NOAA Technical Memorandum NOS NGS 19

HOACOS: A PROGRAM FOR ADJUSTING HORIZONTAL NETWORKS IN THREE DIMENSIONS

Rockville, Md.
July 1979

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NOAA geodetic publications

Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys. Federal Geodetic Control Committee, John O. Phillips (Chairman), Department of Commerce, NOAA, NOS, 1974 reprinted annually, 12 pp (PB265442). National specifications and tables show the closures required and tolerances permitted for first-, second-, and third-order geodetic control surveys.

Specifications To Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys. Federal Geodetic Control Committee, John O. Phillips (Chairman), Department of Commerce, NOAA, NOS, 1975, reprinted annually, 30 pp (PB261037). This publication provides the rationale behind the original publication, "Classification, Standards of Accuracy, ..." cited above.

NOAA Technical Memorandums, NOS/NGS subseries

NOS NGS-1 Use of climatological and meteorological data in the planning and execution of National Geodetic Survey field operations. Robert J. Leffler, December 1975, 30 pp (PB249677). Availability, pertinence, uses, and procedures for using climatological and meteorological data are discussed as applicable to NGS field operations.

NOS NGS-2 Final report on responses to geodetic data questionnaire. John F. Spencer, Jr., March 1976, 39 pp (PB254641). Responses (20%) to a geodetic data questionnaire, mailed to 36,000 U.S. land surveyors, are analyzed for projecting future geodetic data needs.

NOS NGS-3 Adjustment of geodetic field data using a sequential method. Marvin C. Whiting and Allen J. Pope, March 1976, 11 pp (PB253967). A sequential adjustment is adopted for use by NGS field parties.

NOS NGS-4 Reducing the profile of sparse symmetric matrices. Richard A. Snay, June 1976, 24 pp (PB-258476). An algorithm for improving the profile of a sparse symmetric matrix is introduced and tested against the widely used reverse Cuthill-McKee algorithm.

NOS NGS-5 National Geodetic Survey data: availability, explanation, and application. Joseph F. Dracup, June 1976, 45 pp (PB258475). The summary gives data and services available from from NGS, accuracy of surveys, and uses of specific data.

(Continued at end of publication)

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HOACOS: A PROGRAM FOR ADJUSTING HORIZONTAL NETWORKS IN THREE DIMENSIONS

T. Vincenty

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UNITED STATES DEPARTMENT OF COMMERCE
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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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HOACOS: A PROGRAM FOR ADJUSTING HORIZONTAL NETWORKS IN THREE DIMENSIONS

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ABSTRACT: Horizontal networks are adjusted in the simplest way in the height-controlled spatial system without reducing observations to the ellipsoid. The mathematical model of the adjustment is based on the known principles of three-dimensional geodesy. A computer program based on this method is described.

1. INTRODUCTION

HOACOS is an acronym for Horizontal Adjustment in Controlled Space. It is a computer program for adjusting geodetic networks in three dimensions, with heights and astronomic coordinates held fixed.

The pervading feature of the mathematical model for the adjustment is the forsaking of the ellipsoid as a reference surface. As used in the adjustment, distances are straight lines in space between reference points (marks on the ground), and directions are those observed in the plane of the astronomic horizon perpendicular to the direction of gravity.

Since this system was first proposed (Vincenty and Bowring 1978) it has undergone some modifications and acquired the designation of a height-controlled three-dimensional system (Vincenty 1979b). HOACOS puts this method to practical use.

2. NOTATION

X, Y, Z	Cartesian coordinates in the equatorial system
ϕ, λ	astronomic latitude and longitude (ground level values), positive north and east respectively
A	astronomic azimuth, clockwise from north
S	spatial distance
B, L	geodetic latitude and longitude
H	height above the ellipsoid
a	equatorial radius of the ellipsoid

e	first eccentricity of the ellipsoid
M, N	principal radii of curvature
dx, dy	linear shifts of positions in an astronomic horizon plane, positive north and east respectively

3. MATHEMATICAL MODEL

The position of each point in space is defined by

$$X = (N + H) \cos B \cos L$$
$$Y = (N + H) \cos B \sin L$$
$$Z = [N(1 - e^2) + H] \sin B. \qquad (1)$$

If the coordinates of two points and astronomic latitude and longitude of the standpoint are given, the length of the line and the astronomic azimuth at the standpoint can be computed by closed equations as follows:

$$\Delta X = X_2 - X_1 \qquad \Delta Y = Y_2 - Y_1 \qquad \Delta Z = Z_2 - Z_1$$

$$C_1 = - \sin \phi_1 (\Delta X \cos \lambda_1 + \Delta Y \sin \lambda_1) + \Delta Z \cos \phi_1$$

$$D_1 = - \Delta X \sin \lambda_1 + \Delta Y \cos \lambda_1$$

$$S^2 = \Delta X^2 + \Delta Y^2 + \Delta Z^2 \qquad (2)$$

$$\tan A_{12} = D_1/C_1. \qquad (3)$$

Similarly, we have for the reverse direction

$$C_2 = \sin \phi_2 (\Delta X \cos \lambda_2 + \Delta Y \sin \lambda_2) - \Delta Z \cos \phi_2$$

$$D_2 = \Delta X \sin \lambda_2 - \Delta Y \sin \lambda_2$$

$$\tan A_{21} = D_2/C_2. \qquad (4)$$

The observation equations for azimuth and distance observations have the form

$$v = a_1 dx_1 + a_2 dy_1 + a_3 dx_2 + a_4 dy_2 + K, \qquad (5)$$

in which the constant term K is the difference between the computed and the observed value.

Putting $R_1{}^2 = C_1{}^2 + D_1{}^2$ and $\Delta\lambda = \lambda_2 - \lambda_1$, the coefficients of azimuth observation equations are computed by

$$a_1 = D_1/R_1{}^2$$

$$a_2 = -C_1/R_1{}^2$$

$$a_3 = -[D_1(\cos\phi_1\cos\phi_2 + \sin\phi_1\sin\phi_2\cos\Delta\lambda) + C_1\sin\phi_2\sin\Delta\lambda]/R_1^{\,2}$$

$$a_4 = (C_1\cos\Delta\lambda - D_1\sin\phi_1\sin\Delta\lambda)/R_1^{\,2}.$$

The coefficients of distance observation equations are

$$a_1 = -C_1/S \qquad a_3 = -C_2/S$$

$$a_2 = -D_1/S \qquad a_4 = -D_2/S.$$

The azimuth observation equation is used also for unoriented horizontal directions, with the addition of an orientation unknown common to all members of the set, with a coefficient of -1.

Relative (unscaled) distances, used for determining the shape of the network, are treated in the same way as in program HAVAGO (Vincenty 1979a). Each such distance receives a scale unknown which is common to all members of the group, with a coefficient of -S. In a special case of this class of observations all distances may be assigned the same scale unknown.

Relative distances depend on a source of scale, such as at least one base line (a distance without scale unknown) or two or more fixed or constrained points. If no source of scale exists, a solution for average scale may be performed. In this case an observation equation is used to make the sum of the scale corrections equal to zero.

A position is constrained by two equations:

$$v_{dx} = dx + K_{dx} \tag{6a}$$

$$v_{dy} = dy + K_{dy}. \tag{6b}$$

The constant terms of position equations are computed initially by

$$K_{dx} = (B - B_0)(M + H)$$

$$K_{dy} = (L - L_0)(N + H)\cos B,$$

where B, L are assumed coordinates and B_0, L_0 are constraint values. After each iteration they are updated by adding the shifts dx and dy, respectively, as determined in the adjustment.

After each iteration the Cartesian coordinates are updated by

$$dX = -\sin\phi\cos\lambda\, dx - \sin\lambda\, dy$$

$$dY = -\sin\phi\sin\lambda\, dx + \cos\lambda\, dy$$

$$dZ = \cos\phi\, dx. \tag{7}$$

Adjusted Cartesian coordinates are transformed to geographic coordinates by

$$\tan B = (Z/p)/(1 - e_0{}^2) \tag{8}$$

$$\tan L = Y/X, \tag{9}$$

using

$$N \simeq a(1 + \frac{1}{2}e^2\sin^2\phi)$$

$$e_0{}^2 = e^2N/(N + H).$$

4. DESCRIPTION OF THE PROGRAM

4.1 Input Formats

The input was designed to be compatible with the existing formats of the TRAV10 program (Schwarz 1978). A set of input cards for TRAV10 is known as a "travdeck." HOACOS contains some additions to the formats of TRAV10 but they do not interfere with the structure of existing travdecks.

4.2 Option Card

The option card contains the deck name and various option flags for the execution of the program. Some options applicable to TRAV10 are not used and some have been added. Among the added options are the following:

- A flag instructs the program to read a card containing the parameters of the ellipsoid on which the preliminary geodetic positions have been computed.

- The adjustment may be performed with a solution for a scale unknown common to all distance observations.

- A section of input containing relative distances has been added. Each group of such distances is assigned a separate scale unknown.

- If relative distances are used, an option may be exercised whereby a solution for the average scale of the distances will be performed.

4.3 Processing of Input Data

Before HOACOS can be executed, the input deck must be run through a preprocessor (QUIKPROC) that assigns consecutive numbers to the stations and places appropriate station numbers on observation records.

4.3.1 Station Data

The data for each station include station name, preliminary geodetic latitude and longitude, height above sea level, geoid height, and some identifying information of no interest in the adjustment. As the cards are read in, the sines and the cosines of latitudes and longitudes are computed and stored in arrays. At this time the Cartesian coordinates of the points are computed and are also placed in arrays. Station names are stored on a disk unit.

4.3.2 Constrained Positions

Each record of this section of the input consists of station name, constrained latitude and longitude, and standard deviations of the constraints. If the coordinates are left blank, the program assumes that they are the same as the corresponding preliminary values. Default values of standard deviations are 0.1 mm for latitude and longitude. The observations are written on a disk.

4.3.3 Astronomic Coordinates

As astronomic coordinates are read in, their sines and cosines are computed and stored in arrays, overwriting the previously computed geodetic values. This means that if an astronomic latitude or longitude is not furnished, it is assumed to be the same as the corresponding preliminary geodetic value. Thereafter, the input values will not be used again by the program.

4.3.4 Observations Between Stations

As the observations are read, their variances are computed using standard deviation codes (which may be furnished on the observation card or deduced from the observation type code on the card). All information that will be needed later for the formation of observation equations is stored on a disk.

Occasionally sea level distances are encountered. These are converted to mark-to-mark distances as follows:

$$q = (\sin \phi_1 + \sin \phi_2)/2$$

$$N = \frac{a}{\sqrt{1-e^2 q^2}}$$

$$R = \frac{N}{1 + e^2 (N/s)^2 (\sin \phi_2 - \sin \phi_1)^2 / (1-e^2)}$$

$$D = s - s^3/(24\ R^2)$$

$$S = \sqrt{D^2 (R + H_1)(R + H_2) + (R\ \Delta H)^2}\ /R, \qquad (10)$$

where s is sea level distance.

4.4 Observation Equations

The observation equations are formed before the initial adjustment and before each iteration. The observation data previously stored on a disk are read sequentially, and the equations are formed and written on another unit for use by the adjustment package. The weight of each observation is the reciprocal of its variance.

No trigonometric functions are computed in forming the observation equations except for an arc tangent for each azimuth and unoriented direction (eq. 3).

Distances computed from most recent coordinates are needed only in distance observation equations. They are obtained without square roots from S^2 and the observed value S_0 by

$$S = (S^2/S_0 + S_0)/2. \qquad (11)$$

4.5 Adjustment

The adjustment is performed using an adjustment subroutine package prepared by William E. Dillinger. The package reads the observation equations, reorders the unknowns to reduce the profile of the matrix of normal equations, forms and solves normal equations, and after the last iteration inverts the matrix. Reordering of the unknowns may be suppressed as an option. The adjustment is assumed to have converged when the shift of each point from the previous to the current value is smaller than 0.01 m.

4.6 Postadjustment Computations

The residuals are computed by substituting the values of the unknowns in the observation equations. Normalized residuals are also computed.

The full variance-covariance matrix of adjusted unknowns is used to determine the standard errors of adjusted unknowns and the standard errors of adjusted distances and azimuths over lines between any points specified in the input.

The adjusted distances are always printed as straight lines in space. The adjusted azimuths are astronomic if observed; otherwise they are given as normal section azimuths between points in space and referred to the chosen ellipsoid. Geodesic distances and azimuths are not computed.

5. CONCLUSION

The height-controlled three-dimensional method of adjusting geodetic networks differs from the general three-dimensional approach in two respects. It requires a previous determination of heights of all points and it treats astronomic coordinates as invariable.

The direction of gravity, expressed by astronomic coordinates, should be known at all stations from which directions are measured, which is also true of classical ellipsoidal geodesy. If it is not known at some stations, the results will be falsified to some extent, sometimes seriously, irrespective of what computational system is used.

The equations for computing distances and azimuths are exact and stable. The accuracy of coefficients of observation equations does not depend on the length of the line but only on the relative accuracy of preliminary coordinates. Thus the height-controlled method can be used safely in all situations, regardless of lengths of the lines.

Reductions of directions and distances to the ellipsoid are not used in the program. These reductions, while useful in adjustments by the method of conditions, are unnecessary in modern adjustments by variation of parameters.

REFERENCES

Schwarz, C. R., 1978: TRAV10 horizontal network adjustment program. NOAA Technical Memorandum NOS NGS-12, Dept. Commerce, Washington, D.C., 52 pp. (Available from National Technical Information Service, Springfield, VA 22161, accession #PB283087.)

Vincenty, T., 1979a: The HAVAGO three-dimensional adjustment program. NOAA Technical Memorandum NOS NGS-17, Dept. Commerce, Washington, D.C., 18 pp. (Available from NTIS, Springfield, VA 22161.)

Vincenty, T., 1979b: Height-controlled three-dimensional system for adjustment of networks. (Submitted to Bulletin Géodésique.)

Vincenty, T. and Bowring, B. R., 1978: Application of three-dimensional geodesy to adjustments of horizontal networks. NOAA Technical Memorandum NOS NGS-13, Dept. Commerce, Washington, D.C., 7 pp. (Available from NTIS, Springfield, VA 22161, accession #PB286672.)

APPENDIX.--EXAMPLE

INPUT   FRIDAY   JULY 13,1979   PAGE 1

GEODETIC POSITIONS

NO.	NAME	LATITUDE	LONGITUDE	ELEVATION	G.H.	CLASS
1	STATION A	30 40 0.0	40 10 0.0	1002.00	-2.0	11
2	STATION B	30 10 0.20000	40 0 0.10000	1497.50	2.5	11
3	STATION C	30 0 0.0	41 0 0.20000	2501.50	-1.5	11
4	INTERSECTION	30 50 0.30000	40 40 0.50000	3000.00	0.0	11

INPUT   FRIDAY   JULY 13,1979   PAGE 2

CONSTRAINED POSITIONS

L.N.	NO.	NAME	LATITUDE	LONGITUDE	CONSTRAINTS	
5	1	STATION A			0.0	0.0

INPUT   FRIDAY   JULY 13,1979   PAGE 3

ASTRONOMIC COORDINATES

L.N.	NO.	NAME	LATITUDE	LONGITUDE
6	1	STATION A	30 40 10.00	40 10 20.00
7	2	STATION B	30 10 15.00	40 0 15.00
8	3	STATION C	30 0 20.00	41 0 10.00

INPUT FRIDAY JULY 13,1979 PAGE 4

DIRECTIONS

L.N.	FROM	TO	LIST	DATE	CODE	FROM	TO	DIRECTION	S.D.CODE
9	1	4	1		1	STATION A	INTERSECTION	0 0 0.0	0.8
10	1	3	1		1	STATION A	STAT ON C	63 42 14.00	0.8
11	1	2	1		1	STATION A	STATION B	127 23 13.00	0.8
12	2	1	1		1	STATION B	STATION A	0 0 0.0	0.8
13	2	4	1		1	STATION B	INTERSECTION	24 39 1.00	0.8
14	2	3	1		1	STATION B	STATION C	84 31 34.00	0.8
15	3	2	1		1	STATION C	STATION B	0 0 0.0	0.8
16	3	1	1		1	STATION C	STATION A	31 47 39.00	0.8
17	3	4	1		1	STATION C	INTERSECTION	59 51 54.00	0.8

INPUT FRIDAY JULY 13,1979 PAGE 5

ASTRONOMIC AZIMUTHS

L.N.	FROM	TO	DATE	CODE	FROM	TO	AZIMUTH	ST.DEV.	CODE
18	1	2		A	STATION A	STATION B	196 9 33.00	1.5	
19	2	1		A	STATION B	STATION A	16 4 25.00	1.5	
20	3	2		A	STATION C	STATION B	281 6 3.00	1.5	

INPUT FRIDAY JULY 13,1979 PAGE 6

DISTANCES

L.N.	FROM	TO	DATE	CODE	FROM	TO	DISTANCE	ST.DEV.	CODES
21	1	2		Y	STATION A	STATION B	57711.000	20.0	3.0
22	1	3		Y	STATION A	STATION C	109054.200	20.0	3.0
23	2	3		Y	STATION B	STATION C	98198.500	20.0	3.0

TEST QUAD

JOB STATISTICS

A = 6378388.000 1/F = 297.0000000

S.E. OF UNIT WEIGHT = 0.939, VARIANCE = 0.881, 6 DEGREES OF FREEDOM.

LONGITUDE POSITIVE EAST.
AZIMUTH FROM NORTH.
OBSERVED AZIMUTHS ARE ASTRONOMIC.
AZIMUTHS COMPUTED FROM ADJUSTED COORDINATES ARE NORMAL SECTION AZIMUTHS TO FOREPOINTS IN SPACE.
DISTANCES ARE STRAIGHT LINES BETWEEN MARKS.

1 ITERATION
4 STATIONS
1 CONSTRAINED POSITION
3 ASTRONOMIC LATITUDES
3 ASTRONOMIC LONGITUDES
9 DIRECTIONS
3 AZIMUTHS
3 DISTANCES
0 RELATIVE DISTANCES
3 LISTS OF DIRECTIONS
0 GROUPS OF DISTANCES
11 UNKNOWNS
17 OBSERVATIONS

ADJUSTED DATA

ADJUSTED POSITIONS

NO.	NAME	LATITUDE	STD.ERROR	LONGITUDE	STD.ERROR	ELEVATION	GEOID HT.	GEOD.HT.
1	STATION A	30 40 0.00000	0.00000	40 10 0.00000	0.00000	1002.00	-2.0	1000.00
2	STATION B	30 9 59.99955	0.00508	40 0 0.01127	0.00870	1497.50	2.5	1500.00
3	STATION C	29 59 59.98322	0.01278	40 59 59.99715	0.01352	2501.50	-1.5	2500.00
4	INTERSECTION	30 50 0.01280	0.01093	40 40 0.02837	0.01519	3000.00	0.0	3000.00

ADJUSTED DATA — FRIDAY — JULY 13,1979 — PAGE 9

CONSTRAINED POSITIONS

L.N.	NO.	NAME	LATITUDE	V	V'	LONGITUDE	V	V'
5	1	STATION A	30 40 0.00000	-0.00000	-0.00	40 10 0.00000	-0.00000	-0.00

ADJUSTED DATA — FRIDAY — JULY 13,1979 — PAGE 10

DIRECTIONS

L.N.	LIST	FROM	TO	DIRECTION	V	V'	AZIMUTH	DISTANCE
9	1	STATION A	INTERSECTION	0 0 0.000	-0.362	-0.45	68 46 7.627	51375.9096
10	1	STATION A	STATION C	63 42 13.916	-0.446	-0.56	132 28 21.552	109054.2052
11	1	STATION A	STATION B	127 23 14.171	0.808	1.01	196 9 21.849	57711.0801
12	2	STATION B	STATION A	0 0 0.000	-0.930	-1.16	16 4 18.103	57711.0801
13	2	STATION B	INTERSECTION	24 39 2.725	0.795	0.99	40 43 20.937	97814.1993
14	2	STATION B	STATION C	84 31 35.065	0.135	0.17	100 35 53.234	98198.3601
15	3	STATION C	STATION B	0 0 0.000	0.249	0.31	281 5 57.766	98198.3601
16	3	STATION C	STATION A	31 47 38.875	0.124	0.16	312 53 36.564	109054.2052
17	3	STATION C	INTERSECTION	59 51 53.379	-0.373	-0.47	340 57 51.488	97822.2863

ADJUSTED DATA — FRIDAY — JULY 13,1979 — PAGE 11

ASTRONOMIC AZIMUTHS

L.N.	FROM	TO	AZIMUTH	V	V'	DISTANCE
18	STATION A	STATION B	196 9 32.107	-0.893	-0.60	57711.0801
19	STATION B	STATION A	16 4 25.745	0.745	0.50	57711.0801
20	STATION C	STATION B	281 6 3.149	0.149	0.10	98198.3601

ADJUSTED DATA FRIDAY JULY 13,1979 PAGE 12

DISTANCES

L.N.	FROM	TO	DISTANCE	V	V'	AZIMUTH
21	STATION A	STATION B	57711.0801	0.0801	0.46	196 9 21.849
22	STATION A	STATION C	109054.2052	0.0052	0.02	132 28 21.552
23	STATION B	STATION C	98198.3601	-0.1599	-0.47	100 35 53.234

ADJUSTED DATA FRIDAY JULY 13,1979 PAGE 13

ACCURACIES

L.N.	FROM	TO	AZIMUTH	S.E.	DISTANCE	S.E.	CORR.COEF.
24	STATION A	STATION B	196 9 21.849	0.84	57711.0801	0.152	0.05
25	STATION A	STATION C	132 28 21.552	0.92	109054.2052	0.220	0.05
26	STATION A	INTERSECTION	68 46 7.627	1.20	51375.9096	0.433	-0.15
27	STATION B	STATION C	100 35 53.234	0.93	98198.3601	0.217	-0.11
28	STATION B	INTERSECTION	40 43 20.937	0.96	97814.1993	0.420	0.21
29	STATION C	INTERSECTION	340 57 51.488	1.26	97822.2863	0.311	0.25

FRIDAY JULY 13,1979 PAGE 14

CPU TIMES

SECONDS	ACTION
0.06	PROCESSING INPUT DATA
0.0	REORDERING UNKNOWNS
	AVERAGE PER ADJUSTMENT (2 ADJUSTMENTS)
0.03	FORMING OBSERVATION EQUATIONS
0.04	FORMING NORMAL EQUATIONS
0.01	SOLVING NORMAL EQUATIONS
0.00	UPDATING COORDINATES
0.02	COMPUTING MATRIX INVERSE, SOLUTION VECTOR, AND PRECISION OF UNKNOWNS
0.06	COMPUTING RESIDUALS, INVERSE DISTANCES AND AZIMUTHS, AND TRANSFORMING X,Y,Z TO GEODETIC COORDINATES
0.01	COMPUTING ACCURACIES
0.30	TOTAL IN HOACUS

(Continued from inside front cover)

NOS NGS-6 Determination of North American Datum 1983 coordinates of map corners. T. Vincenty, October 1976, 8 pp (PB262442). Predictions of changes in coordinates of map corners are detailed.

NOS NGS-7 Recent elevation change in Southern California. S.R. Holdahl, February 1977, 19 pp (PB265-940). Velocities of elevation change were determined from Southern Calif. leveling data for 1906-62 and 1959-76 epochs.

NOS NGS-8 Establishment of calibration base lines. Joseph F. Dracup, Charles J. Fronczek, and Raymond W. Tomlinson, August 1977, 22 pp (PB277130). Specifications are given for establishing calibration base lines.

NOS NGS-9 National Geodetic Survey publications on surveying and geodesy 1976. September 1977, 17 pp (PB275181). Compilation lists publications authored by NGS staff in 1976, source availability for out-of-print Coast and Geodetic Survey publications, and subscription information on the Geodetic Control Data Automatic Mailing List.

NOS NGS-10 Use of calibration base lines. Charles J. Fronczek, December 1977, 38 pp (PB279574). Detailed explanation allows the user to evaluate electromagnetic distance measuring instruments.

NOS NGS-11 Applicability of array algebra. Richard A. Snay, February 1978, 22 pp (PB281196). Conditions required for the transformation from matrix equations into computationally more efficient array equations are considered.

NOS NGS-12 The TRAV-10 horizontal network adjustment program. Charles R. Schwarz, April 1978, 52 pp (PB283087). The design, objectives, and specifications of the horizontal control adjustment program are presented.

NOS NGS-13 Application of three-dimensional geodesy to adjustments of horizontal networks. T. Vincenty and B. R. Bowring, June 1978, 7 pp (PB286672). A method is given for adjusting measurements in three-dimensional space without reducing them to any computational surface.

NOS NGS-14 Solvability analysis of geodetic networks using logical geometry. Richard A. Snay, October 1978, 29 pp (PB291286). No algorithm based solely on logical geometry has been found that can unerringly distinguish between solvable and unsolvable horizontal networks. For leveling networks such an algorithm is well known.

NOS NGS-15 Goldstone validation survey - phase 1. William E. Carter and James E. Pettey, November 1978, 44 pp (PB292310). Results are given for a space system validation study conducted at the Goldstone, Calif., Deep Space Communication Complex.

NOS NGS-16 Determination of North American Datum 1983 coordinates of map corners (Second Prediction). T. Vincenty, April 1979, 6 pp. New predictions of changes in coordinates of map corners are given.

NOS NGS-17 The HAVAGO three-dimensional adjustment program. T. Vincenty, May 1979, 18 pp. The HAVAGO computer program adjusts numerous kinds of geodetic observations for high precision special surveys and ordinary surveys.

NOS NGS-18 Determination of astronomic positions for California-Nevada boundary monuments near Lake Tahoe. James E. Pettey, March, 1979. Astronomic observations of the 120th meridian were made at the request of the Calif. State Lands Commission.

NOAA Technical Reports, NOS/NGS subseries

NOS 65 NGS 1 The statistics of residuals and the detection of outliers. Allen J. Pope, May 1976, 133 pp (PB258428). A criterion for rejection of bad geodetic data is derived on the basis of residuals from a simultaneous least-squares adjustment. Subroutine TAURE is included.

NOS 66 NGS 2 Effect of Geoceiver observations upon the classical triangulation network. R. E. Moose and S. W. Henriksen, June 1976, 65 pp (PB260921). The use of Geoceiver observations is investigated as a means of improving triangulation network adjustment results.

(Continued on inside back cover)

NOS 67 NGS 3 Algorithms for computing the geopotential using a simple-layer density model. Foster Morrison, March 1977, 41 pp (PB266967). Several algorithms are developed for computing with high accuracy the gravitational attraction of a simple-density layer at arbitrary altitudes. Computer program is included.

NOS 68 NGS 4 Test results of first-order class III leveling. Charles T. Whalen and Emery Balazs, November 1976, 30 pp (GPO# 003-017-00393-1) (PB265421). Specifications for releveling the National vertical control net were tested and the results published.

NOS 70 NGS 5 Selenocentric geodetic reference system. Frederick J. Doyle, Atef A. Elassal, and James R. Lucas, February 1977, 53 pp (PB266046). Reference system was established by simultaneous adjustment of 1,233 metric-camera photographs of the lunar surface from which 2,662 terrain points were positioned.

NOS 71 NGS 6 Application of digital filtering to satellite geodesy. C. C. Goad, May 1977, 73 pp (PB-270192). Variations in the orbit of GEOS-3 were analyzed for M_2 tidal harmonic coefficient values which perturb the orbits of artificial satellites and the Moon.

NOS 72 NGS 7 Systems for the determination of polar motion. Soren W. Henriksen, May 1977, 55 pp (PB274698). Methods for determining polar motion are described and their advantages and disadvantages compared.

NOS 73 NGS 8 Control leveling. Charles T. Whalen, May 1978, 23 pp (GPO# 003-017-00422-8) (PB286838). The history of the National network of geodetic control, from its origin in 1878, is presented in addition to the latest observational and computational procedures.

NOS 74 NGS 9 Survey of the McDonald Observatory radial line scheme by relative lateration techniques. William E. Carter and T. Vincenty, June 1978, 33 pp (PB287427). Results of experimental application of the "ratio method" of electromagnetic distance measurements are given for high resolution crustal deformation studies in the vicinity of the McDonald Lunar Laser Ranging and Harvard Radio Astronomy Stations.

NOS 75 NGS 10 An algorithm to compute the eigenvectors of a symmetric matrix. E. Schmid, August 1978, 5 pp (PB287923). Method describes computations for eigenvalues and eigenvectors of a symmetric matrix.

NOS 76 NGS 11 The application of multiquadric equations and point mass anomaly models to crustal movement studies. Rolland L. Hardy, November 1978, 63 pp (PB293544). Multiquadric equations, both harmonic and non-harmonic, are suitable as geometric prediction functions for surface deformation and have potentiality for usage in analysis of subsurface mass redistribution associated with crustal movements.

NOAA Manuals, NOS/NGS subseries

NOS NGS 1 Geodetic bench marks. Lt. Richard P. Floyd, September 1978, 56 pp (GPO# 003-017-00442-2) (PB296427). Reference guide provides specifications for highly stable bench marks, including chapters on installation procedures, vertical instability, and site selection considerations.

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