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APPLICATION OF REMOTE SENSING
FOR FISHERY RESOURCE
ASSESSMENT AND MONITORING

SKYLAB EXPERIMENT NO. 240
CONTRACT NO. T-8217B

MONTHLY PROGRESS REPORT NO. 12
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APPLICATION OF REMOTE SENSING
FOR FISHERY RESOURCE
ASSESSMENT AND MONITORING

INTRODUCTION

This is the twelfth of a monthly series of progress reports required by the statement of work for Skylab Project 240 entitled "Application of Remote Sensing for Oceanic Gamefish Assessment and Monitoring" under Contract No. T8217B.

OVERALL STATUS

Several remaining analyses are being completed and the final report is in preparation.

RESULTS

The Principal Investigator presented a paper entitled "Preliminary Results of Fisheries Investigation Associated with Skylab", at a remote sensing symposium at Willow Run, Michigan, on 15 April 1974.

A plot was drawn of the dolphin catch and the water discontinuities observed in the aerial photography. This plot was similar in format to one made earlier of the white marlin catch relative to the water rips. Neither plot substantiates (as far as white marlin and dolphin are concerned) an opinion held by fishermen that better fishing may be found in the vicinity of rips.

Remotely inferred values for sea surface temperature, chlorophyll-a and turbidity were substituted for sea truth measurements in prediction models developed in previous analysis. Model performance, using the new values, was disappointing.

EXPECTED ACCOMPLISHMENTS

Correlations of dolphin with the environmental parameters will be explored in the time remaining on the project contract. First priority in analysis had been accorded to a billfish species. An analysis relative to white marlin is now complete. Dolphin were selected for follow-on analysis since more dolphin were caught than any other gamefish species during the tournament associated with the project mission phase.

The draft final report will be mailed during the coming month, May 1974, as required contractually.

ABSTRACT

SCALE AND ORIENTATION CONTROL IN GEODETIC
APPLICATIONS OF SATELLITE ALTIMETRY

An analytical method for geodetic computation of the marine geoid (the geoid in the oceans) from satellite altimetry is developed and validated with data from Skylab mission SL-2. The criteria for achieving accurate scale and orientation of satellite altimetry geoid are shown to require marine geodetic control to offset systematic errors in the orbit (orientation is completely orbit dependent) and the altimeter data.

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APPENDIX B

SCALE AND ORIENTATION CONTROL IN GEODETIC
APPLICATIONS OF SATELLITE ALTIMETRY

by

D. M. J. Fubara and A. G. Mourad

May 16, 1974

BATTELLE
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FOURTEENTH PROGRESS REPORT

on

CALIBRATION AND EVALUATION OF SKYLAB ALTIMETRY FOR
GEODETIC DETERMINATION OF THE GEOID (Contract NAS9-13276,
EPN 440) April 1 to April 30, 1974

to

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

from

BATTELLE
Columbus Laboratories

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

A. G. Mourad (Principal Investigator)

Z. H. Byrns, Code TF6 - NASA/JSC Technical Monitor

May 16, 1974

PROGRESS

During this reporting period, our main effort involved

- (1) Completion of our investigation of scale and orientation control in geodetic applications of satellite altimetry. This is an outgrowth and a necessary integral part of our investigation of calibration and evaluation of Skylab altimetry for geodetic determination of the geoid. In particular, the accuracy problems of SKYBET necessitated this investigation. A formal write up of our results is given as Appendix B.
- (2) Continued work on the remaining SL-2 data
- (3) Continued investigation of effect of orbit errors in geoid determination from satellite altimetry
- (4) Quick look examination of SL-4 data tabulations received so far.

SCALE AND ORIENTATION CONTROL IN GEODETIC
APPLICATIONS OF SATELLITE ALTIMETRY

INTRODUCTION

Determination of the geoid in the form of heights above a reference ellipsoid is the basic step in the geodetic applications of satellite altimetry. The geoid to be determined must be in absolute position or geocentric (i.e., centered at the earth's center of mass) and have correct scale, shape and orientation in order to meet the goals of geodesy and also make contributions to the solution of problems in earth gravity modeling, geophysics, oceanography, etc. Correctness of shape depends on the precision of the altimeter and, in theory, absolute centering and orientation are dependent on the satellite orbit ephemeris. The correctness of geoid scale requires that the orbit ephemeris and the altimeter either have no biases or systematic errors, or that such biases and systematic errors must be known to an accuracy better than the error tolerance of the geoid to be computed. Currently and for sometime to come, these two scalar conditions cannot be met because of unknown systematic errors or biases in tracking station geocentric coordinates, the earth's gravity model, the tracking systems and the altimeter itself. There is, therefore, a need for other sources of scale and orientation control. This paper discusses the need for and the use of terrestrial marine geodetic data to obtain scale and orientation control in the computation of the marine geoid (i.e., the geoid in the ocean areas) from satellite altimetry.

Three types of terrestrial geodetic parameters are required for this scale and orientation control: (1) The best available estimates of the figure of the earth in terms of the size and shape of a reference ellipsoid, (2) geoid heights references to this ellipsoid, and (3) marine geodetic controls. The first two of these are required as a priori inputs to provide a coarse scale. The third serves as benchmarks establishing the fine scale and misclosure errors. This is akin to leveling practice on land. Satellite altimetry is simply geodetic leveling from space.

Various estimates of the figure of the earth are in Mueller [1966] and Khan [1973]. The best space age estimates of the equatorial radius value range from 6,378,124 m. [Strange et al. 1971] to 6,378,169 m. [Veis, 1967], with most estimates in 6,378,140 \pm 5 m range and a flattening of 1/298.255. Unfortunately, for the geoid, agreement and/or compatibility of various

authors geoids is considered very discouraging [Decker, 1973 and Fubara, et al. 1972a], particularly in the ocean areas. Vincent and Marsh [1973] geoid based on equatorial radius of 6,378,142 m. and flattening of $1/298.255$ was selected for this investigation. A comparison of marine geoids of Vincent and Marsh [1973], Vincent, Strange and Marsh [1972] (see Figure 3) and Talwani, et al. [1972] shows why the choice of any of them can provide only coarse scale. The fine scale requires the use of marine geodetic control established via the use of satellite geodesy and astrogravimetric techniques [Fubara and Mourad, 1972a, 1972b and Fubara, 1973a, Mourad, et al., 1972a and 1972b].

Figure 1 shows schematic geocentric relations of the various surfaces associated with satellite altimetry. TM is the raw altimeter range which has to be corrected for laboratory instrumental calibration, electro-magnetic effects, sea state, and periodic sea surface influences to give TS. S represents the non-periodic "sea level". CT and CE, the geocentric radii of the altimeter and E, its subsatellite point on the reference ellipsoid, are computed from satellite tracking information. EG is the absolute geoidal undulation to be computed from this investigation, while SG is the quasi-stationary departure of the mean instantaneous sea surface from the geoid - the "undisturbed" mean sea level. Details of the altimetry data from Skylab mission SL-2, EREP pass 9, used in this paper are in Fubara and Mourad [1974].

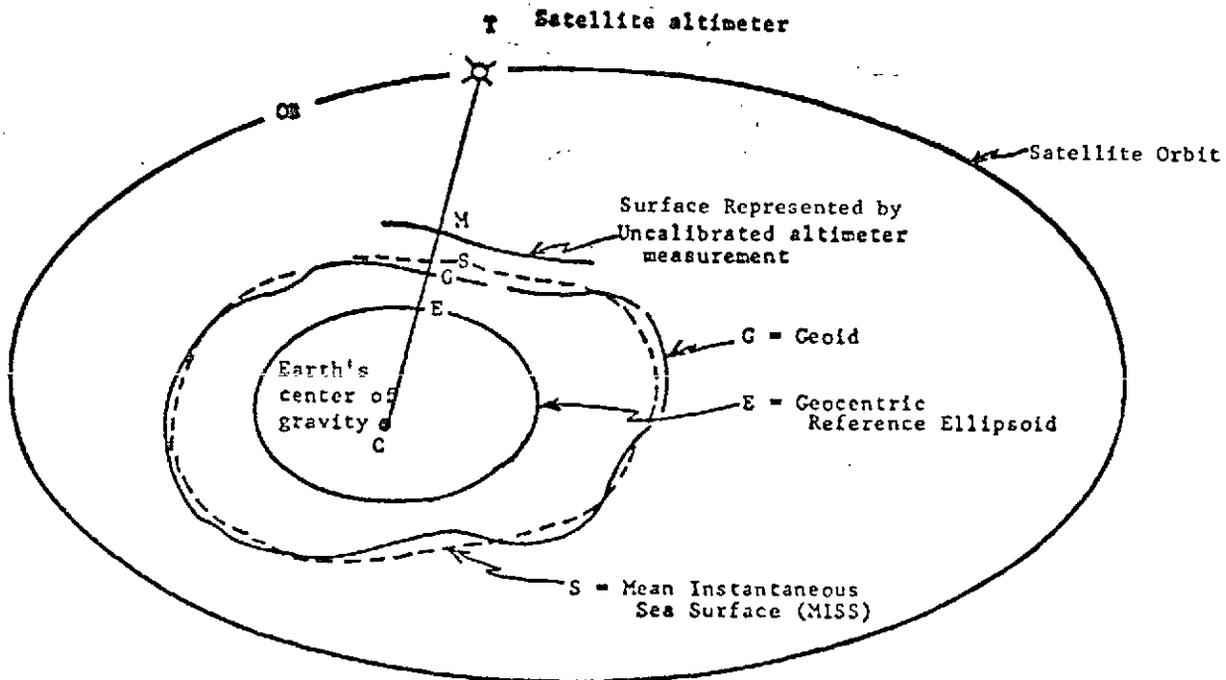


FIGURE 1. GEOCENTRIC RELATIONS OF SURFACES INVOLVED IN SATELLITE ALTIMETRY

ANALYTICAL DATA HANDLING FORMULATIONS

Each measured altimeter range R_i^O with an associated measurement residual v_i is intrinsically related to (1) X_s , Y_s and Z_s (the satellite coordinates at the instant of measurement), (2) the absolute geoidal undulation N_i^a (of the subsatellite point) based on a reference ellipsoid of parameters a (equatorial radius), and e (first eccentricity) and (3) the biases in all measurement systems involved. The condition equation for this intrinsic relationship can be stated as:

$$v_i + R_i^O(1 + \Delta c) - h_i + N_i^O + \Delta N_i = 0 \quad (1)$$

where

$\Delta c = f_i$ (systematic errors in X_s , Y_s , Z_s , the altimeter bias and sea state correction bias) is the total geodetic calibration factor to be determined. This factor controls the scale or the radial relation to geocenter of the geoid deduced from satellite altimetry.

$$N_i^a = N_i^O + \Delta N_i \quad (N_i^O \text{ is an approximate value for } N_i^a) = f_2(a, e);$$

and h_i is the geodetic satellite height above the reference ellipsoid, or

$$h_i = f_2(X_s, Y_s, Z_s, \bar{a}, \bar{e})$$

where \bar{a} and \bar{e} are parameters of the reference ellipsoid for the geodetic datum of the tracking stations whose coordinates are used in computing the satellite coordinates X_s , Y_s , and Z_s . Equation (1) presumes that $a = \bar{a}$ and $e = \bar{e}$; and also that the two reference ellipsoids are concentric and geocentric.

In current geodetic practice, because of multiplicity of geodetic datums and the non-existence of an universally accepted datum, the $a = \bar{a}$, etc. requirements are hardly ever met. A geodetic datum is uniquely determined by seven parameters. One such set of parameters is a , e , Δx , Δy , Δz , $\Delta \xi$ and $\Delta \eta$.

a and e define the size and shape of the reference ellipsoid; Δx , Δy and Δz relate the center of the reference ellipsoid to the geocenter and are purely translatory; while $\Delta \xi$ and $\Delta \eta$ are angular values to ensure parallelity between the minor and major axes of the reference ellipsoid and the mean rotational axis and mean terrestrial equator of the earth respectively. For each geodetic datum, every effort is made to ensure that $\Delta \xi = \Delta \eta = 0$. However, as shown in Fubara and Mourad [1972a], this condition has never been exactly realized but its effect can be neglected.

The change Δh_i in h_i due to the changes Δa and Δf in the dimensions of the reference ellipsoid and Δx_o , Δy_o , and Δz_o in its position relative to geocenter is given by Heiskanen and Moritz [1967] as

$$\Delta h_i = -\cos\varphi \cos\lambda \Delta x_o - \cos\varphi \sin\lambda \Delta y_o - \sin\varphi \Delta z_o - \Delta a + a \sin^2\varphi \Delta f \quad (2)$$

where

$$f = \text{flattening of reference ellipsoid } [f = 1 - (1-e^2)^{1/2}]$$

φ and λ = geodetic latitude and longitude corresponding to X_s , Y_s , and Z_s .

To include the Δh_i correction parameter, Equation (1) should be rewritten as

$$v_i + R_i(1 + \Delta c) - (h_i + \Delta h_i) + N_i^0 + \Delta N_i = 0 \quad (3)$$

to reflect changes in reference ellipsoidal parameters whenever necessary.

Equation (1) or (3) can be rewritten in matrix form as

$$F_1 (X_1^a, X_2^a, L_1^a) = 0, \quad (4)$$

subject to the normalized weighting functions P_1 , P_2 and P_3 associated with X_1 , X_2 and L_1 , respectively.

In this model, all parameters and measurements of the mathematical model are treated as "measurements" and weighted accordingly. This mathematical model for the generalized least squares processing of experimental data is based on works of Schmid and Schmid [1964].

The superscript "a" denotes the exact true values of the "measurements". Usually, these true values are not known. Instead, the corresponding measured or approximate values X_1^o , X_2^o , and L_1^o with associated variance-covariances P_1^{-1} , P_2^{-1} , P_3^{-1} , are estimated or measured. Therefore, Equation (4) can be rewritten in the form

$$F_2 \left[(X_1^o + \Delta_1), (X_2^o + \Delta_2), (L_1^o + V_1) \right] = 0 \quad (5)$$

where in relation to Equations (1) and (3)

$$X_1^a = X_1^o + \Delta_1 = N_i^o + \Delta N_i$$

$$X_2^a = X_2^o + \Delta_2 = R_i^o \Delta C - (h_i + \Delta h_i)$$

$$L_1^a = L_1^o + V_1 = R_i^o + V_i$$

The linearized form of Equation (8) is

$$A_1 \Delta_1 + B_1 \Delta_2 + C_1 V_1 + F_2 (X_1^o, X_2^o, L_1^o) = 0 \quad (6)$$

A_1 , B_1 , and C_1 are the first partial derivatives in a Taylor series expansion of Equation (5), associated with X_1^o , X_2^o , and L_1^o , respectively, while Δ_1 , Δ_2 , and V_1 are the correction parameters to be determined.

The least squares solution of Equation (6) to derive the corrections Δ_1 , Δ_2 , and V_1 to "measured" X_1^o , X_2^o and L_1^o is as developed in Fubara [1973b].

DATA PROCESSING, RESULTS AND ANALYSIS

The data being analyzed consist of two sets - A and B. Set B altimeter ranges are the same as Set A plus some biases, and orbit B and orbit A differ by a set of systematic errors.

The elementary deduction of geoid heights from satellite altimetry is to merely subtract each range measured by the altimeter from the corresponding geodetic height of the satellite computed from the orbit ephemeris.

Compared to Equation (3), this simple form which is shown to have many deficiencies is

$$R_i - (h_i + \Delta h_i) + N_i = 0 \quad (7)$$

Figure 2 gives the results of applying Equation (7) to the four combinations of data Sets A and B, and also a profile of the same segment from Vincent and Marsh [1973] geoid which is reliable to ± 5 to ± 15 meters in the oceans according to the authors. It is obvious, therefore, that as long as computed orbits and the altimeter data have systematic errors or biases, this simple subtraction technique cannot furnish the geoid with correct scale and orientation relative to geocenter.

The results from processing the same data combinations, using the analytical formulations of Equations (3) to (6), and a priori geoid height input from Vincent and Marsh [1973] are shown in Figure 3. The match up between profiles AA and AB (same orbit but different altimeter data biases), and also between BB and BA (same orbit and different altimeter data biases) indicate (a) the analytical processing is efficient; (b) based on this type of processing, input of a priori geoid information does provide useful "coarse scale" to the satellite altimetry geoid irrespective of unknown altimeter system biases; and (c) marine geodetic controls (station whose geocentric three-dimensional coordinates are accurately known) are required to provide the necessary fine scale and absolute orientation unless the orbit is errorless and can be validated by other independent means.

Orbit A and the Vincent and Marsh [1973] geoid were each computed from nearly identical sets of geopotential coefficient. Therefore, the excellent agreement between the satellite altimetry geoid segments AA and AB based on Orbit A and the Vincent and Marsh geoid is not a proof of the accuracy of either the orbit or that geoid. Rather it appears to indicate the precision of the Skylab altimeter.

The effects of errors in a priori geoid height inputs and the scale dependency of satellite altimetry geoid on geodetic control were investigated. The results are shown in Figure 4. Orbit A and Set A altimeter ranges were used and A-I, B-I and GG-73 were the a priori geoid height inputs. The corresponding "satellite altimetry geoid" profiles deduced were A-0, B-0 and AA. These results indicate that, provided the precision of the altimeter is reliable, errors in a priori geoid height input affect only the scale and not the shape of the resultant altimetry geoid.

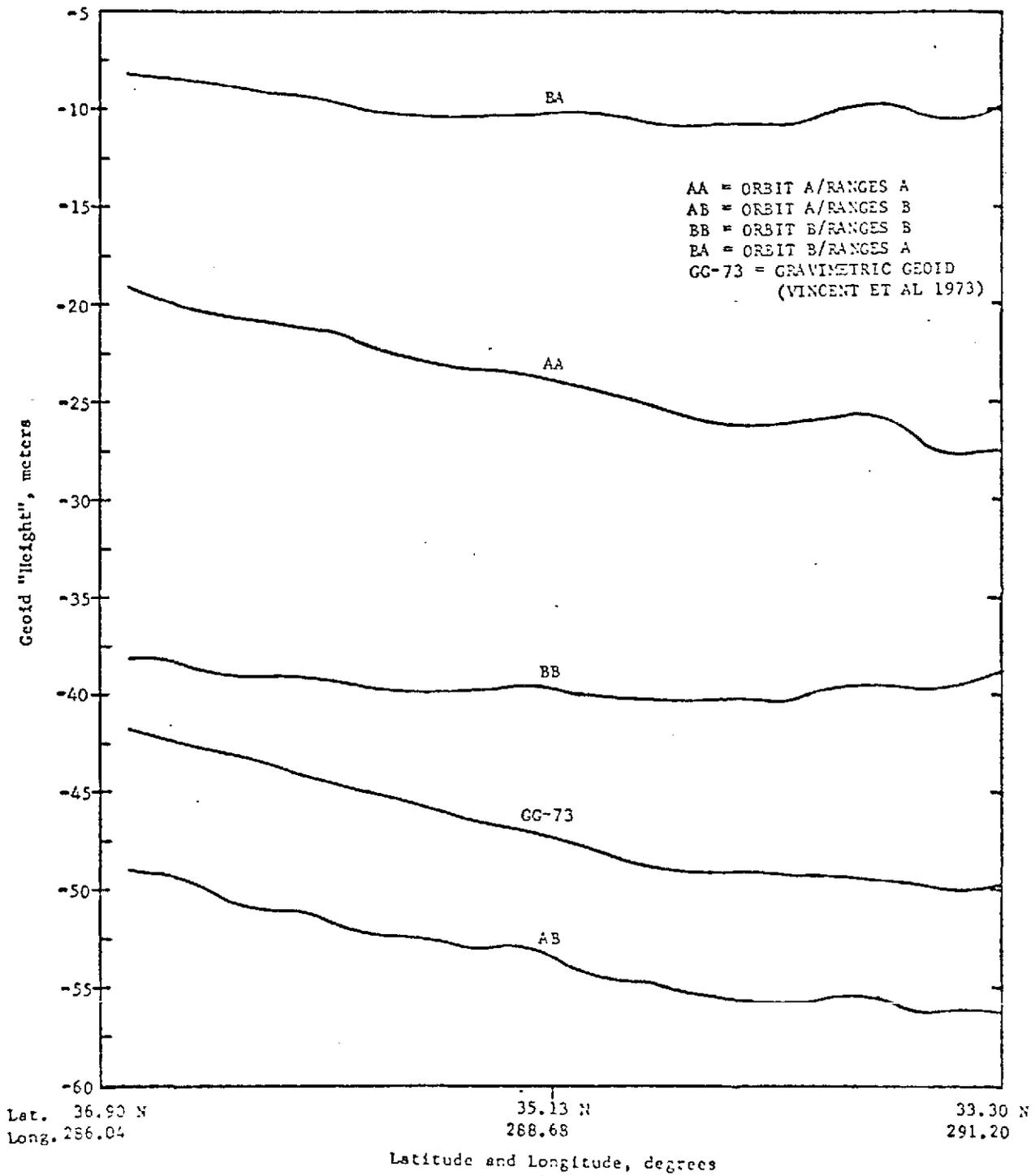


FIGURE 2. SATELLITE HEIGHT MINUS ALTIMETER RANGES AND A CONVENTIONAL GEOID PROFILE (SKYLAB SL-2 EREP PASS 9, MODE 5 DATA)

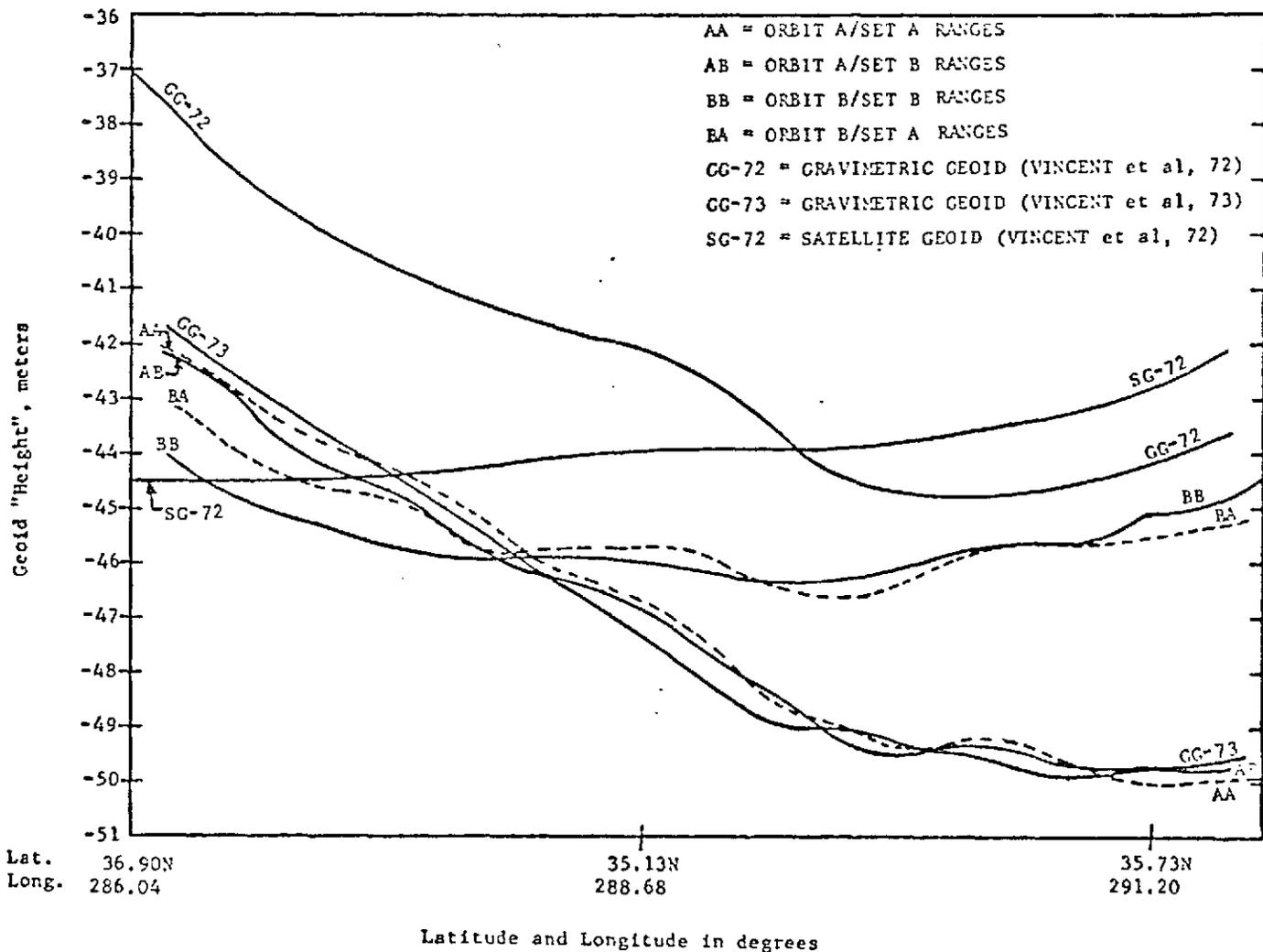


FIGURE 3. CONVENTIONAL GEOID AND SATELLITE ALTIMETRY GEOID SEGEMENTS (SKYLAB SL-2 EREP PASS 9 DATA)

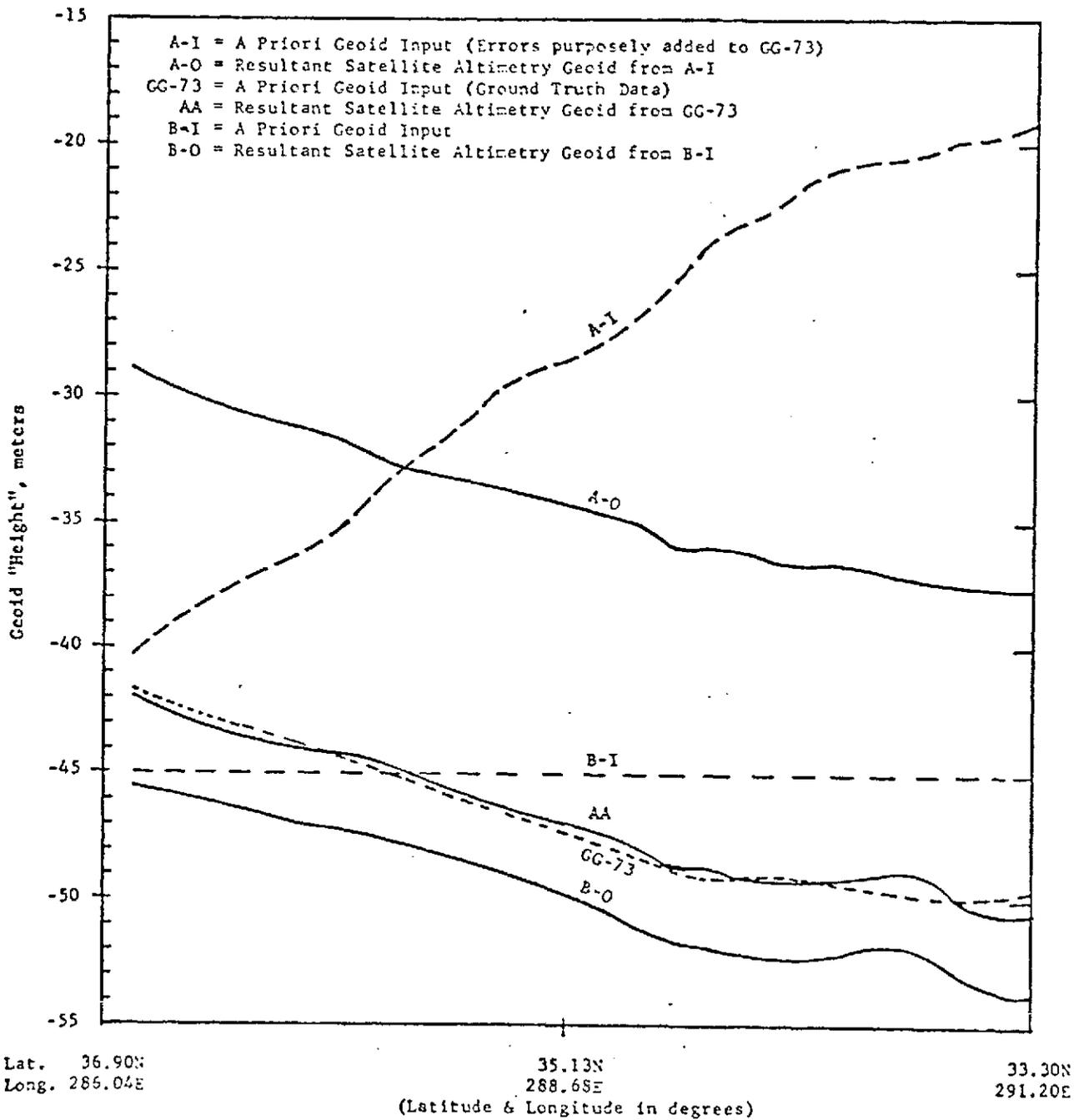


FIGURE 4. EFFECT OF ERRORS IN A PRIORI GEOID HEIGHT INPUTS AND SCALE DEPENDENCY OF SATELLITE ALTIMETRY GEOID HEIGHT ON GEODETIC CONTROL (GROUND TRUTH)

CONCLUSIONS

Based on these investigations, it can be said that:

- (1) Analytical data handling formulations of the type developed are effective and necessary for accommodating data biases to ensure a reliable scale in geodetic application of satellite altimetry.
- (2) A priori geoidal information is required to give a coarse scale. The use of geodetic controls or benchmarks, at which absolute geoid heights are known, is indispensable to ensure that the deduced geodetic heights are absolute, correctly scaled and oriented. The satellite orbit and the altimeter biases or systematic errors are known more accurately than the tolerable error of the computed geoid. The establishment of such controls by marine geodesy from a combination of astrogravimetry and satellite data is discussed in Mourad and Fubara [1972], and in Fubara and Mourad [1972a] and the practical implementation is partially demonstrated in Fubara and Mourad [1972b]. There is an implicit correlation between this conclusion and the conclusion based on a different type of investigation in Rapp [1971] that: "In carrying out simulation studies with non-global data it was concluded that altimetry data could not be used alone for potential coefficient determination... Consequently, the altimetry data was combined with geoid undulation information in non-ocean blocks and with existing terrestrial gravity data". Therefore, marine geodesy appears indispensable for the full achievement of satellite altimetry objectives of GEOS-C, SEASAT and the NASA-proposed "Earth and Ocean Physics Applications Program".
- (3) Accurate deduction of the geoid from satellite altimetry cannot be achieved by merely subtracting altimeter ranges from the corresponding geodetic heights of the satellite unless to present tolerance levels, (a) the satellite orbit is errorless, (b) the altimeter does not drift, and (c) the altimeter system biases are either non-existent or are absolutely known. Even then,

the proof that preset tolerance levels are achieved will depend on marine geodetic control. Therefore, as of now, satellite altimetry ranges cannot be regarded as representing direct determination of absolute geoid heights. However, preliminary results from the Skylab altimeter show that satellite altimetry, backed by marine geodesy can accomplish EOPAP objectives.

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