

8.1 INTRODUCTION

In 1965, the Department of Geodetic Science at The Ohio State University (OSU) was requested to submit a proposal to the National Aeronautics and Space Administration for a multiyear study and analysis of data from satellites launched specifically for geodetic purposes and from other satellites useful in geodetic studies. The program of work included theoretical studies and analysis for the geometric determination of station positions derived from photographic observations of both passive and active satellites and from range observations. This chapter examines the current status of data analysis, processing, and results. Various theoretical studies have been described in the report series of the Department of Geodetic Science (Nos. 106, 110, 114, 118, 139, 147, 150, 177, 184, 185, and 191) and are not repeated here.

The ultimate goal of the data analysis was to obtain an improved global net combining all participating tracking stations in a single worldwide coordinate system. In deriving these results, OSU representatives were to work with other universities and government agencies to prepare a handbook containing the best geodetic data from satellite observations available at the time. This chapter condenses the OSU contribution to this enterprise.

The work performed during the grant period included, but was not limited to, the following:

- (1) Deriving, programming, and testing the necessary mathematical formulations.

- (2) Making use of the observational data as they became available to determine the relative positions of the tracking stations in an arbitrary Cartesian coordinate system.

- (3) Estimating the position of this coordinate system with respect to an absolute (geocentric) system and with respect to coordinate systems used by the other agencies.

- (4) Participating in working groups and other planning meetings to establish desir-

able operational procedures, including tracking procedures, data format, analysis procedures, etc.

- (5) Providing advice to NASA on various aspects of the National Geodetic Satellite Program.

Thus, the primary objective of the OSU investigation was the geometric analysis of geodetic satellite data. The analysis was to be accomplished in three steps:

- (1) A primary network was to be established in which station positions were known to an internal consistency of 10 meters or better to serve the following purposes: (a) to establish the relative relationships between the various geodetic datums in use around the world; (b) to connect isolated tracking stations, islands, navigational beacons, and other points of interest. (In fulfilling the requirement of (a), a minimum of three tracking stations were to be used on any given datum.)

- (2) A densification network was to be established in which station positions were known to an internal consistency of 3 meters or better to serve the following purposes: (a) to improve the internal quality of existing geodetic networks (triangulation, etc.) by establishing "super" control points in sufficient numbers; (b) to provide control for mapping to scales as large as 1:25 000 in areas where no primary geodetic control exists.

- (3) A set of scientific reference stations was to be established in which positions were known to an internal consistency of 1 meter or better for advanced (earth and ocean physics) applications.

This report contains results connected with step 1. The goals of items 2 and 3 will be fulfilled when the quality of the observational material and/or the distribution of tracking stations become better than those made available for this study. Since the National Geodetic Satellite Program is no longer funded,

it is only hoped that these goals will be incorporated into other programs.

This chapter is given in six sections. Following the brief section on instrumentation, section 8.3 contains material on observational and survey data as provided to The Ohio State University by the various data collecting agencies. After the theory is described in section 8.4, the results of the least-squares adjustment are given in section 8.5. Section 8.5 also contains the comparison of these results with various dynamic solutions and survey data. In section 8.6, conclusions are presented with some recommendations for future work. After the section captions, reference is made to the appropriate OSU Department of Geodetic Science report where more detailed information on the content of the section may be found.

Acknowledgments.—This chapter is related to the work performed by the staff of the Department of Geodetic Science, The Ohio State University, sponsored by NASA under the National Geodetic Satellite Program. Grateful acknowledgment is given for the generous support given during the past eight years, which not only made The Ohio State University's participation in this program possible but also provided a total of 34 undergraduate and graduate students with assistantships of various lengths and types during their studies. On NASA's behalf, the project was monitored by Jerome D. Rosenberg (currently Deputy Director, Communication Programs, NASA Headquarters) from 1965 to 1972, whose support and encouragement were felt and appreciated throughout. Because of a reorganization within NASA, his work was taken over with enthusiasm by Benjamin Milwitzky, Deputy Director, and James P. Murphy, Special Programs, NASA Headquarters.

Project staff, with significant contributions, are listed in table 8.1. The proportion of their individual contributions is reflected in a general way by the length of stay and/or by the issue numbers in the report series of

the Department of Geodetic Science to which the individual contributed most. In a university environment, where there are important interactions between the students and the instructional staff, it is generally difficult to separate individual contributions from the team work. Thus the report numbers listed reflect, in most cases, responsibilities in a given area rather than "individual" contributions. Exceptions are the theoretical studies contained in Reports 114, 147, 150, 177, and 185, in which very little input came from students other than the authors.

Students receiving financial assistance other than direct fellowships (such as travel) are noted on table 8.1. In addition to those listed in the table, 15 students also carried short-term appointments for various generally nonprofessional responsibilities.

Graduate students on regular fellowships also received full tuition waivers from the university, which is acknowledged here. Other university contributions came from the Computer Center, which provided a significant amount of free computer time, and from the department in the form of 4.4 percent cost-sharing of the total research budget.

Last but not least, grateful acknowledgment is given to the Defense Mapping Agency (Aerospace and Topographic Centers), NASA (Goddard Space Flight Center and Wallops Flight Center), the National Geodetic Survey/NOS/NOAA, and SAO (Smithsonian Astrophysical Observatory) for supplying the observational and survey data, the basic ingredients of the work, and other information, always without reservations or delay. In this connection, the National Space Science Data Center also played an important role.

8.2 INSTRUMENTATION

The Ohio State University used data provided by other groups and did not make any observations of its own. It did not develop or use any instruments or equipment which were unique to OSU's work. The instruments

used in getting the data used by OSU are described in detail in other chapters, as indicated in table 8.2.

8.3 DATA

Details of the data used by OSU and obtained from various agencies are given in the tables of sections 8.3.1, 8.3.2.1, and 8.3.3. Before reaching OSU, the data were subjected to reductions considered necessary by the respective agencies (Gross, 1968; Hotter, 1967). Most of the data obtained needed some kind of additional treatment before they could be used for analysis; the more important details of this treatment (preprocessing) are given in section 8.3.2.2.

8.3.1 Satellites and Observation Stations (OSU Report 71)

Data used for OSU investigations were obtained by observing the satellites listed in table 8.2. Orbital and other information on these satellites is tabulated in Girnius and Joughin (1968).

Survey information regarding the observation stations is summarized in tables 8.3 and 8.4.

8.3.2 Satellite Observational Data and Their Handling

8.3.2.1 Satellite Observational Data (OSU Reports 187, 188, 193, 195, 196)

Data used in the four OSU partial solutions (networks) reported earlier, namely, MPS, BC, SECOR, and SA, and in the current combined solutions, designated WN (World Net), are summarized in table 8.5. These networks are shown in figures 8.1 through 8.7. Information related to the data used in the solutions is provided in tables 8.6 and 8.7 (a,b,c,d).

8.3.2.2 Data Handling

8.3.2.2.1 PREPROCESSING (OSU Reports 70, 82, 93, 100, 106, 110, 195)

The term preprocessing covers any treatment (reductions, corrections, etc.) that must be applied to the observed data before their analysis, to remove systematic errors burdening the observations. From the point

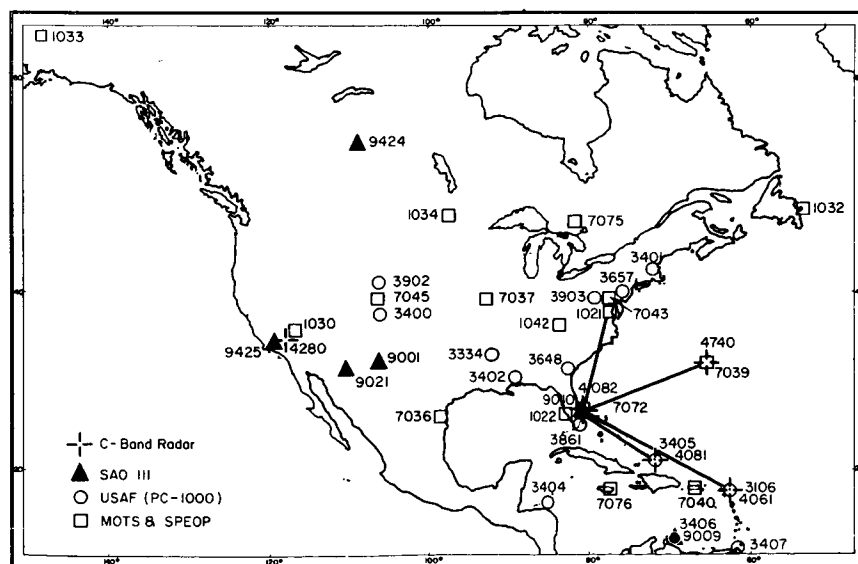


FIGURE 8.1.—MPS stations in North America.

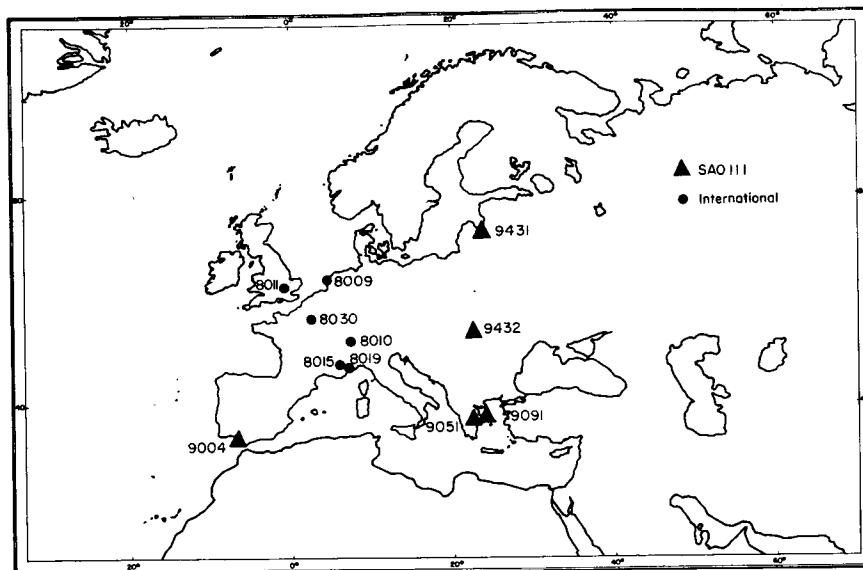


FIGURE 8.2.—MPS stations in Europe.

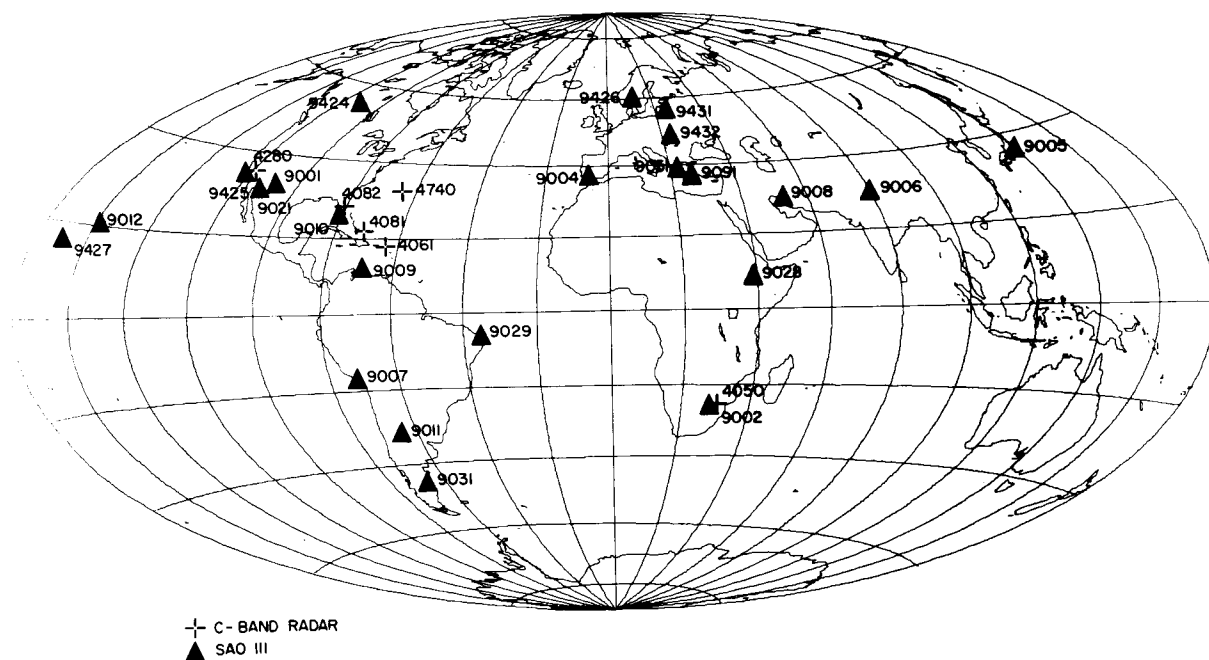


FIGURE 8.3.—SAO and C-band stations in the MPS net.

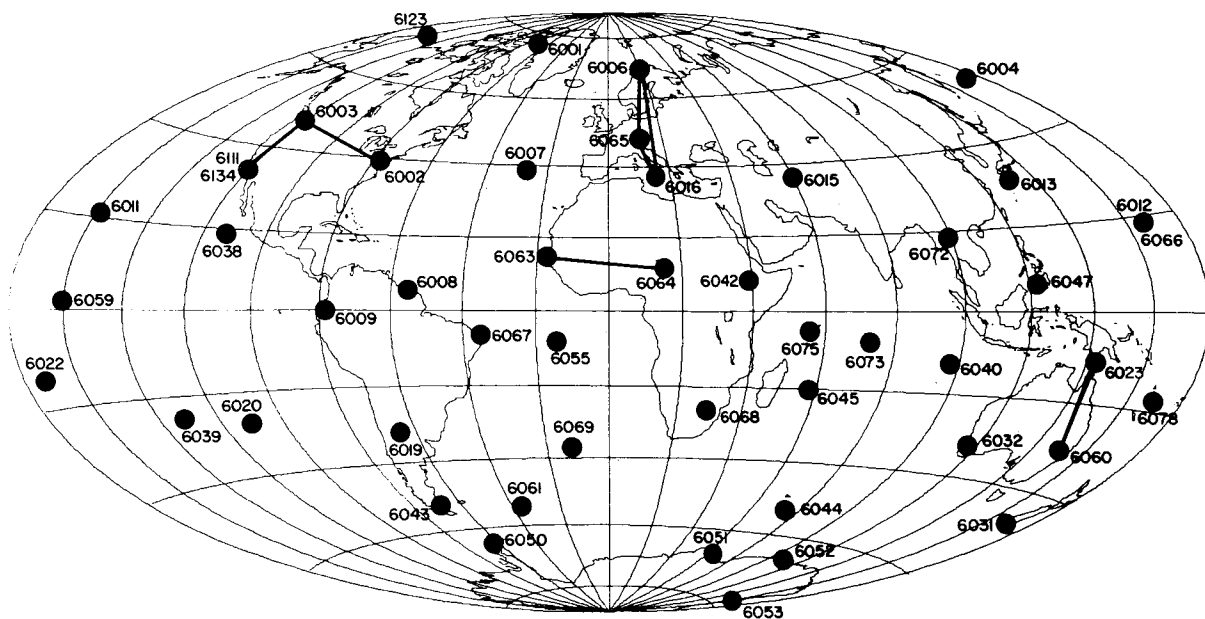


FIGURE 8.4.—BC-4 worldwide geometric satellite network.

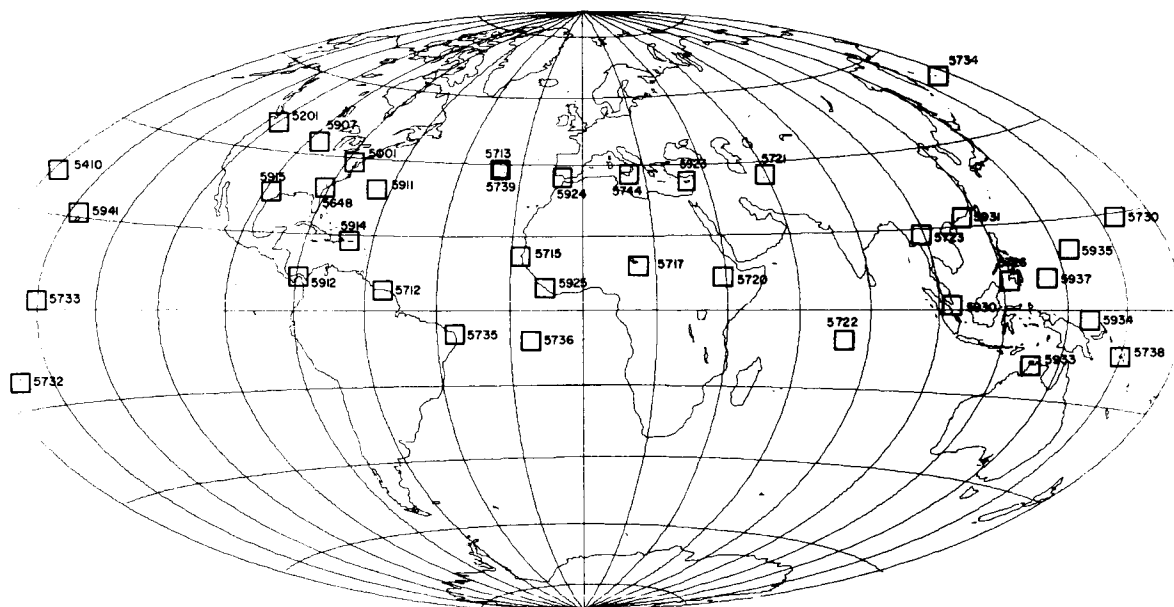


FIGURE 8.5.—SECOR equatorial network.

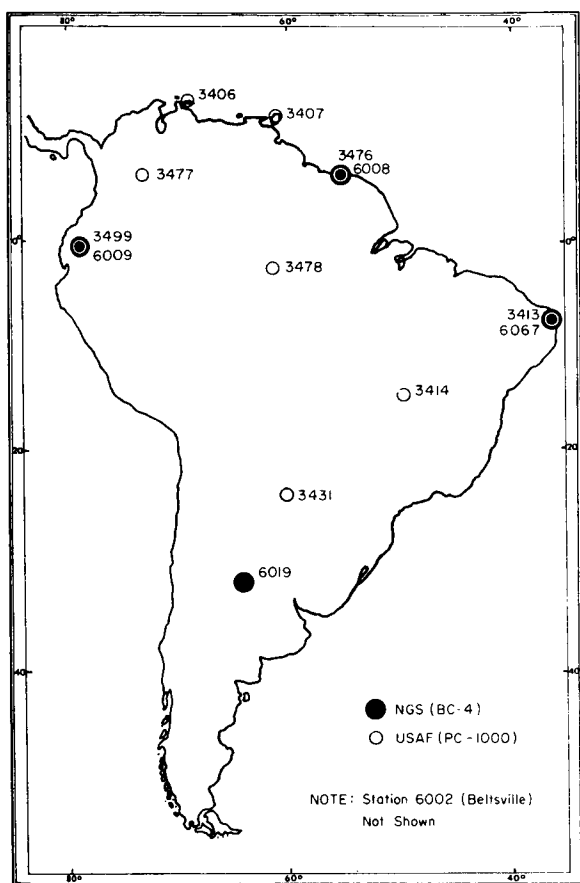


FIGURE 8.6—South American densification net.

of view of the investigator who has not participated in the actual observations, preprocessing can be considered as consisting of two parts:

(1) Reductions and corrections of observed data are made by the respective agencies responsible for the observations before the data are sent either to the National Space Science Data Center or to the individual investigator. This part of the preprocessing is dealt with by Hotter (1967) and by Gross (1968).

(2) Additional corrections to the reduced data, homogenization of the data obtained from various agencies, and screening of data for blunders and ambiguities are the parts of the preprocessing procedure to be done by the investigator.

Figure 8.8 is a self-explanatory summary of both types of preprocessing for camera observations as handled in practice. The shaded blocks represent the portion of the work performed at OSU. For more details see Hotter (1967). Figure 8.9 is a summary of preprocessing applied to the SECOR data. For more details see Gross (1968).

No preprocessing was applied to the C-band radar data (Mueller and Whiting, 1972).

8.3.2.2.2 DETECTION OF BLUNDERS AND REJECTION¹ (OSU Report 86)

Camera Data.—Blunders in the observed declinations and right ascensions and/or observing ground station coordinates are detected during the formation of the normal equations. The procedure used is to test the variance of unit weight that would result from a preliminary least-squares adjustment of each simultaneous event. In this adjustment the ground stations are held fixed. The residuals on the i th observed α, δ pair from such a preliminary adjustment are the first two elements of the 3×1 vector

$$V_{ij} = B_{ij}^{-1}(\mathbf{X}_i - \mathbf{X}_j^0) \mathbf{X}_j^0 = \left\{ \sum_i M_{ij}^{-1} \right\}^{-1} \left\{ \sum_i M_{ij}^{-1} \mathbf{X}_i \right\}$$

(The third element is the range to the preliminary adjusted satellite position.) Thus

$$\sum_i V_{ij}' P_{ij} V_{ij} = \sum_i (\mathbf{X}_i - \mathbf{X}_j^0)' M_{ij}^{-1} (\mathbf{X}_i - \mathbf{X}_j^0)$$

since the third element is dispensed within the product

$$P_{ij} B_{ij}^{-1} (\mathbf{X}_i - \mathbf{X}^s)$$

(see eq. (8.34)). Therefore the variance of unit weight is computed from

$$\sigma_0^2 = \frac{\sum_{\text{event}} (\mathbf{X}_i^0 - \mathbf{X}_j^0)' M_{ij}^{-1} (\mathbf{X}_i^0 - \mathbf{X}_j^0)}{2n - 3} \quad (8.1)$$

¹ To appreciate this section the reader is advised to study section 8.4 first.

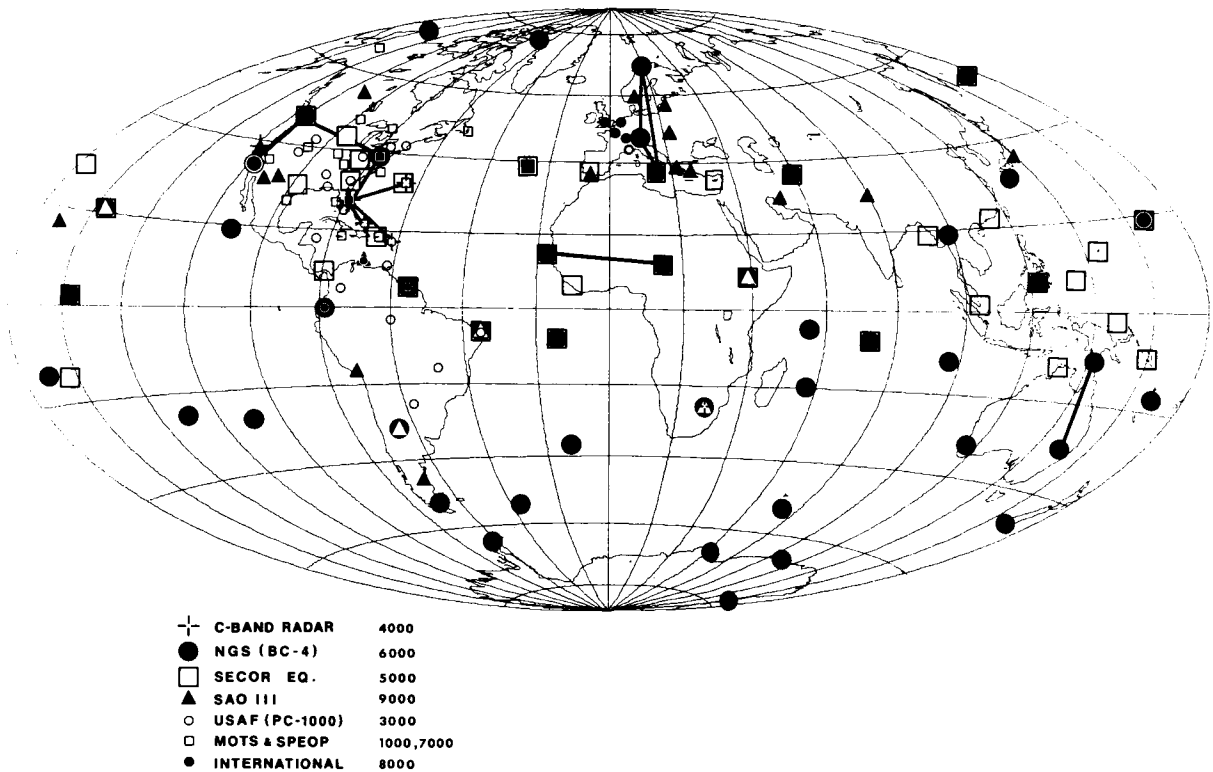


FIGURE 8.7.—OSU geometric satellite network (WN).

CAMERA		NAME	DMA	NGS	NASA/GSFC	SAO					
			PC-1000	BC-4 (ASTRO) BC-4 (COSMO)	MOTS 24 MOTS 40 PTH 100	BAKER-NUNN K-50					
CATALOGUE			SAO	SAO	SAO	SAO					
CALIBRATION	TYPE	PHOTO	PHOTO	PHOTO	ASTRO						
	NO. OF STARS	25-30	120	40-50	B-10						
	NO. OF SAT. IMAGES (PASSIVE)	-	800		1						
	NO. OF PARAMETERS	18 (EXT. INT: 6 REFRACT: 2)	14-20 (EXT. INT: 6 DIST: 6 NON I: 1 DIFF. SC.: 1 AVAIL.: 6)	8 (EXT. INT: 6 REFRACT: 2)	6						
	LENS DIST. PREDETERMINED	YES	NO	YES							
TIME SYNCHRONIZATION			PORTABLE CLOCK & VLF	PORTABLE CLOCK & VLF	ACTIVE SAT. ONLY	PORTABLE CLOCK & VLF					
STAR UPDATING AND SATELLITE IMAGE CORRECTIONS	PROPER MOTION	STAR	SATELLITE	TIME	STAR	SATELLITE	TIME	STAR	SATELLITE	TIME	
	PRECESSION	C			M			C			
	NUTATION	C			M						
	ANNUAL ABERRATION	C			C						
	DIURNAL ABERRATION	C			C						
	ASTRO. REFRACTION (GARFINKEL)	CP	-CP WITH ADJ. COEF.		CP	-CP		CP	-CP WITH ADJ. COEF.		IMPLICIT IN PLATE REDUCTION
	PARALL. REFRACTION							C			
	SAT. ABERRATION										
	(LIGHT TIME)										
	UTC → UTI										
M: MATRIX CORRECTION C: CONVENTIONAL CORR. CP: CONVENTIONAL DUR. ING PLATE PROCESSING P.S.O.: PASSIVE SAT. ONLY A.S.O.: ACTIVE SAT. ONLY	UTC → A.S.										
	A.S. → UTI										
	PHASE (PASSIVE ONLY)										

■ PREPROCESSING
CORRECTION NEEDED

FIGURE 8.8.—Camera data preprocessing procedure summary for major U.S. agencies.

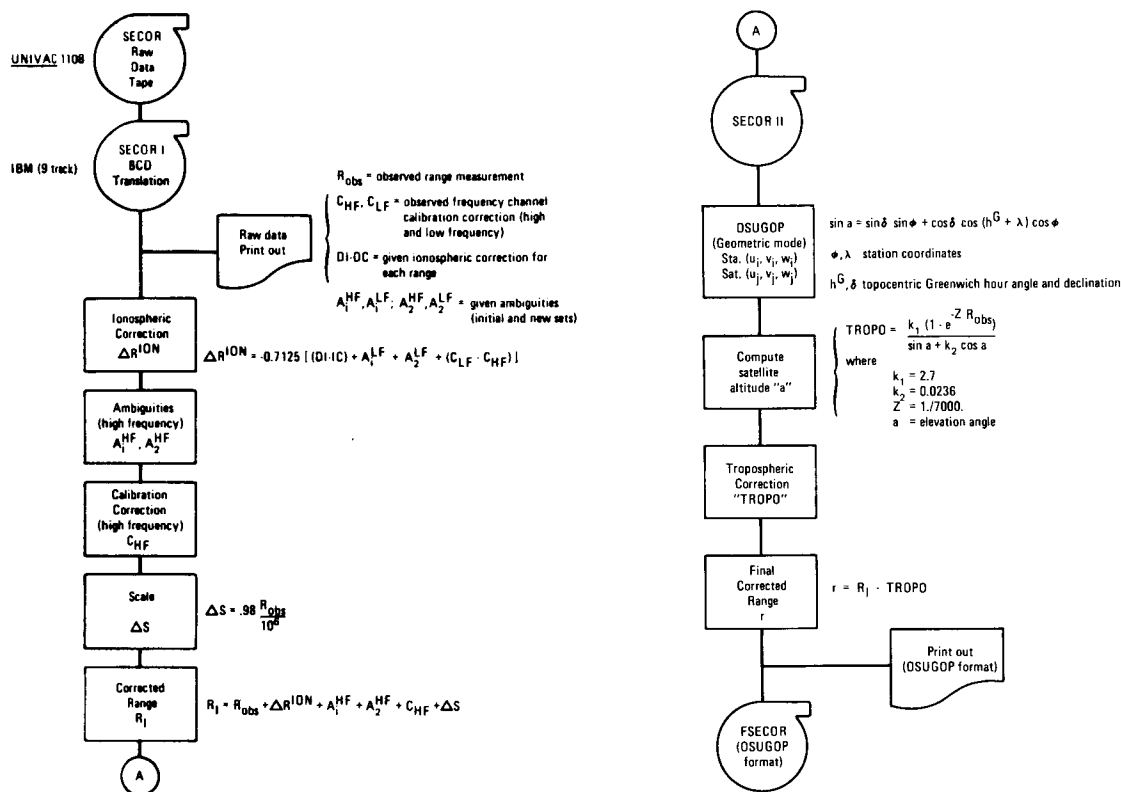


FIGURE 8.9.—Scheme of SECOR preprocessing procedure at OSU.

where the numerator can be shown to be the sum square of the weighted residuals (arc seconds squared) of all the observed declinations and right ascensions in the event and where n is the number of ground stations in the event.

If a number of rejected simultaneous events repeatedly contain a particular ground station, a blunder probably occurs in the coordinates of the particular ground station rather than in the observed quantities. In this case, the preliminary coordinates of that ground station should be verified.

Range Data.—Blunders in the observed topocentric ranges and/or ground station coordinates are detected during the formation of the normal equations. The procedure used is to test the variance of unit weight (eq. (8.10)) arising from a preliminary least-squares adjustment of each simultaneous event.

The preliminary adjustment is basically an iterative adjustment for the u_j, v_j, w_j rectangular coordinates of the satellite position by fixing the ground stations and applying the residuals of the adjustment to the observed ranges. The approximation to the parameters u_j, v_j, w_j is obtained by converting the so-called approximate geodetic coordinates of the satellite into rectangular coordinates by use of equation (8.36). The approximate geodetic coordinates of the satellite are obtained by averaging the latitudes and longitudes of the ground stations involved in the simultaneous event and estimating the ellipsoidal height of the satellite. The idea that this determination is crude is immediately rejected upon the knowledge that at most four iterations (to a tolerance of 1 cm in u_j, v_j, w_j) are required and that the electronic computers perform these iterations in less time than is necessary to solve the corresponding simultaneous exact second-order equations.

The equation giving the mathematical structure of this preliminary adjustment is identical to equation (8.75), the mathematical structure for the main range adjustment. Since only three parameters are involved, the linearized form of the mathematical structure for n ground stations in one simultaneous event becomes

$$AX - \bar{V} + W = 0 \quad (8.2)$$

where the coefficient matrix

$$A = \begin{bmatrix} \frac{u_j^o - u_1^o}{r_{1j}^o} & \frac{v_j^o - v_1^o}{r_{1j}^o} & \frac{w_j^o - w_1^o}{r_{1j}^o} \\ \frac{u_j^o - u_2^o}{r_{2j}^o} & \frac{v_j^o - v_2^o}{r_{2j}^o} & \frac{w_j^o - w_2^o}{r_{2j}^o} \\ \vdots & \vdots & \vdots \\ \frac{u_j^o - u_k^o}{r_{kj}^o} & \frac{v_j^o - v_k^o}{r_{kj}^o} & \frac{w_j^o - w_k^o}{r_{kj}^o} \\ \vdots & \vdots & \vdots \\ \frac{u_j^o - u_m^o}{r_{mj}^o} & \frac{v_j^o - v_m^o}{r_{mj}^o} & \frac{w_j^o - w_m^o}{r_{mj}^o} \end{bmatrix} \quad (8.3)$$

the correction vector for the satellite coordinates

$$X = \begin{bmatrix} du_j \\ dv_j \\ dw_j \end{bmatrix} \quad (8.4)$$

the residual vector for the ranges

$$\bar{V} = \begin{bmatrix} \bar{v}_{1j} \\ \bar{v}_{2j} \\ \vdots \\ \bar{v}_{kj} \\ \vdots \\ \bar{v}_{nj} \end{bmatrix} \quad (8.5)$$

and the constant vector

$$W = \begin{bmatrix} r_{1j}^o - r_{1j}^b \\ r_{2j}^o - r_{2j}^b \\ \vdots \\ r_{nj}^o - r_{nj}^b \end{bmatrix} \quad (8.6)$$

where r_{ij}^o and r_{ij}^b are preliminary and observed ranges, respectively.

The normal equations

$$NX + U = 0 \quad (8.7)$$

where

$$N = A'PA \quad (8.8)$$

$$U = A'PW \quad (8.9)$$

are solved for X by iteration until the elements of the vector X are less than 1 cm. At this point, X is entered into equation (8.2) and the vector of residuals $\bar{V}$ is determined; the variance of unit weight is then computed according to

$$\sigma_0^2 = \frac{\bar{V}'P\bar{V}}{n-3} \quad (8.10)$$

The complete set of data for the simultaneous event is printed out for evaluation in the case that the particular σ_0^2 is greater than a chosen input value. At the same time, no contribution is made to the normal equations by the rejected event.

8.3.3 Constraints

For the explanation of the type of constraints used in the solution see section 8.4.5. Only the data used in applying the various constraints are summarized here in tables 8.8 to 8.11.

8.4 THEORY AND MATHEMATICAL MODELS

(OSU Reports 86, 150, 185, 191)

This section presents almost the complete theory used in transforming the observational data (sec. 8.3) into geodetic results. Left out of this section and given in section 8.3 instead is that part of the theory that con-

cerns the preprocessing procedure of the observed data where systematic errors in the observed data are removed, detected, and eliminated, or where generally the necessary corrections to the observed data are made before they are inserted into the method of least-squares adjustment.

8.4.1 Definitions and Coordinate Systems (OSU Report 86)

8.4.1.1 Basic Concepts and Statement of the Problem

A theory proceeds from a set of known facts or assumptions called the data, and by manipulating these according to accepted rules, called theory, certain conclusions, called results are produced. This process is started in response to the posing of a problem. The problem in this case can be stated as follows:

Given are the approximate coordinates of a number of points (stations) on the surface of the Earth, which are assumed to be in error by unknown amounts. Also given are measured directions and/or distances from these points to other points on and also above the surface of the Earth (artificial satellites); the observations occur in sets, all observations within a given set being made at the same time. The problem is then to find the most probable values for the unknown errors in the coordinates of points (stations) on the Earth's surface.

Thus, in this "space triangulation" (or trilateration) method, satellites are observed simultaneously from groups of known and unknown ground stations. This method permits a purely geometric solution. Its main characteristic is that orbital elements are not required. If the satellite positions are needed, they can be computed from the preliminary coordinates of the ground stations and the observations themselves.

The method used to get a solution is therefore (1) to set up the equations giving the observations (angle or distance) in terms of observer and satellite coordinates, (2) to linearize these equations to give observation

residuals in terms of corrections to the observer and satellite coordinates, (3) to select from the data available those which can be put into simultaneity sets, and (4) from known and assumed statistical properties of the observations to solve the equations of (2) with the use of the data of (4).

Since the method is geometric and involves coordinates of points on the Earth's surface and of points in "inertial" space, transformation between coordinate systems occurs frequently. The systems used and their interrelation are described in sections 8.4.1.2 and 8.4.1.3, respectively.

8.4.1.2 Coordinate Systems

The camera observations after preprocessing (section 8.3.2.2) are assumed to be in the true topocentric celestial system, whereas the preprocessed topocentric ranging data are independent of the coordinate systems used.

Two distinct types of coordinate systems have been used here: the terrestrial (average and instantaneous) system and the celestial (true) system.

The following summary of these systems assumes righthanded rectangular coordinates with axes numbered according to figure 8.10. Generally, the origin of the coordinate system coincides with or is near the center of gravity of the Earth.

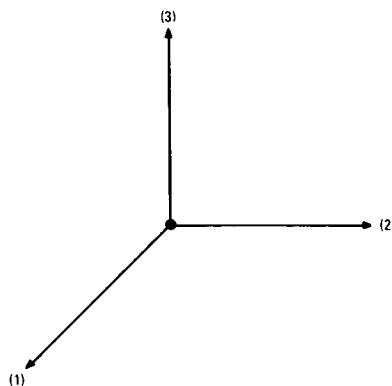


FIGURE 8.10.—Numbering of coordinate axes.

8.4.1.2.1 AVERAGE TERRESTRIAL (X)

(1) The 3 axis is directed toward the average north terrestrial pole as defined by the International Polar Motion Service (IPMS), commonly known as the Conventional International Origin (CIO) (Mueller, 1969, p. 351).

(2) The 1-3 plane is parallel to the mean Greenwich astronomic meridian as defined by the Bureau International de l'Heure (BIH) (Mueller, 1969, p. 343).

This system is the geodetic (terrestrial) coordinate system, later also referred to as the u, v, w system.

8.4.1.2.2 INSTANTANEOUS TERRESTRIAL (Y)

(1) The 3 axis is directed toward the instantaneous rotation axis of the Earth (true celestial pole), the coordinates of which are given by the IPMS or by the BIH with respect to the CIO.

(2) The 1-3 plane contains the point where the mean Greenwich astronomic meridian intersects the true equator of date.

This coordinate system is used as the intermediate connection between the terrestrial and celestial coordinate systems.

8.4.1.2.3 TRUE CELESTIAL (Z)

(1) The 3 axis is equivalent to the 3 axis of the instantaneous terrestrial system (true celestial pole).

(2) The 1 axis is directed toward the true vernal equinox of date.

These and still other coordinate systems are discussed in detail by Veis (1963a) and Mueller (1969).

8.4.1.3 Transformations of Coordinate Systems

Transformation between terrestrial and celestial coordinate systems becomes necessary when topocentric directions to satellites are obtained by photographing the satellite

against a background of stars. After corrections for the physical effects, such as differential refraction and aberration, shimmer, etc. (Mueller, 1964, pp. 309-317; Hotter, 1967), have been applied, the resulting topocentric right ascension and declination form the purely geometric ground-to-satellite direction. In terms of the corresponding direction cosines, Z can be expressed by the column vector

$$Z = \begin{bmatrix} \cos \delta & \cos \alpha \\ \cos \delta & \sin \alpha \\ \sin \delta \end{bmatrix} = \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \end{bmatrix} \quad (8.11)$$

In order to transform Z from the celestial to the average terrestrial system (in which the mathematical model for the adjustment is expressed), rotations about the coordinate axes are required.

Transformation is first made into the instantaneous terrestrial system (see fig. 8.11). This transformation is a function of a single finite rotation through the Greenwich apparent sidereal time (GAST). A vector Z in the true celestial system is transformed into the instantaneous terrestrial system by the following equation:

$$Y = R_s (\text{GAST}) Z \quad (8.12)$$

where Y is the resulting vector in the instantaneous terrestrial system and $R_s (\text{GAST})$ is a 3×3 matrix that expresses a counterclock-

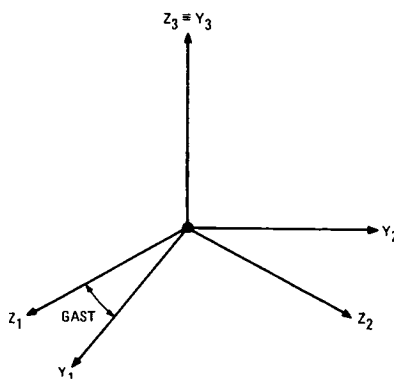


FIGURE 8.11.—True celestial and instantaneous terrestrial coordinate systems.

wise rotation, as viewed from the positive end of the 3 axis, by the amount GAST, namely,

$$R_3(\text{GAST}) = \begin{bmatrix} \cos(\text{GAST}) & \sin(\text{GAST}) & 0 \\ -\sin(\text{GAST}) & \cos(\text{GAST}) & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (8.13)$$

Next the vector **Y** in the instantaneous terrestrial system (**Y**) is transformed to the average terrestrial (**X**) system (see fig. 8.12). This transformation is a function of two rotations through the x and y coordinates of the instantaneous terrestrial pole.

$$\mathbf{X} = R_2(-x) R_1(-y) \mathbf{Y} \quad (8.14)$$

where **X** is the resulting vector in the average terrestrial coordinate system; $R_1(-y)$ and $R_2(-x)$ are 1-axis and 2-axis rotations through $-y$ and $-x$. Since the x and y values are differentially small, the finite rotations may be replaced by differential rotations and equation (8.14) is reduced to

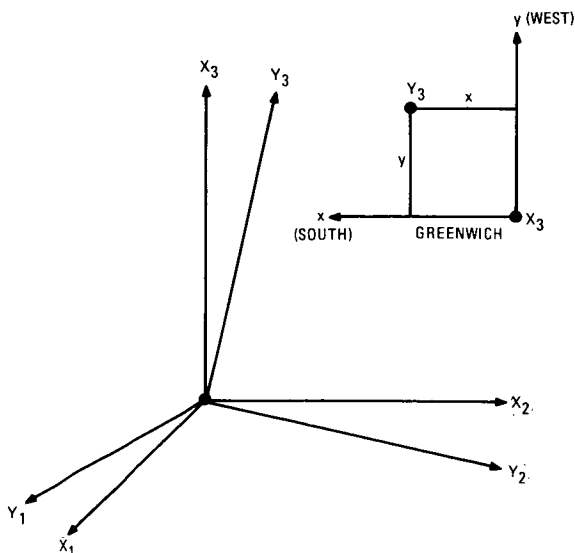


FIGURE 8.12.—Instantaneous and average terrestrial coordinate systems.

$$\mathbf{X} = \begin{bmatrix} 1 & 0 & x \\ 0 & 1 & -y \\ -x & y & 1 \end{bmatrix} \mathbf{Y} \quad (8.15)$$

by omitting the products of x and y . Thus the transformation from the true celestial to the average terrestrial coordinate system is achieved by combining the rotations expressed in equations (8.12) and (8.14), namely

$$\mathbf{X} = R_2(-x) R_1(-y) R_3(\text{GAST}) \mathbf{Z} \quad (8.16)$$

and, after equation (8.15) is considered, the matrix form is

$$\mathbf{X} = \mathbf{S} \mathbf{Z} \quad (8.17)$$

where **S** is given in inset on page 659. The quantities x , y and GAST in the above equation are obtained by the method described in Mueller (1969, pp. 80, 153, 337).

8.4.2 The Direction Adjustment

8.4.2.1 Uncorrelated Events (OSU Report 86)

8.4.2.1.1 THE MATHEMATICAL MODEL

The adjustment method is by least squares, where the parameters are the three-dimensional rectangular coordinates of the ground stations and satellite positions,² while the observables are the topocentric range, and topocentric declination and right ascension of the satellite.

The mathematical structure relating the parameters and the observables is a function of three vectors. As depicted in figure 8.13, the three vectors are as follows: **X_i**, the coordinate system origin to ground station vector; **X_j**, the coordinate system origin to satellite position vector; and **X_{ij}**, the ground station i to satellite position j vector. (Symbols in bold face will be reserved for vectors that

² These are needed in the algebraic derivation, but in the numerical computation they are either not needed or obtained to a sufficient accuracy from the observed quantities.

$$S = \begin{bmatrix} \cos(\text{GAST}) & \sin(\text{GAST}) & x \\ -\sin(\text{GAST}) & \cos(\text{GAST}) & -y \\ -x \cos(\text{GAST}) - y \sin(\text{GAST}) & -x \sin(\text{GAST}) + y \cos(\text{GAST}) & 1 \end{bmatrix} \quad (8.18)$$

have a finite magnitude as opposed to, say, vectors containing differential corrections.) Thus

$$\mathbf{X}_j - \mathbf{X}_i = \mathbf{X}_{ji} \quad (8.19)$$

or

$$F_{ij} = \mathbf{X}_j - \mathbf{X}_i - \mathbf{X}_{ij} = 0 \quad (8.20)$$

where

$$\mathbf{X}_j = \begin{bmatrix} u_j \\ v_j \\ w_j \end{bmatrix} \quad (8.21a)$$

is a vector composed of the rectangular coordinates of an arbitrary satellite position;

$$\mathbf{X}_i = \begin{bmatrix} u_i \\ v_i \\ w_i \end{bmatrix} \quad (8.21b)$$

is a vector composed of the rectangular coordinates of an arbitrary ground station:

$$\mathbf{X}_{ij} = S \begin{bmatrix} r_{ij} \cos \delta_{ij} \cos \alpha_{ij} \\ r_{ij} \cos \delta_{ij} \sin \alpha_{ij} \\ r_{ij} \sin \delta_{ij} \end{bmatrix} \quad (8.22)$$

r_{ij} , δ_{ij} , α_{ij} being the topocentric range, true declination, and right ascension from i to j , respectively, while S is the matrix that transforms the vector from the true celestial to the average terrestrial coordinate system (sec. 8.4.1.3).

The point-by-point buildup of the network can be visualized in the following way. Given the components of the vectors $\mathbf{X}_i$ and $\mathbf{X}_{ij}$, $\mathbf{X}_j$ is computed. Then with this position j as known, and a known vector from an unknown k station to j , the coordinates of the unknown station $\mathbf{X}_k$ are computed (see fig. 8.13). This step is extended to include many unknown and known stations, along with many redundant observations, thereby necessitating an adjustment.

Strictly speaking, pure direction or range data do not permit such a procedure to be literally followed; however, the adjustment framework (a form of collinearity) remains applicable.

The mathematical structure (eq. (8.20)) is linearized by a Taylor series expansion about the preliminary values of the ground stations and satellite positions and the observed topocentric values of the range, declination, and right ascension. The result is the following matrix equation :

$$AX + BV + W = 0 \quad (8.23)$$

which represents the general linearized mathematical model.

In this equation, the design matrix A is composed of submatrices of the form

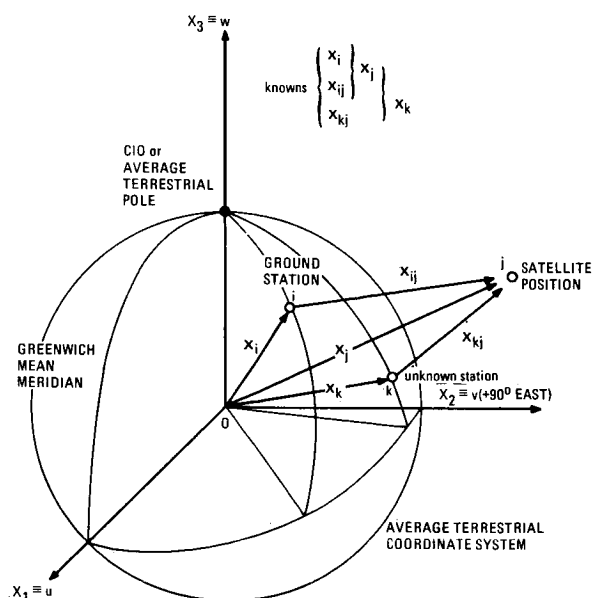


FIGURE 8.13.—The adjustment coordinate system.

$$A_{ij} = \frac{\partial F_{ij}}{\partial X_j, \partial X_i} = \begin{bmatrix} 1 & 0 & 0 & -1 & 0 & 0 \\ 0 & 1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 1 & 0 & 0 & -1 \end{bmatrix} \\ = [I_3 | -I_3] \quad (8.24)$$

and the unknown X vector is composed of subvectors of the form

$$X_{ij} = \begin{bmatrix} X_j \\ X_i \end{bmatrix} \quad (8.25)$$

where

$$X_j = \begin{bmatrix} du_j \\ dv_j \\ dw_j \end{bmatrix} \quad X_i = \begin{bmatrix} du_i \\ dv_i \\ dw_i \end{bmatrix} \quad (8.26)$$

are corrections to the preliminary values of the satellite positions and ground stations, respectively. The design matrix B is composed of 3×3 submatrices of the form

$$B_{ij} = \frac{\partial F_{ij}}{\partial \delta_{ij}, \partial \alpha_{ij}, \partial r_{ij}} \\ = SR_3(-\alpha_{ij})R_2(-90^\circ + \delta_{ij}) \\ \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & -\cos \delta_{ij} & 0 \\ 0 & 0 & -1 \end{bmatrix} \quad (8.28)$$

where S is defined by equation (8.18); R_3 and R_2 are rotation matrices.

The matrix

$$\begin{bmatrix} r_{ij} & 0 & 0 \\ 0 & r_{ij} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

is omitted from the expression for B_{ij} , since it is multiplied into the vector of residuals V composed of the subvectors

$$V_{ij} = \begin{bmatrix} r_{ij}\delta\delta_{ij} \\ (r_{ij}\cos\delta_{ij})\delta\alpha_{ij} \\ \delta r_{ij} \end{bmatrix} \quad (8.29)$$

These are the residuals of the adjustment in units of meters ($\delta\delta_{ij}$ and $\delta\alpha_{ij}$ are in radians). Observe that $\delta\delta_{ij}$ is measured on the circle of radius r_{ij} , while $\delta\alpha_{ij}$ is measured on the circle of radius of $r_{ij}\cos\delta_{ij}$.

Finally, the misclosure vector W is composed of the subvectors

$$W_{ij} = X_j^o - X_i^o - X_{ij}^b \quad (8.30)$$

where o designates "evaluated at preliminary values" and b designates "evaluated at observed values."

8.4.2.1.2 WEIGHTING OF OBSERVATIONS

The observed quantities in the case of camera observations are the topocentric declinations δ and right ascensions α . The corresponding accuracy estimates resulting from a photographic plate adjustment or some other a priori estimate are σ_δ^2 and σ_α^2 , the variances, and $\sigma_{\alpha\delta} = \sigma_{\delta\alpha}$, the covariance. All units are arc seconds squared.

It is important to note that the weighting of the declinations and right ascensions is made on the basis of the estimates of variances of δ and α obtained from the plate adjustments and that it is assumed that the variances of δ and α do not vary according to the distance of the satellite from the particular observing station.

On the other hand, the weighted sum of squares of the residuals is conveniently chosen to have units of arc seconds squared; thus the weights are to have units of (arc sec)²m⁻², since the units of the residuals have been stipulated (eq. (8.29)) to be meters. Therefore, it is necessary to transform σ_δ^2 , σ_α^2 , and $\sigma_{\delta\alpha}$ into linear units (meters) by the following formulas:

$$(\sigma_\delta)^2 = \left| r \frac{\sigma_\delta''}{\rho''} \right|^2 \quad (8.31)$$

$$(\sigma_\alpha)^2 = \left| r \frac{\sigma_\alpha''}{\rho''} \right|^2 \cos^2 \delta \quad (8.32)$$

$$\sigma_{\delta\alpha} = r^2 \frac{(\sigma_{\delta\alpha}'')^2}{(\rho'')^2} \cos \delta \quad (8.33)$$

where r is the approximate topocentric range and

$$\rho'' = \frac{1}{\sin 1''}$$

With the estimated accuracy in linear units the following variance-covariance matrix is formulated:

$$\Sigma_{\delta, \alpha, r} = \begin{bmatrix} \sigma_{\delta}^2 & \sigma_{\delta\alpha} & \sigma_{\delta r} \\ & \sigma_{\alpha}^2 & \sigma_{\alpha r} \\ \text{same} & & \\ \text{as above} & & \sigma_r^2 \\ \text{diagonal} & & \end{bmatrix}$$

where the new quantities σ_r^2 , $\sigma_{\delta r}$, and $\sigma_{\alpha r}$ are the variance of the range, covariance between the declination and range, and the covariance between the right ascension and range, respectively. If the correlation coefficients

$$\rho_{\delta r} = \frac{\sigma_{\delta r}}{\sigma_{\delta} \sigma_r} = 0$$

$$\rho_{\alpha r} = \frac{\sigma_{\alpha r}}{\sigma_{\alpha} \sigma_r} = 0$$

and

$$\sigma_r \rightarrow \infty$$

the weight matrix for a single direction is

$$P_{ij} = \sigma_0^2 \begin{bmatrix} \begin{bmatrix} \sigma_{\delta}^2 & \sigma_{\delta\alpha} \\ \sigma_{\alpha\delta} & \sigma_{\alpha}^2 \end{bmatrix}^{-1} & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (8.34)$$

where σ_0^2 is the a priori variance of unit weight.

Corresponding to P_{ij} , P denotes the weight matrix for the observed topocentric directions of the adjustment. P has the characteristic of containing nonzero 3×3 matrices only along the diagonal, since the individual directions are assumed to be independent.

The topocentric range is needed in equations (8.31) to (8.33) to convert the estimated accuracy of the directions from arc units into linear (meters) units. Four significant figures are required in the topocentric range. Equation (8.31) shows that the range need have no more significant figures than σ_{δ}'' or σ_{α}'' .

The topocentric range from an arbitrary ground station i in a given simultaneous event j is computed from

$$r_{ij} = [(u_j'' - u_i'')^2 + (v_j'' - v_i'')^2 + (w_j'' - w_i'')^2]^{1/2} \quad (8.35)$$

$i = 1, 2, \dots, n$ (number of stations in the event). u_i'' , v_i'' , w_i'' are the preliminary rectangular coordinates of the i th ground station and are computed from

$$\mathbf{X}_i'' = \begin{bmatrix} u_i'' \\ v_i'' \\ w_i'' \end{bmatrix} = \begin{bmatrix} (N+h) \cos \phi \cos \lambda \\ (N+h) \cos \phi \sin \lambda \\ [N(1-e^2) + h] \sin \phi \end{bmatrix} \quad (8.36)$$

ϕ , λ , h , N being the geodetic latitude and longitude, the geodetic height, and radius of curvature in the prime vertical at point i , respectively, while e is the eccentricity of the reference ellipsoid. u_j'' , v_j'' , w_j'' are the preliminary rectangular coordinates of the j th satellite position and are computed (note that these are needed only for the purpose of getting the approximate topocentric range) as follows:

(1) The ground vector $\mathbf{X}_{ik}$ between the first two stations listed in the particular simultaneous event

$$\mathbf{X}_{ik} = \begin{bmatrix} u_k - u_i \\ v_k - v_i \\ w_k - w_i \end{bmatrix} \quad (8.37)$$

(2) The unit vector (direction) $\mathbf{X}_{ij}$ from the ground station i to the satellite position j is computed from

$$\mathbf{X}_{ij} = S \begin{bmatrix} \cos \delta_{ij} \cos \alpha_{ij} \\ \cos \delta_{ij} \sin \alpha_{ij} \\ \sin \delta_{ij} \end{bmatrix} \quad (8.38)$$

where S is the transformation matrix of the true celestial to the average terrestrial coordinate systems (sec. 8.4.1.3).

(3) In the same way the direction $\mathbf{X}_{kj}$ is computed.

(4) The angle A_k at ground station k is computed from (fig. 8.14)

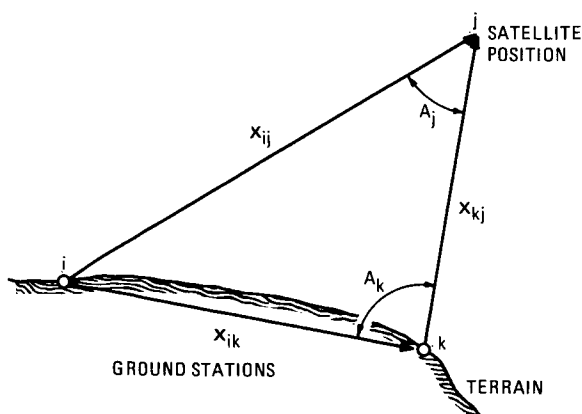


FIGURE 8.14.—The approximate satellite vector.

$$\cos A_k = \frac{\mathbf{X}_{ki} \cdot \mathbf{X}_{kj}}{|\mathbf{X}_{ki}| |\mathbf{X}_{kj}|} \quad (8.39)$$

(5) The angle A_j at the satellite position is computed from

$$\cos A_j = \frac{\mathbf{X}_{ji} \cdot \mathbf{X}_{jk}}{|\mathbf{X}_{ji}| |\mathbf{X}_{jk}|} \quad (8.40)$$

(6) Finally, the satellite position vector $\mathbf{X}_j^0$ to be used in equation (8.35) is computed from

$$\mathbf{X}_j^0 = \mathbf{X}_i^0 + r_{ij} \mathbf{X}_{ij} = \begin{bmatrix} u_j^0 \\ v_j^0 \\ w_j^0 \end{bmatrix} \quad (8.41)$$

where

$$r_{ij} = |\mathbf{X}_{ik}| \frac{\sin A_k}{\sin A_j} \quad (8.42)$$

8.4.2.1.3 THE NORMAL EQUATIONS

The normal equations are derived by minimizing the quadratic form

$$V'PV + X'P_xX$$

subject to the relation (eq. (8.23))

$$AX + BV + W = 0$$

$$\left[\begin{array}{c|c} \sum_i (B_{ij}P_{ij}^{-1}B'_{ij})^{-1} + P_j & - (B_{ij}P_{ij}^{-1}B'_{ij})^{-1} \\ \hline - (B_{ij}P_{ij}^{-1}B'_{ij})^{-1} & \sum_j (B_{ij}P_{ij}^{-1}B'_{ij})^{-1} + P_i \end{array} \right] \left[\begin{array}{c} X_j \\ X_i \end{array} \right] + \left[\begin{array}{c} U_j = \sum_i (B_{ij}P_{ij}^{-1}B'_{ij})^{-1} W_{ij} \\ U_i = - \sum_j (B_{ij}P_{ij}^{-1}B'_{ij})^{-1} W_{ij} \end{array} \right] = 0 \quad (8.47)$$

Upon introduction of Lagrange multipliers K , the variation function is

$$\Phi = V'PV + X'P_xX - 2K'(AX + BV + W) \quad (8.43)$$

where

V is the vector of residuals corresponding to the α 's and δ 's
 X is the vector of corrections to the preliminary ground and satellite positions
 P is the weight matrix for the α 's and δ 's
 P_x is the weight matrix for the ground and satellite positions

As is described in section 8.4.2.1.1, A and B are the design matrices and W is the constant vector.

Upon the differentiation of equation (8.43) for the minimum condition (Uotila, unpublished lecture notes, 1967), the expanded form of the normal equations becomes

$$\begin{bmatrix} -P_x & 0 & A' \\ 0 & -P & B' \\ A & B & 0 \end{bmatrix} \begin{bmatrix} X \\ V \\ K \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ W \end{bmatrix} = 0 \quad (8.44)$$

By a row and column transformation, the residual vector V is eliminated and the normal equations become

$$\begin{bmatrix} BP^{-1}B' & A \\ A' & -P_x \end{bmatrix} \begin{bmatrix} K \\ X \end{bmatrix} + \begin{bmatrix} W \\ 0 \end{bmatrix} = 0 \quad (8.45)$$

Next, the correlates are eliminated, resulting in

$$[A'(BP^{-1}B')^{-1}A + P_x]X + A'(BP^{-1}B')^{-1}W = 0 \quad (8.46)$$

The following summation form of the non-zero 3×3 submatrices of the above equation is found by replacing the A , B , and P matrices with their expanded forms in terms of 3×3 submatrices (eqs. (8.24), (8.28), and (8.34)):

where the nonzero 3×3 submatrices occur only on the diagonal and those ij 3×3 positions corresponding to a ground-to-satellite observation; Σ indicates a summation over all ground stations observing satellite position j ; $\sum_j$ indicates a summation over all satellite positions observed from ground station i . All summations contain only 3×3 and/or 3×1 matrices.

Elimination of X_j , the corrections to the satellite positions, from the above yields the following reduced normal equations

$$N X + U = 0 \quad (8.48)$$

in which the X vector will now represent the unknown corrections to the preliminary rectangular coordinates of the ground stations only; U is the constant vector; and N is the coefficient matrix.

The coefficient matrix N is made up of 3×3 matrices. By letting

$$M_{ij}^{-1} = (B_{ij} P_{ij}^{-1} B_{ij}')^{-1} \quad (8.49)$$

$$= (B_{ij}')' P_{ij} B_{ij}^{-1} \quad (8.50)$$

in equation (8.47), the expression for the 3×3 diagonal matrix corresponding to the k th ground station is given by (Krakiwsky and Pope, 1967)

$$N_{kk} = \sum_j M_{kj}^{-1} - \sum_j \left\{ M_{kj}^{-1} \left(\sum_i M_{ij}^{-1} \right)^{-1} M_{kj}^{-1} \right\} + P_k \quad (8.51)$$

Note the weight, P_j , for the j th satellite position has been dropped in the second term of the above equation. The expression for the off-diagonal 3×3 matrix corresponding to the k th and the l th ground station is

$$N_{kl} = - \sum_j \left\{ M_{kj}^{-1} \left(\sum_i M_{ij}^{-1} \right)^{-1} M_{lj}^{-1} \right\} \quad (8.52)$$

where the summation Σ is performed over all satellite events observed simultaneously from both ground stations k and l .

The constant vector of the normal equations (eq. (8.48)) is made up of 3×1 vectors corresponding to each ground station. The vector U_k for the k th ground station is given by

$$U_k = - \left(\sum_j M_{kj}^{-1} W_{kj} \right) + \sum_j \left\{ M_{kj}^{-1} \left(\sum_i M_{ij}^{-1} \right)^{-1} \left(\sum_i M_{ij}^{-1} W_{ij} \right) \right\} \quad (8.53)$$

where, according to equation (8.30),

$$W_{ij} = X_j^o - X_i^o - X_{ij}^b \quad (8.54)$$

and

$$W_{kj} = X_j^o - X_k^o - X_{kj}^b \quad (8.55)$$

At first sight it seems that the preliminary coordinates of each satellite position are required; however, substitution of equations (8.54) and (8.55) into equation (8.53) results in the cancellation or dropping out of terms containing X_j^o and the observed vector X_{ij}^b or X_{kj}^b . Specifically,

$$\begin{aligned} U_k &= - \sum_j \left\{ M_{kj}^{-1} \left(X_j^o - X_k^o - X_{kj}^b \right) \right\} \\ &\quad + \sum_j \left\{ M_{kj}^{-1} \left(\sum_i M_{ij}^{-1} \right)^{-1} \left[\sum_i M_{ij}^{-1} \left(X_j^o - X_i^o - X_{ij}^b \right) \right] \right\} \\ &= - \sum_j \left\{ M_{kj}^{-1} X_j^o \right\} + \left(\sum_j M_{kj}^{-1} \right) X_k^o + \sum_j \left\{ M_{kj}^{-1} X_{kj}^b \right\} \\ &\quad + \sum_j \left\{ M_{kj}^{-1} \left(\sum_i M_{ij}^{-1} \right)^{-1} \left(\sum_i M_{ij}^{-1} X_j^o \right) \right\} \\ &\quad - \sum_j \left\{ M_{kj}^{-1} \left(\sum_i M_{ij}^{-1} \right)^{-1} \left(\sum_i M_{ij}^{-1} X_i^o \right) \right\} \\ &\quad - \sum_j \left\{ M_{kj}^{-1} \left(\sum_i M_{ij}^{-1} \right)^{-1} \left(\sum_i M_{ij}^{-1} X_{ij}^b \right) \right\} \end{aligned} \quad (8.56)$$

$$\quad (8.57)$$

Terms 1 and 4 in the above expression cancel (i.e., X_j^o , satellite coordinates drop out) be-

cause $\mathbf{X}_j^o$ can be factored out of $\sum_i$ in term 4, i.e.,

$$\sum_j \left\{ M_{kj}^{-1} \left(\sum_i M_{ij}^{-1} \right)^{-1} \left(\sum_i M_{ij}^{-1} \right) \mathbf{X}_j^o \right\} = \left(\sum_j M_{kj}^{-1} \mathbf{X}_j^o \right) \quad (8.58)$$

which has an opposite sign to that of term 1. Terms 3 and 6 drop out because they are identically zero. This happens because both terms contain products like

$$B_{ij}^{-1} \mathbf{X}_{ij}^b \text{ or } B_{kj}^{-1} \mathbf{X}_{kj}^b$$

where (taking into consideration the orthogonality property of the rotation matrices and S)

$$B_{ij}^{-1} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1/\cos \delta_{ij} & 0 \\ 0 & 0 & -1 \end{bmatrix} \quad R_2(90^\circ - \delta_{ij}) \quad R_3(\alpha_{ij}) \quad S'$$

and after elementary matrix operations we have

$$B_{ij}^{-1} \mathbf{X}_{ij}^b = \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix} r_{ij}^b$$

Since in the optical adjustment, P_{ij} has the form

$$P_{ij} = \begin{bmatrix} \begin{bmatrix} * & * \\ * & * \end{bmatrix}^{-1} & 0 \\ 0 & 0 \end{bmatrix}$$

and from equation (8.50)

$$M_{ij}^{-1} \mathbf{X}_{ij}^b = 0 \quad (8.59)$$

the final expression for the constant column becomes

$$U_k = \sum_j M_{kj}^{-1} \left\{ \mathbf{X}_k^o - \left(\sum_i M_{ij}^{-1} \right)^{-1} \left(\sum_i M_{ij}^{-1} \mathbf{X}_i^o \right) \right\} \quad (8.60)$$

In summary, the normal equations in the adjustment of camera observations are formed by equations (8.51), (8.54), and (8.60).

8.4.2.2 Correlated Events (OSU Report 193)

8.4.2.2.1 THE MATHEMATICAL MODEL

The theory and the mathematical model for a generalized least-squares adjustment for simultaneous directions without correlation has been described (sec. 8.4.2.1). In that case each simultaneously observed satellite image was taken as an independent event; thus the correlation between satellite directions on the same plate was not considered. The following is a description of how the mathematical model is manipulated to take care of possible correlations between directions, such as occur in the case of the NGS (National Geodetic Survey) BC-4 Type II data, where each given event consists of seven fictitious directions (Greenwich hour angle h and declination δ relative to the 1900-1905 CIO mean pole) per station and the full 14×14 variance-covariance matrix associated with the set.

The basic geometric figure to begin the mathematical development is that of a single ground station observing one satellite position, shown in figure 8.13. Using vector notation, as we know, we can write the mathematical model as

$$F_{ijm} = \mathbf{X}_{jm} - \mathbf{X}_i - \mathbf{X}_{ijm} = 0 \quad (8.61)$$

where now m will identify a fictitious satellite image within the event j , i.e., $m=1,2,\dots,m_x$ (generally $4 \leq m_x \leq 7$).

The vector $\mathbf{X}_{ijm}$ with this type of data takes the form

$$\mathbf{X}_{ijm} = \begin{bmatrix} r_{ijm} & \cos \delta_{ijm} & \cos h_{ijm} \\ -r_{ijm} & \cos \delta_{ijm} & \sin h_{ijm} \\ r_{ijm} & \sin \delta_{ijm} & 0 \end{bmatrix} \quad (8.62)$$

The linearized mathematical model can be written as follows

$$[A_1 \mid A_2] \begin{bmatrix} \mathbf{X}_j \\ \mathbf{X}_i \end{bmatrix} + B\mathbf{V} + W = 0 \quad (8.63)$$

Since all observations from one station to all fictitious satellite directions on a given plate are correlated, it is necessary to build up the model using all these satellite directions. Thus the design matrix A is divided in sub-matrices of the form

$$\begin{aligned}
 A_{ijm} &= \frac{\partial F_{ijm}}{\partial X_{jm}, X_i} \\
 &= \begin{bmatrix} A_{1ijm} & A_{2ijm} \end{bmatrix} \\
 &= \begin{bmatrix} & & -I_3 \\ & & -I_3 \\ I_{3m_x} & & \vdots \\ & & \vdots \\ & & -I_3 \end{bmatrix}_{\substack{3m_x \quad 3m_x \quad 3m_x \quad 3}} \quad (8.64)
 \end{aligned}$$

and the design matrix B is of the form

$$\begin{aligned}
 B_{ijm} &= \\
 (3m_x \times 3m_x) & \begin{bmatrix} \boxed{3 \times 3} & & & & & & 0 \\ & \boxed{3 \times 3} & & & & & \\ & & \boxed{3 \times 3} & & & & \\ & & & \ddots & & & \\ & & & & \ddots & & \\ 0 & & & & & \boxed{3 \times 3} & \end{bmatrix} \quad (8.65)
 \end{aligned}$$

After minimizing $V'PV$ under the condition (8.63), the vector of Lagrange multipliers can be expressed as

$$K = -(BP^{-1}B')^{-1}(A_1X_j + A_2X_i + W) \quad (8.66)$$

and the normal equations will take the form

$$\begin{aligned}
 &\begin{bmatrix} A_1'(BP^{-1}B')^{-1}A_1 & A_1'(BP^{-1}B')^{-1}A_2 \\ A_2'(BP^{-1}B')^{-1}A_1 & A_2'(BP^{-1}B')^{-1}A_2 \end{bmatrix} \begin{bmatrix} X_j \\ X_i \end{bmatrix} \\
 &+ \begin{bmatrix} A_1'(BP^{-1}B')^{-1}W \\ A_2'(BP^{-1}B')^{-1}W \end{bmatrix} = 0 \quad (8.67)
 \end{aligned}$$

8.4.2.2.2 THE WEIGHTING TECHNIQUE USING THE FULL VARIANCE-COVARIANCE MATRIX OF THE OBSERVED QUANTITIES

Before proceeding further, it is necessary to explain how the above equations (8.66) are actually solved. For a particular station i and event j , the B matrix has dimensions (21×21) , but the original given P^{-1} matrix is (14×14) . The P^{-1} matrix refers only to the actual observed quantities, which are the Greenwich hour angle h and the declinations δ , and therefore it has to be modified before it is substituted in equation (8.66). The easiest way to explain this is to look only at that part of B_{ij} that corresponds to observations on the first satellite position only:

$$B_{ij1} \equiv B_1 = \begin{bmatrix} \frac{\partial F_1}{\partial h_1} & \frac{\partial F_1}{\partial \delta_1} & \frac{\partial F_1}{\partial r_1} \\ \frac{\partial F_2}{\partial h_1} & \frac{\partial F_2}{\partial \delta_1} & \frac{\partial F_2}{\partial r_1} \\ \frac{\partial F_3}{\partial h_1} & \frac{\partial F_3}{\partial \delta_1} & \frac{\partial F_3}{\partial r_1} \end{bmatrix}_{i,j_1} \quad (8.68)$$

The matrix P_1 (not P_1^{-1}) would have to be of the form

$$P_{ij1} \equiv P_1 = \begin{bmatrix} \sigma_{h_1}^2 & \sigma_{h_1\delta_1} & \sigma_{h_1r_1} \\ \sigma_{h_1\delta_1} & \sigma_{\delta_1}^2 & \sigma_{\delta_1r_1} \\ \sigma_{h_1r_1} & \sigma_{\delta_1r_1} & \sigma_{r_1}^2 \end{bmatrix}_{i,j_1}^{-1} \quad (8.69)$$

and for a single satellite image using equation (8.34) we can write

$$P_1 = \begin{bmatrix} \sigma_{h_1}^2 & \sigma_{h_1\delta_1} & 0 \\ \sigma_{h_1\delta_1} & \sigma_{\delta_1}^2 & 0 \\ 0 & 0 & 0 \end{bmatrix}_{i,j_1}^{-1} \quad (8.70)$$

What is really needed is $(B_1P_1^{-1}B_1')^{-1}$, but $B_1P_1^{-1}B_1'$ is singular. However, the matrix B_1 is square and nonsingular. Knowing this, we can rearrange $(B_1P_1^{-1}B_1')^{-1}$ as follows:

$$(B_1P_1^{-1}B_1')^{-1} = (B_1')^{-1}P_1B_1^{-1} = (B_1^{-1})'P_1B_1^{-1} \quad (8.71)$$

where P_1 is defined by equation (8.70).

The preceding description applies to the case of one satellite position j_1 . For the seven satellite positions the dimension of the p^{-1} matrix is (14×14) . The matrix P_1 in equation (8.71) must have the dimension (21×21) and be of the form of equation (8.70). The matrix P_{ij} for the BC-4 observations can be written as follows:

$$P_{ij} = \begin{bmatrix} \sigma^2 h_1 & \sigma h_1 \delta_1 & \cdots & \cdot & \sigma h_1 \delta_7 \\ \cdot & \sigma^2 \delta_1 & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \sigma^2 h_7 & \cdot \\ \sigma h_1 \delta_7 & \cdot & \cdot & \cdot & \sigma^2 \delta_7 \end{bmatrix}_{i,j}^{-1}$$

$$= \begin{bmatrix} W_{1,1} & W_{1,2} & \cdots & W_{1,14} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ W_{14,1} & \cdot & \cdots & W_{14,14} \end{bmatrix}_{i,j} \quad (8.72)$$

Now the (21×21) version of equation (8.70) will be equation (8.73) given below. With P defined, considering equation (8.73), we can form the matrix M^{-1} using the technique shown in equation (8.71):

$$M^{-1} = (B P^{-1} B')^{-1} = (B^{-1})' P B^{-1} \quad (8.74)$$

8.4.2.2.3 THE REDUCED NORMAL EQUATIONS

Equation (8.67) can be referred to as the conventional normal equation, where the satellite position X_j is among the parameters. Since the satellite position is of no interest, it is eliminated from the solution by solving for X_j in terms of the other parameters and substituting this into the remaining equations.

After elimination of X_j from equation (8.67), we will obtain the reduced normal equations. The (3×3) and (3×1) block elements of the coefficient matrix and constant vector, respectively, can be obtained by expressions similar to equations (8.51), (8.52), and (8.53). The only difference is that now the term P_k in equation (8.51) will drop out because we are only minimizing $V'PV$ (Mueller *et al.*, 1973a).

8.4.3 The Range Adjustment

(OSU Reports 86, 140)

8.4.3.1 The Mathematical Model

Figure 8.15 shows the average terrestrial coordinate system uvw (sec. 8.4.1.2) with a ground station i and a satellite position j . The observed quantity is the topocentric range r_{ij} from ground station i to satellite position j . The parameters u_i, v_i, w_i and u_j, v_j, w_j are the Cartesian coordinates of the ground station i and the satellite position j , respectively.

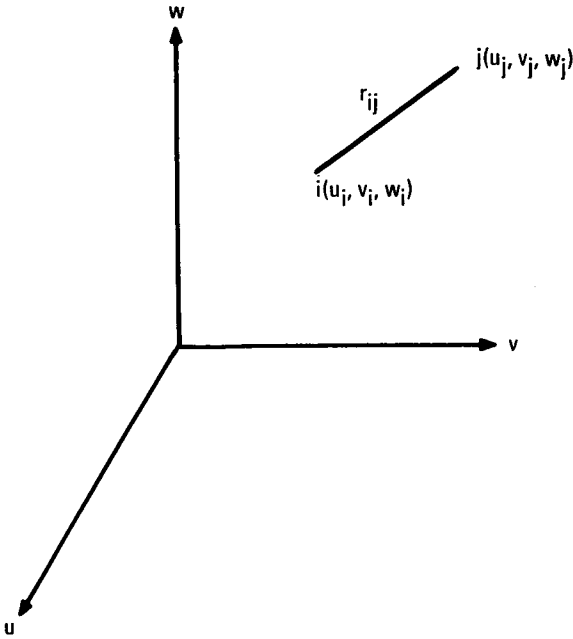
From figure 8.15 it can easily be seen that the mathematical model can be written as

$$r_{ij} = [(u_j - u_i)^2 + (v_j - v_i)^2 + (w_j - w_i)^2]^{1/2} \quad (8.75)$$

$$F_{ij} = [(u_j - u_i)^2 + (v_j - v_i)^2 + (w_j - w_i)^2]^{1/2} - r_{ij} = 0 \quad (8.76)$$

The basic mathematical model above is extended to include simultaneous ranges from three or more ground stations. When increasing the number of simultaneous events

$$P_{ij} = \begin{bmatrix} W_{1,1} & W_{1,2} & 0 & W_{1,3} & W_{1,4} & 0 & \cdots & W_{1,13} & W_{1,14} & 0 \\ W_{2,1} & W_{2,2} & 0 & W_{2,3} & W_{2,4} & 0 & \cdots & W_{2,13} & W_{2,14} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0 \\ W_{13,1} & W_{13,2} & 0 & W_{13,3} & W_{13,4} & 0 & \cdots & W_{13,13} & W_{13,14} & 0 \\ W_{14,1} & W_{14,2} & 0 & W_{14,3} & W_{14,4} & 0 & \cdots & W_{14,13} & W_{14,14} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \end{bmatrix}_{i,j} \quad (8.73)$$

FIGURE 8.15.—The uvw coordinate system.

along with the number of known and unknown ground stations, an adjustment is necessary.

The mathematical model (8.76) is linearized by a Taylor series expansion about the preliminary values of the ground stations and satellite positions and the observed value of the topocentric range. The expression for the linearized mathematical model, as in the optical case, has the form

$$AX + BV + W = 0 \quad (8.77)$$

where now the design matrix B is a negative unit matrix and the design matrix A is formed by submatrices of the form in the inset below.

The unknown vector X is made up of sub-vectors

$$X_{ij} = \begin{bmatrix} X_j \\ X_i \end{bmatrix} \quad (8.79)$$

where

$$X_i = \begin{bmatrix} du_i \\ dv_i \\ dw_i \end{bmatrix} \quad (8.80)$$

$$X_j = \begin{bmatrix} du_j \\ dv_j \\ dw_j \end{bmatrix} \quad (8.81)$$

The misclosure vector W is formed by the individual differences

$$W_{ij} = r_{ij}^c(\text{computed}) - r_{ij}^b(\text{observed}) \quad (8.82)$$

The residual vector V is composed of the individual residuals V_{ij} (in meters) corresponding to the observed ranges r_{ij}^b .

Giving consideration to the characteristic of the design matrices, we can write the final equation for the linearized model in the range adjustment as

$$AX - V + W = 0 \quad (8.83)$$

8.4.3.2 Weighting of Observed Ranges

The weighting of the observed topocentric range from ground station i to satellite position j is achieved by the following:

$$p_{ij} = \frac{\sigma_0^2}{\sigma_{ij}^2} \quad (8.84)$$

where σ_0^2 is the variance of unit weight and σ_{ij}^2 is the variance of the observed range in meters squared. P will denote the diagonal weight matrix containing all the independent weights P_{ij} to be used in the adjustment.

8.4.3.3 The Normal Equations

The variation function for the range adjustment is similar to the function for adjust-

$$A_{ij} = \frac{\partial F_{ij}}{\partial X_j^0, \partial X_i^0} = \left[\frac{u_j^0 - u_i^0}{r_{ij}^0}, \frac{v_j^0 - v_i^0}{r_{ij}^0}, \frac{w_j^0 - w_i^0}{r_{ij}^0} \right] - \left[\frac{u_j^0 - u_i^0}{r_{ij}^0}, \frac{v_j^0 - v_i^0}{r_{ij}^0}, \frac{w_j^0 - w_i^0}{r_{ij}^0} \right] = [a_{ij} \mid -a_{ij}] \quad (8.78)$$

where r_{ij}^0 is computed from (8.75) using the initial approximate values for the stations and satellite coordinates, the latest coordinates resulting from a preliminary least-squares adjustment (for each event j) with the co-observing stations held fixed.

ment of camera observations, namely,

$$\Phi = V'PV + X'P_xX - 2K'(AX - V + W) \quad (8.85)$$

where

V is the vector of residuals corresponding to the range observations

X is the vector of corrections to the preliminary ground and satellite positions³

P is the weight matrix for the ranges

P_x is the weight matrix for the ground and satellite positions

K is the vector of correlates

The differentiation of equation (8.85) for the minimum condition results in the following expanded form of the normal equations:

$$\begin{bmatrix} -P_x & 0 & A' \\ 0 & -P & -I \\ A & -I & 0 \end{bmatrix} \begin{bmatrix} X \\ V \\ K \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ W \end{bmatrix} = 0 \quad (8.86)$$

After the elimination of the correlates and residuals and the expansion of the A and P matrices, the following expression results:

$$\begin{bmatrix} \sum_i a'_{ij} p_{ij} a_{ij} + p_j & -a'_{ij} p_{ij} a_{ij} \\ -a'_{ij} p_{ij} a_{ij} & \sum_j a'_{ij} p_{ij} a_{ij} + P_j \end{bmatrix} \begin{bmatrix} X_j \\ X_i \end{bmatrix} + \begin{bmatrix} U_j = \sum_i a'_{ij} p_{ij} W_{ij} \\ U_i = -\sum_j a'_{ij} p_{ij} W_{ij} \end{bmatrix} = 0 \quad (8.87)$$

Elimination of the corrections to the preliminary coordinates of the satellite position, namely X_j , from equation (8.87) results in the following three expressions: The 3×3 diagonal matrix corresponding to the k th ground station is given by

³ As in the case of the optical adjustment, satellite positions will be considered "nuisance" parameters and therefore eliminated from the solution.

$$N_{kk} = \left(\sum_j a'_{kj} p_{kj} a_{kj} \right) - \sum_j \left\{ a'_{kj} p_{kj} a_{kj} \left(\sum_i a'_{ij} p_{ij} a_{ij} \right)^{-1} \times a'_{kj} p_{kj} a_{kj} \right\} + P_k \quad (8.88)$$

The 3×3 off-diagonal matrix corresponding to the k th and the l th ground stations is given by

$$N_{kl} = - \sum_j \left\{ a'_{kj} p_{kj} a_{kj} \left(\sum_i a'_{ij} p_{ij} a_{ij} \right)^{-1} a'_{lj} p_{lj} a_{lj} \right\} \quad (8.89)$$

where the main summation $\sum_j$ is performed over all satellite positions observed simultaneously from both ground stations k and l ; the constant vector of the k th ground station is

$$U_k = - \left(\sum_j a'_{kj} p_{kj} W_{kj} \right) + \sum_j \left\{ a'_{kj} p_{kj} a_{kj} \left(\sum_i a'_{ij} p_{ij} a_{ij} \right)^{-1} \sum_i a'_{ij} p_{ij} W_{ij} \right\} \quad (8.90)$$

In the above expressions, the weight matrix P_j of each satellite position was set equal to zero as there is no independent external source from which to get a priori variance estimates which could be used to derive weights.

The equivalent expression for the constant column U_k can be shown to have the following form:

$$U_k = - \sum_j a'_{kj} p_{kj} \bar{v}_{kj} \quad (8.91)$$

where $\bar{v}_{kj}$ is the residual of the particular observed range r_{kj} arising from a least-squares adjustment of one simultaneous event with ground stations held fixed.

The quantities a_{kj} and $\bar{v}_{kj}$ needed in the formation of the reduced normal equations (eqs. (8.88), (8.89), and (8.91)) are a side product of the preliminary adjustment of each simultaneous event. Specifically, a_{kj} is contained in the A matrix given by equation (8.3) and $\bar{v}_{kj}$ is an element of the $\bar{V}$ vector of equation (8.5).

8.4.4 Addition of Normal Equations

Independent sets of normal equations formed from two or more batches of camera and/or range data can be added together. The basic idea of the combination of the normal equations is simply the algebraic addition of their corresponding terms. Letting n sets of normal equations be represented by

$$\begin{aligned} N_1 X + U_1 &= 0 \\ N_2 X + U_2 &= 0 \\ &\vdots \\ N_n X + U_n &= 0 \end{aligned} \quad (8.92)$$

and their corresponding variances of unit weight as $\sigma_{01}^2, \sigma_{02}^2, \dots, \sigma_{0n}^2$, we can show the addition is

$$(N_1 + p_{12}N_2 + \dots + p_{1n}N_n)X + (U_1 + p_{12}U_2 + \dots + p_{1n}U_n) = 0 \quad (8.93)$$

In the above, the weights may be obtained as follows:

$$\begin{aligned} p_{12} &= \frac{\sigma_{01}^2}{\sigma_{02}^2} \\ &\vdots \\ p_{1n} &= \frac{\sigma_{01}^2}{\sigma_{0n}^2} \end{aligned} \quad (8.94)$$

where $\sigma_{01}^2, \sigma_{02}^2, \dots, \sigma_{0n}^2$ must have the same a priori variance of unit weight (see secs. 8.4.2.1.2 and 8.4.3.2).

The advantage of the above is obvious, namely batches of observed data may be adjusted separately or as a part of a combined adjustment. The same holds for the addition of two or more independent sets of range normal equations and for the addition of camera and range normal equations to each other.

The weighting of the two or more different sets of normal equations (e.g., N_{11} , U_{11} , and

N_{22} , U_{22}) is a function of the goodness of the observations involved and the geometry existing between the unknown parameters and the respective observables. The first item is taken care of by proper weighting as a function of the estimated variance-covariance matrix of the observations, and this weighting is reflected in the quantities N_{11} , N_{22} , U_{11} , and U_{22} . The geometry aspect is implicit in the coefficient matrices A and B which enter into N_{11} , and so forth.

8.4.5 Contributions of Constraints to the Normal Equations

(OSU Reports 86, 140, 148)

8.4.5.1 General

Since the coefficient matrix of normal equations is singular, a unique least-squares solution is not possible. A minimal set of constraints to the normal equations provides a unique solution (Blaha, 1971).

Two alternative definitions exist for the term "constraints": the absolute constraints represent certain conditions which have to be fulfilled exactly and with no uncertainties. The relative constraints (or weighted constraints) have the same characteristics as the observations.

In general, the contribution of the functional constraint equation

$$G(X, L_c) = 0$$

to the reduced normal equations $\bar{N}X + \bar{U} = 0$ can be found by bordering the normal equation matrix ⁴

$$\begin{bmatrix} \bar{N} & C' \\ C & -P_c^{-1} \end{bmatrix} \begin{bmatrix} X \\ -K_c \end{bmatrix} + \begin{bmatrix} \bar{U} \\ W_c \end{bmatrix} = 0$$

where

$$C = \frac{\partial G}{\partial X_i}$$

After elimination of K_c , where

⁴ The quantities $\bar{N}$ and $\bar{U}$ represent the original reduced normal equations (without constraints).

$$K_c = -P_c(CX + W^c) \quad (8.95a)$$

it is easy to find

$$\begin{aligned} [\bar{N} + C'P_cC]X + \bar{U} + C'P_cW^c &= 0 \\ [\bar{N} + N^c]X + U + U^c &= 0 \end{aligned} \quad (8.95b)$$

where N^c and U^c are the contributions to the coefficient matrix and constant vector of the normal equation due to the application of constraints.

After the constraints are added, the normal equations will take the usual form

$$NX + U = 0$$

and we are in the position to obtain the contribution from a new set of constraints.

Constraints can be applied between two stations k and l or to a single station. The contribution of these constraints to the matrix $\bar{N}$ (3×3 blocks) and $\bar{U}$ (3×1 blocks) can be schematically expressed in two different ways as shown on page 671.

These blocks obtained as indicated for the corresponding case will be the only ones computed and added to the original normal equations as expressed by formula (8.95b).

8.4.5.2 Relative Position Constraints

Relative position constraints are used in order to combine the normal equations obtained from various satellite nets and to constrain "double" stations or closely situated stations of the same net. The expression for the combination of normals can be written as follows:

$$[\bar{N} + N^R]X + \bar{U} + U^R = 0$$

where N^R and U^R , computed from (8.96a) and (8.96b), are the contribution to the original combined normal equations ($\bar{N}X + \bar{U} = 0$).

If the relative position (Δu^o , Δv^o , Δw^o) of two stations is known, along with the standard deviation of these relative positions, the

constraints can be formed. In this case the functional constraint equations are

$$\begin{aligned} u_k^o - u_l^o &= \Delta u^o \\ v_k^o - v_l^o &= \Delta v^o \\ w_k^o - w_l^o &= \Delta w^o \end{aligned}$$

Therefore

$$\begin{aligned} C_k^R &= I_{3 \times 3} & C_l^R &= -I_{3 \times 3} \\ U_k^R &= 0_{3 \times 1} & U_l^R &= 0_{3 \times 1} \end{aligned}$$

because $W^R = G^R (X^o, L_c^o) = 0$. Also,

$$P_R = \sigma_0^2 \begin{bmatrix} \frac{1}{\sigma_{\Delta u^o}^2} & 0 & 0 \\ 0 & \frac{1}{\sigma_{\Delta v^o}^2} & 0 \\ 0 & 0 & \frac{1}{\sigma_{\Delta w^o}^2} \end{bmatrix}$$

where $\sigma_0^2 \equiv$ a priori variance of unit weight and

$$\begin{aligned} N_{kk}^R &= IP_R I = P_R_{3 \times 3} \\ N_{ll}^R &= IP_R I = P_R_{3 \times 3} \\ N_{kl}^R &= N_{lk}^R = IP_R (-I) = -P_R_{3 \times 3} \end{aligned}$$

Thus, the diagonal elements of P_R are added to each element of the diagonal of the blocks kk and ll of the coefficient matrix of the combined normals $\bar{N}$ and subtracted from the diagonal elements of the blocks kl and lk of $\bar{N}$. There is no contribution to the vector $\bar{U}$.

8.4.5.3 Length (Chord) Constraints

Chord constraints are introduced when scalar information is available between ground stations (e.g., distances determined through high-precision geodimeter traversing). The functional constraint equation in this case is

$$G^c(X, L_c) = 0$$

or

The diagram illustrates the structure of the matrix N^c_{kk} and its components. The matrix is partitioned into blocks labeled P_c , C_k , C , C' , $C'P_c$, N^c , C'_k , and N^c_{kk} . To the right, a vertical vector W^c is shown, with its components U^c_i and U^c_k . The equations $N^c_{kk} = C'_k P_c C_k$ and $U^c_k = C'_k P_c W^c$ are also displayed.

(2) Contribution to the normals due to the constraint between stations k and l :

		P_c			C_k			C_l			W^c																																				
C_k^c		<table style="border-collapse: collapse; width: 100%;"> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> </table>															<table style="border-collapse: collapse; width: 100%;"> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> </table>															<table style="border-collapse: collapse; width: 100%;"> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> </table>															
					N_{kk}^c			N_{kl}^c																																							
C_l^c		<table style="border-collapse: collapse; width: 100%;"> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> </table>															<table style="border-collapse: collapse; width: 100%;"> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> </table>															<table style="border-collapse: collapse; width: 100%;"> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td></tr> </table>															
					N_{lk}^c			N_{ll}^c																																							

$$\begin{aligned}
N_{kk}^c &= C_k^c P_c C_k; & N_{kl}^c &= C_l^c P_c C_k \\
N_{lk}^c &= C_k^c P_c C_l; & N_{ll}^c &= C_l^c P_c C_l \\
U_k^c &= C_k^c P_c W^c; & U_l^c &= C_l^c P_c W^c
\end{aligned}$$

(8.96b)

$$[(u_k - u_l)^2 + (v_k - v_l)^2 + (w_k - w_l)^2]^{1/2} = D_{kl} \quad (8.97)$$

Therefore

$$C_k^c = \left[\frac{u_k^o - u_l^o}{D_{kl}^o}, \frac{v_k^o - v_l^o}{D_{kl}^o}, \frac{w_k^o - w_l^o}{D_{kl}^o} \right]$$

$$C_l^c = \left[-\frac{u_k^o - u_l^o}{D_{kl}^o}, -\frac{v_k^o - v_l^o}{D_{kl}^o}, -\frac{w_k^o - w_l^o}{D_{kl}^o} \right]$$

$$P_c = \frac{\sigma_0^2}{\sigma_{kl}^2} = \frac{\text{a priori variance of unit weight}}{\text{variance of the chord}}$$

Then the contributions to the normals are obtained by applying equations (8.96a) and (8.96b).

$$N_{kk}^c = (C_k^c)' P_c C_k^c$$

$$N_{ll}^c = (C_l^c)' P_c C_l^c$$

$$N_{kl}^c = (C_l^c)' P_c C_k^c$$

$$U_k^c = (C_k^c)' P_c W^c$$

$$U_l^c = (C_l^c)' P_c W^c$$

The first three expressions in the above are added, respectively, to the blocks $\bar{N}_{kk}$, $\bar{N}_{ll}$ and $\bar{N}_{kl}$ of $\bar{N}$; the last two expressions are added, respectively, to the constant subvectors $\bar{U}_k$ and $\bar{U}_l$ of $\bar{U}$.

8.4.5.4 Station Position Constraint

Station position constraint is used for the purpose of defining the origin of the coordinate system. If the station coordinates (u_k^o, v_k^o, w_k^o) of station k are to be constrained and if the computed (known) variances of its approximate coordinates are $\sigma_{u_k^o}^2$, $\sigma_{v_k^o}^2$, $\sigma_{w_k^o}^2$, then the equations given in section 8.4.5.2 are valid by merely deleting the terms with index l ; then $\Delta u^o = u_k^o$, $\Delta v^o = v_k^o$, $\Delta w^o = w_k^o$. Then

$$N_{kk}^s = I P_s I = P_s$$

where

$$P_s = \sigma_0^2 \begin{bmatrix} \frac{1}{\sigma_{u_k^o}^2} & 0 & 0 \\ 0 & \frac{1}{\sigma_{v_k^o}^2} & 0 \\ 0 & 0 & \frac{1}{\sigma_{w_k^o}^2} \end{bmatrix}$$

8.4.5.5 Height Constraints

If the geodetic height of the station k is to be constrained, then

$$N_{kk}^h = (C_k^h)' P_h C_k^h$$

where

$$C_k^h = [\cos \phi_k^o \cos \lambda_k^o, \cos \phi_k^o \sin \lambda_k^o, \sin \phi_k^o]$$

and

$$P_h = \frac{1}{\sigma_{h_k}^2}$$

where ϕ_k^o and λ_k^o are the approximate geodetic coordinates and $\sigma_{h_k}^2$ is the variance of the height for station k .

The constant vector U_k^h can be computed from

$$U_k^h = (C_k^h)' P_h W^h$$

where

$$W^h = h_k - h_k^o$$

8.4.5.6 Directional Constraints

Directional constraints are introduced when the orientation of the coordinate system is not defined through the observations (e.g., in the case of a ranging network).

The directional constraint between two stations k and l is accomplished by applying weights to two angles α^o and β^o defining the direction between them and computed from the approximate (u^o, v^o, w^o) coordinates of the two stations as follows:

$$\alpha^o = \tan^{-1} \frac{\Delta v^o}{\Delta u^o}$$

$$\beta^o = \tan^{-1} \frac{\Delta w^o}{R^o}$$

where

$$\Delta u^o = u_k^o - u_l^o$$

$$\Delta v^o = v_k^o - v_l^o$$

$$\Delta w^o = w_k^o - w_l^o$$

$$R^o = (\Delta u^{o2} + \Delta v^{o2})^{1/2}$$

The matrix C^D of partial derivatives is then formed

$$C_k^D = \begin{bmatrix} \frac{\partial \alpha^o}{\partial \Delta u^o} & \frac{\partial \Delta u^o}{\partial u_k^o} & \frac{\partial \alpha^o}{\partial \Delta v^o} & \frac{\partial \Delta v^o}{\partial v_k^o} & \frac{\partial \alpha^o}{\partial \Delta w^o} & \frac{\partial \Delta w^o}{\partial w_k^o} \\ \frac{\partial \beta^o}{\partial \Delta u^o} & \frac{\partial \Delta u^o}{\partial u_k^o} & \frac{\partial \beta^o}{\partial \Delta v^o} & \frac{\partial \Delta v^o}{\partial v_k^o} & \frac{\partial \beta^o}{\partial \Delta w^o} & \frac{\partial \Delta w^o}{\partial w_k^o} \end{bmatrix}$$

where

$$\frac{\partial \alpha^o}{\partial \Delta u^o} = \cos^2 \alpha^o \tan \alpha^o / \Delta u^o$$

$$\frac{\partial \alpha^o}{\partial \Delta v^o} = -\cos^2 \alpha^o / \Delta u^o$$

$$\frac{\partial \alpha^o}{\partial \Delta w^o} = 0$$

$$\frac{\partial \beta^o}{\partial \Delta u^o} = \Delta u^o \cos^2 \beta^o \tan^2 \beta^o / R^{o2}$$

$$\frac{\partial \beta^o}{\partial \Delta v^o} = \frac{\partial \beta^o}{\partial \Delta w^o} \tan \alpha^o$$

$$\frac{\partial \beta^o}{\partial \Delta w^o} = -\cos^2 \beta^o / R^o$$

and clearly $C_l^D = -C_k^D$. Then the matrix

$$N^D = (C^D)' P_D C^D \quad (8.98)$$

is formed according to (8.96b), where P_D is the weight matrix estimated from the statistics of α^o and β^o in the customary way,

$$P_D = \sigma_0^2 \begin{bmatrix} \sigma_{\alpha^o}^2 & \sigma_{\alpha^o \beta^o} \\ \sigma_{\alpha^o \beta^o} & \sigma_{\beta^o}^2 \end{bmatrix}^{-1}$$

The matrix N^D is then added to the block elements of the reduced normal equations which correspond to each of the ground stations; i.e., its diagonal blocks will be added to $\bar{N}_{kk}$ and $\bar{N}_{ll}$ and subtracted from the off-diagonal elements $\bar{N}_{kl}$ and $\bar{N}_{lk}$.

8.4.5.7 Inner Constraints (Free Adjustment)

Even though the selection of a coordinate system is arbitrary in the case of a minimum constraint adjustment, e.g., in the case of ranging, the selection of the six coordinates (at more than two stations) to be constrained is very critical, since one set of constraints would give a different solution than another set. The "best" solution is arrived at in a coordinate system defined through the use of a set of constraint equations called "inner" constraints (Rinner *et al.*, 1967). In this sense, "best" means resulting in the smallest covariance matrix for the unknowns. Covariance matrices may be compared by means of their traces. The inner constraint equations are characterized by the property that the trace of the covariance matrix obtained with their use is a minimum among those obtained by adjusting a given set of observations augmented by a minimal set of constraint equations. This property also implies that the mean square uncertainty of the unknowns is smaller when the inner adjustment equations are used. The resulting adjustment is called a "free" adjustment. The functional inner constraints equations can be written as

$$C'X = 0$$

where X is the set of corrections of the approximate coordinates of the unknown points and in the most general application when the "best" origin, orientation, and scale are sought.

$$C' = \begin{bmatrix} C_1' \\ C_2' \\ C_3' \end{bmatrix} = \begin{bmatrix} I & I & \cdots \\ 3 \times 3 & 3 \times 3 & \cdots \\ \hline 0 & w_1^o & -v_1^o & 0 & w_2^o & -v_2^o & \cdots \\ -w_1^o & 0 & u_1^o & -w_2^o & 0 & u_2^o & \cdots \\ v_1^o & -u_1^o & 0 & v_2^o & -u_2^o & 0 & \cdots \\ \hline u_1^o & v_1^o & w_1^o & u_2^o & v_2^o & w_2^o & \cdots \end{bmatrix}$$

The symbols (u_i^o, v_i^o, w_i^o) denote the approxi-

mate coordinates of the i^{th} unknown point where both the ground points and the satellite positions are considered.

It is also possible to design a set of constraints that will result in the "best" solution for only a subset of the points. In the adjustments reported here we were only interested in the ground station unknowns, implying that the trace of only that portion of the covariance matrix corresponding to the ground station unknowns should be minimized, while the variances of the satellite position unknowns should not be included in the minimum sum. The constraint equations that will produce such a solution have the same form as those producing the "best" solution for all the points. However, 3×3 blocks of zeros are inserted into those positions of C' which correspond to unknowns whose variances are not to be included in the minimum sum.

The inner adjustment constraint equations can be given a geometrical interpretation that appeals to intuition. Let X_i^a denote the set of approximate coordinates of the i^{th} unknown point, dX_i denote the corrections to these coordinates, and X_i^a denote the adjusted coordinates, i.e.,

$$X_i^a = X_i^a + dX_i$$

The first set of constraint equations, $C_1'X = 0$, is then equivalent to the set of conditions

$$\sum_i dX_i = 0$$

The geometrical interpretation of these conditions is that the center of gravity of all the points will not change after adjustment, i.e.,

$$\sum_i X_i^a = \sum_i X_i^a$$

The second set of constraint equations, $C_2'X = 0$, corresponds to the conditions

$$\sum_i X_i^a \times dX_i = 0$$

If the center of the system remains fixed, then the cross products $X_i^a \times dX_i$ reflect rota-

tions of the points around the fixed center. These constraint equations ensure that the sums of the rotations around all three coordinate axes are zero. The corresponding geometrical interpretation is that the mean orientation of the system of points will not change after adjustment either.

Thus, the respective equations $C_1'X = 0$ and $C_2'X = 0$ effectively specify the origin and the orientation of the adjustment coordinate system. A third "inner adjustment" equation $C_3'X = 0$ specifies the scale of the system. However, this scale equation is only used when the observations themselves do not determine the scale.

A more complete description of the inner adjustment is described in Blaha (1971).

In summary, if the normal equations with the contribution of all the constraints (except inner constraints) are represented by

$$[\bar{N} + N^R + N^C + N^S + N^H + N^D] X + \bar{U} + U^R + U^C + U^S + U^H + U^D = 0$$

or

$$NX + U = 0 \quad (8.99)$$

then the inner adjustment can be obtained by bordering the coefficient matrix N of the normal equations as

$$\begin{bmatrix} N & (C')' \\ C' & 0 \end{bmatrix} \begin{bmatrix} X \\ -K_I \end{bmatrix} = \begin{bmatrix} -U \\ 0 \end{bmatrix} \quad (8.100)$$

Upon the addition of any kind of constraint to the normal equations, it becomes necessary to consider also its contribution to $\sum V'PV$. The degrees of freedom change as well. In order to compute the proper variance of unit weight, the latter must be taken into consideration.

8.4.6 Solution of Normal Equations and Formation of the Inverse Weight Matrix (OSU Report 86)

8.4.6.1 Introduction

The normal equations for the camera and range adjustments are given in the previous

section. The general form of the normal equations is

$$NX + U = 0 \quad (8.101)$$

where N is the coefficient matrix, X is the vector of unknowns, and U is the constant vector.

The adjusted values of the Cartesian coordinates of the observing ground stations are obtained by adding the corrections X to the preliminary values X^0 , namely,

$$X^a = X^0 + X \quad (8.102)$$

Section 8.4.7 deals with obtaining the precision estimate of X^a through the inverse matrix N^{-1} . For this reason the method of formation of N^{-1} will be dealt with in section 8.4.6.4 along with the method of solving for X .

The procedure used to solve the normal equations is a Gauss reduction (sec. 8.4.6.2) and back solution (sec. 8.4.6.3) and computation of the inverse by the method established by Banachiewicz (sec. 8.4.6.4).

Two features which are peculiar to the specific procedure used here are: (1) the coefficient matrix N is broken down into 3×3 submatrices, and similarly the U vector is treated as being composed of 3×1 vectors; and (2) the coefficient matrix N is compacted so that 3×3 zero submatrices are neither stored nor used in the computation.

The first feature is achieved rather naturally; it occurs because of the form of the expressions given in sections 8.4.2–8.4.5, which are used to build up N and U . On the other hand, the second feature is achieved through programming logic. Specifically, a matrix L is used to tag each 3×3 nonzero submatrix of N with a row and column number. A second matrix F with a one-to-one correspondence to the first is then employed to tag the storage assigned to the particular 3×3 submatrix. The individual elements of the 3×3 submatrices are all stored in one large linear array E .

The reduced elements of N are stored in the locations previously created for elements

in N . During reduction, additional 3×3 matrices arise in locations where there were none originally in N ; thus “drag storage” must be assigned. In doing so, the guide matrix L and the storage tagging matrix F are updated to account for these additional matrices. Similar “drag storage” is also determined during the formation of the inverse N^{-1} .

Once the “drag storage” is determined, the reduction, back solution, and inverse determinations are guided by L , the storage located by F , and the elements to be used in the computation found in E .

8.4.6.2 Reduction

The coefficient matrix of the normal equations is written as

$$N = SR \quad (8.103)$$

where S is a lower triangular matrix with 3×3 identity matrices along the diagonal, and R is an upper triangular matrix. All matrices and vectors discussed here are stipulated to be composed of 3×3 submatrices and 3×1 subvectors, respectively.

The reduction is accomplished by computing

$$S = I - T \quad (8.104)$$

from

$$N = R - TR \quad (8.105)$$

or

$$R = N + TR \quad (8.106)$$

where R and T (thus S) are built up simultaneously. The augmented matrix

$$[N, U] = \begin{bmatrix} n_{011} & n_{012} & n_{013} & \cdots & n_{01n} & u_{01} \\ n'_{012} & n_{022} & n_{023} & \cdots & n_{02n} & u_{02} \\ n'_{013} & n'_{023} & n_{033} & \cdots & n_{03n} & u_{03} \\ n'_{014} & & & & & u_{04} \\ \cdot & & & \cdot & & \cdot \\ \cdot & & & & \cdot & \cdot \\ \cdot & & & & & \cdot \\ n'_{01n} & & & & n_{0nn} & u_{0n} \end{bmatrix} \quad (8.107)$$

is first reduced according to the algorithms

$$\begin{aligned} n_{k,i,j} &= n_{k-1,i,j} - n_{k-1,k,i}^{-1} n_{k-1,k,k} n_{k-1,k,j} \\ k &= 1, 2, \dots, n-1 \\ i &= k+1, k+2, \dots, n \\ j &= i, i+1, \dots, n \end{aligned} \quad (8.108)$$

defining

$$R = \begin{bmatrix} n_{011} & n_{012} & \dots & \dots & n_{01n} \\ & n_{122} & n_{123} & \dots & n_{12n} \\ & & \cdot & & \cdot \\ \text{zeros} & & & & \cdot \\ \text{below} & & & & \cdot \\ \text{diagonal} & & & & n_{n-1,n,n} \end{bmatrix}$$

and

$$\begin{aligned} u_{k,i} &= u_{k-1,i} - n_{k-1,k,i}^{-1} n_{k-1,k,k} u_{k-1,k} \\ k &= 1, 2, \dots, n-1 \\ i &= k+1, \dots, n \end{aligned}$$

defining

$$\bar{C} = \begin{bmatrix} u_{01} \\ u_{12} \\ u_{23} \\ \vdots \\ u_{n-1,n} \end{bmatrix} \quad (8.109)$$

A second algorithm, performed as part of equation (8.108), namely

$$\bar{n}_{k-1,k,j} = n_{k-1,k,k}^{-1} n_{k-1,k,j} \quad (8.110)$$

$$\bar{n}_{k-1,k,k} = I \quad (8.111)$$

$$\begin{aligned} \bar{u}_{k-1,k} &= n_{k-1,k,k}^{-1} u_{k-1,k} \\ j &= k+1, k+2, \dots, n \\ k &= 1, 2, \dots, n-1 \end{aligned} \quad (8.112)$$

results in the following reduced matrices:

$$S' = \begin{bmatrix} I & \bar{n}_{012} & \bar{n}_{013} & \dots & \bar{n}_{01n} \\ 0 & I & \bar{n}_{123} & & \bar{n}_{12n} \\ 0 & 0 & I & & \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & 0 & I \end{bmatrix} \quad (8.113)$$

$$-\bar{D} = \begin{bmatrix} \bar{u}_{01} \\ \bar{u}_{12} \\ \bar{u}_{23} \\ \vdots \\ \bar{u}_{n-1,n} \end{bmatrix} \quad (8.114)$$

S' and $\bar{D}$ are used to obtain solution vector X (see sec. 8.4.6.3)

$$R^{-1} = \begin{bmatrix} n_{011}^{-1} & & & \text{elements} \\ & n_{122}^{-1} & & \text{above} \\ \text{zeros} & & n_{233}^{-1} & \text{diagonal} \\ \text{below} & & & \vdots \\ \text{diagonal} & & & n_{n-1,n,n}^{-1} \end{bmatrix} \quad (8.115)$$

which is used to obtain the inverse (see sec. 8.4.6.4).

8.4.6.3 Back Solution

The back solution involves the determination of the unknown vector X from elements of the reduced matrices S' and $\bar{D}$. Without derivation (Uotila, unpublished lecture notes, 1967), it can be shown that

$$X = T'X - \bar{D} \quad (8.116)$$

recalling

$$T = I - S'$$

or in summation form

$$X_i = \sum_{j=i+1}^n \bar{n}_{i-1,i,j} X_j + \bar{u}_{i-1,i} \quad (8.117)$$

8.4.6.4 Formation of Inverse

The inverse matrix N^{-1} will be computed by the method associated with the name of Banachiewicz (Uotila, unpublished lecture notes, 1967). According to equation (8.103), N^{-1} can be computed from

$$N^{-1} = R^{-1} S^{-1} \quad (8.118)$$

However, it turns out that N^{-1} can be formed without the aid of S^{-1} , and further only the diagonal elements of R^{-1} are needed.

The diagonal elements of R^{-1} are readily available, since the inverse of an upper triangular matrix has as its diagonal elements the reciprocal of the diagonal elements of the triangular matrix itself and the same result holds if "elements" is taken to mean 3×3 . The diagonal elements of R^{-1} are computed by inverting the 3×3 diagonal matrices of R and for reasons of saving computer space are stored along the diagonal of S' (eq. (8.113)).

From equation (8.118)

$$R^{-1} = N^{-1}S \quad (8.119)$$

Further, if substitution for S is made from equation (8.104),

$$R^{-1} = N^{-1}(I - T) \quad (8.120)$$

$$= N^{-1} - N^{-1}T \quad (8.121)$$

Finally,

$$N^{-1} = R^{-1} + N^{-1}T \quad (8.122)$$

The corresponding summation equation for computing any 3×3 matrix of N^{-1} is

$$n^{ij} = \sum_{k=i+1}^n \bar{n}_{i-1,i,k} n^{kj} + \delta_{ij} n_{i-1,i,i}^{-1} \quad (8.123)$$

where δ_{ij} is the Kronecker delta defined by

$$\delta_{ij} = \begin{cases} 1 & i=j \\ 0 & i \neq j \end{cases} \quad (8.124)$$

and

$$n^{ij} = (n^{ji})' \quad (8.125)$$

8.4.7 Statistical Evaluation (Precision of Ground Stations After Adjustment) (OSU Report 86)

8.4.7.1 Variance of Unit Weight

The variance of unit weight for the total adjustment is given by

$$\sigma_0^2 = \frac{V'PV}{df} \quad (8.126)$$

where $V'PV$ is the sum of the squares of the weighted residuals of all observed quantities and df is the number of degrees of freedom in the least-squares adjustment.

8.4.7.1.1 ADJUSTMENT TO CAMERA OBSERVATIONS

Equation (8.126) will now be considered for the adjustment of camera observations. The linearized mathematical structure according to section 8.4.2 was shown to be of the form

$$AX + BV + W = 0 \quad (8.127)$$

The general expression for the computation of $V'PV$ is

$$V_c'P_cV_c = -W'K - \sum_c^c (W_c)'K_c \quad (8.128)$$

where the first term is the contribution from equation (8.127) and the second term is the contribution from the c constraints applied. Without taking into consideration the contribution of the constraints

$$V'PV = -W'K \quad (8.129)$$

and by considering an expression for K and X from equations (8.45) and (8.46), respectively,

$$V'PV = W'(BP^{-1}B')^{-1}(AX + W) \quad (8.130)$$

$$X = -\{A'M^{-1}A + A + P_x\}^{-1}A'M^{-1}W \quad (8.131a)$$

Denoting

$$M = BP^{-1}B' \quad (8.131b)$$

we see that equation (8.130) with equations (8.47) and 8.131b) gives

$$V'PV = W'M^{-1}W - [U_j' U_i'] \begin{bmatrix} X_j \\ X_i \end{bmatrix} \quad (8.132)$$

Let the partitioning of equation (8.47) be denoted as

$$\begin{bmatrix} N_{11} & N_{12} \\ N_{21} & N_{22} \end{bmatrix} \begin{bmatrix} X_j \\ X_i \end{bmatrix} + \begin{bmatrix} U_j \\ U_i \end{bmatrix} = 0 \quad (8.133)$$

Then, by means of

$$\begin{aligned} & \begin{bmatrix} N_{11} & N_{12} \\ N_{21} & N_{22} \end{bmatrix}^{-1} \\ &= \begin{bmatrix} Q_{11} & Q_{12} \\ Q_{21} & Q_{22} \end{bmatrix} \\ &= \begin{bmatrix} N_{11}^{-1} + N_{11}^{-1}N_{12}E N_{21}N_{11}^{-1} & -N_{11}^{-1}N_{12}E \\ -E N_{21}N_{11}^{-1} & E \end{bmatrix} \end{aligned} \quad (8.134a)$$

where

$$E = (N_{22} - N_{21}N_{11}^{-1}N_{12})^{-1} \quad (8.134b)$$

equation (8.132) becomes

$$V'PV = W'M^{-1}W - [U_j' U_i'] \begin{bmatrix} Q_{11}U_j + Q_{12}U_i \\ Q_{21}U_j + Q_{22}U_i \end{bmatrix}$$

After substituting the values from equation (8.134a) and simplifying

$$\begin{aligned} V'PV &= W'M^{-1}W - U_j'N_{11}^{-1}U_i \\ &\quad + (U_i - N_{21}N_{11}^{-1}U_j)'E(U_i - N_{21}N_{11}^{-1}U_j) \end{aligned} \quad (8.135)$$

but by elimination of X_j from equation (8.133) we get

$$X_i = -[N_{22} - N_{21}N_{11}^{-1}N_{12}]^{-1} [U_i - N_{21}N_{11}^{-1}U_j]$$

or, using the notation of equation (8.101), we have

$$X = -N^{-1}U$$

Thus we see that

$$E = N^{-1}$$

and

$$U = U_i - N_{21}N_{11}^{-1}U_j$$

and finally

$$V'PV = W'M^{-1}W - U_j'N_{11}^{-1}U_j + U'X \quad (8.136)$$

Denoting

$$Q = W'M^{-1}W - U_j'N_{11}^{-1}U_j \quad (8.137)$$

and considering equation (8.49), we find

$$\begin{aligned} Q &= \sum_{ij} W'_{ij} M_{ij}^{-1} W_{ij} - \sum_j \left\{ \sum_i M_{ij}^{-1} W_{ij} \right\}' \\ &\quad \left\{ \sum_i M_{ij}^{-1} \right\}^{-1} \left\{ \sum_i M_{ij}^{-1} W_{ij} \right\} \end{aligned} \quad (8.138)$$

Now using equations (8.54) and (8.58) and factorization and cancellation analogous to that in equations (8.57) to (8.58), we get

$$\begin{aligned} Q &= \sum_{ij} X_i' M_{ij}^{-1} X_i - \sum_j \left\{ \sum_i M_{ij}^{-1} X_i \right\}' \\ &\quad \left\{ \sum_i M_{ij}^{-1} \right\}^{-1} \left\{ \sum_i M_{ij}^{-1} X_i \right\} \end{aligned} \quad (8.139)$$

which is easily shown to be identically equal to

$$Q = \sum_{ij} (X_i - X_j^0)' M_{ij}^{-1} (X_i - X_j^0)$$

with

$$X_j^0 = \left\{ \sum_i M_{ij}^{-1} \right\}^{-1} \left\{ \sum_i M_{ij}^{-1} X_i \right\}$$

so that finally, after the constraints are taken into consideration,

$$\begin{aligned} V_c' P_c V_c &= \sum_{ij} (X_i - X_j^0)' M_{ij}^{-1} (X_i - X_j^0) \\ &\quad + U'X - \sum_c (W^c)' K_c \end{aligned} \quad (8.140)$$

The first term in the above is the quadratic form of all the residuals arising from all simultaneous event adjustments with ground stations held fixed and is computed and summed for each event by means of equation (8.1), for the purpose of blunder detection (sec. 8.3.2.2.2); the second term is found from

$$U'X = \bar{D}'\bar{C} \quad (8.141)$$

where the vectors $\bar{D}'$ and $\bar{C}$, a by-product in the solution of the normal equations, are defined by equations (8.114) and (8.109), respectively. K_c is obtained from equation (8.95a), where X is the solution of equation (8.100).

The total number of degrees of freedom, df , to be used in equation (8.126) is

$$\begin{aligned} df &= \text{number of equations} \\ &\quad - \text{number of unknowns} \\ df &= \left(\sum_j 2n + n_c \right) - (3s + 3g) \end{aligned} \quad (8.142)$$

where $2n$ is the number of equations resulting from one simultaneous event (n = number of ground stations in a particular event j) and the summation is performed over all simultaneous events; n_c is the number of constraint equations; $3s$ is the number of unknowns due to s number of satellite positions; $3g$ is the number of unknowns due to g number of unknown ground stations. In conclusion the a posteriori variance of unit weight for the optical adjustment will be

$$\sigma_0^2 = \frac{V_c' P_c V_c}{df} \quad (8.143)$$

8.4.7.1.2 RANGE ADJUSTMENT

Equations (8.126) will now be discussed in the light of the range adjustment. First, the expression for computing $V'PV$ by an analogous argument to the optical case is

$$V_c'PV = \bar{V}'P\bar{V} - X'U \quad (8.144)$$

where $\bar{V}'P\bar{V}$ is the quadratic form of the residuals arising from the adjustment of simultaneous events, the ground stations being held fixed. The second term

$$X'U = \bar{D}'\bar{C} \quad (8.145)$$

is computed according to equations (8.114) and (8.109), respectively.

The degrees of freedom, df , in the range adjustment is as usual

$$df = \text{number of equations} - \text{number of unknowns}$$

$$= \left(\sum_j n + n_r \right) - (3s + 3g) \quad (8.146)$$

where n is the number of ground stations (thus observed ranges) in a particular simultaneous event, and the summation is performed over all simultaneous events; n_r again is the number of constraint equations in the range adjustment; $3s$ and $3g$ are the number of unknowns due to s number of satellite positions and g number of unknown ground stations, respectively.

In summary,

$$\sigma_0^2 = \frac{V_c' P_c V_c}{df} \quad (8.147)$$

8.4.7.2 Variances and Covariances of Ground Stations

8.4.7.2.1 CARTESIAN COORDINATES

The variance-covariance matrix giving the accuracy of the adjusted rectangular ground station coordinates is

$$\sum_{\substack{u \\ v \\ w}} = \sigma_0^2 N^{-1} \quad (8.148)$$

where σ_0^2 is the variance of unit weight arising from the adjustment (sec. 8.4.7.1) and N^{-1} is the coefficient matrix discussed in section 8.4.6.4. The units for the variance-covariance matrix for the optical and range adjustments are meters squared. The square root of the diagonal elements of the variance-covariance matrix yields the corresponding standard deviations in meters.

8.4.7.2 GEODETIC COORDINATES

The propagation of variances and covariances from curvilinear coordinates (geodetic latitude ϕ and longitude λ and height h) in meters to three-dimensional rectangular coordinates (u, v, w) is achieved by the following matrix equation:

$$\sum_{\substack{u \\ v \\ w}} = G \sum_{\substack{\phi \\ \lambda \\ h}} G' \quad (8.149)$$

where

$$G = \begin{bmatrix} -\sin \phi & \cos \lambda & -\cos \phi & \sin \lambda & \cos \phi & \cos \lambda \\ -\sin \phi & \sin \lambda & \cos \phi & \cos \lambda & \cos \phi & \sin \lambda \\ -\cos \phi & & 0 & & \sin \phi & \end{bmatrix} \quad (8.150)$$

When the transformation depicted by equation (8.149) is reversed, the 3×3 variance-covariance matrix corresponding to ϕ , λ , h is

$$\sum_{\substack{\phi \\ \lambda \\ h}} = G^{-1} \sum_{\substack{u \\ v \\ w}} (G')^{-1} = \begin{bmatrix} \sigma_{\phi}^2 & \sigma_{\phi\lambda} & \sigma_{\phi h} \\ \sigma_{\lambda\phi} & \sigma_{\lambda}^2 & \sigma_{\lambda h} \\ \sigma_{h\phi} & \sigma_{h\lambda} & \sigma_h^2 \end{bmatrix} \quad (8.151)$$

all in units of (meters)².

In order to obtain the units

$$\begin{aligned} \sigma_{\phi}^2 & \quad (\text{arc-sec})^2 \\ \sigma_{\lambda}^2 & \quad (\text{arc-sec})^2 \\ \sigma_{\phi\lambda} \equiv \sigma_{\lambda\phi} & \quad (\text{arc-sec})^2 \\ \sigma_h^2 & \quad \text{meters}^2 \\ \sigma_{\phi h} \equiv \sigma_{h\phi} & \quad \text{arc-sec} \times \text{meters} \\ \sigma_{\lambda h} \equiv \sigma_{h\lambda} & \quad \text{arc-sec} \times \text{meters} \end{aligned} \quad (8.152)$$

the elements of equation (8.151) require the following modifications:

$$\begin{aligned} \sigma_{\phi}''^2 &= \left(\frac{\rho''}{R+h} \sigma_{\phi} \right)^2 \\ \sigma_{\lambda}''^2 &= \left(\frac{\rho''}{R+h} \sigma_{\lambda} \right)^2 \\ \sigma_{\phi\lambda} \equiv \sigma_{\lambda\phi} &= \left(\frac{\rho''}{R+h} \right)^2 \sigma_{\phi\lambda} \end{aligned} \quad (8.153)$$

$$\begin{aligned} \sigma_{h\phi} \equiv \sigma_{\phi h} &= \frac{\rho''}{R+h} \sigma_{h\phi} \\ \sigma_{h\lambda} \equiv \sigma_{\lambda h} &= \frac{\rho''}{R+h} \sigma_{h\lambda} \end{aligned}$$

where

$$\begin{aligned} \rho'' &= \frac{1}{\sin 1''} \\ R &= 6\,370\,000 \text{ m} \end{aligned}$$

(Note: R replaces the radius of curvature N in the prime vertical plane in the rigorous case; justification for simplification is given by the fact that only three significant figures are meaningful in propagation of variances whose magnitudes in m² or (arc-sec)² are in the units' place.)

8.4.7.3 Correlation Between Ground Stations

The amount of correlation between the adjusted ground station coordinates is described in terms of the correlation coefficient. The correlation coefficient is defined as

$$\rho_{ij} = \frac{\sigma_{ij}}{\sigma_i \sigma_j} \quad (8.154)$$

where i and j represent any two quantities associated with a variance-covariance matrix such as that of equation (8.148); σ_{ij} is the covariance, namely, the off-diagonal term of equation (8.148); and σ_i and σ_j are the standard deviations or square root of the i th and j th variances (diagonal terms), respectively.

8.4.7.4 Error Ellipsoid Computation

Error ellipsoid computation is made for each observing ground station considered as an unknown in the adjustment. The eigenvalues and eigenvectors are computed in a topocentric three-dimensional rectangular coordinate system with its origin at the particular ground station and its axes parallel to the mean terrestrial coordinate system (sec. 8.4.1.2). For each point, one eigenvalue (λ_{ii}) corresponds to each of the three mutually perpendicular axes of the ellipsoid; the

direction of the three axes is given by their corresponding eigenvector (T^i).

The actual computation is as follows. The 3×3 on-diagonal variance-covariance matrix Σ of equation (8.148) is subjected to an orthogonal transformation

$$T' \Sigma T = \Lambda \quad (8.155)$$

where Λ is a diagonal matrix and T is the orthogonal transformation matrix to be found which diagonalizes Σ . The transformation results in three homogeneous linear equations, namely,

$$[\Sigma - \lambda_{ii} I] T^i = 0 \quad (8.156)$$

which has a solution only if the determinant of the coefficient vanishes, i.e.,

$$|\Sigma - \lambda_{ii} I| = 0$$

or

$$\begin{vmatrix} \sigma_{11}^2 - \lambda_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22}^2 - \lambda_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33}^2 - \lambda_{33} \end{vmatrix} = 0 \quad (8.157)$$

Once the eigenvalues are obtained from equation (8.157), their corresponding eigenvectors are obtained from equation (8.156) after substitution of λ_{11} .

The length of the axes of the error ellipsoid are the square roots of the corresponding eigenvalues. The spherical coordinates (spherical latitude θ and longitude λ) which given the direction of each ellipsoidal axis are obtained from the components of the eigenvector

$$T^i = \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix}$$

namely

$$\tan \theta = \frac{t_3}{\sqrt{t_1^2 + t_2^2}} \quad (8.158)$$

and

$$\tan \lambda = \frac{t_2}{t_1} \quad (8.159)$$

These angles can easily be converted to altitude and azimuth if so desired.

8.4.8 Computer Programming

(OSU Reports 87, 88, 190, 193)

Computer programs related to section 8.4 may be found in Reilly *et al.* (1972) and in Mueller *et al.* (1973a).

8.5 RESULTS (SOLUTION WN14)

(OSU Reports 187, 188, 193, 195, 196, 199)

8.5.1 Reference Ellipsoid, Origin, Orientation, and Scale

The least-squares adjustment of the observations listed in tables 8.7 is performed in terms of the Cartesian coordinates of the tracking stations. The results are also converted into geodetic coordinates (latitude, longitude, height) referred to a rotational ellipsoid of the following parameters:

$$\begin{aligned} a &= 6\,378\,155.00 \text{ m} \\ b &= 6\,356\,769.70 \text{ m} \end{aligned}$$

The corresponding flattening is

$$f = 1/298.249\,498\,5 = 0.003\,352\,897\,507$$

The origin of the coordinate system (or the center of the above reference ellipsoid) is free as determined through the "inner" constraints explained in section 8.4.5.7. The orientation of the system is inherent in the camera observations, through the star positions in the SAO catalog (referenced to the FK4 system) updated to their apparent positions at the epoch of the observation, and through UT1, x and y (coordinates of the true pole with respect to the CIO) as derived by the BIH. Thus the positive end of the axis u is in the direction of the Greenwich Mean Astronomical Meridian (and the zero geodetic meridian of the reference ellipsoid); the positive w axis passes through the Conventional International Origin (and coincides with the minor axis of the reference ellipsoid). The axis y completes the right-handed

coordinate system in the direction of the 90° (E) meridian and with the u axis defines the plane of the average terrestrial (geodetic) equator.

The scale in the solution is defined through the dominating nearly 30 000 SECOR range observations, through the lengths of eight EDM (Geodimeter or Tellurometer) and three C-band baselines, and also through a special procedure using constrained ellipsoidal heights.

The SECOR observations have an a posteriori standard deviation of ± 4.1 m or approximately one part per million (Mueller et al., 1973b). The scale is propagated into the network through 13 camera stations whose relative positions with respect to the nearby SECOR stations are maintained in the adjustment, with their survey coordinate-differences entered as weighted constraints (see table 8.9).

The available EDM and C-band baselines are listed in table 8.11. The chord distances shown are entered in the adjustment as weighted constraints with weights computed from their estimated a priori standard deviations as listed in the table. The reasons for rejecting the east-west Australian tellurometer line (6032–6060) are explained in Mueller et al. (1973a). Three C-band lines were also rejected because of suspected errors in the survey coordinates of the terminal stations (Kauai (4742) in Hawaii and Pretoria (4050) in South Africa) needed to tie them to the nearest camera stations (9012 and 9002, respectively). Though these four lines were not constrained, at the end of the analysis two of them (6032–6060 and 4082–4050) compared well with the lengths computed from the adjusted coordinates (see table 8.17). Thus the only station with survey coordinates in definite error is Kauai.

The use of geodetic (ellipsoidal) heights as weighted constraints as a contribution to the scale requires a more detailed explanation (fig. 8.16). The height h above a geocentric reference ellipsoid has two main components: the orthometric (mean sea level) height MSL and the geoid undulation N . In this geocentric case, N consists of a long-wavelength

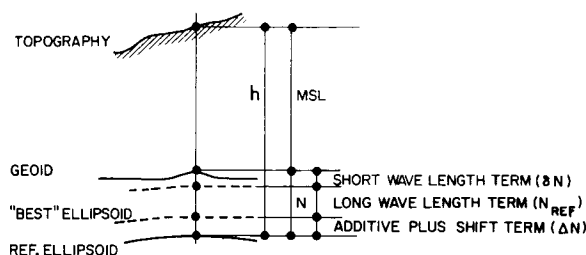


FIGURE 8.16.—Height components.

component N_{REF} , a short-wavelength term δN , and an additive part Δa . The term N_{REF} generally corresponds to regional gravitational effects and can be computed, e.g., from a truncated spherical harmonic series. The short-wavelength part δN corresponds to local gravity or mass disturbances and is generally not contained in the spherical harmonic representation. The additive part Δa is the so-called zero-degree term, which may exist because the ellipsoid may not be the same size (though it may have the same flattening) as the "best" (mean earth) level ellipsoid to which the undulations, N_{REF} , are referred. Since the N_{REF} undulations are, within reasonable limits, insensitive to the semidiameter of the level ellipsoid, it is difficult to define a correct value for Δa . If the reference ellipsoid is nongeocentric, as is the case in this solution, an additional height term dh arises because of the "shift" of the origin (ellipsoidal center) with respect to the geocenter.

Thus the geodetic height may have the following components:

$$h = MSL + N \quad (8.160)$$

$$N = N_{REF} + \delta N + \Delta N \quad (8.161)$$

where (Heiskanen and Moritz, 1967, p. 207)

$$\begin{aligned} \Delta N &= \Delta a + dh \\ &= \Delta a + u_0 \cos \phi \cos \lambda + v_0 \cos \phi \sin \lambda + w_0 \sin \phi \end{aligned} \quad (8.162)$$

$$\Delta a = a \text{ (level ellipsoid)} - a \text{ (reference ellipsoid)}$$

u_0 , v_0 , w_0 are the coordinates of the geocenter with respect to the center of the reference

ellipsoid (origin), and ϕ, λ are the geodetic coordinates of the station to which h refers.

In practice at most satellite tracking stations, the quantity $MSL + N_{REF}$ is well known, and generally it constitutes the largest portion of the total height above the level ellipsoid. The additive+shift term ΔN can be determined empirically through an iterative interpolation procedure, as described later. Since $MSL + N_{REF} + \Delta N$ constitutes the largest portion of the total height above the reference ellipsoid, it seems reasonable not to ignore this, admittedly partial, information on the height of the station and to include it in the adjustment as a constraint ($h_{CONSTR} = MSL + N_{REF} + \Delta N$) with such a weight that the adjustment should be able to "pull out" the only remaining component, the short-wavelength term δN together with possible errors in h_{CONSTR} . In this solution the standard deviations used in computing the weights vary from ± 2.5 m to ± 8 m, depending mostly on the location of the station, from the point of view of the extent of the available surface gravity observations in the area included in the spherical harmonic expansion for N_{REF} (Rapp, 1973). Table 8.10 lists these standard deviations and the quantities h_{CONSTR} for all the stations.

In trying to determine the "best" scale for the solution or, which is the same, the "best" additive term Δa , the first step is to establish the relationship between them. This problem differently stated is the determination of the relationship between the additive term and the semidiameter of the "best" level ellipsoid to which the quantity N_{REF} refers. The meaning of the term "best" will be elaborated on later in this section. This is accomplished empirically from a set of solutions with height constraints containing different additive terms, from $\Delta a = 0$ to 30 m. The shift term dh initially is estimated from comparisons with various dynamic solutions, resulting in the coordinates u_0, v_0 , and w_0 needed in equation (8.162).

These solutions result in sets of geodetic heights (h_{WNI}) above the reference ellipsoid and in sets of undulations after subtracting the MSL :

$$N_{WNI} = h_{WNI} - MSL$$

These undulations thus refer to the reference ellipsoid of $a = 6\,378\,155$ m, whose origin is set by the inner constraint. Disregarding the short-wave length term, the relationship between the undulations N_{WNI} and N_{REF} is given by equations (8.161) and (8.162), from which, for any station and for the solution WNI ,

$$(N_{WNI} - N_{REF}) - (\Delta a_i + u_{oi} \cos \phi \cos \lambda + v_{oi} \cos \phi \sin \lambda + w_{oi} \sin \phi) = 0$$

Since the quantity $(N_{WNI} - N_{REF})$ is known at all stations, the parameters $\Delta a_i, u_{oi}, v_{oi}, w_{oi}$ can be calculated (iterated) from least-squares adjustments for each set i . This is the same as determining the size (scale) and the origin of the level ellipsoid that best fits the geoid defined for a given set by the undulations N_{WNI} . Its size is

$$a_i = 6\,378\,155 + \Delta a_i$$

and its origin with respect to the origin of the reference ellipsoid is defined by the coordinates u_{oi}, v_{oi} , and w_{oi} . After some iterations these coordinates hardly change from solution (set) to solution (set), regardless of the initial selection of Δa ; thus the relationship between the input additive term and the resulting semidiameter, $a = f(\Delta a)$, becomes straightforward and linear.

This empirically determined relationship is shown in figure 8.17, as the dashed line drawn from the lower left corner towards the upper right. The corresponding ordinate is on the right-hand side of the diagram. The line now allows us either to pick the correct initial additive term, which when used in the height constraints would result in an a priori defined semi-diameter (scale), or to determine which semidiameter (scale) would correspond to an a priori defined additive term. As an example, if the semidiameter of the level ellipsoid best fitting the geoid was 6 378 142 m, the WN solution would require height constraints computed with an additive term of -15 m.

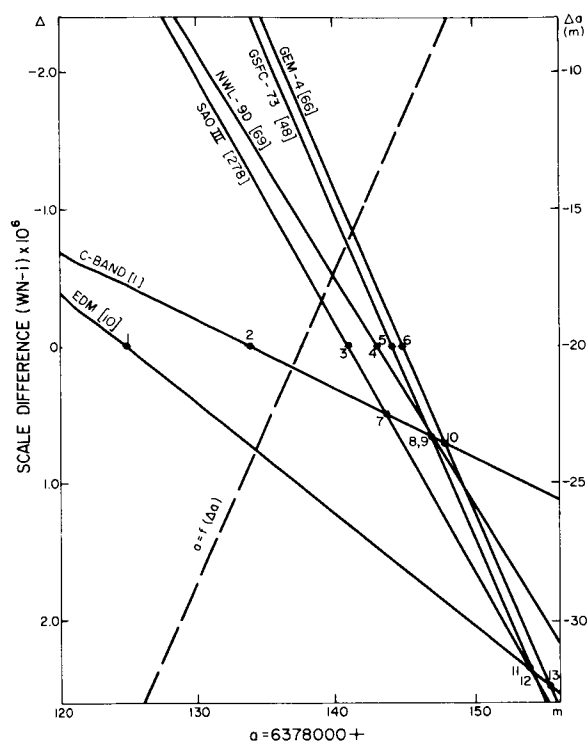


FIGURE 8.17.—Determination of scale.

The next question, of course, is just how big should this desired semidiameter be. Putting it differently, what criterion should be used to select the "best" scale? If the scale were to be determined only from the EDM and C-band baselines and/or the SECOR observations, these questions would not arise, since the scale would be inherently defined.

The use of weighted height constraints, as explained above, provides a unique tool for selecting the scale to fit some criterion. There could be several noninclusive criteria, e.g.,

(1) The lengths of the EDM baselines as computed from the adjusted coordinates of the terminal stations should be exactly the same as the lengths given in table 8.11 or their differences would be within the limit of one (average) standard deviation or within a certain limit, e.g., 1:1 000 000, etc.

(2) The lengths of the C-band baselines as computed from the adjusted coordinates of the terminal stations should be exactly the same as the lengths given in table 8.11 or

their differences should be within the limit of one (average) standard deviation or within a certain limit, e.g., 1:1 000 000, etc.

(3) The scale difference as determined from the station coordinates of the WN solution, and from the same coordinates of a dynamic solution should be exactly zero, within the limit of one standard deviation of the scale difference factor, or within 1:1 000 000, etc.

(4) The scale difference as determined in (3) should be within a certain limit with respect to all of the dynamic solutions.

(5) The scale difference should be within a certain limit with respect to all of the dynamic solutions and the EDM and C-band baselines.

To be able to enforce any of these criteria, the relationship between the scale difference factor and the semidiameter has to be established. This relationship is established empirically by determining the scale differences between the different WN_i solutions (used to determine the function $a=f(\Delta a)$) and the EDM and C-band baselines and the dynamic solutions NWL-9D (Anderle, 1974), SAO Standard Earth III (Gaposchkin *et al.*, 1974), GEM 4 (Lerch *et al.*, 1972a), and GSFC 73 (Marsh *et al.*, 1973). The method of calculating the scale difference factor is described in Kumar (1972). The results are shown in figure 8.17, in which, with the ordinate on the lefthand side, the scale differences are plotted against the semidiameters corresponding to the various Δa 's used in the height constraints. The numbers on the lines indicate relative weights based on the uncertainties of the scale difference determinations. It can be seen that the lines representing the geometric (EDM and C-band) scale differences are much less well determined than the dynamic ones. As an example, the scale difference factor, between the WN_i solution computed with $\Delta a = -15$ m ($a = 6\,378\,142$ m) and the solutions NWL-9D is -0.18×10^{-6} ; the GEM 4 is -0.68×10^{-6} (the dynamic scales are larger). Also, the lengths of the EDM baselines from the adjustment differ from their directly measured values by 1.38×10^{-6} (the measured values are smaller).

The diagram is used by recognizing the importance of the various intersection points, marked by numbers. For example, point 1 illustrates the fact that if the semidiameter of the level ellipsoid was 6 378 125 m, the difference between the adjusted chord lengths and their given values would be zero; point 4 shows that with an $a=6\,378\,143$ m there would be no scale difference between WN1 and NWL-9D. Fourteen similar intersection points are listed in table 8.12 with weights and interpretation.

From the table it is immediately clear that if the weighted mean of the intersection points is taken from the "geometric" scalars (points 1 and 2), the "best" semidiameter is 6 378 125.8 m, whereas if the mean is taken from the "dynamic" lines (points 3-6), it is 6 378 142.0 m. The difference of some 16 m, or about 2.5 parts in a million, seems to be real but unexplained at this time. The combined weighted mean from points 1-6 is 6 378 141.7 m, whereas from all the points (1-14) it is 6 378 142.7 m.

For the solution reported here (WN14), the criterion for the scale is (5) above, i.e., the scale should correspond well to all geometric and dynamic information available at present. On the basis of the numbers above and of previously published parameters, $a=6\,378\,142$ m was selected. This then requires an adjustment in which the scale is defined, in addition to the SECOR, EDM, and C-band observations, through height constraints with the initial additive constant $\Delta a = -15$ m. As can be seen from figure 8.17, at this semidiameter the maximum scale difference expected between WN14 and any of the dynamic solutions is about 0.8×10^{-6} and with respect to the EDM about 1.4×10^{-6} or 1:700 000 which is about the average standard deviation of the EDM baselines. From this scale the resulting geoid undulations

$$N = h_{\text{WN14}} - \text{MSL} - \Delta N \quad (8.163)$$

where

$$\begin{aligned} \Delta N \text{ (meters)} = & -13 - 23.2 \cos \phi \cos \lambda \\ & - 2.9 \cos \phi \sin \lambda + 2.7 \sin \phi \end{aligned}$$

are consistent with dynamically computed ones when the following set of constants defining the gravity field of the level ellipsoid (Heiskanen and Moritz, 1967, p. 64) are used:

$$\begin{aligned} f &= 1/298.25 \\ \omega &= 0.729\,211\,514\,67 \times 10^{-4} \text{ rad sec}^{-1} \\ &\quad \text{(rotational velocity)} \\ a &= 6.378\,142 \text{ m} \\ W_0 &= 6\,263\,688.00 \text{ kGal m} \\ &\quad \text{(geopotential on the geoid)} \end{aligned}$$

Derived from these are the following:

$$\begin{aligned} \text{GM} &= 3.986\,009\,22 \times 10^{14} \text{ m}^3 \text{ sec}^{-2} \\ &\quad \text{(gravitational constant} \times \text{earth mass)} \\ \gamma_e &= 978.032\,26 \text{ cm sec}^{-2} \\ &\quad \text{(equatorial normal gravity)} \\ C_2^0 &= -1\,082.686\,3 \times 10^{-6} \\ &\quad \text{(second-degree harmonic)} \end{aligned}$$

All the above constants are in good agreement with their current best estimates. The parameters in equation (8.163) ($\Delta a = -13 \pm 0.7$ m, $u_0 = -23.2 \pm 0.9$ m, $v_0 = -2.9 \pm 0.8$ m, $w_0 = 2.7 \pm 1.2$ m) are the result of fitting an ellipsoid to the WN14 geoid, as was explained earlier in this section. They represent the size and the position of the best fitting level ellipsoid with respect to the reference ellipsoid (of the same flattening). In case of a good global station distribution the center of this level ellipsoid is the "geometric" center of the geoid. If this point is assumed to be identical with the center of mass, then the above coordinates are its coordinates with respect to the reference-ellipsoid origin and with opposite signs they can be used to shift the WN14 coordinates to the geocenter:

$$\begin{aligned} u \text{ (geocentric)} &= u_{\text{WN14}} + 23.2 \text{ m} \\ v \text{ (geocentric)} &= v_{\text{WN14}} + 2.9 \text{ m} \\ w \text{ (geocentric)} &= w_{\text{WN14}} - 2.7 \text{ m} \end{aligned} \quad (8.164)$$

8.5.2 Cartesian and Geodetic Coordinates

The Cartesian and geodetic coordinates resulting from the WN14 solution are listed

in table 8.14. Standard deviations of both types of coordinates are also given together with the parameters of the error ellipsoid (see sec. 8.4.7.4.). The first section of table 8.14 explains the format and the units used. Table 8.13 is a summary of the average standard deviations. The values are also broken down to the constituent networks. The notation is explained in the first section of table 8.14, except for the average standard deviation, which is $\sigma = \sqrt{(\sigma_u^2 + \sigma_v^2 + \sigma_w^2)/3}$. As can be seen, the weakest portion of the network is the MPS, and the strongest is the SECOR. The average standard deviation in a Cartesian coordinate is ± 3.9 m. See table 8.18 for comparison with solutions: (1) without the weighted height constraints (WN12) and (2) without chord constraints (WN16) (see sec. 8.5.3).

The full variance-covariance matrix cannot be presented here because of lack of space; however, the correlation coefficients ρ_{ij} (see eq. (8.154)) between the u, v, w coordinates of stations i and j (the off-diagonal 3×3 matrices) are listed in table 8.15 where $\rho_{ij} > 0.75$. The 3×3 correlation coefficient matrices with any element greater than 0.925 are marked by asterisks. Comparison with table 8.9 reveals that all of these station pairs have their relative positions constrained; thus such correlations are expected. Table 8.16 contains the correlation coefficients between the u, v, w coordinates of a given station, i.e., the 3×3 matrices along the diagonal of the full correlation coefficient matrix.

8.5.3 Comparisons With Geometric Information

In addition to solution WN14, two other adjustments were also performed with the same data. The only differences were that in one of them (WN12) the weighted height constraints were not applied; thus the scale is defined through the SECOR, EDM, and C-band data. In the other (WN16), the EDM and C-band lengths were not entered as weighted constraints; thus the scale is through the SECOR and the weighted height constraints. Coordinates from solution WN16

are not given; only some revealing information in a summary form, which can be compared with the WN14 results, is included.

Table 8.17 contains the differences between the adjusted and given chord lengths (table 8.11) from the three solutions. The lines originating from station 4742 (Kauai) are not listed (see sec. 8.5.1). When solutions WN14 and WN12 are compared, the effect of including the heights is not very significant. The average length discrepancy decreases to 0.48×10^{-6} for the EDM and 0.60×10^{-6} for the C-band, both numbers being within the noise level. At first glance the difference between WN14 and WN16 seems to be significant, since the average length discrepancy increases by about 4×10^{-6} or 1:250 000 for both types of observations. Close inspection, however, reveals that though the inclusion of the EDM and C-band chords in the solution improves the positions of stations 6111 (Wrightwood), 6065 (Hohenpeissenberg), and 4081 (Grand Turk), it does not otherwise contribute to the overall scale determination significantly. If the above-mentioned stations are left out of the comparison, the average length discrepancies in the WN16 solution decrease to 2.76×10^{-6} for the EDM and 1.81×10^{-6} for the C-band, both being within the noise level from WN14 (about 1×10^{-6}).

The above conclusion is also strengthened by the content of table 8.18, in which the average standard deviations of the coordinates and the heights from the three solutions are compared. It is seen that, while the inclusion of the weighted heights decreases the standard deviations significantly, the exclusion of the geometric scalars hardly changes the results.

Table 8.19 shows the results of a coordinate transformation between solutions WN14 and WN16. Inspection of the residuals given in the table shows that they are insignificant except probably at the stations already mentioned, though even there the discrepancies are within or near the noise level. That the chords 6003-6111 and 6016-6065 improve the positions of stations 6111 and 6065 (while the other chords have little effect on their

terminal stations) is not surprising, once it is recognized that these lines are too short to be determined well from observations on PAGEOS.

Table 8.20 contains the results of the transformation between WN14 and WN12. The effect of the missing height constraints is well recognizable both in the scale and in the residuals.

In the tables, the rotations, ω , ψ , and ϵ are about the w , v , and u axes, respectively. The unit in the variance-covariance matrix, for the elements corresponding to the rotations, is radian squared.

Table 8.21 shows a height analysis computed for the purpose of inspecting the height residuals from solution WN14, which, according to the explanation offered in section 8.5.1, are mostly the short-wavelength components (δN) of the geoid undulation. In the table, N_{OSUGC} denotes the quantity $h_{\text{WN14}} - \text{MSL} - dh$ where dh is computed with $u_0 = -23.2$ m, $v_0 = -2.9$ m, and $w_0 = 2.7$ m.

In case of a uniform global station distribution, the average value of $N_{\text{OSUGC}} - N_{\text{REF}}$ should be equal to the additive term from the best fit, $\Delta a = -13$ m. As is seen at the end of table 8.21, this number is -12.94 m. The root mean square value of the residuals is ± 6.42 m. The respective numbers from the WN12 solution (no weighted height constraints) are -1.24 and ± 13.45 m. From this, it seems that the semidiameter of the level ellipsoid best fitting the geoid (defined through the N_{WN12} undulations) is $6\,378\,153.8 \pm 13.5$ m, as opposed to that of the WN14 solution, $6\,378\,142.1 \pm 6.4$ m. The proximity of these values and their noise level are only indications that the "best" semidiameter of the level ellipsoid still needs to be determined; at the present time it can only be defined to fit some criteria, as in section 8.5.1.

Table 8.22 contains the results of an independent height comparison in which undulations (N) from the WN14 solution referred to the defined level ellipsoid are compared with those (N_V) from Vincent *et al.* (1972b). The quantity

$$N = h_{\text{WN14}} - \text{MSL} - \Delta N = N_{\text{OSUGC}} - \Delta a$$

The average difference $N - N_V$ taken over the stations where N_V is available is -0.3 m, and the rms of the residuals is ± 6.1 m. Similar comparisons with the WN12 solution show an average difference of -0.2 m and the rms of the residuals of ± 16.1 m.

8.5.4 Comparisons With Dynamic Solutions

Table 8.23 is a compilation of transformation parameters between the WN₁₄ (World Net) coordinates and those from the dynamic solutions NWL-9D, SAO Standard Earth III, GEM-4, and GSFC 73. The method of computing the parameters is described in Kumar (1972). In the table, the positive angles ω , ψ , and ϵ are counterclockwise rotations about the w , v , and u axes, respectively, as viewed from the end of the positive axis. The scale difference factor Δ is in units of ppm. In the transformations, the variances of both sets of the coordinates are taken into account. If the variances of the WN solution are taken as standard, the variances of the dynamic solutions are scaled by the weight factors indicated. These numbers are also indicative of the overoptimism over the quality of some of the published solutions. For example, a weight factor of 25 would indicate that the published standard deviations of a given solution need to be multiplied by $\sqrt{25} = 5$.

Tables 8.24 to 8.27 contain the variance-covariance matrices, the correlation coefficients, and the residuals after transformation for the solutions mentioned above.

As is seen, there is a good agreement between the translational elements Δu 's and Δv 's of the main (all stations included) dynamic solutions and a discrepancy of about 8.5 ± 1.7 m with respect to the geometric values (see eq. (8.164)). The largest discrepancy occurs in the Δw components, where there seems to be a 14.2 ± 2.8 m difference between the SAO Standard Earth III and the GEM-4 solutions. When the SAO Standard Earth III value is eliminated, all Δw 's, including the geometric one, are within the noise level. The weighted mean shifts from the main dynamic solutions (excluding Δw

from SAO Standard Earth III, or the coordinates of the geocenter with respect to the WN14 origin), are listed in table 8.28.

The quantity $r_0 = \sqrt{u_0^2 + v_0^2}$ is the distance of the WN14 origin from the rotation axis of the earth. Calculating the same number from the JPL-LS 37 coordinates of the Deep Space Network (stations DSN1=4711, DSN2=4712, DSN4=4714, DSN6=4742 and DSN7=4751) as given in Gaposchkin (1974), one gets $r_0 = 25.9 \pm 2.5$ m, which is nearest to the value calculated from the geometric fit.

The differences in scale between the dynamic solutions are significant (see fig. 8.17 for comparison). The largest discrepancy is between the SAO Standard Earth III and NWL-9D with $\Delta = (0.58 \pm 0.27) \times 10^{-6}$, which is larger than what one would expect from the noise. The other dynamic scales are within near noise level and, on the average, differ from the scale of the WN14 solution by $\Delta = (0.70 \pm 0.30) \times 10^{-6}$ or about one part in 1.4 million.

The largest discrepancies occur in the orientation of the various dynamic systems with respect to each other and to WN14. In the rotation about the w axis (ω), the largest difference occurs between the NWL-9D and the GSFC 73 solutions, where $\omega = 1''.1$, or about 34 m on the equator (fig. 8.18). The other differences are smaller but are significant. These rotations may be partly due to the definition of the zero meridian in the case of purely electronic systems (e.g., Doppler), partly to the various definitions of the vernal equinox in the star catalogs used, and also

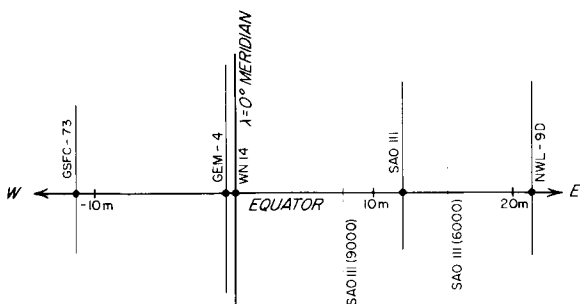


FIGURE 8.18.—Dynamic zero meridians relative to the WN14 zero meridian.

partly to its motion with respect to inertial space, in the case of camera observations. The latter alone requires a correction to the FK4 right ascensions amounting to $+0''.65$ at 1960.0, changing with a rate of $+1''.36$ per century (Martin and Van Flandern, 1970).

The rotations about the axes u and v are even more confusing. Figure 8.19 illustrates the situation at the pole. The weighted means of the dynamic solutions are $\psi = -0''.03 \pm 0''.50$ and $\epsilon = -0''.04 \pm 0''.02$. The discrepancy between the poles, as determined separately from the SAO Standard Earth III 6000 stations and then from the 9000 stations, is unexplained at this time. It is interesting to note that the weighted mean pole and zero meridian positions computed from the dynamic solutions hardly differ from those of the WN14 solution.

The only general conclusion that one can draw from the rotation parameters is that the coordinate systems used in the dynamic solutions need to be more carefully defined and conditions enforcing these definitions

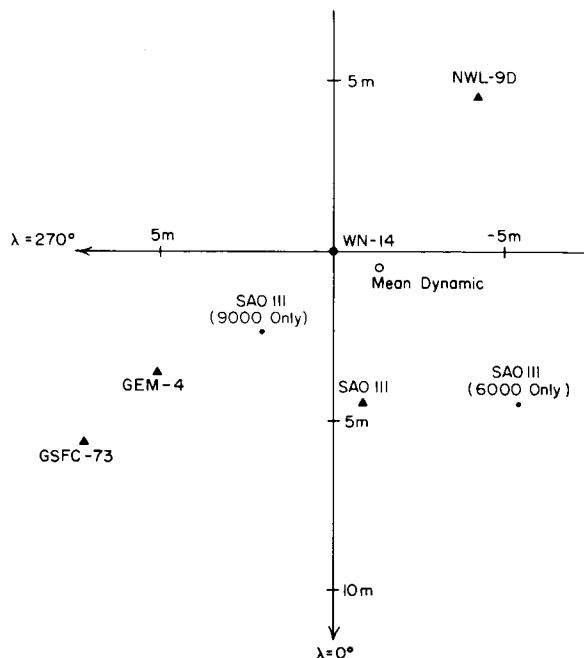


FIGURE 8.19.—Dynamic pole positions relative to the WN14 pole.

more strongly applied than is evidenced from the solutions discussed.

8.5.5 Comparisons With Geodetic Datums

In a planning document prepared in 1966, it was shown that the various countries in the world use or have used 90 different geodetic datums in their mapping activities (Mueller, 1966). Since many of these datums have been tied together with ground survey, it is possible to combine them into about 20 large and/or independent datum blocks (fig. 8.20). The original OSU goal, outlined in section 8.1, called for at least three well-distributed tracking stations on each of these datum blocks. As of the writing of this report, this goal has been accomplished only on the following datums: Australian (3 stations), European 50 (16 stations, but marginal accuracy), North American 1927 (21 stations), and South American 1969 (10 stations).

On the Tokyo datum there are also several stations, but only one of them is independently determined in the WN14 solution. In order to meet the original requirement, additional stations or observations will have to be included in future solutions in the following general areas in order of preference: Europe, the Soviet Union, India, Japan, the Philippines, the Cape (South Africa), Madagascar, New Zealand, North Africa. Observations have already been taken and will become available within reasonable time in Europe and North Africa.

Relationships between the geodetic datums and the WN14 coordinate system, as reflected from the data included, are summarized in table 8.29. Parameter values given only to the nearest meter represent estimated values, while the other parameters are the results of regular seven parameter transformations.

If the geodetic coordinates referred to in any of the datums listed are to be shifted to the "best" geocenter, subtract from the Cartesian datum coordinates the values Δu , Δv , Δw listed and add 16 m, 5 m, and -3 m (or other values from table 8.28), respectively.

The variance-covariance matrix, the coefficients of correlation, and the residuals after adjustment for those datum blocks where three or more stations are available are shown in tables 8.30 to 8.36. The datum with the poorest fit is the European 50, followed by the South American 1969.

8.6 SUMMARY AND CONCLUSIONS

The OSU WN14 solution is a geometric adjustment for the coordinates of 158 tracking stations.

The coordinate system in which the coordinates are presented is oriented towards the Greenwich Mean Astronomical Meridian (u axis) and the Conventional International Origin (w axis), both as defined by the Bureau International de l'Heure. The v axis forms a right-handed system with the u and w , and with u defines the average geodetic equator. The coordinates of the origin with respect to the geocenter are suggested to be

$$u_{WN14}^0 + 16 \text{ m}, v_{WN14}^0 = 5 \text{ m}, w_{WN14}^0 = -3 \text{ m}$$

The scale in the solution is defined through SECOR observations and weighted height constraints. Chord distances derived from C-band radar observations and from electronic distance measurements (geodimeter and tellurometer) are also included as weighted constraints, but they seem to have little or no effect. The main reason that the SECOR observations are successfully utilized (perhaps for the first time) is that the ill-conditioning arising in quadrilateration when the four stations lie near a plane (which is always the case with SECOR) is eliminated by "pinning down" the stations to the geoid through the height constraints and the directions defined by the camera observations from the collocated stations.

The scale in the solution is such that when the coordinates are transformed to a geocentric rotational ellipsoid of $a = 6\,378\,142$ m and $1/f = 298.25$, they produce geoid undulations consistent with dynamically determined ones with $GM = 3.986\,009\,2 \times 10^{14} \text{ m}^3 \text{ sec}^{-2}$ and $\gamma_e = 978.032\,6 \text{ cm sec}^{-2}$.

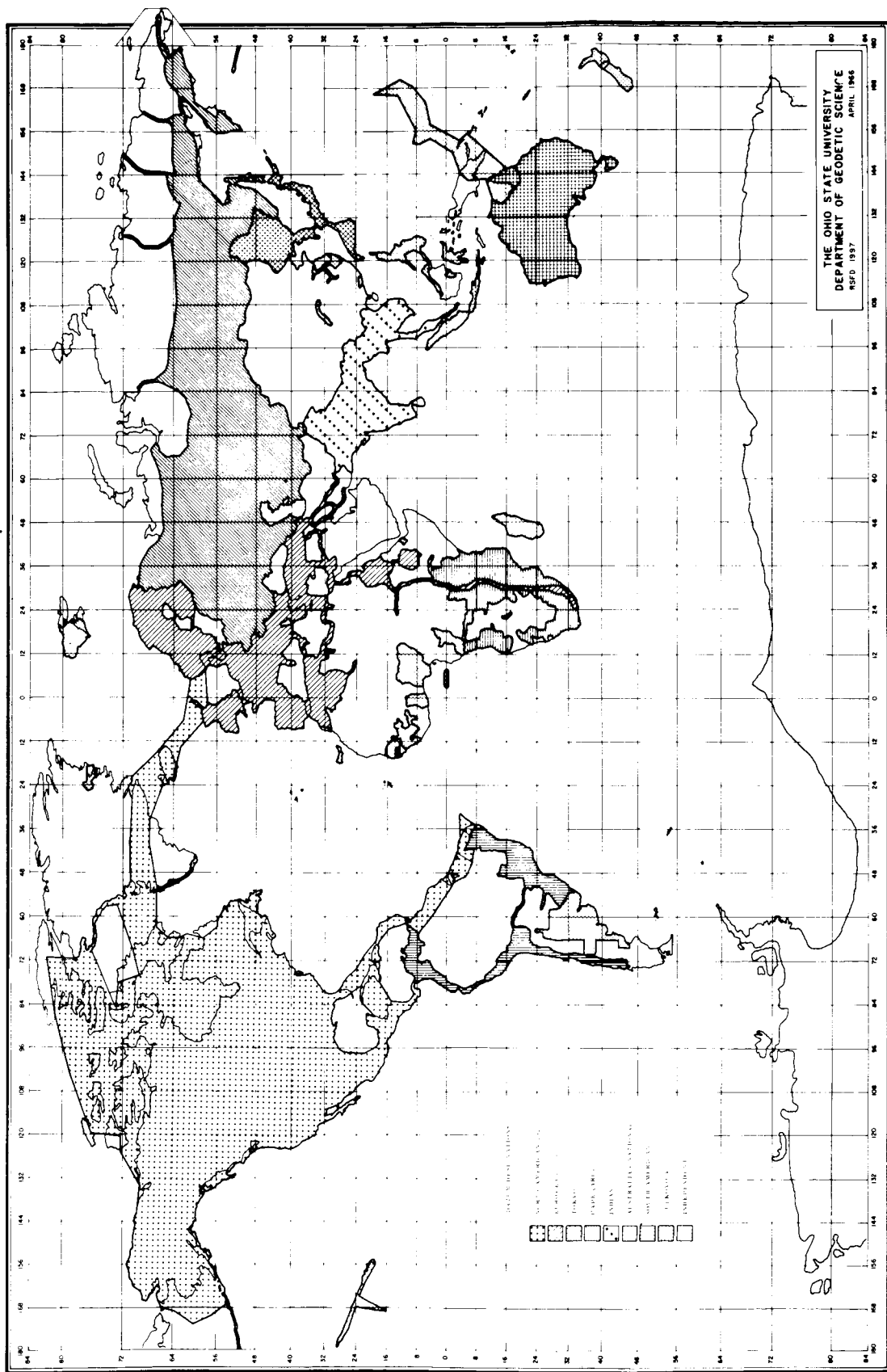


FIGURE 8.20.—Major geodetic datum blocks.

The consistency of the solution is represented by the average standard deviation in a Cartesian coordinate of ± 3.9 m and in height of ± 2.9 m. The correlations between the coordinates of a given station and those between different stations are low, except at those nearby stations where the relative positions are maintained at the surveyed values with weighted constraints.

Comparisons with the EDM chords show an average agreement of 1:575 000 with 1:2 700 000 at best and 1:330 000 at worst. The average agreement with the C-band chords is 1:1 000 000, varying between 1:2 100 000 and 1:525 000. The scale agreement with the dynamic solutions on the average is 1:3 600 000, with 1:1 000 000 at worst and 1:5 900 000 at best.

Comparisons with coordinates from dynamic satellite solutions show significant inconsistencies in the orientation of the coordinate systems, which need to be resolved. The residuals after transformation are all within the noise level.

Table 8.37 is a summary of the Cartesian coordinates from solutions WN12 and WN14. As was mentioned earlier, the WN12 solution differs from the WN14 only in that in it the heights are not constrained. The scale in

WN12 is such that when the coordinates are transformed to a geocentric rotational ellipsoid of $a = 6\,378\,154$ m and $1/f = 298.25$, they produce geoid undulations consistent with dynamically determined ones with $GM = 3.986\,008\,9 \times 10^{14} \text{ m}^3 \text{ sec}^{-2}$ and $\gamma_e = 978.028\,5 \text{ cm sec}^{-2}$. For various comparisons between solutions WN12 and WN14 see tables 8.17, 8.18, and 8.20.

Comparisons with geoid undulations from satellite and surface gravimetric solutions in the case of the WN14 solution show an rms residual of ± 6.1 m, with an average of only -0.3 m. Similar comparison with the WN12 solution, where the heights are not constrained, shows that the rms of the residuals is ± 16.1 m and the average -0.2 m.

Comparisons with survey coordinates result in satisfactory transformation parameters for the NAD 1927, the Australian, and the South American 1969 datums and marginal ones for the European 1950 datum. In order to fulfill the "three station per datum" general requirement for the other major datum blocks, additional observations are needed from Europe, the Soviet Union, India, Japan, the Philippines, South Africa, Madagascar, New Zealand, and North Africa, in order of preference.

APPENDIX

TABLE 8.1.—Contributors to the NGSP Report, OSU

	1965		1966		1967		1968		1969		1970		1971		1972		1973		Contributions to Department of Geo- detic Science Reports ^a	Degrees earned		
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II		BS	MS	PhD
Administrative assistants																						
Miller, J. R.		x	x	x	x	x	x	x														
Preston, J. C.		x	x	x	x	x	x	x														
Tesfai, I.							x	x	x	x	x											
Rist, E.												x	x	x	x	x	x					
Student assistants or associates																						
Preuss, H. D.		x	x															70		x	x	
Krakiwsky, E. J.		x	x	x	x	x	x	x										86,87,88,114		x	x	x
Ferrier, J.			x	x														87,88				
Pope, A. J.				x														86			x	
Hotter, F. D. ^b				x	x													82			x	
Blaha, G.					x	x	x	x	x	x	x	x	x					87,140,148,150				x
Reilly, J. P.						x	x	x	x	x	x	x	x	x	x	x		88,125,140,187,190,193,199		x		
Schwarz, C. R.						x	x	x	x	x	x	x						118,125,140,147,190			x	x
Hornbarger, D. H. ^b						x	x											106			x	
Veach, J. P. ^b						x	x											110			x	
Gross, J. ^b						x	x											100			x	
Arur, M. G. ^b										x	x							139			x	
Whiting, M.												x	x	x	x			188,190,199		x	x	
Kumar, M.													x	x	x	x		184,193,195,196,199			x	
Soler, T.													x	x	x	x		187,195,199				
Tsimis, E.													x	x	x			185,191			x	
Joshi, C. S. ^b															x			192			x	
Research associate Saxena, N. K.											x	x	x	x	x	x		177,193,199				

^a Index to reports of the Department of Geodetic Science produced under this project.^b Students receiving financial assistance other than direct fellowships.

Report No.	Author	Report No.	Author	Report No.	Author
70	Preuss (1966)	114	Krakiwsky (1968)	185	Tsimis (1972)
71	Mueller (1966)	118	Schwarz (1968)	187	Mueller <i>et al.</i> (1972)
82	Hotter (1967)	125	Mueller <i>et al.</i> (1969)	188	Mueller and Whiting (1972)
86	Krakiwsky and Pope (1967)	139	Arur (1970)	190	Reilly <i>et al.</i> (1972)
87	Krakiwsky <i>et al.</i> (1968)	140	Mueller <i>et al.</i> (1970b)	191	Tsimis (1973)
88	Krakiwsky <i>et al.</i> (1967)	147	Schwarz (1970)	193	Mueller <i>et al.</i> (1973a)
93	Mueller (1967)	148	Blaha (1971)	195	Mueller <i>et al.</i> (1973b)
100	Gross (1968)	150	Blaha (1971)	196	Mueller and Kumar (1973)
106	Hornbarger (1968)	177	Saxena (1972)	199	Mueller <i>et al.</i> (1973c)
110	Veach (1968)	184	Kumar (1972)		

TABLE 8.2.—*Summary of Observed Satellites: Index to Descriptions of Instruments Used in Producing Data for OSU Work*

	Designation	Responsible group	Description given in chapter
1. Satellite instrumentation			
ANNA 1B -----	62 60 1	APL ^a	2
Courier 1B -----	60 13 1		
Dash 2 -----	63 30 4		
Echo 1 rocket -----		NASA ^b	5
Echo 1 rocket -----	60 09 2		
Echo 2 -----		NASA	5
Elektron 3 -----	64 38 1		
Explorer 9 -----	61 04 1		
Explorer 19 -----	63 53 1		
GEOS-1 -----	65 89 1	APL	
GEOS-2 -----	68 02 1	APL	2
Midas 4 -----	61 28 1		
Midas 7 -----	63 30 1		
PAGEOS -----	66 56 1	NASA	5
RCS -----	65 34 3		
Relay 1 -----	62 68 1		
SECOR (EGRS) -----	1967 65A	DOD/DMA ^c	3
Telstar 1 -----	62 20 1		
2. Ground instrumentation			
2.1 Cameras			
2.1.1 PC-1000 -----	-----	DOD/DMA	3
2.1.2 BC-4 -----	-----	NGS ^d	7
2.1.3 MOTS -----	-----	NASA	5
2.1.4 Baker-Nunn -----	-----	SAO ^e	9
2.1.5 Other -----	-----		
2.2 Radar			
2.2.1 C-band -----	-----	NASA/DMA	6
2.2.2 SECOR -----	-----	DOD/DMA	3

^a Applied Physics Laboratory.^b National Aeronautics and Space Administration.^c Department of Defense/Defense Mapping Agency.^d National Geodetic Survey.^e Smithsonian Astrophysical Observatory.

TABLE 8.3.—Survey Information of Observation Stations

NO	STATION NAME	DATUM	SURVEY COORDINATE S ²		MSL ³ (M)	INSTR. HEIGHT ⁴ (M)	INSTR. TYPE	SOURCE CODE
			LATITUDE	LONGITUDE				
1021	BLOSSOM POINT	29	38° 25' 49.628	282° 54' 48.225	7.0	1.23	MOTS 40	1
1022	FORT MYERS	29	26 32 51.891	278 8 3.926	21.0	1.23	MOTS 40	1
1030	GOLDSTONE	29	35 19 48.088	243 6 2.730	907.0	1.71	MOTS 40	1
1032	ST. JOHN'S	29	47 44 29.739	307 16 43.369	106.0	1.95	MOTS 40	1
1033	FAIRBANKS	29	64 52 19.721	212 9 47.168	185.0	2.18	MOTS 40	2
1034	E. GRAND FORKS	29	48 1 21.403	262 59 21.561	256.0	252.58	MOTS 40	1
1042	ROSHAN	29	35 12 6.926	277 7 41.008	916.0	1.69	MOTS 40	1
3106	ANTIGUA	29	17 8 52.685	298 12 37.552	8.0	*	PC-1000	1
3334	STONEVILLE	29	33 25 31.950	269 5 11.350	44.0	*	PC-1000	1
3400	COLORADO SPRINGS	29	39 0 22.440	255 7 1.010	2191.0	*	PC-1000	1
3401	BEDFORD	29	42 27 17.530	288 43 35.033	89.0	1.32	PC-1000	1
3402	SEMMES	29	30 46 49.350	271 44 52.370	80.0	*	PC-1000	1
3404	SWAN ISLAND	*	17 24 16.570	276 3 29.870	*	*	PC-1000	1
3405	GRAND TURK	29	21 25 46.796	288 51 13.786	8.0	*	PC-1000	1
3406	CURACAO	41	12 5 26.843	291 9 45.803	-4.0	1.25	PC-1000	1
3407	TRINIDAD	41	10 44 35.844	298 23 25.652	237.0	1.25	PC-1000	1
3413	NATAL	41	-5 54 56.253	324 49 57.605	63.0	*	PC-1000	1
3414	BRASILIA	41	-15 51 35.540	312 6 2.679	1059.0	1.14	PC-1000	2
3431	ASUNCION	41	-25 18 56.192	302 25 15.376	162.0	1.65	PC-1000	2
3476	PARAMARIBO	41	5 26 54.645	304 47 44.226	8.6	1.25	PC-1000	2
3477	BOGOTA	41	4 49 2.379	285 55 35.482	2586.0	1.25	PC-1000	2
3478	MANAUS	*	-3 8 44.820	300 0 59.620	*	*	PC-1000	3
3499	QUITO	41	-0 5 50.468	281 34 49.212	2706.4	83.60	PC-1000	1
3648	HUNTER AFB	29	32 0 5.868	278 50 46.359	17.0	1.32	PC-1000	1
3657	ABERDEEN	29	39 28 18.971	283 55 44.780	6.0	1.32	PC-1000	1
3861	HOMESTEAD	29	25 30 24.690	279 36 42.690	16.0	0.20	PC-1000	1
3902	CHEYENNE	29	41 7 59.200	255 8 2.650	1890.0	1882.20	PC-1000	1
3903	HERNDON	29	38 59 32.360	282 40 21.200	169.0	168.00	PC-1000	1
4050	PRETORIA	3	-25 56 35.340	28 21 29.950	1592.0	1584.00	MPS-25	2
4061	ANTIGUA	29	17 8 34.780	298 12 24.470	48.0	42.30	FPQ-6	2
4081	GRAND TURK	29	21 27 43.490	288 52 3.050	42.0	36.00	TPQ-18	2
4082	MERRITT ISLAND	29	28 25 27.930	279 20 7.380	21.0	11.25	TPQ-18	2
4280	VANDENBERG AFB	29	34 39 57.130	239 25 10.430	89.0	123.00	TPQ-18	2
4740	BERNDA	29	32 20 52.300	295 20 44.300	11.0	19.86	FPS-16	2
4742	KAUAI	33	22 7 35.830	200 19 53.960	1151.0	1155.00	FPS-16	2
5001	HERNDON	29	38 59 37.697	282 40 16.705	129.0	127.80	SECOR	1
5201	MOSES LAKE	29	47 11 5.916	240 39 50.463	358.0	368.92	SECOR	1
5410	SAND ISLAND	27	28 12 32.061	182 37 49.531	6.0	6.10	SECOR	2
5648	FORT STEWART	29	31 55 18.405	278 26 0.260	34.0	27.80	SECOR	1
5712	PARAMARIBO	41	5 26 59.817	304 47 44.990	12.0	21.50	SECOR	1
5713	TERCEIRA	17	38 45 36.725	332 54 21.064	56.0	56.00	SECOR	1
5715	DAKAR	50	14 44 41.008	342 30 52.935	27.0	27.50	SECOR	1
5717	FORT LAMY	1	12 7 49.300	15 2 6.148	320.0	298.50	SECOR	1
5720	ADDIS ABABA	1	8 46 9.479	38 59 49.196	1881.0	1889.40	SECOR	1
5721	MASHAD	16	36 14 30.404	59 37 40.105	962.0	994.40	SECOR	1
5722	DIEGO GARCIA	*	-7 20 57.440	72 28 31.570	*	6.10	SECOR	2
5723	CHIANG MAI	*	18 47 26.213	99 00 14.0	*	310.80	SECOR	1
5726	ZAMBOANGA	26	6 55 26.213	122 4 3.558	14.0	13.30	SECOR	2
5730	MAKE ISLAND	49	19 17 24.100	166 36 41.206	8.0	8.10	SECOR	1

TABLE 8.3.—(Cont'd)

STATION NO	NAME	DATUM		SURVEY COORDINATE S ²		MSL ³ (M)	INSTR. HEIGHT ⁴ (M)	INSTR. TYPE	SOURCE CODE
		CODE ¹		LATITUDE	LONGITUDE				
5732	PAGO PAGO	*				*	*	SECOR	1
5733	CHRISTMAS ISLAND	12	2 0	35.622	202 35	3.50	2.29	SECOR	1
5734	SHENYA	29	52 42	54.894	174 7	39.30	1.50	SECOR	1
5735	NATAL	41	-5 54	56.253	324 49	39.40	*	SECOR	1
5736	ASCENSION ISLAND	5	-7 58	15.220	345 35	74.00	4.32	SECOR	1
5739	TERCEIRA	17	38 45	36.311	332 54	56.10	4.25	SECOR	1
5744	CATANIA	16	37 26	40.831	15 2	11.80	4.17	SECOR	1
5907	WORTHINGTON	*				*	*	SECOR	
5911	BERNUDA	*				*	*	SECOR	
5912	PANAMA	*				*	*	SECOR	
5914	PUERTO RICO	*				*	*	SECOR	
5915	AUSTIN	*				*	*	SECOR	
5923	CYPRUS	*				*	*	SECOR	
5924	ROTA	*				*	*	SECOR	
5925	ROBERTS FIELD	*				*	*	SECOR	
5930	SINGAPORE	*				*	*	SECOR	
5931	HONG KONG	*				*	*	SECOR	
5933	DARWIN	*				*	*	SECOR	
5934	MANUS	*				*	*	SECOR	
5935	GUAM	*				*	*	SECOR	
5937	PALAU	*				*	*	SECOR	
5938	GUADALCANAL	*				*	*	SECOR	
5941	MAUI	*				*	*	SECOR	2
6001	THULE	29	76 30	3.411	291 27	206.00	1.50	BC-4	1
6002	BELTSVILLE	29	39 1	39.003	283 10	44.50	1.50	BC-4	1
6003	MOSES LAKE	29	47 11	7.132	240 39	368.74	1.50	BC-4A	1
6004	SHENYA	29	52 42	54.890	174 7	36.80	1.50	BC-4	1
6006	TRONSO	16	69 39	44.270	18 56	106.00	1.50	BC-4	2
6007	TERCEIRA	17	38 45	36.725	332 54	53.30	1.49	BC-4	1
6008	PARAMARIBO	41	5 26	55.325	304 47	18.38	1.49	BC-4	1
6009	QUITO	41	-0 5	50.468	281 34	2682.10	1.50	BC-4	1
6011	MAUI	33	20 42	38.561	203 44	3049.27	1.50	BC-4	4
6012	WAKE ISLAND I	49	19 17	23.227	166 36	3.50	1.50	BC-4	4
6013	KANDYA	46	31 23	30.140	130 52	65.90	1.50	BC-4	1
6015	MASHHAD	16	36 14	29.527	59 37	991.00	1.50	BC-4	1
6016	CATANIA	16	37 26	42.628	15 2	9.24	1.50	BC-4A	1
6019	VILLA DOLORES	41	-31 56	33.954	294 53	608.18	1.50	BC-4	2
6020	EASTER ISLAND	15	-27 10	39.213	250 34	231.0	1.50	BC-4	1
6022	TUTUILA	2	-14 20	12.216	189 17	5.34	1.50	BC-4A	1
6023	THURSDAY ISLAND	6	-10 35	8.037	142 12	62.0	1.50	BC-4	2
6031	INVERCARGILL	28	-46 25	3.491	168 19	0.90	1.49	BC-4	1
6032	CAVERSHAM	6	-31 50	28.992	115 58	26.30	*	BC-4	2
6038	SOCORRO ISLAND	23	18 43	44.930	249 2	23.20	1.50	BC-4	1
6039	PITCAIRN ISLAND	36	-25 4	7.146	229 53	339.40	1.50	BC-4	1
6040	COCOS ISLAND	1	-12 11	57.910	96 49	4.40	*	BC-4	2
6042	ADDIS ABABA	39	8 46	8.501	38 59	1886.46	1.52	BC-4	1
6043	CERRO SOMBRERO	20	-52 46	52.468	290 46	80.70	1.48	BC-4A	1
6044	HEARD ISLAND	20	-53 1	12.030	73 23	3.80	1.50	BC-4	1
6045	MAURITIUS	*	-20 13	50	57 25	149.40	*	BC-4	1

TABLE 8.3.—(Cont'd)

NO	STATION NAME	DATUM CODE ¹	SURVEY COORDINATES ²			MSL ³ (M)	INSTR. ⁴ (M)	INSTR. TYPE	SOURCE CODE
			LATITUDE	LONGITUDE	ELL. HGM				
6047	ZAMBOANGA	26	6 55 26.132	122 4 4.838	9.0	9.39	1.50	BC-4	2
6050	PALMER STATION	51	-64 46 33.980	295 56 37.040	16.0	16.44	1.58	BC-4	2
6051	MANSON STATION	*	-67 36 3.080	62 52 24.410	*	11.30	*	BC-4	2
6052	WILKES STATION	*	-66 16 45.120	110 32 4.610	*	*	1.50	BC-4	2
6053	MCMURDO STATION	10	-77 50 46.249	166 38 7.584	19.0	19.00	1.50	BC-4	1
6055	ASCENSION ISLAND	5	-7 58 16.634	345 35 32.764	71.0	70.94	1.50	BC-4	1
6059	CHRISTMAS ISLAND	12	2 0 35.622	202 35 21.962	3.0	2.75	1.50	BC-4A	1
6060	CULGOORA	6	-30 18 39.418	149 33 36.892	212.0	211.08	*	BC-4	2
6061	SOUTH GEORGIA IS.	43	-54 16 39.515	323 30 42.531	4.0	4.20	1.49	BC-4A	1
6063	DAKAR	50	14 44 44.228	342 30 55.594	26.0	26.30	1.50	BC-4A	1
6064	FORT LAMY	1	12 7 51.750	15 2 6.151	316.0	295.40	1.50	BC-4A	1
6065	HONENPEISENBERG	16	47 48 7.011	11 1 29.378	943.0	943.20	*	BC-4A	1
6066	WAKE ISLAND II	49	19 17 24.100	166 36 41.206	5.0	5.30	1.51	BC-4	1
6067	NATAL	41	-5 55 37.414	324 50 6.200	66.7	40.63	*	BC-4A	1
6068	JOHANNESBURG	3	-25 52 56.980	27 42 25.170	1531.8	1523.80	*	BC-4	4
6069	TRISTAN DA CUNHA	47	-37 3 26.257	347 40 53.555	25.0	24.80	*	BC-4	1
6072	CHIANG MAI	*	18 46 10	98 58 15	*	319.20	*	BC-4	1
6073	DIEGO GARCIA	*	-7 20 58.527	72 28 32.156	*	3.90	1.50	BC-4	2
6075	MAHE	42	-4 40 7.230	55 28 50.380	589.0	588.98	1.55	BC-4A	1
6078	PORT VILA	52	-17 41 46.956	168 17 57.921	15.0	15.20	1.50	BC-4	2
6111	WRIGHTWOOD I	29	34 22 54.537	242 19 9.484	2259.0	2284.30	1.50	BC-4	2
6122	POINT BARROW	29	71 18 49.882	203 21 20.720	-6.0	8.30	*	BC-4	2
6134	WRIGHTWOOD II	29	34 22 44.444	242 19 9.259	2173.0	2198.40	1.50	BC-4	2
7036	EDINBURG	29	26 22 45.443	261 40 9.033	66.0	59.59	1.11	MOTS 40	1
7037	COLUMBIA	29	38 53 36.068	267 47 42.120	273.0	272.68	1.11	MOTS 40	1
7039	BERNADA	29	32 21 48.790	295 20 32.460	23.0	31.18	1.13	MOTS 40	1
7040	SAN JUAN	29	18 15 26.216	294 0 22.174	59.0	49.70	1.07	MOTS 40	1
7043	GREENBELT	29	39 1 15.014	283 10 19.934	55.0	53.46	0.64	PTH-100	1
7045	DENVER	29	39 38 48.026	255 23 41.194	1796.0	1789.63	1.11	MOTS 40	1
7072	JUPITER	29	27 1 13.168	279 53 12.485	26.0	14.19	1.10	MOTS 40	1
7075	SUBURY	29	46 27 20.988	279 3 10.354	281.0	281.90	1.17	MOTS 40	1
7076	KINGSTON	29	18 4 31.980	283 11 26.528	486.0	445.90	1.07	MOTS 40	1
8009	WIPOLDER	16	52 0 9.240	4 22 21.230	21.0	24.70	*	BOUMERS	2
8010	ZIMMERWALD	16	46 52 40.300	7 27 58.070	900.0	903.44	*	SCHM H	1
8011	MALVERN	16	52 8 39.130	358 1 59.470	109.0	113.20	*	SCHM A	1
8015	HAUTE PROVENCE	16	43 56 1.140	5 42 49.280	651.0	659.00	*	SCHM D	2
8019	NICE	16	43 43 36.496	7 18 3.309	369.0	377.42	*	ANTARES	1
8030	MEUDON	16	48 48 25.354	7 13 51.339	155.0	165.46	*	REFR A	1
9001	ORGAN PASS	29	32 25 24.560	253 26 51.170	1650.0	1651.33	*	B-N	1
9002	OLIFANTSFONTEIN	3	-25 57 33.850	28 14 53.910	1552.1	1544.10	*	B-N	4
9004	SAN FERNANDO	16	36 27 51.370	353 47 42.090	-9.0	25.90	*	B-N	1
9005	TOKYO	46	35 40 11.078	139 32 28.222	60.0	59.77	*	B-N	1
9006	NAINI TAL	16	29 21 38.970	79 27 25.510	1827.0	1927.00	*	B-N	1
9007	AREQUIPA	41	-16 27 55.085	288 30 26.814	2486.0	2451.86	*	B-N	1
9008	SHIRAZ	16	29 38 18.112	52 31 11.445	1553.0	1597.40	*	B-N	2
9009	CURACAO	41	12 5 25.912	291 9 46.078	-2.0	8.70	*	B-N	1
9010	JUPITER	29	27 1 12.882	279 53 13.008	27.0	15.13	*	B-N	1
9011	VILLA DOLORES	41	-31 56 33.228	294 53 38.949	621.0	608.00	*	B-N	4
9012	MAUI	33	20 42 37.500	203 44 24.080	3026.1	3034.14	*	B-N	4

TABLE 8.3.—(Cont'd)

STATION NO	NAME	DATUM		SURVEY COORDINATES ²			MSL ³ (M)	INSTR. ⁴ HEIGHT ⁴ (M)	INSTR. TYPE	SOURCE CODE
		CODE ¹		LATITUDE	LONGITUDE	ELL. H(M)				
9021	MOUNT HOPKINS	29	31 41	26.670	249 7	2371.0	2382.00	*	B-N	1
9028	ADDIS ABABA	1	8 44	47.230	38 57	30.480	1925.20	*	B-N	2
9029	NATAL	41	-5 55	38.616	324 50	8.660	45.34	*	B-N	4
9031	COMODORO RIVADAVIA	41	-45 53	11.028	292 23	12.215	173.0	*	B-N	1
9051	ATHENS	16	37 58	40.310	23 46	42.890	186.54	*	GEO 36	1
9091	DIONYSOS	16	38 4	48.240	23 56	1.610	180.0	*	B-N	1
9424	COLD LAKE	29	54 44	33.858	249 57	26.389	467.00	*	B-N	1
9425	EDWARDS AFB	29	34 57	50.742	242 5	11.584	704.60	*	B-N	1
9426	HARESTUA	16	60 12	40.380	10 45	8.740	784.23	*	B-N	1
9427	JOHNSTON ISLAND	24	16 44	45.390	190 29	5.590	575.92	*	B-N	1
9431	RIGA	16	56 56	54.980	24 3	37.810	5.00	*	AFU 75	1
9432	UZHGOROD	*	48 38	4.560	22 17	57.880	8.00	*	AFU 75	1
DSN1	GOLDSTONE	29	35 23	22.346	243 9	5.262	189.00	*	85° H-D	4
DSN2	GOLDSTONE	29	35 17	59.854	243 11	43.414	1036.30	11.80	85° H-D	4
DSN4	GOLDSTONE	29	35 25	33.340	243 6	40.850	988.90	11.70	85° H-D	4
DSN6	TIDBINBILLA	6	-35 24	8.038	148 58	48.206	1031.80	15.50	210° A-E	4
DSN7	JOHANNESBURG	3	-25 53	21.150	27 41	8.530	656.08	15.08	85° H-D	4
							1391.00	13.00	85° H-D	4

* INSUFFICIENT DATA

1 REFER TO TABLE 8.4

2 GEODETIC COORDINATES OF THE INSTRUMENTAL REFERENCE POINT (OPTICAL/ELECTRONIC CENTER, ETC.) ON THE LOCAL GEODETIC DATUM

3 MEAN SEA LEVEL HEIGHT OF THE INSTRUMENTAL REFERENCE POINT

4 HEIGHT OF INSTRUMENTAL REFERENCE POINT ABOVE SURVEY MONUMENT

NOTE : ZERO IN THE LAST DIGIT MAY INDICATE THAT THE DIGIT IS UNKNOWN.

TABLE 8.4.—*Geodetic Datums*

Code	Datum	Ellipsoid	Origin	Latitude	Longitude
1 ----	Adindan (Ethiopia)	Clarke 1880	STATION Z5 ADINDAN	22°10'07"110	31°29'21"608
2 ----	American Samoa 1962	Clarke 1866	BETTY 13 ECC	-14°20'08"341	189°17'07"750
3 ----	Arc-Cape (South Africa)	Clarke 1880	Buffelsfontein	-33°59'32"000	25°30'44"622
4 ----	Argentine	International	Campo Inchauspe	-35°58'17"	297°49'48"
5 ----	Ascension Island 1958	International	Mean of three stations	-07°57'	345°37'
6 ----	Australian Geodetic	Australian National	Johnston Memorial Cairn	-25°56'54"55	133°12'30"08
7 ----	Bermuda 1957	Clarke 1866	FT. GEORGE B 1937	32°22'44"360	295°19'01"890
8 ----	Berne 1898	Bessel	Berne Observatory	46°57'08"660	07°26'22"335
9 ----	Betio Island, 1966	International	1966 SECOR ASTRO	01°21'42"03	172°55'47"90
10 ----	Camp Area Astro 1961-62 USGS	International	CAMP AREA ASTRO	-77°50'52"521	166°40'13"753
11 ----	Canton Astro 1966	International	1966 CANTON SECOR ASTRO	-02°46'28"99	188°16'43"47
12 ----	Christmas Island Astro 1967	International	SAT.TRI.STA. 059 RM3	02°00'35"91	202°35'21"82
13 ----	Chua Astro (Brazil-Geodetic)	International	CHUA	-19°45'41"16	311°53'52"44
x4 ----	Corrego Alegre (Brazil-Mapping)	International	CORREGO ALEGRE	-19°50'15"140	311°02'17"250
15 ----	Easter Island 1967 Astro	International	SATRIG RM No. 1	-27°10'39"95	250°34'16"81
16 ----	European	International	Helmert Tower	52°22'51"45	13°03'58"74
17 ----	Graciosa Island (Azores)	International	SW BASE	39°03'54"934	331°57'36"118
18 ----	Gizo, Provisional DOS	International	GUX 1	-09°27'05"272	159°58'31"752
19 ----	Guam	Clarke 1866	TOGCHA LEE NO. 7	13°22'38"49	144°45'51"56
20 ----	Heard Astro 1969	International	INTSATRIG 0044 ASTRO	-53°01'11"68	73°23'22"64
21 ----	Iben Astro, Navy 1947 (Truk)	Clarke 1866	IBEN ASTRO	07°29'13"05	151°49'44"42
22 ----	Indian	Everest	Kalianpur	24°07'11"26	77°39'17"57
23 ----	Isla Socorro Astro	Clarke 1866	Station 038	18°43'44"93	249°02'39"28
24 ----	Johnston Island 1961	International	JOHNSTON ISLAND 1961	16°44'49"729	190°29'04"781
25 ----	Kusaie, Astro 1962, 1965	International	ALLEN SODANO LIGHT	05°21'48"80	162°58'03"28
26 ----	Luzon 1911 (Philippines)	Clarke 1866	BALANCAN	13°33'41"000	121°52'03"000
27 ----	Midway Astro 1961	International	MIDWAY ASTRO 1961	28°11'34"50	182°36'24"28
28 ----	New Zealand 1949	International	PAPATAHI	-41°19'08"900	175°02'51"000

TABLE 8.4.—(Cont'd)

Code	Datum	Ellipsoid	Origin	Latitude	Longitude
29 ----	North American 1927	Clarke 1866	MEADES RANCH	39°13'26".686	261°27'29".494
30 ----	NAD 1927 (Cape Canaveral) ^a	Clarke 1866	CENTRAL	28°29'32".364	279°25'21".230
31 ----	NAD 1927 (White Sands) ^a	Clarke 1866	KENT 1909	32°30'27".079	253°31'01".306
32 ----	Old Bavarian	Bessel	Munich	48°08'20".000	11°34'26".483
33 ----	Old Hawaiian	Clarke 1866	OAHU WEST BASE	21°18'13".89	202°09'04".20
34 ----	Ordinance Survey G.B. 1936	Airy	Herstmonceux	50°51'55".271	00°20'45".882
35 ----	Pico de las Nieves (Canaries)	International	PICO DE LAS NIEVES	27°57'41".273	344°25'49".476
36 ----	Pitcairn Island Astro	International	PITCAIRN ASTRO 1967	-25°04'06".97	229°53'12".17
37 ----	Potsdam	Bessel	Helmert Tower	52°22'53".954	13°04'01".153
38 ----	Provisional S. American 1956	International	LA CANOA	08°34'17".17	296°08'25".12
39 ----	Provisional S. Chile 1963	International	HITO XVIII	-53°57'07".76	291°23'28".76
40 ----	Pulkovo 1942	Krassovski	Pulkovo Observatory	59°46'18".55	30°19'42".09
41 ----	South American 1969	South American 1969	CHUA	-19°45'41".653	311°53'55".936
42 ----	Southeast Island (Mahe)	Clarke 1880		-04°40'39".460	55°32'00".166
43 ----	South Georgia Astro	International	ISTS 061 ASTRO POINT 1968	-54°16'38".93	323°30'43".97
44 ----	Swallow Islands (Solomons)	International	1966 SECOR ASTRO	-10°18'21".42	166°17'56".79
45 ----	Tananarive	International	Tananarive Observatory	-18°55'02".10	47°33'06".75
46 ----	Tokyo	Bessel	Tokyo Observatory (old)	35°39'17".51	139°44'40".50
47 ----	Tristan Astro 1968	International	INTSATRIG 069 RM No. 2	-37°03'26".79	347°40'53".21
48 ----	Viti Levu 1916 (Fiji)	Clarke 1880	MONAVATU (latitude only)	-17°53'28".285	
			SUVA (longitude only)		178°25'35".835
49 ----	Wake Island, Astronomic 1952	International	ASTRO 1952	19°17'19".991	166°38'46".294
50 ----	Yof Astro 1967 (Dakar)	Clarke 1880	YOF ASTRO 1967	14°44'41".62	342°30'52".98
51 ----	Palmer Astro 1969	International	ISTS 050	64°40'25".71	295°56'39".53
52 ----	Eftate	International	Belle Vue IGN	-17°44'17".400	168°20'33".250

^a Local datums of special purpose, based on NAD 1927 values for the origin stations.

TABLE 8.5—*Basic Information on the OSU Solutions (Networks)*

OSU solution (network)	No. of stations	No. of observations	Number of constraints used						σ_0 ($^{\circ}$)	Refer- ence ($^{\circ}$)	Figure
			Origin	Relative position	Scale (length)	Station position	Height	Directional			
MPS ^a -----	66	28 774	Inner	9	7	-----	63	-----	1.07	188	8.1,2,3
BC ^b -----	49	30 302	Inner	2	7	-----	48	-----	2.80	193	8.4
SECOR ^c ----	50	28 844	Inner	14	-----	-----	37	9	1.37	195	8.5
SA ^d -----	14	2 524	Inner	3	1	-----	14	-----	2.50	196	8.6
WN ^e -----	158	90 444	Inner	43	11	-----	158	-----	1.02	199	8.7

^a MPS includes 14 PC-1000 stations, 15 MOTS-40 stations, 1 PTH-100 station, 7 C-band stations, 6 European stations (8000 series), and 23 SAO stations (9000 series).

^b BC includes all 49 stations of BC-4 Worldwide Geometric Satellite Network.

^c SECOR includes 37 SECOR stations of the Equatorial Network and 13 collocated BC-4 camera stations.

^d SA includes 9 PC-1000 stations of South American Densification Net and 5 BC-4 stations.

^e WN includes all the above-mentioned four networks, namely, MPS (less one C-band station: 4742), BC, SECOR, and SA.

^f A posteriori standard deviation of unit weight.

^g OSU Department of Geodetic Science Report Number.

TABLE 8.6.—*Summary of Observation Types*

Instrument	NASA series no.	Satellite observed	OSU network where used	Data source
MOTS -----	1000	GEOS-1	MPS	NSSDC ^a
PC-1000 -----	3000	GEOS-1	MPS	NSSDC
PC-1000				
So. America ---	3000	ECHO 1, 2 PAGEOS GEOS-2	SA	DMA/Aerospace Center ^b
C-band radar ----	4000	GEOS-2	MPS	NASA/Wallops Flight Center
SECOR -----	5000	SECOR (EGRS)	SECOR	DMA/Topographic Center
BC-4 -----	6000	PAGEOS	BC, SA	NGS ^c , NSSDC
Special				
optical -----	7000	GEOS-1	MPS	NSSDC
International				
optical -----	8000	GEOS-1, 2 PAGEOS ECHO 1, 2	MPS	SAO ^d
Smithsonian				
optical -----	9000	ANNA 1B Courier 1B Dash 2 ECHO 1 rocket Elektron 3 Explorer 9, 19 MIDAS 4, 7 RCS, Relay 1 Telstar 1	MPS	SAO

^a National Space Science Data Center.

^b Defense Mapping Agency.

^c National Geodetic Survey.

^d Smithsonian Astrophysical Observatory.

TABLE 8.7a.—*Summary of Simultaneous Observations
by Line (MPS Network)*

Line station-station	No. of pairs	Line station-station	No. of pairs
1021-1022	47	1030-1042	34
1021-1030	11	1030-3401	4
1021-1032	4	1030-3402	22
1021-1034	35	1030-3404	4
1021-1042	39	1030-3657	6
1021-3106	6	1030-3861	12
1021-3401	25	1030-3903	6
1021-3402	17	1030-7036	94
1021-3405	22	1030-7037	75
1021-3406	13	1030-7043	20
1021-3407	6	1030-7045	98
1021-3648	5	1030-7072	10
1021-3657	36	1030-7075	35
1021-3861	13	1032-1042	3
1021-7036	24	1032-3401	3
1021-7037	41	1032-7043	6
1021-7039	6	1032-7072	1
1021-7040	29	1033-1034	13
1021-7043	59	1033-7045	9
1021-7045	11	1033-9425	10
1021-7072	10	1034-1042	117
1021-7075	31	1034-3334	4
1021-9001	14	1034-3400	6
1021-9010	24	1034-3401	33
1022-1030	60	1034-3402	24
1022-1034	78	1034-3404	4
1022-1042	127	1034-3648	5
1022-3106	31	1034-3657	15
1022-3400	5	1034-3861	27
1022-3401	81	1034-3902	5
1022-3402	62	1034-3903	6
1022-3404	53	1034-7036	51
1022-3405	24	1034-7037	163
1022-3406	54	1034-7039	12
1022-3407	4	1034-7040	4
1022-3648	28	1034-7043	24
1022-3657	50	1034-7045	84
1022-3861	114	1034-7072	14
1022-3903	6	1034-7075	36
1022-7036	109	1034-7076	6
1022-7037	91	1034-9001	51
1022-7039	52	1034-9010	49
1022-7040	90	1034-9424	20
1022-7043	88	1034-9425	63
1022-7045	43	1042-3106	12
1022-7072	221	1042-3400	8
1022-7075	31	1042-3401	26
1022-7076	44	1042-3402	46
1030-1033	10	1042-3404	16
1030-1034	97	1042-3406	15

TABLE 8.7a.—(Cont'd)

Line station-station	No. of pairs	Line station-station	No. of pairs
1042-3648 -----	5	3401-7039 -----	11
1042-3657 -----	7	3401-7040 -----	16
1042-3861 -----	15	3401-7043 -----	39
1042-3903 -----	6	3401-7072 -----	39
1042-7036 -----	19	3401-7076 -----	22
1042-7037 -----	86	3402-3405 -----	6
1042-7040 -----	22	3402-3406 -----	6
1042-7043 -----	51	3402-3648 -----	6
1042-7045 -----	35	3402-3657 -----	23
1042-7072 -----	34	3402-3861 -----	42
1042-7075 -----	53	3402-3902 -----	4
1042-7076 -----	5	3402-7036 -----	23
1042-9001 -----	13	3402-7037 -----	22
1042-9009 -----	7	3402-7039 -----	10
1042-9010 -----	20	3402-7040 -----	6
1042-9424 -----	7	3402-7043 -----	20
1042-9425 -----	19	3402-7072 -----	13
3106-3401 -----	14	3402-7076 -----	8
3106-3402 -----	10	3404-3401 -----	14
3106-3404 -----	13	3404-3402 -----	17
3106-3405 -----	7	3404-3405 -----	4
3106-3406 -----	41	3404-3406 -----	7
3106-3407 -----	23	3404-3407 -----	5
3106-3648 -----	18	3404-3648 -----	12
3106-3657 -----	4	3404-3657 -----	7
3106-3861 -----	10	3404-3861 -----	29
3106-7039 -----	16	3404-7037 -----	9
3106-7040 -----	64	3404-7039 -----	6
3106-7043 -----	10	3404-7040 -----	28
3106-7072 -----	20	3404-7043 -----	7
3106-7076 -----	5	3404-7072 -----	3
3334-3400 -----	4	3404-7076 -----	4
3334-3402 -----	7	3405-3406 -----	7
3334-3404 -----	4	3405-3407 -----	12
3334-7036 -----	12	3405-3657 -----	12
3334-7037 -----	2	3405-3861 -----	6
3334-7045 -----	4	3405-7036 -----	9
3400-3902 -----	6	3405-7037 -----	6
3400-7036 -----	13	3405-7039 -----	5
3400-7037 -----	3	3405-7040 -----	19
3400-7045 -----	13	3405-7043 -----	13
3401-3402 -----	17	3405-7072 -----	6
3401-3406 -----	9	3406-3407 -----	19
3401-3407 -----	7	3406-3861 -----	23
3401-3648 -----	9	3406-3903 -----	5
3401-3657 -----	25	3406-7036 -----	11
3401-3861 -----	37	3406-7037 -----	5
3401-3903 -----	4	3406-7039 -----	21
3401-7036 -----	10	3406-7040 -----	31
3401-7037 -----	12	3406-7043 -----	3

TABLE 8.7a.—(Cont'd)

Line station-station	No. of pairs	Line station-station	No. of pairs
3406-7072	25	7037-7072	24
3406-7076	19	7037-7075	48
3407-3657	6	7037-7076	29
3407-3861	14	7037-9001	27
3407-7039	4	7037-9009	6
3407-7040	31	7037-9010	57
3407-7043	7	7037-9425	38
3648-3657	10	7039-7040	10
3648-3861	28	7039-7072	5
3648-7036	6	7039-7075	21
3648-7037	20	7039-7076	17
3648-7039	6	7039-9010	18
3648-7040	7	7040-7043	18
3648-7072	16	7040-7072	9
3657-3861	24	7040-7075	7
3657-7036	19	7040-7076	10
3657-7037	15	7040-9009	7
3657-7039	4	7040-9010	22
3657-7040	6	7043-7045	33
3657-7043	31	7043-7072	24
3657-7045	6	7043-7076	6
3657-7072	28	7045-7072	9
3861-7036	33	7045-7075	11
3861-7037	34	7045-7076	4
3861-7039	5	7045-9001	6
3861-7040	8	7045-9010	11
3861-7043	8	7045-9024	11
3861-7072	73	7045-9025	54
3861-7076	13	7072-7076	29
3902-7036	12	7075-7076	7
3902-7037	12	7075-9010	22
3902-7045	6	7076-9010	21
3903-7037	6	8009-8010	4
3903-7043	6	8009-8011	10
3903-7045	6	8009-8015	10
7036-7037	124	8009-8019	11
7036-7039	14	8009-9431	8
7036-7043	6	8009-9432	4
7036-7045	56	8010-8015	58
7036-7072	44	8010-8019	48
7036-7075	31	8010-9004	74
7036-7076	43	8010-9051	6
7036-9001	66	8010-9431	27
7036-9009	6	8010-9432	11
7036-9010	49	8011-8030	7
7036-9425	17	8011-9004	4
7037-7039	27	8011-9008	5
7037-7040	5	8011-9426	1
7037-7043	33	8011-9431	7
7037-7045	63	8015-8019	112

TABLE 8.7a.—(Cont'd)

Line station-station	No. of pairs	Line station-station	No. of pairs
8015-9004 -----	68	9005-9427 -----	3
8015-9051 -----	39	9006-9008 -----	181
8015-9091 -----	16	9006-9028 -----	30
8015-9431 -----	16	9006-9426 -----	19
8015-9432 -----	48	9007-9009 -----	276
8019-8030 -----	7	9007-9010 -----	92
8019-9004 -----	349	9007-9011 -----	467
8019-9091 -----	83	9007-9029 -----	5
8019-9431 -----	44	9007-9031 -----	36
8019-9432 -----	13		
		9008-9028 -----	11
8030-9004 -----	7	9008-9051 -----	16
9001-9007 -----	35	9008-9426 -----	45
9001-9009 -----	189	9009-9010 -----	117
9001-9010 -----	288	9009-9011 -----	76
9001-9012 -----	205	9009-9424 -----	7
9001-9424 -----	74	9010-9012 -----	3
9001-9427 -----	17	9010-9424 -----	12
9002-9008 -----	7	9011-9029 -----	4
9002-9028 -----	30	9011-9031 -----	9
9004-9006 -----	14		
		9012-9021 -----	32
9004-9008 -----	146	9012-9424 -----	26
9004-9009 -----	44	9012-9427 -----	247
9004-9010 -----	43	9021-9425 -----	61
9004-9028 -----	44	9028-9091 -----	49
9004-9029 -----	48	9029-9031 -----	32
9004-9051 -----	40	9091-9431 -----	17
9004-9091 -----	381	9091-9432 -----	23
9004-9424 -----	1	9424-9425 -----	56
9004-9426 -----	89	9424-9426 -----	5
9004-9431 -----	74		
		9424-9427 -----	2
9005-9006 -----	63	9425-9427 -----	15
9005-9008 -----	3	9431-9432 -----	21
9005-9012 -----	3		

TABLE 8.7b.—*Summary of Simultaneous Observations by Line
(BC Network)*

Line station-station	No. of pairs	Line station-station	No. of pairs
6001-6002	105	6011-6012	71
6001-6003	121	6011-6022	12
6001-6004	37	6011-6038	67
6001-6006	103	6011-6059	114
6001-6007	33	6011-6111	32
6001-6011	7	6011-6134	64
6001-6015	7	6012-6013	60
6001-6016	18	6012-6022	41
6001-6038	7	6012-6023	57
6001-6065	60	6012-6059	57
6001-6123	43	6012-6060	7
6002-6003	156	6013-6015	14
6002-6006	7	6013-6040	8
6002-6007	57	6013-6047	87
6002-6008	93	6013-6072	57
6002-6009	39	6013-6078	4
6002-6038	71	6015-6016	170
6002-6111	79	6015-6040	41
6002-6134	21	6015-6042	99
6003-6004	52	6015-6045	58
6003-6011	84	6015-6064	65
6003-6012	11	6015-6065	80
6003-6038	96	6015-6072	75
6003-6111	89	6015-6073	77
6003-6123	24	6015-6075	44
6003-6134	32	6016-6042	23
6004-6006	4	6016-6063	61
6004-6011	7	6016-6064	113
6004-6012	53	6016-6065	108
6004-6013	60	6019-6020	35
6004-6123	24	6019-6043	132
6006-6007	30	6019-6061	77
6006-6015	87	6019-6067	70
6006-6016	94	6019-6069	8
6006-6065	76	6020-6038	60
6007-6016	125	6020-6039	18
6007-6055	14	6020-6043	52
6007-6063	111	6022-6023	15
6007-6064	25	6022-6031	44
6007-6065	40	6022-6039	14
6007-6067	28	6022-6059	103
6008-6009	53	6022-6060	33
6008-6019	87	6022-6078	21
6008-6061	4	6023-6031	51
6008-6063	4	6023-6032	116
6008-6067	29	6023-6040	14
6009-6019	69	6023-6047	50
6009-6020	22	6023-6060	224
6009-6038	67	6023-6066	29
6009-6043	25	6023-6072	28

TABLE 8.7b.—(Cont'd)

Line station-station	No. of pairs	Line station-station	No. of pairs
6023-6078 -----	28	6045-6051 -----	42
6031-6032 -----	102	6045-6068 -----	112
6031-6039 -----	15	6045-6073 -----	99
6031-6051 -----	7	6045-6075 -----	90
6031-6052 -----	57	6047-6060 -----	8
6031-6053 -----	101	6047-6072 -----	88
6031-6059 -----	4	6047-6078 -----	4
6031-6060 -----	305	6050-6051 -----	7
6031-6078 -----	28	6050-6052 -----	14
6032-6040 -----	72	6050-6053 -----	25
6032-6044 -----	36	6050-6061 -----	63
6032-6045 -----	18	6051-6052 -----	100
6032-6047 -----	54	6051-6053 -----	103
6032-6051 -----	12	6051-6061 -----	35
6032-6052 -----	34	6051-6068 -----	106
6032-6053 -----	8	6052-6053 -----	98
6032-6060 -----	174	6052-6060 -----	47
6032-6072 -----	7	6053-6060 -----	35
6038-6039 -----	55	6053-6061 -----	7
6038-6059 -----	35	6055-6061 -----	14
6038-6134 -----	71	6055-6063 -----	101
6039-6059 -----	49	6055-6064 -----	99
6040-6044 -----	4	6055-6067 -----	86
6040-6045 -----	96	6055-6068 -----	11
6040-6047 -----	36	6055-6069 -----	47
6040-6060 -----	19	6061-6067 -----	18
6040-6072 -----	16	6061-6068 -----	18
6040-6073 -----	52	6061-6069 -----	29
6040-6075 -----	53	6063-6064 -----	84
6042-6045 -----	93	6063-6065 -----	7
6042-6064 -----	96	6063-6067 -----	62
6042-6068 -----	93	6063-6069 -----	14
6042-6073 -----	22	6064-6068 -----	106
6042-6075 -----	75	6067-6069 -----	4
6043-6050 -----	74	6068-6069 -----	21
6043-6061 -----	88	6068-6075 -----	14
6044-6045 -----	11	6072-6073 -----	15
6044-6051 -----	33	6072-6075 -----	14
6044-6052 -----	7	6073-6075 -----	80
6044-6068 -----	4		

TABLE 8.7c.—*Summary of Simultaneous Observations by Line (SA Network)*

Line station-station	No. of pairs	Line station-station	No. of pairs
6002-6008 -----	23	6019-3476 -----	19
6002-3406 -----	14	6019-3477 -----	6
6002-3407 -----	11	6067-3407 -----	3
6002-3476 -----	7	3406-3407 -----	9
6002-3477 -----	7	3406-3413 -----	25
6008-6009 -----	10	3406-3414 -----	41
6008-6019 -----	36	3406-3431 -----	53
6008-6067 -----	14	3406-3476 -----	20
6008-3406 -----	26	3406-3477 -----	13
6008-3477 -----	3	3406-3478 -----	14
6008-3478 -----	6	3406-3499 -----	4
6009-6019 -----	7	3407-3431 -----	16
6009-3406 -----	14	3407-3476 -----	19
6009-3407 -----	6	3407-3477 -----	23
6009-3476 -----	6	3407-3478 -----	9
6009-3477 -----	5	3413-3414 -----	29
6009-3499 -----	9	3413-3431 -----	2
6019-6067 -----	35	3414-3431 -----	22
6019-3406 -----	19	3476-3477 -----	15
6019-3407 -----	38	3477-3478 -----	2
6019-3431 -----	4	3477-3499 -----	5

TABLE 8.7d.—*Summary of SECOR Observations by Quadrangle*

Quad stations involved	No. of observations	Quad stations involved	No. of observations
5001-5907-5648-5911 -----	432	5721-5720-5722-5723 -----	296
5911-5001-5648-5914 -----	168	5923-5721-5722-5723 -----	36
5911-5907-5915-5912 -----	1008	5723-5721-5722-5930 -----	460
5911-5915-5912-5712 -----	92	5723-5722-5930-5931 -----	588
5911-5907-5912-5712 -----	260	5722-5723-5930-5726 -----	68
5911-5915-5912-5712 -----	228	5931-5723-5930-5726 -----	768
5911-5912-5712-5713 -----	684	5931-5930-5726-5933 -----	1064
5713-5911-5712-5715 -----	1220	5723-5930-5726-5933 -----	652
5715-5713-5712-5735 -----	548	5726-5930-5933-5934 -----	644
5715-5739-5712-5735 -----	288	5726-5933-5934-5935 -----	808
5715-5712-5735-5736 -----	660	5931-5726-5934-5935 -----	1144
5715-5735-5736-5717 -----	640	5935-5726-5934-5730 -----	2048
5715-5736-5717-5744 -----	28	5935-5726-5934-5937 -----	1264
5739-5715-5717-5744 -----	384	5730-5935-5934-5938 -----	2216
5715-5736-5717-5744 -----	464	5730-5935-5938-5732 -----	1380
5744-5715-5717-5923 -----	868	5730-5938-5732-5733 -----	756
5744-5715-5717-5924 -----	804	5730-5732-5733-5411 -----	752
5744-5715-5717-5925 -----	612	5730-5733-5411-5410 -----	648
5923-5744-5717-5720 -----	1236	5730-5733-5411-5734 -----	508
5923-5717-5720-5721 -----	772	5734-5410-5411-5201 -----	312
5744-5717-5720-5721 -----	20	5734-5730-5411-5201 -----	264
5721-5923-5720-5722 -----	752		

TABLE 8.8.—*Summary of Constraint Types With the Source Information*

Code	Constraint type	Source (agency) ^a
<u>Relative position</u>		
1 ----	BC-4—Baker-Nunn	SAO, NGS
2 ----	BC-4—SECOR	DMA/TC
3 ----	BC-4—BC-4	NGS
4 ----	Others	OSU
<u>Height</u>		
5 ----	MSL (mean sea level heights)	CSC, NGS, NWL
6 ----	Geoidal undulations	OSU (Rapp, 1973)
<u>Length (chord)</u>		
7 ----	North America	NGS
8 ----	Europe	NGS, DGFI
9 ----	Africa	NGS
10 ----	Australia	NGS, DNP
11 ----	C-band	NASA/WFC
^a CSC	Computer Sciences Corporation	
DGFI	Deutsche Geodätisches Forschungs Institut	
DMA/TC	Defense Mapping Agency/Topographic Center	
DNP	Division of National Mapping, Department of National Development, Australia	
NGS	National Geodetic Survey	
NWL	Naval Weapons Laboratory	
SAO	Smithsonian Astrophysical Observatory	
WFC	Wallops Flight Center	

TABLE 8.9.—*Relative Position Constraints*

STATIONS	RELATIVE	COORDINATES	(METERS)	WEIGHTS ¹	SOURCE
	Δu	Δv	Δw	($1/\sigma^2$)	CODE ²
1033-6123	-417481.74	-633256.41	-267774.54	0.01	4
3106-4061	245.98	359.44	514.15	0.75	4
3405-4081	-928.41	-1670.35	-3352.87	0.75	4
3406-9009	-10.62	4.41	27.55	3.00	4
3413-6067	-48.64	-289.13	1258.05	3.00	4
3476-6008	36.31	22.94	-20.80	3.00	4
3499-6009	0.0	0.0	0.0	100.00	4
3648-5648	37875.28	10510.31	7502.84	3.00	4
4050-9002	-4500.31	10094.67	1601.88	0.75	4
4082-9010	-65710.25	62288.48	137731.57	0.28	4
4280-9425	-221861.49	103220.84	-27546.08	0.12	4
4740-7039	674.06	-699.92	-1476.31	0.75	4
4742-9012	-77910.13	349731.80	145328.72	0.05	4
5201-6003	29.55	-48.21	-25.52	1.00	2
5712-6008	48.95	45.97	137.68	1.00	2
5713-5739	8.05	33.26	9.95	20.00	2
5713-6007	2.08	-1.06	1.88	1.00	2
5715-6063	1.05	-83.72	-95.45	1.00	2
5720-6042	-1.87	-0.26	30.16	1.00	2
5720-9028	-2977.60	3046.18	2495.80	1.00	4
5721-6015	49.67	-44.84	23.59	1.00	2
5726-6047	30.82	24.81	3.07	1.00	2
5730-6012	-4.69	-41.68	26.66	1.00	2
5733-6059	-0.92	-0.38	0.04	1.00	2
5734-6004	-1.20	0.12	1.59	1.00	2
5735-6067	-46.20	-290.84	1257.74	1.00	2
5736-6055	5.82	-13.48	42.60	1.00	2
5744-6016	49.84	-46.49	-42.16	1.00	2
6002-7043	56.22	499.51	568.41	3.00	4
6011-9012	49.30	-118.74	35.91	3.00	4
6012-6066	1.93	42.34	-25.67	100.00	3
6013-9005	380844.93	754432.31	-395410.11	0.01	4
6019-9011	52.02	37.19	-18.98	3.00	1
6042-9028	-2975.73	3046.44	2465.64	3.00	1
6067-9029	-44.28	-61.36	37.21	3.00	1
6068-9002	28721.97	-46167.30	7673.52	2.50	1
6111-6134	53.73	90.04	305.32	100.00	3
6111-9425	1159.34	-43554.36	-52281.82	1.62	4
6134-9021	-512117.65	409642.99	250524.73	0.02	4
7072-9010	-15.04	2.34	7.39	3.00	4
8015-8019	-1141.50	-128638.06	16776.51	0.45	4
8015-8030	372698.34	294250.47	-373345.41	0.02	4
9051-9091	11702.66	-9725.37	-9108.39	3.00	4

¹ APPLIED EQUALLY TO ALL THREE RELATIVE COORDINATES IN M⁻² UNIT² REFER TO TABLE 8.8

TABLE 8.10.—*Geoidal Undulations and Heights Used in the Constraints*

S T A T I O N		NREF ¹	HCONSTR ²	$\sigma_{HCONSTR}$ ³
NO	N A M E	(M)	(M)	(M)
1021	BLOSSOM POINT	-37.32	-45.65	2.5
1022	FORT MYERS	-31.58	-39.92	4.0
1030	GOLDSTONE	-30.00	896.45	4.0
1032	ST. JOHN'S	11.57	61.03	4.0
1033	FAIRBANKS	9.11	168.16	6.0
1034	E. GRAND FORKS	-25.47	218.56	2.5
1042	ROSMAN	-34.38	862.55	4.0
3106	ANTIGUA	-49.83	-68.70	8.0
3334	STONEVILLE	-31.54	-2.54	4.0
3400	COLORADO SPRINGS	-18.42	2159.63	2.5
3401	BEDFORD	-30.59	36.93	2.5
3402	SEMMES	-29.04	33.07	4.0
3404	SWAN ISLAND	-6.69	20.89	6.0
3405	GRAND TURK	-49.77	-64.73	6.0
3406	CURACAO	-29.19	-41.02	4.0
3407	TRINIDAD	-38.57	194.88	4.0
3413	NATAL	-12.03	-5.87	6.0
3414	BRASILIA	- 9.88	1021.23	6.0
3431	ASUNCION	11.98	137.72	6.0
3476	PARAMARIBO	-28.31	-34.02	6.0
3477	BOGOTA	10.71	2551.44	6.0
3478	MANAUS	- 7.17	53.63	6.0
3499	QUITO	16.73	2682.74	6.0
3648	HUNTER AFB	-35.70	-36.84	2.5
3657	ABERDEEN	-36.55	-45.38	2.5
3861	HOMESTEAD	-33.70	-47.20	4.0
3902	CHEYENNE	-16.53	1859.48	2.5
3903	HERNDON	-36.87	117.14	6.0
4050	PRETORIA	24.12	1573.21	6.0
4061	ANTIGUA	-49.83	-28.30	8.0
4081	GRAND TURK	-49.84	-31.01	6.0
4082	MERRITT ISLAND	-35.74	-37.91	4.0
4280	VANDERBERG AFB	-36.78	84.53	4.0
4740	BERMUDA	-43.45	-41.92	4.0
4742	KAUAI	5.61	1166.61	8.0
5001	HERNDON	-36.87	76.95	6.0

TABLE 8.10.—(Cont'd)

S T A T I O N		NREF ¹	HCONSTR ²	σ_{HCONSTR} ³
NO	N A M E	(M)	(M)	(M)
5201	MOSES LAKE	-17.65	347.84	4.0
5410	MIDWAY ISLANDS	- 4.13	7.51	8.0
5648	FORT STEWART	-35.07	-20.18	2.5
5712	PARAMARIBO	-28.31	-30.79	4.0
5713	TERCEIRA	54.00	83.29	4.0
5715	DAKAR	27.20	21.50	4.0
5717	FORT LAMY	10.35	273.29	6.0
5720	ADDIS ABABA	- 5.78	1850.34	6.0
5721	MASHHAD	-20.67	949.29	4.0
5722	DIEGO GARCIA	-73.64	-92.76	8.0
5723	CHIANG MAI	-40.39	256.21	8.0
5726	ZAMBOANGA	62.16	69.14	8.0
5730	WAKE ISLAND	13.75	26.83	8.0
5732	PAGO PAGO	27.35	40.70	6.0
5733	CHRISTMAS ISLAND	16.07	25.90	8.0
5734	SHEMYA	6.22	45.72	8.0
5735	NATAL	-12.03	-3.37	6.0
5736	ASCENSION ISLAND	16.26	55.09	8.0
5739	TERCEIRA	54.00	83.39	4.0
5744	CATANIA	37.43	18.89	4.0
5907	WORTHINGTON	-28.11	445.03	2.5
5911	BERMUDA	-43.44	-39.80	8.0
5912	PANAMA	6.16	0.39	6.0
5914	PUERTO RICO	-50.08	-5.07	6.0
5915	AUSTIN	-26.32	172.03	2.5
5923	CYPRUS	24.64	158.72	8.0
5924	ROTA	54.48	36.90	6.0
5925	ROBERTS FIELD	33.75	10.31	6.0
5930	SINGAPORE	8.28	1.16	6.0
5931	HONG KONG	2.32	155.02	6.0
5933	DARWIN	50.66	61.75	8.0
5934	MANUS	74.75	81.69	8.0
5935	GUAM	48.15	86.00	8.0
5937	PALAU	69.93	137.52	8.0
5938	GUADALCANAL	59.97	74.99	8.0
5941	MAUI	2.05	40.25	8.0

TABLE 8.10.—(Cont'd)

S T A T I O N		NREF ¹	HCONSTR ²	$\sigma_{HCONSTR}$ ³
NO	N A M E	(M)	(M)	(M)
6001	THULE	11.66	204.62	8.0
6002	BELTSVILLE	-36.90	-6.73	2.5
6003	MOSES LAKE	-17.65	347.66	4.0
6004	SHEMYA	6.22	43.22	8.0
6006	TROMSO	27.06	113.19	4.0
6007	TERCEIRA	54.00	80.59	4.0
6008	PARAMARIBO	-28.31	-33.91	4.0
6009	QUITO	16.73	2683.04	6.0
6011	MAUI	1.75	3056.88	8.0
6012	WAKE ISLAND I	13.75	22.23	8.0
6013	KANOYA	34.27	96.47	6.0
6015	MASHHAD	-20.67	945.89	4.0
6016	CATANIA	37.43	16.33	4.0
6019	VILLA DOLORES	22.80	609.43	6.0
6020	EASTER ISLAND	- 4.75	219.02	8.0
6022	TUTUILA	27.35	38.04	8.0
6023	THURSDAY ISLAND	67.94	127.40	4.0
6031	INVERCARGILL	8.68	6.35	8.0
6032	CAVERSHAM	-30.51	-15.59	6.0
6038	SOCORRO ISLAND	-35.47	-15.81	6.0
6039	PITCAIRN ISLAND	-16.68	321.45	8.0
6040	COCOS ISLAND	-38.11	-50.26	8.0
6042	ADDIS ABABA	- 5.78	1847.40	6.0
6043	CERRO SOMBRERO	15.60	76.25	8.0
6044	HEARD ISLAND	36.61	17.16	8.0
6045	MAURITIUS	- 6.07	113.55	8.0
6047	ZAMBOANGA	62.17	65.24	8.0
6050	PALMER STATION	15.70	11.71	6.0
6051	MAWSON STATION	29.20	17.68	6.0
6053	MCMURDO STATION	-56.10	-50.90	6.0
6055	ASCENSION ISLAND	16.26	52.04	8.0
6059	CHRISTMAS ISLAND	16.07	25.15	8.0
6060	CULGOORA	27.33	236.27	6.0
6061	SOUTH GEORGIA	11.28	-10.88	8.0
6063	DAKAR	27.20	20.50	4.0
6064	FORT LAMY	10.35	270.19	6.0

TABLE 8.10.—(Cont'd)

S T A T I O N		NREF ¹	HCONSTR ²	σ_{HCONSTR} ³
NO	N A M E	(M)	(M)	(M)
6065	HOHENPEISSENBERG	44.23	960.09	2.5
6066	WAKE ISLAND II	13.74	24.02	8.0
6067	NATAL	-12.03	-2.14	6.0
6068	JOHANNESBURG	24.65	1513.46	6.0
6069	TRISTAN DA CUNHA	25.52	17.30	8.0
6072	CHIANG MAI	-40.39	264.61	8.0
6073	DIEGO GARCIA	-73.64	-94.96	8.0
6075	MAHE	-44.40	514.23	8.0
6078	PORT VILA	63.10	81.72	8.0
6111	WRIGHTWOOD I	-33.18	2248.74	4.0
6123	POINT BARROW	-1.40	1.62	6.0
6134	WRIGHTWOOD II	-33.19	2162.83	4.0
7036	EDINBURG	-19.78	32.17	4.0
7037	COLUMBIA	-33.87	229.20	2.5
7039	BERMUDA	-43.43	-30.60	4.0
7040	SAN JUAN	-50.55	-20.06	6.0
7043	GREENBELT	-36.91	2.46	2.5
7045	DENVER	-18.10	1765.36	2.5
7072	JUPITER	-36.04	-35.56	4.0
7075	SUDBURY	-39.20	230.07	2.5
7076	KINGSTON	-26.62	403.91	8.0
8009	WIPPOLDER	42.33	41.11	4.0
8010	ZIMMERWALD	44.77	920.58	2.5
8011	MALVERN	47.43	134.97	4.0
8015	HAUTE PROVENCE	46.38	676.87	4.0
8019	NICE	45.91	394.73	4.0
8030	MEUDON	44.64	183.23	2.5
9001	ORGAN PASS	-22.93	1623.14	4.0
9002	OLIFANTSFONTEIN	24.27	1533.45	6.0
9004	SAN FERNANDO	54.57	50.44	6.0
9005	TOKYO	30.20	88.17	6.0
9006	NAINI TAL	-48.12	1858.89	6.0
9007	AREQUIPA	31.82	2464.57	6.0
9008	SHIRAZ	-10.91	1559.17	6.0
9009	CURACAO	-29.19	-39.15	4.0
9010	JUPITER	-36.04	-34.63	4.0

TABLE 8.10.—(Cont'd)

S T A T I O N		NREF ¹	HCONSTR ²	σ_{HCONSTR} ³
NO	N A M E	(M)	(M)	(M)
9011	VILLA DOLORES	22.80	609.25	6.0
9012	MAUI	1.76	3041.76	8.0
9021	MOUNT HOPKINS	-27.00	2351.01	4.0
9028	ADDIS ABABA	- 5.78	1886.15	6.0
9029	NATAL	-12.03	2.57	6.0
9031	COMODORO RIVADAVIA	13.43	179.36	8.0
9051	ATHENS	32.81	190.96	8.0
9091	DIONYSOS	32.84	470.13	8.0
9424	COLD LAKE	-26.21	672.13	2.5
9425	EDWARDS AFB	-32.39	749.47	4.0
9426	HARESTUA	36.39	589.17	2.5
9427	JOHNSTON ISLAND	8.83	20.59	8.0
9431	RIGA	25.67	9.76	2.5
9432	UZHGOROD	39.71	201.99	2.5

¹ FROM [RAPP,1973]

² HCONSTR = MSL + NREF + ΔN (SEE SECTION 8.5.1)

³ USED IN COMPUTING THE WEIGHTS OF THE HEIGHT CONSTRAINTS

TABLE 8.11.—*Chord Constraints*

Station-station	Chord distance (meters)	$\sigma \times 10^6$ (^a)	Source code ^b
6002-6003-----	3 485 363.232	1.00	7
6003-6111-----	1 425 876.452	1.11	7
6006-6065-----	2 457 765.810	1.43	8
6016-6065-----	1 194 793.601	1.18	8
6063-6064-----	3 485 550.755	1.18	9
6023-6060-----	2 300 209.803	2.00	10
6032-6060-----	3 163 623.866	Rejected	10
6006-6016-----	3 545 871.454	1.00	8
3861-7043-----	1 531 562.9	1.33	7
4082-4050-----	10 909 592	Rejected	11
4082-4742-----	7 362 142	Rejected	11
4082-4740-----	1 593 106	2.00	11
4082-4081-----	1 230 691	2.00	11
4082-4061-----	1 288 026	2.00	11
4742-4280-----	3 977 684	Rejected	11

^a Used in computing the weights.^b Refer to table 8.8.TABLE 8.12.—*Determination of Scale*

Point	Interpretation	Weight	a (m)	Weighted mean a (m)
1 -----	WN = EDM	10	6 378 125.0	6 378 125.8
2 -----	WN = C-band	1	6 378 133.7	(from points 1 and 2)
3 -----	WN = SAO III	278	6 378 140.8	6 378 141.7
4 -----	WN = NWL 9D	69	6 378 143.0	(from points 1-6)
5 -----	WN = GSFC 73	66	6 378 144.9	6 378 142.0
6 -----	WN = GEM 4	48	6 378 144.1	(from points 3-6)
7 -----	C-band = SAO III	1	6 378 143.6	6 378 142.7
8 -----	C-band = GSFC 73	1	6 378 146.8	(from points 1-14)
9 -----	C-band = NWL 9D	1	6 378 147.1	
10 -----	C-band = GEM 4	1	6 378 147.8	
11 -----	EDM = SAO III	10	6 378 153.7	
12 -----	EDM = GSFC 73	8	6 378 154.0	
13 -----	EDM = GEM 4	9	6 378 155.2	
14 -----	EDM = NWL 9D	9	6 378 160.5	

TABLE 8.13.—Average Standard Deviations
(Solution WN14)

Average standard deviations	Constituent networks				WN14
	BC	SECOR	MPS	SA	
σ_u (m) -----	3.3	2.5	4.9	4.0	3.8
σ_v (m) -----	3.3	2.6	5.1	3.4	3.9
σ_w (m) -----	3.9	3.2	4.4	4.7	4.0
σ_ϕ (arc sec) ----	0.1	0.1	0.2	0.2	0.1
σ_λ (arc sec) ----	0.2	0.1	0.3	0.1	0.2
σ_h (m) -----	3.2	2.4	2.9	3.0	2.9
σ (m) -----	3.5	2.8	4.8	4.1	3.9

TABLE 8.14.—Cartesian and Geodetic Coordinates (Solution WN 14)

Sta. no.	u	σ_u	v	σ_v	w	σ_w
	ϕ	σ_ϕ	λ	σ_λ	h	σ_h
		r_a	A_a	r_a		
		s_b	A_b	r_b		
		a_c	A_c	r_c		

u, v, w Cartesian coordinates in meters (orientation: u = the Greenwich meridian as defined by the Bureau International de l'Heure; $v = \lambda = 90^\circ$ (E); w = Conventional International Origin).

ϕ, λ Geodetic latitude and longitude in angular units (degrees, minutes and seconds of arc) computed from the Cartesian coordinates and referred to a rotational ellipsoid of $a = 6\,378\,155.00$ m and $b = 6\,356\,769.70$ m.

h Geodetic (ellipsoidal) height in meters referred to the same ellipsoid.

$\sigma_u, \sigma_v, \sigma_w$ Standard deviations of the Cartesian coordinates in meters.

$\sigma_\phi, \sigma_\lambda$ Standard deviations of the geodetic coordinates in seconds of arc.

σ_h Standard deviations of the geodetic height in meters.

a_a, A_a, r_a Altitude (elevation angle), azimuth and magnitude of the major semiaxis of the error ellipsoid, respectively. Angles in degrees, magnitude in meters. Altitude is positive above the horizon. Azimuth is positive east reckoned from the north (see sec. 8.4.7.4).

a_b, A_b, r_b Same as above for the mean axis of the error ellipsoid.

a_c, A_c, r_c Same as above for the minor axis of the error ellipsoid.

TABLE 8.14.—(Cont'd)

1021	1118023.12	2.84	-4876323.36	2.61	3942963.91	2.83
	38 25 49.56	0.10	282 54 48.07	0.12	-47.77	2.05
		0.08	16.31	3.25		
		-2.59	106.30	2.86		
		-87.41	-71.85	2.04		

1022	807851.91	2.25	-5651989.58	1.94	2833500.22	2.32
	26 32 52.94	0.08	278 8 3.56	0.08	-32.58	1.92

6.37	-26.03	2.39
11.15	65.23	2.20
-77.12	34.75	1.90

1030	-2357242.91	5.62	-4646338.51	3.30	3668306.76	3.24
	35 19 47.44	0.10	243 5 59.26	0.23	889.58	2.84

-0.27	79.87	5.97
30.63	-9.97	3.16
-59.37	-10.59	2.71

1032	2602688.61	39.33	-3419228.93	46.69	4697637.28	13.76
	47 44 28.60	0.65	307 16 41.12	2.84	60.96	4.05

-0.33	73.10	61.68
-1.46	163.11	9.76
88.51	150.35	4.05

1033	-2299282.59	6.92	-1445693.70	9.72	5751811.65	5.67
	64 52 17.50	0.24	212 9 35.93	0.74	170.23	5.15

-1.11	-71.88	9.98
4.10	18.04	6.97
85.75	-146.80	5.14

1034	-521704.47	3.09	-4242064.34	2.95	4718716.85	2.69
	48 1 20.63	0.11	262 59 19.55	0.15	217.55	1.97

0.01	138.01	3.88
1.65	48.01	2.57
88.35	-131.79	1.97

TABLE 8.14.—(Cont'd)

1042	647497.49 35 12 7.07	2.77 0.09	-5177935.64 277 7 40.08	2.43 0.11	3656705.89 863.40	2.84 2.42
		8.15	-32.33	2.99		
		21.12	60.84	2.66		
		-67.22	37.74	2.37		
3106	2881838.31 17 8 54.85	3.72 0.13	-5372164.61 298 12 39.03	3.32 0.13	1868538.63 -58.68	4.25 3.35
		18.24	-31.23	4.45		
		17.20	64.62	3.62		
		-64.49	15.09	3.17		
3334	-84963.76 33 25 31.00	13.62 0.34	-5327974.93 269 5 11.03	6.79 0.53	3493428.28 -2.60	8.96 3.90
		-2.81	71.02	13.96		
		0.27	-18.96	10.11		
		-87.18	-103.43	3.84		
3400	-1275207.22 39 0 21.73	9.06 0.23	-4798029.30 255 6 58.20	5.11 0.38	3994208.30 2160.40	5.67 2.50
		-3.41	77.30	9.15		
		-1.14	-12.77	7.12		
		-86.41	-121.20	2.45		
3401	1513136.10 42 27 17.69	3.18 0.12	-4463576.80 288 43 35.29	3.44 0.15	4283055.82 34.52	2.99 2.23
		-5.50	38.05	4.08		
		-0.81	128.13	3.07		
		84.44	46.50	2.20		
3402	167259.66 30 46 49.95	3.91 0.11	-5481970.99 271 44 51.37	2.81 0.15	3245036.99 27.89	3.46 2.78
		10.37	74.47	3.96		
		9.33	-17.25	3.48		
		-75.98	31.59	2.71		

TABLE 8.14.—(Cont'd)

3404	642491.44	4.70	-6053940.27	3.73	1895688.60	4.89
	17 24 19.15	0.16	276 3 28.80	0.16	-1.41	3.78
		13.00	40.70	5.32		
		12.19	133.56	4.28		
		-72.03	85.31	3.64		
3405	1919482.89	3.30	-5621088.11	3.47	2315775.25	3.95
	21 25 48.55	0.13	288 51 14.23	0.17	-67.11	3.39
		16.02	4.06	3.96		
		-37.11	81.52	3.58		
		48.44	112.95	3.17		
3406	2251800.21	2.41	-5816912.95	2.07	1327191.09	3.37
	12 5 25.86	0.11	291 9 43.37	0.08	-37.08	2.02
		8.37	-21.06	3.51		
		-5.58	68.11	2.30		
		-79.92	-55.22	1.98		
3407	2979891.14	4.67	-5513530.88	3.36	1181129.32	5.25
	10 44 34.89	0.17	298 23 23.41	0.16	186.66	3.11
		7.22	-41.79	6.26		
		23.36	51.35	3.61		
		-65.42	32.14	2.91		
3413	5186348.44	2.15	-3654222.39	2.22	-653018.86	2.67
	- 5 54 57.54	0.09	324 49 55.40	0.08	-0.16	2.02
		-10.20	5.19	2.68		
		4.99	94.29	2.35		
		78.62	-21.40	2.00		
3414	4114977.82	7.65	-4554142.51	6.11	-1732153.99	7.24
	-15 51 37.38	0.24	312 5 59.86	0.28	1016.74	5.00
		1.84	51.81	9.40		
		0.35	-38.20	5.91		
		-88.12	41.00	4.99		

TABLE 8.14.—(Cont'd)

3431	3093045.37	7.59	-4870081.66	6.52	-2710823.02	10.84
	-25 18 57.42	0.38	302 25 12.37	0.27	145.11	5.06
		-2.01	12.62	11.79		
		-4.59	102.79	7.31		
		84.99	78.99	5.03		
3476	3623277.34	2.20	-5214210.74	2.03	601515.27	2.97
	5 26 52.73	0.10	304 47 41.50	0.07	-36.82	1.95
		1.89	-9.70	2.99		
		4.74	80.46	2.24		
		-84.90	58.64	1.94		
3477	1744650.18	10.18	-6114286.71	6.63	532208.62	9.56
	4 49 0.25	0.31	285 55 32.03	0.35	2555.03	5.51
		-2.04	49.78	13.43		
		-51.04	142.31	5.74		
		-38.88	-41.86	5.07		
3478	3185777.03	18.72	-5514585.85	14.46	-347703.19	35.12
	- 3 8 45.73	1.15	300 0 54.12	0.74	53.58	5.97
		0.31	-32.05	41.22		
		-25.68	57.80	8.05		
		64.32	58.59	5.37		
3499	1280834.24	3.59	-6250955.94	3.43	-10800.58	4.11
	- 0 5 51.49	0.13	281 34 47.08	0.12	2683.81	3.36
		22.05	-0.15	4.24		
		-15.59	83.36	3.69		
		-62.50	-39.06	3.14		
3648	832566.24	3.56	-5349540.70	2.49	3360585.27	3.62
	32 0 6.28	0.13	278 50 46.17	0.14	-36.10	1.67
		2.59	22.92	4.07		
		-5.52	112.67	3.57		
		-83.90	-42.00	1.64		

TABLE 8.14.—(Cont'd)

3657	1186787.14 39 28 19.01	3.14 0.11	-4785193.13 283 55 44.44	3.05 0.14	4032882.32 -44.57	2.98 2.22
		-4.73 -2.52 84.64	33.47 123.68 61.63	3.69 3.09 2.20		
3861	961767.93 25 30 26.08	2.97 0.08	-5679156.55 279 36 42.74	2.33 0.11	2729883.49 -43.47	2.61 2.50
		-9.63 56.43 -31.81	116.13 40.95 20.09	3.08 2.58 2.21		
3902	-1234700.68 41 7 57.30	8.59 0.27	-4651242.77 255 8 0.09	6.25 0.37	4174758.60 1859.36	6.26 2.53
		-1.99 -3.73 -85.78	105.25 15.12 -136.72	8.74 8.35 2.46		
3903	1088989.74 38 59 34.10	12.11 0.36	-4843005.39 282 40 21.55	8.51 0.50	3991776.62 110.47	8.91 5.67
		0.38 -5.48 64.51	120.87 30.91 26.96	12.59 10.42 5.60		
4050	5051608.05 -25 56 37.88	3.18 0.14	2726603.28 28 21 28.57	3.18 0.12	-2774166.82 1575.91	4.35 2.91
		-9.93 -13.22 73.36	1.93 94.29 56.07	4.46 3.38 2.82		
4061	2881592.34 17 8 36.95	3.76 0.14	-5372523.89 298 12 25.95	3.47 0.13	1868024.39 -18.85	4.35 3.49
		20.20 11.03 -66.75	-26.66 67.45 4.42	4.48 3.76 3.31		

TABLE 8.14.—(Cont'd)

4081	1920410.93 21 27 45.25	3.32 0.13	-5619417.80 288 52 3.48	3.57 0.12	2319128.45 -33.03	4.00 3.47
		10.81 -47.10 40.87	17.91 96.05 117.42	4.05 3.64 3.18		
4082	910567.21 28 25 28.69	2.64 0.09	-5539113.24 279 20 7.01	2.36 0.10	3017965.30 -35.47	2.80 2.25
		4.20 1.40 -85.57	-14.50 75.60 4.05	2.91 2.62 2.24		
4280	-2671873.84 34 39 56.78	3.83 0.13	-4521210.51 239 25 6.35	3.32 0.16	3607490.37 85.34	3.57 2.65
		0.76 2.23 -87.65	75.54 -14.49 4.40	4.06 3.87 2.65		
4740	2308887.30 32 20 52.79	3.35 0.13	-4874298.20 295 20 46.55	3.14 0.13	3393082.09 -40.55	3.77 2.60
		1.12 -10.00 79.94	-14.90 74.90 81.43	4.19 3.32 2.58		
5001	1088849.37 38 59 37.46	3.64 0.13	-4842748.67 282 40 16.38	3.00 0.15	3991840.18 83.52	3.69 2.48
		12.35 13.94 -71.21	37.45 130.56 87.39	4.41 3.36 2.26		
5201	-2127802.21 47 11 5.15	2.28 0.08	-3785911.53 240 39 45.48	2.20 0.11	4656012.10 341.28	2.44 2.14
		18.51 -4.92 -70.81	20.45 -67.90 36.41	2.56 2.24 2.08		

TABLE 8.14.—(Cont'd)

5410	-5618754.08	2.29	-258237.50	2.76	2997250.19	3.62
	28 12 43.31	0.12	182 37 53.25	0.10	21.73	2.38
		17.94	-6.80	3.68		
		12.06	-100.76	2.79		
		-68.14	-42.96	2.16		
5648	794691.02	3.59	-5360051.05	2.51	3353082.41	3.65
	31 55 18.82	0.13	278 26 0.03	0.14	-19.05	1.68
		2.34	23.32	4.11		
		-6.03	113.08	3.60		
		-83.53	-45.56	1.64		
5712	3623289.81	2.06	-5214188.02	1.95	601673.22	2.91
	5 26 57.88	0.10	304 47 42.25	0.07	-33.31	1.87
		1.26	-5.25	2.92		
		1.18	84.78	2.12		
		-88.27	37.82	1.87		
5713	4433637.78	1.98	-2268153.21	2.19	3971656.80	2.46
	38 45 36.52	0.08	332 54 24.11	0.10	91.71	1.82
		17.42	-22.37	2.58		
		6.62	69.72	2.27		
		71.29	179.77	1.72		
5715	5884468.78	1.60	-1853580.06	1.96	1612760.08	2.33
	14 44 39.23	0.08	342 30 56.94	0.07	31.00	1.52
		6.24	-7.11	2.35		
		4.07	83.34	2.01		
		82.54	-153.76	1.50		
5717	6023410.73	2.00	1617946.48	2.04	1331655.76	2.68
	12 7 52.22	0.09	15 2 7.09	0.07	284.13	1.96
		-3.82	-6.72	2.74		
		14.20	82.31	2.01		
		75.28	-82.00	1.95		

TABLE 8.14.—(Cont'd)

5720	4900749.06 8 46 13.32	2.03 0.09	3968252.96 38 59 52.49	2.06 0.07	966354.69 1853.32	2.86 1.94
		2.64 -0.51 87.31	-0.20 89.78 168.84	2.87 2.14 1.94		
5721	2604404.77 36 14 26.73	2.05 0.09	4444122.35 59 37 41.76	2.13 0.09	3750344.33 952.30	2.65 1.91
		11.32 12.51 73.01	-2.43 90.12 -133.34	2.79 2.14 1.85		
5722	1905127.03 - 7 21 6.16	3.49 0.13	6032287.50 72 28 21.92	4.05 0.11	-810716.17 -91.66	4.30 4.23
		-46.43 32.30 25.81	5.87 54.23 -53.57	4.79 3.66 3.28		
5723	-941709.38 18 46 11.15	2.54 0.11	5967444.99 98 58 3.96	2.31 0.09	2039322.91 252.51	3.46 2.48
		20.63 5.06 68.70	9.18 -82.73 174.16	3.48 2.53 2.30		
5726	-3361946.83 6 55 20.64	2.29 0.10	5365837.02 122 4 8.62	2.20 0.08	763627.83 85.43	3.16 2.10
		14.84 5.92 73.97	-0.73 -92.31 156.56	3.18 2.44 1.99		
5730	-5858574.55 19 17 29.46	2.06 0.10	1394467.24 166 36 41.38	2.51 0.09	2093847.41 24.96	3.14 2.22
		17.68 16.86 -65.17	1.19 -94.35 -45.28	3.14 2.51 2.05		

TABLE 8.14.—(Cont'd)

5732	-6099970.46	3.56	-997355.27	3.54	-1568570.89	4.15
	-14 19 53.84	0.13	189 17 8.85	0.12	38.64	3.64
	-24.28		33.76	4.47		
	-62.75		-175.08	3.46		
	-11.61		-61.56	3.23		
5733	-5885333.94	2.75	-2448380.44	2.91	221670.69	3.86
	2 0 18.39	0.13	202 35 16.75	0.09	25.88	2.77
	8.46		17.66	3.97		
	12.89		-74.29	2.77		
	-74.50		-39.91	2.74		
5734	-3851799.01	2.72	396409.29	3.31	5051342.05	3.90
	52 42 48.32	0.11	174 7 26.66	0.17	51.71	3.45
	35.90		29.49	4.03		
	42.09		-101.36	3.35		
	-27.04		-38.82	2.47		
5735	5186350.63	2.02	-3654223.69	2.06	-653018.90	2.54
	- 5 54 57.54	0.08	324 49 55.41	0.07	2.36	1.93
	-14.68		-5.18	2.55		
	2.64		84.13	2.16		
	75.08		-15.82	1.88		
5736	6118340.28	2.30	-1571761.88	2.25	-878553.62	2.74
	- 7 58 13.62	0.09	345 35 33.46	0.08	56.48	2.26
	-14.58		3.92	2.75		
	35.15		83.37	2.41		
	-51.08		112.70	2.11		
5739	4433629.32	1.98	-2268186.23	2.20	3971646.99	2.47
	38 45 36.11	0.08	332 54 22.73	0.10	91.43	1.83
	17.59		-22.26	2.58		
	6.31		69.75	2.28		
	71.24		178.75	1.73		

TABLE 8.14.—(Cont'd)

5744	4896437.74 37 26 37.31	1.82 0.08	1316125.03 15 2 42.23	2.16 0.09	3856626.21 18.41	2.28 1.65
		3.13 16.86 72.83	-20.27 70.68 -120.48	2.54 2.04 1.60		
5907	-449417.54 43 38 57.03	4.17 0.17	-4600905.48 264 25 15.72	3.18 0.18	4380288.13 444.85	4.54 2.26
		8.60 -11.78 -75.34	27.67 115.86 -27.02	5.61 3.54 2.04		
5911	2307991.25 32 21 45.57	2.56 0.09	-4873773.25 295 20 24.17	2.34 0.10	3394463.39 -26.09	2.96 2.40
		21.55 28.27 -53.18	33.67 135.92 91.83	3.18 2.42 2.19		
5912	1142644.48 8 58 26.82	3.06 0.14	-6196109.11 280 26 55.35	3.45 0.10	988336.58 -5.02	4.06 3.28
		-24.25 37.82 -42.44	0.41 69.95 114.73	4.45 3.12 2.88		
5914	2349456.86 18 29 39.35	10.50 0.24	-5576027.12 292 50 53.18	7.01 0.37	2010342.57 -9.38	6.44 5.38
		4.84 -27.05 62.45	88.74 1.21 -10.60	10.84 8.04 4.33		
5915	-744091.08 30 13 45.90	3.84 0.19	-5465238.69 262 14 48.71	3.80 0.14	3192467.45 170.93	4.73 2.25
		-8.00 -5.64 -80.19	11.70 102.50 -132.69	5.83 3.62 2.09		

TABLE 8.14.—(Cont'd)

5923	4363332.16 35 11 30.32	1.88 0.09	2862254.91 33 15 50.54	2.07 0.08	3655380.73 170.07	2.44 1.77
		5.75 15.87 73.07	-9.41 82.23 -118.73	2.63 1.96 1.74		
5924	5093556.18 36 37 36.90	1.87 0.09	-565322.26 353 40 0.45	2.61 0.10	3784268.29 19.25	2.93 1.99
		22.12 1.36 67.83	-10.48 80.07 173.41	3.00 2.60 1.76		
5925	6237366.27 6 13 54.17	2.27 0.10	-1140241.51 349 38 24.92	2.56 0.08	687740.16 15.82	3.01 2.21
		-17.07 -14.31 67.43	-2.36 92.13 40.01	3.15 2.56 2.07		
5930	-1542549.36 1 22 23.73	2.61 0.11	6186956.66 103 59 58.99	2.67 0.09	151833.76 18.73	3.42 2.57
		9.95 33.76 -54.41	3.46 -93.28 -72.35	3.44 2.86 2.37		
5931	-2423914.92 22 11 55.70	2.49 0.11	5388250.32 114 13 14.49	2.52 0.09	2394869.19 140.80	3.64 2.91
		34.18 54.97 6.78	1.63 167.23 -93.00	3.69 2.48 2.47		
5933	-4071568.36 -12 27 15.12	3.16 0.12	4714253.33 130 48 58.51	3.24 0.10	-1366528.34 76.62	3.75 3.28
		-15.03 66.67 -17.41	4.38 -47.11 -90.45	3.75 3.25 3.14		

TABLE 8.14.—(Cont'd)

5934	-5367663.14	2.46	3437869.92	2.55	-225415.97	3.28
	- 2 2 20.34	0.11	147 21 40.80	0.09	82.38	2.38
		8.39	6.55	3.31		
		3.83	-84.02	2.60		
		-80.76	-18.35	2.36		
5935	-5059825.71	2.08	3591185.96	2.22	1472762.50	2.84
	13 26 22.08	0.09	144 38 5.87	0.08	97.15	2.05
		9.68	9.47	2.86		
		7.47	-81.81	2.26		
		-77.73	-28.90	2.02		
5937	-4433463.64	2.22	4512930.31	2.23	809958.73	3.17
	7 20 40.34	0.10	134 29 27.89	0.08	135.86	2.06
		11.68	4.19	3.18		
		3.10	-86.45	2.42		
		-77.90	-11.10	2.00		
5938	-5915096.47	2.96	2146860.80	2.97	-1037909.46	3.49
	- 9 25 40.94	0.11	160 3 6.61	0.10	80.95	2.97
		-1.29	5.77	3.51		
		55.71	-82.34	3.00		
		-34.26	-85.11	2.90		
5941	-5467757.28	2.52	-2381246.70	2.79	2254033.75	3.78
	20 49 54.72	0.12	203 32 0.47	0.09	59.12	2.59
		11.30	7.83	3.83		
		-28.47	-75.95	2.79		
		-58.98	78.43	2.44		
6001	546568.68	2.57	-1389993.74	2.44	6180236.66	3.40
	76 30 4.71	0.07	291 27 56.08	0.38	211.60	3.39
		76.47	40.98	3.42		
		-11.64	72.10	2.84		
		-6.80	-19.31	2.10		

TABLE 8.14.—(Cont'd)

6002	1130764.85 39 1 39.35	2.04 0.07	-4830831.87 283 10 27.05	1.71 0.08	3994704.05 -6.70	1.92 1.52
		3.64 3.11 -85.21	-36.38 53.82 4.20	2.13 1.98 1.51		
6003	-2127832.13 47 11 6.36	2.11 0.07	-3785862.99 240 39 43.11	2.02 0.10	4656037.23 340.92	2.30 2.02
		23.12 -1.56 -66.83	23.42 -65.92 27.72	2.41 2.07 1.94		
6004	-3851797.46 52 42 48.33	2.74 0.11	396409.38 174 7 26.64	3.30 0.17	5051340.48 49.54	3.91 3.45
		34.79 43.25 -26.91	28.69 -102.14 -40.66	4.05 3.37 2.45		
6006	2102927.39 69 39 45.17	2.36 0.09	721668.52 18 56 27.07	2.92 0.25	5958180.80 111.31	2.89 2.81
		-18.55 68.66 10.18	137.52 106.71 -135.93	3.14 2.79 2.20		
6007	4433637.30 38 45 36.50	2.04 0.08	-2268151.36 332 54 24.17	2.17 0.10	3971655.01 89.60	2.49 1.88
		17.05 7.87 71.11	-22.41 70.03 -176.12	2.62 2.24 1.78		
6008	3623241.00 5 26 53.40	2.13 0.10	-5214233.74 304 47 40.10	1.96 0.07	601536.05 -36.69	2.93 1.89
		1.99 4.43 -85.14	-8.96 81.19 56.94	2.95 2.17 1.88		

TABLE 8.14.—(Cont'd)

6009	1280834.24	3.58	-6250955.94	3.43	-10800.59	4.10
	- 0 5 51.49	0.13	281 34 47.08	0.12	2683.81	3.36
		22.07	-0.16	4.24		
		-15.60	83.34	3.69		
		-62.48	-39.07	3.14		
6011	-5466018.63	3.02	-2404431.52	2.88	2242224.36	3.34
	20 42 26.97	0.10	203 44 38.68	0.11	3074.38	2.86
		8.35	42.07	3.79		
		-62.48	115.71	2.94		
		-26.02	-43.83	2.36		
6012	-5858569.26	2.14	1394508.74	2.60	2093820.34	3.17
	19 17 28.58	0.10	166 36 39.96	0.09	20.23	2.30
		18.21	3.06	3.17		
		17.08	-92.74	2.60		
		-64.60	-43.08	2.13		
6013	-3565892.77	3.28	4120713.58	4.43	3303428.26	4.93
	31 23 42.60	0.16	130 52 17.54	0.16	93.70	3.68
		9.78	33.58	5.53		
		56.25	-71.37	3.80		
		-31.94	-50.25	3.11		
6015	2604353.27	2.06	4444166.00	2.18	3750320.52	2.64
	36 14 25.88	0.09	59 37 44.42	0.09	947.60	1.91
		10.34	-3.33	2.79		
		15.69	89.61	2.19		
		71.06	-125.44	1.84		
6016	4896388.34	1.81	1316172.12	2.19	3856668.20	2.24
	37 26 39.09	0.08	15 2 44.60	0.09	15.77	1.66
		2.05	-24.93	2.51		
		17.19	65.71	2.05		
		72.68	-121.51	1.62		

TABLE 8.14.—(Cont'd)

6019	2280627.09	2.37	-4914543.17	2.71	-3355402.77	3.67
	-31 56 34.93	0.12	294 53 38.32	0.09	606.26	2.55
		-11.54	-1.78	3.81		
		-54.22	104.68	2.54		
		33.33	80.51	2.34		
6020	-1888614.27	5.37	-5354894.35	4.50	-2895749.01	5.53
	-27 10 35.94	0.16	250 34 22.07	0.18	217.23	5.41
		-58.94	24.67	5.79		
		-7.72	127.67	5.42		
		-29.88	-137.86	4.10		
6022	-6099961.67	3.42	-997362.18	3.56	-1568585.49	4.66
	-14 19 54.37	0.15	189 17 9.12	0.12	34.93	3.48
		-10.68	25.44	4.93		
		-77.02	170.33	3.42		
		-7.29	-65.94	3.18		
6023	-4955386.85	3.24	3842247.82	3.04	-1163847.43	3.97
	-10 35 2.97	0.13	142 12 40.14	0.11	120.39	2.64
		6.82	21.74	4.17		
		-5.41	-67.61	3.37		
		81.28	-119.52	2.60		
6031	-4313825.29	3.41	891333.91	3.91	-4597265.83	3.84
	-46 24 57.86	0.12	168 19 32.46	0.19	-0.11	3.43
		-11.19	-106.82	4.17		
		-37.93	-7.95	3.86		
		-49.86	149.61	3.06		
6032	-2375420.64	3.29	4875546.73	3.21	-3345411.07	3.90
	-31 50 25.25	0.12	115 58 33.09	0.13	-6.10	3.13
		-21.80	-2.12	3.93		
		13.36	-86.66	3.50		
		64.06	32.57	2.94		

TABLE 8.14.—(Cont'd)

6038	-2160980.91 18 43 58.27	2.52 0.13	-5642710.55 249 2 41.03	2.80 0.09	2035367.82 -15.49	3.83 2.62
		6.05 -42.31 -47.05	-7.29 -91.76 76.18	3.89 2.79 2.43		
6039	-3724765.86 -25 4 6.38	6.17 0.16	-4421237.60 229 53 12.56	5.42 0.21	-2686084.74 316.49	5.55 6.20
		-65.27 -15.82 -18.50	61.40 -66.56 -162.00	6.38 6.01 4.63		
6040	-741981.69 -12 11 43.94	4.50 0.13	6190792.95 96 50 3.98	3.69 0.15	-1338546.30 -49.01	4.16 3.77
		1.81 -32.17 57.76	-81.59 7.28 11.28	4.54 4.23 3.57		
6042	4900750.71 8 46 12.37	2.04 0.09	3968252.68 38 59 52.45	2.08 0.07	966325.28 1849.93	2.86 1.94
		2.48 -1.20 87.25	-0.62 89.33 153.48	2.87 2.17 1.94		
6043	1371375.89 -52 46 52.54	3.30 0.17	-3614750.34 290 46 33.27	3.84 0.16	-5055927.83 71.89	4.77 3.52
		-17.66 -68.07 -12.57	5.08 -137.21 99.15	5.36 3.29 2.96		
6044	1098897.91 -53 1 9.71	6.82 0.25	3684606.64 73 23 35.89	6.17 0.38	-5071873.13 24.18	7.78 5.98
		-25.82 -14.04 60.10	17.19 -79.76 -15.53	8.32 7.05 5.12		

TABLE 8.14.—(Cont'd)

6045	3223432.02	3.16	5045336.27	3.15	-2191805.72	3.94
	-20 13 53.35	0.13	57 25 32.73	0.11	114.46	3.13
	-19.28		1.28		3.94	
	-10.91		-92.59		3.30	
	67.63		-30.53		3.00	
6047	-3361976.90	2.37	5365811.89	2.30	763624.74	3.23
	6 55 20.56	0.10	122 4 9.88	0.08	79.76	2.21
	14.53		-1.10		3.25	
	6.31		-92.75		2.51	
	74.10		154.41		2.11	
6050	1192678.77	4.86	-2451015.64	6.15	-5747034.19	6.09
	-64 46 26.04	0.25	295 56 52.19	0.33	7.95	4.57
	16.30		-178.22		7.90	
	-24.63		99.49		4.39	
	-59.83		-118.43		4.10	
6051	1111336.13	4.89	2169262.66	3.72	-5874334.05	4.44
	-67 36 5.21	0.14	62 52 24.45	0.39	21.81	4.09
	-16.78		-47.12		5.12	
	-45.30		60.62		4.26	
	39.90		28.28		3.62	
6052	-902608.85	4.44	2409522.13	3.95	-5816551.79	5.45
	-66 16 45.08	0.14	110 32 9.56	0.34	-5.35	5.41
	-75.06		12.80		5.49	
	-11.85		-129.08		4.52	
	8.96		-40.97		3.81	
6053	-1310852.27	4.63	311257.54	4.53	-6213276.48	4.33
	-77 50 41.09	0.15	166 38 33.62	0.69	-51.41	4.19
	22.34		157.08		4.95	
	-11.26		-117.61		4.48	
	-64.71		127.48		4.02	

TABLE 8.14.—(Cont'd)

6055	6118334.19	2.35	-1571748.31	2.34	-878596.53	2.82
	- 7 58 15.04	0.09	345 35 33.84	0.08	53.25	2.29
		-12.50	3.22	2.82		
		31.06	85.55	2.51		
		-55.98	112.39	2.16		
6059	-5885333.51	2.71	-2448379.00	2.86	221671.07	3.84
	2 0 18.41	0.13	202 35 16.72	0.09	24.95	2.72
		8.72	16.80	3.94		
		18.01	-76.05	2.75		
		-69.86	-48.46	2.68		
6060	-4751649.95	3.27	2792058.10	3.27	-3200163.95	3.66
	-30 18 34.11	0.12	149 33 41.79	0.13	233.02	2.79
		-4.36	32.86	3.85		
		-15.01	-58.31	3.55		
		-74.34	138.63	2.72		
6061	2999915.62	3.66	-2219369.35	5.66	-5155245.98	5.32
	-54 17 1.10	0.15	323 30 20.06	0.31	-6.94	4.39
		13.73	125.85	6.13		
		-43.95	49.47	5.02		
		42.82	22.76	3.30		
6063	5884467.41	1.73	-1853495.77	2.05	1612855.09	2.46
	14 44 42.44	0.08	342 30 59.62	0.07	29.43	1.65
		6.88	-5.34	2.47		
		5.69	85.35	2.11		
		81.06	-145.36	1.63		
6064	6023386.68	2.73	1617931.85	2.59	1331733.18	3.24
	12 7 54.86	0.11	15 2 6.83	0.09	273.97	2.73
		-2.20	-0.39	3.27		
		80.49	76.34	2.73		
		-9.25	89.97	2.55		

TABLE 8.14.—(Cont'd)

6065	4213564.60	2.02	820829.99	2.44	4702784.39	2.35
	47 48 4.49	0.08	11 1 24.71	0.12	959.58	1.86
		8.80	-34.04	2.69		
		14.81	58.31	2.25		
		72.67	-153.77	1.80		
6066	-5858571.20	2.14	1394466.40	2.60	2093846.01	3.17
	19 17 29.45	0.10	166 36 41.39	0.09	21.23	2.30
		18.20	3.07	3.17		
		17.08	-92.72	2.60		
		-64.61	-43.07	2.14		
6067	5186397.12	2.08	-3653933.25	2.15	-654276.92	2.61
	- 5 55 38.70	0.09	324 50 4.00	0.07	3.57	1.96
		-10.64	5.08	2.62		
		5.06	94.12	2.28		
		78.19	-20.94	1.93		
6068	5084830.42	2.99	2670341.23	2.93	-2768095.23	4.18
	-25 52 59.53	0.14	27 42 23.71	0.11	1516.09	2.77
		-11.23	1.97	4.26		
		17.98	-84.34	3.13		
		68.59	61.55	2.64		
6069	4978421.74	6.50	-1086874.04	6.44	-3823167.78	8.08
	-37 3 53.78	0.26	347 41 4.53	0.27	18.79	6.22
		-16.86	-0.53	8.33		
		25.74	81.06	6.81		
		58.51	-60.86	5.76		
6072	-941702.05	5.74	5967455.05	3.96	2039311.64	4.25
	18 46 10.71	0.13	98 58 3.66	0.19	257.21	4.26
		-0.82	-73.76	5.83		
		59.89	14.83	4.46		
		30.10	-163.28	3.57		

TABLE 8.14.—(Cont'd)

6073	1905134.13	3.43	6032282.45	3.72	-810732.67	4.19
	- 7 21 6.70	0.14	72 28 21.65	0.12	-92.21	3.62
		-15.47	-13.67	4.23		
		44.62	60.49	3.76		
		41.30	-89.60	3.34		
6075	3602820.62	3.75	5238240.67	3.58	-515948.29	4.02
	- 4 40 14.71	0.13	55 28 48.41	0.12	518.71	3.77
		-29.52	-18.96	4.24		
		43.81	-76.08	3.77		
		31.83	50.46	3.30		
6078	-5952303.44	9.70	1231904.93	8.02	-1925972.50	12.38
	-17 41 31.46	0.46	168 18 25.18	0.26	79.53	7.18
		18.89	-8.89	15.06		
		-12.67	-94.48	7.43		
		-66.98	27.46	5.44		
6111	-2448853.28	2.56	-4667985.83	2.11	3582754.93	2.36
	34 22 54.30	0.08	242 19 5.62	0.11	2251.54	1.73
		5.18	77.41	2.75		
		7.60	-13.29	2.47		
		-80.79	21.41	1.70		
6123	-1881799.41	4.61	-812438.96	4.39	6019590.66	4.46
	71 18 47.70	0.14	203 21 5.60	0.50	4.04	4.21
		-1.38	62.03	5.25		
		53.91	-26.08	4.55		
		-36.05	-28.97	3.49		
6134	-2448907.01	2.56	-4668075.88	2.11	3582449.61	2.36
	34 22 44.21	0.08	242 19 5.40	0.11	2165.54	1.73
		5.18	77.46	2.75		
		7.59	-13.23	2.47		
		-80.79	21.45	1.71		

TABLE 8.14.—(Cont'd)

7036	-828486.97 26 22 46.30	3.47 0.09	-5657471.26 261 40 7.52	2.44 0.13	2816816.00 34.35	2.95 2.53
		7.95 25.78 -62.84	67.30 -26.56 -6.90	3.59 2.81 2.43		
7037	-191291.02 38 53 35.51	2.88 0.09	-4967293.86 267 47 40.64	2.15 0.12	3983252.57 232.83	2.42 1.82
		0.13 7.61 -82.39	124.91 34.89 35.87	3.11 2.42 1.81		
7039	2308213.41 32 21 49.28	3.31 0.13	-4873598.28 295 20 34.72	3.07 0.13	3394558.48 -28.44	3.63 2.54
		1.38 -8.95 80.94	-15.89 73.90 82.79	4.03 3.32 2.52		
7040	2465049.46 18 15 28.38	3.69 0.13	-5534929.97 294 0 23.01	3.20 0.13	1985513.10 -8.68	4.01 3.20
		15.92 -73.82 -2.82	-44.27 -54.87 44.92	4.74 3.04 2.87		
7043	1130708.65 39 1 15.36	2.05 0.07	-4831331.29 283 10 20.04	1.72 0.09	3994135.53 3.15	1.91 1.52
		-2.98 2.53 -86.09	141.75 51.88 2.07	2.14 1.99 1.52		
7045	-1240470.24 39 38 47.63	4.15 0.10	-4760242.12 255 23 38.90	2.76 0.18	4048985.26 1767.76	2.88 2.11
		-0.61 4.15 -85.80	100.02 10.07 1.71	4.32 3.16 2.11		

TABLE 8.14.—(Cont'd)

7072	976261.31	2.15	-5601399.89	1.82	2880241.91	2.26
	27 1 14.12	0.07	279 53 12.13	0.08	-30.55	1.75
		7.46	-28.42	2.39		
		-0.71	61.49	2.09		
		-82.50	-33.92	1.74		
7075	692620.68	3.74	-4347076.48	3.81	4600475.43	3.45
	46 27 20.82	0.15	279 3 10.28	0.18	230.94	2.27
		-2.83	13.39	4.61		
		-1.69	103.47	3.75		
		86.71	44.29	2.26		
7076	1384158.71	4.13	-5905662.00	4.44	1966545.66	5.31
	18 4 34.63	0.17	283 11 26.83	0.14	410.95	4.55
		19.91	-26.78	5.59		
		-67.02	4.56	4.42		
		11.01	67.26	3.76		
8009	3923397.43	8.48	299869.39	10.07	5002975.49	6.86
	52 0 6.51	0.34	4 22 14.44	0.52	44.12	3.84
		-0.72	139.13	11.46		
		-5.58	49.06	8.65		
		84.37	56.47	3.76		
8010	4331306.98	5.71	567490.82	8.28	4633108.30	5.44
	46 52 36.97	0.25	7 27 51.89	0.39	920.89	2.26
		-0.12	119.88	8.51		
		0.46	-150.12	7.30		
		89.52	43.97	2.26		
8011	3920153.49	8.86	-134804.48	14.27	5012734.75	6.95
	52 8 36.27	0.34	358 1 49.85	0.76	138.88	3.84
		-0.31	115.65	15.38		
		2.38	-154.37	8.90		
		87.60	32.94	3.83		

TABLE 8.14.—(Cont'd)

8015	4578322.11	4.19	457936.54	8.00	4403195.29	4.38
	43 55 57.85	0.19	5 42 42.79	0.35	679.03	2.23
		-0.72	109.93	8.21		
		-1.37	19.91	5.33		
		88.46	47.83	2.23		
8019	4579463.17	4.12	586573.52	7.91	4386419.17	4.31
	43 43 33.30	0.18	7 17 56.93	0.35	394.39	2.17
		0.08	110.52	8.11		
		-1.33	20.52	5.26		
		88.67	16.92	2.17		
8030	4205626.92	6.46	163683.38	9.66	4776540.59	5.80
	48 48 22.24	0.27	2 13 43.79	0.47	182.83	2.37
		-1.15	117.70	10.06		
		1.18	-152.32	7.88		
		88.35	72.00	2.35		
9001	-1535750.66	4.17	-5167014.38	2.81	3401039.43	2.70
	32 25 24.39	0.08	253 26 48.80	0.17	1623.61	2.65
		1.24	98.65	4.42		
		59.41	6.55	2.75		
		-30.56	9.38	2.33		
9002	5056108.42	3.01	2716508.67	2.98	-2775768.77	4.21
	-25 57 36.39	0.14	28 14 52.52	0.11	1536.20	2.77
		-10.82	2.06	4.31		
		-15.92	95.19	3.18		
		70.59	59.23	2.66		
9004	5105581.46	3.42	-555271.46	9.96	3769675.97	3.97
	36 27 46.88	0.15	353 47 34.93	0.40	51.52	2.82
		-6.73	87.80	9.97		
		-0.33	-2.24	4.54		
		83.26	84.99	2.58		

TABLE 8.14.—(Cont'd)

9005	-3946730.47 35 40 22.02	9.20 0.27	3366286.15 139 32 17.28	8.99 0.45	3698822.94 94.06	7.51 5.29
		-1.55 3.04 86.58	-79.69 10.23 -142.70	11.28 8.18 5.27		
9006	1018164.52 29 21 34.71	12.37 0.19	5471108.70 79 27 28.60	5.48 0.47	3109625.60 1861.67	5.96 4.96
		-2.35 14.93 74.88	-91.67 -2.29 -172.95	12.60 6.00 4.86		
9007	1942760.95 -16 27 56.11	2.50 0.15	-5804088.24 288 30 23.66	2.88 0.09	-1796900.88 2469.27	4.38 2.72
		-2.85 -78.35 11.28	-8.78 95.21 80.65	4.50 2.72 2.48		
9008	3376875.17 29 38 13.87	6.75 0.20	4403976.17 52 31 11.20	6.11 0.29	3136257.32 1553.30	6.09 4.75
		5.39 8.26 80.12	-74.43 16.35 162.78	7.81 6.08 4.69		
9009	2251810.73 12 5 24.93	2.40 0.11	-5816917.57 291 9 43.64	2.07 0.08	1327163.44 -34.94	3.37 2.02
		8.42 -6.32 -79.44	-21.00 68.06 -58.40	3.50 2.29 1.97		
9010	976276.17 27 1 13.84	2.14 0.07	-5601402.23 279 53 12.65	1.81 0.08	2880234.50 -29.59	2.26 1.74
		7.47 -0.22 -82.52	-27.81 62.16 -29.48	2.38 2.07 1.73		

TABLE 8.14.—(Cont'd)

9011	2280575.30	2.37	-4914580.22	2.72	-3355383.71	3.70
	-31 56 34.20	0.12	294 53 35.94	0.09	606.19	2.56
	-11.45		-2.47	3.84		
	-54.53		104.05	2.55		
	33.04		79.96	2.34		
9012	-5466067.81	3.04	-2404312.68	2.92	2242188.45	3.35
	20 42 25.91	0.10	203 44 34.24	0.11	3059.03	2.87
	7.79		42.85	3.82		
	-62.21		117.81	2.96		
	-26.49		-43.24	2.38		
9021	-1936789.30	7.11	-5077714.74	5.34	3331922.70	5.30
	31 41 2.94	0.19	249 7 18.06	0.30	2349.90	3.25
	0.72		113.76	8.28		
	1.22		23.74	5.30		
	-88.58		54.04	3.25		
9028	4903726.56	2.06	3965206.29	2.10	963859.55	2.88
	8 44 51.11	0.09	38 57 33.76	0.07	1866.93	1.96
	2.55		-0.59	2.89		
	-0.88		89.37	2.18		
	87.31		160.38	1.95		
9029	5186441.45	2.14	-3653871.87	2.22	-654314.14	2.67
	- 5 55 39.91	0.09	324 50 6.46	0.08	8.29	2.02
	-10.14		5.92	2.68		
	4.56		95.10	2.34		
	78.86		-18.80	2.00		
9031	1693797.28	8.28	-4112353.08	8.75	-4556621.98	11.18
	-45 53 11.72	0.43	292 23 8.87	0.33	177.97	6.32
	-6.68		10.74	13.68		
	8.70		99.71	6.73		
	-79.00		137.78	6.15		

TABLE 8.14.—(Cont'd)

9051	4606861.50 37 58 37.26	4.19 0.18	2029692.20 23 46 38.43	10.29 0.41	3903562.20 192.42	4.42 3.34
		6.15 -2.74 83.26	108.28 18.58 -47.49	10.52 4.72 3.15		
9091	4595158.88 38 4 45.20	4.16 0.18	2039417.60 23 55 57.16	10.27 0.41	3912670.58 471.05	4.39 3.31
		6.26 -2.72 83.17	108.39 18.69 -47.93	10.51 4.69 3.12		
9424	-1264831.95 54 44 33.04	4.75 0.21	-3466915.40 249 57 23.60	5.54 0.27	5185450.92 669.87	4.32 2.39
		0.79 -0.26 89.17	-7.27 82.73 154.71	6.60 4.76 2.39		
9425	-2450012.65 34 57 50.43	2.64 0.08	-4624431.57 242 5 7.68	2.17 0.11	3635036.58 752.76	2.43 1.78
		4.51 7.40 -81.32	76.25 -14.34 17.38	2.83 2.56 1.75		
9426	3121261.30 60 12 39.83	8.63 0.34	592605.66 10 45 1.00	9.36 0.58	5512722.95 588.48	5.77 2.46
		-0.81 1.29 88.47	151.36 61.38 -150.80	11.01 8.25 2.44		
9427	-6007428.66 16 44 38.39	8.87 0.30	-1111852.47 190 29 8.26	19.80 0.71	1825733.94 25.36	8.62 5.10
		4.74 51.86 -37.74	-111.38 -15.32 -25.05	22.43 5.30 3.72		

TABLE 8.14.—(Cont'd)

9431	3183897.57	12.32	1421426.70	9.36	5322814.69	7.01
	56 56 55.73	0.39	24 3 28.83	0.69	8.09	2.38
		-0.46	-137.19	14.53		
		-0.58	132.81	8.47		
		89.27	171.15	2.38		
9432	3907419.17	7.93	1602378.59	10.36	4763922.08	5.86
	48 38 2.34	0.27	22 17 52.28	0.55	202.70	2.44
		-0.06	75.84	11.46		
		-0.05	165.84	8.19		
		89.92	116.63	2.44		

TABLE 8.15.—Station-to-Station Correlation Coefficients $\rho_{ij} > 0.75$
(Solution WN14)

* STA.NO.3106 WITH STA.NO.4061			* STA.NO.3405 WITH STA.NO.4081		
0.952	0.143	-0.121	0.939	0.119	0.029
0.141	0.942	-0.130	0.119	0.946	0.037
-0.116	-0.128	0.963	0.041	0.034	0.957
* STA.NO.3406 WITH STA.NO.9009			STA.NO.3413 WITH STA.NO.5735		
0.971	0.156	-0.290	0.853	0.145	-0.040
0.157	0.961	-0.057	0.138	0.861	0.038
-0.292	-0.058	0.985	-0.064	0.032	0.905
* STA.NO.3413 WITH STA.NO.6067			* STA.NO.3413 WITH STA.NO.9029		
0.962	0.157	-0.021	0.926	0.154	-0.019
0.157	0.965	0.047	0.153	0.930	0.047
-0.022	0.048	0.976	-0.018	0.047	0.952
STA.NO.3476 WITH STA.NO.5712			* STA.NO.3476 WITH STA.NO.6008		
0.857	0.120	-0.103	0.964	0.129	-0.107
0.119	0.838	-0.014	0.129	0.958	-0.021
-0.088	0.008	0.923	-0.107	-0.019	0.980
* STA.NO.3499 WITH STA.NO.6009			* STA.NO.3648 WITH STA.NO.5648		
1.000	0.107	0.063	0.987	0.275	0.002
0.107	1.000	-0.184	0.273	0.973	0.617
0.063	-0.184	1.000	0.003	0.617	0.987
* STA.NO.4050 WITH STA.NO.6068			STA.NO.4050 WITH STA.NO.9002		
0.910	-0.124	0.178	0.931	-0.126	0.180
-0.125	0.908	0.139	-0.127	0.930	0.140
0.175	0.138	0.952	0.180	0.142	0.963
STA.NO.4082 WITH STA.NO.9010			* STA.NO.4740 WITH STA.NO.7039		
0.741	0.022	-0.113	0.940	0.060	-0.281
0.020	0.662	0.159	0.061	0.931	0.290
-0.102	0.161	0.756	-0.275	0.283	0.951
STA.NO.5001 WITH STA.NO.5907			STA.NO.5001 WITH STA.NO.5911		
0.844	0.307	0.313	0.809	-0.055	0.314
-0.059	0.761	0.497	0.108	0.857	0.273
0.420	0.643	0.806	0.237	0.320	0.784
STA.NO.5001 WITH STA.NO.5915			STA.NO.5201 WITH STA.NO.6003		
0.767	0.306	0.395	0.899	-0.019	0.156
-0.225	0.565	0.477	-0.023	0.890	0.083
0.273	0.657	0.777	0.155	0.080	0.912
STA.NO.5410 WITH STA.NO.5730			STA.NO.5410 WITH STA.NO.5941		
0.778	0.133	0.098	0.716	-0.259	0.136
-0.099	0.746	-0.064	0.052	0.755	-0.016
0.129	-0.069	0.814	0.253	-0.044	0.834
STA.NO.5410 WITH STA.NO.6012			STA.NO.5410 WITH STA.NO.6066		
0.695	0.116	0.091	0.695	0.116	0.091
-0.079	0.699	-0.066	-0.079	0.698	-0.066
0.114	-0.072	0.778	0.113	-0.072	0.777
STA.NO.5712 WITH STA.NO.5912			* STA.NO.5712 WITH STA.NO.6008		
0.686	-0.002	-0.118	0.889	0.119	-0.088
-0.112	0.489	0.045	0.121	0.875	0.008
0.132	0.104	0.809	-0.103	-0.012	0.941
STA.NO.5713 WITH STA.NO.5715			* STA.NO.5713 WITH STA.NO.5739		
0.591	0.189	-0.331	0.994	0.206	-0.250
0.216	0.772	0.013	0.207	0.995	0.015
-0.340	0.075	0.651	-0.250	0.016	0.996

* $\rho_{ij} > 0.925$

TABLE 8.15.—(Cont'd)

STA.NO.5713 WITH STA.NO.5924			STA.NO.5713 WITH STA.NO.6007		
0.797	0.126	-0.275	0.886	0.190	-0.253
0.329	0.565	-0.063	0.204	0.904	0.002
-0.272	0.067	0.491	-0.244	0.014	0.921
STA.NO.5715 WITH STA.NO.5736			STA.NO.5715 WITH STA.NO.5739		
0.412	0.240	0.121	0.593	0.215	-0.340
0.145	0.765	-0.031	0.190	0.770	0.075
0.142	0.017	0.699	-0.330	0.015	0.650
STA.NO.5715 WITH STA.NO.5925			STA.NO.5715 WITH STA.NO.6063		
0.642	0.116	-0.022	0.838	0.194	-0.123
0.131	0.722	0.020	0.183	0.901	0.002
-0.036	-0.023	0.784	-0.117	-0.004	0.918
STA.NO.5717 WITH STA.NO.5720			STA.NO.5717 WITH STA.NO.6042		
0.649	-0.180	-0.032	0.610	-0.176	-0.033
0.019	0.751	0.015	0.007	0.706	0.010
0.029	-0.085	0.776	0.022	-0.082	0.751
* STA.NO.5720 WITH STA.NO.6042			* STA.NO.5720 WITH STA.NO.9028		
0.932	-0.096	-0.062	0.931	-0.095	-0.062
-0.097	0.934	-0.054	-0.095	0.934	-0.054
-0.060	-0.056	0.965	-0.060	-0.055	0.965
STA.NO.5721 WITH STA.NO.5923			* STA.NO.5721 WITH STA.NO.6015		
0.855	0.133	-0.194	0.892	-0.068	-0.151
-0.128	0.814	-0.260	-0.074	0.899	-0.256
-0.194	-0.320	0.715	-0.154	-0.246	0.931
STA.NO.5723 WITH STA.NO.5726			STA.NO.5723 WITH STA.NO.5930		
0.821	0.057	-0.000	0.817	0.191	-0.044
0.300	0.713	0.027	0.183	0.702	0.105
0.008	0.035	0.782	-0.039	-0.034	0.820
STA.NO.5723 WITH STA.NO.5931			STA.NO.5723 WITH STA.NO.6047		
0.897	-0.121	-0.057	0.750	0.057	-0.001
0.186	0.863	0.018	0.278	0.646	0.025
-0.062	0.075	0.891	0.004	0.031	0.745
STA.NO.5726 WITH STA.NO.5930			STA.NO.5726 WITH STA.NO.5931		
0.899	0.307	-0.024	0.838	0.179	0.002
0.044	0.773	0.127	0.149	0.711	-0.008
-0.119	0.083	0.831	0.010	0.034	0.823
STA.NO.5726 WITH STA.NO.5933			STA.NO.5726 WITH STA.NO.5934		
0.755	0.153	-0.118	0.792	0.109	-0.126
0.234	0.710	0.149	0.337	0.762	0.051
-0.082	0.142	0.822	-0.055	0.104	0.806
STA.NO.5726 WITH STA.NO.5935			* STA.NO.5726 WITH STA.NO.5937		
0.865	0.108	-0.093	0.962	0.132	-0.086
0.291	0.751	0.004	0.246	0.870	0.062
-0.024	-0.072	0.831	-0.050	0.044	0.893
* STA.NO.5726 WITH STA.NO.6047			STA.NO.5730 WITH STA.NO.5935		
0.909	0.169	-0.056	0.772	0.129	0.084
0.171	0.903	0.101	-0.030	0.905	-0.112
-0.052	0.096	0.951	0.033	-0.067	0.782
* STA.NO.5730 WITH STA.NO.6012			* STA.NO.5730 WITH STA.NO.6066		
0.890	-0.029	0.015	0.889	-0.029	0.015
-0.023	0.926	-0.018	-0.023	0.925	-0.018
0.008	-0.016	0.950	0.008	-0.017	0.950

TABLE 8.15.—(Cont'd)

STA.NO.5732 WITH STA.NO.5733			STA.NO.5732 WITH STA.NO.5938		
0.627	-0.199	0.084	0.750	0.043	-0.071
0.003	0.780	-0.301	-0.298	0.814	-0.070
-0.160	-0.125	0.790	0.041	-0.276	0.760
STA.NO.5732 WITH STA.NO.6059			STA.NO.5733 WITH STA.NO.5941		
0.582	-0.187	0.075	0.751	-0.061	0.146
0.000	0.731	-0.294	-0.041	0.765	-0.231
-0.153	-0.129	0.764	-0.111	-0.060	0.886
* STA.NO.5733 WITH STA.NO.6059			* STA.NO.5734 WITH STA.NO.6004		
0.933	-0.018	-0.000	0.934	-0.281	0.046
-0.021	0.940	-0.217	-0.287	0.954	-0.158
-0.001	-0.219	0.966	0.055	-0.153	0.967
STA.NO.5735 WITH STA.NO.5736			* STA.NO.5735 WITH STA.NO.6067		
0.763	0.058	0.028	0.887	0.139	-0.067
0.258	0.804	0.049	0.146	0.893	0.033
-0.029	-0.049	0.760	-0.043	0.041	0.928
STA.NO.5735 WITH STA.NO.9029			* STA.NO.5736 WITH STA.NO.6055		
0.853	0.136	-0.064	0.911	0.137	-0.038
0.142	0.861	0.033	0.130	0.911	0.045
-0.038	0.040	0.905	-0.037	0.038	0.938
STA.NO.5739 WITH STA.NO.5924			STA.NO.5739 WITH STA.NO.6007		
0.801	0.125	-0.274	0.880	0.190	-0.253
0.329	0.564	-0.062	0.203	0.899	0.002
-0.271	0.067	0.491	-0.243	0.013	0.917
STA.NO.5744 WITH STA.NO.5923			STA.NO.5744 WITH STA.NO.5924		
0.926	0.015	-0.291	0.849	0.155	-0.313
0.158	0.932	-0.228	0.044	0.750	-0.074
-0.307	-0.199	0.812	-0.390	-0.110	0.624
STA.NO.5744 WITH STA.NO.6016			STA.NO.5907 WITH STA.NO.5911		
0.868	0.132	-0.337	0.763	-0.202	0.425
0.117	0.903	-0.167	0.236	0.608	0.573
-0.315	-0.168	0.909	0.250	0.409	0.599
STA.NO.5907 WITH STA.NO.5915			STA.NO.5911 WITH STA.NO.5912		
0.902	0.387	0.458	0.587	0.116	0.367
0.120	0.859	0.717	-0.329	0.273	0.150
0.203	0.793	0.894	-0.040	0.288	0.802
STA.NO.5912 WITH STA.NO.6008			STA.NO.5923 WITH STA.NO.6015		
0.600	-0.085	0.120	0.793	-0.117	-0.195
0.005	0.422	0.094	0.107	0.746	-0.316
-0.127	0.019	0.762	-0.204	-0.250	0.689
STA.NO.5923 WITH STA.NO.6016			STA.NO.5930 WITH STA.NO.5937		
0.810	0.156	-0.306	0.822	0.102	-0.153
0.036	0.849	-0.197	0.370	0.584	0.065
-0.275	-0.224	0.750	-0.015	0.075	0.708
STA.NO.5930 WITH STA.NO.6047			STA.NO.5931 WITH STA.NO.5935		
0.816	0.044	-0.113	0.798	0.033	0.078
0.281	0.697	0.081	0.232	0.560	-0.063
-0.022	0.115	0.792	-0.005	-0.085	0.645
STA.NO.5931 WITH STA.NO.5937			STA.NO.5931 WITH STA.NO.6047		
0.794	0.119	0.065	0.767	0.140	0.009
0.237	0.562	-0.034	0.168	0.645	0.032
0.006	-0.029	0.681	0.000	-0.005	0.782

TABLE 8.15.—(Cont'd)

STA.NO.5933 WITH STA.NO.5934			STA.NO.5933 WITH STA.NO.5937		
0.845	-0.031	-0.179	0.754	0.141	-0.169
0.174	0.837	0.005	0.190	0.678	0.113
-0.093	0.066	0.853	-0.110	0.079	0.783
STA.NO.5933 WITH STA.NO.5938			STA.NO.5933 WITH STA.NO.6047		
0.743	-0.118	-0.180	0.682	0.212	-0.077
0.194	0.786	-0.048	0.139	0.639	0.137
-0.056	0.091	0.731	-0.102	0.138	0.782
STA.NO.5934 WITH STA.NO.5935			STA.NO.5934 WITH STA.NO.5937		
0.807	0.168	-0.133	0.856	0.216	-0.113
0.155	0.816	0.018	0.102	0.863	0.075
-0.072	-0.052	0.899	-0.124	0.015	0.857
STA.NO.5934 WITH STA.NO.5938			STA.NO.5934 WITH STA.NO.6047		
0.905	-0.044	-0.149	0.718	0.304	-0.052
0.107	0.925	-0.025	0.103	0.688	0.103
-0.102	0.052	0.893	-0.108	0.052	0.765
STA.NO.5935 WITH STA.NO.5937			STA.NO.5935 WITH STA.NO.5938		
0.920	0.187	-0.025	0.583	0.099	-0.093
0.097	0.884	-0.076	0.192	0.669	-0.047
-0.079	-0.025	0.881	-0.158	0.074	0.780
STA.NO.5935 WITH STA.NO.6012			STA.NO.5935 WITH STA.NO.6047		
0.682	-0.026	0.026	0.792	0.266	-0.023
0.113	0.839	-0.072	0.103	0.682	-0.065
0.057	-0.106	0.737	-0.079	0.009	0.789
STA.NO.5935 WITH STA.NO.6066			STA.NO.5937 WITH STA.NO.6047		
0.682	-0.026	0.026	0.876	0.225	-0.048
0.113	0.839	-0.072	0.125	0.787	0.045
0.057	-0.106	0.737	-0.074	0.060	0.849
STA.NO.5941 WITH STA.NO.6059			* STA.NO.6002 WITH STA.NO.7043		
0.709	-0.043	-0.107	0.959	0.030	-0.116
-0.066	0.724	-0.065	0.031	0.943	0.264
0.135	-0.231	0.858	-0.116	0.264	0.954
STA.NO.6011 WITH STA.NO.6059			* STA.NO.6011 WITH STA.NO.9012		
0.441	-0.254	0.002	0.981	-0.242	0.114
-0.133	0.756	-0.158	-0.242	0.980	-0.365
0.037	-0.277	0.219	0.116	-0.365	0.985
* STA.NO.6012 WITH STA.NO.6066			STA.NO.6016 WITH STA.NO.6065		
0.999	-0.026	0.004	0.697	0.106	-0.407
-0.025	0.999	-0.021	0.077	0.790	-0.227
0.004	-0.021	0.999	-0.436	-0.240	0.686
* STA.NO.6019 WITH STA.NO.9011			STA.NO.6023 WITH STA.NO.6060		
0.970	-0.027	0.120	0.829	0.329	-0.199
-0.024	0.977	-0.254	0.283	0.802	0.039
0.117	-0.256	0.987	-0.267	-0.095	0.707
STA.NO.6031 WITH STA.NO.6060			STA.NO.6038 WITH STA.NO.6111		
0.847	0.311	-0.166	0.807	-0.180	0.211
0.385	0.605	-0.137	-0.052	0.292	-0.031
-0.108	0.021	0.634	0.167	-0.111	0.233
STA.NO.6038 WITH STA.NO.6134			STA.NO.6038 WITH STA.NO.9425		
0.808	-0.179	0.211	0.770	-0.177	0.208
-0.052	0.293	-0.032	-0.054	0.270	-0.025
0.167	-0.112	0.233	0.162	-0.099	0.220

TABLE 8.15.—(Cont'd)

* STA.NO.6042 WITH STA.NO.9028			STA.NO.6050 WITH STA.NO.6061		
0.965	-0.102	-0.060	0.109	-0.358	0.106
-0.102	0.966	-0.057	0.222	0.840	-0.153
-0.060	-0.055	0.982	-0.116	-0.438	0.314
* STA.NO.6067 WITH STA.NO.9029			* STA.NO.6068 WITH STA.NO.9002		
0.962	0.155	-0.022	0.977	-0.125	0.175
0.154	0.965	0.049	-0.125	0.977	0.140
-0.019	0.049	0.976	0.177	0.142	0.988
* STA.NO.6111 WITH STA.NO.6134			* STA.NO.6111 WITH STA.NO.9425		
0.999	-0.312	0.157	0.954	-0.304	0.158
-0.312	0.999	0.187	-0.308	0.933	0.191
0.157	0.187	0.999	0.159	0.195	0.946
STA.NO.6134 WITH STA.NO.9425			* STA.NO.7072 WITH STA.NO.9010		
0.953	-0.304	0.158	0.964	0.034	-0.140
-0.308	0.932	0.191	0.035	0.949	0.156
0.159	0.195	0.945	-0.141	0.157	0.967
STA.NO.8009 WITH STA.NO.8010			STA.NO.8009 WITH STA.NO.8015		
0.619	0.149	-0.610	0.545	0.182	-0.545
0.047	0.794	-0.168	0.095	0.778	-0.236
-0.593	-0.217	0.602	-0.532	-0.242	0.559
STA.NO.8009 WITH STA.NO.8019			STA.NO.8010 WITH STA.NO.8015		
0.551	0.173	-0.550	0.717	0.093	-0.679
0.092	0.777	-0.242	0.083	0.931	-0.296
-0.537	-0.232	0.564	-0.695	-0.268	0.762
STA.NO.8010 WITH STA.NO.8019			* STA.NO.8015 WITH STA.NO.8019		
0.726	0.085	-0.682	0.950	0.095	-0.707
0.079	0.936	-0.303	0.098	0.986	-0.321
-0.701	-0.261	0.768	-0.709	-0.310	0.954
STA.NO.8015 WITH STA.NO.8030			STA.NO.8015 WITH STA.NO.9004		
0.591	0.125	-0.561	0.593	0.386	-0.335
0.124	0.787	-0.186	0.059	0.788	-0.313
-0.560	-0.273	0.592	-0.436	-0.532	0.556
STA.NO.8019 WITH STA.NO.8030			STA.NO.8019 WITH STA.NO.9004		
0.578	0.123	-0.551	0.615	0.391	-0.328
0.118	0.779	-0.179	0.064	0.786	-0.322
-0.553	-0.274	0.581	-0.437	-0.540	0.581
STA.NO.9004 WITH STA.NO.9051			STA.NO.9004 WITH STA.NO.9091		
0.551	0.197	-0.518	0.555	0.198	-0.521
0.305	0.136	-0.224	0.307	0.137	-0.225
-0.263	-0.433	0.812	-0.264	-0.433	0.818
STA.NO.9004 WITH STA.NO.9426			STA.NO.9007 WITH STA.NO.9011		
0.322	-0.003	-0.267	0.752	-0.080	0.167
0.460	0.811	-0.538	-0.006	0.376	-0.049
-0.264	-0.131	0.277	0.058	0.051	0.512
* STA.NO.9051 WITH STA.NO.9091			STA.NO.9051 WITH STA.NO.9431		
0.990	-0.299	-0.208	0.540	-0.152	-0.528
-0.301	0.998	-0.383	-0.523	0.826	0.283
-0.207	-0.381	0.991	-0.102	-0.354	0.250
STA.NO.9051 WITH STA.NO.9432			STA.NO.9091 WITH STA.NO.9431		
0.598	-0.196	-0.530	0.543	-0.152	-0.531
-0.470	0.809	0.047	-0.523	0.828	0.283
-0.151	-0.334	0.371	-0.103	-0.355	0.252
STA.NO.9091 WITH STA.NO.9432			STA.NO.9431 WITH STA.NO.9432		
0.602	-0.196	-0.533	0.808	-0.451	-0.617
-0.471	0.810	0.047	-0.373	0.847	-0.085
-0.152	-0.335	0.374	-0.750	0.180	0.721

TABLE 8.16.—Station Correlation Coefficients $\rho_{ij} > 0.75$ (Solution WN14)

* STA.NO.1032			STA.NO.3478		
1.000	0.967	0.779	1.000	0.875	-0.919
0.967	1.000	0.880	0.875	1.000	-0.837
0.779	0.880	1.000	-0.919	-0.837	1.000
STA.NO.3902			STA.NO.8010		
1.000	-0.155	0.087	1.000	0.027	-0.817
-0.155	1.000	0.813	0.027	1.000	-0.206
0.087	0.813	1.000	-0.817	-0.206	1.000
STA.NO.8011			STA.NO.8030		
1.000	0.408	-0.752	1.000	0.139	-0.845
0.408	1.000	-0.382	0.139	1.000	-0.241
-0.752	-0.382	1.000	-0.845	-0.241	1.000
STA.NO.9426			STA.NO.9427		
1.000	0.230	-0.857	1.000	-0.858	0.636
0.230	1.000	-0.353	-0.858	1.000	-0.813
-0.857	-0.353	1.000	0.636	-0.813	1.000
STA.NO.9431					
1.000	-0.441	-0.870			
-0.441	1.000	0.129			
-0.870	0.129	1.000			

* $\rho_{ij} > 0.925$

TABLE 8.17.—*Chord Length Comparisons (Solutions WN12, WN14, and WN16)*

Type	Line	Adjusted—given length					
		WN12		WN14		WN16	
		m	ppM	m	ppM	m	ppM
EDM	6002-6003-----	8.3 ± 2.5	2.38	2.7 ± 2.3	0.78	5.9 ± 3.0	1.70
	6003-6111-----	2.7 ± 1.4	1.90	2.3 ± 1.4	1.60	11.4 ± 3.1	8.00
	6006-6065-----	7.7 ± 2.1	3.13	6.1 ± 2.0	2.47	19.9 ± 3.5	8.13
	6016-6065-----	-2.8 ± 1.3	2.30	-2.9 ± 1.3	2.47	-18.9 ± 3.4	15.87
	6006-6016-----	2.7 ± 2.2	0.77	1.3 ± 2.1	0.37	1.6 ± 3.3	0.46
	6063-6064-----	13.7 ± 2.4	3.94	10.6 ± 2.3	3.03	15.2 ± 2.8	4.37
	6023-6060-----	7.9 ± 3.1	3.42	5.9 ± 3.0	2.55	9.6 ± 3.8	4.16
	6032-6060-----	-2.4 ± 3.9	0.76	-4.5 ± 3.6	1.42	-2.9 ± 3.7	0.92
	3861-7043-----	2.2 ± 1.8	1.44	1.5 ± 1.8	0.99	7.6 ± 3.7	5.00
C-band	4082-4050-----	26.5 ± 6.9	2.42	-5.2 ± 3.9	0.48	-4.2 ± 4.0	0.39
	4082-4740-----	2.0 ± 2.7	1.25	1.3 ± 2.7	1.90	6.6 ± 5.0	4.13
	4082-4081-----	3.0 ± 2.3	2.40	2.3 ± 2.3	0.79	17.9 ± 6.2	14.49
	4082-4061-----	-0.4 ± 3.6	0.19	-1.5 ± 3.6	0.65	2.1 ± 6.1	0.93
Average	EDM -----		2.22		1.74		5.40
	C-band -----		1.56		0.96		4.98
	All -----		2.02		1.50		5.27

^a Not constrained in WN12 and WN14.TABLE 8.18.—*Standard Deviation Comparisons (Solutions WN12, WN14, and WN16)^a*

Solution	Constituent Networks								WN _i	
	BC		SECOR		MPS		SA			
	σ	σ _h	σ	σ _h	σ	σ _h	σ	σ _h	σ	σ _h
WN12 ----	4.4	5.0	4.2	4.8	6.9	7.6	5.2	5.9	5.5	6.2
WN14 ----	3.5	3.2	2.8	2.4	4.8	2.9	4.1	3.0	3.9	2.9
WN16 ----	3.5	3.2	2.8	2.4	4.9	2.9	4.1	3.0	4.0	2.9

^a All units in meters.

TABLE 8.19.—Transformation: WN14 - WN16

 SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

 SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.0+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-0.08	-0.57	-0.04	-0.06	-0.00	0.00	0.01
± 0.25	± 0.25	± 0.30	± 0.00	± 0.00	± 0.00	± 0.00

 VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 0.22$$

0.6420-01	0.3990-04	-0.1180-03	-0.1160-10	0.6330-10	0.1860-09	-0.3560-11
0.3990-04	0.6450-01	0.1940-03	0.1590-10	0.7280-10	-0.3610-11	-0.1940-09
-0.1180-03	0.1940-03	0.9300-01	-0.2190-10	0.6820-11	-0.1020-09	-0.1470-09
-0.1160-10	0.1590-10	-0.2190-10	0.1410-16	0.6380-20	-0.5830-20	0.2720-19
0.6330-10	0.7280-10	0.6820-11	0.6380-20	0.9930-16	-0.1140-16	0.1550-17
0.1860-09	-0.3610-11	-0.1020-09	-0.5830-20	-0.1140-16	0.1400-15	-0.3430-17
-0.3560-11	-0.1940-09	-0.1470-09	0.2720-19	0.1550-17	-0.3430-17	0.1340-15

 COEFFICIENTS OF CORRELATION

0.1000+01	0.6190-03	-0.1530-02	-0.1220-01	0.2510-01	0.6210-01	-0.1210-02
0.6190-03	0.1000+01	0.2500-02	0.1670-01	0.2880-01	-0.1200-02	-0.6590-01
-0.1530-02	0.2500-02	0.1000+01	-0.1910-01	0.2240-02	-0.2820-01	-0.4160-01
-0.1220-01	0.1670-01	-0.1910-01	0.1000+01	0.1700-03	-0.1310-03	0.6230-03
0.2510-01	0.2880-01	0.2240-02	0.1700-03	0.1000+01	-0.9620-01	0.1340-01
0.6210-01	-0.1200-02	-0.2820-01	-0.1310-03	-0.9620-01	0.1000+01	-0.2490-01
-0.1210-02	-0.6590-01	-0.4160-01	0.6230-03	0.1340-01	-0.2490-01	0.1000+01

TABLE 8.19.—(Cont'd)

RESIDUALS V											
V1(WN - 16)				V2(WN - 14)				V1 - V2			
-----				-----				-----			
3861	0.2	-0.9	-1.6	3861	-0.2	1.0	2.6	0.4	-1.9	-4.2	
4061	0.4	-0.4	-0.9	4061	-0.7	0.5	1.3	1.1	-0.9	-2.2	
4081	3.2	-0.2	-3.9	4081	-6.7	0.2	7.0	9.9	-0.5	-10.9	
4082	-0.9	-0.5	-0.3	4082	1.1	0.5	0.3	-1.9	-1.0	-0.5	
4740	1.2	0.4	-0.5	4740	-2.1	-0.5	0.5	3.3	0.8	-1.0	
6001	-0.7	0.7	-0.0	6001	0.7	-0.7	0.0	-1.5	1.4	-0.1	
6002	0.5	0.4	0.5	6002	-0.6	-0.4	-0.6	1.2	0.8	1.2	
6003	-0.5	1.3	1.4	6003	0.6	-1.5	-1.7	-1.0	2.8	3.1	
6004	-0.2	0.4	0.5	6004	0.2	-0.4	-0.5	-0.4	0.8	1.0	
6006	-1.0	0.8	0.7	6006	1.2	-0.9	-0.9	-2.1	1.7	1.5	
6007	-0.1	-0.3	0.4	6007	0.1	0.3	-0.5	-0.2	-0.5	0.9	
6008	0.1	-0.2	0.5	6008	-0.1	0.2	-0.5	0.1	-0.4	1.0	
6009	0.1	-0.1	0.3	6009	-0.1	0.1	-0.3	0.2	-0.3	0.5	
6011	-0.7	0.3	-0.5	6011	0.7	-0.3	0.5	-1.5	0.6	-1.0	
6012	0.1	0.2	0.1	6012	-0.1	-0.2	-0.1	0.3	0.3	0.2	
6013	0.2	-0.0	0.2	6013	-0.2	0.0	-0.2	0.4	-0.0	0.4	
6015	0.2	0.2	0.4	6015	-0.2	-0.2	-0.4	0.4	0.4	0.8	
6016	-0.5	0.1	1.1	6016	0.5	-0.1	-1.3	-1.1	0.1	2.4	
6019	0.1	-0.5	0.5	6019	-0.1	0.5	-0.5	0.1	-1.0	1.0	
6020	-0.7	-0.3	0.5	6020	0.7	0.3	-0.5	-1.4	-0.6	1.0	
6022	-0.1	-0.0	0.6	6022	0.1	0.0	-0.6	-0.2	-0.0	1.1	
6023	-0.1	-0.0	1.3	6023	0.1	0.0	-1.5	-0.3	-0.1	2.8	
6031	-0.1	-0.4	0.0	6031	0.1	0.4	-0.0	-0.2	-0.9	0.1	
6032	0.3	-0.1	0.1	6032	-0.3	0.1	-0.1	0.7	-0.2	0.1	
6038	-1.0	0.1	-0.0	6038	1.1	-0.1	0.0	-2.1	0.2	-0.1	
6039	-0.5	-0.0	0.6	6039	0.5	0.0	-0.6	-1.1	-0.1	1.2	
6040	0.3	-0.2	0.4	6040	-0.3	0.2	-0.4	0.7	-0.4	0.9	
6042	-0.2	-0.1	0.4	6042	0.2	0.1	-0.4	-0.4	-0.2	0.8	
6043	-0.0	-0.5	0.3	6043	0.0	0.5	-0.3	-0.0	-0.9	0.7	
6044	0.1	-0.0	0.4	6044	-0.1	0.0	-0.4	0.2	-0.1	0.8	
6045	0.1	-0.2	0.7	6045	-0.1	0.2	-0.7	0.2	-0.4	1.4	
6047	0.4	-0.2	0.2	6047	-0.4	0.2	-0.2	0.8	-0.4	0.4	
6050	0.0	-0.5	0.3	6050	-0.0	0.5	-0.3	0.0	-1.0	0.7	
6051	0.1	-0.2	0.4	6051	-0.1	0.2	-0.4	0.2	-0.4	0.8	
6052	0.2	-0.3	0.2	6052	-0.2	0.3	-0.2	0.3	-0.7	0.5	
6053	0.0	-0.5	0.2	6053	-0.0	0.5	-0.2	0.0	-0.9	0.5	
6055	-0.3	-0.6	0.5	6055	0.3	0.6	-0.5	-0.6	-1.2	1.1	
6059	-0.3	0.2	0.6	6059	0.3	-0.2	-0.6	-0.5	0.5	1.2	
6060	-0.1	-0.7	-0.2	6060	0.1	0.8	0.2	-0.1	-1.5	-0.5	
6061	0.1	-0.5	0.4	6061	-0.1	0.5	-0.4	0.1	-0.9	0.7	
6063	-0.4	-0.7	0.7	6063	0.4	0.8	-0.7	-0.8	-1.5	1.4	
6064	-0.0	1.3	0.6	6064	0.0	-1.6	-0.6	-0.0	2.9	1.2	
6065	2.5	2.6	-4.3	6065	-3.3	-2.9	7.3	5.8	5.5	-11.6	
6066	0.1	0.2	0.1	6066	-0.1	-0.2	-0.1	0.3	0.3	0.2	
6067	-0.0	-0.5	0.7	6067	0.0	0.5	-0.7	-0.1	-1.1	1.4	

TABLE 8.19.—(Cont'd)

RESIDUALS V											
V1(WN - 16)				V2(WN - 14)				V1 - V2			
-----				-----				-----			
6068	-0.1	0.3	1.1	6068	0.1	-0.3	-1.1	-0.3	0.6	2.2	
6069	-0.1	-0.7	0.4	6069	0.1	0.7	-0.4	-0.1	-1.4	0.9	
6072	0.3	-0.2	0.2	6072	-0.3	0.2	-0.2	0.7	-0.4	0.5	
6073	0.2	-0.3	0.6	6073	-0.2	0.3	-0.6	0.4	-0.5	1.1	
6075	0.0	-0.2	0.6	6075	-0.0	0.2	-0.6	0.0	-0.5	1.1	
6078	-0.3	-0.3	1.1	6078	0.3	0.3	-1.1	-0.5	-0.7	2.1	
6111	-0.9	-1.0	-1.8	6111	1.0	1.3	2.6	-1.9	-2.3	-4.4	
6123	-0.5	0.7	0.0	6123	0.6	-0.7	-0.0	-1.1	1.3	0.1	
6134	-0.9	-1.0	-1.8	6134	1.0	1.3	2.6	-1.9	-2.3	-4.4	
7043	0.5	0.4	0.5	7043	-0.6	-0.5	-0.7	1.2	0.9	1.2	

UNIT OF RESIDUALS (METERS)

TABLE 8.20.—Transformation: WN14 - WN12

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.0+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
1.02	-1.87	4.53	-1.94	-0.04	-0.05	-0.05
± 0.50	± 0.52	± 0.62	± 0.01	± 0.00	± 0.00	± 0.00

VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 0.68$$

0.246D+00	0.652D-04	-0.285D-03	-0.175D-09	0.284D-09	0.757D-09	-0.155D-10
0.652D-04	0.270D+00	0.416D-03	0.187D-09	0.255D-09	-0.139D-10	-0.705D-09
-0.285D-03	0.416D-03	0.384D+00	-0.320D-09	0.289D-10	-0.382D-09	-0.499D-09
-0.175D-09	0.187D-09	-0.320D-09	0.215D-15	0.622D-19	-0.677D-19	0.346D-18
0.284D-09	0.255D-09	0.289D-10	0.622D-19	0.378D-15	-0.472D-16	0.611D-17
0.757D-09	-0.139D-10	-0.382D-09	-0.677D-19	-0.472D-16	0.534D-15	-0.140D-16
-0.155D-10	-0.705D-09	-0.499D-09	0.346D-18	0.611D-17	-0.140D-16	0.523D-15

COEFFICIENTS OF CORRELATION

0.100D+01	0.253D-03	-0.927D-03	-0.241D-01	0.294D-01	0.661D-01	-0.137D-02
0.253D-03	0.100D+01	0.129D-02	0.246D-01	0.252D-01	-0.116D-02	-0.593D-01
-0.927D-03	0.129D-02	0.100D+01	-0.353D-01	0.240D-02	-0.267D-01	-0.352D-01
-0.241D-01	0.246D-01	-0.353D-01	0.100D+01	0.218D-03	-0.200D-03	0.103D-02
0.294D-01	0.252D-01	0.240D-02	0.218D-03	0.100D+01	-0.105D+00	0.137D-01
0.661D-01	-0.116D-02	-0.267D-01	-0.200D-03	-0.105D+00	0.100D+01	-0.265D-01
-0.137D-02	-0.593D-01	-0.352D-01	0.103D-02	0.137D-01	-0.265D-01	0.100D+01

TABLE 8.20.—(Cont'd)

RESIDUALS V									

V1(WN - 12)				V2(WN - 14)				V1 - V2	
-----				-----				-----	
3861	-0.2	-1.5	2.7	3861	0.3	3.8	-5.4	-0.5	-5.3
4061	-0.5	-2.7	3.9	4061	0.6	5.0	-5.1	-1.1	-7.6
4081	-1.0	0.1	1.3	4081	1.2	-0.4	-2.0	-2.2	0.5
4082	0.7	-2.4	2.4	4082	-0.9	6.2	-4.3	1.6	-8.6
4740	-0.2	-2.4	2.2	4740	0.3	7.0	-4.1	-0.5	-9.4
6001	-0.3	-0.1	-0.8	6001	0.3	0.2	1.4	-0.6	-0.3
6002	-0.7	0.3	0.3	6002	0.8	-0.8	-0.9	-1.5	1.1
6003	-0.4	1.0	-1.4	6003	0.5	-1.8	3.3	-0.9	2.9
6004	0.1	1.0	-1.2	6004	-0.2	-1.3	1.9	0.3	2.3
6006	0.5	0.6	-2.0	6006	-0.6	-0.8	4.5	1.0	1.3
6007	3.5	-1.2	3.4	6007	-6.3	1.9	-7.9	9.7	-3.1
6008	3.2	1.5	0.1	6008	-8.1	-4.2	-0.1	11.3	5.7
6009	-0.3	0.1	-0.9	6009	0.3	-0.2	1.1	-0.6	0.2
6011	-2.6	1.5	0.5	6011	5.5	-2.0	-0.6	-8.1	3.6
6012	1.1	0.6	-0.4	6012	-2.0	-0.9	0.5	3.1	1.6
6013	-0.3	-0.7	-0.6	6013	0.4	0.9	0.9	-0.7	-1.6
6015	-0.7	-2.8	-0.4	6015	1.1	4.9	0.8	-1.8	-7.7
6016	-0.6	-0.1	-0.4	6016	1.0	0.2	0.8	-1.6	-0.3
6019	0.1	1.6	-1.9	6019	-0.2	-2.7	3.8	0.3	4.3
6020	-1.0	1.7	-1.5	6020	1.2	-3.1	2.4	-2.2	4.8
6022	-0.5	1.7	0.3	6022	1.0	-2.1	-0.3	-1.5	3.8
6023	1.8	-0.8	0.3	6023	-3.6	1.3	-0.4	5.4	-2.1
6031	1.1	1.5	0.9	6031	-1.9	-1.8	-1.8	3.1	3.4
6032	-0.6	-0.0	-0.3	6032	0.7	0.1	0.5	-1.3	-0.1
6038	-0.9	0.3	-0.0	6038	1.2	-0.6	0.0	-2.1	0.9
6039	-0.3	3.5	-0.0	6039	0.5	-6.3	0.0	-0.8	9.8
6040	-1.6	-1.1	-0.9	6040	1.7	1.9	1.2	-3.3	-3.1
6042	-2.7	-2.2	-1.6	6042	4.9	4.3	2.3	-7.7	-6.5
6043	-0.7	2.8	-1.9	6043	0.8	-3.4	4.2	-1.5	6.2
6044	-1.2	1.2	-4.0	6044	1.2	-1.4	8.1	-2.3	2.7
6045	-1.7	-1.3	-1.3	6045	2.2	2.1	1.8	-3.9	-3.3
6047	0.1	-1.4	0.3	6047	-0.1	2.9	-0.4	0.2	-4.3
6050	-0.8	3.3	-0.9	6050	0.9	-3.5	2.5	-1.7	6.8
6051	-0.9	1.3	-1.4	6051	0.9	-1.7	3.7	-1.8	3.0
6052	-0.7	1.1	-0.5	6052	0.8	-1.3	1.0	-1.5	2.4
6053	-0.2	1.9	-0.2	6053	0.2	-2.1	0.6	-0.4	4.0
6055	1.5	0.6	-0.1	6055	-2.9	-0.9	0.1	4.3	1.5
6059	-1.1	2.6	-1.1	6059	2.7	-3.8	1.5	-3.8	6.4
6060	1.4	0.1	0.8	6060	-2.6	-0.1	-1.4	4.0	0.2
6061	0.0	3.5	-2.4	6061	-0.0	-3.7	5.3	0.0	7.2
6063	0.8	0.7	1.2	6063	-1.5	-1.1	-2.1	2.2	1.8
6064	-1.2	-0.8	-0.2	6064	1.7	1.1	0.3	-2.9	-1.9
6065	-0.2	-0.0	-1.0	6065	0.4	0.0	2.3	-0.6	-0.0
6066	1.1	0.6	-0.4	6066	-2.0	-0.9	0.5	3.1	1.6
6067	2.6	1.3	0.0	6067	-6.7	-2.3	-0.0	9.3	3.6

TABLE 8.20.—(Cont'd)

RESIDUALS V											

V1(WN - 12)				V2(WN - 14)				V1 - V2			
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6068	-1.1	-0.1	-1.8	6068	2.2	0.2	2.9	-3.3	-0.3	-4.7	
6069	-0.1	2.4	-3.5	6069	0.1	-2.5	5.9	-0.1	4.9	-9.4	
6072	-1.7	-2.5	-0.9	6072	1.8	4.1	1.2	-3.5	-6.6	-2.1	
6073	-1.7	-1.3	-1.2	6073	2.0	2.2	1.5	-3.7	-3.5	-2.6	
6075	-1.4	-1.4	-1.6	6075	1.7	2.3	2.0	-3.1	-3.7	-3.6	
6078	1.5	0.3	-0.5	6078	-6.2	-0.4	0.9	7.6	0.7	-1.3	
6111	-0.9	-0.2	0.4	6111	1.2	0.4	-1.1	-2.1	-0.5	1.6	
6123	-0.9	0.8	0.5	6123	1.0	-0.9	-1.2	-1.8	1.7	1.7	
6134	-0.9	-0.2	0.4	6134	1.2	0.4	-1.1	-2.1	-0.5	1.6	
7043	-0.7	0.3	0.4	7043	0.9	-0.7	-0.9	-1.6	0.9	1.3	

UNIT OF RESIDUALS (METERS)

TABLE 8.21.—*Height Residuals (Solution WN14)*

STN. NO.	NOSUGC	N REF	NOSUGC-N REF	RESIDUALS
1021	-53.33	-37.32	-16.01	-3.07
1022	-38.20	-31.58	-6.62	6.33
1030	-51.74	-30.00	-21.74	-8.79
1032	-2.12	11.57	-13.69	-0.75
1033	-3.91	9.11	-13.02	-0.08
1034	-40.84	-25.47	-15.37	-2.42
1042	-47.53	-34.38	-13.15	-0.20
3106	-53.30	-49.83	-3.47	9.47
3334	-45.79	-31.54	-14.25	-1.30
3400	-32.19	-18.42	-13.77	-0.82
3401	-46.81	-30.59	-16.22	-3.28
3402	-48.34	-29.04	-19.30	-6.36
3404	-43.00	-6.69	-36.31	-23.36
3405	-65.84	-49.77	-16.07	-3.12
3406	-38.89	-29.19	-9.70	3.24
3407	-60.27	-38.57	-21.70	-8.76
3413	-19.55	-12.03	-7.52	5.43
3414	-27.84	-9.88	-17.96	-5.02
3431	5.59	11.98	-6.39	6.56
3476	-44.50	-28.31	-16.19	-3.25
3477	0.51	10.71	-10.20	2.74
3478	-20.75	-7.17	-13.58	-0.64
3499	3.87	16.73	-12.86	0.09
3648	-48.91	-35.70	-13.21	-0.26
3657	-49.62	-36.55	-13.07	-0.13
3861	-43.88	-33.70	-10.18	2.76
3902	-31.19	-16.53	-14.66	-1.72
3903	-57.45	-36.87	-20.58	-7.63
5001	-44.20	-36.87	-7.33	5.62
5201	-39.05	-17.65	-21.40	-8.46
5410	-6.20	-4.13	-2.07	10.88
5648	-47.90	-35.07	-12.83	0.12
5712	-44.22	-28.31	-15.91	-2.97
5713	49.11	54.00	-4.89	8.05
5715	23.59	27.20	-3.61	9.33

TABLE 8.21.—(Cont'd)

STN. NO.	NCSUGC	N REF	NOSUGC-N REF	RESIDUALS
5717	7.70	10.35	-2.65	10.30
5720	-16.89	-5.78	-11.11	1.84
5721	-32.25	-20.67	-11.58	1.37
5722	-87.78	-73.64	-14.14	-1.19
5723	-59.91	-40.39	-19.52	-6.58
5726	61.98	62.16	-0.18	12.76
5730	-4.72	13.75	-18.47	-5.53
5732	8.67	27.35	-18.68	-5.73
5733	-0.23	16.07	-16.30	-3.35
5734	-3.56	6.22	-9.78	3.17
5735	-19.53	-12.03	-7.50	5.45
5736	4.41	16.26	-11.85	1.10
5739	48.73	54.00	-5.27	7.67
5744	23.35	37.43	-14.08	-1.14
5907	-42.61	-28.11	-14.50	-1.56
5911	-43.33	-43.44	0.11	13.05
5912	-13.16	6.16	-19.32	-6.38
5914	-67.99	-50.08	-17.91	-4.97
5915	-41.79	-26.32	-15.47	-2.52
5923	22.05	24.64	-2.59	10.35
5924	23.49	54.48	-30.99	-18.04
5925	26.11	33.75	-7.64	5.31
5930	9.73	8.28	1.45	14.39
5931	-28.03	2.32	-30.35	-17.40
5933	48.80	50.66	-1.86	11.09
5934	58.59	74.75	-16.16	-3.22
5935	42.62	48.15	-5.53	7.42
5937	51.60	69.93	-18.33	-5.38
5938	49.03	59.97	-10.94	2.01
5941	4.87	2.05	2.82	15.76
6001	4.33	11.66	-7.33	5.61
6002	-50.76	-36.90	-13.86	-0.92
6003	-39.23	-17.65	-21.58	-8.64
6004	-3.23	6.22	-9.45	3.50
6006	11.02	27.06	-16.04	-3.09

TABLE 8.21.—(Cont'd)

STN. NO.	NOSUGC	N REF	NOSUGC-N REF	RESIDUALS
6007	49.70	54.00	-4.30	8.64
6008	-44.48	-28.31	-16.17	-3.23
6009	3.57	16.73	-13.16	-0.21
6011	3.20	1.75	1.45	14.40
6012	-4.85	13.75	-18.60	-5.66
6013	15.27	34.27	-19.00	-6.06
6015	-33.55	-20.67	-12.88	0.07
6016	23.27	37.43	-14.16	-1.22
6019	5.60	22.80	-17.20	-4.25
6020	-21.60	-4.75	-16.85	-3.90
6022	7.62	27.35	-19.73	-6.78
6023	44.08	67.94	-23.86	-10.92
6031	-14.32	8.68	-23.00	-10.05
6032	-37.42	-30.51	-6.91	6.03
6038	-49.95	-35.47	-14.48	-1.54
6039	-37.29	-16.68	-20.61	-7.66
6040	-52.86	-38.11	-14.75	-1.81
6042	-17.34	-5.78	-11.56	1.39
6043	-3.29	15.60	-18.89	-5.95
6044	28.18	36.61	-8.43	4.52
6045	-20.02	-6.07	-13.95	-1.00
6047	60.22	62.17	-1.95	10.99
6050	-2.81	15.70	-18.51	-5.56
6051	18.02	29.20	-11.18	1.76
6053	-72.38	-56.10	-16.28	-3.33
6055	4.24	16.26	-12.02	0.93
6059	-0.41	16.07	-16.48	-3.53
6060	7.28	27.33	-20.05	-7.10
6061	0.96	11.28	-10.32	2.62
6063	23.02	27.20	-4.18	8.76
6064	0.64	10.35	-9.71	3.23
6065	30.04	44.23	-14.19	-1.24
6066	-5.65	13.74	-19.39	-6.45
6067	-19.55	-12.03	-7.52	5.43
6068	13.16	24.65	-11.49	1.45

TABLE 8.21.—(Cont'd)

STN. NO.	NOSUGC	N REF	NOSUGC-N REF	RESIDUALS
6069	13.23	25.52	-12.29	0.66
6072	-63.61	-40.39	-23.22	-10.28
6073	-86.13	-73.64	-12.49	0.46
6075	-54.59	-44.40	-10.19	2.75
6078	44.05	63.10	-19.05	-6.10
6111	-45.28	-33.18	-12.10	0.65
6123	-14.02	-1.40	-12.62	0.33
6134	-45.38	-33.19	-12.19	0.75
7036	-31.99	-19.78	-12.21	0.73
7037	-44.47	-33.87	-10.60	2.34
7039	-54.88	-43.43	-11.45	1.49
7040	-52.74	-50.55	-2.19	10.75
7043	-50.11	-36.91	-13.20	-0.26
7045	-30.24	-18.10	-12.14	0.81
7072	-44.94	-36.04	-8.90	4.04
7075	-52.35	-39.20	-13.15	-0.21
7076	-33.40	-26.62	-6.78	6.16
8009	31.67	42.33	-10.66	2.28
8010	31.46	44.77	-13.31	-0.37
8011	37.72	47.43	-9.71	3.23
8015	34.99	46.38	-11.39	1.55
8019	32.00	45.91	-13.91	-0.97
8030	30.64	44.64	-14.00	-1.06
9001	-37.07	-22.93	-14.14	-1.19
9002	12.89	24.27	-11.38	1.56
9004	42.32	54.57	-12.25	0.69
9005	19.87	30.20	-10.33	2.62
9006	-60.51	-48.12	-12.39	0.56
9007	22.60	31.82	-9.22	3.73
9008	-31.19	-10.91	-20.28	-7.34
9009	-38.62	-29.19	-9.43	3.51
9010	-44.91	-36.04	-8.87	4.07
9011	5.71	22.80	-17.09	-4.14
9012	2.98	1.76	1.22	14.17
9021	-42.84	-27.00	-15.84	-2.89

TABLE 8.21.—(Cont'd)

STN. NO.	NOSUGC	N REF	NOSUGC-N REF	RESIDUALS
9028	-39.07	-5.78	-33.29	-20.34
9029	-19.54	-12.03	-7.51	5.44
9031	-2.31	13.43	-15.74	-2.80
9051	20.50	32.81	-12.31	0.64
9091	19.99	32.84	-12.85	0.10
9424	-43.09	-26.21	-16.88	-3.93
9425	-44.00	-32.39	-11.61	1.34
9426	21.80	36.39	-14.59	-1.64
9427	-2.77	8.83	-11.60	1.34
9431	10.01	25.67	-15.66	-2.71
9432	26.58	39.71	-13.13	-0.19

AVERAGE

SIGMA

-0.1294D+02

0.6420D+01

SEMI-MAJOR AXIS

6378142.06

TABLE 8.22.—*Undulation Comparison (Solution WN14)*

Sta.	N _{REF}	MSL	-dH	H _{WN14}	N	N _v	Diff.
1021	-37.32	5.76	0.20	-47.77	-40.39	-34.50	-5.89
1022	-31.58	4.81	-0.81	-32.58	-25.25	-29.50	4.25
1030	-30.00	929.10	-12.22	889.58	-38.79	-31.90	-6.89
1032	11.57	69.00	5.92	60.96	10.82	12.50	-1.68
1034	-25.47	252.58	-5.81	217.55	-27.89	-26.70	-1.19
1042	-34.38	909.40	-1.53	863.40	-34.58	-30.30	-4.28
3106	-49.83	1.90	7.28	-58.68	-40.36	-54.80	14.44
3334	-31.54	39.00	-4.19	-2.60	-32.84	-28.70	-4.14
3400	-18.42	2184.10	-8.49	2160.40	-19.24	-17.50	-1.74
3401	-30.59	83.00	1.67	34.52	-33.87	-28.40	-5.47
3402	-29.04	73.00	-3.23	27.89	-35.40	-30.40	-5.00
3405	-49.77	2.20	3.47	-67.11	-52.89	-53.30	0.41
3406	-29.19	6.83	5.02	-37.08	-25.95	-35.50	9.55
3407	-38.57	254.80	7.87	186.66	-47.33	-46.20	-1.13
3648	-35.70	12.00	-0.81	-36.10	-35.96	-31.70	-4.26
3657	-36.55	5.50	0.45	-44.57	-36.68	-33.90	-2.78
3861	-33.70	0.20	-0.21	-43.47	-30.94	-31.00	0.06
3902	-16.53	1882.20	-8.35	1859.36	-18.25	-16.40	-1.85
3903	-36.87	168.00	0.08	110.47	-44.50	-34.00	-10.50
5001	-36.87	127.80	0.08	83.52	-31.25	-34.00	2.75
5201	-17.65	368.92	-11.41	341.28	-26.11	-20.90	-5.21
5648	-35.07	27.90	-0.95	-19.05	-34.95	-30.90	-4.05
5715	27.20	27.30	19.89	31.00	36.53	25.50	11.03
5739	54.00	56.10	13.40	91.43	61.67	60.30	1.37
5744	37.43	11.80	16.74	18.41	36.29	40.80	-4.51
5907	-28.11	481.90	-5.56	444.85	-29.67	-27.90	-1.77
5911	-43.44	22.00	4.76	-26.09	-30.39	-39.20	8.81
5912	6.16	9.10	0.96	-5.02	-0.22	1.10	-1.32
5914	-50.08	63.80	5.19	-9.38	-55.05	-55.90	0.85
5915	-26.32	206.20	-6.52	170.93	-28.84	-27.10	-1.74
5924	54.48	12.40	16.64	19.25	36.44	48.60	-12.16
6002	-36.90	44.30	0.24	-6.70	-37.82	-34.00	-3.82
6003	-17.65	368.74	-11.41	340.92	-26.29	-20.90	-5.39
6006	27.06	105.70	5.41	111.31	23.97	26.00	-2.03
6007	54.00	53.30	13.40	89.60	62.64	60.30	2.34
6016	37.43	9.24	16.74	15.77	36.21	40.80	-4.59
6023	67.94	60.50	-15.81	120.39	57.02	71.30	-14.28
6032	-30.51	26.30	-5.02	-6.10	-24.48	-21.50	-2.98
6060	27.33	211.08	-14.66	233.02	20.23	31.60	-11.37
6063	27.20	26.30	19.89	29.43	35.96	25.50	10.46
6065	44.23	943.20	13.66	959.58	42.99	44.50	-1.51
6111	-33.18	2284.30	-12.52	2251.54	-32.33	-34.50	2.17
7036	-19.78	59.59	-6.75	34.35	-19.05	-24.00	4.95
7037	-33.87	272.68	-4.62	232.83	-31.53	-32.30	0.77
7040	-50.55	49.70	5.64	-8.68	-39.80	-52.30	12.50
7045	-18.10	1789.63	-8.37	1767.76	-17.29	-18.40	1.11
7072	-36.04	14.20	-0.19	-30.55	-32.00	-36.30	4.30
7075	-39.20	281.90	-1.39	230.94	-39.41	-36.90	-2.51
7076	-26.62	445.90	1.55	410.95	-20.46	-32.00	11.54
9001	-22.93	1651.33	-9.35	1623.61	-24.12	-22.80	-1.32
9004	54.57	25.90	16.70	51.52	55.26	48.40	6.86
9009	-29.19	8.70	5.02	-34.94	-25.68	-35.70	10.02
9010	-36.04	15.13	-0.19	-29.59	-31.97	-36.30	4.33
9021	-27.00	2382.00	-10.74	2349.90	-29.89	-28.10	-1.79
9051	32.81	187.90	15.98	192.42	33.45	40.60	-7.15
9091	32.84	467.00	15.94	471.05	32.94	40.60	-7.66

TABLE 8.22.—(Cont'd)

Sta.	N _{REF}	MSL	-dH	H _{WN14}	N	N _v	Diff.
9424	-26.21	704.60	-8.36	669.87	-30.14	-20.20	-9.94
9425	-32.39	784.23	-12.53	752.76	-31.05	-33.90	2.85
9426	36.39	575.92	9.24	588.48	34.75	36.60	-1.85
6134	-33.19	2198.40	-12.52	2165.54	-32.44	-34.50	2.06
8009	42.33	24.70	12.25	44.12	44.61	41.60	3.01
8010	44.77	903.44	14.01	920.89	44.40	46.10	-1.70
8011	47.43	113.20	12.04	138.88	50.66	47.00	3.66
8015	46.38	647.00	14.96	679.03	59.93	49.30	10.63
8019	45.91	377.42	15.03	394.39	44.94	47.30	-2.36
8030	44.64	165.50	13.31	182.83	43.58	43.60	-0.02
9431	25.67	8.00	9.92	8.09	22.96	16.80	6.16
9432	39.71	189.00	12.88	202.70	39.52	41.10	-1.58

TABLE 8.23.—Relationships Between Various Dynamics and the WN Systems
(Dynamic - WN14)

Solution	NWL-9D				SAO III		GEM 4	GSFC 73
Sta. considered	5000	6000	All	6000	9000	All	All	All
No. stations	12	22	32	47	22	73	30	26
Weight factor ^a	1.5	7.75	~ 4	2	2	2	50	22
Δu (m)	13.8 ± 1.5	16.7 ± 1.2	16.3 ± 1.0	19.6 ± 1.2	14.1 ± 3.1	15.7 ± 1.4	15.5 ± 2.2	15.0 ± 2.2
Δv (m)	11.2 ± 1.6	9.6 ± 1.2	10.1 ± 1.0	14.2 ± 1.2	16.1 ± 3.0	15.3 ± 1.4	10.9 ± 2.2	11.3 ± 2.4
Δw (m)	-3.6 ± 1.8	-3.3 ± 1.2	-3.5 ± 1.1	-11.3 ± 1.3	-13.4 ± 3.4	-12.0 ± 1.5	2.2 ± 2.4	-1.9 ± 2.9
Δ (10 ⁻⁹)	0.69 ± 0.70	0.30 ± 0.52	0.39 ± 0.16	0.60 ± 0.18	1.09 ± 0.45	0.97 ± 0.22	0.74 ± 0.32	0.74 ± 0.34
ω (°)	0.86 ± 0.15	0.69 ± 0.05	0.72 ± 0.04	0.53 ± 0.05	0.32 ± 0.13	0.38 ± 0.05	0.02 ± 0.08	-0.34 ± 0.08
ψ (°)	0.00 ± 0.20	-0.16 ± 0.05	-0.15 ± 0.04	0.01 ± 0.06	-0.05 ± 0.14	0.02 ± 0.06	0.14 ± 0.10	0.23 ± 0.11
ϵ (°)	0.13 ± 0.29	-0.17 ± 0.06	-0.17 ± 0.05	-0.18 ± 0.06	0.00 ± 0.13	0.00 ± 0.06	0.18 ± 0.09	0.29 ± 0.11
σ_e^2	1.31	0.93	1.16	1.14	1.06	0.97	1.14	1.10

^a Weight factor = $\sigma_{u,v,w}^2 / \sigma_{u,v,w,NW14}^2$

TABLE 8.24.—Transformation: WN14 - NWL 9D

 SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

 SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
15.89	10.27	-3.38	0.29	0.71	-0.15	-0.14

VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 0.87$$

0.957D+00	-0.812D-03	-0.133D-02	0.958D-10	0.151D-08	0.433D-08	0.502D-09
-0.812D-03	0.955D+00	0.127D-02	0.109D-08	-0.877D-09	-0.248D-09	-0.603D-08
-0.133D-02	0.127D-02	0.112D+01	-0.293D-08	-0.205D-09	-0.708D-09	-0.196D-08
0.958D-10	0.109D-08	-0.293D-08	0.185D-14	-0.436D-18	0.277D-17	-0.530D-18
0.151D-08	-0.877D-09	-0.205D-09	-0.436D-18	0.285D-14	-0.592D-16	0.446D-15
0.433D-08	-0.248D-09	-0.708D-09	0.277D-17	-0.592D-16	0.289D-14	0.167D-15
0.502D-09	-0.603D-08	-0.196D-08	-0.530D-18	0.446D-15	0.167D-15	0.394D-14

COEFFICIENTS OF CORRELATION

0.100D+01	-0.849D-03	-0.129D-02	0.228D-02	0.289D-01	0.823D-01	0.817D-02
-0.849D-03	0.100D+01	0.123D-02	0.260D-01	-0.168D-01	-0.472D-02	-0.983D-01
-0.129D-02	0.123D-02	0.100D+01	-0.646D-01	-0.363D-02	-0.125D-01	-0.296D-01
0.228D-02	0.260D-01	-0.646D-01	0.100D+01	-0.190D-03	0.120D-02	-0.196D-03
0.289D-01	-0.168D-01	-0.363D-02	-0.190D-03	0.100D+01	-0.207D-01	0.133D+00
0.823D-01	-0.472D-02	-0.125D-01	0.120D-02	-0.207D-01	0.100D+01	0.494D-01
0.817D-02	-0.983D-01	-0.296D-01	-0.196D-03	0.133D+00	0.494D-01	0.100D+01

TABLE 8.24.—(Cont'd)

RESIDUALS V											
V1(NWL-9D)				V2(WN14)				V1 - V2			
5410	0.2	-0.1	-0.3	700	-13.2	3.8	10.5	13.4	-3.9	-10.9	
5648	0.1	0.0	0.6	708	-1.6	-1.4	-17.7	1.7	1.5	18.3	
5713	0.0	0.4	-0.0	713	-3.1	-21.4	0.0	3.1	21.8	-0.0	
5733	-6.7	5.0	-4.3	733	3.0	-1.3	1.1	-9.7	6.3	-5.4	
5915	2.1	0.5	4.5	709	-19.1	-2.9	-33.4	21.2	3.4	37.9	
5923	-0.3	-0.4	0.1	719	11.6	8.8	-1.7	-11.9	-9.3	1.7	
5924	0.1	0.6	0.0	740	-11.6	-20.3	-0.5	11.8	20.9	0.6	
5933	0.3	-0.8	0.3	727	-11.8	18.7	-10.1	12.1	-19.5	10.5	
5934	-0.0	-0.1	-0.3	729	0.7	1.9	12.1	-0.7	-1.9	-12.4	
5935	0.3	0.0	0.2	728	-21.2	-1.5	-8.0	21.4	1.5	8.2	
6001	0.8	0.1	-2.8	18	-2.0	-0.2	3.9	2.9	0.3	-6.6	
6002	-0.1	0.2	1.1	742	0.5	-1.1	-4.9	-0.6	1.3	6.0	
6003	0.7	-0.4	-0.1	738	-2.6	1.5	0.4	3.3	-1.8	-0.6	
6004	3.7	-5.4	-5.5	739	-8.1	8.1	5.9	11.8	-13.6	-11.4	
6006	0.6	-2.3	1.3	818	-1.8	4.5	-2.5	2.5	-6.8	3.7	
6008	1.4	-0.8	2.9	815	-5.2	3.5	-5.4	6.7	-4.3	8.2	
6011	-0.7	0.3	-4.3	811	1.3	-0.6	6.3	-2.0	0.9	-10.7	
6012	0.0	0.0	-0.5	708	-0.2	-0.8	6.1	0.2	0.8	-6.6	
6015	-1.1	-1.0	-1.1	817	4.4	3.5	2.6	-5.5	-4.5	-3.7	
6016	0.7	1.5	0.1	812	-3.5	-5.0	-0.5	4.1	6.5	0.6	
6022	-1.8	0.8	-1.9	117	2.5	-1.1	1.4	-4.2	1.9	-3.3	
6023	-0.3	0.4	1.1	744	0.4	-0.8	-1.2	-0.7	1.2	2.3	
6031	-0.2	2.7	3.3	809	0.3	-2.9	-3.6	-0.5	5.5	6.9	
6038	-0.2	-0.1	-0.2	831	2.3	0.9	0.9	-2.5	-1.0	-1.1	
6043	-1.5	-4.3	6.7	847	2.2	4.8	-4.8	-3.7	-9.1	11.4	
6053	-2.0	1.7	1.0	19	1.5	-1.4	-0.8	-3.5	3.1	1.8	
6055	1.4	-0.1	-0.5	722	-4.1	0.3	1.0	5.5	-0.4	-1.5	
6060	-0.1	-0.4	0.8	805	1.1	4.8	-6.7	-1.2	-5.3	7.4	
6064	-0.7	2.2	-1.3	822	1.4	-5.4	2.1	-2.1	7.6	-3.4	
6065	-0.3	-0.7	-0.2	830	1.4	1.8	0.7	-1.7	-2.5	-1.0	
6068	0.0	-0.1	1.5	115	-0.1	1.2	-9.7	0.1	-1.2	11.1	
6075	-0.1	0.4	0.3	717	0.2	-0.5	-0.3	-0.3	1.0	0.5	

TABLE 8.25.—*Transformation: WN14 - SAO III*

 SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

 SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.0+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
13.93	13.62	-10.35	-0.17	0.37	0.15	-0.03

VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 1.14$$

0.155D+01	-0.247D-04	-0.818D-03	-0.382D-08	0.357D-08	0.355D-08	0.310D-09
-0.247D-04	0.167D+01	0.118D-02	0.288D-08	0.473D-08	-0.579D-09	-0.329D-08
-0.818D-03	0.118D-02	0.167D+01	-0.300D-08	0.342D-09	-0.584D-08	-0.491D-08
-0.382D-08	0.288D-08	-0.300D-08	0.190D-14	-0.693D-18	-0.100D-17	0.301D-17
0.357D-08	0.473D-08	0.342D-09	-0.693D-18	0.274D-14	-0.152D-15	-0.474D-16
0.355D-08	-0.579D-09	-0.584D-08	-0.100D-17	-0.152D-15	0.300D-14	0.304D-15
0.310D-09	-0.329D-08	-0.491D-08	0.301D-17	-0.474D-16	0.304D-15	0.306D-14

COEFFICIENTS OF CORRELATION

0.100D+01	-0.153D-04	-0.509D-03	-0.704D-01	0.548D-01	0.521D-01	0.450D-02
-0.153D-04	0.100D+01	0.705D-03	0.511D-01	0.699D-01	-0.819D-02	-0.459D-01
-0.509D-03	0.705D-03	0.100D+01	-0.534D-01	0.507D-02	-0.826D-01	-0.688D-01
-0.704D-01	0.511D-01	-0.534D-01	0.100D+01	-0.304D-03	-0.421D-03	0.125D-02
0.548D-01	0.699D-01	0.507D-02	-0.304D-03	0.100D+01	-0.530D-01	-0.164D-01
0.521D-01	-0.819D-02	-0.826D-01	-0.421D-03	-0.530D-01	0.100D+01	0.100D+00
0.450D-02	-0.459D-01	-0.688D-01	0.125D-02	-0.164D-01	0.100D+00	0.100D+01

TABLE 8.25—(Cont'd)

RESIDUALS V											
V1 (SAO-III)				V2 (WN14)				V1 - V2			
6002	1.7	-2.9	4.3	6002	-3.4	8.1	-9.6	5.1	-11.0	13.8	
6003	0.0	0.1	0.4	6003	-0.7	-1.6	-8.2	0.7	1.7	8.6	
6004	0.2	0.0	0.1	6004	-14.4	-2.4	-4.7	14.5	2.5	4.8	
6006	0.0	-0.3	0.0	6006	-1.6	6.8	-0.5	1.6	-7.1	0.6	
6007	-0.1	0.2	-0.3	6007	6.2	-8.7	10.0	-6.3	8.8	-10.3	
6008	0.1	-0.0	0.2	6008	-6.2	2.1	-6.0	6.3	-2.2	6.1	
6009	0.1	0.2	-0.3	6009	-3.5	-5.5	6.5	3.6	5.7	-6.8	
6011	-0.6	1.0	0.4	6011	6.8	-12.3	-4.2	-7.4	13.3	4.7	
6012	0.3	0.0	-0.4	6012	-26.6	-1.3	15.3	26.9	1.3	-15.7	
6013	0.9	-0.1	0.1	6013	-24.8	1.8	-1.0	25.7	-1.9	1.0	
6015	-0.1	-0.4	0.1	6015	4.2	16.0	-4.0	-4.3	-16.4	4.2	
6016	-0.1	-0.3	0.2	6016	3.3	7.8	-5.4	-3.4	-8.1	5.6	
6019	0.3	-0.3	-3.0	6019	-3.4	3.2	16.8	3.6	-3.5	-19.8	
6020	0.3	0.4	-0.2	6020	-7.8	-14.7	4.4	8.1	15.1	-4.6	
6022	0.2	0.8	0.2	6022	-4.8	-19.5	-3.0	5.0	20.2	3.2	
6023	1.2	-0.0	0.2	6023	-19.7	0.8	-2.5	20.8	-0.9	2.7	
6031	0.8	1.0	0.1	6031	-13.2	-12.4	-1.9	14.0	13.3	2.1	
6032	1.3	0.1	1.4	6032	-29.0	-2.9	-22.3	30.3	3.1	23.7	
6038	-0.1	-0.0	0.0	6038	2.2	0.1	-0.1	-2.3	-0.2	0.1	
6039	0.3	0.7	-0.1	6039	-6.4	-20.1	3.6	6.7	20.8	-3.8	
6040	1.0	-0.2	0.2	6040	-17.6	4.1	-4.7	18.6	-4.3	4.9	
6042	-0.5	-0.7	1.2	6042	13.7	16.5	-16.0	-14.2	-17.1	17.1	
6043	0.1	0.1	-1.4	6043	-4.2	-2.8	20.0	4.3	2.9	-21.4	
6044	0.4	1.1	0.6	6044	-7.5	-27.4	-9.7	7.9	28.4	10.3	
6045	-0.1	-0.4	1.1	6045	1.9	6.4	-12.1	-2.0	-6.8	13.1	
6047	0.5	-0.1	0.2	6047	-34.2	7.4	-8.7	34.7	-7.5	9.0	
6050	0.1	1.1	-1.1	6050	-4.0	-20.2	21.1	4.1	21.2	-22.2	
6051	0.5	0.3	0.0	6051	-7.2	-7.1	-0.9	7.7	7.4	0.9	
6052	1.1	0.6	0.1	6052	-20.0	-13.7	-1.6	21.1	14.3	1.7	
6053	1.1	0.9	-0.1	6053	-17.2	-14.7	2.7	18.3	15.6	-2.8	
6055	-0.3	0.2	-0.2	6055	9.8	-5.8	3.6	-10.1	6.0	-3.7	
6059	-0.1	0.7	0.2	6059	2.5	-20.0	-2.9	-2.5	20.7	3.1	
6060	2.2	1.2	0.3	6060	-14.7	-8.0	-1.8	16.9	9.3	2.1	
6061	0.3	0.8	-0.9	6061	-10.8	-11.0	13.9	11.2	11.9	-14.8	
6063	-1.3	0.5	-0.4	6063	21.0	-5.2	3.1	-22.3	5.7	-3.5	
6064	-0.5	-0.2	0.4	6064	8.7	4.8	-4.6	-9.2	-5.1	5.0	
6065	-0.1	-1.1	-1.4	6065	1.3	7.8	11.2	-1.5	-8.9	-12.6	

TABLE 8.25—(Cont'd)

RESIDUALS V											
V1(SAO-III)				V2(WN14)				V1 - V2			
-----				-----				-----			
6067	0.9	0.5	-0.1	6067	-12.2	-6.3	1.3	13.1	6.8	-1.4	
6068	-0.2	-0.8	-0.3	6068	0.4	1.4	0.3	-0.7	-2.2	-0.6	
6069	0.1	0.3	0.3	6069	-2.1	-8.0	-5.8	2.2	8.3	6.1	
6072	1.0	-0.6	0.3	6072	-10.7	13.8	-5.3	11.7	-14.4	5.5	
6073	0.1	-0.6	0.7	6073	-1.3	12.5	-11.9	1.4	-13.2	12.6	
6075	-0.3	-0.6	0.8	6075	4.7	11.5	-12.2	-5.0	-12.0	13.0	
6078	-0.8	0.9	5.6	6078	10.0	-15.5	-40.4	-10.8	16.3	46.0	
6111	-0.4	-0.0	0.7	6111	2.8	0.0	-5.5	-3.3	-0.0	6.1	
6123	0.3	0.0	0.3	6123	-7.3	-0.6	-8.0	7.6	0.6	8.3	
6134	-0.4	-0.0	0.7	6134	2.8	0.1	-5.5	-3.2	-0.1	6.2	
8010	-9.2	13.4	0.0	8010	7.2	-5.0	-0.0	-16.4	18.3	0.0	
8011	-2.1	39.2	-5.1	8011	2.1	-14.9	8.2	-4.1	54.1	-13.3	
8015	-5.7	20.6	-3.5	8015	3.1	-3.1	1.7	-8.8	23.7	-5.2	
8019	-1.3	14.8	-1.5	8019	5.6	-17.0	5.8	-6.9	31.8	-7.4	
9001	-3.2	0.9	0.8	9001	13.5	-8.3	-7.7	-16.7	9.2	8.5	
9002	-0.3	-1.1	-0.9	9002	0.3	1.1	0.4	-0.7	-2.2	-1.3	
9004	-3.1	20.1	-8.7	9004	4.2	-3.2	8.7	-7.4	23.3	-17.5	
9005	4.5	-1.5	2.9	9005	-16.6	5.8	-15.8	21.1	-7.3	18.6	
9006	11.1	-1.8	1.9	9006	-9.9	8.2	-7.2	21.0	-10.0	9.1	
9007	1.8	-4.0	-8.5	9007	-3.5	6.0	5.6	5.3	-10.1	-14.1	
9008	0.9	-1.8	-1.0	9008	-3.3	7.9	4.4	4.2	-9.7	-5.4	
9009	0.5	-0.2	-1.5	9009	-6.1	3.7	9.7	6.6	-3.9	-11.2	
9010	0.4	0.1	0.4	9010	-6.3	-1.2	-5.5	6.7	1.3	5.8	
9011	0.2	-0.3	-3.1	9011	-3.2	3.1	16.7	3.4	-3.4	-19.8	
9012	-0.6	1.0	0.5	9012	7.0	-12.4	-4.2	-7.6	13.5	4.7	
9021	1.0	-3.3	0.2	9021	-0.6	3.6	-0.3	1.7	-6.9	0.5	
9028	0.1	-0.2	1.5	9028	-2.1	3.8	-19.2	2.1	-3.9	20.7	
9029	1.0	0.5	-0.2	9029	-12.2	-6.2	1.3	13.2	6.7	-1.4	
9031	-0.4	0.2	-7.0	9031	1.6	-0.7	16.8	-2.0	0.9	-23.7	
9091	-1.2	15.2	-1.5	9091	12.9	-26.1	14.2	-14.1	41.3	-15.7	
9424	-4.4	2.0	1.5	9424	8.2	-2.7	-3.4	-12.6	4.8	5.0	
9425	-0.1	-0.0	0.2	9425	3.6	0.6	-7.0	-3.7	-0.6	7.2	
9426	1.2	3.2	-2.6	9426	-5.7	-12.4	27.0	6.9	15.5	-29.6	
9427	1.1	-12.9	2.9	9427	-4.8	11.0	-12.9	5.9	-23.9	15.8	
9431	-11.2	6.9	-0.5	9431	28.4	-30.4	3.8	-39.6	37.3	-4.3	
9432	-0.2	2.1	-0.4	9432	6.7	-51.3	32.3	-6.8	53.4	-32.7	

TABLE 8.26.—Transformation: WN14 - GEM 4

 SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

 SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
14.52	11.64	1.91	0.93	-0.02	0.12	0.17

VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 1.11$$

0.268D+01	-0.378D-01	-0.116D-01	-0.932D-08	0.235D-07	0.392D-07	0.510D-08
-0.378D-01	0.251D+01	0.761D-02	0.364D-07	0.709D-08	-0.110D-07	-0.345D-07
-0.116D-01	0.761D-02	0.291D+01	-0.305D-07	0.612D-08	-0.212D-07	-0.395D-07
-0.932D-08	0.364D-07	-0.305D-07	0.111D-13	-0.437D-16	-0.536D-17	0.402D-16
0.235D-07	0.709D-08	0.612D-08	-0.437D-16	0.999D-14	-0.204D-14	-0.166D-14
0.392D-07	-0.110D-07	-0.212D-07	-0.536D-17	-0.204D-14	0.176D-13	0.387D-14
0.510D-08	-0.345D-07	-0.395D-07	0.402D-16	-0.166D-14	0.387D-14	0.127D-13

COEFFICIENTS OF CORRELATION

0.100D+01	-0.146D-01	-0.414D-02	-0.540D-01	0.144D+00	0.180D+00	0.277D-01
-0.146D-01	0.100D+01	0.282D-02	0.218D+00	0.448D-01	-0.523D-01	-0.193D+00
-0.414D-02	0.282D-02	0.100D+01	-0.170D+00	0.359D-01	-0.939D-01	-0.205D+00
-0.540D-01	0.218D+00	-0.170D+00	0.100D+01	-0.415D-02	-0.384D-03	0.338D-02
0.144D+00	0.448D-01	0.359D-01	-0.415D-02	0.100D+01	-0.154D+00	-0.147D+00
0.180D+00	-0.523D-01	-0.939D-01	-0.384D-03	-0.154D+00	0.100D+01	0.259D+00
0.277D-01	-0.193D+00	-0.205D+00	0.338D-02	-0.147D+00	0.259D+00	0.100D+01

TABLE 8.26.—(Cont'd)

RESIDUALS V											
V1 (GEM-4)				V2 (WN14)				V1 - V2			
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1021	-0.1	-0.2	0.1	1021	2.3	5.3	-2.1	-2.4	-5.5	2.2	
1022	0.4	-0.1	0.4	1022	-3.2	0.4	-3.0	3.5	-0.5	3.4	
1030	-4.3	-0.9	1.0	1030	4.5	1.8	-3.3	-8.8	-2.6	4.3	
1032	45.0	63.5	7.1	1032	-8.7	-10.0	-10.6	53.7	72.5	17.7	
1034	-1.1	0.5	0.3	1034	9.8	-5.3	-3.8	-10.9	5.8	4.0	
1042	1.8	-0.6	0.1	1042	-12.2	3.7	-0.9	14.0	-4.3	1.1	
7036	-1.9	1.3	-0.1	7036	8.1	-7.8	0.4	-10.0	9.1	-0.5	
7037	-0.7	1.0	0.6	7037	3.7	-6.2	-4.5	-4.4	7.1	5.1	
7039	-1.1	-0.7	1.7	7039	6.3	5.3	-10.2	-7.3	-6.0	11.9	
7040	-0.1	0.5	1.4	7040	0.3	-2.1	-4.7	-0.4	2.7	6.1	
7043	-0.2	-0.0	-0.0	7043	7.9	1.9	0.9	-8.1	-2.0	-0.9	
7045	-3.7	1.0	-0.7	7045	9.0	-4.5	3.6	-12.7	5.5	-4.3	
7072	0.2	0.0	-0.1	7072	-5.1	-0.9	3.1	5.4	0.9	-3.2	
7075	-1.0	-0.5	0.3	7075	9.6	4.7	-2.9	-10.7	-5.2	3.2	
7076	-1.0	-3.0	-0.7	7076	5.1	10.4	2.4	-6.1	-13.3	-3.1	
9001	-0.9	0.8	0.8	9001	1.2	-2.0	-3.4	-2.1	2.8	4.7	
9002	0.6	0.7	-1.1	9002	-1.6	-2.3	1.7	2.2	3.0	-2.8	
9004	-1.7	30.2	-3.4	9004	2.3	-5.8	5.4	-4.0	35.9	-8.8	
9005	13.0	-11.9	9.1	9005	-7.8	7.9	-10.0	20.8	-19.9	19.1	
9006	13.0	-9.6	1.7	9006	-2.2	6.5	-1.5	15.2	-16.1	3.2	
9008	-2.4	2.1	2.1	9008	2.9	-3.0	-4.4	-5.3	5.2	6.5	
9009	1.3	-0.4	-0.6	9009	-12.0	6.1	3.1	13.3	-6.5	-3.7	
9010	0.9	-0.9	-0.3	9010	-5.4	6.4	2.2	6.2	-7.2	-2.5	
9012	1.5	0.8	-1.3	9012	-3.3	-2.0	3.1	4.8	2.8	-4.5	
9021	2.6	-0.4	-1.6	9021	-5.0	1.3	6.5	7.6	-1.7	-8.2	
9028	1.0	-0.2	0.3	9028	-13.7	2.4	-2.2	14.8	-2.6	2.5	
9031	-5.6	1.8	-20.9	9031	5.2	-2.3	10.7	-10.9	4.1	-31.5	
9091	-4.1	17.8	-2.4	9091	10.3	-7.3	7.4	-14.4	25.1	-9.6	
9425	-0.1	-0.4	-0.4	9425	1.5	8.6	7.5	-1.6	-8.9	-7.9	
9427	2.1	-32.0	2.2	9427	-4.6	9.9	-5.2	6.7	-41.9	7.4	

TABLE 8.27.—Transformation: WN14 - GSFC 73

 SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

 SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.0+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
13.73	12.86	-1.70	0.96	-0.38	0.19	0.24

VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 1.09$$

0.218D+01	-0.646D-01	-0.166D-01	-0.125D-07	0.265D-07	0.500D-07	0.629D-08
-0.646D-01	0.203D+01	0.449D-01	0.508D-07	0.113D-07	-0.190D-07	-0.542D-07
-0.166D-01	0.449D-01	0.362D+01	-0.369D-07	0.132D-07	-0.343D-07	-0.648D-07
-0.125D-07	0.508D-07	-0.369D-07	0.123D-13	-0.133D-15	-0.537D-16	0.132D-15
0.265D-07	0.113D-07	0.132D-07	-0.133D-15	0.111D-13	-0.380D-14	-0.308D-14
0.500D-07	-0.190D-07	-0.343D-07	-0.537D-16	-0.380D-14	0.223D-13	0.595D-14
0.629D-08	-0.542D-07	-0.648D-07	0.132D-15	-0.308D-14	0.595D-14	0.179D-13

COEFFICIENTS OF CORRELATION

0.100D+01	-0.308D-01	-0.592D-02	-0.761D-01	0.170D+00	0.227D+00	0.318D-01
-0.308D-01	0.100D+01	0.166D-01	0.321D+00	0.753D-01	-0.894D-01	-0.284D+00
-0.592D-02	0.166D-01	0.100D+01	-0.174D+00	0.660D-01	-0.121D+00	-0.254D+00
-0.761D-01	0.321D+00	-0.174D+00	0.100D+01	-0.113D-01	-0.323D-02	0.889D-02
0.170D+00	0.753D-01	0.660D-01	-0.113D-01	0.100D+01	-0.241D+00	-0.218D+00
0.227D+00	-0.894D-01	-0.121D+00	-0.323D-02	-0.241D+00	0.100D+01	0.297D+00
0.318D-01	-0.284D+00	-0.254D+00	0.889D-02	-0.218D+00	0.297D+00	0.100D+01

TABLE 8.27.—(Cont'd)

RESIDUALS V											
V1 (GSFC-73)				V2 (WN14)				V1 - V2			
1021	0.2	-0.3	-0.3	1021	-1.3	2.7	3.5	1.5	-3.0	-3.8	
1022	0.9	0.2	0.0	1022	-3.8	-0.6	-0.3	4.7	0.8	0.3	
1030	-4.7	-0.6	1.1	1030	2.7	0.7	-4.5	-7.4	-1.2	5.5	
1034	-1.1	1.3	0.7	1034	2.5	-2.3	-4.2	-3.6	3.6	4.9	
1042	3.7	-1.0	-0.3	1042	-10.0	2.2	1.9	13.7	-3.2	-2.2	
7036	-2.9	2.0	-0.1	7036	6.2	-5.4	0.9	-9.1	7.4	-1.0	
7037	0.2	1.5	0.5	7037	-0.4	-4.0	-3.4	0.6	5.5	3.8	
7039	0.2	-2.1	1.8	7039	-0.5	5.3	-8.1	0.7	-7.5	9.9	
7040	0.6	0.7	0.3	7040	-1.2	-1.5	-1.1	1.8	2.3	1.4	
7045	-3.9	0.6	-0.1	7045	4.7	-1.3	0.8	-8.7	1.9	-0.9	
7072	0.7	-0.3	-0.3	7072	-7.9	4.6	4.4	8.6	-4.9	-4.7	
7075	-2.0	-0.5	0.6	7075	4.5	0.9	-2.6	-6.5	-1.4	3.1	
7076	-1.8	-5.7	-3.3	7076	3.5	7.4	7.8	-5.3	-13.0	-11.1	
9001	-2.0	0.1	0.1	9001	3.7	-0.4	-0.7	-5.7	0.5	0.8	
9002	1.1	-0.9	0.8	9002	-1.9	2.6	-1.8	3.0	-3.6	2.6	
9004	-1.8	25.5	-2.1	9004	1.7	-5.0	4.7	-3.5	30.5	-6.8	
9005	5.9	-4.8	3.6	9005	-11.2	23.7	-13.1	17.0	-28.4	16.7	
9006	11.1	-5.4	0.2	9006	-7.7	15.3	-0.7	18.9	-20.8	0.9	
9008	-2.2	-0.1	0.6	9008	14.3	0.6	-6.2	-16.5	-0.6	6.8	
9009	0.6	-0.2	-0.0	9009	-17.2	9.6	1.0	17.8	-9.8	-1.1	
9012	1.6	-0.2	0.3	9012	-5.7	0.8	-1.9	7.2	-0.9	2.2	
9021	2.1	-3.3	-3.1	9021	-1.6	2.8	6.7	3.7	-6.2	-9.8	
9028	0.6	-0.2	0.9	9028	-10.1	3.1	-9.9	10.7	-3.3	10.7	
9031	-9.8	5.1	-14.7	9031	4.0	-5.3	10.4	-18.8	10.4	-25.1	
9091	-3.2	24.9	-1.8	9091	4.4	-7.1	5.0	-7.6	32.0	-6.9	
9425	-0.0	-0.5	-0.2	9425	0.4	5.8	2.9	-0.4	-6.3	-3.0	

TABLE 8.28.—Shifts to the Geocenter (Solution WN14)

Source	u_o (m)	v_o (m)	w_o (m)	r_o (m)
1. Dynamic comparison -----	15.9 ± 0.3	11.7 ± 1.3	-5.0 ± 2.6	19.5 ± 1.1
2. Geometric fit (sec. 8.5.1) ----	23.2 ± 0.9	2.9 ± 0.8	-2.7 ± 1.2	23.4 ± 1.2
3. Weighted mean of 1 and 2 --	16.4 ± 1.9	5.4 ± 4.0	-3.1 ± 0.9	21.8 ± 1.2
4. JPL/DSN -----	-----	-----	-----	25.9 ± 2.5

TABLE 8.29.—*Relationship Between Various Geodetic Datums and the WN System*
(Datum - WN14)

Datum no.	Datum name ^a	No. of stations	Δu (m) (^b)	Δv (m) (^b)	Δw (m) (^b)	ω (") (^c)	ψ (") (^c)	ϵ (") (^c)	Δ ($\times 10^6$)
1	Adindan (Ethiopia)	2	184 $\pm$ 19	21 $\pm$ 11	-200 $\pm$ 6	-----	-----	-----	-----
2	American Samoa 1962	1	119 $\pm$ 8	-105 $\pm$ 8	-413 $\pm$ 10	-----	-----	-----	-----
3	Arc Cape (South Africa)	1	152 $\pm$ 7	126 $\pm$ 7	298 $\pm$ 10	-----	-----	-----	-----
5	Ascension Island 1958	1	227 $\pm$ 7	-93 $\pm$ 7	-58 $\pm$ 8	-----	-----	-----	-----
6	Australian Geodetic Camp Area Astro 1961/62 (USGS)	3	157.0 $\pm$ 3.2	59.2 $\pm$ 3.2	-131.2 $\pm$ 3.6	1.03 $\pm$ 0.49	0.97 $\pm$ 0.48	-27.0 $\pm$ 0.59	-1.14 $\pm$ 1.83
10	Christmas Island Astro 1967	1	111 $\pm$ 10	148 $\pm$ 9	-238 $\pm$ 10	-----	-----	-----	-----
15	Easter Island Astro 1967	1	-182 $\pm$ 10	-138 $\pm$ 10	-128 $\pm$ 11	-----	-----	-----	-----
16	European-50 (W) ^d	11	100.0 $\pm$ 5.3	125.8 $\pm$ 5.2	115.8 $\pm$ 5.3	-1.06 $\pm$ 1.37	0.10 $\pm$ 1.03	0.11 $\pm$ 1.60	-8.43 $\pm$ 4.34
17	European-50 (All stations) ^e	16	99.4 $\pm$ 5.0	132.2 $\pm$ 5.0	116.4 $\pm$ 4.8	-0.08 $\pm$ 0.67	0.03 $\pm$ 0.93	-41.0 $\pm$ 0.74	-6.06 $\pm$ 2.83
20	Graciosa Island (Azores)	1	123 $\pm$ 17	-147 $\pm$ 9	37 $\pm$ 17	-----	-----	-----	-----
22	Heard Astro 1969	1	182 $\pm$ 12	56 $\pm$ 12	-114 $\pm$ 14	-----	-----	-----	-----
23	Indian ^f	1	-165 $\pm$ 17	-711 $\pm$ 10	-228 $\pm$ 11	-----	-----	-----	-----
24	Isla Socorro Astro 1961	1	-134 $\pm$ 12	-206 $\pm$ 7	-503 $\pm$ 9	-----	-----	-----	-----
26	Johnston Island 1961	1	-161 $\pm$ 13	51 $\pm$ 25	211 $\pm$ 13	-----	-----	-----	-----
27	Luzon 1911 (Philippines)	1	151 $\pm$ 10	51 $\pm$ 7	111 $\pm$ 8	-----	-----	-----	-----
28	Midway Astro 1961	1	-377 $\pm$ 7	84 $\pm$ 7	-279 $\pm$ 9	-----	-----	-----	-----
29	New Zealand 1949	1	-61 $\pm$ 8	41 $\pm$ 9	-192 $\pm$ 9	-----	-----	-----	-----
36	North American 1927 (W) ^g	8	20.6 $\pm$ 2.7	-139.3 $\pm$ 3.1	-179.6 $\pm$ 2.7	0.22 $\pm$ 0.44	0.49 $\pm$ 0.48	-0.30 $\pm$ 0.52	-7.60 $\pm$ 1.66
36	North American 1927 (E) ^h	13	54.5 $\pm$ 19.5	-144.2 $\pm$ 11.5	-196.7 $\pm$ 11.6	0.96 $\pm$ 0.56	-0.03 $\pm$ 0.46	0.54 $\pm$ 0.40	2.26 $\pm$ 1.62
36	North American (all stations) ⁱ	21	31.6 $\pm$ 1.7	-142.1 $\pm$ 1.6	-177.3 $\pm$ 1.5	0.89 $\pm$ 0.20	0.23 $\pm$ 0.19	0.38 $\pm$ 0.34	0.96 $\pm$ 0.98
39	Pitcairn Island Astro	1	157 $\pm$ 12	-168 $\pm$ 11	-60 $\pm$ 11	-----	-----	-----	-----
41	Provisional South Chile 1963	1	0 $\pm$ 8	-196 $\pm$ 8	-93 $\pm$ 9	-----	-----	-----	-----
42	South American 1969 ^j	10	97.1 $\pm$ 4.0	13.4 $\pm$ 4.3	29.8 $\pm$ 4.1	-0.59 $\pm$ 0.43	0.25 $\pm$ 0.31	-0.11 $\pm$ 0.34	6.66 $\pm$ 1.41
43	Southeast Island (Mahe)	1	54 $\pm$ 8	186 $\pm$ 8	272 $\pm$ 9	-----	-----	-----	-----
46	South Georgia Astro	1	820 $\pm$ 8	-101 $\pm$ 11	291 $\pm$ 11	-----	-----	-----	-----
47	Tokyo	1	183 $\pm$ 10	-506 $\pm$ 9	-686 $\pm$ 9	-----	-----	-----	-----
49	Tristan Astro 1968	1	654 $\pm$ 14	-420 $\pm$ 11	622 $\pm$ 13	-----	-----	-----	-----
50	Wake Island Astronomic 1952	1	-260 $\pm$ 7	67 $\pm$ 12	-140 $\pm$ 8	-----	-----	-----	-----
51	Yof Astro 1967 (Dakar)	1	55 $\pm$ 6	-143 $\pm$ 7	-95 $\pm$ 7	-----	-----	-----	-----
51	Palmer Astro 1969	1	-218 $\pm$ 9	-8 $\pm$ 12	-226 $\pm$ 12	-----	-----	-----	-----

^a See table 8.4 for datum description and other related information.

^b If (datum-geocenter) is sought, add to the tabulated values of Δu , Δv , Δw the respective quantities -16 m, -5 m, 3 m (see table 8.28).

^c ω , ψ , ϵ , when positive, represent counterclockwise rotations about the respective w , v , u axes, as viewed from the end of the positive axis.

^d Stations included are Tromsø (6006), Catania (6016), Hohenpeissenberg (6065) Wippolder (8009) Zimmerwald (8010), Haute Provence (8015), Nice (8019), Meudon (8030), San Fernando (9004), Dionysos (9091), and Harestua (9426).

^e Stations included are as in (d) and Mashhad (6015), Malvern (8011), Naini Tal (9006), Shiraz (9008), and Riga (9431).

^f Based on p. 70, *Bulletin Geodesique*, 107, 1973.

^g Stations included are Goldstone (1030), Colorado Springs (3400), Vandenberg AFB (4280), Wrightwood II (6134), Moses Lake (6003), Edinburg (7036), Denver (7045), and Organ Pass (9001).

^h Stations included are Blossom Point (1021), Fort Myers (1022), E. Grand Forks (1034), Rosman (1042), Bedford (3401), Semmes (3402), Hunter AFB (3648), Aberdeen (3657), Homestead (3861), Beltsville (6002), Greenbelt (7043), Jupiter (7072), and Sudbury (7075).

ⁱ Stations included are as in (g) and (h) above.

^j Stations included are Brasilia (3414), Asunción (3431), Bogotá (3477), Paramaribo (6008), Quito (6009), Villa Dolores (6019), Natal (6067), Arequipa (9007), Curaçao (9009), and Comodoro Rivadavia (9031).

TABLE 8.30.—*Transformation: WN14 - Australian Datum*

 SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

 SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-156.97	-59.14	131.23	1.20	-1.03	-0.99	0.25
± 1.85	± 1.82	± 2.03	± 0.71	± 0.18	± 0.18	± 0.22

 VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 0.48$$

0.341D+01	0.615D-02	0.258D-01	0.511D-07	0.236D-06	0.104D-06	-0.628D-07
0.615D-02	0.331D+01	0.444D-01	0.172D-06	0.125D-07	-0.775D-07	-0.224D-06
0.258D-01	0.444D-01	0.410D+01	-0.903D-07	0.135D-06	-0.560D-07	-0.384D-06
0.511D-07	0.172D-06	-0.903D-07	0.507D-12	0.335D-14	-0.155D-13	-0.457D-14
0.236D-06	0.125D-07	0.135D-06	0.335D-14	0.765D-12	-0.148D-12	-0.408D-12
0.104D-06	-0.775D-07	-0.560D-07	-0.155D-13	-0.148D-12	0.748D-12	0.379D-12
-0.628D-07	-0.224D-06	-0.384D-06	-0.457D-14	-0.408D-12	0.379D-12	0.114D-11

 COEFFICIENTS OF CORRELATION

0.100D+01	0.183D-02	0.690D-02	0.389D-01	0.146D+00	0.652D-01	-0.318D-01
0.183D-02	0.100D+01	0.120D-01	0.133D+00	0.787D-02	-0.492D-01	-0.115D+00
0.690D-02	0.120D-01	0.100D+01	-0.626D-01	0.763D-01	-0.320D-01	-0.177D+00
0.389D-01	0.133D+00	-0.626D-01	0.100D+01	0.539D-02	-0.252D-01	-0.600D-02
0.146D+00	0.787D-02	0.763D-01	0.539D-02	0.100D+01	-0.196D+00	-0.436D+00
0.652D-01	-0.492D-01	-0.320D-01	-0.252D-01	-0.196D+00	0.100D+01	0.410D+00
-0.318D-01	-0.115D+00	-0.177D+00	-0.600D-02	-0.436D+00	0.410D+00	0.100D+01

TABLE 8.30.—(Cont'd)

RESIDUALS V										
V1 (AUS.NAT.)				V2 (WN- 14)				V1 - V2		
6023	0.9	-0.4	-2.9	6023	-0.8	0.4	1.8	1.7	-0.8	-4.8
6032	1.0	1.2	0.7	6032	-0.9	-1.2	-0.5	2.0	2.4	1.2
6060	-1.9	-0.8	1.9	6060	1.8	0.7	-1.4	-3.7	-1.5	3.2

UNIT OF RESIDUALS (METERS)

TABLE 8.31.—*Transformation: WN14 - European 50 Datum (W)*

 SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

 SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-99.58	-124.88	-116.37	7.75	1.37	-0.04	0.13
± 4.26	± 4.42	± 4.25	± 1.39	± 0.50	± 0.38	± 0.58

 VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 0.82$$

0.181D+02	-0.196D-01	0.421D+00	-0.736D-06	0.125D-05	-0.146D-05	-0.956D-06
-0.196D-01	0.195D+02	-0.165D+00	0.275D-06	0.572D-06	0.168D-07	0.159D-05
0.421D+00	-0.165D+00	0.181D+02	0.753D-06	0.974D-06	-0.140D-05	-0.162D-05
-0.736D-06	0.275D-06	0.753D-06	0.194D-11	0.377D-14	-0.622D-15	-0.703D-14
0.125D-05	0.572D-06	0.974D-06	0.377D-14	0.588D-11	-0.788D-12	-0.406D-11
-0.146D-05	0.168D-07	-0.140D-05	-0.622D-15	-0.788D-12	0.338D-11	0.785D-12
-0.956D-06	0.159D-05	-0.162D-05	-0.703D-14	-0.406D-11	0.785D-12	0.793D-11

 COEFFICIENTS OF CORRELATION

0.100D+01	-0.104D-02	0.233D-01	-0.124D+00	0.121D+00	-0.186D+00	-0.797D-01
-0.104D-02	0.100D+01	-0.878D-02	0.446D-01	0.534D-01	0.207D-02	0.128D+00
0.233D-01	-0.878D-02	0.100D+01	0.127D+00	0.945D-01	-0.179D+00	-0.135D+00
-0.124D+00	0.446D-01	0.127D+00	0.100D+01	0.112D-02	-0.243D-03	-0.179D-02
0.121D+00	0.534D-01	0.945D-01	0.112D-02	0.100D+01	-0.177D+00	-0.594D+00
-0.186D+00	0.207D-02	-0.179D+00	-0.243D-03	-0.177D+00	0.100D+01	0.152D+00
-0.797D-01	0.128D+00	-0.135D+00	-0.179D-02	-0.594D+00	0.152D+00	0.100D+01

TABLE 8.31.—(Cont'd)

RESIDUALS V											
<u>V1(ED-50(W))</u>				<u>V2(WN- 14)</u>				<u>V1 - V2</u>			
6006	-0.0	-0.7	0.4	6006	0.2	19.5	-11.4	-0.2	-20.1	11.8	
6016	0.4	-1.0	-0.0	6016	-16.8	31.3	1.4	17.2	-32.3	-1.4	
6065	0.2	-0.7	-0.3	6065	-3.5	9.1	3.6	3.6	-9.8	-3.9	
8009	-3.3	1.8	0.4	8009	11.8	-4.5	-2.1	-15.2	6.3	2.5	
8010	-1.4	2.5	0.9	8010	11.0	-9.5	-7.7	-12.5	12.1	8.6	
8015	-0.3	6.5	-0.1	8015	2.5	-14.6	1.1	-2.8	21.1	-1.3	
8019	-0.0	2.1	-0.1	8019	1.5	-21.1	1.8	-1.5	23.2	-1.9	
8030	-2.4	9.5	0.4	8030	8.3	-14.7	-1.6	-10.8	24.3	2.0	
9004	0.0	2.0	-0.0	9004	-1.7	-20.8	0.3	1.8	22.8	-0.4	
9091	0.0	6.8	-0.3	9091	-1.0	-28.5	6.1	1.1	35.3	-6.4	
9426	0.1	3.2	-0.4	9426	-0.5	-16.2	5.0	0.5	19.4	-5.4	

UNIT OF RESIDUALS (METERS)

TABLE 8.32.—Transformation: WN14 - European 50 Datum

 SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

 SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.0+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-99.43	-132.00	-115.98	6.75	0.31	-0.14	0.48
± 4.39	± 4.54	± 4.34	± 0.84	± 0.21	± 0.32	± 0.23

 VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 1.03$$

0.193D+02	0.187D+00	0.172D+00	-0.153D-06	0.101D-06	-0.102D-05	0.306D-06
0.187D+00	0.206D+02	0.100D+00	-0.129D-06	0.228D-06	-0.406D-06	0.597D-06
0.172D+00	0.100D+00	0.188D+02	0.316D-06	0.109D-06	-0.557D-06	0.302D-06
-0.153D-06	-0.129D-06	0.316D-06	0.700D-12	-0.168D-14	-0.167D-15	-0.241D-15
0.101D-06	0.228D-06	0.109D-06	-0.168D-14	0.105D-11	-0.490D-12	0.986D-13
-0.102D-05	-0.406D-06	-0.557D-06	-0.167D-15	-0.490D-12	0.236D-11	-0.698D-12
0.306D-06	0.597D-06	0.302D-06	-0.241D-15	0.986D-13	-0.698D-12	0.126D-11

 COEFFICIENTS OF CORRELATION

0.100D+01	0.936D-02	0.901D-02	-0.417D-01	0.225D-01	-0.151D+00	0.621D-01
0.936D-02	0.100D+01	0.508D-02	-0.339D-01	0.491D-01	-0.583D-01	0.117D+00
0.901D-02	0.508D-02	0.100D+01	0.870D-01	0.246D-01	-0.837D-01	0.621D-01
-0.417D-01	-0.339D-01	0.870D-01	0.100D+01	-0.196D-02	-0.130D-03	-0.256D-03
0.225D-01	0.491D-01	0.246D-01	-0.196D-02	0.100D+01	-0.312D+00	0.858D-01
-0.151D+00	-0.583D-01	-0.837D-01	-0.130D-03	-0.312D+00	0.100D+01	-0.405D+00
0.621D-01	0.117D+00	0.621D-01	-0.256D-03	0.858D-01	-0.405D+00	0.100D+01

TABLE 8.32.—(Cont'd)

RESIDUALS V											
V1(ED- 50)				V2(WN- 14)				V1 - V2			
6006	0.1	-1.1	0.4	6006	-2.9	33.2	-12.0	2.9	-34.3	12.4	
6015	0.1	0.0	0.1	6015	-12.4	-4.3	-14.6	12.4	4.3	14.7	
6016	0.3	-1.2	-0.0	6016	-13.1	35.0	1.1	13.4	-36.2	-1.1	
6065	0.2	-1.1	-0.2	6065	-3.3	14.1	3.1	3.5	-15.3	-3.3	
8009	-2.7	0.1	0.6	8009	9.5	-0.2	-3.3	-12.2	0.3	3.9	
8010	-1.3	1.6	1.0	8010	10.1	-5.8	-8.7	-11.4	7.3	9.7	
8011	-0.5	10.0	0.2	8011	3.9	-30.7	-2.1	-4.3	40.6	2.2	
8015	-0.2	5.4	0.0	8015	1.4	-12.1	-0.1	-1.6	17.4	0.1	
8019	-0.0	1.8	-0.0	8019	0.9	-17.6	0.7	-1.0	19.3	-0.7	
8030	-1.7	7.7	0.7	8030	5.8	-11.9	-2.9	-7.4	19.5	3.6	
9004	0.1	1.9	0.0	9004	-7.3	-19.8	-3.0	7.4	21.7	3.1	
9006	-1.5	0.4	-0.2	9006	6.0	-8.4	3.9	-7.5	8.8	-4.1	
9008	-0.5	0.9	0.7	9008	7.5	-15.7	-12.5	-8.1	16.6	13.3	
9091	-0.2	5.7	-0.3	9091	5.9	-23.6	6.9	-6.1	29.3	-7.2	
9426	0.4	1.6	-0.3	9426	-2.6	-8.2	4.4	3.1	9.9	-4.7	
9431	-0.5	14.0	-3.6	9431	1.4	-70.5	32.4	-1.9	84.5	-36.0	

UNIT OF RESIDUALS (METERS)

TABLE 8.33.—Transformation: WN14 - NAD 1927 (W)

 SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

 SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.0+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-20.07	139.51	179.29	7.91	-0.21	-0.59	0.45
± 1.87	± 1.89	± 1.72	± 0.46	± 0.20	± 0.21	± 0.23

 VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 0.29$$

0.350D+01	0.278D+00	-0.387D+00	0.188D-06	-0.174D-06	-0.465D-06	0.261D-06
0.278D+00	0.357D+01	-0.520D+00	0.803D-08	-0.107D-05	-0.630D-06	0.893D-06
-0.387D+00	-0.520D+00	0.295D+01	0.549D-07	0.351D-06	0.996D-06	-0.421D-06
0.188D-06	0.803D-08	0.549D-07	0.207D-12	-0.639D-14	-0.580D-14	0.102D-13
-0.174D-06	-0.107D-05	0.351D-06	-0.639D-14	0.930D-12	0.395D-12	-0.382D-12
-0.465D-06	-0.630D-06	0.996D-06	-0.580D-14	0.395D-12	0.105D-11	-0.579D-12
0.261D-06	0.893D-06	-0.421D-06	0.102D-13	-0.382D-12	-0.579D-12	0.123D-11

 COEFFICIENTS OF CORRELATION

0.100D+01	0.787D-01	-0.120D+00	0.220D+00	-0.966D-01	-0.242D+00	0.126D+00
0.787D-01	0.100D+01	-0.160D+00	0.933D-02	-0.586D+00	-0.325D+00	0.426D+00
-0.120D+00	-0.160D+00	0.100D+01	0.702D-01	0.212D+00	0.565D+00	-0.221D+00
0.220D+00	0.933D-02	0.702D-01	0.100D+01	-0.146D-01	-0.124D-01	0.201D-01
-0.966D-01	-0.586D+00	0.212D+00	-0.146D-01	0.100D+01	0.400D+00	-0.356D+00
-0.242D+00	-0.325D+00	0.565D+00	-0.124D-01	0.400D+00	0.100D+01	-0.508D+00
0.126D+00	0.426D+00	-0.221D+00	0.201D-01	-0.356D+00	-0.508D+00	0.100D+01

TABLE 8.33.—(Cont'd)

RESIDUALS V											
<u>V1(NAD27(W))</u>				<u>V2(WN- 14)</u>				<u>V1 - V2</u>			
1030	-0.9	0.4	1.6	1030	4.6	-1.5	-6.9	-5.5	2.0	8.5	
3400	2.2	0.5	3.0	3400	-6.9	-2.9	-6.8	9.2	3.4	9.8	
4280	0.1	-0.2	-0.9	4280	-0.5	0.9	3.8	0.6	-1.1	-4.7	
6003	0.2	-0.1	-0.2	6003	-4.5	4.3	1.7	4.7	-4.4	-1.9	
6134	0.2	-0.2	-0.6	6134	-2.5	1.8	4.9	2.7	-2.0	-5.5	
7036	-0.1	-0.4	-1.0	7036	0.2	1.6	3.6	-0.4	-2.0	-4.5	
7045	-1.1	0.5	0.0	7045	2.3	-2.0	-0.0	-3.4	2.5	0.0	
9001	-0.2	0.1	0.5	9001	2.7	-2.0	-5.4	-2.9	2.2	5.9	

UNIT OF RESIDUALS (METERS)

TABLE 8.34.—Transformation: WN14 - NAD 1927 (E)

 SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

 SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.0+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-30.98	140.97	174.93	-2.15	-1.01	0.01	-0.54
± 1.76	± 2.01	± 1.88	± 0.62	± 0.19	± 0.16	± 0.14

 VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 0.76$$

0.311D+01	-0.113D+00	0.392D-01	-0.566D-06	-0.258D-08	-0.127D-06	0.628D-08
-0.113D+00	0.404D+01	-0.871D+00	0.770D-07	0.128D-05	0.571D-06	0.210D-07
0.392D-01	-0.871D+00	0.355D+01	0.109D-06	-0.598D-06	-0.956D-06	0.505D-07
-0.566D-06	0.770D-07	0.109D-06	0.379D-12	0.130D-14	-0.194D-14	0.207D-15
-0.258D-08	0.128D-05	-0.598D-06	0.130D-14	0.866D-12	0.392D-12	-0.101D-12
-0.127D-06	0.571D-06	-0.956D-06	-0.194D-14	0.392D-12	0.618D-12	-0.676D-13
0.628D-08	0.210D-07	0.505D-07	0.207D-15	-0.101D-12	-0.676D-13	0.462D-13

 COEFFICIENTS OF CORRELATION

0.100D+01	-0.320D-01	0.118D-01	-0.521D+00	-0.157D-02	-0.918D-01	0.524D-02
-0.320D-01	0.100D+01	-0.230D+00	0.622D-01	0.686D+00	0.362D+00	0.154D-01
0.118D-01	-0.230D+00	0.100D+01	0.941D-01	-0.341D+00	-0.645D+00	0.395D-01
-0.521D+00	0.622D-01	0.941D-01	0.100D+01	0.227D-02	-0.400D-02	0.495D-02
-0.157D-02	0.686D+00	-0.341D+00	0.227D-02	0.100D+01	0.535D+00	-0.159D+00
-0.918D-01	0.362D+00	-0.645D+00	-0.400D-02	0.535D+00	0.100D+01	-0.126D+00
0.524D-02	0.154D-01	0.395D-01	0.495D-02	-0.159D+00	-0.126D+00	0.100D+01

TABLE 8.34.—(Cont'd)

RESIDUALS V											
V1(NAD27(E))				V2(WN- 14)				V1 - V2			
1021	0.6	0.2	1.3	1021	-2.5	-1.0	-3.8	3.1	1.2	5.1	
1022	0.1	0.8	0.5	1022	-0.7	-4.7	-2.5	0.8	5.5	3.0	
1034	-3.2	1.1	0.6	1034	6.0	-3.2	-2.0	-9.2	4.3	2.6	
1042	2.4	0.3	0.9	1042	-7.2	-1.1	-2.7	9.6	1.5	3.6	
3401	1.6	-0.9	-1.0	3401	-6.7	3.5	2.9	8.3	-4.4	-3.8	
3402	0.5	-0.5	0.4	3402	-0.8	1.7	-1.0	1.4	-2.2	1.4	
3648	-1.2	0.4	1.4	3648	2.7	-1.7	-2.6	-3.9	2.1	4.1	
3657	2.0	0.6	-0.4	3657	-7.3	-2.4	1.0	9.3	3.0	-1.4	
3861	-1.3	-0.3	-0.0	3861	4.3	1.5	0.2	-5.7	-1.8	-0.2	
6002	-0.1	-0.6	-0.9	6002	1.1	5.8	6.6	-1.3	-6.3	-7.5	
7043	-0.2	-0.6	-0.9	7043	1.1	5.8	6.5	-1.3	-6.4	-7.4	
7072	0.4	0.4	0.5	7072	-4.4	-4.4	-5.1	4.8	4.7	5.5	
7075	-3.4	-1.2	-0.3	7075	7.9	3.5	0.9	-11.3	-4.8	-1.2	

UNIT OF RESIDUALS (METERS)

TABLE 8.35.—Transformation: WN14 - NAD 1927

 SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

 SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.0+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-31.71	142.34	177.32	-0.80	-0.86	-0.23	-0.33
± 1.35	± 1.26	± 1.23	± 0.27	± 0.06	± 0.05	± 0.10

 VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 0.76$$

0.1820+01	-0.2580-02	-0.2800-02	-0.7240-07	0.5210-08	-0.2160-07	0.8230-08
-0.2580-02	0.1590+01	0.1540-02	0.1030-07	0.6240-07	-0.3180-08	0.8560-07
-0.2800-02	0.1540-02	0.1510+01	0.2070-07	-0.7570-08	-0.5650-07	0.1310-07
-0.7240-07	0.1030-07	0.2070-07	0.7340-13	-0.2000-15	0.1910-16	0.2620-15
0.5210-08	0.6240-07	-0.7570-08	-0.2000-15	0.7710-13	0.9590-14	-0.1000-13
-0.2160-07	-0.3180-08	-0.5650-07	0.1910-16	0.9590-14	0.6950-13	-0.2930-13
0.8230-08	0.8560-07	0.1310-07	0.2620-15	-0.1000-13	-0.2930-13	0.2420-12

 COEFFICIENTS OF CORRELATION

0.1000+01	-0.1510-02	-0.1690-02	-0.1980+00	0.1390-01	-0.6070-01	0.1240-01
-0.1510-02	0.1000+01	0.9920-03	0.3020-01	0.1780+00	-0.9560-02	0.1380+00
-0.1690-02	0.9920-03	0.1000+01	0.6210-01	-0.2220-01	-0.1740+00	0.2170-01
-0.1980+00	0.3020-01	0.6210-01	0.1000+01	-0.2660-02	0.2670-03	0.1970-02
0.1390-01	0.1780+00	-0.2220-01	-0.2660-02	0.1000+01	0.1310+00	-0.7340-01
-0.6070-01	-0.9560-02	-0.1740+00	0.2670-03	0.1310+00	0.1000+01	-0.2260+00
0.1240-01	0.1380+00	0.2170-01	0.1970-02	-0.7340-01	-0.2260+00	0.1000+01

TABLE 8.35.—(Cont'd)

RESIDUALS V											
V1(NAD-27)				V2(WN- 14)				V1 - V2			
-----				-----				-----			
1021	1.0	0.2	1.3	1021	-3.9	-0.9	-3.8	4.8	1.1	5.1	
1022	0.0	0.5	0.5	1022	-0.1	-3.0	-2.3	0.2	3.5	2.8	
1030	-0.5	-0.3	1.4	1030	2.7	0.9	-6.2	-3.2	-1.2	7.6	
1034	-7.9	1.8	1.2	1034	5.4	-5.4	-3.9	-8.3	7.1	5.0	
1042	2.5	0.2	1.1	1042	-7.6	-0.8	-3.1	10.1	1.0	4.1	
3400	0.5	0.6	2.2	3400	-1.5	-3.2	-5.1	2.0	3.8	7.4	
3401	2.2	-0.8	-1.1	3401	-9.1	3.1	3.1	11.3	-3.9	-4.2	
3402	0.2	-0.7	0.7	3402	-0.3	2.4	-1.6	0.5	-3.1	2.3	
3648	-1.1	0.2	1.5	3648	2.5	-0.8	-2.7	-3.6	1.0	4.2	
3657	2.5	0.6	-0.4	3657	-8.8	-2.4	1.0	11.3	3.1	-1.4	
3861	-1.5	-0.8	-0.2	3861	4.7	3.4	0.6	-6.2	-4.1	-0.8	
4280	0.9	-1.0	-0.9	4280	-4.4	5.1	4.1	5.3	-6.1	-5.1	
6002	0.1	-0.6	-0.9	6002	-0.5	5.8	6.5	0.5	-6.3	-7.4	
6003	0.0	-0.5	-0.9	6003	-0.5	17.5	6.9	0.6	-18.1	-7.7	
6134	0.5	-0.4	-0.6	6134	-5.5	4.5	5.2	6.0	-4.9	-5.8	
7036	-2.2	2.2	0.2	7036	4.5	-9.6	-0.7	-6.7	11.7	0.9	
7043	0.1	-0.6	-0.9	7043	-0.5	5.8	6.4	0.5	-6.4	-7.3	
7045	-3.6	0.5	-0.6	7045	7.5	-1.9	2.0	-11.1	2.5	-2.6	
7072	0.4	0.2	0.4	7072	-4.1	-2.5	-4.7	4.5	2.7	5.1	
7075	-2.7	-0.8	-0.1	7075	6.3	2.3	0.2	-9.0	-3.1	-0.3	
9001	-0.4	0.4	0.6	9001	5.2	-6.8	-6.2	-5.6	7.1	6.8	

UNIT OF RESIDUALS (METERS)

TABLE 8.36.—Transformation: WN14 - South American 1969 Datum

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-96.57	-13.67	-29.36	-6.67	0.63	-0.17	0.12
± 3.02	± 3.02	± 3.15	± 0.59	± 0.17	± 0.12	± 0.13

VARIANCE - COVARIANCE MATRIX

$$\sigma_0^2 = 0.97$$

0.915D+01	-0.172D+00	-0.202D+00	0.419D-06	0.325D-06	0.291D-06	0.674D-07
-0.172D+00	0.912D+01	0.697D-01	0.231D-06	-0.769D-06	0.579D-07	-0.409D-06
-0.202D+00	0.697D-01	0.989D+01	-0.410D-06	-0.122D-06	0.346D-06	-0.185D-06
0.419D-06	0.231D-06	-0.410D-06	0.352D-12	0.128D-14	0.159D-14	0.252D-14
0.325D-06	-0.769D-06	-0.122D-06	0.128D-14	0.657D-12	-0.103D-12	0.463D-14
0.291D-06	0.579D-07	0.346D-06	0.159D-14	-0.103D-12	0.340D-12	0.585D-13
0.674D-07	-0.409D-06	-0.185D-06	0.252D-14	0.463D-14	0.585D-13	0.373D-12

COEFFICIENTS OF CORRELATION

0.100D+01	-0.188D-01	-0.212D-01	0.234D+00	0.133D+00	0.165D+00	0.365D-01
-0.188D-01	0.100D+01	0.734D-02	0.129D+00	-0.314D+00	0.329D-01	-0.222D+00
-0.212D-01	0.734D-02	0.100D+01	-0.219D+00	-0.479D-01	0.189D+00	-0.965D-01
0.234D+00	0.129D+00	-0.219D+00	0.100D+01	0.266D-02	0.458D-02	0.696D-02
0.133D+00	-0.314D+00	-0.479D-01	0.266D-02	0.100D+01	-0.219D+00	0.934D-02
0.165D+00	0.329D-01	0.189D+00	0.458D-02	-0.219D+00	0.100D+01	0.164D+00
0.365D-01	-0.222D+00	-0.965D-01	0.696D-02	0.934D-02	0.164D+00	0.100D+01

TABLE 8.36.—(Cont'd)

RESIDUALS V											
V1 (SAD-69)				V2 (WN- 14)				V1 - V2			
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3414	4.1	-1.3	6.3	3414	-1.8	0.8	-3.0	5.9	-2.1	9.2	
3431	-1.0	2.5	0.1	3431	1.1	-3.7	-0.1	-2.0	6.2	0.2	
3477	16.3	2.3	13.9	3477	-10.1	-3.4	-9.8	26.3	5.8	23.7	
6008	0.0	0.3	2.0	6008	-0.3	-5.1	-14.6	0.4	5.4	16.6	
6009	-2.0	-1.0	-1.9	6009	9.9	5.4	7.1	-11.9	-6.4	-9.0	
6019	-0.1	-0.2	-0.8	6019	1.5	2.1	3.8	-1.6	-2.3	-4.6	
6067	-0.2	-0.5	-0.8	6067	2.8	7.4	7.5	-3.0	-7.9	-8.3	
9007	1.0	0.4	-1.2	9007	-10.7	-2.9	3.9	11.8	3.3	-5.1	
9009	-0.5	0.0	-1.9	9009	5.8	-0.6	10.8	-6.3	0.6	-12.8	
9031	-5.0	1.6	2.2	9031	4.6	-1.3	-1.1	-9.6	2.9	3.3	

UNIT OF RESIDUALS (METERS)

TABLE 8.37.—Summary of Cartesian Coordinates (Solutions WN12 and WN14)

S T A T I O N			S O L U T I O N WN-12						S O L U T I O N WN-14					
NO	N A M E	U	V	W	σ_u	σ_v	σ_w	U	V	W	σ_u	σ_v	σ_w	
1021	BLOSSOM POINT	1118021.8	-4876331.7	3942970.9	3.1	4.0	4.2	1118023.1	-4876323.4	3942963.9	2.8	2.6	2.8	
1022	FORT MYERS	807850.8	-5652004.0	2833509.0	2.6	3.3	3.3	807851.9	-5651989.6	2833500.2	2.2	1.9	2.3	
1030	GOLDSTONE	-2357249.2	-4646346.4	3668312.5	6.1	4.4	4.7	-2357242.9	-4646338.5	3668306.8	5.6	3.3	3.2	
1032	ST. JOHN'S	2602704.3	-3419179.7	4697621.1	49.1	89.5	29.9	2602688.6	-3419228.9	4697637.3	39.3	46.7	13.8	
1033	FAIRBANKS	-2299292.3	-1445690.5	5751823.3	7.5	10.0	10.5	-2299282.6	-1445693.7	5751811.6	6.9	9.7	5.7	
1034	E. GRAND FORKS	-521708.3	-4242074.9	4718726.5	3.5	4.0	4.4	-521704.5	-4242064.3	4718716.8	3.1	3.0	2.7	
1042	ROSMAN	647495.9	-5177948.0	3656714.4	3.1	3.6	4.0	647497.5	-5177935.6	3656705.9	2.8	2.4	2.8	
3106	ANTIGUA	2881840.5	-5372180.7	1868584.5	4.1	4.6	4.9	2881838.3	-5372164.6	1868538.6	3.7	3.3	4.3	
3334	STONEVILLE	-84969.1	-5327986.3	3493434.3	15.6	14.0	10.8	-84963.8	-5327974.9	3493428.3	13.6	6.8	9.0	
3400	COLORADO SPRINGS	-1275239.4	-4798062.9	3994229.5	16.3	12.4	8.6	-1275207.2	-4798029.3	3994208.3	9.1	5.1	5.7	
3401	BEDFORD	1513134.8	-4463580.1	4283061.2	3.5	5.3	4.6	1513136.1	-4463576.8	4283055.8	3.2	3.4	3.0	
3402	SEWES	167256.1	-5481980.4	3245042.6	4.2	4.3	4.6	167259.7	-5481971.0	3245037.0	3.9	2.8	3.5	
3404	SWAN ISLAND	642485.7	-6053942.4	1895690.5	5.0	5.3	5.5	642491.4	-6053940.3	1895688.6	4.7	3.7	4.9	
3405	GRAND TURK	1919482.1	-5621096.5	2315780.1	3.6	5.6	4.9	1919482.9	-5621088.1	2315775.3	3.3	3.5	4.0	
3406	CURACAO	2251802.9	-5816929.0	1327197.4	2.8	3.5	3.8	2251800.2	-5816912.9	1327191.1	2.4	2.1	3.4	
3407	TRINIDAD	2979892.9	-5513532.6	1181126.8	5.2	5.1	5.9	2979891.1	-5513530.9	1181129.3	4.7	3.4	5.3	
3413	NATAL	5186366.4	-3654225.1	-653022.7	3.4	2.9	3.2	5186348.4	-3654222.4	-653018.9	2.1	2.2	2.7	
3414	BRASILIA	4114987.8	-4554148.5	-1732166.1	9.9	8.4	7.9	4114977.8	-4554142.5	-1732154.0	7.7	6.1	7.2	
3431	ASUNCION	3093056.1	-4870100.4	-2710845.8	8.5	9.3	12.5	3093045.4	-4870081.7	-2710823.0	7.6	6.5	10.8	
3476	PARAMARIBO	3623293.6	-5214213.7	601514.0	3.4	3.3	3.6	3623277.3	-5214210.7	601515.3	2.2	2.0	3.0	
3477	BOGOTA	1744649.6	-6114305.6	532205.2	10.4	13.7	9.8	1744650.2	-6114286.7	532208.6	10.2	6.6	9.6	
3478	MANAUS	3185785.4	-5514574.5	-347713.2	19.3	35.4	35.8	3185777.0	-5514585.9	-347703.2	18.7	14.5	35.1	
3499	QUITO	1280834.0	-6250966.2	-10805.5	3.8	5.9	4.5	1280834.2	-6250955.9	-10800.6	3.6	3.4	4.1	
3648	HUNTER AFB	832562.6	-5349553.4	3360596.4	4.1	5.0	5.4	832566.2	-5349540.7	3360585.3	3.6	2.5	3.6	
3657	ABERDEEN	1186786.1	-4785205.1	4032892.3	3.4	5.0	4.5	1186787.1	-4785193.1	4032882.3	3.1	3.0	3.0	
3861	HOMESTEAD	961766.7	-5679170.6	2729893.8	3.3	3.8	3.7	961767.9	-5679156.6	2729883.5	3.0	2.3	2.6	
3902	CHEYENNE	-1234689.4	-4651235.9	4174763.4	28.6	32.1	11.3	-1234700.7	-4651242.8	4174758.6	8.6	6.3	6.3	
3903	HERNDON	1088980.0	-4842973.2	3991763.9	12.3	15.5	11.4	1088989.7	-4843005.4	3991776.6	12.1	8.5	8.9	
4050	PRETORIA	5051614.8	-2726608.6	-2774181.0	4.4	3.8	5.5	5051608.1	-2726603.3	-2774166.8	3.2	3.2	4.4	
4061	ANTIGUA	2881594.5	-5372540.2	1868034.3	4.2	4.7	5.0	2881592.3	-5372523.9	1868024.4	3.8	3.5	4.3	
4081	GRAND TURK	1920409.9	-5619426.1	2319133.4	3.7	5.7	5.0	1920410.9	-5619417.8	2319128.5	3.3	3.6	4.0	
4082	MERRITT ISLAND	910567.9	-5539130.2	3017974.8	2.9	3.8	3.7	910567.2	-5539113.2	3017965.3	2.6	2.4	2.8	
4280	VANDENBERG AFB	-2671883.7	-4521217.3	3607495.0	4.3	4.4	4.8	-2671873.8	-4521210.5	3607490.4	3.8	3.3	3.6	
4740	BERMUDA	2308888.6	-4874314.8	3393092.0	3.8	5.4	5.1	2308887.3	-4874298.2	3393082.1	3.3	3.1	3.8	
5001	HERNDON	1088874.4	-4842954.9	3991857.8	4.9	10.2	7.9	1088849.4	-4842948.7	3991840.2	3.6	3.0	3.7	
5201	MOSES LAKE	-2127810.4	-3785912.3	4656011.9	2.7	2.8	3.7	-2127802.2	-3785911.5	4656012.1	2.3	2.2	2.4	
5410	MIDWAY ISLANDS	-5618764.5	-258231.5	2997243.8	2.9	3.2	4.1	-5618754.1	-258237.5	2997250.2	2.3	2.8	3.6	
5448	FORT STEWART	794687.3	-5360063.7	3353093.5	4.2	5.0	5.5	794691.0	-5360051.1	3353082.4	3.6	2.5	3.6	
5712	PARAMARIBO	3623307.1	-5214190.5	601672.3	3.4	3.3	3.6	3623289.8	-5214188.0	601673.2	2.1	2.0	2.9	
5713	TERCEIRA	4433654.4	-2268159.2	3971673.1	2.7	2.8	3.8	4433637.8	-2268153.2	3971656.8	2.0	2.2	2.5	

TABLE 8.37—(Cont'd)

STATION		SOLUTION MW-12					SOLUTION WN-14				
NO	NAME	U	V	W	σ_u	σ_v	U	V	W	σ_u	σ_v
5715	DAKAR	5884479.9	-1853580.1	1612763.8	2.3	2.5	5884468.8	-1853580.1	1612760.1	1.6	2.0
5717	FORT LAMY	6023416.1	1617949.5	1331651.2	2.7	2.8	6023410.7	1617946.5	1331655.8	2.0	2.0
5720	ADDIS ABABA	4900750.1	3968255.1	966334.3	2.7	2.9	4900749.1	3968253.0	966354.7	2.0	2.1
5721	MASHAD	2604406.6	4444124.9	3150345.7	2.6	2.8	2604404.8	4444122.3	3150344.3	2.1	2.7
5722	MIEGO GARCIA	1905122.3	6032294.5	-810776.4	4.2	5.5	1905127.0	6032287.5	-810716.2	3.5	4.1
5723	CHIANG MAI	-941713.7	5967448.6	2039317.5	3.1	3.3	-941709.4	5967445.0	2039322.9	2.5	2.3
5726	ZAMBANGA	-3361953.2	5365845.5	763673.4	3.0	3.3	-3361946.8	5365837.0	763627.8	2.3	2.2
5730	MAE ISLAND	-5858583.8	1394474.9	2093844.7	2.8	3.1	-5858584.6	1394467.2	2093847.4	2.1	2.5
5732	PAGO PAGO	-6099984.0	-997345.6	-1568577.0	5.7	4.4	-6099970.5	-997355.3	-1568570.9	3.6	3.5
5733	CHRISTMAS ISLAND	-5885350.8	-2448375.3	221663.1	4.4	3.5	-5885333.9	-2448380.4	221670.7	2.7	2.9
5734	SHEVA	-3851808.1	396416.1	505134.3	3.2	3.7	-3851799.0	396409.3	5051342.0	2.7	3.3
5735	NATAL	5186368.5	-3654226.0	-653022.6	3.3	2.8	5186350.6	-3654223.7	-653018.9	2.0	2.1
5736	ASCENSION ISLAND	6118355.5	-1571763.1	-878558.4	3.3	2.9	6118340.3	-1571761.9	-878553.6	2.3	2.2
5739	TERCEIRA	4433646.0	-2268192.2	3971663.3	2.7	2.8	4433629.3	-2268186.2	3971647.0	2.0	2.2
5744	CATANIA	4896444.1	1316129.4	3856628.8	2.4	2.8	4896437.7	1316125.0	3856626.2	1.8	2.2
5907	NORTHINGTON	-449391.6	-4600910.6	4380315.4	5.8	13.8	-449417.5	-4600905.5	4380288.1	4.2	3.2
5911	BERMUDA	2308010.4	-4873778.3	3394476.1	3.6	4.9	2307991.2	-4873773.2	3394463.4	2.6	2.3
5912	PANAMA	1142664.4	-6196104.1	988340.8	4.8	9.1	1142644.5	-6196109.1	988336.6	3.1	3.4
5914	PUERTO RICO	2349423.9	-5576023.2	2010340.5	13.5	21.1	2349456.9	-5576027.1	2010342.6	10.5	7.0
5915	AUSTIN	-744066.7	-5465234.3	3192485.8	5.6	15.3	-744091.1	-5465238.7	3192467.4	3.8	3.8
5923	CYPRUS	4363335.9	2862258.8	3655360.7	2.5	2.7	4363332.2	2862254.9	3655380.7	1.9	2.1
5924	ROTA	5093565.8	-565319.1	3784273.1	2.4	3.1	5093556.2	-565322.3	3784268.3	1.9	2.6
5925	ROBERTS FIELD	6237376.8	-1140241.8	687740.0	3.0	3.1	6237366.3	-1140241.5	687740.2	2.3	2.6
5930	SINGAPORE	-1542556.4	6186984.6	151827.8	3.3	3.4	-1542549.4	6186956.7	151833.8	2.6	2.7
5931	HONG KONG	-2423919.1	5388254.8	2394863.4	3.1	3.5	-2423914.9	5388250.3	2394869.2	2.5	2.5
5933	DARWIN	4071578.3	4714267.0	-1366533.3	4.3	4.4	4071568.4	4714253.3	-1366528.3	3.2	3.2
5934	MANUS	-5367671.7	3437881.4	-225419.4	3.6	3.5	-5367663.1	3437869.9	-225416.0	2.5	2.5
5935	GUAM	-5059832.6	3591194.2	1472759.4	2.9	3.0	-5059825.7	3591186.0	1472762.5	2.1	2.2
5937	PALAU	-4433470.5	4512939.3	809955.3	3.1	3.2	-4433463.6	4512930.3	809958.7	2.2	2.2
5938	GUADALCANAL	-5915106.0	2146873.2	-1037912.8	4.4	3.9	-5915096.5	2146860.8	-1037909.5	3.0	3.0
5941	MAUI	-5467771.9	2254024.0	2254024.0	3.5	3.2	-5467757.3	-2381246.7	2254033.8	2.5	2.8
6001	THULE	546566.4	-1389993.6	6180242.4	2.7	2.7	546568.7	-1389993.7	6180236.7	2.6	2.4
6002	BELTSVILLE	1130762.7	-4830837.6	3994709.9	2.2	2.7	1130764.9	-4830831.9	3994704.0	2.0	1.7
6003	MOSES LAKE	-2127839.9	-3785864.2	4655037.4	2.5	2.7	-2127832.1	-3785863.0	4656037.2	2.1	2.0
6004	SHEMYA	-3851806.8	396416.1	5051341.7	3.2	3.7	-3851797.5	396409.4	5051340.5	2.7	3.3
6006	TROMSD	2102930.3	721674.1	5953181.7	2.7	3.3	2102927.4	721668.5	5958180.8	2.4	2.9
6007	TERCEIRA	4433653.3	-2268156.9	3971671.0	2.7	2.7	4433637.3	-2268151.4	3971655.0	2.0	2.2
6008	PARAMARIBO	3623257.3	-5214236.7	601534.8	3.4	3.3	3623241.0	-5214233.7	601536.1	2.1	2.0
6009	QUITO	1280834.0	-6250966.2	-10805.5	3.8	5.9	1280834.2	-6250955.9	-10800.6	3.6	3.4
6011	MAUI	-5466039.2	-2404429.3	2242224.6	4.4	3.4	-5466018.6	-2404431.5	2242224.4	3.0	2.9

TABLE 8.37—(Cont'd)

S T A T I O N			S O L U T I O N WN-12							S O L U T I O N WN-14						
NO	I	N A M E	U	V	W	σ_u	σ_v	σ_w	U	V	W	σ_u	σ_v	σ_w		
6012		WAKE ISLAND I	-5858578.8	1394516.4	2093817.4	2.9	3.2	3.8	-5858569.3	1394508.7	2093820.3	2.1	2.6	3.2		
6013		KANDYA	-3565901.4	4120723.2	3303426.9	4.0	5.2	5.9	-3565892.8	4120713.6	3303428.3	3.3	4.4	4.9		
6015		MASHHAD	2604355.4	4444169.2	3750321.7	2.6	2.9	3.5	2604353.3	4444166.0	3750320.5	2.1	2.2	2.6		
6016		CATANIA	4896394.6	1316176.2	3856670.7	2.4	2.8	3.2	4896388.3	1316172.1	3856668.2	1.8	2.2	2.2		
6019		VILLA DOLORES	2280630.7	-4914547.7	-3355417.9	2.7	3.6	5.2	2280627.1	-4914543.2	-3355402.8	2.4	2.7	3.7		
6020		EASTER ISLAND	-1888621.5	-5354898.4	-2895762.3	6.0	6.1	6.9	-1888614.3	-5354894.4	-2895749.0	5.4	4.5	5.5		
6022		TUTUILA	-997357.9	-997357.7	-1568593.6	4.8	3.9	5.2	-997362.2	-997362.2	-1568585.5	3.4	3.6	4.7		
6023		THURSDAY ISLAND	-4955391.2	3842255.7	-1163855.5	4.5	3.9	4.7	-4955386.8	3842247.8	-1163847.4	3.2	3.0	4.0		
6031		INVERCARGILL	-4313830.4	891340.6	-4597277.7	4.4	4.2	5.3	-4313825.3	891333.9	-4597265.8	3.4	3.9	3.8		
6032		CAVERSHAM	-2375426.0	4875557.6	-3345424.5	3.7	4.3	5.0	-2375420.6	4875546.7	-3345411.1	3.5	3.2	3.9		
6038		SOCORRO ISLAND	-2160989.6	-5642717.9	2035368.0	2.9	3.8	4.4	-2160980.9	-5642710.5	2035367.8	2.5	2.8	3.8		
6039		PITCAIRN ISLAND	-3724775.0	-4421234.4	-2686094.4	7.9	7.2	7.3	-3724765.9	-4421237.6	-2686084.7	6.2	5.4	5.5		
6040		COCOS ISLAND	-741986.1	6190803.6	-1338557.1	4.7	4.8	4.7	-741981.7	6190792.9	-1338546.3	4.5	3.7	4.2		
6042		ADDIS ABABA	4900752.0	3968225.1	966318.9	2.7	2.9	3.4	4900750.7	3968252.7	966325.3	2.0	2.1	2.9		
6043		CERRO SOMBRERO	1371376.5	-3614750.6	-5055947.1	3.5	4.2	7.0	1371375.9	-3614750.3	-5055927.8	3.3	3.8	4.8		
6044		HEARD ISLAND	1098898.5	3684617.0	-5071900.1	6.9	6.7	11.1	1098897.9	3684606.6	-5071873.1	6.8	6.2	7.8		
6045		MAURITIUS	3223434.7	5045343.6	-2191818.0	3.6	4.0	4.6	3223432.0	5045336.3	-2191805.7	3.2	3.1	3.9		
6047		ZAMBOANGA	-3361983.5	5365820.6	763620.5	3.1	3.4	3.8	-3361976.9	5365811.9	763624.7	2.4	2.3	3.2		
6050		PALMER STATION	1192679.3	-2451013.2	-5747052.4	5.0	6.3	9.8	1192678.8	-2451015.6	-5747034.2	4.9	6.1	6.1		
6051		MANSON STATION	1111337.1	2169270.2	-5874355.2	5.0	4.2	7.3	1111336.1	2169262.7	-5874334.1	4.9	3.7	4.4		
6052		WILKES STATION	-902611.4	2409530.0	-5816569.9	4.6	4.4	7.4	-902608.8	2409522.1	-5816551.8	4.4	4.0	5.4		
6053		MCMURDO STATION	-1310854.8	311262.9	-6213294.3	4.8	4.8	7.4	-1310852.3	311257.5	-6213276.5	4.6	4.5	4.3		
6055		ASCENSION ISLAND	6118349.3	-1571749.2	-878601.3	3.3	2.9	3.4	6118334.2	-1571748.3	-878596.5	2.3	2.3	2.8		
6059		CHRISTMAS ISLAND	-5885350.2	-2448374.4	221663.6	4.3	3.4	4.5	-5885333.5	-2448379.0	221671.1	2.7	2.9	3.8		
6060		CULGOORA	-4751655.0	2792065.7	-3200174.2	4.5	4.0	4.7	-4751650.0	2792058.1	-3200164.0	3.3	3.3	3.7		
6061		SOUTH GEORGIA IS.	2999921.2	-2219366.3	-5155267.1	3.9	5.9	7.8	2999915.6	-2219369.3	-5155246.0	3.7	5.7	5.3		
6063		DAKAR	5884479.3	-1853496.4	1612856.7	2.4	2.6	3.2	5884467.4	-1853495.8	1612855.1	1.7	2.1	2.5		
6064		FORT LAMY	6023394.4	1617934.2	1331731.7	3.3	3.1	3.7	6023386.7	1617931.9	1331733.2	2.7	2.6	3.2		
6065		HOHENPEISENBERG	4213570.2	820833.7	4702786.5	2.6	3.0	3.6	4213564.6	820830.0	4702784.4	2.0	2.4	2.3		
6066		WAKE ISLAND II	-5858580.7	1394474.0	2038843.0	2.9	3.2	3.8	-5858571.2	1394466.4	2038846.0	2.1	2.6	3.2		
6067		NATAL	5186415.0	-3653935.9	-654280.7	3.3	2.8	3.1	5186397.1	-3653933.3	-654276.9	2.1	2.2	2.6		
6068		JOHANNESBURG	5084837.1	2670346.5	-2768109.3	4.2	3.5	5.3	5084830.4	2670341.2	-2768095.2	3.0	2.9	4.2		
6069		TRISTAN DA CUNHA	-1086871.1	-3823187.7	8.3	6.6	10.4	4978421.7	-1086874.0	-3823167.8	6.5	6.4	8.1			
6072		CHIANG MAI	941707.8	5967462.5	2039307.4	5.9	5.1	4.9	-941702.1	5967455.1	2039311.6	5.7	4.0	4.3		
6073		DIEGO GARCIA	1905134.3	6032292.0	-810742.3	3.7	4.8	4.7	1905134.1	6032282.4	-810732.7	3.4	3.7	4.2		
6075		MAHE	3602824.5	5238248.2	-515957.7	4.2	4.6	4.5	3602820.6	5238240.7	-515948.3	3.8	3.6	4.0		
6078		PORT VILA	-952307.7	1231910.5	-525983.7	19.9	9.4	16.6	-952303.4	1231904.9	-525972.5	9.7	8.0	12.4		
6111		WRIGHTWOOD I	-2448862.8	-4667992.3	3582759.4	3.0	3.2	3.8	-2448853.3	-4667985.8	3582754.9	2.6	2.1	2.4		
6123		POINT BARROW	-1881807.4	-812435.3	6019599.3	4.9	4.6	7.1	-1881799.4	-812439.0	6019590.7	4.6	4.4	4.5		
6134		WRIGHTWOOD II	-2448916.5	-4668082.4	3582454.1	3.0	3.2	3.8	-2448907.0	-4668075.9	3582449.6	2.6	2.1	2.4		

TABLE 8.37—(Cont'd)

STATION		SOLUTION MN-12						SOLUTION MN-14					
NO	NAME	U	V	W	σ_u	σ_v	σ_w	U	V	W	σ_u	σ_v	σ_w
7036	EDINBURG	-828491.0	-5657486.5	2816825.5	3.8	3.9	4.0	-828487.0	-5657471.3	2816816.0	3.5	2.4	2.9
7037	COLUMBIA	-191294.8	-4967308.3	3983264.5	3.2	3.5	3.9	-191291.0	-4967293.9	3983252.6	2.9	2.2	2.4
7039	BERMUDA	2308214.8	-4873614.8	3394568.4	3.7	5.3	5.0	2308213.4	-4873598.3	3394558.5	3.3	3.1	3.6
7040	SAN JUAN	2465050.9	-5534945.5	1985222.2	4.0	4.4	4.7	2465049.5	-5534930.0	1985513.1	3.7	3.2	4.0
7043	GREENBELT	1130706.5	-4831337.2	3994141.4	2.2	2.7	3.1	1130708.6	-4831331.3	3994135.5	2.0	1.7	1.9
7045	DENVER	-1240475.1	-4760256.0	4048997.8	4.6	4.2	4.7	-1240470.2	-4760242.1	4048985.3	4.2	2.8	2.9
7072	JUPITER	976261.3	-5601416.4	2830251.4	2.5	3.3	3.3	976261.3	-5601399.9	2880241.9	2.2	1.8	2.3
7075	SUBURY	692618.7	-4347090.4	4600487.7	4.0	5.7	5.4	692620.7	-4347076.5	4600475.4	3.7	3.8	3.4
7076	KINGSTON	1384159.2	-5905680.0	1966554.4	4.3	5.8	5.9	1384158.7	-5905662.0	1966545.7	4.1	4.4	5.3
8009	WIPPOLEDER	3923429.9	299866.1	503013.3	13.3	13.1	15.2	3923397.4	299869.4	5002975.5	8.5	10.1	6.9
8010	ZIMMERWALD	4331312.7	567499.7	4633118.9	7.9	10.9	11.5	4331307.0	567490.8	4633108.3	5.7	8.3	5.4
8011	MALVERN	3920188.9	-134806.7	5012776.2	12.8	16.5	15.5	3920153.5	-134804.5	5012734.8	8.9	14.3	6.9
8015	HAUTE PROVENCE	4578328.1	457945.6	4403204.8	6.4	10.7	10.2	4578322.1	457936.5	4403195.3	4.2	8.0	4.4
8019	NICE	4579469.1	58582.7	438428.4	6.3	10.6	10.1	4579463.2	586573.5	4386419.2	4.1	7.9	4.3
8030	MEUDON	4205629.1	163695.4	4776550.9	9.0	12.3	11.8	4205626.9	163683.4	4776540.6	6.5	9.7	5.8
9001	ORGAN PASS	-1535755.1	-5167026.6	3401047.1	4.6	3.9	3.8	-1535750.7	-5167014.4	3401039.4	4.2	2.8	2.7
9002	OLIFANTSFONTEIN	5056115.1	2716514.0	-2775782.9	4.2	3.6	5.3	5056108.4	2716508.7	-2775768.8	3.0	3.0	4.2
9004	SAN FERNANDO	5105589.8	-555269.7	3759680.6	6.3	12.9	8.5	5105581.5	-555271.5	3769676.0	3.4	10.0	4.0
9005	TOKYO	-3946751.4	3366303.2	3698330.3	11.2	10.3	9.8	-3946730.5	3366286.1	3698822.9	9.2	9.0	7.5
9006	NAINI TAL	1018153.3	5471119.3	3109622.2	14.2	10.9	9.6	1018164.5	5471108.7	3109625.6	12.4	5.5	6.0
9007	AREQUIPA	1942762.4	-5804101.6	-1796905.8	2.8	4.0	5.3	1942760.9	-5804088.2	-1796900.9	2.5	2.9	4.4
9008	SHIRAZ	3376872.6	4403980.0	3136250.1	8.1	10.3	9.5	3376875.2	4403976.2	3136257.3	6.8	6.1	6.1
9009	CURACAO	2251813.5	-5816933.6	1327169.7	2.8	3.5	3.8	2251810.7	-5816917.6	1327163.4	2.4	2.1	3.4
9010	JUPITER	976276.2	-5601418.8	2880244.0	2.5	3.3	3.3	976276.2	-5601402.2	2880234.5	2.1	1.8	2.3
9011	VILLA DOLORES	2280578.9	-4914584.8	-3355398.8	2.7	3.6	5.3	2280575.3	-4914580.2	-3355383.7	2.4	2.7	3.7
9012	MAUI	-5466088.5	-2404310.5	2242188.7	4.5	3.4	3.9	-5466067.8	-2404312.7	2242188.4	3.0	2.9	3.3
9021	MOUNT HOPKINS	-1936799.1	-5077719.4	3331276.1	7.3	6.8	6.4	-1936789.3	-5077714.7	333122.7	7.1	5.3	5.3
9028	ADDIS ABABA	4903727.7	3965208.6	963593.2	2.8	2.9	3.4	4903726.6	3965206.3	963859.6	2.1	2.1	2.9
9029	NATAL	5186459.5	-3653874.6	-654317.9	3.4	2.9	3.2	5186441.4	-3653871.9	-654314.1	2.1	2.2	2.7
9031	COMODORO R'DAVIA	1693795.3	-4112354.3	-455644.1	8.4	9.4	14.3	1693797.3	-4112353.1	-455642.0	8.3	8.8	11.2
9051	ATHENS	4606866.7	2029708.0	3903567.4	6.0	12.6	8.9	4606861.5	2029692.2	3903562.2	4.2	10.3	4.4
9091	DIONYSOS	4595164.1	2039433.4	3912675.8	6.0	12.6	8.9	4595158.9	2039417.6	3912670.6	4.2	10.3	4.4
9424	COLD LAKE	-1264834.5	-3466912.6	5185449.2	5.2	6.5	7.7	-1264831.9	-3466915.4	5185450.9	4.7	5.5	4.3
9425	EDWARDS AFB	-2450022.2	-4624438.2	3635041.1	3.1	3.2	3.8	-2450012.7	-4624431.6	3635036.6	2.6	2.2	2.4
9426	HARESTUA	3121262.6	51592607.0	351270.9	9.6	11.4	15.5	3121261.3	51592605.7	3512723.0	8.6	9.4	5.8
9427	JOHNSTON ISLAND	-6007458.1	-1111834.2	1825130.0	10.9	20.6	8.8	-6007428.7	-1111852.5	1825733.9	8.9	19.8	8.6
9431	RIGA	3183891.2	1421439.3	532219.8	13.1	11.7	14.7	3183897.6	1421426.7	5322814.7	12.3	9.4	7.0
9432	UZMGOROD	3907423.8	1602394.2	4763532.7	10.2	12.6	13.7	3907419.2	1602378.6	4763922.1	7.9	10.4	5.9