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OBSERVATIONAL DATA FORMATS AND IDENTIFICATION OF SUPPLEMENTARY DOCUMENTATION FOR THE NATIONAL GEODETIC SATELLITE PROGRAM

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for
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ABSTRACT

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Presented are results of a survey conducted among principal investigators and data collectors associated with the National Geodetic Satellite Program (NGSP). The results of this survey are observational data formats for geodetic/tracking data and an identification of supplementary documentation required for the data analyst.

Author

1.0 GENERAL

A survey conducted among the principal investigators and data collectors associated with the National Geodetic Satellite Program (NGSP), has resulted in the NGSP formats for observational data (contained in Figures 1 through 4) and an identification of supporting information necessary in order for investigators to properly achieve the goals of the National Geodetic Satellite Program.

As a point of interest, most computer programs that will be used by the various organizations for reduction of the observational data, have already been established. The Geodetic Satellites Data Center (GSDC) data format therefore will most likely require some reformatting prior to use by the individual investigators. The general consensus among the investigators regarding this fact however, was that the most important thing was to provide all pertinent information associated with the observational data in a well defined, well documented manner. Everyone recognized that some manipulation of the observational data would be required but felt that this would be of only incidental consequence.

Prior to conducting the survey a roster of principal investigators and data takers was provided by NASA. The total input to the survey somewhat surpassed this original list due to referrals to other sources for additional comments. Appendix A contains a list of individuals who provided input to this survey.

2.0 SUMMARY OF SURVEY RESULTS

The approach taken by the Wolf Research and Development Corporation (WRDC) in this survey was to use, as a point of departure, existing ANNA data formats for Optical, Range and TRANET Doppler data, point out what were felt to be shortcomings and limitations of this format and then proceed to a more detailed exploration of the subject with the various investigators. Specifically, the WRDC suggestions made and incorporated into the first draft were:

2.1 To more thoroughly define and/or identify the observation time and all corrections applied to it.

2.2 To completely define the equator and equinox to which right ascension and declination observations are referenced.

2.3 To more completely identify the star catalog(s) used in the reduction of optical data.

2.4 To identify the manner in which an observation was obtained, (i.e., an optical observation could be obtained actively from an observation of the beacon, passively in a chopping shutter mode, in conjunction with a laser illumination of the satellite; a range measurement could be obtained by radar, laser, etc.).

2.5 To provide an identifier code on the observation card which would reference a supplementary "Preprocessing Report" describing the plate reduction procedures used and the agency performing the reduction.

2.6 To provide a code on the observation card which would reference a supplementary "Preprocessing Report" that completely describes the smoothing, filtering, or preprocessing to which the observational data has been subjected.

2.7 To provide a supplementary "Preprocessing Report" containing a complete description of the geodetic position of the observer (more fully discussed in 3.1).

Additional requirements resulting from the survey relative to optical data and the number of investigators requesting them are as follows:

2.8 Where optical data is obtained in quantity (e.g., in the chopping shutter mode utilized by USC and GS) it is requested that the raw data also be made available in addition to the one smoothed observation normally obtained (1 request).

2.9 Each data reduction and/or modification should be identified by the date of that reduction and/or modification. (2 requests).

2.10 Provide information pertaining to the star residuals for each reduction (1 request).

2.11 Provide the whole covariance matrix describing the random component of the error associated with an optical observation instead of only the standard deviation (2 requests).

2.12 All observations should be referenced to one standard catalog. It was recommended at the Smithsonian Star Catalogue be used since it will be available on tape, cards, or in manual form (1 request).

2.13 Reference right ascensions and declinations to the equator and equinox of the adopted catalog. Individual investigators should perform their own updating (1 request).

2.14 The epoch of the catalogue should be updated periodically initially to 1965.0. This updating should be performed by one central agency (1 request).

2.15 Investigators will need approximate orbital parameters for each given day; recommend periodic publishing of a bulletin containing this information; suggested publishing biweekly (1 request).

2.16 Standardize plate reduction procedures. Complete specifications should be developed and followed by all reduction facilities (1 request).

2.17 Provide definitive information on equator and equinox used in the reduction. This data to occupy separate fields in the format, i.e., one field for equator information and one field for equinox information (1 request).

Additional requirements relative to the electronic data and the number of investigators making the requests:

2.18 Provide all range rate data in the form of meters per second rather than as a frequency shift. Accompanying this would be the value for the speed of light used and the associated uncertainty in this value (5 requests).

2.19 Identify the electronic range measurements as to the manner in which they were obtained (i.e., SECOR, laser, etc.) (3 requests).

2.20 Maintain all raw data associated with the project in the Geodetic Satellites Data Center (1 request).

2.21 Provide an estimate of the total system error (random plus systematic) for all types of observations (1 request).

2.22 Use metric units for all range measurements (4 requests).

2.23 If the surveyed position of a particular system is movable, (e.g. feeder horn on a radar), the data taker should be responsible for correcting the data so obtained, to a fixed point that is defined to be the position of the tracker (e.g. intersection of the horizontal and vertical axes of rotation) (1 request).

2.24 Provide for two digits to the left of the decimal in the field describing the standard deviation in the SECOR range measurement (1 request).

2.25 Provide a frequently published bulletin listing all successful observations made to date in order that those who desire to utilize only selected observations may do so (4 requests).

2.26 Provide all information that will allow a detailed insight as to the quality of the data (e.g., noise level in raw data, nature of the scattering about the curve, etc.), also provide information as to how the random error associated with a measurement is determined (1 request).

2.27 All modifications to raw data should be described to the extent that anyone reading the description could perform the calculation and obtain the same result (4 requests).

Requirements or suggestions relative to the time associated with the various observations and the number of investigators making the requests:

2.28 Provide all observation time in "satellite time" corrected for propagation delays; all corrections applied should be thoroughly identified (1 request).

2.29 Provide a report (to be supplied and prepared by NASA if necessary) completely describing the various timing systems, conversions from one system to another, etc., for specific use with this project (1 request).

2.30 Require everyone to use one standard time; this time should be referred to a signal where a comparison can be made with an atomic clock; examples of such signals are WWV and WWVH (2 requests).

2.31 Recommend that observers not perform any time corrections. This should be left to the investigator. However, if-time corrections are applied, the observer should furnish enough information so that the investigator could duplicate the calculations. (e.g., If the BIH correction for polar motion is applied, specify where polar coordinates were obtained, i.e., Bulletin X, Series Y of BIH etc., and specify what equations were used to compute the motion of the poles.) (1 request).

2.32 Observers should identify which frequency was used and the exact time when comparisons were made with the time standard (2 requests).

Requirements or suggestions relative to the observing station numbering system and the number of investigators making the requests:

2.33 Require that the station numbering system utilized be either that used for the ANNA project or that set forth by COSPAR (2 requests).

2.34 Require that any physical movement of a station be noted by a corresponding change in the station number (6 requests).

2.35 Require observation stations to be tied to existing primary control by first order methods (1 request).

2.36 Provide positional data on the observer as follows (1 request):

a. Geodetic latitude, longitude of observation station and azimuth to another station.

b. Size and shape of ellipsoid used.

c. Astronomic latitude and longitude, geodetic latitude and longitude of initial point of triangulation.

d. Geoid heights and undulations.

e. Astronomic and geodetic azimuth from initial point to another station in the same net.

Requirements or suggestions relative to the medium of transmission for observational data and the number of investigators making the requests:

2.37 Provide all observations on cards with one observation per card (15 requests).

2.38 Provide all observations on magnetic tape (2 requests).

2.39 Provide all observations on cards with more than one observation per card; suggested using binary cards (2 requests).

2.40 Definitely opposed to use of binary cards (8 requests).

2.41 A weekly or biweekly report should be published showing where the observing stations are located and an indication as to when and where they will be moved (5 requests).

2.42 A complete list and definition of all constants used should be published (1 request).

2.43 Provide for an exchange of all computer programs used by the various agencies in the data reduction processes (1 request).

The foregoing recommendations were incorporated in a first draft. This draft was then distributed to all the principal investigators and data takers for comment. Upon receipt of the annotated formats from those noted, a second format was prepared in the same manner as the first draft. (An attempt was made to accommodate all requests for changes). The resulting formats were termed "GEOS Observational Formats (Revision 1)" and resubmitted to all persons listed in Appendix A. The principal investigators reviewed the revised formats. The recommendations made were minor in nature indicating general approval of the revised formats. These minor changes are incorporated in the enclosed formats which are submitted to the National Geodetic Satellite Program Office for formal approval.

3.0 NECESSARY SUPPORTING DOCUMENTATION

When processing the observational data and analyzing the results, it is imperative to make judicious use of all available a priori information in order to invoke proper constraints on the solutions. The parameter estimation and the associated error analysis is most sensitive to this information. Therefore, to assist the analyst in the assessment of proper weights and constraints to impose on a given reduction, certain information regarding the observer's positioning is necessary. Similarly, information concerning the preprocessing (e. g., filtering or smoothing for electronic data, plate reduction procedures for optical data), to which the data has been subjected is also essential in explaining certain patterns in the reduction results. It is strongly recommended that all pertinent information of this sort be prepared and supplied in the form of supplementary documentation to those performing an analysis of the results.

3.1 Documentation of Tracking Station Position Description

Kaula, in a memorandum to the NASA Earth and Lunar Model Committee at the Conference on Astronomical and Geodetic Constants held at GSFC on May 16, 1963, outlined his suggested standards for describing the location of tracking stations. These standards (listed in Appendix B) are quite complete and it is suggested that this information be made available for all tracking sites; it will be extremely valuable for influencing and assessing the results of a given analysis. The NGSP Project Office, in a letter to the Principal Investigators, dated June 25, 1965, has specifically requested that this information be furnished by all participating agencies.

As noted in 2.33, suggestions for the station numbering system have centered around that used for ANNA and the COSPAR System. Depending upon the amount of information desired to discern from the station number, each system seems to have definite limitations. For example, certain liberties appear to have been taken with the COSPAR system in numbering the SAO Baker Nunn sites. In the COSPAR system, the "thousands" digit represents a systems code, while the remaining three digits indicate geographical location. (e.g., 001-199 = U.S. and U.S. territories except Alaska, 200-399 = Japan, etc.). Yet the SAO Baker Nunn Cameras are numbered from 9001 to 9012 regardless of their geographic location. In this instance the interpretation of the system resulted in the stations being numbered according to the geographic location of the co-ordinating agency rather than the locations themselves. If this numbering system were used, certain interpretations of the specifications would have had to be agreed upon prior to its implementation.

One of the more obvious limitations of the ANNA numbering system was that the system clearly identified the NASA and SAO optical stations from all the others that participated in the program. However the parent agency of the remaining stations (USC and GS, USNHO and PMR Cameras) was not discernible.

The numbering system noted in the NGSP Observation formats of Figures 1 through 4 logically accommodates most conceivable contingencies.

3.2 Periodic Reports

As noted in 2.15, 2.25 and 2.41, there is a need to periodically disseminate information to qualified users relative to the current inventory of observations, nominal orbital elements, information pertaining to the present general location of all tracking stations and plans relative to their movement. Some of these services will be provided by the GSDC. They are preparing a separate report describing, in detail, the services to be provided. This report will be disseminated to all participants as soon as it is published.

3.3 Data Reduction and Preprocessing of Data

3.3.1 Optical Data

As outlined in Section 2.16, a recommendation was made to standardize the plate reduction procedures. Had this recommendation been adopted, the specifications set forth for this standard procedure could have served as the required supporting documentation. However, since various agencies use different reduction procedures, a separate supplementary document completely describing each of the procedures is being prepared. These reports will contain, as a minimum, the following information.

a. A description of the time associated with the observation, including all corrections applied and the formulas used to obtain the corrections.

b. A description of the plate transformation equations.

c. A description of the method used to obtain plate constants.

d. A description of the method used in computing the variance and covariance associated with a given observation.

e. A description of the plate reading method (i.e., how many stars and data points read, by how many operators, what is the rejection criteria, etc.)

f. Description of the physical equipment used and calibration procedures associated with the equipment (i.e., what type of comparator, have lead screws been calibrated, how, etc.)

g. Definition of all constants used and their associated uncertainties.

h. Definition of the refraction corrections applied and the formulas used, (i.e., was a specific atmospheric model used? etc.)

i. Any information relative to emulsion creep, method used to resolve it (e.g., reseau used, etc.)

Undoubtedly there will be additional suggestions made by the principal investigators as to the content of these documents. However when being prepared it will be kept in mind that the intent of the documents is to supply the investigator with all pertinent information relative to the reduction procedure in sufficient detail that he may reconstruct the calculations and arrive at the same result.

3.3.2 Electronic Data

Most electronic tracking data is subjected to filtering or smoothing prior to utilization for parameter estimation. This preprocessing is necessary, for in addition to the usual purpose of filtering (to separate signal from noise), the high data rates of the sensors make it impractical to process each observation. Also random errors in successive measurements are rarely independent, i.e., the errors are serially correlated, which adversely effects the error analysis associated with estimation process. However, during the filtering process additional measurement bias is sometimes introduced. Therefore to assist the principal investigators in their analyses, a detailed description of the preprocessing will be provided. The survey has indicated all agencies can make this information available.

3.4 Timing Report

In 2.29 it was requested that the NGSP Project Office provide a report that discusses in detail the various timing systems currently in use. A document of this sort may exist however the limited time available for this survey did not allow for a complete bibliographic research. In any event, it is felt that such a document would be extremely useful to those reducing the data.

Appendix A

PERSONNEL CONTACTED DURING THE COURSE OF THE SURVEY

Mr. J. Berbert	NASA/GSFC
Mr. J. Oosterhout	NASA/GSFC
Mr. D. Harris	NASA/GSFC
Mr. J. Kohout	NASA/GSFC
Mr. E. Watkins	NASA/GSFC
Mr. N. McAvoy	NASA/GSFC
Mr. D. Clemmons	NASA/LRC
Dr. D. Bowker	NASA/LRC
Mr. G. Hadgigeorge	AFCRL
Mr. P. Dishong	AFCRL
Mr. I. Iszak	SAO
Mr. L. Solomon	SAO
Mr. R. Martin	SAO
Capt. L. Swanson	USC and GS
Cdr. E. Taylor	USC and GS
Mr. S. Griffith	OCE
Mr. J. McCall	OCE
Mr. A. Mancini	GIMRADA
Mr. F. Culley	AMS
Mr. M. Hoepken	AMS
Mr. W. Doxey	AMS
Mr. E. Earley	AMS
Mr. E. Rutscheidt	AMS
Mr. H. Acrivos	AMS
Mr. R. Vitek	AMS
Dr. I. Mueller	OSU
Cdr. C. Limerick	BUWEPS
Mr. P. Kuldell	BUWEPS
Mr. R. Anderle	NWL
Mr. W. Kaula	UCLA

Appendix B

Standards for Geodetic Location of Tracking Stations

The following material was originally presented as a memorandum from W. M. Kaula (GSFC) to the NASA Earth and Lunar Model Committee at the Conference on Astronomical and Geodetic Constants held at GSFC on May 16, 1963.

MEMORANDUM DATE: June 20, 1963

TO: NASA Earth and Lunar Model Committee

FROM: W M Kaula

SUBJECT: Standards for Geodetic Location of Tracking Stations

1 Reference.

Memo, MSFC, "Conference on Astronomical and Geodetic Constants (Earth and Lunar Models) held at GSFC on May 16, 1963," dtd May 20, 1963, Par. 2.

2. Purposes.

a To recommend standards for the measurement, computation, and documentation of tracking station positions

b To furnish guidance as to the means of accomplishing geodetic location.

c. To recommend the information regarding tracking station position which should be provided to users of tracking data

d To furnish guidance to evaluate accuracy of geodetic positions

3. Survey of Tracking Station Positions:

a. Information as to the below listed items should always be sought from the Director, U S Coast and Geodetic Survey, Washington 25, D C., for stations within the U S , and from the Commanding Officer, U.S Army Map Service, Washington 25, D.C , for stations outside the U.S.

(1) Location and description of the nearest geodetic control points, horizontal and vertical, to the tracking station.

(2) The recommended method to obtain the position of the tracking station with respect to the nearest geodetic control points within ±5 meters

(3) The recommended agencies to accomplish the survey, or to furnish further information

b. If the tracking station is of high accuracy (i e , directions within ±3", or ranges within ±25 meters, or velocities within ±10 cm/sec), it is worthwhile to connect it by triangulation or traverse to geodetic control points up to 150 miles away. The normal method of survey connection--i.e., overland for distances less than a few tens of miles--will be a two-way traverse using a tellurometer for the distances and a Wild T-2 theodolite for horizontal and vertical angles. In addition, an astronomic azimuth should be observed at the station with the theodolite.

c. If the tracking station is not within 150 miles of geodetic control, an astronomic position and azimuth should be observed with a T-2. Such locations will normally be near the sea; the elevation above sea level should be obtained by leveling or carefully controlled barometric altimetry. If the location is a small island, astronomic positions should be observed on opposite sides, connections made by traverse to the tracking stations, and the mean of the two positions thus obtained taken as the station's position.

4. Computation of Tracking Station Position:

A standard method prescribed in U.S.C. and G.S. and A.M.S. manuals should be used to calculate latitude and longitude (geodetic or astronomic) and elevation above sea level. If the geoid height is calculated for a station connected to a geodetic control system, the height must be taken from a geoid map calculated from astro-geodetic data (not gravimetric) on the same datum and ellipsoid as was used to calculate the station latitude and longitude. (For a station position based on astronomic observations, a gravimetric geoid height may be used.)

Rectangular coordinates (u, v, w) referred to axes in the direction (0°, 0°), (0°, 90°E), (90°N) should be calculated by:

a_e = semimajor axis of reference ellipsoid
f = flattening of reference ellipsoid
ϕ = geodetic latitude
λ = longitude
h = elevation above sea level
N = geoid height

$$e^2 = 2f - f^2 \quad (1)$$

$$\nu = a_e(1 - e^2 \sin^2\phi)^{-1/2} \quad (2)$$

$$u = (\nu + h + N) \cos\phi \cos\lambda \quad (3)$$

$$v = (\nu + h + N) \cos\phi \sin\lambda \quad (4)$$

$$w = \left[(1 - e^2)\nu + h + N\right] \sin\phi \quad (5)$$

Datum shifts are preferably expressed as translations in rectangular coordinates Δu, Δv, Δw. This manner of expression eliminates the ambiguity which can occur in expressing a datum shift in geodetic coordinates concurrent with a change of reference ellipsoid dimensions (i. e., given $\Delta\phi$, $\Delta\lambda$, ΔN, Δa_e, Δf, do the $\Delta\phi$, $\Delta\lambda$, ΔN reflect only the change due to Δu, Δv, Δw, or do they also include the effect of Δa_e, Δf?)

The relationships between corrections amounting to shifts of less than 5 km can be expressed quite accurately by simple differentials of equations (1) through (5).

Rectangular coordinates for station positions based on astronomic observations should be calculated using an a_e of 6378165 (or 6) meters and an f of 1/298.30.

5. Documentation of Tracking Station Position:

a. The following information should be provided in the station position description. The enclosed example "SECOR SITE NEW HAVEN, INDIANA" (Encl 1) includes items (1)-(9), (11)-(13) on the list:

(1) Date records received at office of record.

(2) General description of survey

(3) Instrumentation and method of observation.

(4) All misclosures and other indicators of accuracy.

(5) Datum and ellipsoid on which computations were performed.

(6) Location of description, computations, and field records.

(7) A sketch map of the survey.

(8) Geodetic latitude and longitude (ϕ, λ) of station.

(9) Name and date of datum; if nonstandard, plus reference to publication or other source.

(10) Semimajor axis and flattening of ellipsoid.

(11) Elevation above sea level, h.

(12) Sketch and verbal description of station location.

(13) Azimuths and distances to adjacent control stations.

(14) Geoid height (N), if available.

(15) Description of geoid height calculation, including full reference to any publication used.

(16) Astronomic latitude and longitude of the station, or any other directions used for referring altitude-and-azimuth or direction cosine measurements.

(17) Rectangular coordinates (u, v, w) of the station, based on items (8), (9), (10), (11), and (14) above.

(18) Shifts (Δu, Δv, Δw) to other datums, if available, including the names of the other datums and full reference to the publications or documents from which the shifts were obtained or a description of how the shifts were calculated.

(19) Number of the station in any system in which it has been numbered, such as the COSPAR system (see COSPAR Information Bull. No. 10, Aug. 1962, and also SAO Spec. Rep. No. 69, July 1961), or the AFCRL system (see AFCRL Operational Plan for Project ANNA, September 1962).

b. Remarks

(1) If uncertainties have been estimated for any of the coordinates or shifts in items (8), (14), (17), or (18) above, they may be included in the station description provided that there is a careful statement of what the uncertainties are--i.e., with respect to the nearest geodetic control (usually on the order of ±2 meters), or to the origin of the geodetic datum (from ±5 to ±25 meters), or to the Earth's center of mass (from ±25 to ±300 meters).

(2) Range and range rate observations should always be corrected to refer to the fixed point to which the coordinates (8), (14), (17), or (18) apply; if the electronic measurement is made to a point which moves around appreciably (as, e.g., on the large Goldstone dish), this correction should be applied by the observing agency and not left to the user.

(3) It should always be clearly designated what reference axes are used to refer published altitude-and-azimuth or direction cosine measurements: the astronomic latitude and longitude or the geodetic latitude and longitudes.

(4) The number of the station in item (19) above should be changed if the station is shifted more than 5 meters.

(5) It is desirable that all stations be numbered in the largest system thereof extant--i.e., the COSPAR system. This system is maintained by Dr. B. G. Pressey, Radio Research Center, Slough, England. Part I, Optical Stations, was published in 1962; Part II, Radio Stations, will be published shortly.

(6) In any list or other abbreviated description of tracking stations in any system, the minimum information provided should include items (6), (8), (9), (10), (11), (14), (17), and (19) of the full description. Item (18) should also be given if the station position is not referred to a standard geodetic datum (e.g., NAD 1927)

6. Evaluation of Tracking Station Position Accuracy.

a. The remarks on pages 2-6 of Enclosure B to the Minutes of the NASA Earth Model meeting May 4, 1961 (Encl 2) still apply. In particular, the remarks at the top of page 4 apply to the manner of location of the Goldstone radar: being in a mountainous area, its astronomic position would have an uncertainty on the order of ±350 meters, and the device of matching slopes with the geoid map would at best remove the ±170 meters "continental" part, leaving about

$$\sqrt{350^2 - 170^2} = \pm 300 \text{ meters}$$

b. Indications of datum position accuracy obtained from satellite tracking. The following shifts from NASA 702 positions were obtained from Baker-Nunn camera observations of five satellites ranging from 33 to 96 deg in inclination:

		Shift	σ(NASA TN 702)
		Meters	Meters
Americas	Δu	-24	±26
	Δv	-33	22
	Δw	-2	22
Europe-Africa-Siberia-India	Δu	+37	23
	Δv	-57	29
	Δw	+12	23
Japan-Korea-Manchuria	Δu	-57	40
	Δv	+60	53
	Δw	+10	40
Australia	Δu	-110	75
	Δv	+33	90
	Δw	+67	35
Argentina	Δu	+244	180
	Δv	-15	160
	Δw	+36	160
Hawaii	Δu	-26	140
	Δv	+59	230
	Δw	-290	±230

The σ's suggested in Enclosure 2 thus seem to be only slightly on the low side.

The uncertainties of the shifts obtained from satellites indicated by the scatter of solutions from different orbits ranged from ±4 to ±23 meters; more realistic values based on comparison of the geometric geoid heights resulting and the gravitational geoid heights would be ±30 meters for the major triangulation systems and ±60 meters for the isolated stations. Accuracy of connection between stations within geodetic datums was checked by solutions in which the stations in South America and South Africa were assumed to be on different datums than the stations in the northern hemisphere connected to the same geodetic system. The South American station shifted 24 meters and the South African station shifted 14 meters with respect to the northern hemisphere datums.

c. Definition of a datum. There seems to be some confusion between two separate matters, geodetic datum and ellipsoid specifications. We propose as the definition of a datum:

> "A location with respect to a geocentric coordinate origin of a set of points fixed to the Earth and all located relative to each other by geodetic triangulation, trilateration, and traverse."

The location can be expressed in any sort of coordinates--rectangular, cylindrical, spherical, or "geodetic": latitude, longitude, and height referred to an ellipsoid of specified dimensions. In all orbit computing systems I know of, the coordinate origin is defined as the Earth's center of mass, either explicitly or implicitly, by making the geodetic-to-inertial transformation as a pure rotation and by not having a first-degree harmonic in the geopotential expression. The significance of specifying that the relationship in position between the points constituting the system be through triangulation, trilateration, and traverse (rather than through gravimetry or astronomy) is that thereby the errors in relative position should be appreciably less than their common error in position with respect to the Earth's center of mass. Hence for applications where the accuracy involved is intermediate in magnitude between these two errors, all stations on the same datum can be considered as translating together.

Of course, stations not connected by triangulation, trilateration, and traverse should never be considered as being put on the same datum merely by referring their positions to ellipsoids of the same dimension.

On the other hand, there often will exist cases where stations which are connected by geodetic control do not have their positions referred to the same datum. If the difference in position between the two datums is not stated by a reliable source in an unequivocal form such as Δu, Δv, Δw, it is advisable to consult the Department of Geodesy, Army Map Service. Such consultation is particularly advisable if the stations are more than about 2000 km apart. Geodetic control is generally calculated in two dimensions, neglecting the scale correction required by the difference between geoid and ellipsoid. Datum shifts covering limited areas are generally made in a two-dimensional manner. The neglect of the third dimension makes little difference for distances less than about 2000 km. At greater distances, the errors due to this neglect will mount rapidly, so that the shape of the geoid must be calculated from deflections of the vertical and the appropriate "Molodenskii corrections" applied to the calculated positions.

7. Comments on Published Listing of Tracking Station Positions:

a. SAO Spec. Pub. 59, 1961: The Position of the Baker-Nunn Camera Stations. The description of the datum transformations applied is correct and unambiguous, and should be understood after referral to p. 101 of Smithsonian Contributions to Astrophysics (Vol. 3, no. 9). However, the description is incomplete in that it fails to give the coordinates of the datum origins or the specifications of the reference ellipsoids, so the reader cannot duplicate the computations. Also, the results are far from the best attainable because the ellipsoid and the deflections of the vertical used are obsolete. The list of station positions is defective in that the datums are not specified Items (1), (2), (3), (4), (6), (7), (12), (13), (16) of the tracking station description in Par. 5a above are not given, nor is it stated whether they are available.

b. JHU-APL SRA-179, 1962: Transit Program Station Locations. Stations which are not connected by geodetic survey are listed as being on the same datum (e.g., Australia and England); it is pointless to say that they are on the same datum with an accuracy of ±800 meters, since a better accuracy with reference to the Earth's center of mass can often be attained. The definition of the coordinate accuracies given is not clear. The specifications of the reference ellipsoids are not given. The method and the numerical parameters involved in the shift to the APL reference system are not given. Items (1), (2), (3), (4), (5), (6), (7), (10), (12), (13), (15), (16), and (18) of the tracking station description in Par. 5a above are not given, nor is it stated whether they are available.

c. NASA-OMSF Prog. Dir. M-DE 8020.008, 1963: Natural Environment and Physical Standards for Project Apollo. The information on page 31 is correct and unambiguous. It perhaps might be emphasized that "a geocentric coordinate system" is not a united datum. A description of the method of datum transformation, the parameters involved, and estimates of accuracy are entirely lacking. The spherical coordinates given are adequate in place of rectangular coordinates, but the station list lacks the geodetic latitude and longitude, elevation, datum and a number for each station, and the address from which further detailed information--items (1) through (16) and (18) of Par. 5a--can be obtained.

8. <u>Recommended Representation on Tracking Station Committee:</u>

NASA HQ; Goddard SFC; JPL; Manned SC, Houston; Marshall SFC; Smithsonian AO; STL; Aerospace; APL; USNWL, Dahlgren; ACIC, St. Louis; AFCRL; USC and GS; Army Map Service.

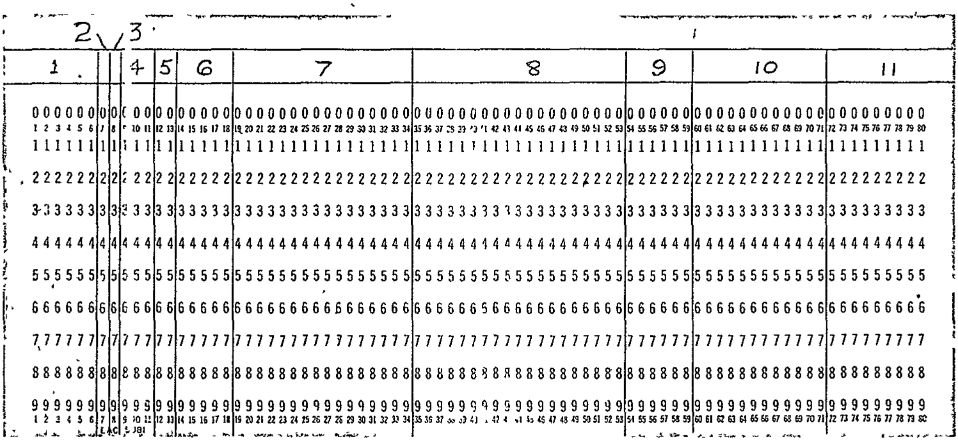
W. M. Kaula

Figure 1

FORMAT

FOR

NGSP OPTICAL OBSERVATIONS



Field	Cols.	Description
1.	1 - 6	Satellite Identification*
	1 - 2	Year of Launch
		64 = 1964
		65 = 1965
		66 = 1966
		etc.
	3 - 5	Order of Launch

*As per COSPAR numbering system

Field	Cols.	Description
	6	Component Identifier
		1 = a
		2 = b
		3 = c
		4 = d
		etc.
2.	7	Type of Coordinates
		1 = Right Ascension and Declination
		2 = Range
		3 = Range Rate
		4 = Frequency Shift
		5 = Direction Cosines
		6 = X, Y Angle
		7 = Azimuth and Elevation Angle
3.	8	Observation Identifier
		0 = Active (Observation on beacon)
		1 = Passive (Chopping Shutter)
		2 = Camera in conjunction with Laser
		3 = Laser Angular data
4.	9 - 11	Timing Standard Deviation
	9	Milliseconds
	10 - 11	.01 Milliseconds

Field	Cols.	Description
5.	12 - 13	Time Identifier
		00 = UT-0 determined at observing station
		01 = UT-1 determined at observing station
		02 = UT-2 determined at observing station
		03 = UT-C determined at observing station
		04 = A. 1 determined at observing station
		05 through 49 Other Systems*
		50 = UT-0 Satellite time
		51 = UT-1 Satellite time
		52 = UT-2 Satellite time
		53 = UT-C Satellite time
		54 = A. 1 Satellite time
		55 through 99 Other Systems*
6.	14 - 18	Station Number
	14	System Designator
		0 = COSPAR
		1 = AFCRL
		2 = SAO
		3 = STADAN
		4 = TRANET DOPPLER
		5 = AMS

*As described in the associated preprocessing report; number assigned at NSSDC before transmitting data to various investigators.

Field	Cols.	Description
		6 = USC+GS
		7 = Naval Observatory
		8 = International Participants
	15 - 18	Station Number
7.	19 - 34	GMT of Observation
	19 - 20	Year of Observation
		64 = 1964
		65 = 1965
		66 = 1966
		etc.
	21 - 22	Month of Observation
	23 - 24	Day of Observation
	25 - 26	Hour of Observation
	27 - 28	Minute of Observation
	29 - 30	Second of Observation
	31 - 34	.0001 Second of Observation
8.	35 - 53	Observation Data
	35 - 37	R. A. (hours)/Azimuth degrees (arc), 0^{o}North/ X angle (degrees arc). Sign of X angle appears in Col. 35
	38 - 39	R. A. minutes (of time)/Azimuth minutes (arc) /X angle .01 degrees (arc)

Field	Cols.	Description
	40 - 41	R. A. seconds (time)/Azimuth seconds (arc)
	42 - 44	R. A. .001 seconds (time)/Azimuth .001 seconds (arc)
	45	Sign of declination/Y angle (+) (-)
	46 - 47	Declination, degrees (arc)/Elevation angle degrees (arc)/ Y angle degrees (arc)
	48 - 49	Declination minutes (arc)/Elevation angle minutes (arc)/Y angle .01 degrees (arc)
	50 - 51	Declination, seconds (arc)/Elevation angle, seconds (arc)
	52 - 53	Declination, .01 seconds (arc)/Elevation angle, .01 seconds (arc)
9.	54 - 59	Date of Plate Reduction
	54 - 55	Year of Reduction 64 = 1964 65 = 1965 66 = 1966 etc.
	56 - 57	Month of Reduction
	58 - 59	Day of Reduction

Field	Cols.	Description
10.	60 - 71	Coded Information
	60 - 61	Supplementary Documentation
		03 = SAO Reduction Precedure Report
		04 = MOTS Plate Reduction Procedure Report
		05 = ACIC Plate Reduction Procedure Report
		06 = USC and GSI Plate Reduction Procedure Report
		07 = NASA Goddard R and R Preprocessing Report
		09 = NASA Goddard Laser Preprocessing Report
		10 = AFCRL LASER Reduction Procedure Report
		11 = International Preprocessing Reports
		12 = AMS Plate Reduction Report
		(additional numbers will be assigned by NSSDC as required)
		n
	62 - 63	Equator Designation
		01 = Mean Standard Equator

Field	Cols.	Description
		02 = Mean Equator at Jan 0.0 of Year of observation
		03 = Mean Equator at instant of observation
		04 = Mean Equator at arbitrary time (arbitrary system to be defined in associated preprocessing report)
		11 = True Standard Equator
		12 = True Equator at Jan 0.0 of year of observation
		13 = True Equator at instant of observation
		14 = True Equator at arbitrary time (arbitrary system to be defined in preprocessing report)
	64 - 65	Equinox Designation
		01 = Mean Standard Equinox
		02 = Mean Equinox at Jan 0.0 of year of observation
		03 = Mean Equinox at instant of observation
		04 = Mean Equinox at arbitrary time (arbitrary system to be defined in associated preprocessing report)
		1 = True Standard Equinox
		12 = True Equinox at Jan 0.0 of year of observation

Field	Cols.	Description
		13 = True Equinox at instant of Observation
		14 = True Equinox at arbitrary time
		(arbitrary system to be defined in associated preprocessing report)
	66 - 67	Instrumentation Type
		00 = PC - 1000 MOD-1
		01 = PC - 1000 MOD-2
		02 = BC - 4 450 mm
		03 = BC - 4 300 mm
		04 = BC - 4 210 mm
		05 = Baker Nunn SAO
		06 = Baker Nunn - Military
		07 = MOTS
		08 = 1200 mm Ballistic Camera
		09 = 600 mm Ballistic Camera
		10 = MOTS 24"
		11 = International Types
	68 - 69	Catalog Identification
		01 = BOSS
		02 = SAO Combined
		03 = FK-4
		04 = NASA Combined

Field	Cols.	Description
		05 = AGK-2
		06 = AMS Combined
		07 = Cape Zone, Volume 1
		08 = Yale, Volume 1
		09 = Others (to be defined in the associated preprocessing reports). Code number to be assigned by NSSDC.
	70 - 71	Catalog Epoch
		01 = 1855.0
		02 = 1875.0
		03 = 1900.0
		04 = 1950.0
		05 = 1965.0
		06 = Others (to be defined in the preprocessing reports); code numbers to be assigned by NSSDC
11/	<u>72 - 80</u>	<u>Description of Random Error</u>
	72	Standard deviation in R.A. (seconds of arc) multiplied by the cosine of the declination/ standard deviation in Az (seconds of arc)/ standard deviation in X angle (degrees of arc)
	73 - 74	Standard deviation R.A. (.01 seconds of arc) multiplied by the cosine of the declination/

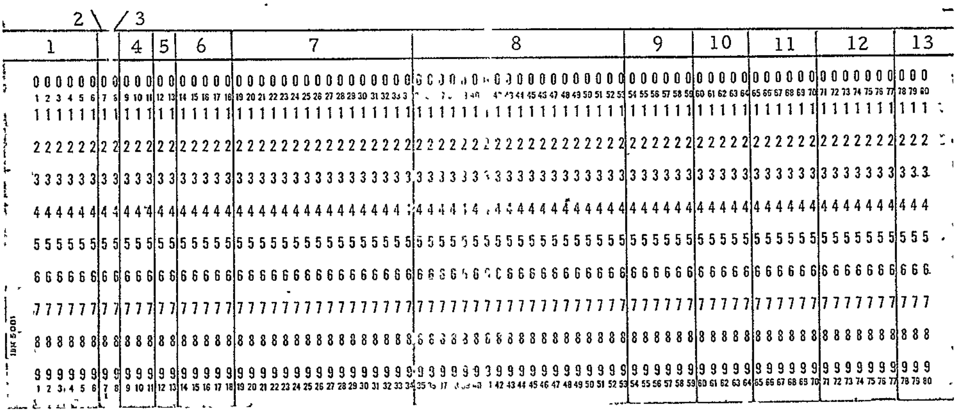
Field	Cols.	Description
		standard deviation in Az (.01 seconds of arc)/standard deviation in X angle (.01 degrees of arc)
	75	Standard deviation in declination (seconds of arc)/standard deviation in elevation angle (seconds of arc)/standard deviation in Y angle (degrees of arc)
	76 - 77	Standard deviation in declination (.01 seconds of arc)/standard deviation in elevation angle (.01 seconds of arc)/standard deviation in Y angle (.01 degrees of arc)
	78 - 80	Covariance; sign in col 78 (+), (-), decimal assumed between col 79 and 80.

Figure 2

FORMAT

FOR

NGSP ELECTRONIC & LASER RANGE OBSERVATIONS



Field	Cols	Description
1.	1 - 6	Satellite Identification*
	1 - 2	Year of Launch
		64 = 1964
		65 = 1965
		66 = 1966
		etc.
	3 - 5	Order of Launch
	6	Component Identifier

*As per COSPAR numbering system

Field	Cols.	Description
		1 = a
		2 = b
		3 = c
		4 = d
		etc.
2.	7	Type of Coordinates
		1 = Right Ascension & Declination
		2 = Range
		3 = Range Rate
		4 = Frequency Shift
		5 = Direction Cosines
		6 = X, Y, Angle
		7 = Azimuth & Elevation Angle
3.	8	Observation Identifier
		8 = Electronic Range
		9 = Laser Range
4.	9 - 11	Timing Standard Deviation
	9	Milliseconds
	10 - 11	.01 Milliseconds
5.	12 - 13	Time Identifier
		00 = UT-0 determined at observing station
		01 = UT-1 determined at observing station

Field	Cols.	Description	
		02 = UT-2 determined at observing station	
		03 = UT-C determined at observing station	
		04 = A. 1 determined at observing station	
		05 through 49	Other Systems.*
		50 = UT-0	Satellite time
		51 = UT-1	Satellite time
		52 = UT-2	Satellite time
		53 = UT-C	Satellite time
		54 = A. 1	Satellite time
		55 through 99	Other Systems.*
6.	<u>14 - 18</u>	<u>Station Number</u>	
	14	System Designator	
		0 = COSPAR	
		1 = AFCRL	
		2 = SAO	
		3 = STADAN	
		4 = TRANET DOPPLER	
		5 = AMS	
		6 = USC+GS	
		7 = Naval Observatory	
		8 = International Participants	

*As described in the associated preprocessing report; number assigned at NSSDC before transmitting data to various investigators.

Field	Cols.	Description
	15 - 18	Station Number
7.	<u>19 - 34</u>	<u>GMT of Observation</u>
	19 - 20	Year of Observation
		64 = 1964
		65 = 1965
		66 = 1966
		etc.
	21 - 22	Month of Observation
	23 - 24	Day of Observation
	25 - 26	Hour of Observation
	27 - 28	Minute of Observation
	29 - 30	Second of Observation
	31 - 34	.0001 Second of Observation
8.	<u>35 - 53</u>	<u>Observation Data</u>
	35 - 50	Range in Meters
	51 - 53	Range in .001 Meters
9.	<u>54 - 59</u>	<u>Date of Reduction</u>
	54 - 55	Year of Reduction
		64 = 1964
		65 = 1965
		66 = 1966
		etc.

Field	Cols.	Description
	56 - 57	Month of Reduction
	58 - 59	Day of Reduction
10.	60 - 64	Coded Information
	60 - 61	Supplementary Documentation
		01 = AMS SECOR Preprocessing Report
		07 = NASA Goddard Range & Range Rate Preprocessing Report
		09 = NASA Goddard Laser Preprocessing Report
		10 = AFCRL Laser Preprocessing Report
	62 - 63	Instrumentation Type
		61 = AMS SECOR System
		62 = GSFC Range & Range Rate System
		63 = GSFC Laser System
		64 = AFCRL Laser System
	64	Tropospheric Correction
		1 = Tropospheric refraction correction Applied
		2 = Tropospheric refraction correction not Applied
11.	65 - 70	Description of Random Error
	65 - 67	Standard Deviation in meters
	68 - 70	Standard Deviation in .001 meters

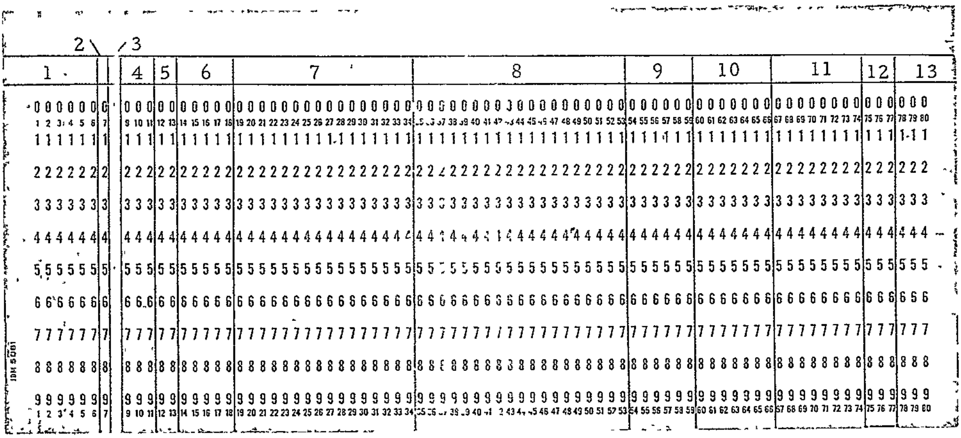
Field	Cols.	Description
12.	71 - 77	Ionospheric Correction
	71 - 76	Meters, XXX.XX (D_1-I_c for SECOR)
	77	Application
		1 = Correction Applied to measurement
		2 = Correction Not Applied to measurement
13.	78 - 80	Blank

Figure 3

FORMAT

FOR

NGSP RANGE RATE OBSERVATIONS



Field	Cols.	Description
1.	1 - 6	Satellite Identification*
	1 - 2	Year of Launch
		64 = 1964
		65 = 1965
		66 = 1966
		etc.
	3 - 5	Order of Launch
	6	Component Identifier

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*As per COSPAR numbering system,

Field	Cols.	Description
		1 = a
		2 = b
		3 = c
		4 = d
		etc.
2.	7	Type of Coordinates
		1 = Right Ascension and Declination
		2 = Range
		3 = Range Rate
		4 = Frequency Shift
		5 = Direction Cosines
		6 = X, Y, Angle
		7 = Azimuth and Elevation Angle
3.	8	Observation Identifier
		5 = Base Frequency
		6 = Observed Frequency
		7 = Range Rate in meters/second
4.	9 - 11	Timing Standard Deviation
	9	Milliseconds
	10 - 11	.01 Milliseconds
5.	12 - 13	Time Identifier
		00 = UT-0 determined at observing station

Field	Cols.	Description	
		01 = UT-1 determined at observing station	
		02 = UT-2 determined at observing station	
		03 = UT-C determined at observing station	
		04 = A.1 determined at observing station	
		05 through 49	Other Systems.*
		50 = UT-0	Satellite time
		51 = UT-1	Satellite time
		52 = UT-2	Satellite time
		53 = UT-C	Satellite time
		54 = A.1	Satellite time
		55 through 99	Other Systems.*
6.	14 - 18	Station Number	
	14	System Designator	
		0 = COSPAR	
		1 = AFCRL	
		2 = SAO	
		3 = STADAN	
		4 = TRANET DOPPLER	
		5 = AMS	
		6 = USC+GS	
		7 = Naval Observatory	
		8 = International Participants	

*As described in the associated preprocessing report; number assigned at NSSDC before transmitting data to various investigators.

Field	Cols.	Description
	15 - 18	Station Number
7.	19 - 34	GMT of Observation
	19 - 20	Year of Observation 64 = 1964 65 = 1965 66 = 1966 etc.
	21 - 22	Month of Observation
	23 - 24	Day of Observation
	25 - 26	Hour of Observation
	27 - 28	Minute of Observation
	29 - 30	Second of Observation
	31 - 34	.0001 Second of Observation
8.	35 - 53	Observation Data
	35 - 50	Cycles per second or meters per second
	51 - 53	.001 cycles per second or .001 meters per second
9.	54 - 59	Date of Reduction
	54 - 55	Year of Reduction 64 = 1964 65 = 1965 66 = 1966 etc.

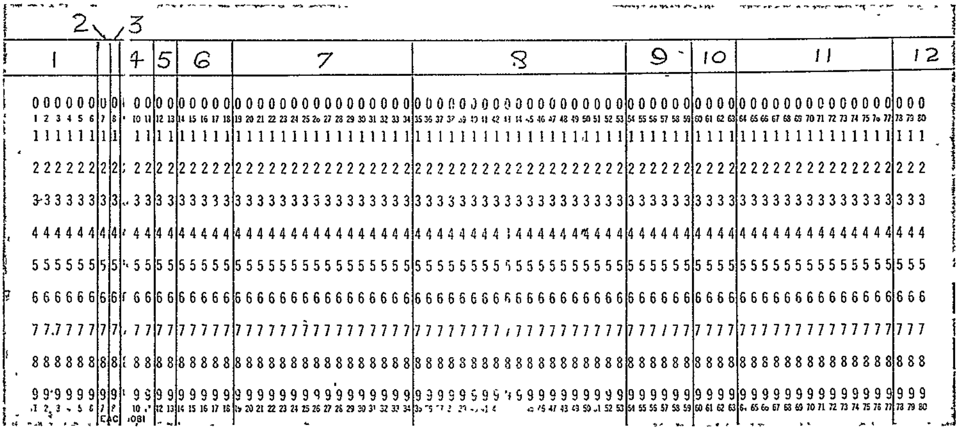
Field	Cols.	Description
	56 - 57	Month of Reduction
	58 - 59	Day of Reduction
10.	<u>60 - 66</u>	<u>Coded Information</u>
	60 - 61	Supplementary Documentation
		02 = NWL Doppler Preprocessing Report
		07 = NASA Goddard Range & Range Rate preprocessing report
	62 - 63	Instrumentation Type
		51 = TRANET Doppler System
		52 = Goddard Range & Range Rate System
	64	Tropospheric Refraction Correction
		1 = Correction Applied
		2 = Correction Not Applied
	65 - 66	Identification of Frequency Pair & Method of Combination (See associated preprocessing report)
11.	<u>67 - 74</u>	<u>Value of C</u>
	67	Kilometers per second (first five digits assumed)
	68 - 69	.01 Kilometers per second
	70 - 74	Uncertainty in C, X.XXX Kilometers/sec.
12.	<u>75 - 77</u>	<u>Description of Random Error</u>
	75 - 77	Standard Deviation in frequency shift, .001 cycles/second or standard deviation in range rate, .001/meters/second
13.	78 - 80	Blank

Figure 4

FORMAT

FOR

NGSP MINITRACK OBSERVATIONS



Field	Cols.	Description
1.	1 - 6	Satellite Identification*
	1 - 2	Year of Launch
		64 = 1964
		65 = 1965
		66 = 1966
		etc.
	3 - 5	Order of Launch
	6	Component Identifier
		1 = a
		2 = b

*As per COSPAR numbering system

Field	Cols.	Description
		3 = c
		4 = d
		etc.
2.	<u>7</u>	<u>Type of Coordinates</u>
		1 = Right Ascension & Declination
		2 = Range
		3 = Range Rate
		4 = Frequency Shift
		5 = Direction Cosines
		6 = X, Y, Angle
		7 = Azimuth & Elevation Angle
3.	<u>8</u>	<u>Observation Identifier</u>
		4 = Minitrack
4.	<u>9 - 11</u>	<u>Timing Standard Deviation</u>
	9	Milliseconds
	10 - 11	.01 Milliseconds
5.	<u>12 - 13</u>	<u>Time Identifier</u>
		00 = UT-0 determined at observing station
		01 = UT-1 determined at observing station
		02 = UT-2 determined at observing station
		03 = UT-C determined at observing station
		04 = A.1 determined at observing station
		05 through 49 Other Systems.*

*As described in the associated preprocessing report; number assigned at NSSDC before transmitting data to various investigators.

Field	Cols.	Description	
		50 - UT-0	Satellite time
		51 = UT-1	Satellite time
		52 = UT-2	Satellite time
		53 = UT-C	Satellite time
		54 = A.1	Satellite time
		55 through 99	Other Systems.*
6.	<u>14 - 18</u>	<u>Station Number</u>	
	14	System Designator	
		0 = COSPAR	
		1 = AFCRL	
		2 = SAO	
		3 = STADAN	
		4 = TRANET DOPPLER	
		5 = AMS	
		6 = USC+GS	
		7 = Naval Observatory	
		8 = International Participants	
	15 - 18	Station Number	
7.	<u>19 - 34</u>	<u>GMT of Observation</u>	
	19 - 20	Year of Observation	
		64 = 1964	
		65 = 1965	

*As described in the associated preprocessing report; number assigned at NSSDC before transmitting data to various investigators.

Field	Cols.	Description
		66 = 1966
		etc.
	21 - 22	Month of Observation
	23 - 24	Day of Observation
	25 - 26	Hour of Observation
	27 - 28	Minute of Observation
	29 - 30	Second of Observation
	31 - 34	.0001 Second of Observation
8.	<u>35 - 53</u>	<u>Observation Data</u>
	35 - 37	Blank
	38	Sign of Cosine Alpha
	39 - 45	Cosine Alpha (decimal in 39)
	46	Sign of Cosine Beta
	47 - 53	Cosine Beta (decimal in 47)
9.	<u>54 - 59</u>	<u>Date of Reduction</u>
	54 - 55	Year of Reduction
		64 = 1964
		65 = 1965
		66 = 1966
		etc.
	56 - 57	Month of Reduction
	58 - 59	Day of Reduction
10.	<u>60 - 63</u>	<u>Coded Information</u>
	60 - 61	Supplementary Documentation

Field	Cols.	Description
		08 = NASA Minitrack preprocessing report
	62 - 63	Instrumentation Type
		70 = NASA Minitrack
		71 = Military Minitrack
11.	<u>64 - 77</u>	<u>Description of Random Error</u>
	64 - 70	Standard Deviation in Cosine Alpha, Decimal in 64
	71 - 77	Standard Deviation in Cosine Beta, Decimal in 71
12.	<u>78 - 80</u>	<u>Blank</u>

REFERENCES

1. "Constants and Related Data for Use in Trajectory Calculations" - V. C. Clarke, Jr. - Jet Propulsion Laboratory Technical Report No. 32-604

2. "AFCRL Operational Plan for Project ANNA" - A. Mancini, H. Kahler

3. "COSPAR World List of Satellite Tracking Stations" - COSPAR Report No. 10