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EIGHTH PROGRESS REPORT

on

CALIBRATION AND EVALUATION OF SKYLAB ALTIMETRY FOR GEODETIC DETERMINATION OF THE GEOID (Contract NAS9-13276, EPN 440), October 1 to October 31, 1973

to

NASA Johnson Space Center
Principal Investigation Management Office
Houston, Texas 77058

from

BATTELLE
Columbus Laboratories

November 16, 1973

Prepared by: D. M. J. Fubara (Co-Investigator)

A. G. Mourad (Principal Investigator)
Z. H. Byrns, Code TF6 - NASA/JSC Technical Monitor

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QUICK-LOOK EVALUATION AND PRELIMINARY DATA ANALYSIS PLAN

In our Seventh Progress Report, Appendix A, the details of our analytical data handling formulations for this investigation were given. The formulations call for the following basic inputs: (1) the altimeter ranges, and exact time (usually GMT) of each measurement to correlate it with (2) the associated orbit ephemeris, and (3) geoidal information used as geodetic control or benchmark along the subsatellite track to help define the geodetic scale of the outputs. The main outputs are: (1) the residual bias of the altimeter or calibration constant required to give a correct absolute geoidal scale, and (2) the geoidal profile, both deduced from the computer processing of the inputs using a sequential least squares processing with parameter weighting according to the aforementioned formulations. The resultant variance factor or standard error of unit weight, and the variance-covariance matrix are statistically analyzed to establish confidence in the outputs as described in Appendix A of the seventh progress report.

Tabulated data from mission SL-2, pertinent to this investigation, have been received for EREP passes 4, 8, 9, and 11 as noted elsewhere in the seventh and this progress report. The corresponding dates for these passes are 155, 160, 161, and 163. We also obtained from NASA/Wallops (Messrs. J. McGoogan and H. R. Stanley) the orbit ephemeris and altimeter ranges they computed independently for EREP pass #9. The NASA/JSC data differ significantly from the NASA/Wallops data, mainly in terms of scale and their computed geographic locations.

Preliminary examination of the data indicate that in general they are good for processing. Apart from the scale problem, the altimeter ranges look much more consistent than had been anticipated. There are, however, several irregularities in the data received. These have been discussed in the Sixth and Seventh Progress Reports and also in Appendix A of this report.

Beginning with EREP pass #9, and in the absence of the computer data tapes requested, selected data from the tabulations received are being punched on cards for processing according to the data handling formulations already discussed. The computer program used in the simulation studies is being modified for real data analysis. The independently computed altimeter ranges and orbit ephemeris received from NASA/JSC and NASA/Wallops present four different data combinations that are being processed. These various combination solutions will permit the analyses of (1) the efficiency of the data handling formulations, (2) the influences of orbit accuracy, choice of weighting functions and a priori geoidal ground truth. Some schools of thought believe that geoidal heights could be obtained by merely subtracting the geodetic heights of the satellite from the corresponding altimeter ranges. We will compute and evaluate results from such a method which we consider invalid due to certain physical limitations.

PROGRESS

All the technical documents and data received and reviewed during this reporting period are listed in Appendix B.

Preliminary quick-look evaluation of the SL-2 data tabulation received has been completed. Various data irregularities and problems that were uncovered have been discussed in person with the responsible NASA/JSC personnel at Houston, on October 11 and 12, 1973. Appendix A is a summary of the outcome of these discussions.

The following operations were initiated in this period and significant results described below were obtained, using data from SL-2 EREP pass #9:

(1) Based on the ephemeris received, the satellite ground track has been plotted on three different geoidal maps from References 1 and 2. This was done to furnish the a priori subsatellite geoidal heights required (a) as basic input into the analytical data processing, (b) for comparative analyses to be performed later, and (c) for evaluation of the role of geoidal ground truth as a "benchmark" or geodetic "leveling" control. Satellite altimetry is "geodetic leveling from space".

(2) Four data combination solutions -- JSC Orbit/JSC altimeter ranges, JSC Orbit/Wallops ranges, Wallops Orbit/JSC ranges, and Wallops Orbit/Wallops ranges -- were performed in accordance with the data analysis plan described. The results are given in Tables 1 through 4, and Figures 1 to 4. The preliminary conclusions drawn are given later.

(3) Using the same four combinations above, the simple satellite geodetic height minus altimeter range computation was performed. The results are shown in Table 5 and Figure 5 and the deficiencies of this approach are discussed below.

DATA PROCESSING RESULTS

For a given satellite orbit and measured altimeter ranges, the overall objective of the investigation is to simultaneously (a) determine a geodetic calibration constant(s) that (b) corrects or adjusts the altimeter ranges for (c) determination of absolute geoidal heights with correct scale. Figures 1 and 2 show the geodetic heights of the orbits and the altimeter ranges as computed by NASA/JSC and NASA/Wallops.

TABLE 1. GEODETIC HEIGHT OF SKYLAB AND A PRIORI GEOIDAL HEIGHTS INVOLVED IN DATA ANALYSIS
(All values are in meters)

Skylab Geodetic Heights Based on		A Prior Geoidal Height
NASA/JSC Orbit	NASA/Wallops Orbit	
438752.0	438771.9	-41.0
55.3	75.0	-41.7
56.0	75.6	-41.8
56.7	76.2	-42.0
59.6	79.4	-42.7
63.5	82.7	-43.5
66.7	86.0	-44.3
70.2	89.3	-45.2
70.8	89.8	-45.3
71.3	90.3	-45.5
73.9	93.0	-45.2
76.5	95.4	-46.9
77.0	95.9	-47.0
77.6	96.4	-47.1
80.4	438798.7	-47.8
83.2	438801.6	-48.7
83.8	2.1	-48.8
84.3	2.5	-49.0
86.7	4.7	-49.0
88.0	6.0	-49.1
88.8	7.0	-49.2
89.3	7.5	-49.3
89.7	7.9	-49.3
92.2	10.2	-49.5
438794.9	438812.5	-49.7

TABLE 2. ANALYTICALLY ADJUSTED RANGES BASED ON NASA/JSC ORBIT EREP PASS 9 OF SL-2 (All values in meters)

Measured Altimeter Ranges		Based on NASA/JSC Orbit Adjusted Altimeter Ranges	
NASA/JSC	NASA/Wallops	NASA/JSC	NASA/Wallops
438814.5	438906.8	438703.8	438704.4
18.6	10.3	07.8	07.9
19.2	11.9	08.5	09.5
19.8	12.3	09.1	09.9
23.4	15.6	12.6	13.2
27.7	19.9	16.9	17.5
31.4	22.2	20.7	19.8
35.2	26.7	24.4	24.3
35.6	26.9	24.8	24.5
36.2	27.9	25.5	25.5
38.9	30.6	28.1	28.2
40.8	32.5	30.0	30.1
41.6	33.2	30.8	30.8
42.0	33.9	31.3	31.5
45.6	36.1	34.8	33.7
48.5	39.9	37.8	37.5
49.1	41.3	38.4	38.9
49.4	41.6	38.7	39.2
51.8	43.1	41.1	40.7
53.2	44.7	42.5	42.3
54.3	45.0	43.6	42.6
55.1	45.9	44.3	43.5
54.6	46.6	43.8	44.2
56.8	47.8	46.1	45.4
438859.7	438950.7	438749.0	438738.3
		Geodetic Calibration Constant	
		-110.7	-202.4

TABLE 3. ANALYTICALLY ADJUSTED RANGES BASED ON NASA/WALLOPS ORBIT EREP PASS 9 OF SL-2

Measured Altimeter Ranges in meters		Based on NASA/Wallops Orbit Adjusted Altimeter Ranges in meters	
NASA/JSC	NASA/Wallops	NASA/JSC	NASA/Wallops
438814.5	438906.8	438722.5	438723.2
18.6	10.3	26.6	26.7
19.2	11.9	27.3	28.3
19.8	12.3	27.9	28.7
23.4	15.6	31.4	32.0
27.7	19.9	35.7	36.3
31.4	22.2	39.5	38.6
35.2	26.7	43.2	43.1
35.6	26.9	43.7	43.3
36.2	27.9	44.2	44.3
38.8	30.6	46.8	47.0
40.8	32.5	48.9	48.9
41.6	33.2	49.6	49.6
42.0	33.9	50.0	50.3
45.6	36.1	53.6	52.5
48.5	39.9	56.5	56.3
49.1	41.3	57.2	57.7
49.4	41.6	57.5	58.0
51.8	43.1	59.9	59.5
53.2	44.7	61.2	61.1
54.3	45.0	62.4	61.4
55.0	45.9	63.1	62.3
54.6	46.6	62.6	63.0
56.8	47.8	64.9	64.2
438859.7	438950.7	438767.8	438767.1
		Geodetic Calibration Constant	
		-91.9	-183.6

TABLE 4. ANALYTICALLY COMPUTED GEOIDAL HEIGHTS FROM DIFFERENT DATA COMBINATIONS
(Values in meters)

	OJJ	OJW	OWW	OWJ
	-48.2	-47.5	-48.7	-49.3
	-47.4	-47.4	-48.3	-48.3
	-47.5	-46.5	-47.3	-48.3
	-47.5	-46.7	-47.5	-48.3
	-47.0	-46.4	-47.4	-48.0
	-46.5	-45.9	-46.4	-46.9
	-46.0	-46.7	-47.4	-46.5
	-45.7	-45.8	-46.2	-46.0
	-45.9	-46.3	-46.5	-46.1
	-45.8	-45.8	-46.0	-46.0
	-45.9	-45.7	-46.0	-46.1
	-46.5	-46.4	-46.5	-46.5
	-46.2	-46.2	-46.3	-46.3
	-46.3	-46.1	-46.1	-46.3
	-45.6	-46.7	-46.2	-45.1
	-45.4	-45.7	-45.3	-45.0
	-45.5	-44.9	-44.4	-44.9
	-45.6	-45.1	-44.5	-45.0
	-45.6	-46.0	-45.2	-44.8
	-45.5	-45.7	-44.9	-44.7
	-45.2	-46.2	-45.6	-44.6
	-45.0	-45.8	-45.2	-44.4
	-45.9	-45.3	-44.9	-45.3
	-46.1	-46.8	-46.0	-45.3
	-45.9	-46.6	-45.4	-44.7
Average Std. Error*	± 3.1	± 3.0	± 3.2	± 3.2

* Std. Error = square root of main diagonal element of variance covariance matrix of the least squares adjustment

<u>Key to Data Combination</u>

OJJ = NASA/JSC Orbit and NASA/JSC Altimeter Ranges

OJW = NASA/JSC Orbit and NASA/Wallops Altimeter Ranges

OWW = NASA/Wallops Orbit and NASA/Wallops Altimeter Ranges

OWJ = NASA/Wallops Orbit and NASA/JSC Altimeter Ranges

TABLE 5. APPARENT "GEOIDAL HEIGHTS" FROM GEODETIC HEIGHT OF SKYLAB ORBIT MINUS ALTIMETER RANGE

OJJ	OJW	OWW	OWJ
-62.5	-154.8	-134.9	-42.6
-62.3	-155.0	-135.3	-43.6
-63.2	-155.9	-136.3	-43.6
-63.2	-155.6	-136.1	-43.6
-63.7	-156.0	-136.2	-44.0
-64.2	-156.4	-137.2	-45.0
-64.7	-155.5	-136.2	-45.4
-65.0	-156.5	-137.4	-45.9
-64.8	-156.1	-137.1	-45.8
-64.9	-156.6	-137.6	-45.9
-64.9	-156.7	-137.6	-45.8
-64.3	-156.0	-137.1	-45.4
-64.5	-156.2	-137.3	-45.7
-64.4	-156.3	-137.5	-45.6
-65.1	-155.7	-137.4	-46.9
-65.3	-156.7	-138.3	-46.9
-65.3	-157.5	-139.2	-47.0
-65.1	-157.3	-139.1	-46.9
-65.1	-156.4	-138.4	-47.1
-65.2	-156.7	-138.7	-47.1
-65.5	-156.2	-138.0	-47.3
-65.8	-156.6	-138.4	-47.6
-64.8	-156.8	-138.7	-46.7
-64.6	-155.6	-137.6	-46.6
-64.8	-155.8	-138.2	-47.2

Key to Data Combination

OJJ = NASA/JSC Orbit and NASA/JSC Altimeter Ranges

OJW = NASA/JSC Orbit and NASA/Wallops Altimeter Ranges

OWW = NASA/Wallops Orbit and NASA/Wallops Altimeter Ranges

OWJ = NASA/Wallops Orbit and NASA/JSC Altimeter Ranges

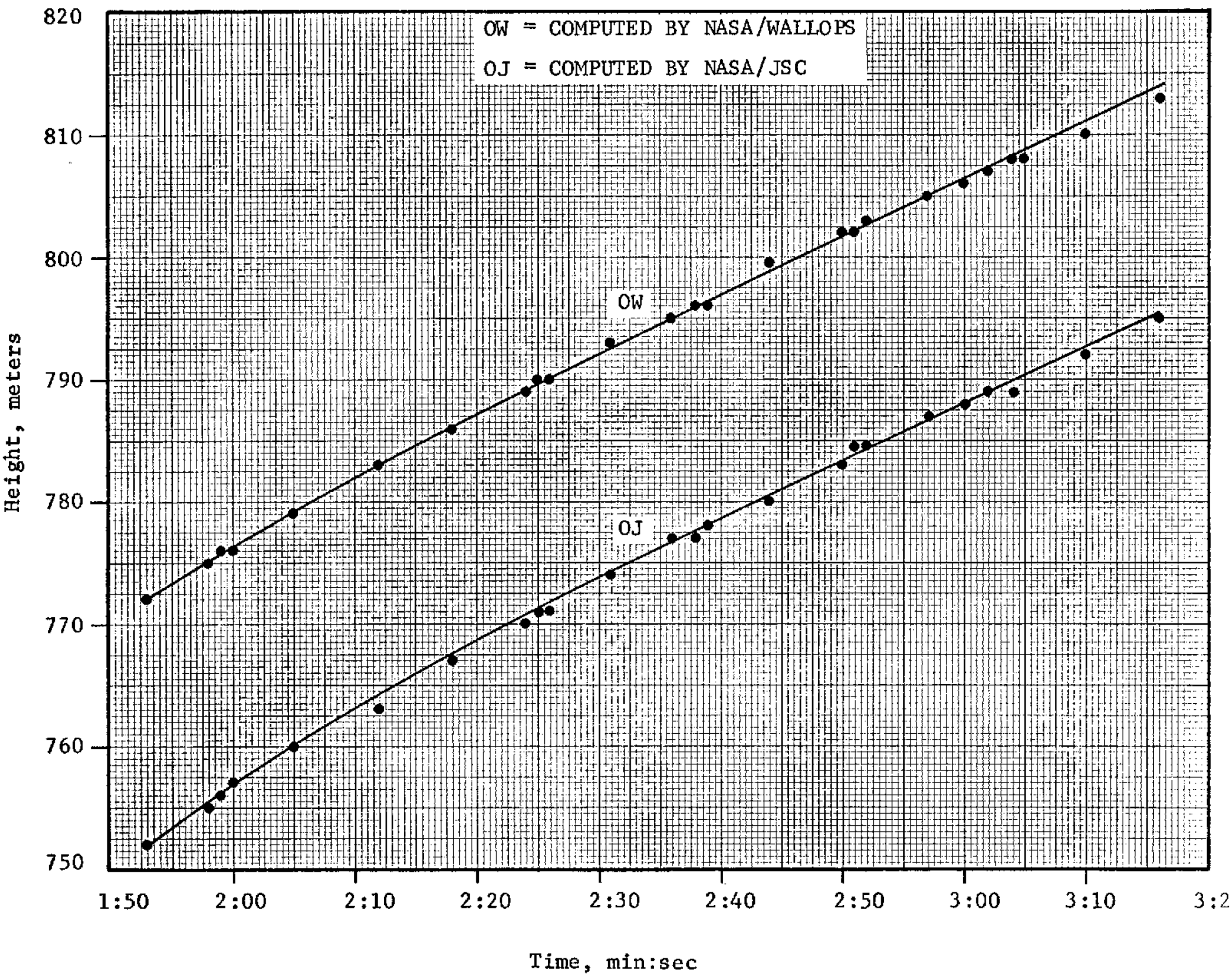

FIGURE 1. GEODETIC HEIGHT OF SKYLAB (SL-2 EREP PASS #9)

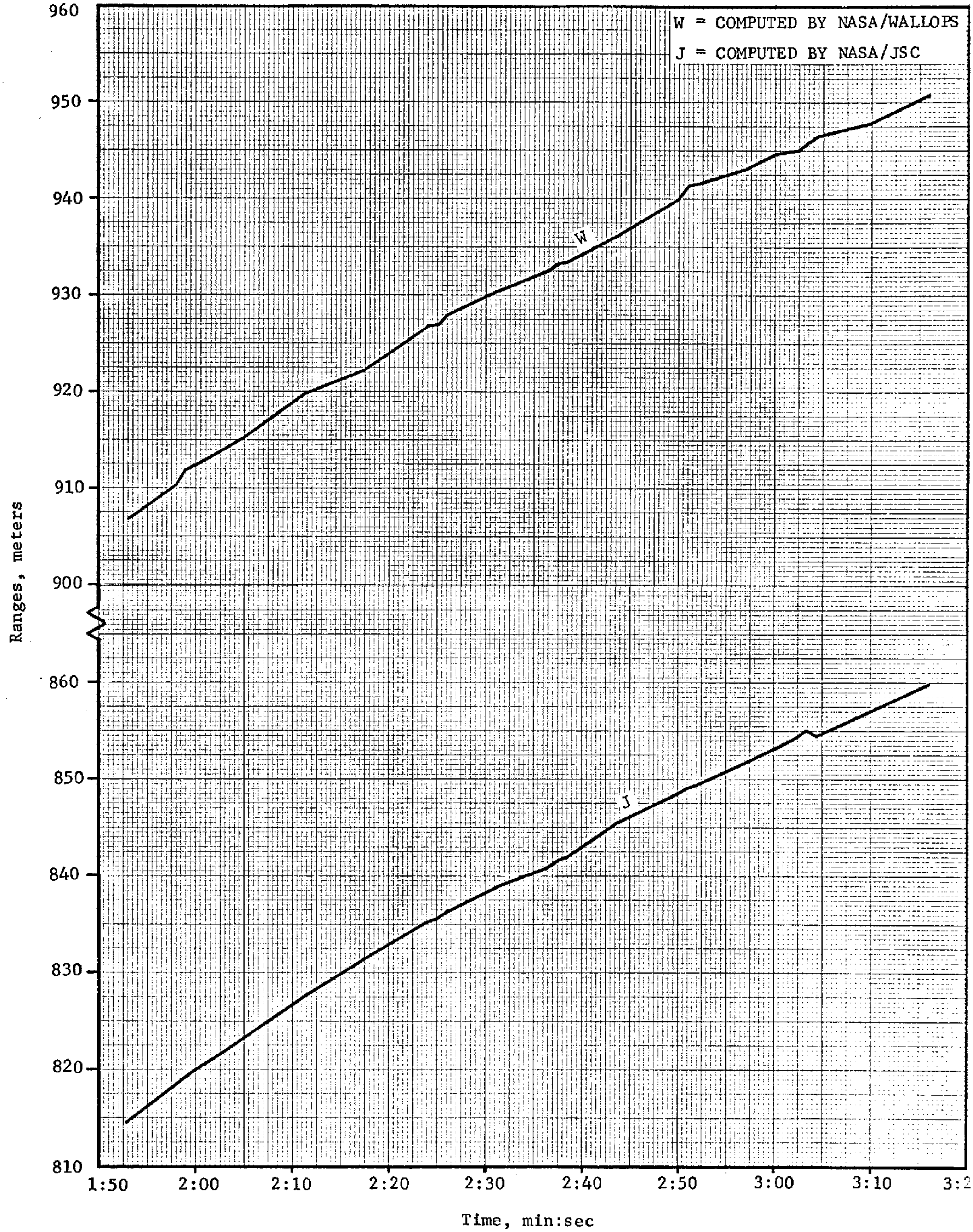

FIGURE 2. ALTIMETER RANGES (SL-2 EREP PASS #9)

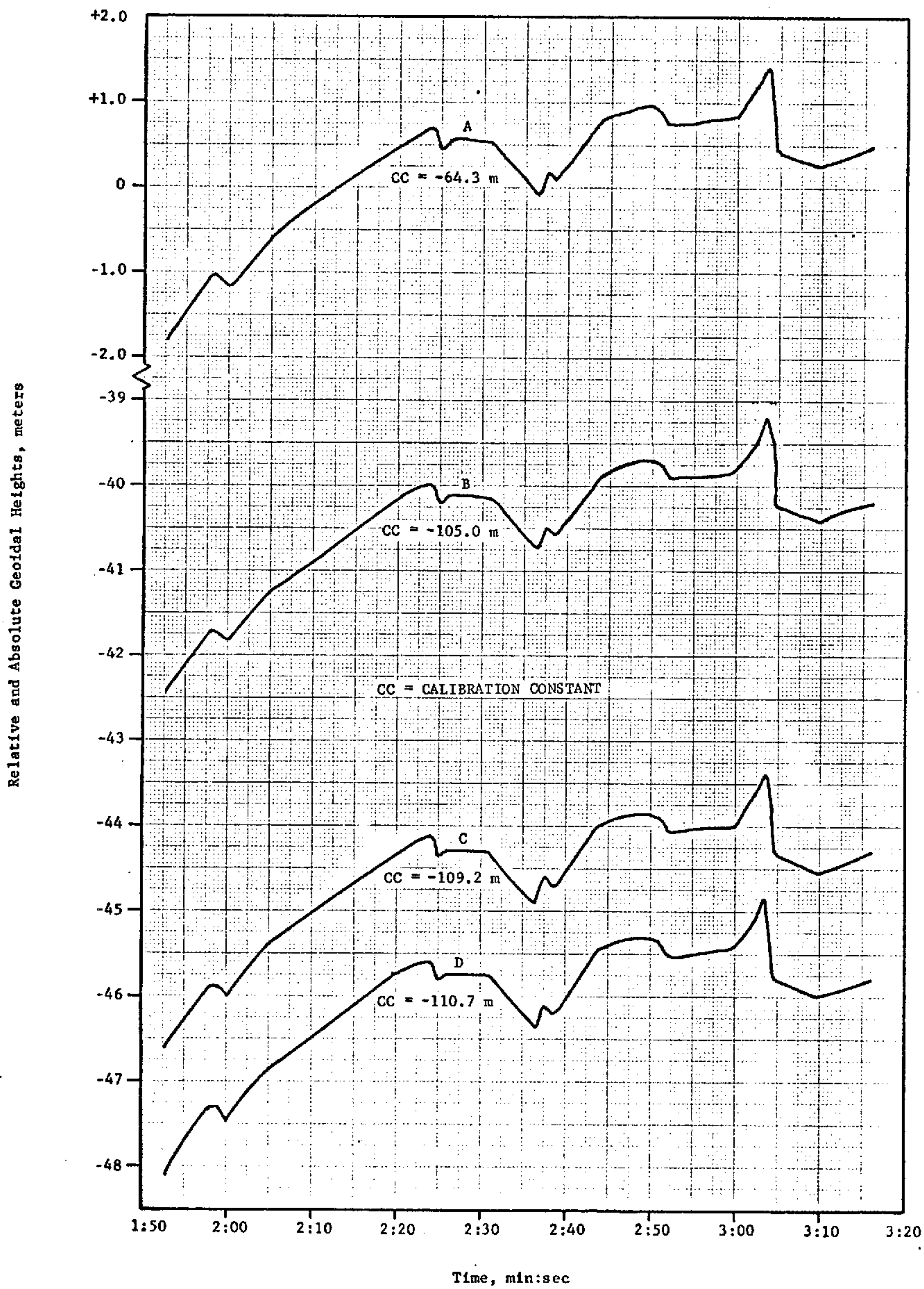

FIGURE 3. DEPENDENCY OF CALIBRATION CONSTANT AND GEOIDAL HEIGHTS GEODETIC CONTROL (GROUND TRUTH)

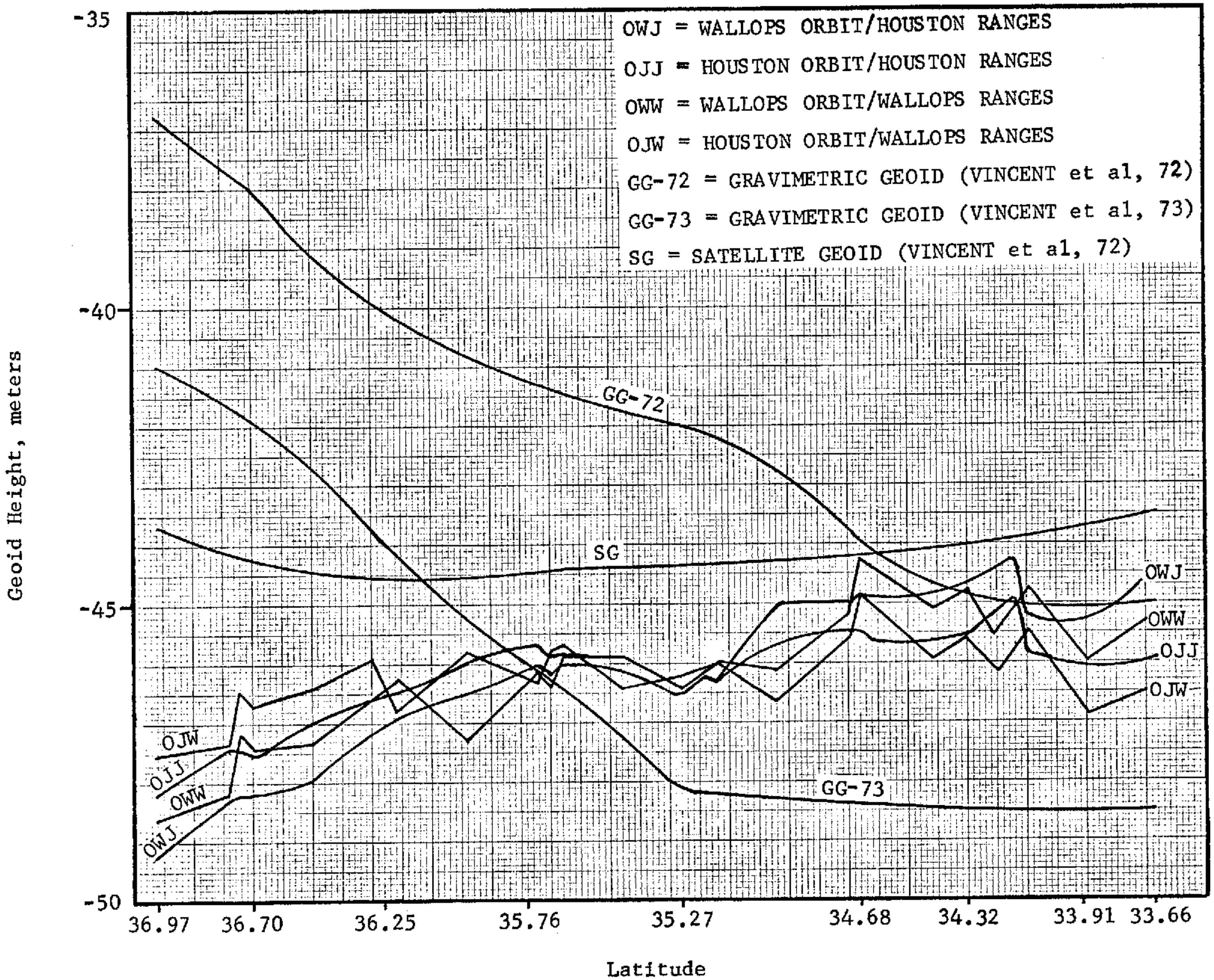

FIGURE 4. CONVENTIONAL GEOID AND SATELLITE ALTIMETRY GEOID SEGMENTS

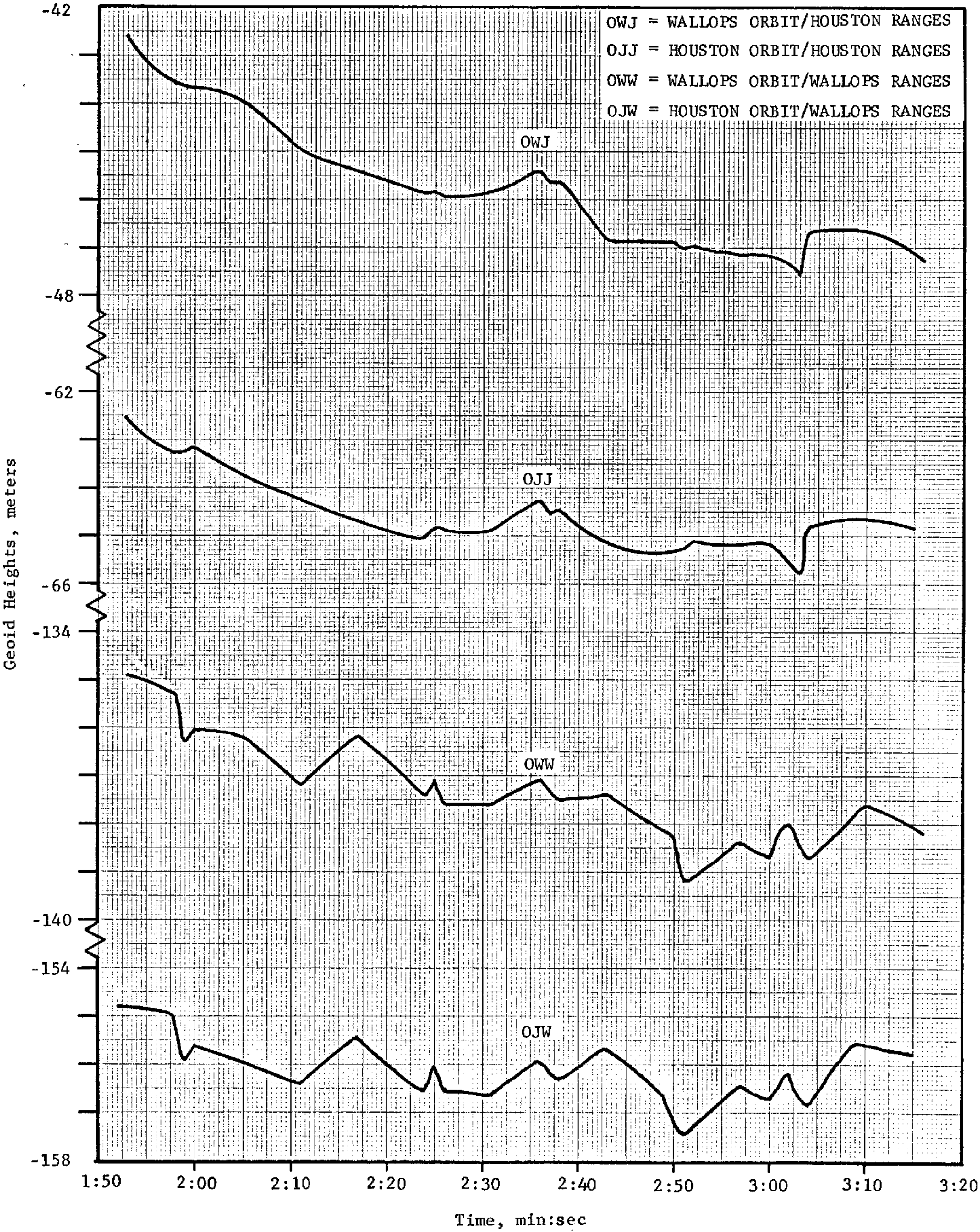

FIGURE 5. SATELLITE HEIGHT MINUS RANGE

Calibration Constants and Adjusted Altimeter Ranges

As developed in the Seventh Progress Report, the altimeter bias, radial errors in orbit determination, and errors from inadequate or total lack of correction for significant sea state variations are all algebraically additive. These errors are inseparable unless two of them are absolutely known. In this investigation, the total sum of all three is the calibration constant to be determined.

Unfortunately, unless the radial orbit error is zero, some known absolute geoidal height must be used as geodetic control or benchmark in order to determine the required calibration constant. In this case, the calibration constant so determined is scalewise-dependent on the a priori geoidal input or the geodetic control used. This is demonstrated in the graphs A, B, C, and D of Figure 3. In graph A, the input is zero for a priori (approximate) geoid heights and no point is held geodetically fixed relative to another. For graph C, instead of zero, the a priori geoidal height input was -45 meters for every point. In graph B and D the approximate geoidal heights input were taken from the geoid of Reference 2, as shown in Figure 4 and Table 1. In graph D, no points were constrained but, in B, the first point (left end) was constrained by weighting. For each case, normalized parameter weighting, consistent with the estimated absolute accuracy of the a priori geoidal height input, was applied. In all cases, even though the resultant geoidal height differences were exactly identical, the deduced calibration constants depended on the weighted a priori geoidal height inputs. Figure 3 definitely shows that such a priori inputs affect only the linear scale of the calibration constant and not the shape of the deduced geoid. Further investigations on the role of the values and errors in the a priori geoidal inputs are in progress.

In the current Skylab data, the altimeter bias appears to vary with the modes and the sub-modes. This is an additional factor taken into account. For the current data processing, the additional assumption is that for a "short time interval", the radial orbit errors are of constant magnitude and sign. These two factors constrain the current "short time interval" for this set of data to be no more than 3 minutes.

A key indicator of the reliability of the analytically computed geodetic calibration constant is the consistency of the adjusted ranges. As stated in Appendix A, and also in the Sixth and Seventh Progress Reports, there are currently some errors in the computed orbit. The differences in both orbit and the range data as computed by NASA/JSC and NASA/Wallops (See Figures 1 and 2 and Tables 1 to 3) confirm that current knowledge of the orbit and the delay constants (biases) for transforming the radar altimeter returns into ranges in engineering units are inaccurate. The mathematical model developed for this analysis anticipated these problems which algebraically add up to be a linear radial error relative to the earth's geocenter. Through the use of the discussed appropriately weighted a priori geoidal heights, no matter what the errors in the different sets of ranges used, the derived adjusted ranges should be identical if the same orbit is used. This is proved by the results of Tables 2 and 3.

Geoidal Heights Analytically Deduced from Satellite Altimetry

Table 4 and Figure 4 show the deduced geoidal heights from the analytical processing of the four data combinations already described. Figure 4 also shows three other profiles for the same segment of the geoid as given by the same authors using different techniques. Our results do not match these other conventional geoid profiles which also disagree with each other significantly. These three are tilted relative to each other and to the general slope of the altimeter geoid. However, the overall slope of the altimeter geoid more closely identifies with the slope of the conventional satellite geoid. The other two conventional geoid seqments are mostly based on global gravity data and satellite-derived geopotential coefficients used in global areas lacking measured gravity data as per References 1 and 2.

It is logical to assume that whatever radial errors exist in the orbits, for the short time period involved, such errors should be constant in magnitude and sign. It is therefore valid to assume that, provided the altimeter system is stable, the deduced altimeter geoid should more closely approximate the true geoid shape of that segment. So far both the influences of sea state and the departure of sea surface topography from the true geoid have been neglected.

By merely subtracting the measured altimeter ranges from the corresponding satellite geodetic heights, the resultant profiles for the four data combinations are shown in Figure 5. Some schools of thought believe that this is all there is to geoid computation from satellite altimetry. The results show 4 surface profiles which, if assumed to be the geoid, represent geoid heights in the range of (1) -42 to -48 meter, (2) -62 to -66 meters, (3) -135 to -139 meters and (4) -155 to -157 meters. In contrast, our preliminary analytically deduced corresponding profiles are -49 to -45 meters, -48 to -46 meters, -49 to -45 meters and -48 to -47 meters from the 4 data combinations.

CONCLUSIONS

The preliminary conclusions from these quick-look data investigations include:

(1) The analytical data handling formulations developed for this investigation appear to be very satisfactory. The main outputs required, the geodetic calibration constant, the geoid height and the corrected altimeter ranges are being reliably determined;

(2) To ensure that the deduced calibration constant and geodetic heights are absolute, the use of geodetic control or a benchmark whose absolute geodetic undulation is known is indispensable;

(3) On the assumption that the altimeter system is stable, and that orbit radial errors for short time periods are constant, the altimeter geoid shows very high frequency details of the geoid or more accurately the sea surface topography;

(4) Subject to additional data processing corrections which the current state of the SL-2 data precludes, these preliminary results indicate that satellite altimetry will be a valid and useful tool for computing quasi-stationary departures of sea surface topography from the geoid. This practical application is important to oceanographic work related to ocean circulation, mass water transport and other ocean current influences. These in turn affect air-sea interaction and the knowledge for global numerical weather prediction. Such oceanographic factors also affect our knowledge of pollution dispersion by the oceans, an important guiding factor in waste disposal and prediction, and control of oil spill hazards;

(5) The preliminary indications are that the general slope of the analytically derived altimeter geoid tends to agree with that computed from purely satellite derived geopotential coefficients and orbit perturbation analysis;

(6) Current orbit computation in which inadequately calibrated altimeter ranges are employed as constraints is not satisfactory for processing altimeter data to compute the geoid. First, the unmodelled range biases introduce large systematic errors that are not admissible in least squares orbit computation. Such systematic errors cannot be accurately eliminated by being modelled unless some valid geodetic controls are used as constraints. Furthermore, the use of orbits constrained with altimeter data to deduce an altimeter geoid from the same altimeter data must produce a geoid that closely matches the original geoid used in applying the altimeter ranges as a constraint. This can be

misleading in several respects. This type of constraint was involved in the NASA/Wallops orbit but not in the NASA/JSC orbit. However, in theory, other salient features of the NASA/JSC orbit computations are much less sophisticated than that of NASA/Wallops;

(7) Deduction of the geoid from satellite altimetry cannot be achieved by merely substracting altimeter ranges from the corresponding geodetic heights of the satellite unless the satellite orbit is errorless and altimeter system biases are either non-existent or are absolutely known.

PROBLEMS

The problems reported in the last progress report still exist. However, the missing S072-2 tabulations for three S-193 EREP passes have now been received. Further details on various irregularities in the data received are discussed in Appendix A. As described under data processing results and conclusions, both the computed orbit for Skylab and the reduction of altimeter returns to ranges by NASA/JSC and NASA/Wallops give significantly different values. This is a highly undesirable situation, expecially for the altimeter ranges.

As indicated by the results in this report the effects of these problems are qualitative. They do not hinder the overall investigation except as noted in Appendix A. In fact, they present additional challenges the possibility of whose existence we had forseen in our preliminary private investigation. We are investigating these challenges at no extra costs, so far, to the contract, and the preliminary results are furnishing excellent insight into the facts that will contribute to the achievement of NASA's objectives for future satellite altimetry programs such as GEOS-C and SEASAT.

RECOMMENDATIONS

(1) Our recommendations 1 (a), (b) and (c) of the previous progress report still stand.

(2) The irregularities in orbit computation should be resolved. The best available tracking from as many stations as are within range of Skylab should be implemented in mission SL-4.

(3) NASA/JSC, NASA/Wallops and the various contractors involved should resolve the differences in the reduction of altimeter radar returns to ensure that the resultant ranges are unique and independent of who did the computation.

NEXT PERIOD AND SUMMARY OUTLINE

We plan to continue preliminary analysis of SL-2 data received, according to the plan submitted, subject to your approval and/or modifications mutually acceptable. The current NASA/JSC values for FOV-Nadir angles are deficient. NASA/Wallops claims they can compute them more accurately from pulse shape analysis. We need these angles for certain necessary corrections. We therefore plan to contact NASA/Wallops for the possibility of obtaining these angles from them.

TRAVEL

During this period, Dr. D. M. Fubara and Mr. G. T. Ruck visited NASA/JSC, Houston, Texas, on October 11 and 12. They represented the PI who is temporarily hospitalized, at the NASA requested S-193 PI Meeting, and held other meetings with personnel of NASA/JSC Mathematical Physics and Data Processing Branches, on the status of problems in the SL-2 S-193 altimeter and supporting data received.

Subject to your approval, Dr. Fubara and Mr. Mourad will present at the 1973 Fall Annual Meeting of the American Geophysical Union in San Francisco, California, December 10-13, a paper entitled "Geodetic Analysis of Skylab Altimetry Preliminary Data". The paper will embody the results in this report and some from the next progress report.

REFERENCES

1. Vincent, S., Strange, W. E., and Marsh, J. G., "A Detailed Gravimetric Geoid of North America, North Atlantic, Eurasia, and Australia", Paper presented at the International Symposium on Earth Gravity Models and Related Problems, 1972.

2. Vincent, S., and Marsh, J. G., "Global Detailed Gravimetric Geoid", Computer Sciences Corporation and NASA/GSFC, 1973.

APPENDIX A

October 30, 1973

Mr. Z. H. Byrns, Code TF6
NASA Johnson Space Center
PI Management Office
Houston, Texas 77058

Dear Mr. Byrns:

Subject: Calibration and Evaluation of Skylab Altimetry for Geodetic Determination of the Geoid (Contract NAS9-13276, EPN440)

Following the S-193 PI meeting called by and held at NASA/JSC, Houston, Dr. Dagogo Fubara and Mr. George Ruck, the Battelle representatives, held other meetings with various NASA/JSC personnel on the subject contract. Dr. Norris asked Dr. Fubara to send him a summary of the discussions of these other meetings. Enclosed is a copy of this report in its entirety as prepared by Dr. Fubara the Co-Investigator on this contract. I am sorry I was unable to attend this meeting due to my recent hospitalization. If you have questions, please do not hesitate to contact me or Dr. Fubara.

Sincerely,

A. George Mourad
Principal Investigator
Project Manager, Geodesy & Ocean Physics
Transportation and Space Systems Department

AGM:vs

Enc.

cc: Dr. D. Norris, Code EG8, NASA-JSC, Houston, Texas

Battelle
Columbus Laboratories

Project Number G-2342-1

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Date October 29, 1973

To A. G. Mourad

From D. M. Fubara

Subject NASA/JSC S-193 Meeting on October 11-12, 1973

During my visit to NASA/JSC on October 11 and 12, Dr. Dean Norris was unable, due to other urgent commitments, to attend two of the meetings he arranged at my request. Although he was represented by Mr. Ray Nelson of NASA/JSC, he indicated that I should submit to NASA my summary of the problems and solution options discussed.

The background to these problems have been discussed in our last four monthly reports.

Preliminary scrutiny of the Skylab altimeter (from SL/2)mission) so far received showed up a number of irregularities. These were discussed in detail with (a) Dr. Emil Schiesser, Mr. Bill Wollenhaupt and other members of the Mathematical Physics Branch responsible for Skylab orbit data computations, SKYBET, and (b) Mr. Joe Snyder of Data Processing Branch, responsible for altimeter data processing. The outcome of these meetings included the following:

> The Mathematical Physics Branch acknowledged the existence of gross errors in the SKYBET data, confirming what we had previously pointed out. Shockingly, they estimated the radial errors to be about $\pm$ 600 meters (3σ). I indicated that in spite of these gross errors, we can still complete our data analysis subject to obtaining several undesirable results including: the analytically recoverable altimeter geodetic calibration constant will absorb the large radial errors in the orbit data and will vary from one EREP pass to another; altimeter drift cannot be investigated; the role and accuracy of geoidal ground truth become more dominant than is desirable; and, overall sensor performance may be settled in terms of precision but not in accuracy.
>
> According to Dr. Schiesser no other investigators besides us have queried the orbit computation accuracy and indicated a need for more accurate orbit data. Dean said that he had not expected such gross errors in orbit data and is therefore investigating the mechanism for and cost of securing more reliable orbit computation -- either from the NASA/JSC Mathematical Physics Branch or NASA/Wallops, having the best current state-of-the-art achievable accuracy. We also discussed the merits and demerits of using long arc or short arc orbits.
>
> Time sychronization to correlate sensor time as indicated by spacecraft clock and GMT by tracking station clocks appear to have 3 sigma errors of about $\pm$ 40 μsec. This problem is not serious for us as it is being handled.

With the Data Processing Branch, we raised three main issues. First, the requested SL/2 mission data on computer compatible tapes have not been received, and the delay is adversely affecting our schedules and optimum utilization of resources. We were promised expedited action on this issue. Secondly, the few data so far received on paper tabulation show a lack of correlation between parameters for spacecraft attitude and the angular differences between the spacecraft nadir and the sensor "field of view" (FOV), as given in Tabulation SO72-7. The changes in this angular difference were too rapid, erratic and appeared unreal. Mr. Snyder explained that the attitude parameters are measurable quantities but there were several measurement failures. The off-nadir FOV angles are theoretically computed based on Earth Centered Inertial (ECI) coordinates of the Skylab as generated in SKYBET. Apparently, the gross orbit computation errors already discussed and other irregularities in the entire SKYBET formulations and programming (NASA/JSC has documented these but is currently doing nothing about their rectification according to a document, memorandum FM85/73-241/Mathematical Physics Branch, given to me) are responsible for the off-nadir angle problems.

It is significant to note that the memo referred to on the subject "Status of Skylab SL-2 EREP SKYBET Tapes" concluded: The test was structered such that single precision (7 digits) verification should have been obtained for most parameters; provided the documentation and computer coding were consistent. The results of the numerical verification ... are summarized in ... . Single precision verification was obtained for only 17 parameters. For 26 parameters, either the formulation in the documentation was incorrect or there were inconsistencies between the documentation and the RTCC SKYBET computer programming."

These off-nadir FOV angles are required as correction parameters in our data processing to eliminate systematic errors which amount to about 439 x (1-cosθ) km., (where θ is the off-Nadir-FOV angle) for each range. The NASA/Wallops altimeter group under Mr. J. McGoogan has indicated that they have computed some and can compute the rest of these angles to better than $\pm$ 0.1 degree from the pulse shape of the radar returns. The only available option seems to be that the PIM office should arrange to obtain these computed angles from NASA/Wallops.

During the S-193 PI meeting on October 11, NRL who are the contractors for the land topography investigation with Skylab altimeter, indicated that they had not begun their data analysis. When they begin, they will have requirements identical to ours, concerning the accuracies of orbit computation and the off-Nadir-FOV angles.

The last problem was a constant difference of about 91 meters between corresponding altimeter ranges computed by NASA/JSC and NASA/Wallops. Mr. Snyder is aware of this problem which is under adequate investigation.

We were informed that several altimeter data were obtained during SL/2 and SL/3 missions for geoid investigation in many ocean regions not stipulated by Battelle-Columbus Laboratories, BCL. As I indicated, BCL will be willing to negotiate to conduct the geoidal computation with the additional data. We believe that such an action will benefit not only Skylab's objectives but also other NASA missions such as GEOS-C, SEASAT and the oceanographic and improved gravity model and marine geophysical objectives of the Earth and Ocean Physics Applications Program.

DMF:vs

APPENDIX B

REPORTS AND DATA RECEIVED

(1) S-193 Microware Radiometer/Scatterometer Altimeter, Calibration Data Report, Flight Hardware, Volumes IA and B, Rev. D, by General Electric for NASA, March, 1973.

(2) "Basic Equations and Logic for the Real-Time Ground Navigation Program for the Skylab Mission", Revision 1, MSC Internal Note No. 71-FM-411 (MSC 05216) by Mathematical Physics Branch, October, 1972.

(3) RTCC Real Time Program Skylab 1/4 MOC System Parameters, GS52-73-111, Flight Support Division, NASA/JSC, September, 1973.

(4) Status of Skylab SL-2 EREP Skylab Tapes, FM85 (73-241), Mathematical Physics Branch, NASA/JSC, October, 1973.

(5) Station Characteristics for Skylab Mission Support, NASA/MSC, February, 1973.

(6) SL-2 Data Received:

D.D.C. Accession No.	DPAR	Date/Time START	Date/Time STOP
32-05962	S193B-069-3-7	161:14:28:00	161:14:38:46
32-05963	S193B-070-3-7	161:14:28:00	161:14:38:46
32-05964	S193B-070-2-4	155:17:11:00	155:17:16:36
32-05965	S193B-069-2-6	160:15:03:30	160:15:18:49
32-15034	193B-070-2-4	155:17:11:11	155:17:16:37
32-15035	193B-069-2-6	160:15:03:39	160:15:18:42
32-15039	193B-070-4-9	163:13:56:20	163:13:18:59
32-15046	193B-070-3-7	161:14:28:12	161:14:38:46
32-15045	193B-069-3-7	161:14:28:12	161:14:38:46
32-15047	193B-069-3-7	160:14:28:46	160:14:38:46
32-15049	193B-069-2-6	160:15:03:39	160:15:18:41
32-15050	193B-069-3-7	160:14:28:12	160:14:38:45
32-15051	193B-070-3-7	160:14:28:12	160:14:38:45
32-15053	S193B-09-2-6-73-7,8		