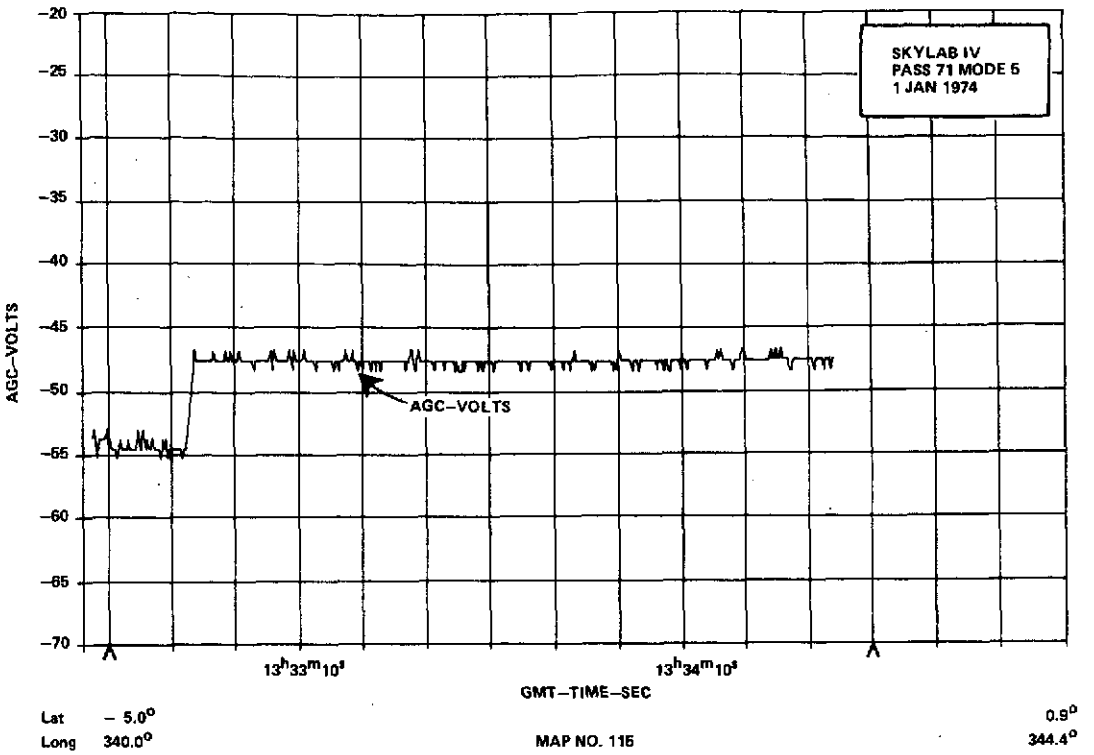
MAP NO. 110

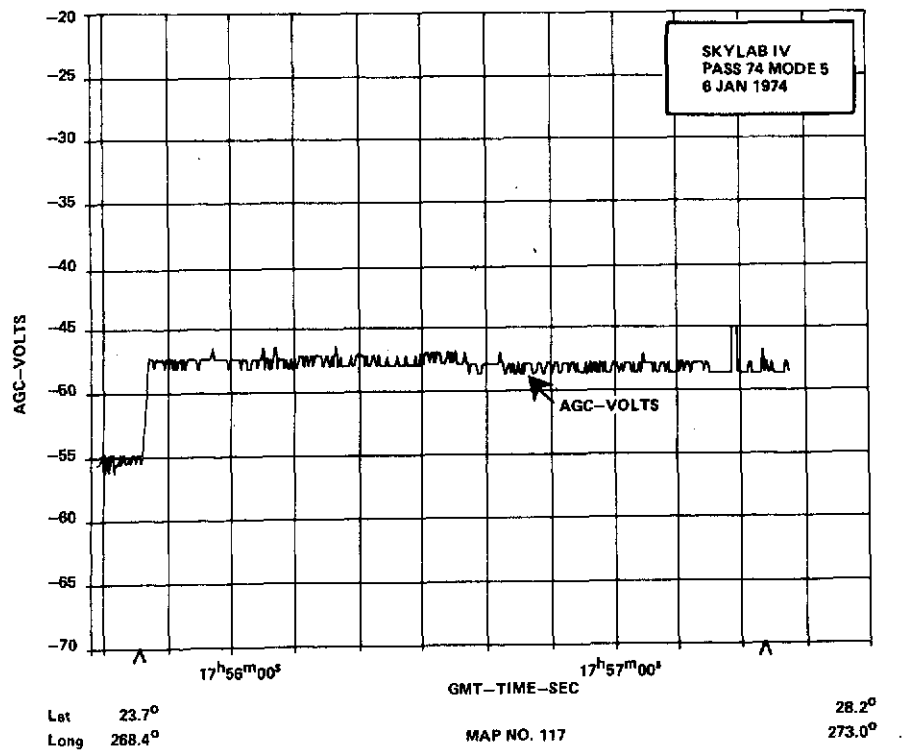


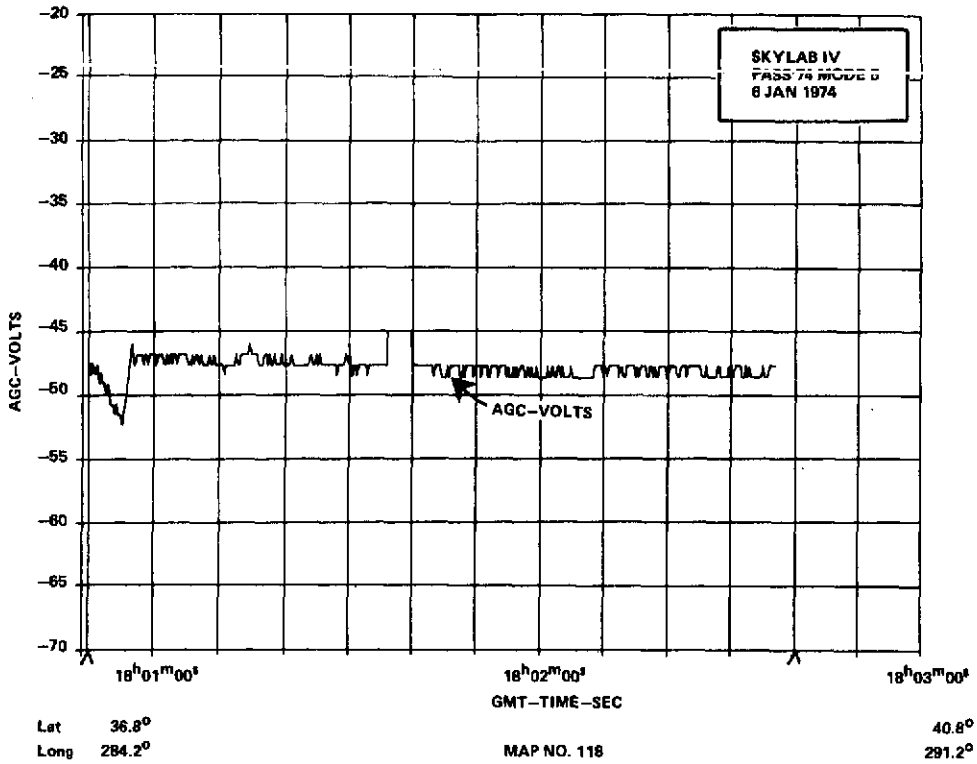
Lat –26.0° –20.5°
Long 322.0° MAP NO. 113 327.3°



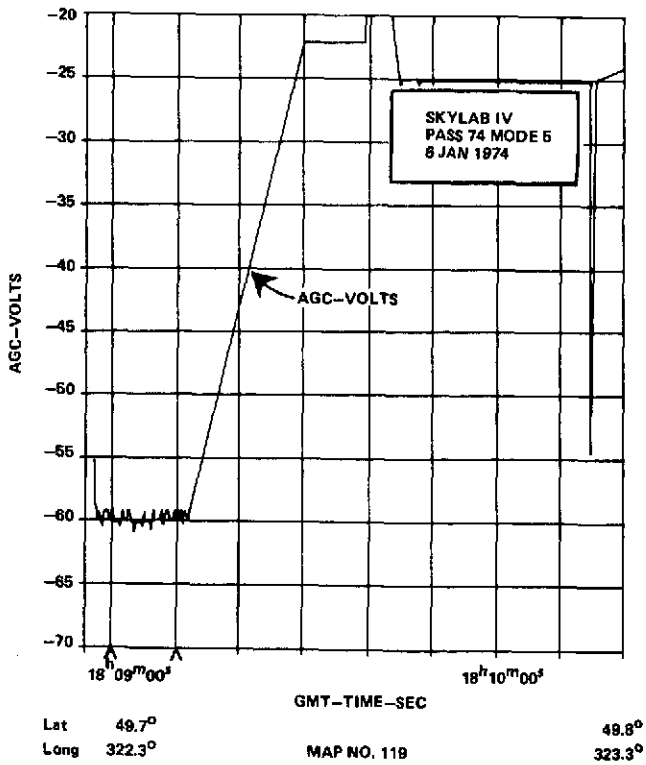
Lat –15.3° –9.5°
Long 331.9° MAP NO. 114 336.6°


SKYLAB IV
PASS 71 MODE 5
1 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
13h33m10s
13h34m10s
GMT–TIME–SEC
Lat – 5.0°
Long 340.0°
MAP NO. 116
0.9°
344.4°

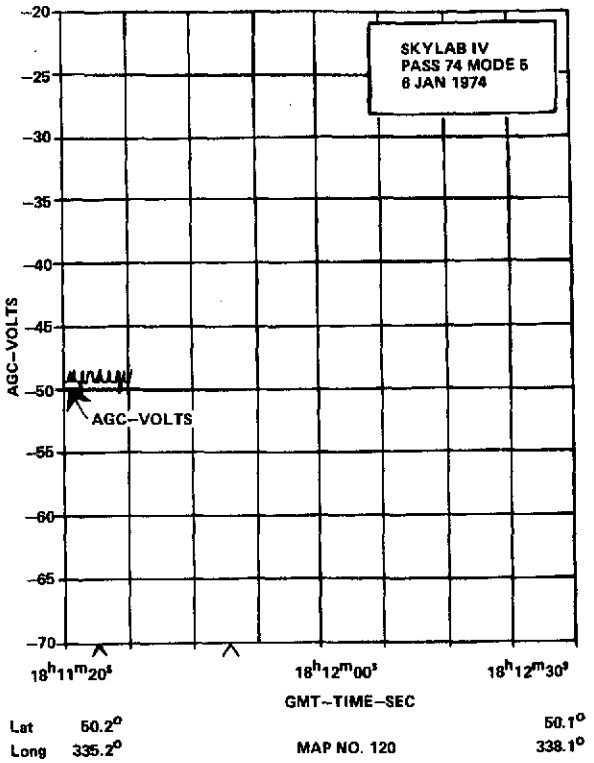

SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
17h56m00s
17h57m00s
GMT–TIME–SEC
Lat 23.7°
Long 268.4°
MAP NO. 117
28.2°
273.0°

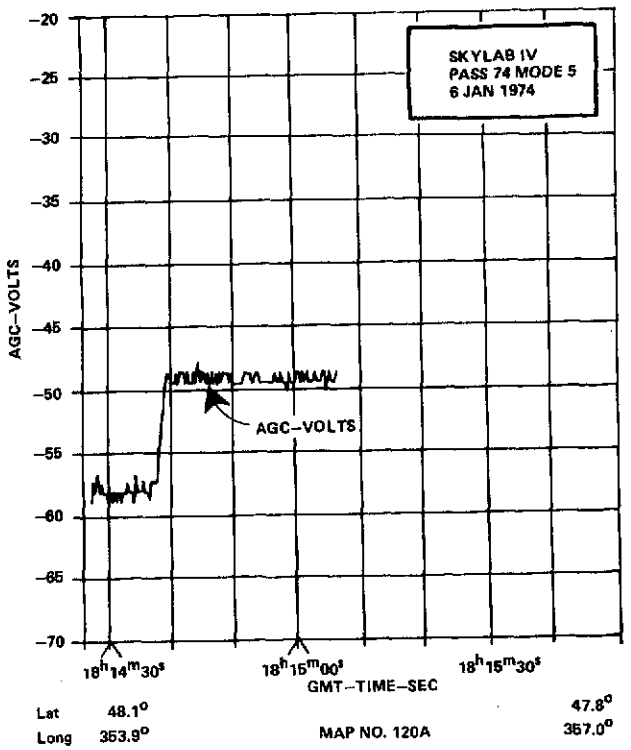


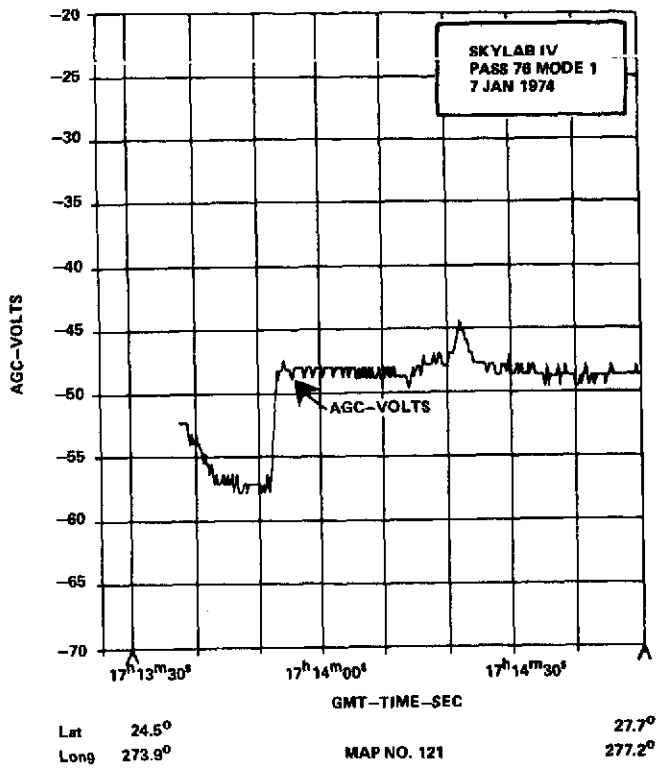
MAP NO. 118

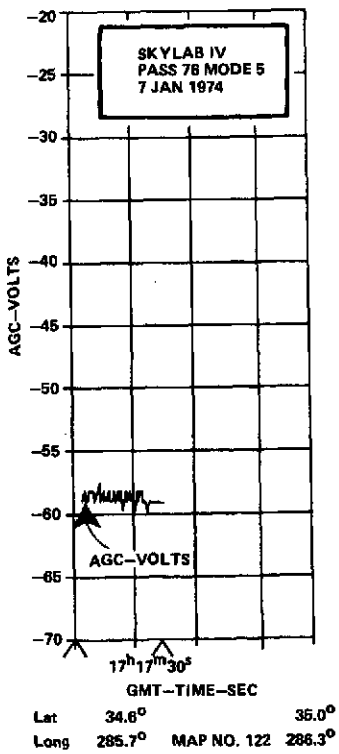


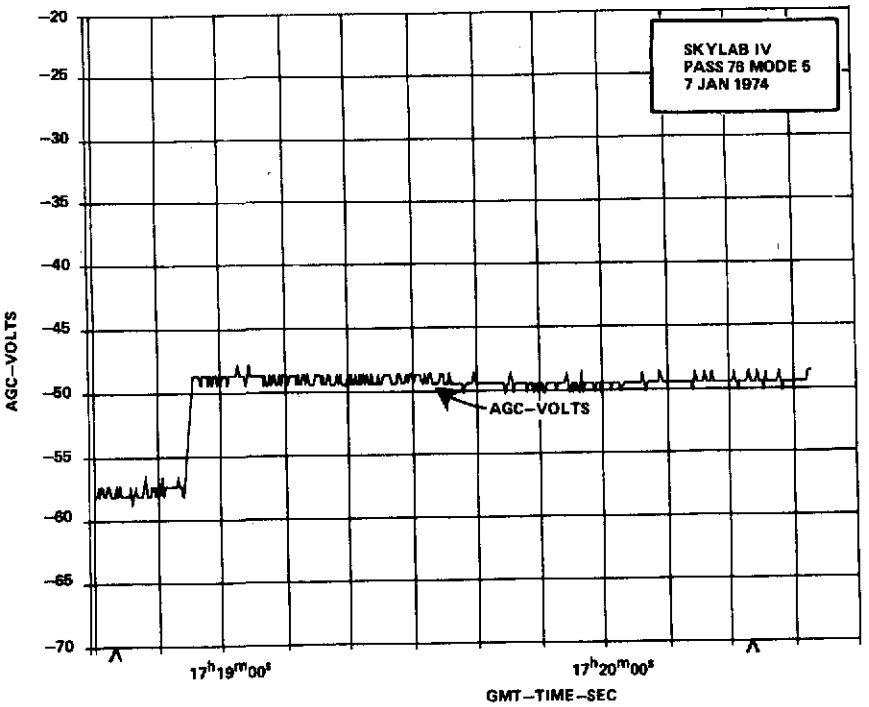
MAP NO. 119


SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
18h11m20s
18h12m00s
18h12m30s
GMT–TIME–SEC
Lat 50.2°
Long 335.2°
MAP NO. 120
50.1°
338.1°


SKYLAB IV
PASS 74 MODE 5
6 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
18h14m30s
18h15m00s
18h15m30s
GMT–TIME–SEC
Lat 48.1°
Long 353.9°
MAP NO. 120A
47.8°
357.0°

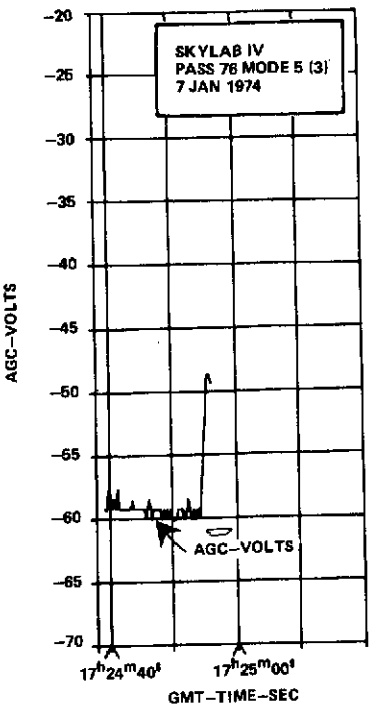

SKYLAB IV
PASS 78 MODE 1
7 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
17h13m30s
17h14m00s
17h14m30s
GMT–TIME–SEC
Lat 24.5° 27.7°
Long 273.9° MAP NO. 121 277.2°


SKYLAB IV
PASS 78 MODE 5
7 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
17h17m30s
GMT–TIME–SEC
Lat 34.6° 35.0°
Long 285.7° MAP NO. 122 286.3°



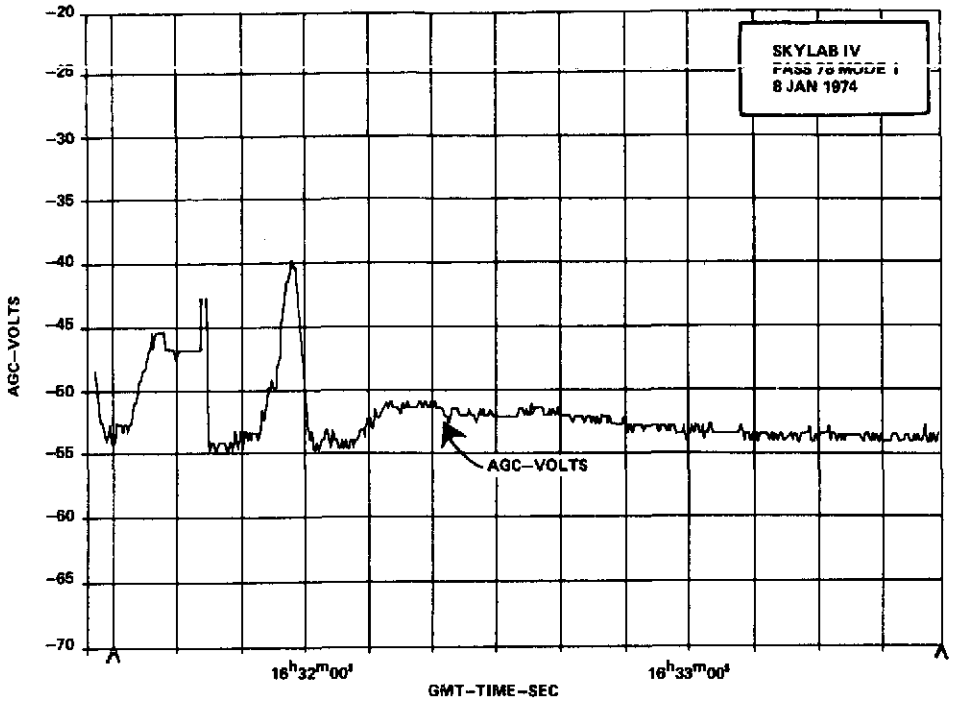
Lat 37.8° 41.4°
Long 290.5° 297.0°

MAP NO. 123

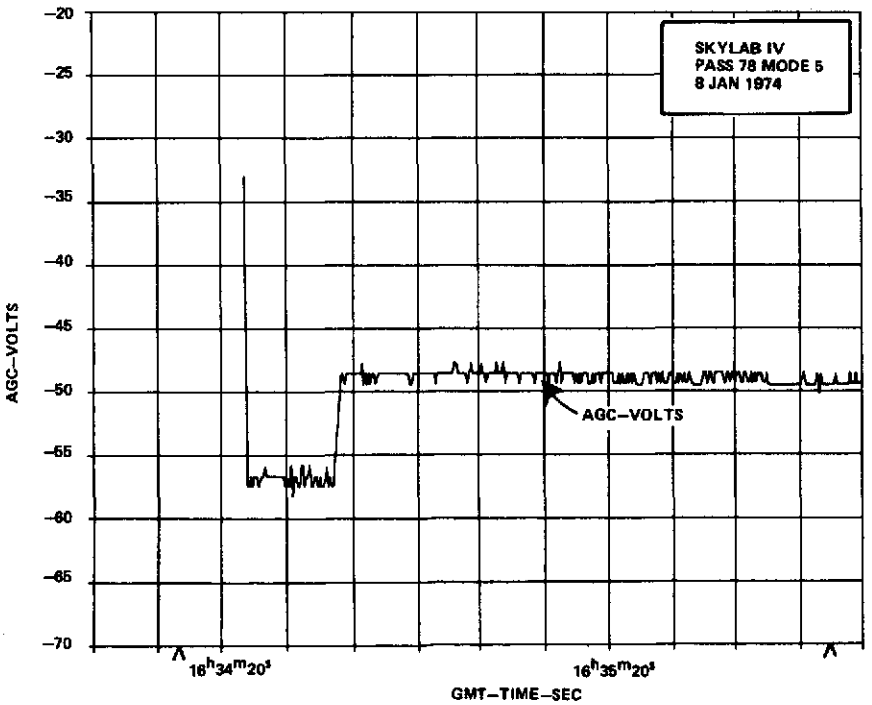


Lat 48.1° 48.5°
Long 317.2° 318.9°

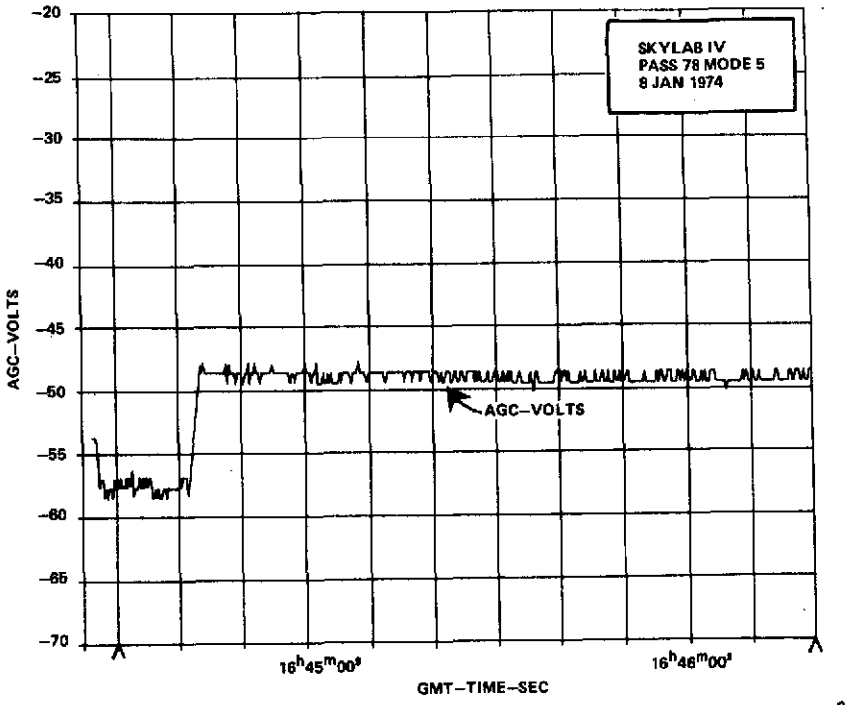
MAP NO. 124



Lat 26.0° 31.3°
Long 280.1° MAP NO. 127 286.1°

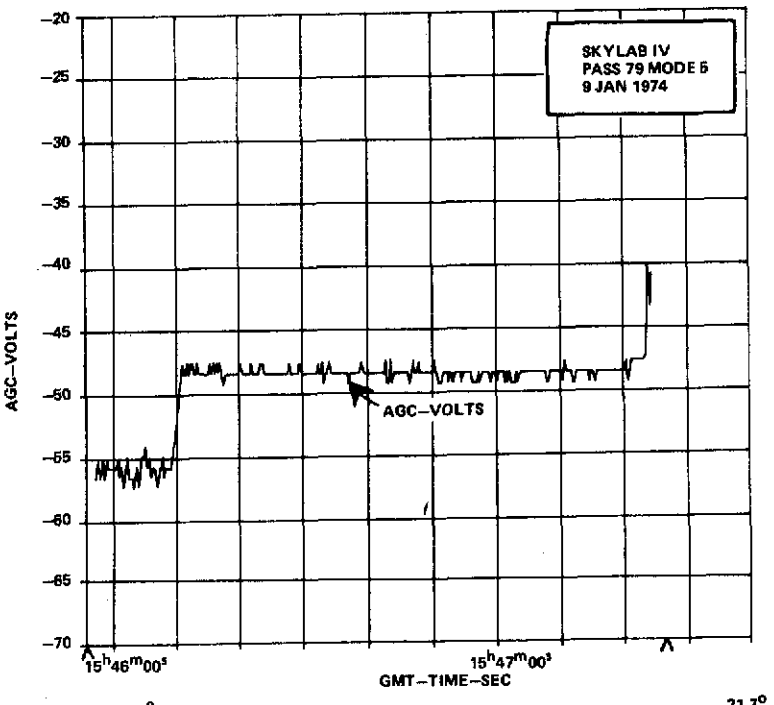


Lat 32.7° 37.1°
Long 287.9° MAP NO. 128 294.2°



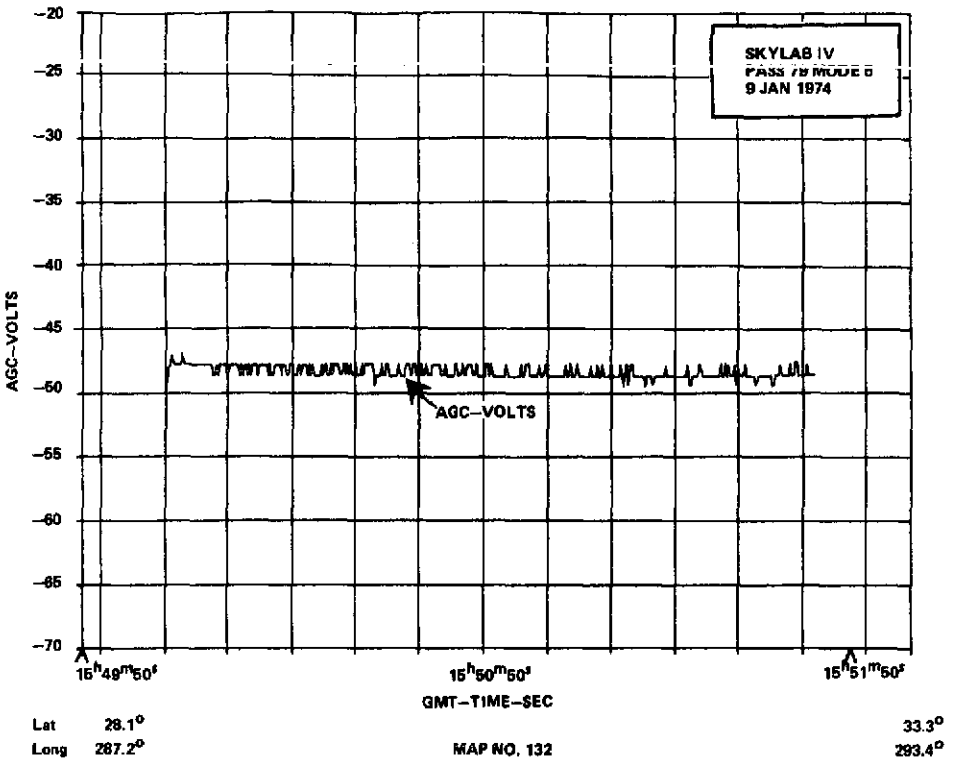
Lat 49.9° 50.1°
Long 334.9° 346.4°

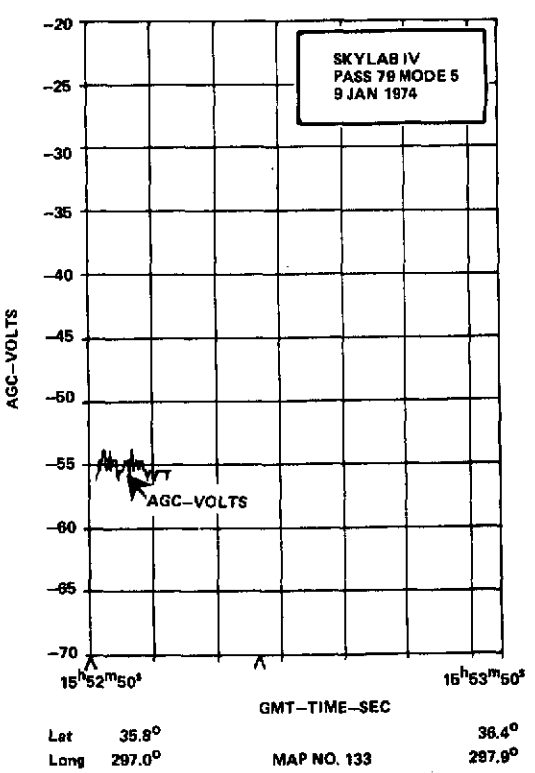
MAP NO. 129

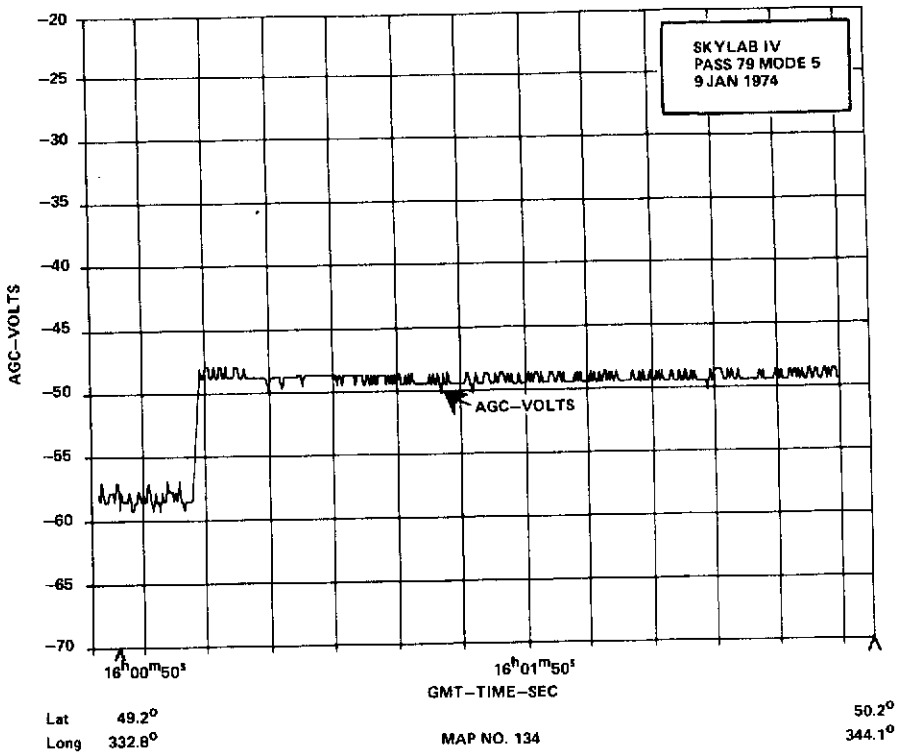


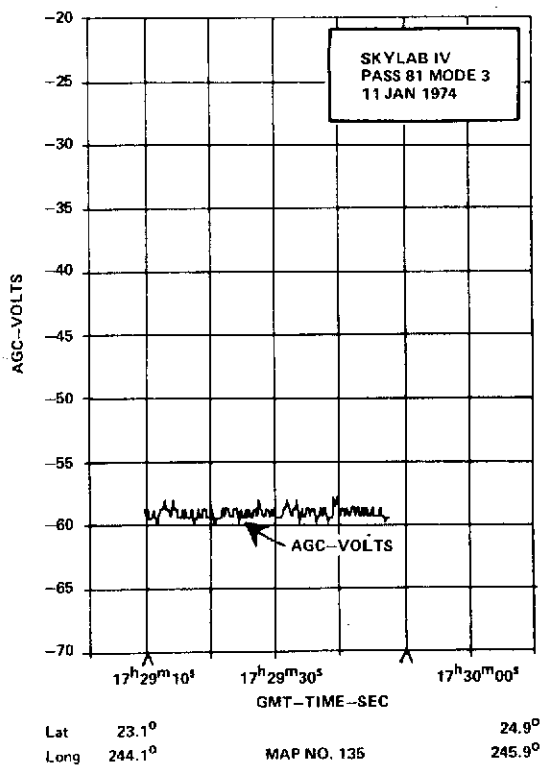
Lat 17.5° 21.7°
Long 276.9° 280.7°

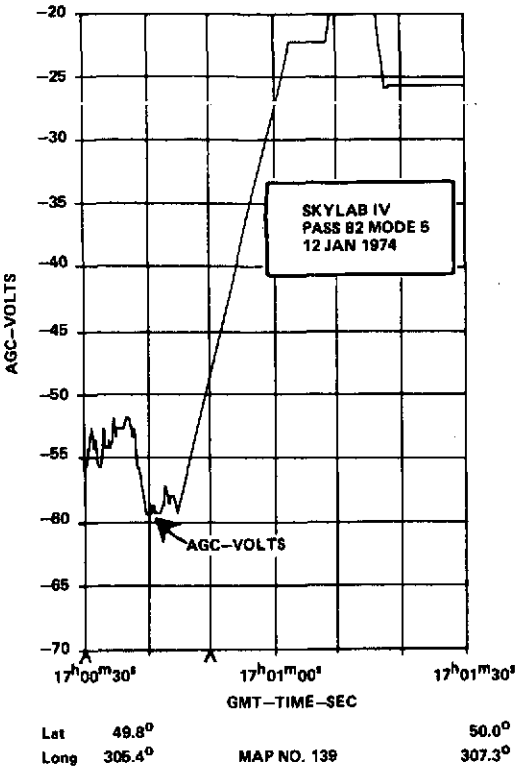
MAP NO. 131

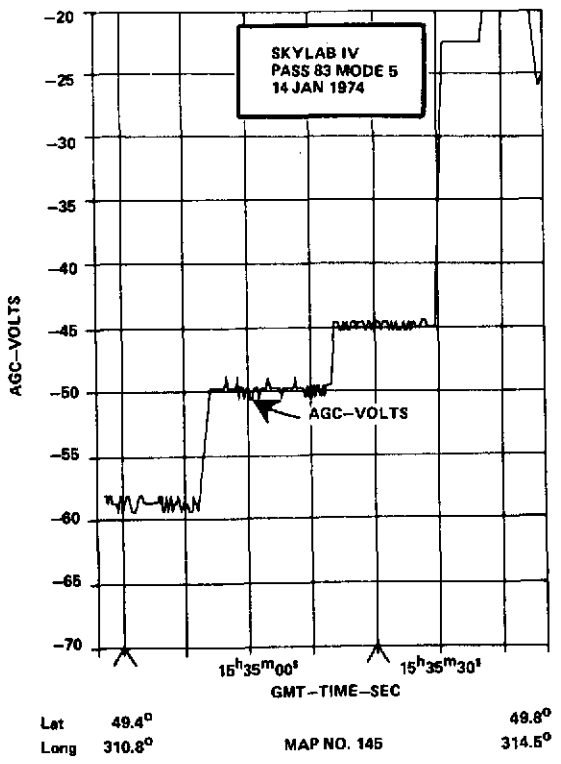

SKYLAB IV
9 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
15h49m50s
15h50m50s
15h51m50s
GMT–TIME–SEC
Lat 28.1° 33.3°
Long 287.2° 293.4°
MAP NO. 132

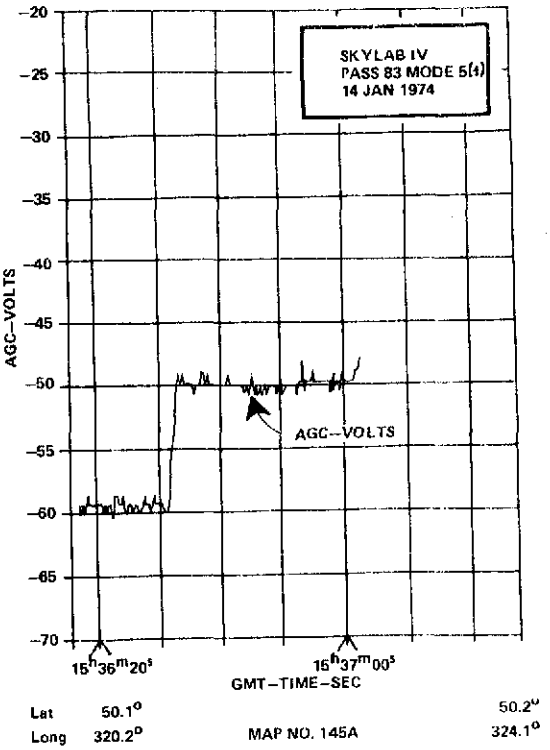

SKYLAB IV
PASS 79 MODE 5
9 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
15h52m50s
15h53m50s
GMT–TIME–SEC
Lat 35.8° 36.4°
Long 297.0° 297.9°
MAP NO. 133

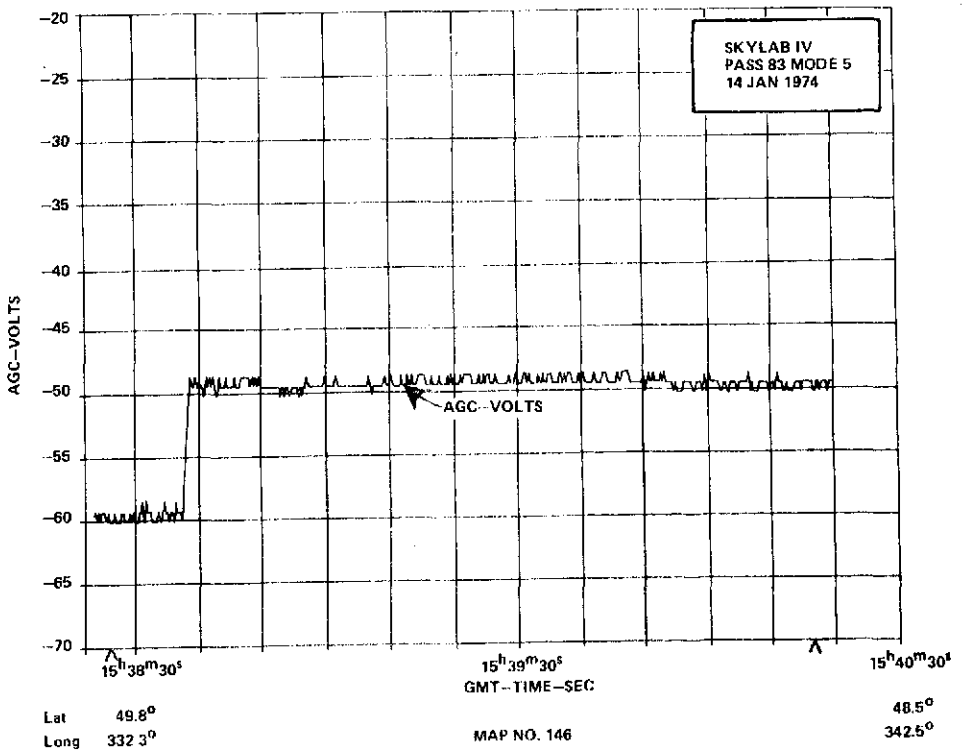

SKYLAB IV
PASS 79 MODE 5
9 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
16h00m50s
16h01m50s
GMT–TIME–SEC
Lat 49.2°
Long 332.8°
MAP NO. 134
50.2°
344.1°

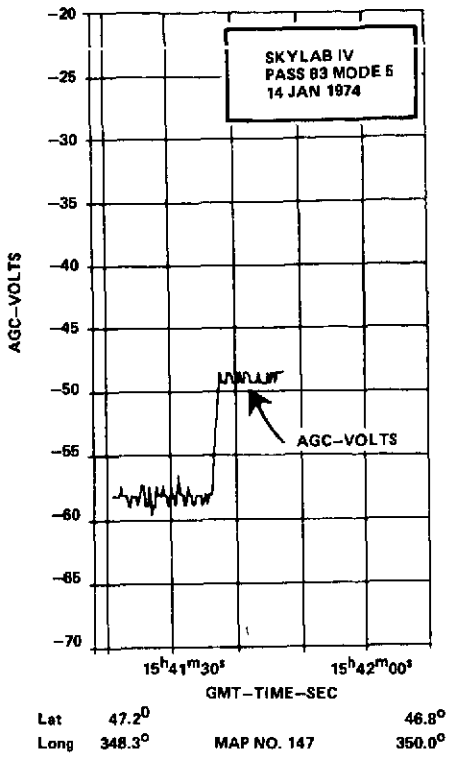

SKYLAB IV
PASS 81 MODE 3
11 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
17h29m10s
17h29m30s
17h30m00s
GMT–TIME–SEC
Lat 23.1°
Long 244.1°
MAP NO. 135
24.9°
245.9°


SKYLAB IV
PASS 82 MODE 5
12 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
17h00m30s
17h01m00s
17h01m30s
GMT–TIME–SEC
Lat 49.8°
Long 305.4°
MAP NO. 139
50.0°
307.3°

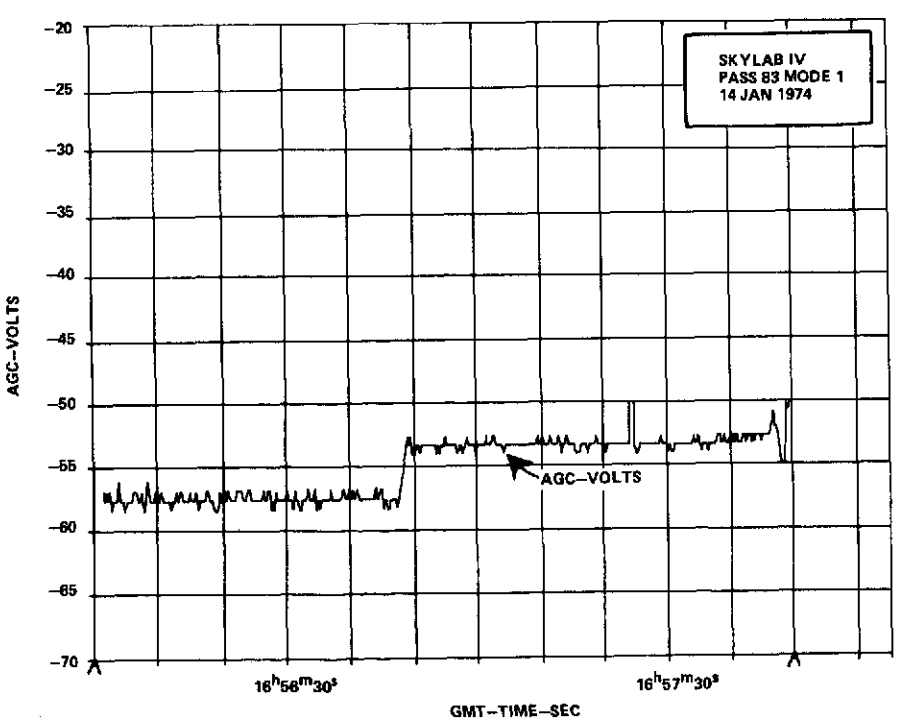

SKYLAB IV
PASS 83 MODE 5
14 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
15h35m00s
15h35m30s
GMT–TIME–SEC
Lat 49.4°
Long 310.8°
MAP NO. 145
49.8°
314.5°


SKYLAB IV
PASS 83 MODE 5(4)
14 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
15h36m20s
15h37m00s
GMT–TIME–SEC
Lat 50.1°
Long 320.2°
MAP NO. 145A
50.2°
324.1°

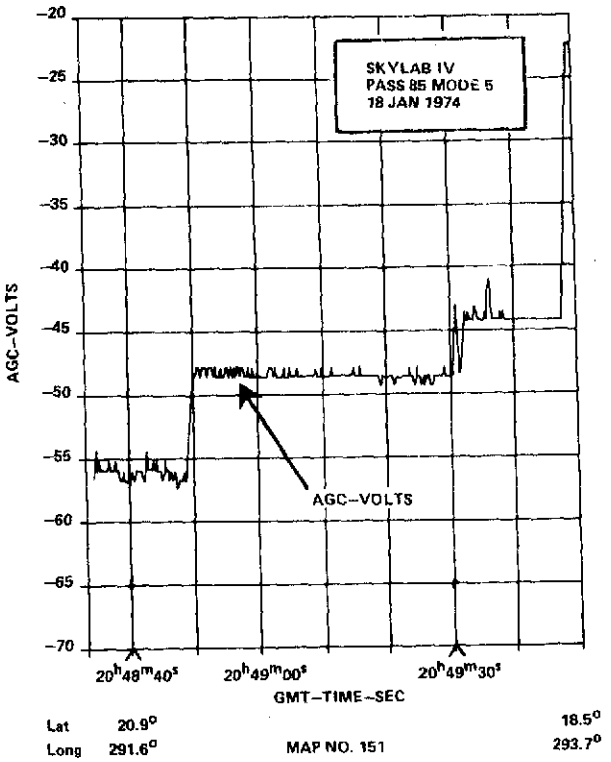

SKYLAB IV
PASS 83 MODE 5
14 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
15h38m30s
15h39m30s
15h40m30s
GMT–TIME–SEC
Lat 49.8°
Long 332.3°
MAP NO. 146
48.5°
342.5°

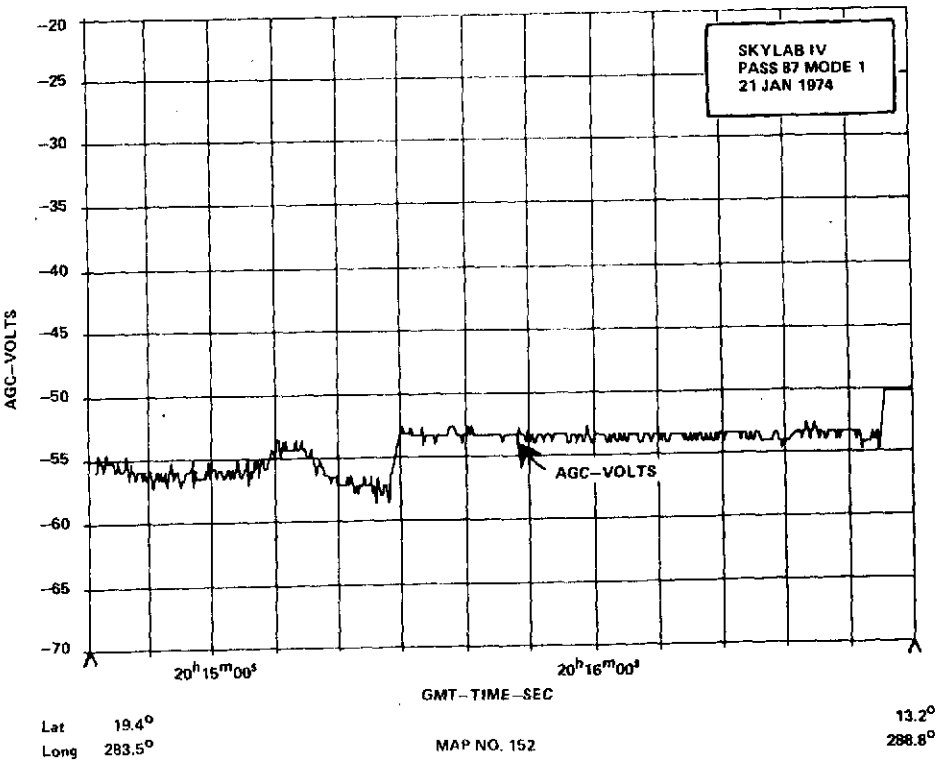


Lat 47.2° 46.8°
Long 348.3° MAP NO. 147 350.0°

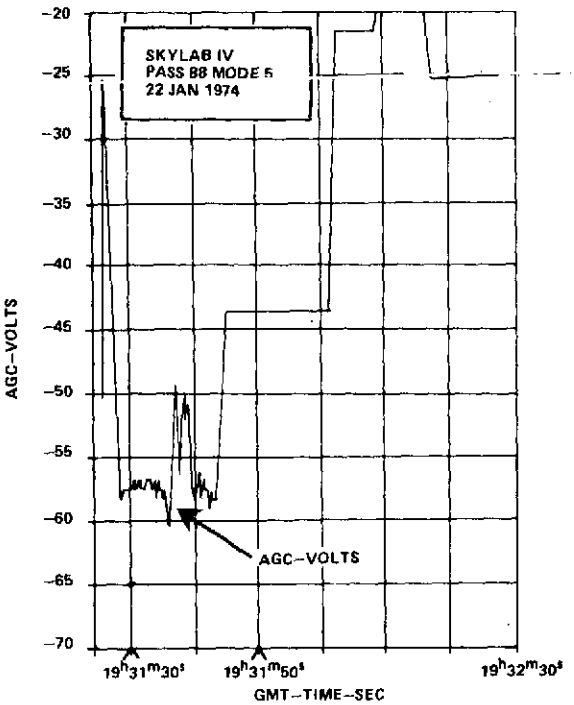


Lat 26.6° 31.5°
Long 238.2° MAP NO. 148 243.7°

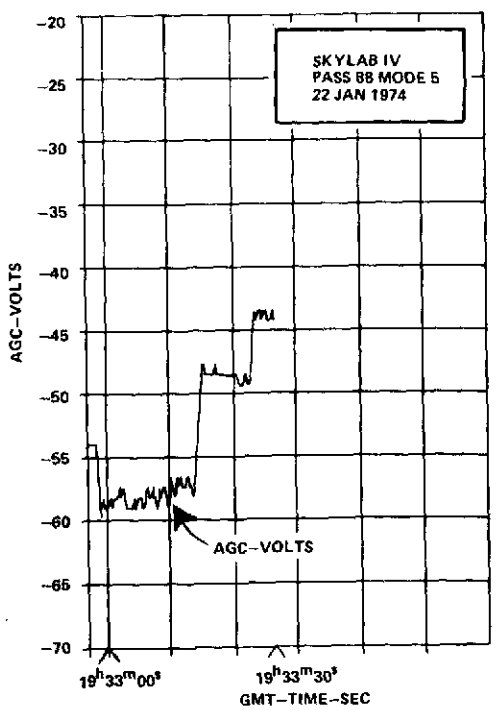

SKYLAB IV
PASS 85 MODE 5
18 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
$20^h48^m40^s$
$20^h49^m00^s$
$20^h49^m30^s$
GMT–TIME–SEC
Lat 20.9°
Long 291.6°
MAP NO. 151
18.5°
293.7°


SKYLAB IV
PASS 87 MODE 1
21 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
$20^h15^m00^s$
$20^h16^m00^s$
GMT–TIME–SEC
Lat 19.4°
Long 283.5°
MAP NO. 152
13.2°
288.8°

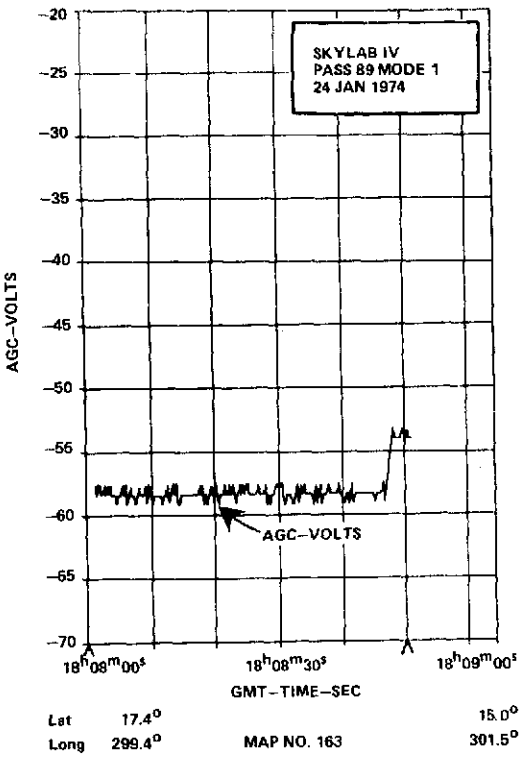
C - 4

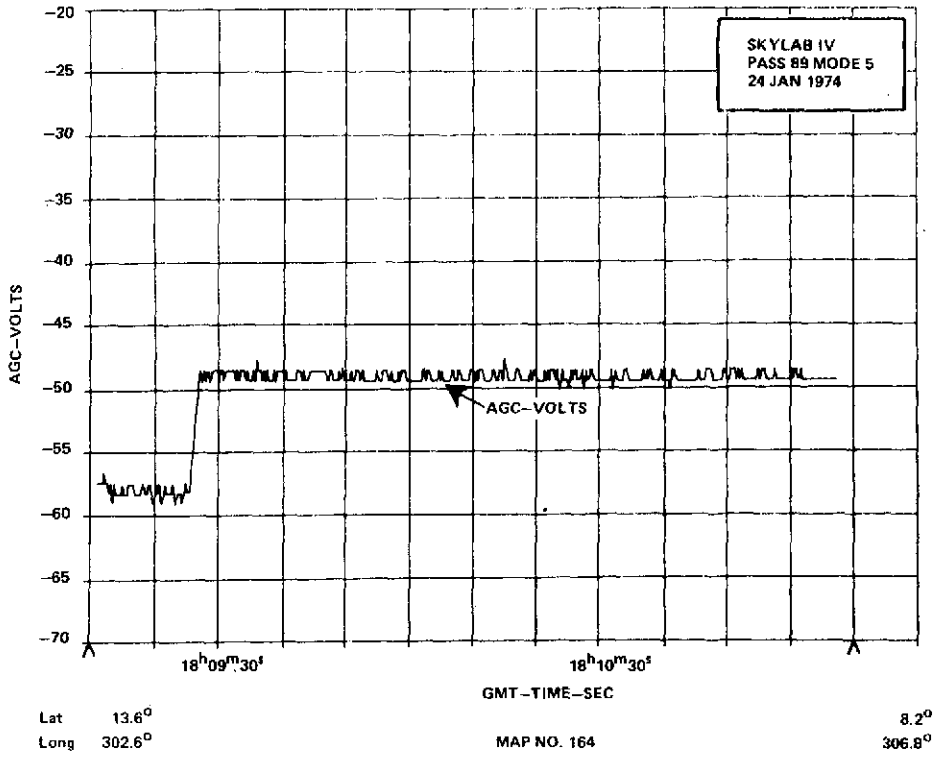


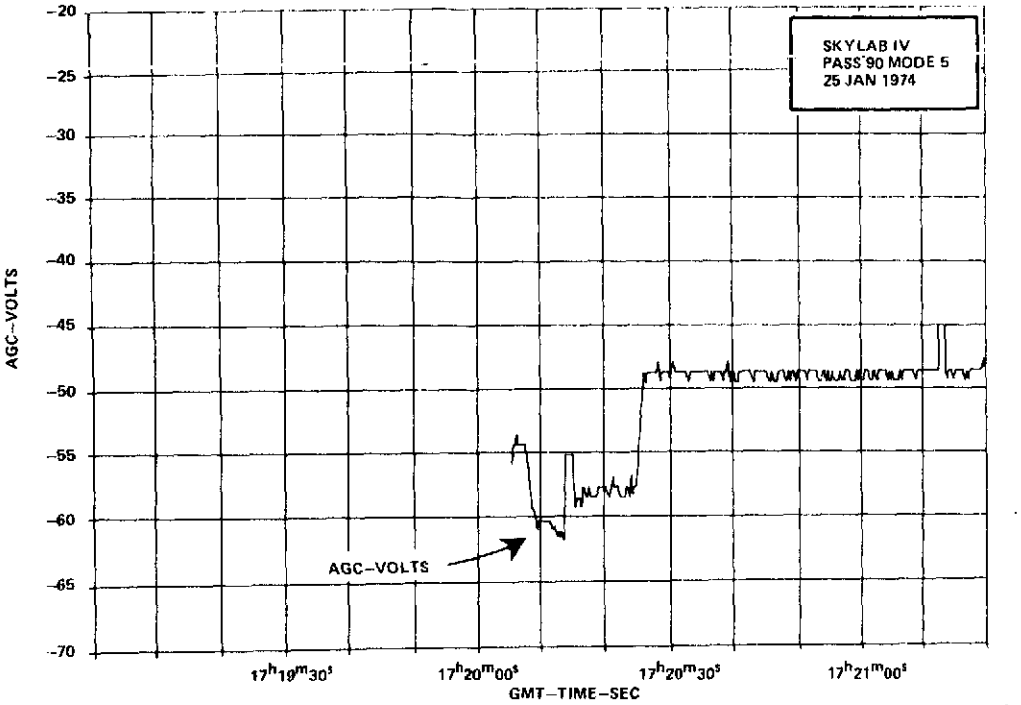
Lat 21.4° 20.5°
Long 286.4° MAP NO. 155 287.2°



Lat 16.9° 16.0°
Long 290.4° MAP NO. 156 291.2°


SKYLAB IV
PASS 89 MODE 1
24 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
18h08m00s
18h08m30s
18h09m00s
GMT–TIME–SEC
Lat 17.4°
Long 299.4°
MAP NO. 163
15.0°
301.5°


SKYLAB IV
PASS 89 MODE 5
24 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
18h09m30s
18h10m30s
GMT–TIME–SEC
Lat 13.6°
Long 302.6°
MAP NO. 164
8.2°
306.8°



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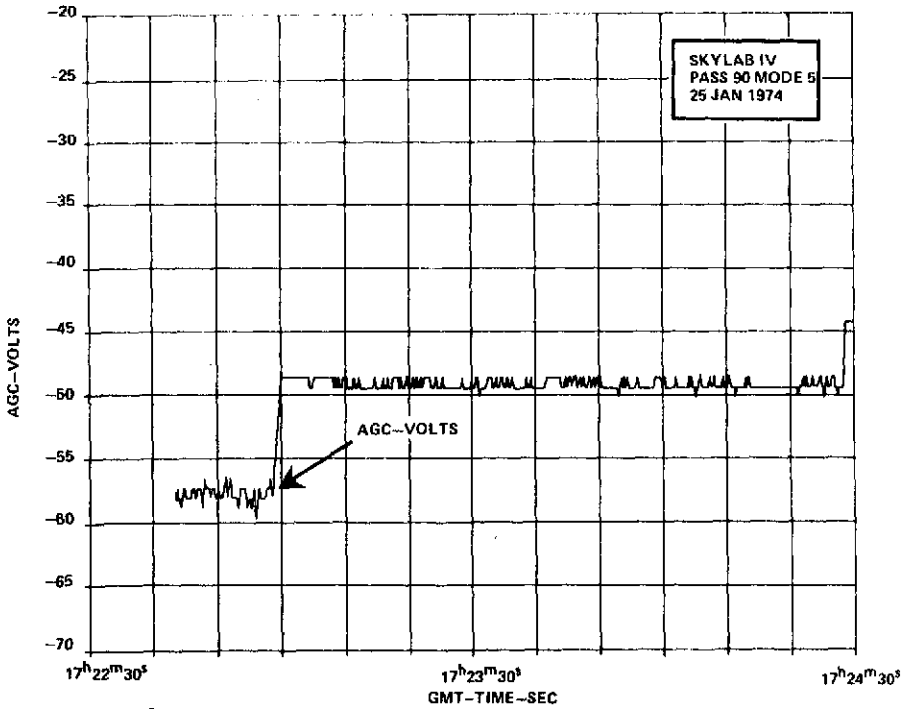

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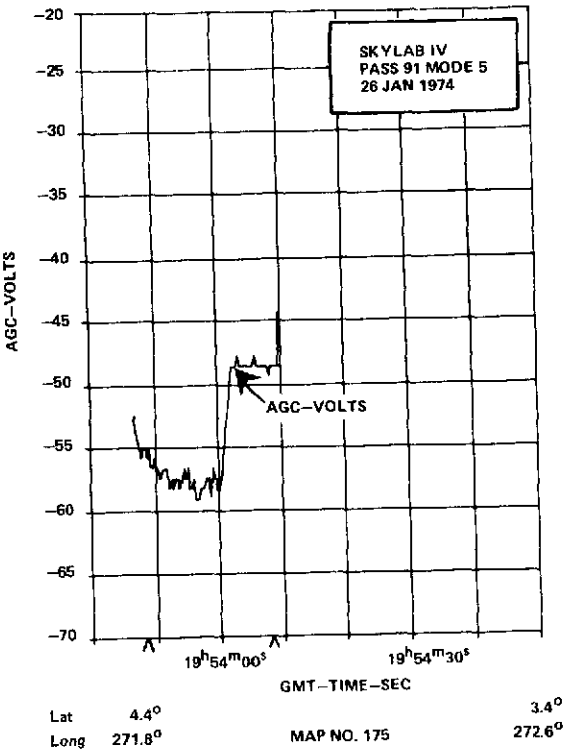
SKYLAB IV
PASS 91 MODE 5
26 JAN 1974
AGC–VOLTS
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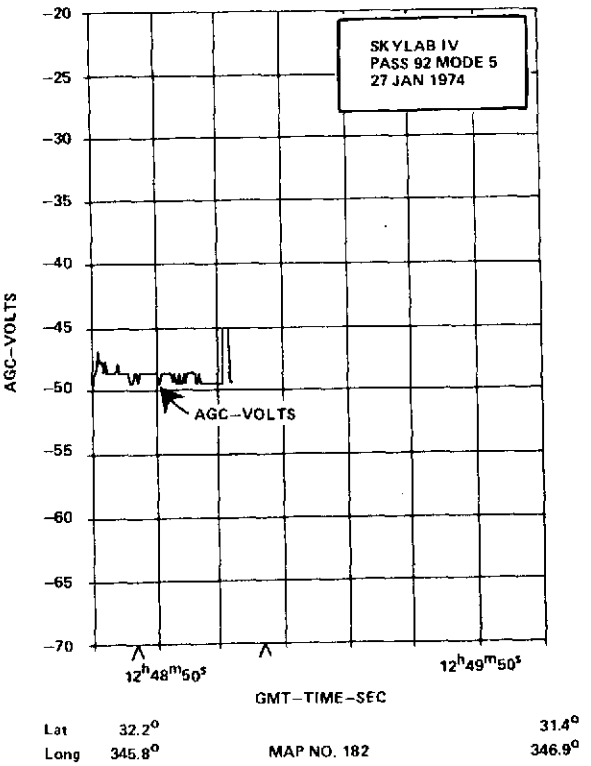
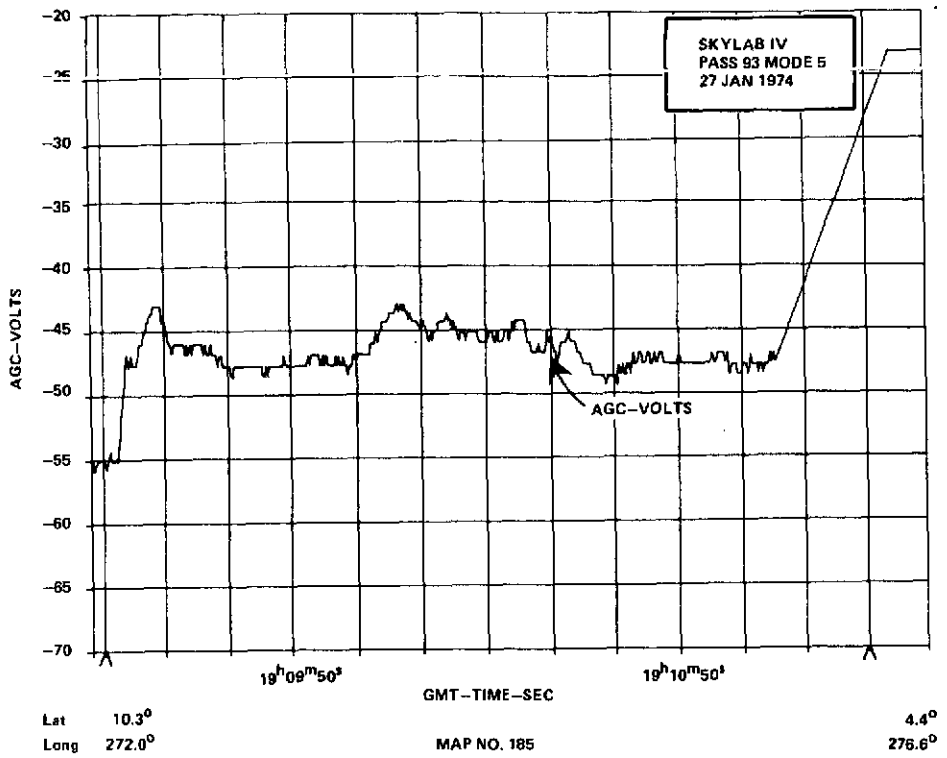
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
19h54m00s
19h54m30s
GMT–TIME–SEC
Lat 4.4°
Long 271.8°
MAP NO. 175
3.4°
272.6°


SKYLAB IV
PASS 92 MODE 5
27 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
12h48m50s
12h49m50s
GMT–TIME–SEC
Lat 32.2°
Long 345.8°
MAP NO. 182
31.4°
346.9°


SKYLAB IV
PASS 93 MODE 5
27 JAN 1974
AGC–VOLTS
–20
–30
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–40
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–50
–55
–60
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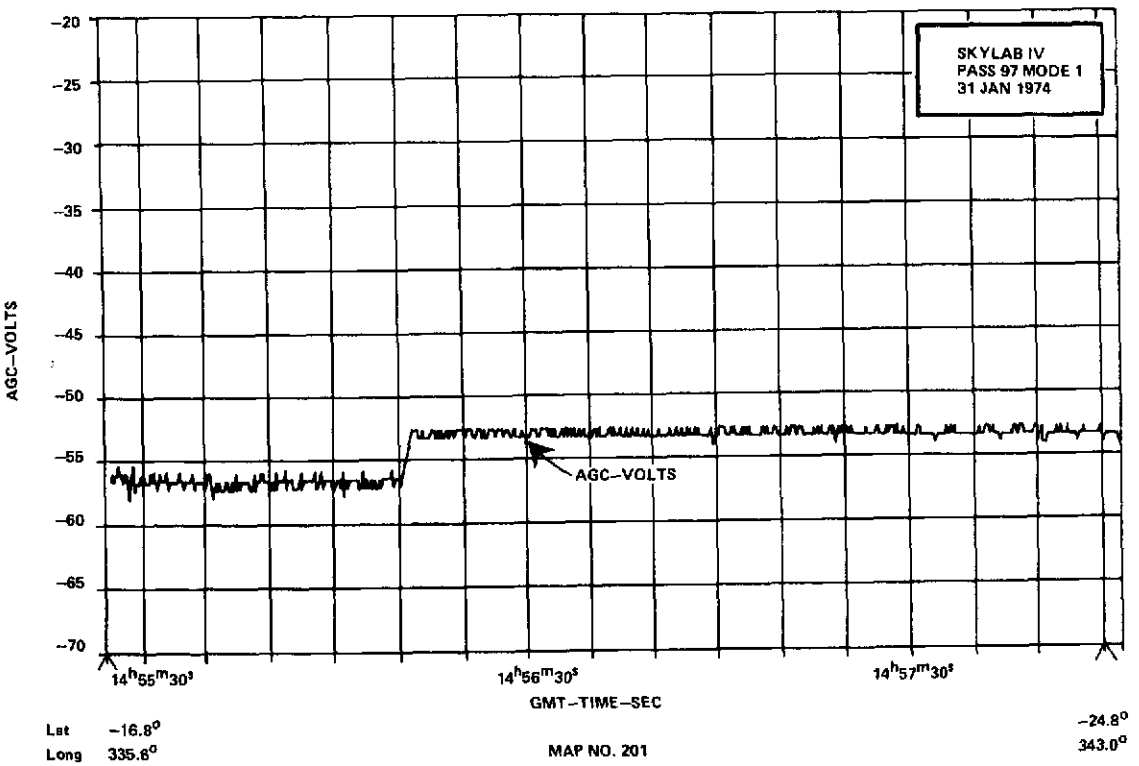
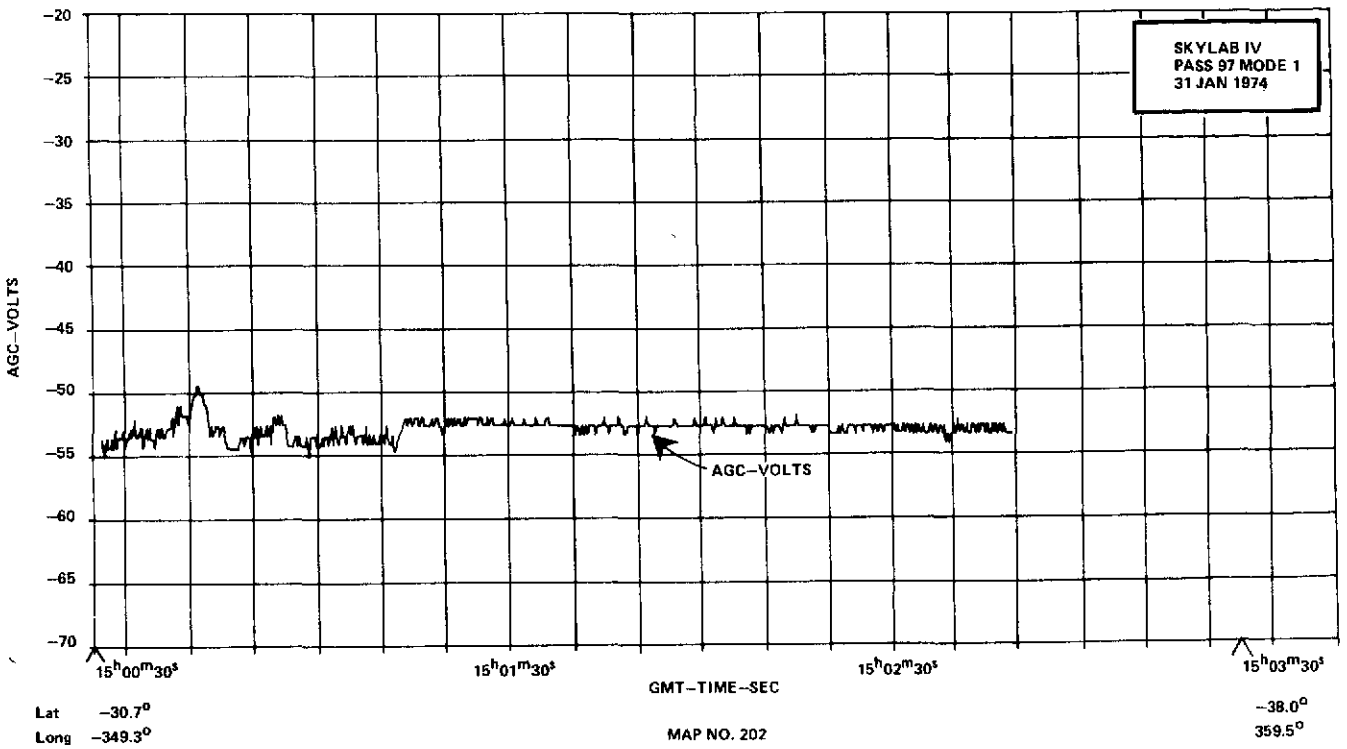
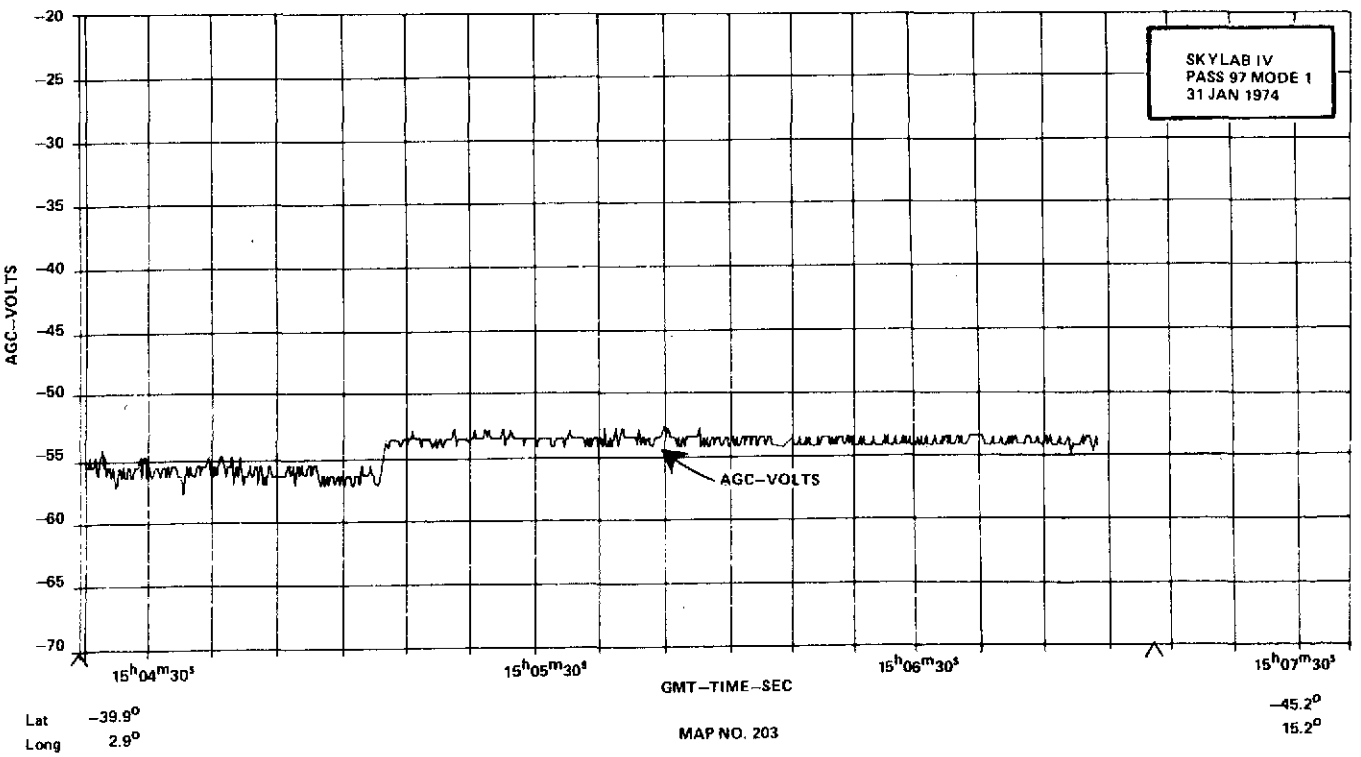
–70
AGC–VOLTS
19h09m50s
19h10m50s
GMT–TIME–SEC
Lat 10.3°
Long 272.0°
4.4°
276.6°
MAP NO. 185

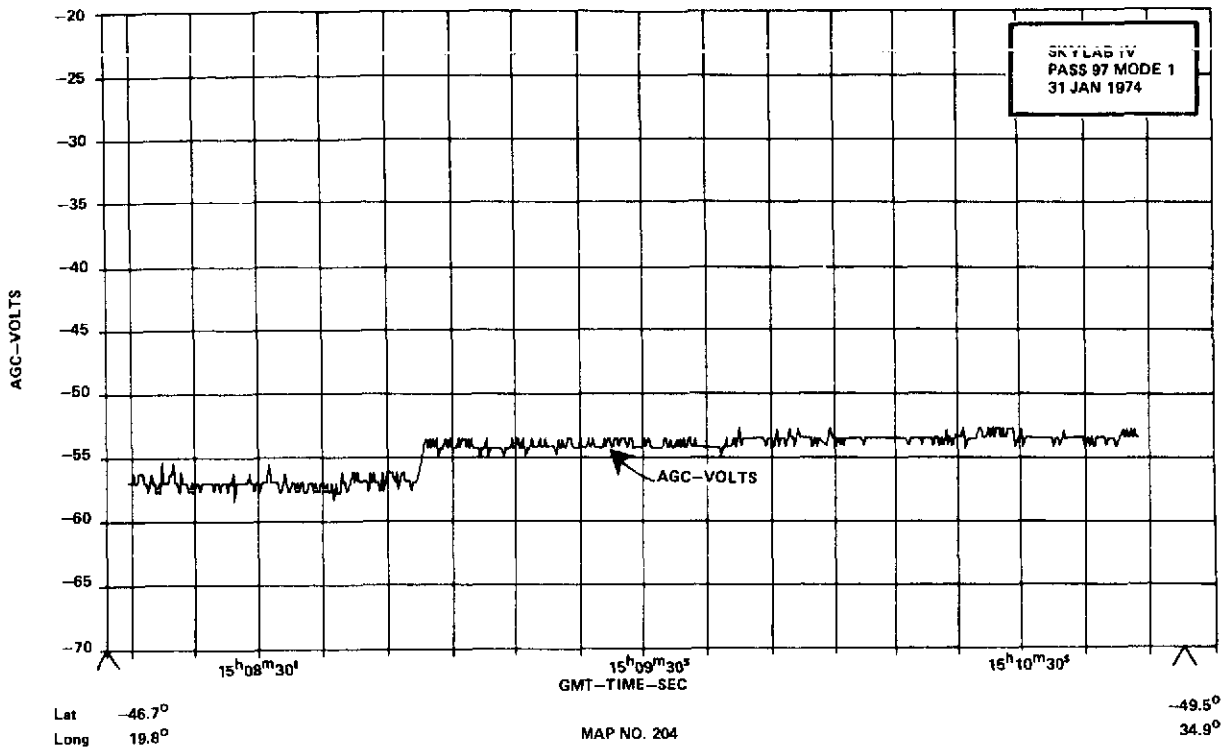

SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
14h55m30s
14h56m30s
14h57m30s
GMT–TIME–SEC
Lat –16.8°
Long 335.8°
–24.8°
343.0°
MAP NO. 201



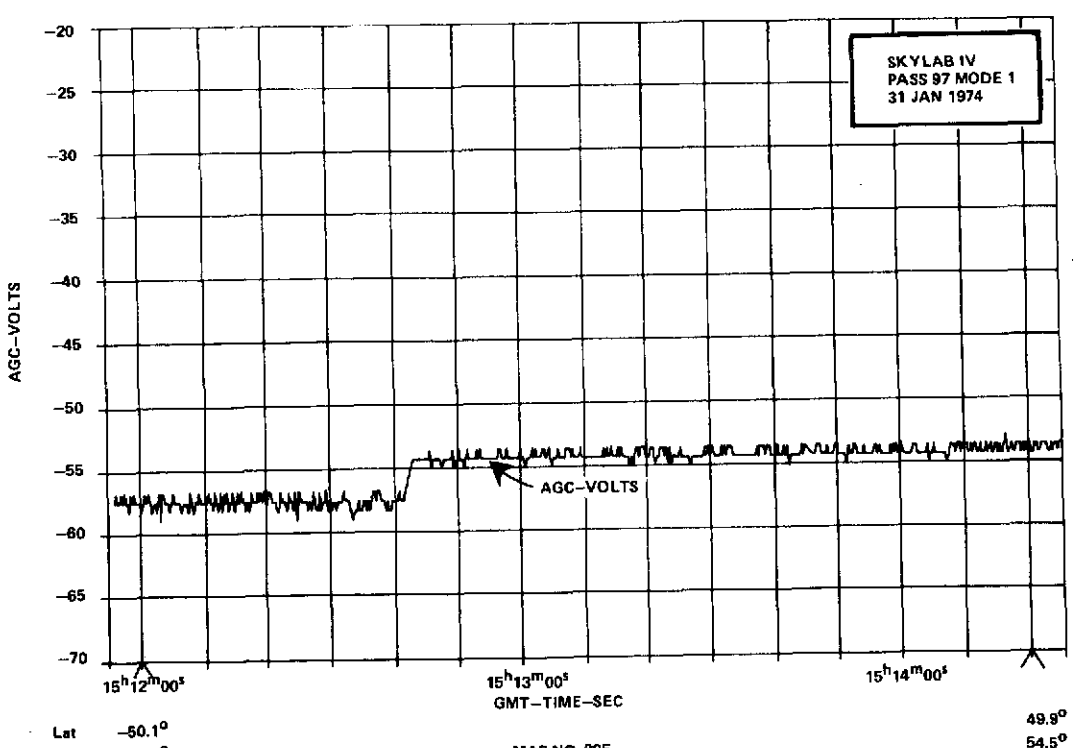
MAP NO. 202



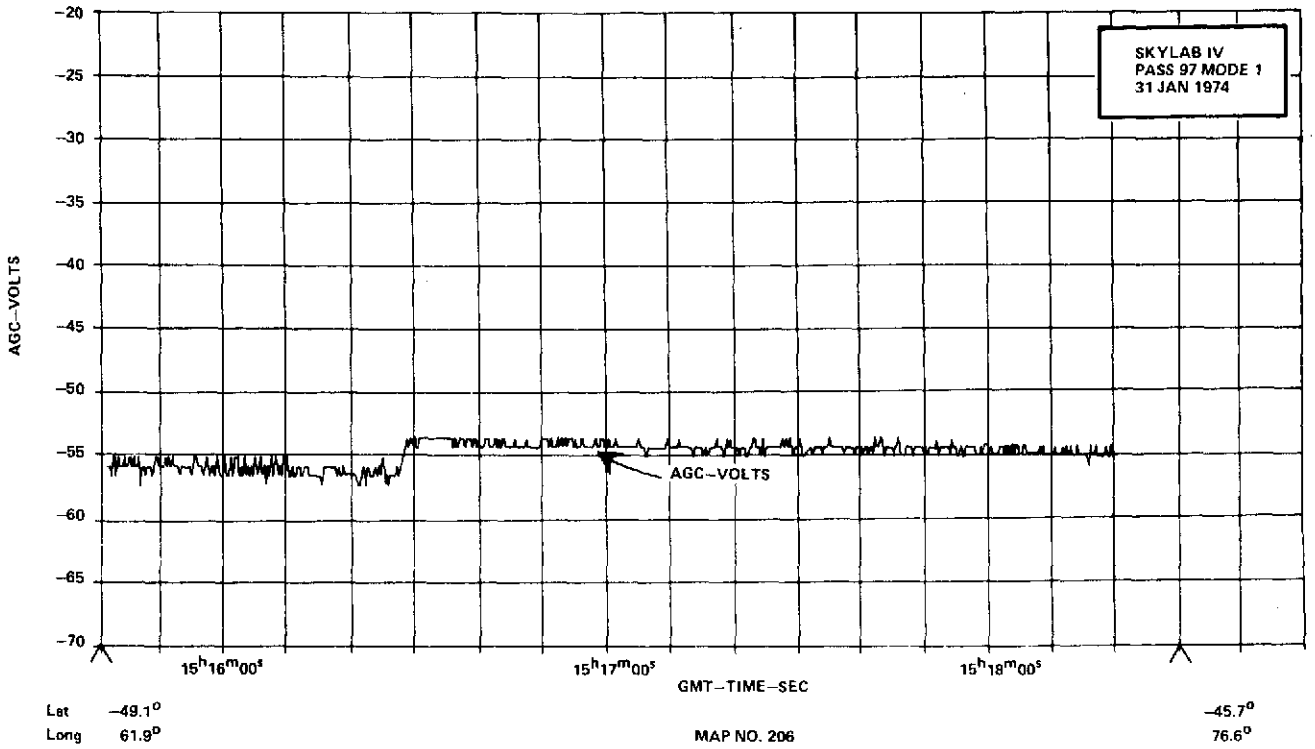
MAP NO. 203



MAP NO. 204

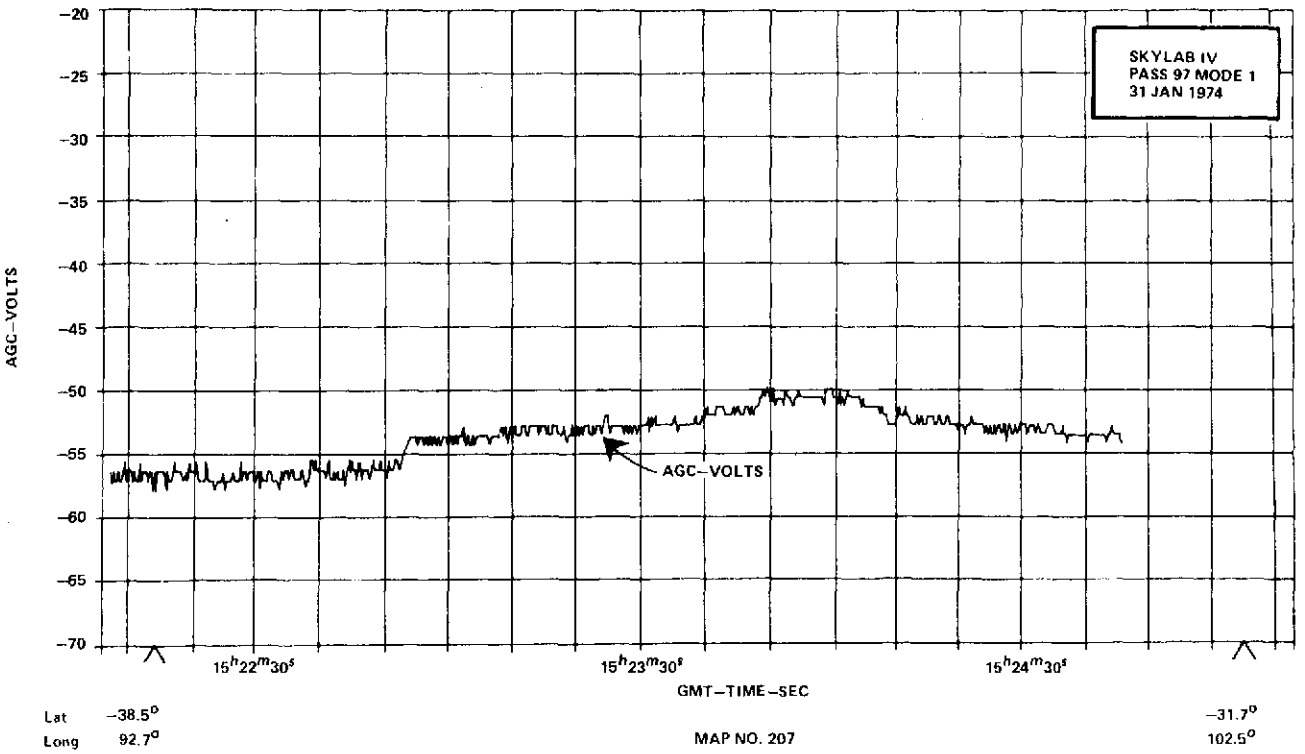


MAP NO. 205



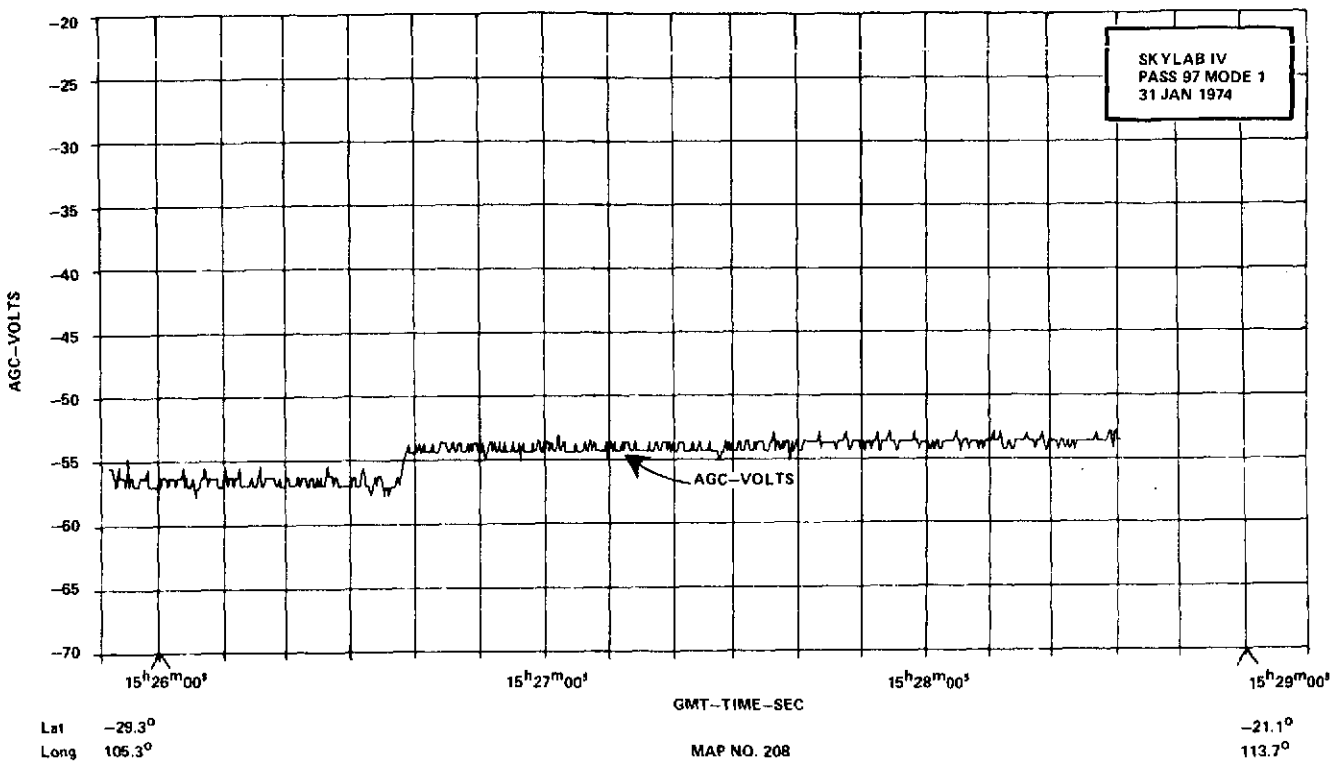
Lat −49.1° −45.7°
Long 61.9° 76.6°

MAP NO. 206

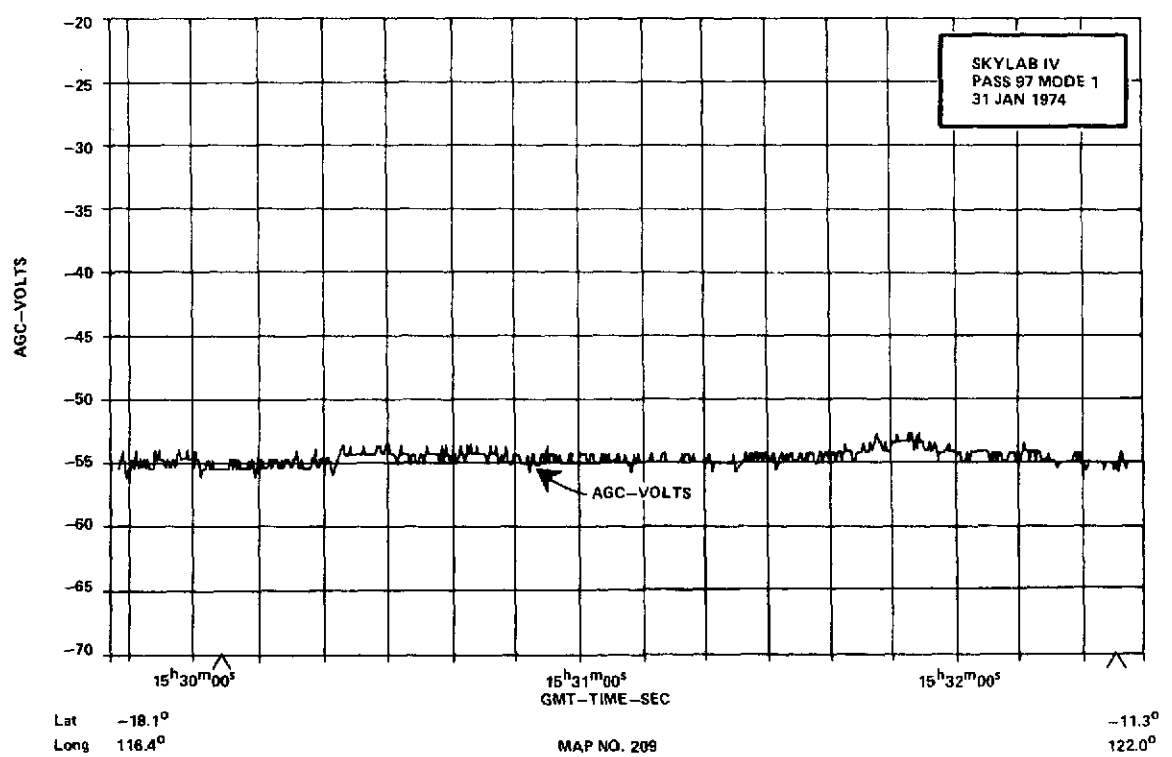


Lat −38.5° −31.7°
Long 92.7° 102.5°

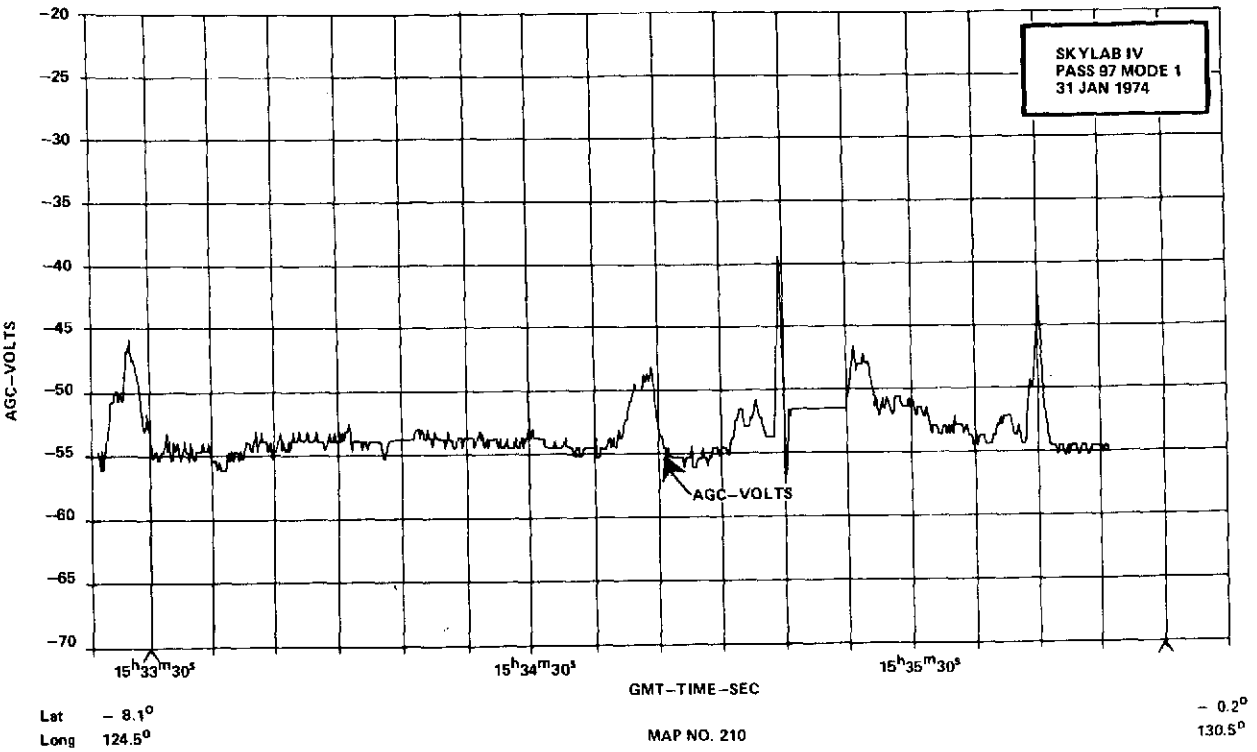
MAP NO. 207



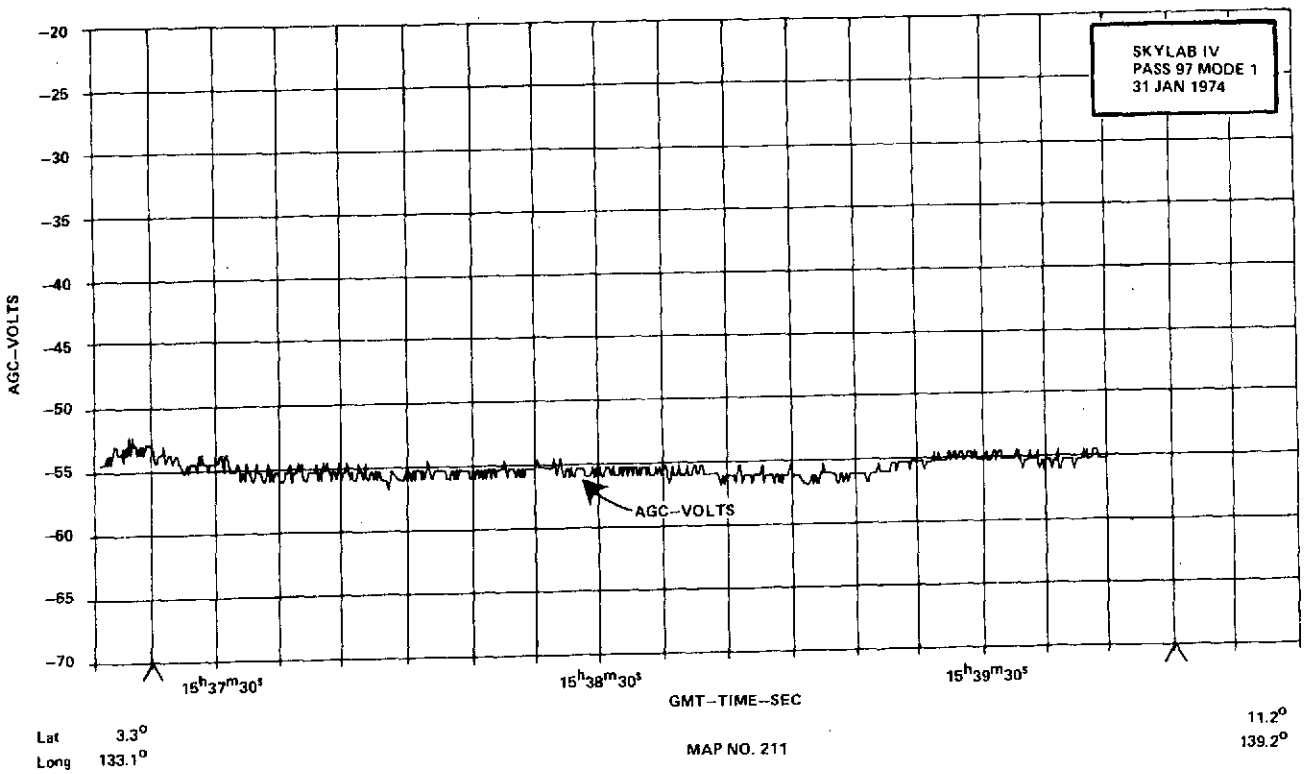
MAP NO. 208



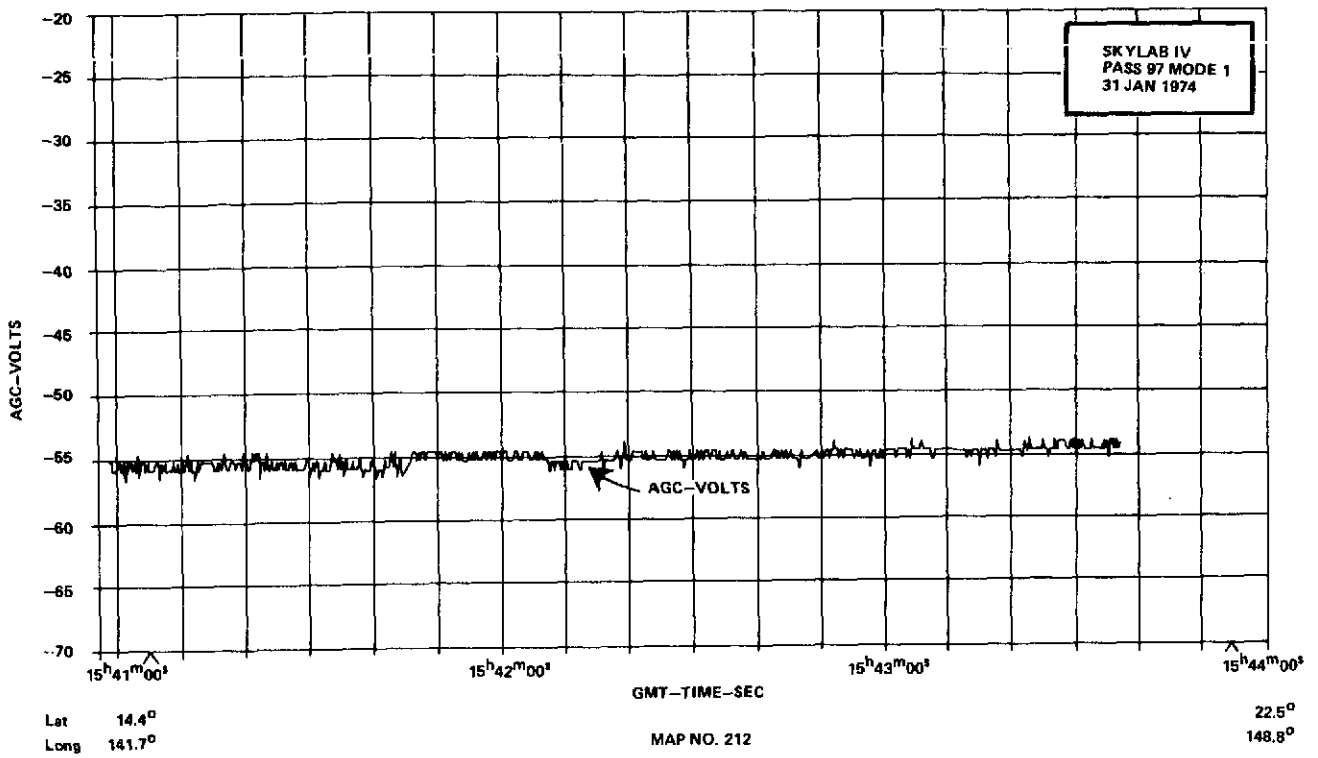
MAP NO. 209



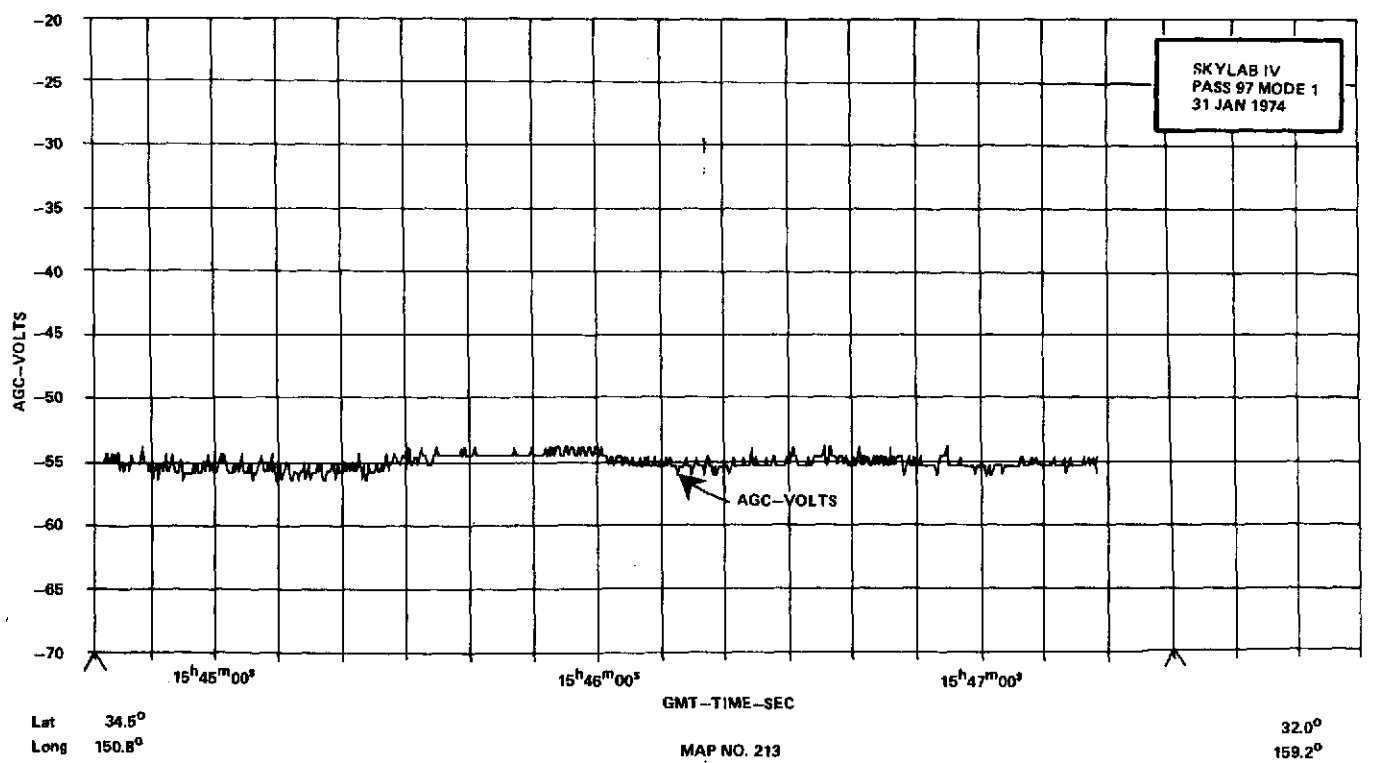
MAP NO. 210



MAP NO. 211



MAP NO. 212



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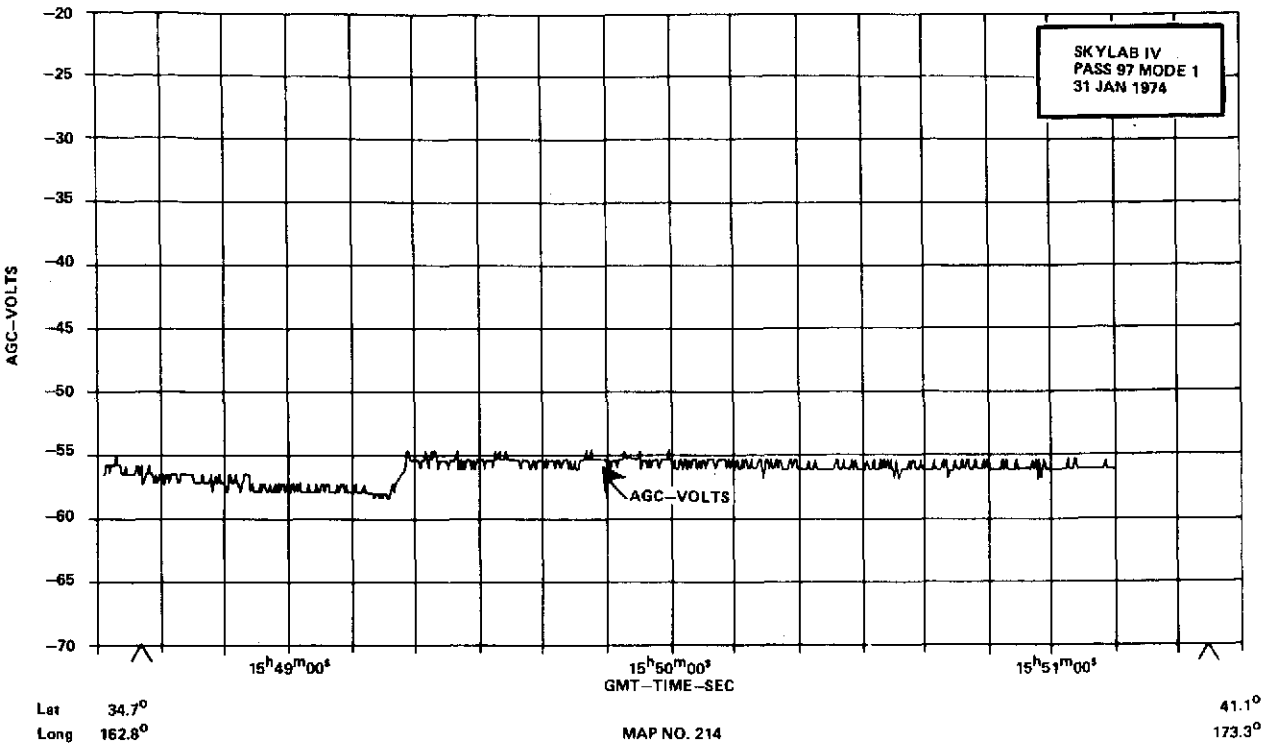

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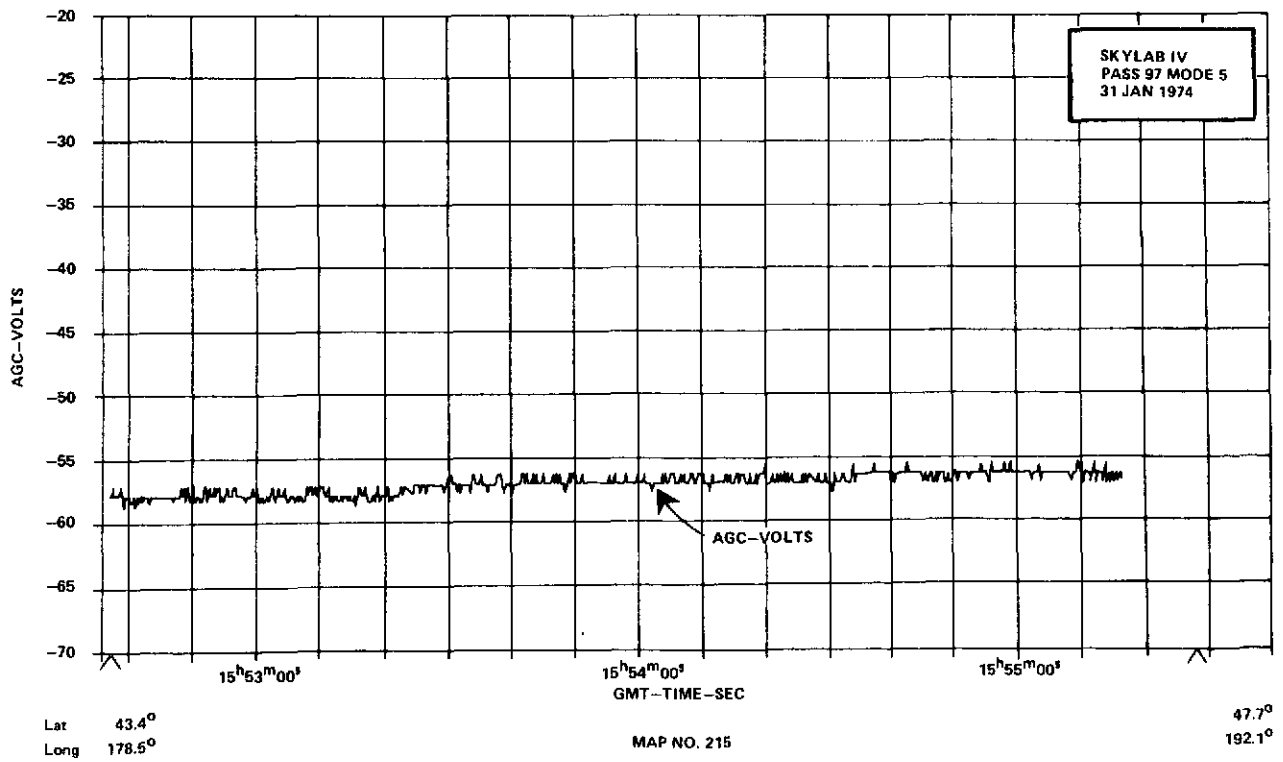

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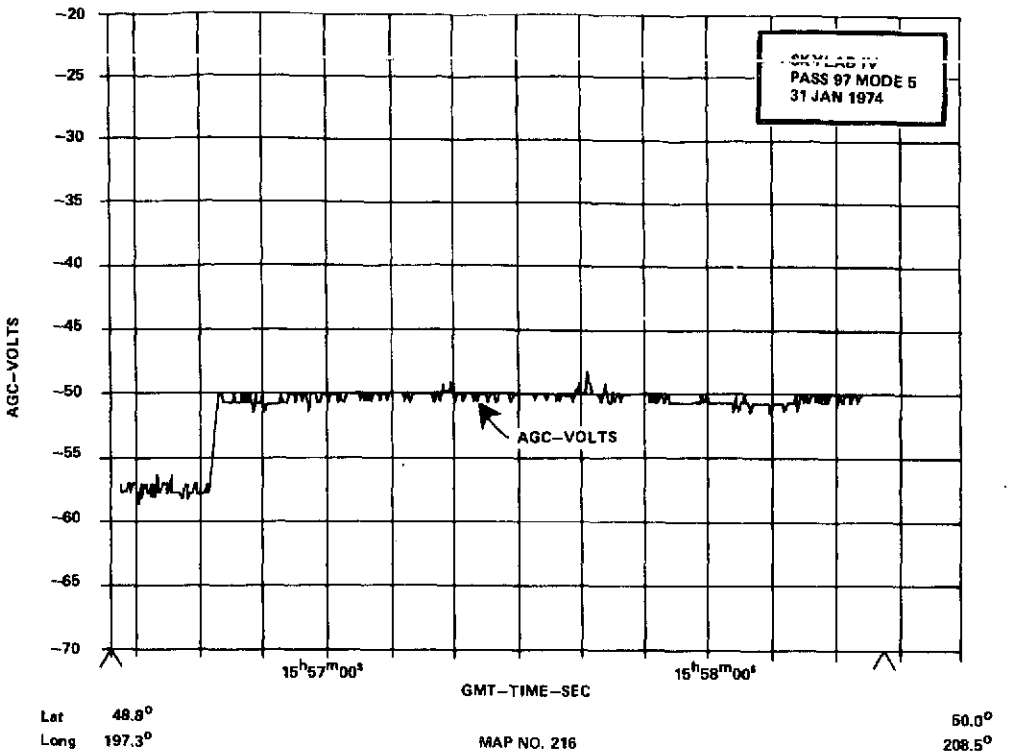
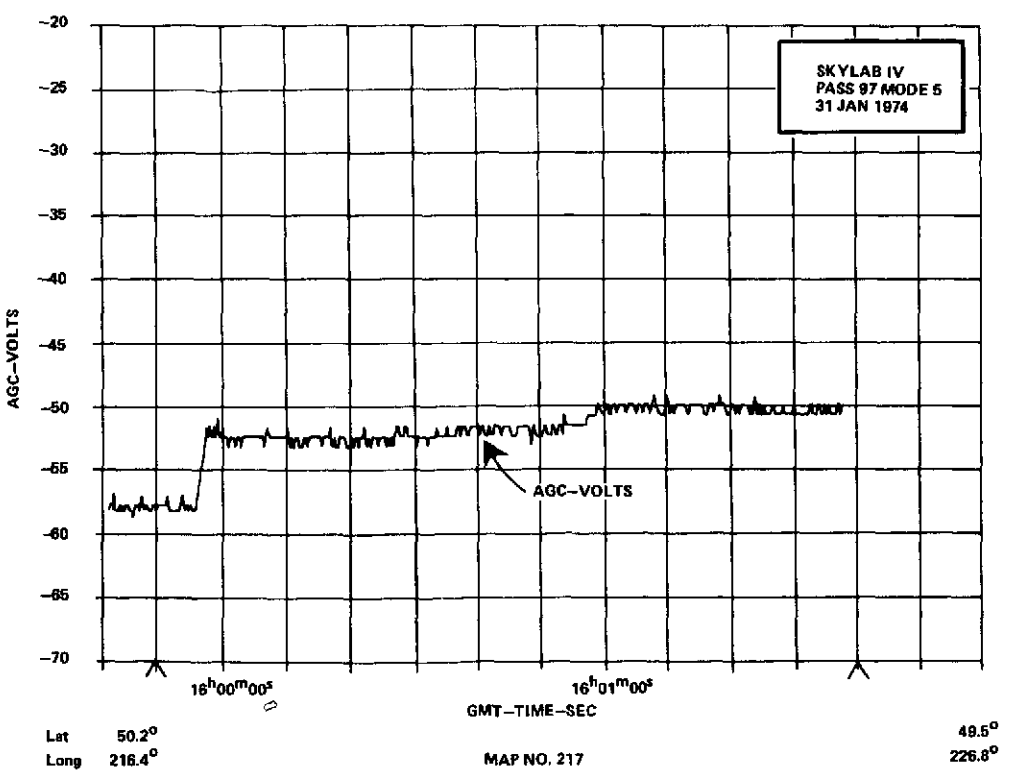
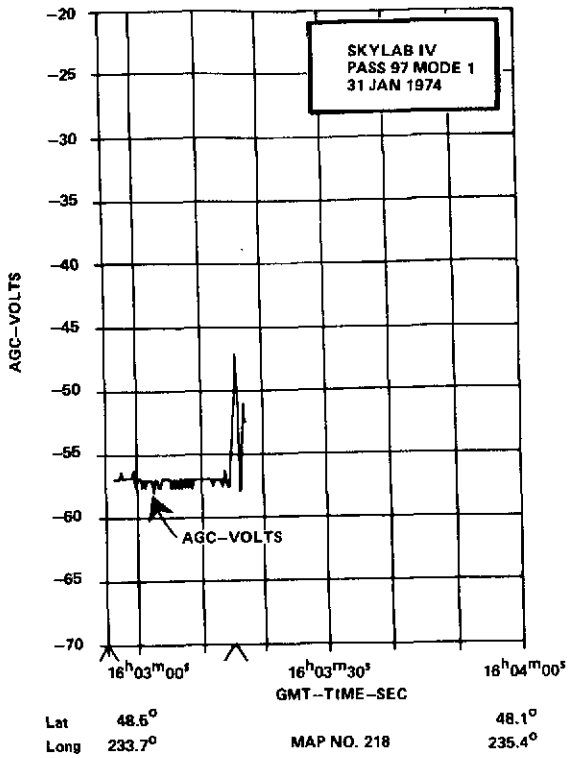

PASS 97 MODE 5
31 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
15h57m00s
15h58m00s
GMT–TIME–SEC
Lat 48.8°
Long 197.3°
MAP NO. 216
50.0°
208.5°


SKYLAB IV
PASS 97 MODE 5
31 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
16h00m00s
16h01m00s
GMT–TIME–SEC
Lat 50.2°
Long 216.4°
MAP NO. 217
49.5°
226.8°


SKYLAB IV
PASS 97 MODE 1
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–30
–35
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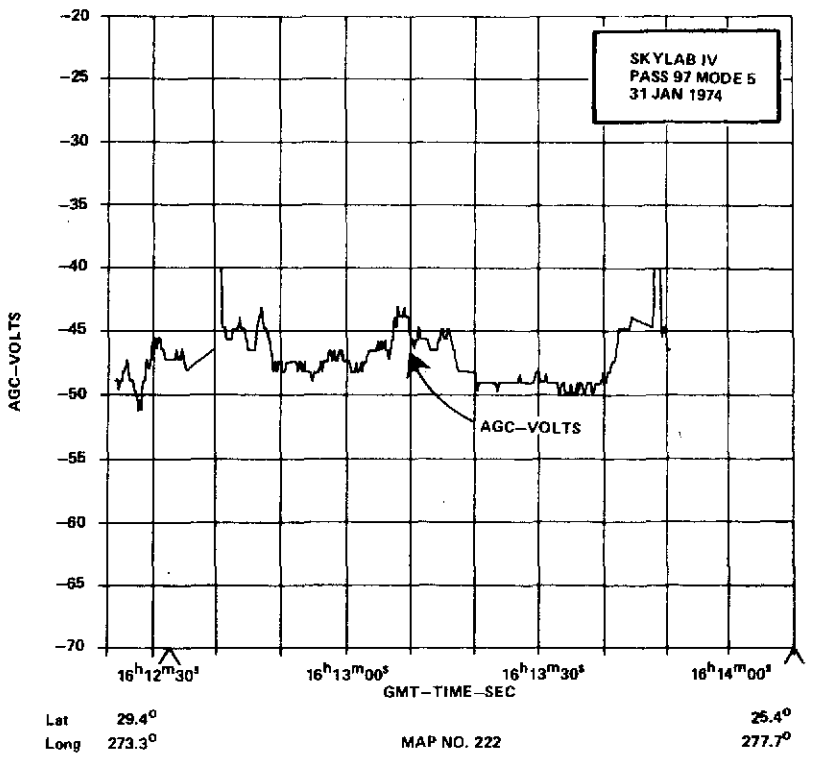
–45
–50
–55
–60
–65
–70
AGC–VOLTS
16h03m00s
16h03m30s
16h04m00s
GMT–TIME–SEC
Lat 48.6° 48.1°
Long 233.7° MAP NO. 218 235.4°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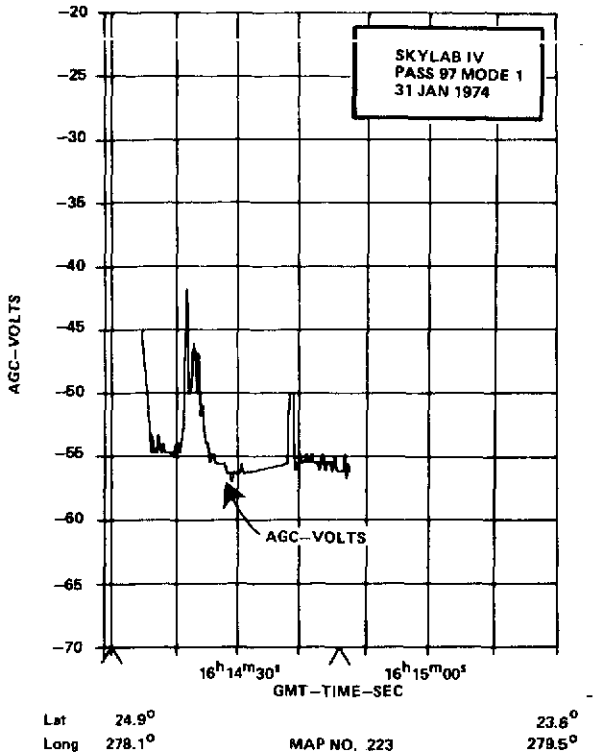
–60
–65
–70
AGC–VOLTS
16h12m30s
16h13m00s
16h13m30s
16h14m00s
GMT–TIME–SEC
Lat 29.4° 25.4°
Long 273.3° MAP NO. 222 277.7°


SKYLAB IV
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–45
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–60
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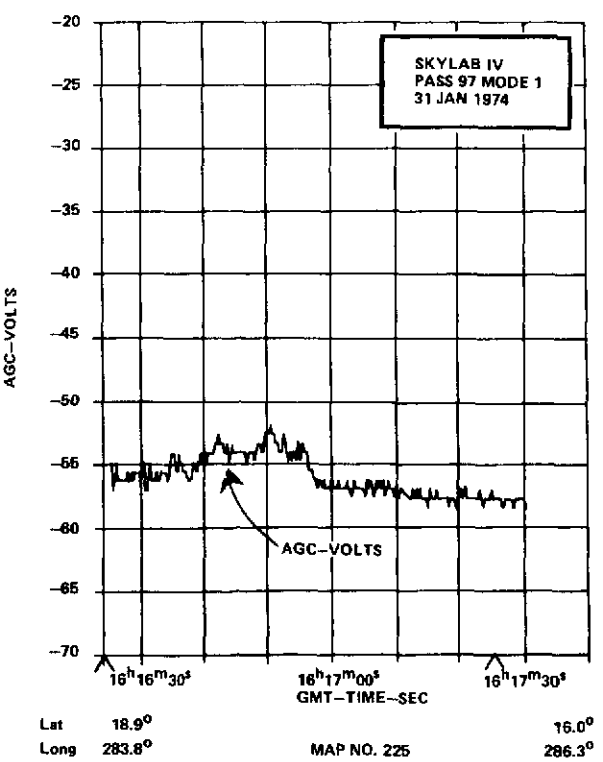
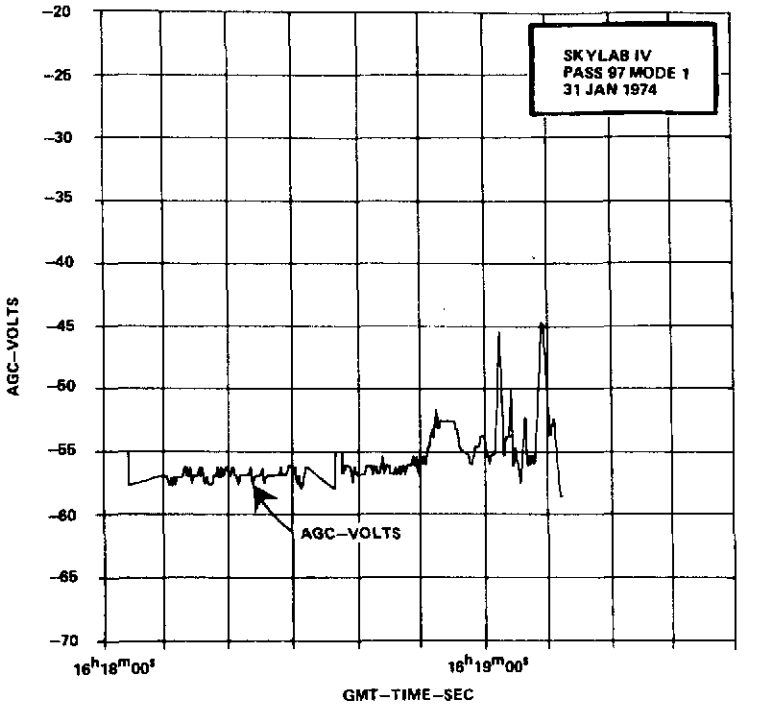
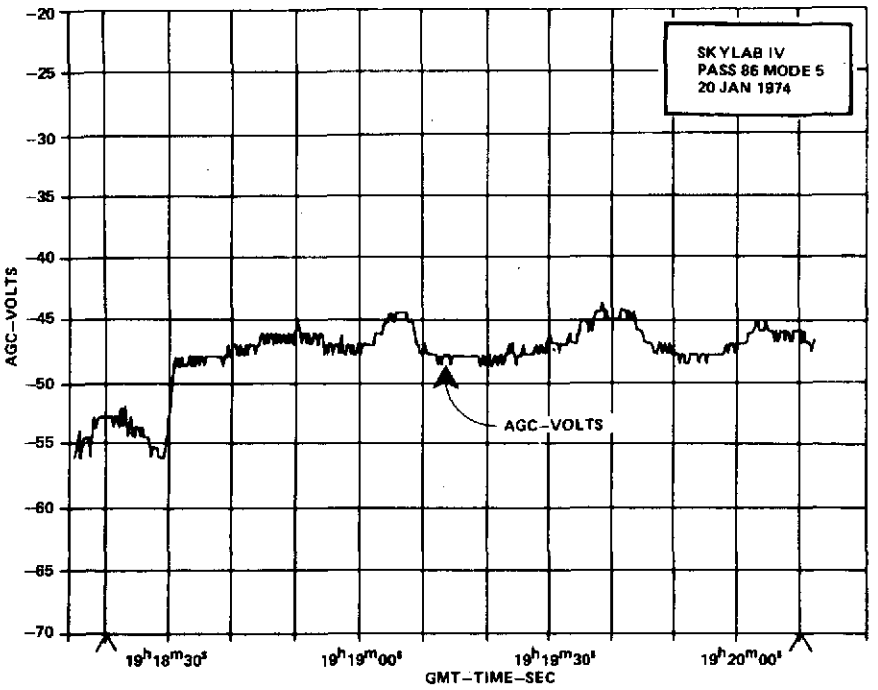
AGC–VOLTS
16h14m30s
16h15m00s
GMT–TIME–SEC
Lat 24.9° 23.8°
Long 278.1° MAP NO. 223 279.5°


SKYLAB IV
PASS 97 MODE 1
31 JAN 1974
AGC–VOLTS
–20
–25
–30
–35
–40
–45
–50
–55
–60
–65
–70
AGC–VOLTS
16h16m30s
16h17m00s
16h17m30s
GMT–TIME–SEC
Lat 18.9° 16.0°
Long 283.8° MAP NO. 225 286.3°



Lat 14.4° 11.4°
Long 287.7° MAP NO. 226 290.0°



Lat 34.7° 30.0°
Long 285.7° MAP NO. 233 291.7°

APPLICATIONS

This section contains some typical ways in which the height data can be utilized. These applications are not intended to be a complete set but are supplied as examples of uses that are readily apparent.

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Correlation with Ocean Floor Topography

During the early phase of the SKYLAB program, the data recorded in the overwater passes off Charleston, S.C., showed abrupt changes in mean sea level which were not immediately obvious in existing geoidal data. Map No. 3 illustrates this effect. Note the 8 meter change which occurs near time $17^h\ 12^m\ 22^s$, also note the Marsh-Vincent geoidal contour. The geoidal data available for use was computed using a 1° x 1° grid. Therefore, to place the altimeter and geoid contours on a comparative basis, the altimeter data was smoothed beyond that required for minimum-mean square error considerations and to a degree which simulates a 1° x 1° resolution. One can easily see that the altimeter has the resolution to detect features that are caused by local topography [9]. Therefore, the altimeter can be used to determine when, where and how to consider local topography in geoid models. In this manner, a large quantity of topographic data can be utilized to improve immediately the resolution of the geoid and might later be used to fill in gaps between satellite altimeter geoid measurements. In addition, in areas where the topography is not well known, the altimeter could contribute to the improved mapping of these features.

Geological Structure

The underwater topography doesn't always correlate with the altimeter measured ocean topography. In fact, since the equipotential gravity field is being measured, the sub-surface structure can cause the surface topography to vary significantly from the sub-surface topography. This effect has been seen off the east coast of the United States and in the Gulf of Mexico.

These areas and similar ones can be geologically important for plate tectonics and geological age studies. In areas where the structure is unknown the altimeter data can be used to test an inferred structure model.

Current Detection

All three parameters (height, waveforms and radar-cross-section) measured by radar altimeters are important for the sensing of currents [2]. The slope of the sea surface perpendicular to the flow for north-south currents should be detectable in the altitude data. The Gulf Stream, for example, has a rise of 1 meter over distances of 50 to 100 km.

Long Arc Analysis

Most of the SKYLAB altimeter missions consisted of two or three individual mode operations per pass. However, one long arc mission was conducted as a climax to the altimetry experiment. This long arc (approximately one revolution, or approximately 35,000 km) pass of radar altimeter data has provided a new comparison for long wavelength features of geoids determined from existing gravity fields and new instrumentation technology for satellite altimetry.

Since the SKYLAB instrument [1,2], [4] and [7] was designed to operate in short, predetermined modes that sequence through a routine of data taking, calibration, and automatic turn off. Therefore, the mission had to be run in a series of short arcs. For that reason the data obtained contains gaps where tracking is re-initialized. The revolution was chosen to maximize tracking coverage (to obtain good orbit determination) and to minimize overland data. However, there was a section of the pass over the United States that created an additional data gap.

The S-193 SKYLAB radar altimeter was operated in a round-the-world pass on January 31, 1974 over a ground track starting off the coast of Brazil and ending in the Carribean Sea (figure 15). The rationale in planning this mission was that the long arc would test the instrument stability over a longer time interval and would provide an independent test of existing gravity models.

Figure 16 presents a geoid profile based upon the global altimeter pass along with detailed geoid profiles computed using the SAO-3 [10], OSU [11], and GEM-6 [8] models. For cross referencing the more detailed individual short arc altimeter residual plots, the map numbers are included in the figure. The overall level of agreement is exceptional. It should be emphasized that no adjustment of scale has been made to the altimeter for this comparison. This indicates that the altimeter geoid not only agrees well in general shape, but also it is evidently well calibrated in scale.

Previous analyses have demonstrated that the satellite altimeter could measure high frequency undulations of the geoid such as the Puerto Rico trench and sea mounts [2,12]. This around-the-world pass shows potential for measuring intermediate and low frequency geoid undulations. In addition, it can be seen that a long arc might have advantages in determining altimeter bias or for detecting trending. For future satellites where long arcs will be more prevalent, tracking coverage will almost certainly be poorly distributed for some passes. Therefore, extreme care should be used in building orbits for these passes, e.g. using altimeter data in the orbit solution. Perhaps the pass will have to be broken into a series of short arcs using a optimum set of stations for each short arc.

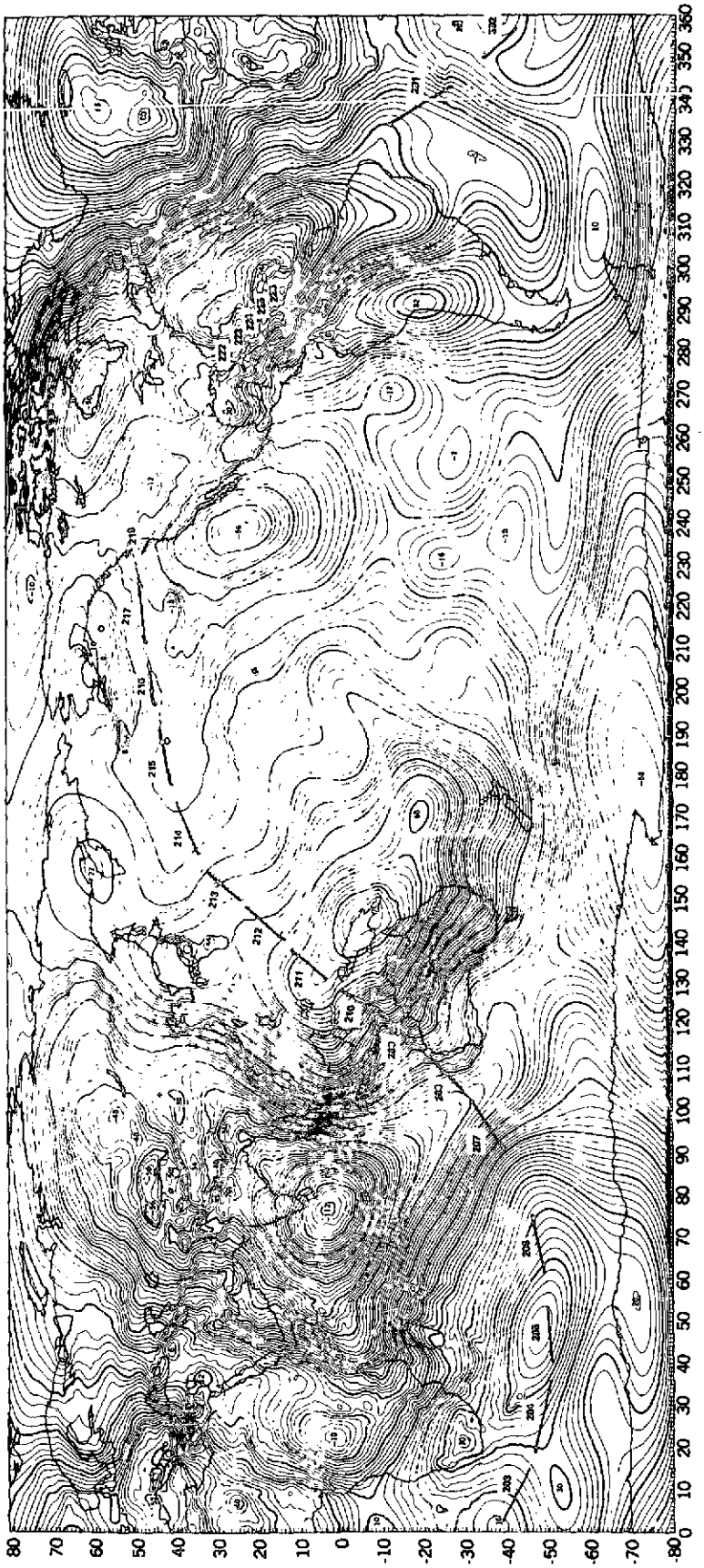

FIGURE 15. ROUND-THE-WORLD GROUND TRACK STARTING OFF THE COAST OF BRAZIL AND ENDING IN THE CARIBBEAN SEA

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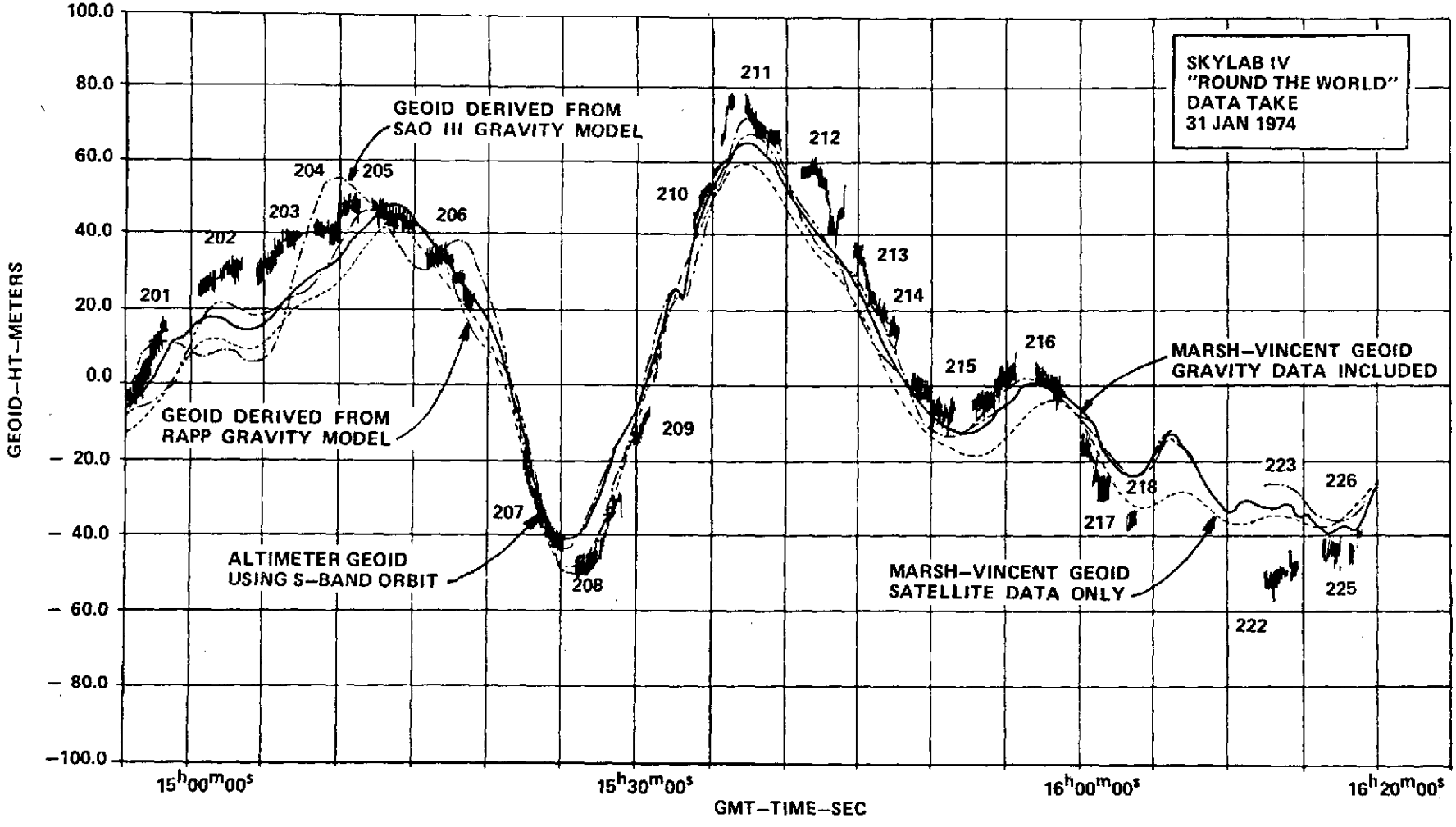

FIGURE 16. "ROUND THE WORLD" DATA TAKE

Geoid Construction

To construct a geoid from altimeter data, several techniques can be employed. The most obvious one would be to assemble the data from numerous passes and apply an interpolation scheme between the data to form a continuous topographic contour map. These contours should form the geoid. Some examples of such a geoid are shown in Figures 16 and 17. The problem in using this technique is that the geoid is very dependent on the absolute accuracy of the orbit. The ground tracks and altimeter geoid values used are shown in Figures 18 and 19, respectively.

Another way would be to lace high density altimeter data together as shown in Figure 20. In this method the altimeter data is constrained to tie-in with itself at regular intervals, and the geoid determined only depends on the orbit shape being accurate over short arcs (the interval length). The geoid constructed in this manner should be shaped correctly but might have an overall bias.

Perhaps some combination of these methods would be superior to either. In addition, one might consider using underwater topography and geological structure to improve this interpolation between the altimeter data passes.

To assess the quality of the geoid constructed, independent alimeter passes over the geoid can be used to test the shape, and a histogram of absolute heights over various grid areas will help establish the repeatability. The absolute accuracy will have to be measured in areas where a high confidence in the absolute height of the ocean surface and the orbit height can be established.

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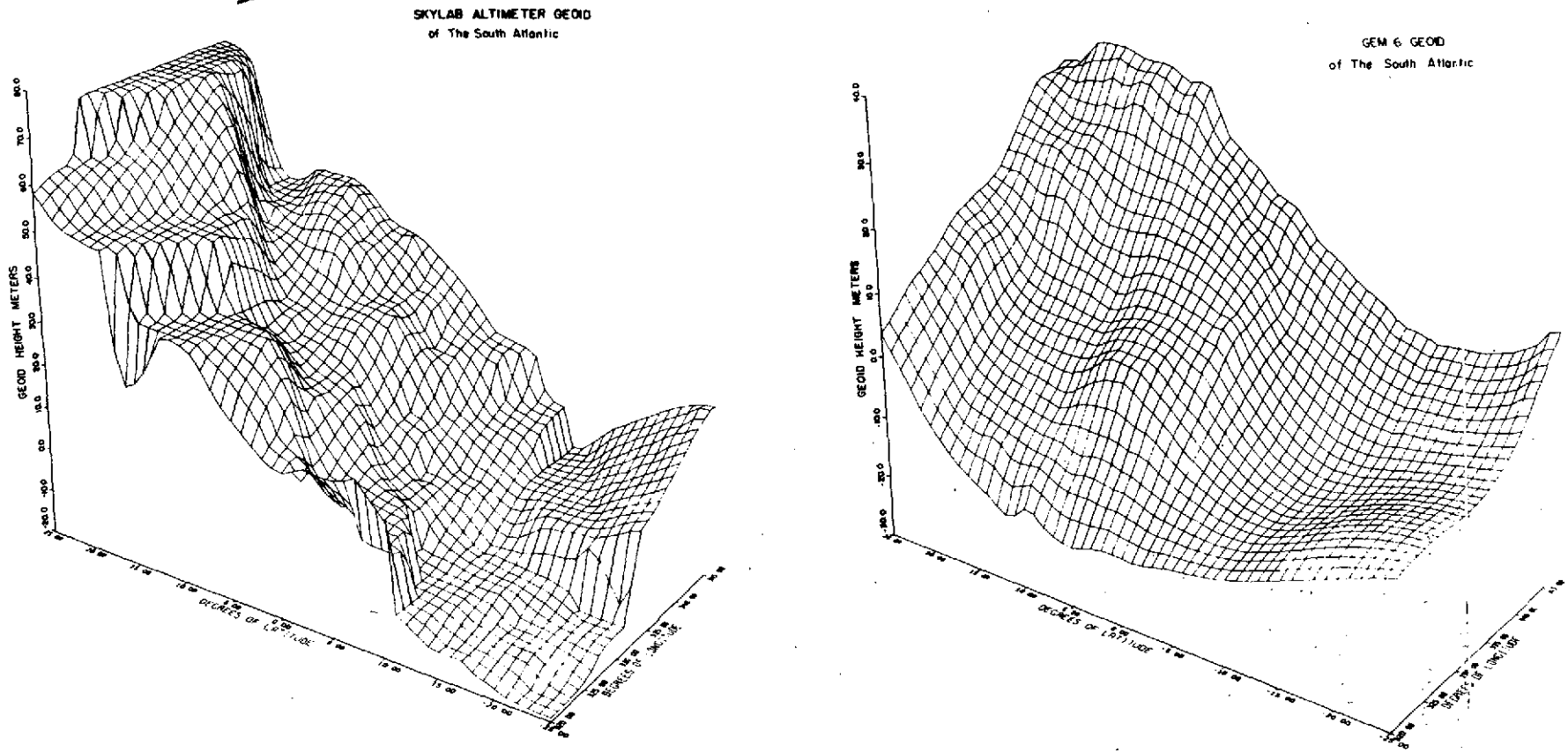

FIGURE 17. SKYLAB ALTIMETER GEOID AND GEM–6 GEOID OF THE SOUTH ATLANTIC

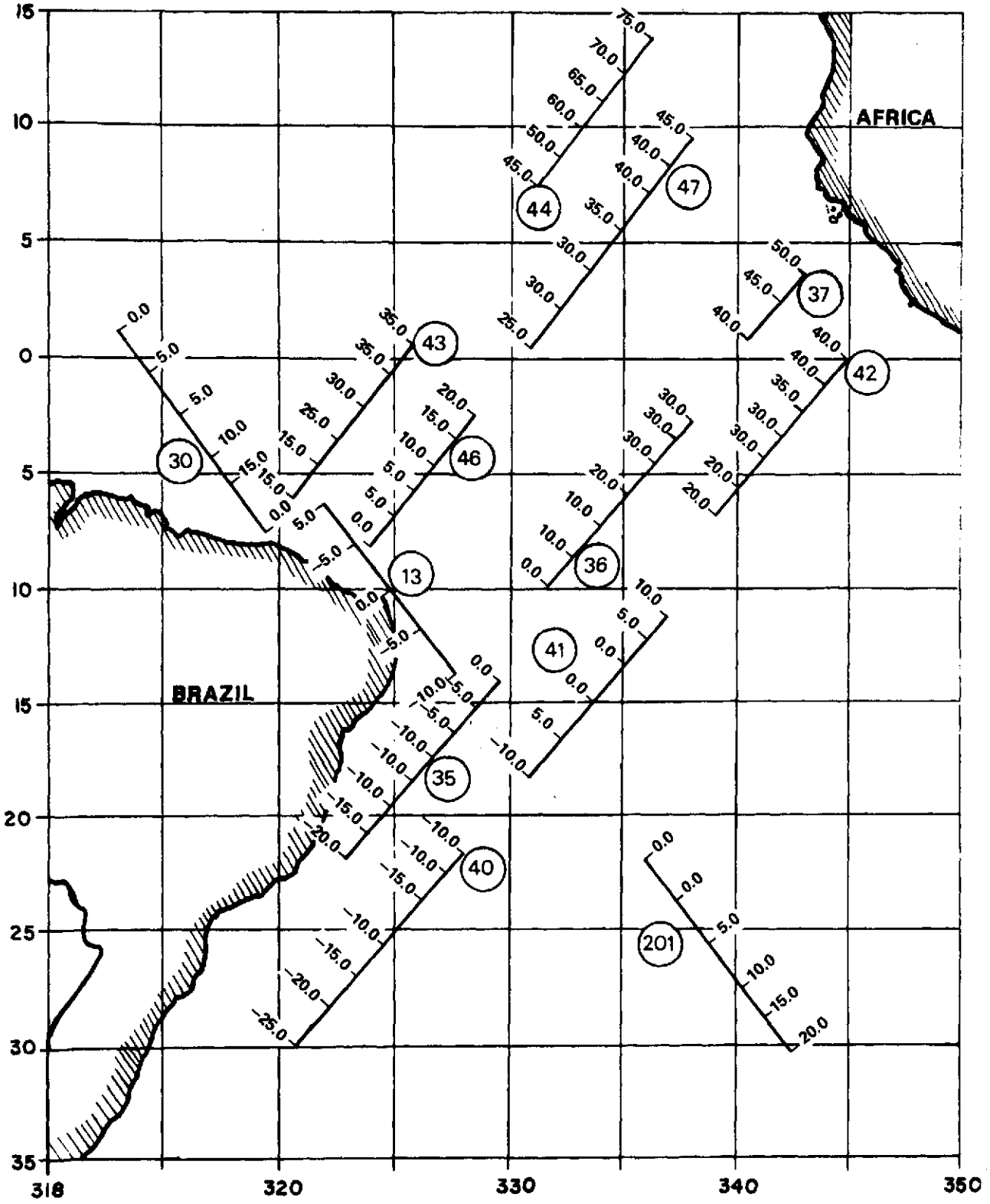

FIGURE 18. GROUND TRACKS AND ALTIMETER GEOID VALUES USED FOR DETERMINATION OF ALTIMETER GEOID FOR SOUTH ATLANTIC AREA

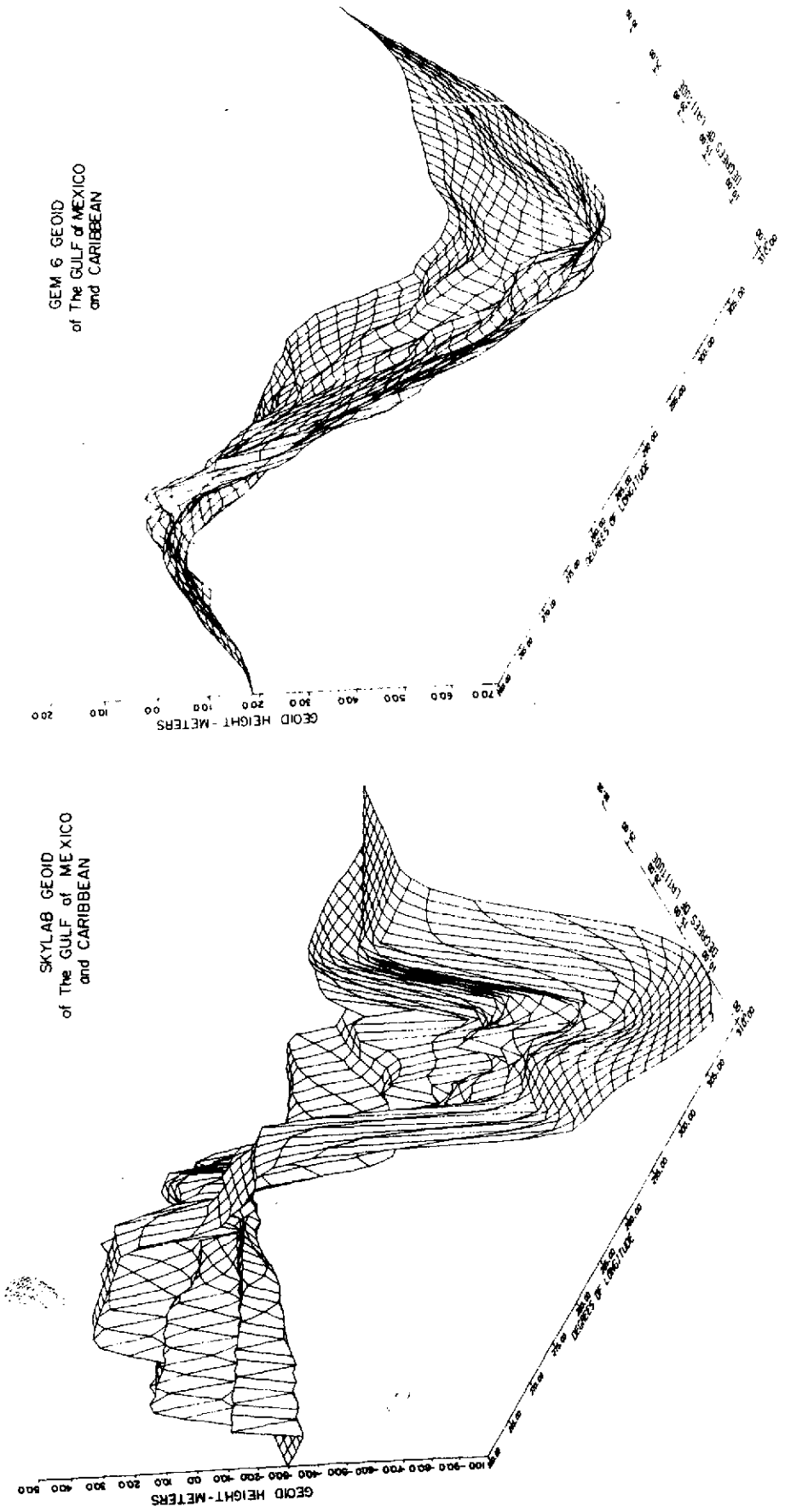

FIGURE 19. SKYLAB GEOID AND GEM–6 GEOID OF THE GULF OF MEXICO AND CARIBBEAN

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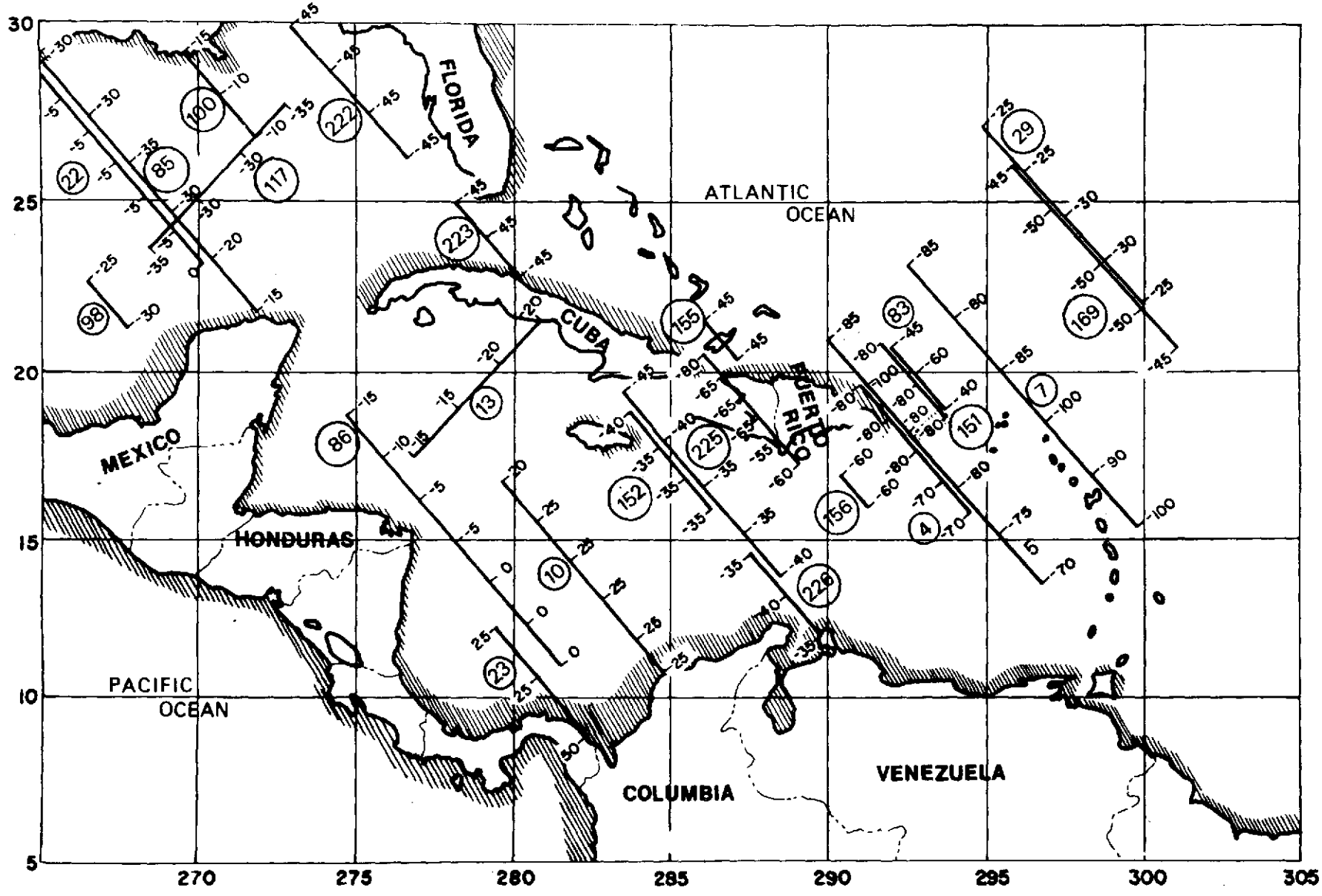

FIGURE 20. GROUND TRACKS AND ALTIMETER GEOID VALUES USED FOR DETERMINATION OF ALTIMETER GEOID FOR GULF OF MEXICO AND CARIBBEAN

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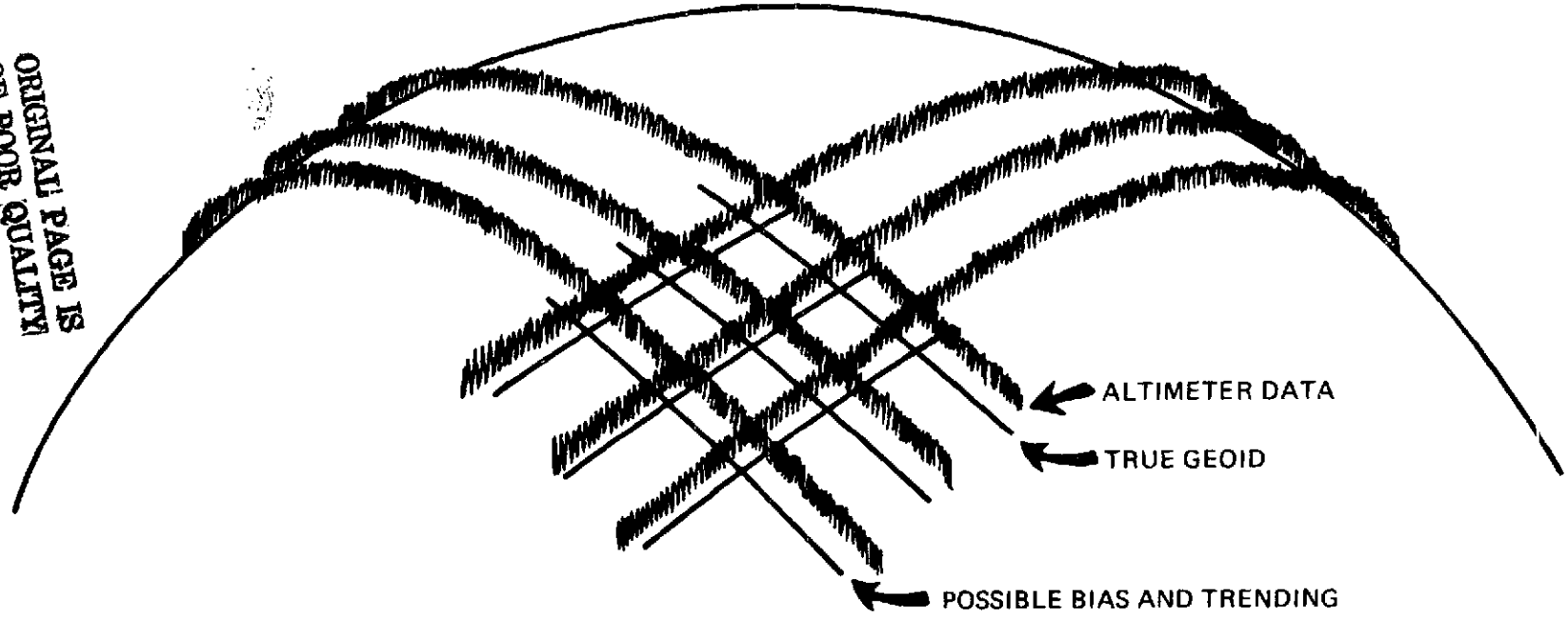

FIGURE 21. GEOID FORMED BY ADJUSTING OVERLAPPING ALTIMETER DATA

Altitude Data Filtering

The plots of altimeter measured geoid heights as a function of time, exhibit a characteristic noisy time series indicative of a typical range servo tracking a signal competing with a noise environment. An estimate of this noise has been calculated to be approximately one meter for data sets when the pointing is good.

Figure 21 displays a power spectral density computed using Fourier Transform methods and a Hanning type window. The altitude data used to compute the spectrum was obtained from SL-2, Pass 4 when the altimeter was passing over the Puerto Rico trench. The arrow corresponds to the density level for which a 3.3 Hz rectangular bandwidth white noise spectrum would yield an rms level of one meter. Since the S-193 tracker has an approximate 3.3 Hz equivalent noise bandwidth, this level is consistent with observed rms noise levels in raw data of one meter [12]. Also note that the spatial filter function [5] arising from the finite zone illuminated by the altimeter corresponds to considerably shorter wavelengths (less than 10 km) and that the calculated PSD should not be contaminated by the altimeter footprint.

The PSD data given may be used to derive altimeter data processing guidelines. Under the assumption of Gaussian statistics, or if a minimum-mean-square linear estimate is desired; the Wiener-Hopf formulation for additive noise measurements shows that the optimum filter $H_o(f)$ transfer function is

$$H_o(f) = \frac{S(f)}{S(f) + N(f)}$$

where S(f) is the geoidal spectrum and N(f) is the additive noise spectrum. As discussed in [13], Kaula's model of one dimensional spectral behavior behaves as f^{-3}. The observed spectrum, S(f), is asymptotic to an approximation of S(f) defined by

$$S(f) = \frac{5.24 \times 10^{-4}}{f^4 + 1.75 \times 10^{-3}} \quad ,$$

and depicted as a dashed plot in figure 21. Solving for the half-power value of $H_o(f)$, it is found to be 0.164 Hz. Using the satellite ground track velocity, this may be expressed as a 45 km wavelength. Therefore, it is concluded that this analysis shows for geoidal regions which contain pronounced short wavelength components, that (1), the Skylab altimeter is limited by measurement noise in profiling wavelengths much below 45 km and (2), data smoothing time constants of several seconds are required to adequately reduce the random error in geoid undulation measurements. This analysis can readily be extended to yield two-sided weighting functions [14], which are applicable to smoothing solutions using both past and future observations--as is appropriate for digital computations.

Certain applications, like ocean current detection, dictate that the raw altimeter data be filtered prior to looking for the signal, since a one meter change over a 100 km wavelength is of the same order as the noise. Ocean geoid computations in general have the same problem, when short wavelength features are sought. Reference [12] shows that the lowest possible noise reduction is to 30 cm without distorting the data.

Figure 22 shows the filtered altimeter-measured geoid heights for SL-2, Pass 9, Mode 5 using a 41 point, frequency constrained, mid point filter. The altimeter was passing over the Gulf Stream at the time noted (from NOAA 2 IR data). Note the agreement of the high frequency components in the altimeter data with the GEM-6 geoid (calculated with 10 minute by 10 minute mean anomalies.) On the other hand, no distinct ocean surface elevation change is seen in the vicinity of the Gulf Stream. Therefore, one or more of the following are conjectured.

1) The instrument is not precise enough for the experiment,
2) the ocean geoid is not known well enough,
3) repeated data sets are required to extract a signal having such a small amplitude or
4) no slope exists when passing over the Gulf Stream.

Since 4 is incorrect, either one or more of the first three reasons explain the lack of obtaining a significant result.

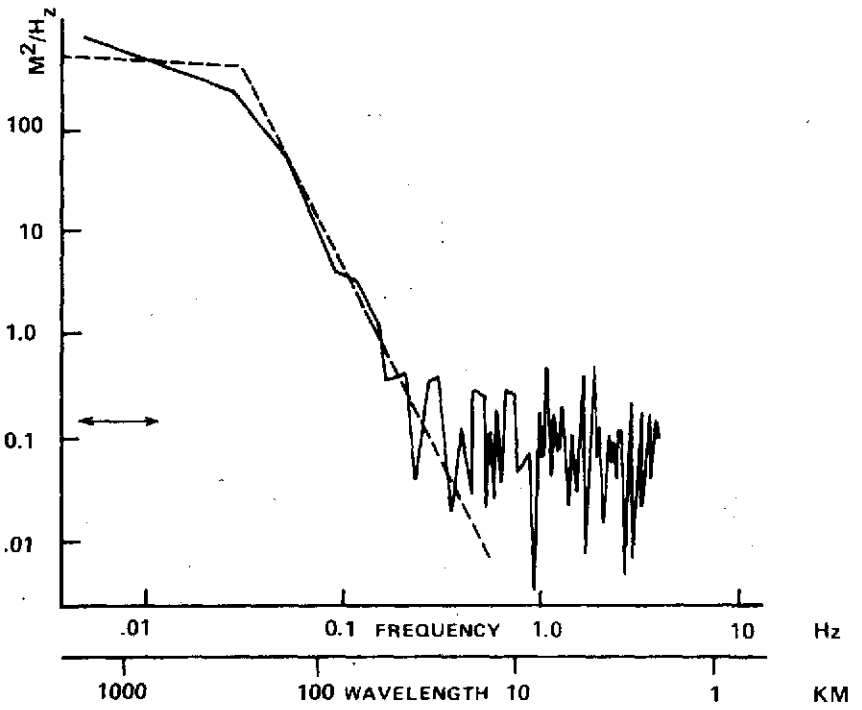

FIGURE 22. POWER SPECTRAL DENSITY COMPUTED USING FOURIER TRANSFORM METHODS AND A HANNING TYPE WINDOW

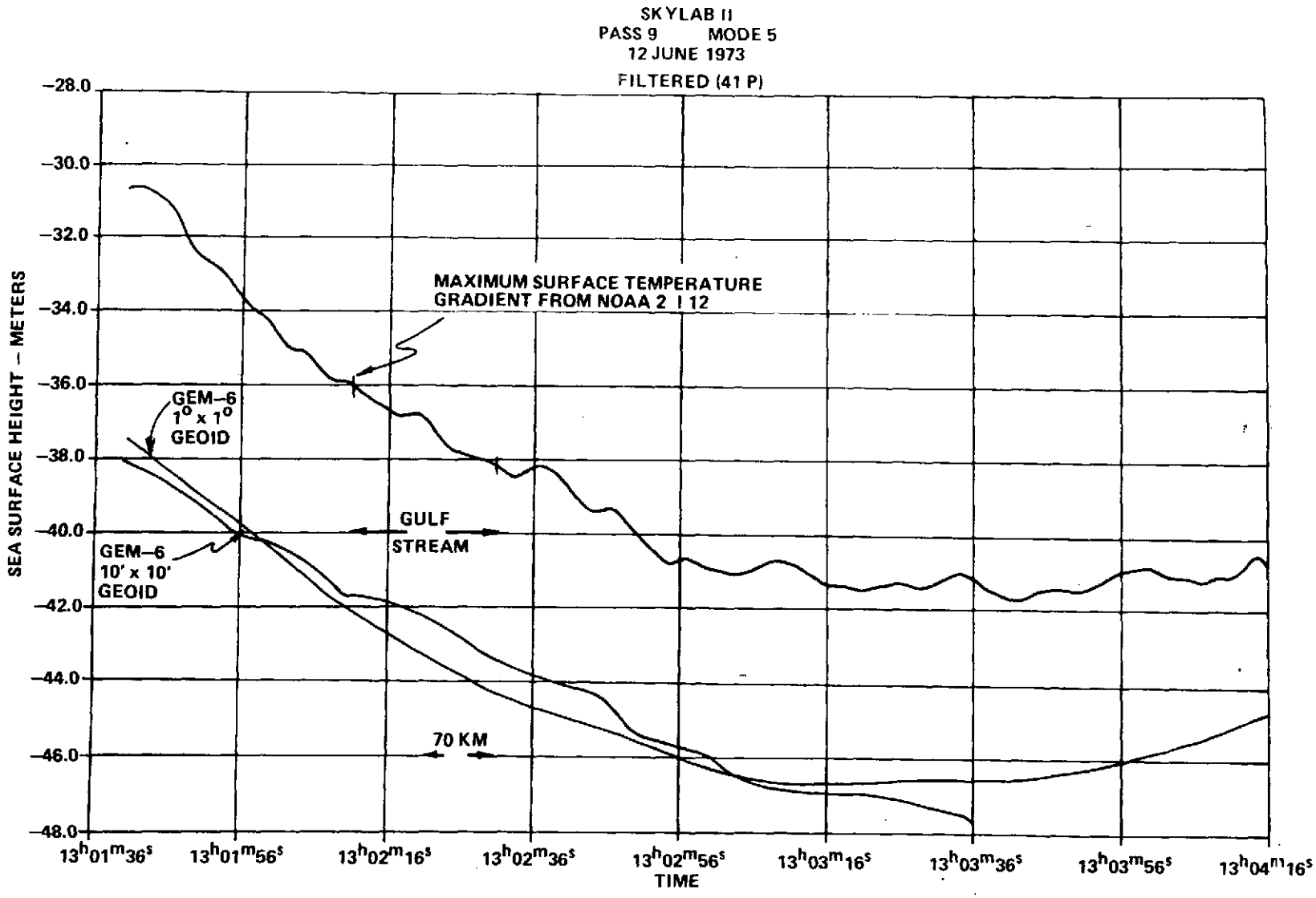

FIGURE 23. FILTERED ALTIMETER GEOID AND GEM–6 GEOID HEIGHTS

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