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NINTH PROGRESS REPORT

on

CALIBRATION AND EVALUATION OF SKYLAB ALTIMETRY FOR
GEODETIC DETERMINATION OF THE GEOID (Contract NAS9-13276,
EPN 440), November 1 to November 30, 1973

to

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

from

BATTELLE
Columbus Laboratories

December 18, 1973

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

A. G. Mourad (Principal Investigator)
Z. H. Byrns, Code TR6 - NASA/JSC Technical Monitor

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PROGRESS

During this period, the main activities included the following:

(1) Detailed evaluation of the quality of the S193-Altimeter and supporting data from mission SL-2 as given in documents S072-1, 2, 4, 6, and 7 and S073-6, 7, 8, and 10 (see Reference 1 for description of contents of captioned documents) for EREP pass numbers 4, 6, 7, and 9. These are the only passes for which we have received tabulated data relevant to our task sites. The objective of this detailed evaluation was to determine the suitability of the altimeter and supporting housekeeping data for geodetic determination of the geoid. In particular, the sensor readouts for the spacecrafts pitch, roll and yaw, the achievement and accuracy of nadir alignment, and the

stability of maintaining the nadir alignment, the altitude residuals and the standard deviations were analyzed. The results of this evaluation are discussed later;

(2) Continuation of geoid computation and results analysis, using EREP pass #9 data, which was begun in the previous period. The results are given below. Meanwhile, the significant results in this and the previous period's report have been combined into a paper to be presented at the Satellite Altimetry Session of Annual Fall Meeting of the American Geophysical Union in San Francisco, California, December 10-13, 1973. A formal write up of this paper has been submitted for the required approval from NASA/JSC;

(3) Deciphering of the data tape (S071-1) received was initiated. The problems encountered are described below;

(4) Modification of computer programs to be responsive to data conditions and achievement of project objectives.

(5) Review of documentations and data records received. These are listed in Appendix A.

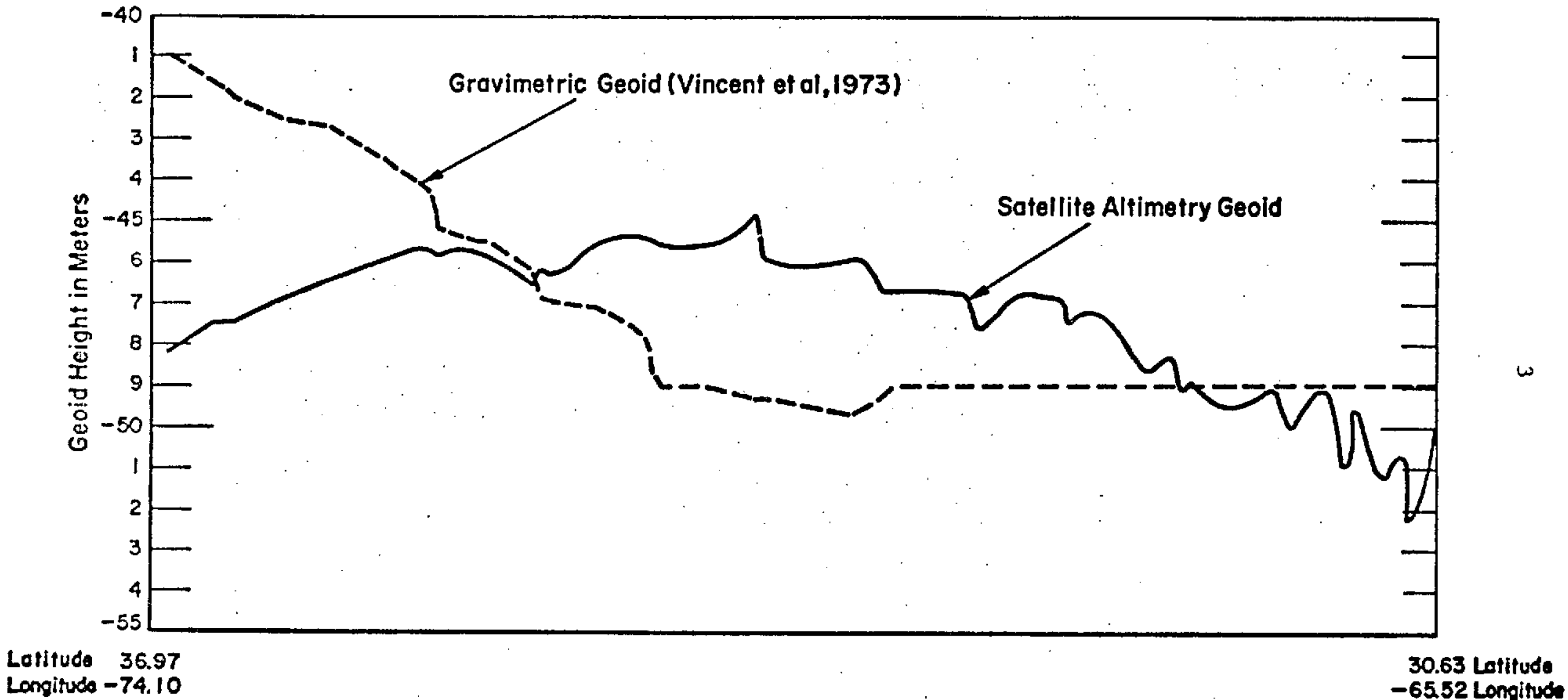
(6) We have initiated studies for qualitative evaluation of oceanographic signatures associated with the data since the altimeter ranges refer directly to sea surface topography which could depart from the geoid by up to 2 meters in our data site, according to References 4 and 5.

DATA PROCESSING RESULTS

Analytical Data Processing

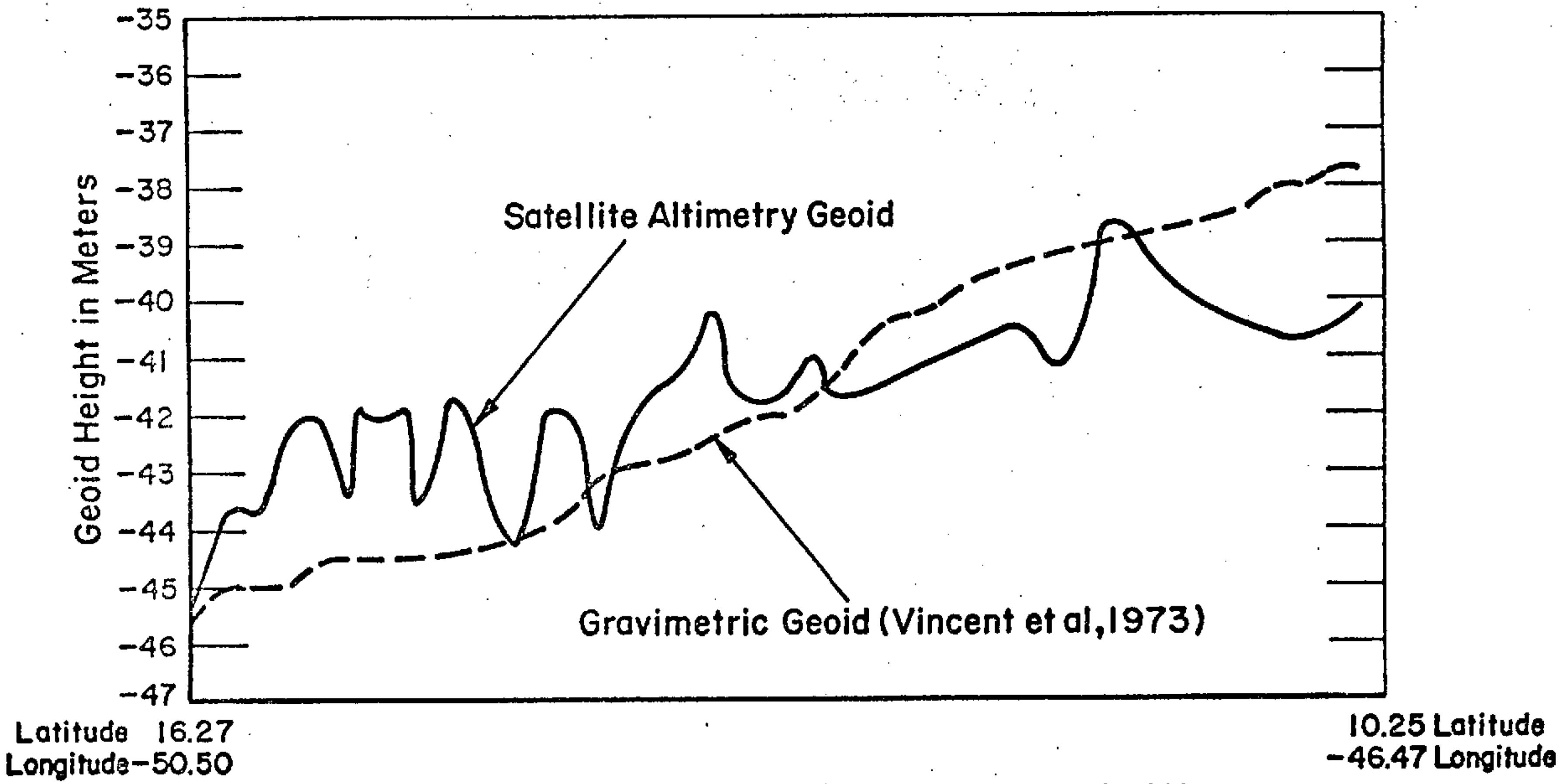
Data processing, according to the "Preliminary Data Analysis Plan" previously submitted, has been completed for the data period 13:01:52 to 13:11:40 GMT of EREP pass #9. The computed geoid segments and calibration constants are given in Figures 1 and 2.

The same figures show the corresponding conventional geoid profiles from Vincent, et al, (Reference 2), as deduced from a combination of terrestrial gravity measurements and satellite derived geopotential coefficients. Precision



GRAVIMETRIC AND SATELLITE ALTIMETRY GEOID
(SL/2 EREP PASS 9-MODE 5)

FIGURE 1



GRAVIMETRIC AND SATELLITE ALTIMETRY GEOID
(SL/2 EREP PASS 9-MODE 3)

FIGURE 2

estimate of this conventional geoid is about $\pm$ 5 to $\pm$ 15 meters in ocean areas, according to the authors. However, from Rapp (Reference 3), this estimate may be optimistic, in view of certain error sources not accounted for in the computation of that conventional geoid. Furthermore, the segment of the conventional geoid plotted, was scaled off a very small scale world map. This latter process would normally introduce errors into the plotted segment. Also, the satellite groundtrack runs nearly parallel to the geoid contours (see Figure 3). This condition easily introduces systematic displacement errors which are not conducive to reliable comparison between the two types of geoid segments.

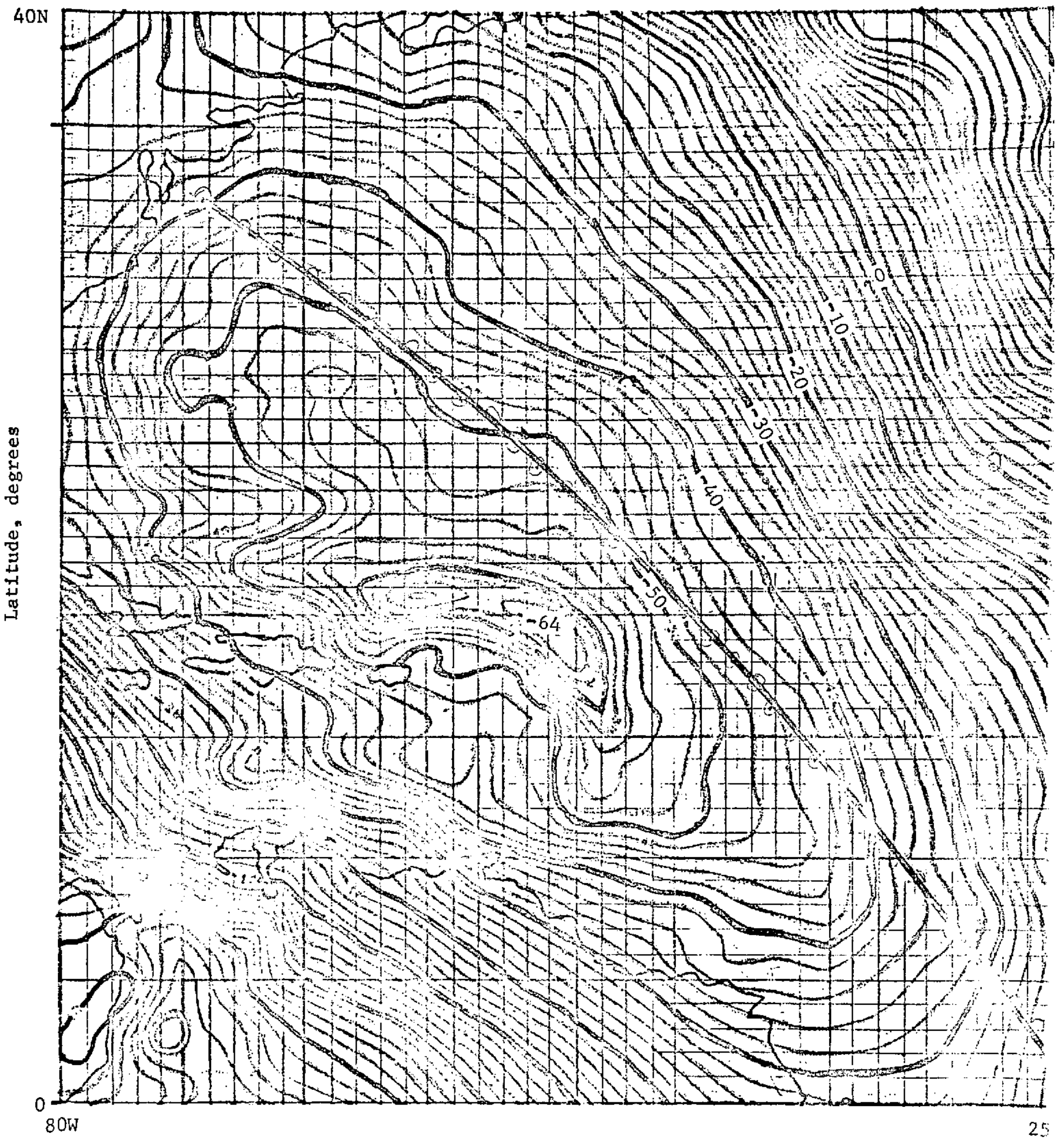
In spite of all these possible sources of discrepancy, and the data errors and uncertainties outlined in previous progress reports, the comparison of features between the altimetry geoid and this particular conventional geoid (no two conventional geoids are alike and often differ by tens of meters and relative tilts) is very encouraging. The current preliminary results have not been corrected for the influences of sea state, possible nadir alignment errors and departures of the sensor field of view from the nadir. Some of the high frequency features of the satellite altimetry geoid may be a reflection of these uncorrected influences. According to Sturges (Reference 5, Figures 1 and 2) there appears to be close similarity in shape between the satellite altimetry geoid segment of our Figure 1 and the expected trend in average sea surface topography of the area. This is being studied further and our computations from EREP pass #4 of SL-2 and data expected from SL-4 should confirm or negate this apparent correlation with sea surface topography.

SL-2 Data Quality Evaluation

This is the result of the detailed evaluation discussed as item #1 under Progress. Table 1 is a brief summary of the findings.

S-193 altimeter and supporting data from EREP passes #4 and #9 appear to be very good and completely satisfactory for processing.

From EREP pass #6, all the data except for the period 15:15:48 to 15:18:24 GMT appear to be inadequate for our investigation. Outside this time period, the roll-pitch-yaw readouts were mostly zero, which meant that



SATELLITE GROUND TRACK EREP PASS #9

FIGURE 3

TABLE 1. STATUS OF S-193 ALTIMETER AND ASSOCIATED DATA FROM SL-2

EREP PASS Number	Date GMT-H:M:S	Spacecraft Attitude Roll/Pitch/Yaw	** N-FOV	Standard Deviation of Moon Range	Altitude Residual	Remarks
4 (*GT #19)	6-4-73 17:11:11 to 17:16:37	Good Readout	Less than 0.6°	Very Good	Accepta-ble	Modes I and V Data. One of best two data sets. Excellent for processing.
6	6-9-73					Not sure if nadir alignment was achieved.
(GT #19) Note: Pass 4 and 6 do not coincide though labelled GT #19	(a)15:03:39 to 15:15:47	Intermittent Readout malfunction	0° to 16	Meaning-less	Unaccept-able	Modes II and VI Data not suitable for project.
	(b)15:15:48 to 15:18:24	Intermittent Readout malfunction	59°	Fair	Meaning-ful	Mode 5 data appears useable for project.
7 (GT #33)	6-10-73 14:28:12 to 14:38:46	No Readout in first and last four minutes. Satisfactory at other times.	Less than 0.7°	Fair to Very Poor	Unexpected Irregular variations	Modes I, III and V data to be processed for further analysis. Nadir alignment may not have been achieved.
9 (GT #61)	6-12-73 (a)13:01:37 to 13:04:26 (b)13:10:00 to 13:12:19 (c)13:15:35 to 13:17:54	Good Readout	Less than 0.6°	Very Good Fair to Good	Accepta-ble	(a) is Mode V, (b) and (c) are Mode III data. One of best two data sets. Good for processing.

* GT = Assigned Satellite Groundtrack number
** N-FOV = Angle between Nadir and Sensor field of view (computed estimates)

the spacecraft altitude was not being monitored as it should. The standard deviations were all zero, of course due to the fact that the altimeter was operating only in modes II and VI when the ranges remained constant. Consequently, the altitude residuals were bad and constant around 33,000 meters. The off-nadir angle of the sensor field of view varied eratically between 0^{o} and 16^{o}, which should not happen.

During the above stated 3 minutes when the altimeter ranges, the altitude residuals and the standard deviations looked good, unfortunately off-nadir angle was constant at about 59^{o}. This is undesirable but the data could still be processed except that, again, the roll-pitch-yaw angles were mostly zero exactly, indicating that the spacecraft altitude measurement systems were then not functioning. It is, therefore, not certain whether or not nadir alignment was achieved and if so, where the sensor was pointing. We will try to process this data on either assumption, i. e., (1) that the S-193 was pointing 59^{o} off nadir in either pitch or roll, resulting in one of four possible ground tracts or (2) that the nadir alignment was actually achieved but the 59^{o} off-angle was a false readout. However, before we attempt this, we would first investigate if the NASA/Wallops S-193 personnel can resolve this ambiguity via their analysis of radar returns pulse shape.

EREP pass #7 had about 10 minutes of our requested data. The first 6-minute data appear acceptable for processing but are not as good as the passes #4 and #9 data. The standard deviations of the mean ranges for each second averaging interval were extremely large, often ten times as big as those in passes #4 and #9. The altitude residuals consistently changed abnormally and irregularly. During the first minute of that 6-minute period, roll-pitch-yaw measurement system was not in operation. However, the off-nadir angles looked normal. The last 2-minute data have problems as in the first-minute data and can be processed for further analysis. The other two minutes of data are not good for further consideration in this project.

CONCLUSIONS

(1) About 60 to 70% of the SL-2, S-193 altimeter and associated data received appear to be suitable for this project. Of this suitable set, about two-thirds look very good and the rest is fair to good. Timewise, the

duration of the data acquisition and hence, the quantity of data exceeds our SL-2 expectations. However, in terms of task site coverage, only about 50% of our specifications were met.

(2) The precision of the best existing conventional geoid computations for ocean areas is $\pm$ 10 meter or more. Therefore, strictly speaking we have no groundtruth or yardstick for assessing the accuracy of the analytically derived satellite altimetry geoid (SAG). However, the fact that so far, the derived SAG is within $\pm$ 7 meters of one of the best conventional geoid computations is an encouraging sign. Further definite conclusions on accuracy will have to await the completion of this project and will depend on repeated S-193 data acquisition over or near the same ground tracks during mission SL-4.

(3) It appears that the Skylab altimeter data may have enough resolution for investigation of quasi-stationary departures of sea surface topography from the geoid. This important oceanographic phenomenon exists under SL-2 EREP passes #4 (GT #19) and #9 (GT #61). It is due to the Gulf Stream and the departure is estimated to be up to 2 meters rise from the U. S. east coast to Bermuda (Reference 5). If Skylab altimetry resolves this issue, an important NASA and national milestone objective of GEOS-C and SEASAT mission will have been confirmed.

PROBLEMS

(1) So far, only two data tapes (S071-1) have been received. Both tapes are for EREP pass #6 data. This is the tape with mostly poor data and the least amount of data that merit further processing. Delay in receiving tapes with the most desirable data is hindering progress and efficiency.

(2) Deciphering on our CDC computer, the tape contents based on the coded instructions in PHO-TR543 (Reference 6) has been an arduous task. As it is being done for S-192 data, if the S-193 altimeter data tapes had been generated on CYBER 73, our difficulties in interpreting the tape would not have existed. Alternatively, the tape structure used in

generating the SKYBET TAPES (PHO-TR543) or BCD format would have eliminated our problems. (Note: as of December 6, 1973, we have succeeded in recovering the numeric but not the alpha-numeric information on the tape).

(3) The S071-1 data tapes do not contain the satellite X, Y, Z, (ECT) coordinates we requested.

RECOMMENDATIONS

(1) Feedback on specific actions being taken or proposed on some of the previously identified problems and recommendations will be helpful.

(2) Previously, we requested for EREP Post Summary Report. All the data we need from that report are on the SKYBET tapes, which also contain the X, Y, Z coordinates which are not on the S071-1 data tapes. We, therefore, request for the SKYBET tapes instead of or in addition to these reports.

(3) Based on work and previous studies discussed in the conclusion of Reference 7, there is need and better merit in analyzing satellite altimetry data on a worldwide basis. It is recommended that necessary steps be taken to enable us use S-193 altimeter data acquired in other parts of the world outside our designated test sites in all three missions.

(4) A speed up of the data tape deliveries will be appreciated. We have received paper printouts of data generated from the tapes but working with the tapes is more efficient than with the paper tabulations.

(5) During SL-4, sea state information should be collected during S-193 altimeter data acquisition whenever possible. This is important to permit positive resolution of the oceanographic phenomenon being investigated.

NEXT PERIOD AND SUMMARY OUTLOOK

Our main efforts for the next period will include:

(1) Continuation of work to complete the computer interpretation of the S071-1 tapes received, and reconstruction of data tape format for generation of new data tapes as required for our investigation. (We do not need about 90% of the S071-1 tape contents);

(2) Dr. D. M. Fubara will present the paper entitled "Geodetic Analysis of Skylab Altimetry Preliminary Data - SL/2 EREP PASS 9" at the Annual Fall Meeting of the American Geophysical Union, in San Francisco, California. His traveling expenses are not being charged to the project;

(3) Discussions on some of the data problems that have arisen will be held with the pertinent personnel of NASA-Wallops and Wolf R. & D. Corporation.

(4) Modification of computer programs as required will continue.

(5) Our investigation is being stretched to identify the possible contribution of this project and satellite altimetry to the solution of oceanographic problems.

TRAVEL

There was no travel during this period. For the next period, the only travel related to this project as mentioned earlier is at no cost to the contract.

REFERENCES

1. Philco-Ford Corp., "Earth Resources Production Processing Requirements for EREP Electronic Sensors", PHO-TR524, Rev. A, Prepared for NASA/JSC, May, 1973.

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

3. Rapp, R. H., "Accuracy of Geoid Undulation Computations", J. of Geophys. Res., Vol. 78, No. 32, pp 7589-7595, 1973.

4. Stommel, H., The Gulf Stream, 2nd Edition, University of California Press, Berkeley, 1965.

5. Sturges, W., "Comments on Oceanic Circulation with Regard to Satellite Altimetry", Proceedings of Conference on Sea Surface Topography from Space, Vol. II, NOAA Tech. Rep.ERL 228-AOML 7-2, U.S. Gov't. Printing Office, Washington, D. C., 1972.

6. NASA/JSC, "Earth Resources Data Format Control Book", Vol. 1, Prepared by Philco-Ford Corp., March, 1973.

7. Fubara, D. M. J., and Mourad, A. G., "Geodetic Analysis of Skylab Altimetry Preliminary Data - SL/2 EREP PASS 9", paper presented at Fall Meeting of American Geophysical Union, San Francisco, California, December, 1973.

APPENDIX A

REPORTS AND DATA RECEIVED

1. EREP Summary Report for SL-2 and SL-3 NASA/JSC, PIM Office, September, 1973.

2. Skylab EREP Field Data Pack SL-4 Mission Supplement, NASA/JSC, November, 1973.

3. Mission Requirements Third Skylab Mission SL-4, I-MRD-001F, Vol. III, Change 6.

4. SLO Time Code, Special Serial Code Type "B" for Strip Chart and Oscillographic Recorders.

5. Earth Resources Requirements, Skylab Mission SL-4, Appendix B, Mission Requirements, Revision C, NASA/JSC, I-MRD-001 Appendix B, November, 1973.

6. SL-2 Data Records Received:

D.D.C. Accession No.	DPAR	Date/Time START	Date/Time STOP
32-04059	S193B-069-2-6	160:15:15:14	160:15:19:10
32-04060	S192B-069-2-6	160:15:15:14	160:15:19:10
32-04061	S192B-070-3-7	161:14:27:50	161:14:31:51
32-04062	S193B-070-3-7	161:14:27:50	161:14:31:51
32-02637	S193B-DPCA-1-0-71-1		
32-02636	S193B-DPCA-1-0-71-1		
32-04079	3B-070-4-9-74-2	163:13:01:30	163:13:04:55
32-04080	3B-070-4-9-74-2	163:13:01:30	163:13:04:55
32-15197	S193B-070-2-4-73-6		
32-15217	S193B-070-4-9-73B		
32-04111	3B-069-2-6-74-2	160:15:15:14	160:15:19:10
32-04112	3B-069-2-6-74-2	160:15:15:14	160:15:19:10
32-04126	3B-069-3-7-74-2	161:14:31:53	161:14:35:10
32-04127	3B-069-3-7-74-2	161:14:31:53	161:14:35:10
32-04128	3B-070-3-7-74-2	161:14:27:50	161:14:31:51
32-04129	3B-070-3-7-74-2	161:14:27:50	161:14:31:51
32-04130	3B-070-2-4-74-2	155:17:11:00	155:17:14:50
32-04131	3B-070-2-4-74-2	155:17:11:00	155:17:14:50
32-04111	3B-069-2-6-74-2	160:15:15:14	160:15:19:10
32-04112	3B-069-2-6-74-2	160:15:15:14	160:15:19:10
32-04126	3B-069-3-7-74-2	161:14:31:53	161:14:35:10
32-04127	3B-069-3-7-74-2	161:14:31:53	161:14:35:10
32-04128	3B-070-3-7-74-2	161:14:27:50	161:14:31:51
32-04129	3B-070-3-7-74-2	161:14:27:50	161:14:31:51
32-04130	3B-070-2-4-74-2	155:17:11:00	155:17:14:50
32-04131	3B-070-2-4-74-2	155:17:11:00	155:17:14:50
32-15375	S193B-070-4-9-73-6		
	S190A 9" TRANSPARENCIES - 1 each POS Mag:10 176/190		
	S190A 9" TRANSPARENCIES - 1 each POS Mag:10 16 (FR. 270/273 & 171/185)		