SMITHSONIAN INSTITUTION

~~ASTROPHYSICAL OBSERVATORY~~

SEP 9 1964

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OPTICAL SATELLITE TRACKING PROGRAM

Carried out under grant number NsG 87/60

from the

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Semiannual Progress Report No. 10

January 1 through June 30, 1964

Project Director: Fred L. Whipple

Cambridge, Massachusetts 02138

[redacted]

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HIGHLIGHTS

With the conspicuous improvement of our knowledge of the Earth's gravitational field and the structure of the atmosphere it has become imperative to refine further the previous techniques of orbit computation. The new differential orbit improvement program of the Observatory now includes not only the most significant lunar perturbations in the motion of satellites, but also the effects of tesseral and sectorial harmonics up to the fifth degree. As a result, the computed residuals of our precisely reduced observations, which constitute the basis of research in satellite geodesy, dropped by about 50%.

Other work in research and analysis is investigating the planetary disturbing function, the geometrical structure of the earth's outer gravitational field, and the heat-flow distribution on the surface of the earth.

Flare star observations have continued in cooperation with Sir Bernard Lovell's Nuffield Astronomy Laboratories at Jodrell Bank, England, and analysis of previous observations is proceeding. At least two separate types of flare phenomena have now been observed, with several major events being recorded both photographically and in the radio frequencies. Estimates have been made of the velocity difference between radio and optical waves; any such difference must be less than 1 part in 10^6 over a frequency range of 2.5 million. Changes in observational procedure will give even more information in both of these studies.

The first orbits of the new comet Tomita-Gerber-Honda were derived from Baker-Nunn observations.

The SAO Star Catalog is now available in several tape formats and is being readied for printing. All positions and proper motions of 259,000 stars are in the FK-4 system.

During this period SAO was responsible for tracking Vanguard II, Vanguard III, Explorer VII, Echo I, and Echo I rocket body, Explorer IX, Explorer XIX, Echo II, SA-5, and Star Flash. In addition, the Observatory provided back-up tracking for NASA launches, and predictions and observations for SAO staff scientists and other agencies requesting them.

Outstanding performances of the Baker-Nunn system included photography of Echo II and associated metal objects within ten minutes after inflation of the balloon, and acquisition of 56 flashes from 64 30A, the Star Flash satellite.

The 12 Baker-Nunn camera stations received 49,158 predictions of satellite passages, from which they made 21,648 successful observations; this represents an increase of 32% in predictions, and 48% in observations over the same period in 1963. The 138 Moonwatch teams and affiliates reported 4,328 observations of 149 orbiting objects.

DATA ACQUISITION

STATION OPERATIONS

(Baker-Nunn Camera Stations)

Station Operations continues to track satellites both on assignment from the National Aeronautics & Space Administration and for the special requirements of the Observatory scientists.

During the period of this report, we sent 49,158 predictions to the Baker-Nunn stations, which made 21,648 successful observations exclusive of special satellites (see Tables 1 and 2); this represents an increase of 32% in predictions and 42% in observations over the same period in 1963.

The simultaneous observation program has been continuously pursued during the report period. All stations are using the requisite equipment to synchronize camera shutters to ± 1 to 2 milliseconds, thus allowing use of passive satellites as triangulation markers. In general, satellites in high orbits, such as objects 61281 (Midas IV), 63304 (a balloon in 2000 mile orbit), and 62681 (Relay 1), are used to perform synchronous photography from two, three, or four stations. To date, 878 successful two-station, 40 three-station and 3 four-station photographs have been obtained. The program is continuing with special emphasis on the Iran station and on a round-the-world network to test the final results.

Observation of ANNA flashes continues, although the satellite is now flashed on by ground-command and the time accuracy is severely restricted. Six two-station simultaneous passes were observed; a total of 16 successful one-station attempts were made out of 69 predictions during this period.

We are furthering the programs to renovate the Baker-Nunn camera optical system, to improve the operation of the Norrman time standard through better training and maintenance, and to test the EECo timing system.

Plans for the establishment of a Baker-Nunn camera station in Ethiopia continue. A provisional site, approximately one-and-a-half miles northeast of Bishoftu (modern name: Debre Zait), has been selected. A survey team will soon be sent to determine the exact location. We are now drafting an agreement with the Geophysical Observatory in Addis Ababa, Ethiopia, for the establishment of the station.

Equipment and instrumentation

Basic equipment at the stations operated successfully, with routine mechanical and electrical maintenance.

Mechanics and optics of Baker-Nunn cameras--Our mechanical engineers overhauled in the field the cameras in Spain, Curacao, and Peru, and inspected and repaired those in South Africa and Argentina. The objective mirrors of the cameras in Curacao, Spain and Peru have been realuminized.

Table 1

COMPARISON OF OPERATIONAL RESULTS

Jan. - June 1963-1964

Number of Predictions

Month	1963	1964
January	5215	8711
February	5771	7804
March	6160	7904
April	6074	8454
May	7069	8715
June	6996	7570
Total.....	37285	49158

Increase in number of predictions.....32%

Number of Successful Observations

Month	1963	1964
January	2005	3263
February	2424	3436
March	2486	3073
April	2348	3609
May	2675	4283
June	3080	3984
Total.....	15018	21648

Increase in number of successful observations...44%

Monthly Station Averages

Average/month/station	1963	1964
Predictions	518	683
Observations	209	301

Table 2

SUCCESSFUL OBSERVATIONS BY INDIVIDUAL TRACKING STATION

Jan. - June 1963-1964

Station	Number of Successful Observations	
	1963	1964
New Mexico (SC-1)	1594	2616
South Africa (SC-2)	1919	2193
Australia (SC-3)	1823	2588
Spain (SC-4)	1076	1864
Japan (SC-5)	905	761
India (SC-6)	1708	2442
Peru (SC-7)	593	1295
Iran (SC-8)	1272	1612
Curacao (SC-9)	883	1469
Florida (SC-10)	966	1482
Argentina (SC-11)	1337	1785
Hawaii (SC-12)	1052	1531
Total.....	15018	21638

The Perkin-Elmer Corporation has completed the refurbished corrector cell with the newly fabricated protective window. The unit was installed and tested at the Curacao station during June. The optical performance is excellent and the protective window should maintain this high level by keeping to a minimum any damage from dirt and moisture.

We have begun a program to determine the focal surface of each Baker-Nunn camera optical system and to compare it with the shape of the present film backup plate. Already we have conducted a test on each camera to provide preliminary data for use in planning future tests.

Intervalometers are being constructed to make automatic camera operation more flexible. These will aid in tracking of faint satellites, in observations of certain launch and rocket plume operations, and in photography of comets and flare stars.

Through the surplus equipment sources of the General Services Administration, we have obtained an air desiccator suitable for use with the Baker-Nunn camera, and have requisitioned six additional air desiccators, manufactured by Gilbarco, to complete such installations in all 12 tracking stations.

Norrman timing system--We have installed improved radio receivers for reception of time signals at Iran, Curacao, Argentina, Australia, Spain, India, and New Mexico; and improved crystal oscillators in Hawaii, Japan, Curacao, Australia, Peru, Iran, and Greece. We have also provided a new battery bank for emergency operation of the time standard at the Argentina station.

Precision timing system--Routine operation of the prototype precision timing system has continued at the Florida tracking station. Meanwhile, we have awarded a contract to the Electronic Engineering Company of California for the manufacture of 12 timing systems, 7 of them single channel and 5 of them dual channel. Design and construction of these units began on May 14, with delivery scheduled for between 23 and 43 weeks thereafter.

Film--Preliminary evaluation of Estar base and new extended-red sensitivity Royal-XPan Recording film is underway. Kodak hopes to replace the present topographic film base with Estar if the latter meets mechanical limitations. The new emulsion should increase camera system sensitivity (denoted as tracking power) by almost 1 magnitude (about a factor of 2).

Station vehicles--Normal operation and maintenance of vehicles has continued. The station in Peru has a new Willys Wagoneer, and that in New Mexico an International Travel-all.

Observer training program

During this period, 10 observer candidates took the training course; 9 of them successfully completed it.

Mr. Mahra, Assistant Astronomer to the station in India, attended a special training course designed to familiarize him with new equipment and procedures.

Two three-week training classes were planned and conducted by Smithsonian personnel to acquaint eight inexperienced USAF personnel with the practical aspects of maintaining and operating a Baker-Nunn station.

Moonwatch

The Moonwatch program continues with 20 precision, 28 standard, and 90 limited teams and independent affiliates. Together, they reported 4328 observations of 149 orbiting objects (see Table 3). Five of the teams demonstrated an observing accuracy comparable to that of the Baker-Nunn field-reduced observations.

Special assignments to Moonwatch included the final tracking of Explorer 9, and tracking of the Gemini GT-1, the Saturn SA-6, and the four Cosmos satellites.

Future plans

We plan to transfer the Australian station to the new space research site at Island Lagoon, Woomera; move the Iranian station to Ethiopia; continue construction of the 12 precision timing systems; aluminize mirrors in 2 or 3 of the cameras; and continue routine maintenance of station mechanical and electronic equipment.

Table 3

MOONWATCH OBSERVATIONS

Jan. - June 1964

Satellite	No. of Observations Received
1958 Alpha	135
Beta 1	1
1959 Alpha 1	117
2	2
Eta	44
Iota 1	1
1960 Beta 2	1
Gamma 2	1
Epsilon 3	35
Zeta 1	13
Eta 1	5
2	3
Iota 1	323
2	139
3	27
5	21
Nu 1	4
2	15
Xi 1	2
2	2
Pi 1	3
1961 Alpha 1	22
2	2
Delta 1	230
2	3
3	1
Nu	21
Omicron 1	53
2	43
4-203	7
Sigma 1	55
A-Delta 1	34
A-Eta 1	3
2	1
3	1
1962 Zeta 1	6
2	1
Kappa 1	49
3	8
4	3
Omicron 1	2
A-Alpha 1	9
A-Epsilon 1	9
2	109
A-Upsilon	43
A-Psi 1	37
B-Alpha 1	6
2	7
B-Theta	115
B-Kappa	69
B-Mu 1	81
2	18
B-Tau 1	2
5	1
6	42
B-Upsilon 2	1
B-Chi	11
B-Psi 1	13
1963 3A	24
9A	2
13A	3
B	23
14A	55
17A	5
G	20
22A	3
24A	1
25B	2
26A	4
27A	23
30A	64
B	4
D	71
E	4
33A	1
38A	14
B	6
C	9
42B	3
43A	86
D	1
47A	163
B	38
C	4
D	24
E	6
F	7
G	69
49A	40
B	24

Table 3 (cont'd)

MOONWATCH OBSERVATIONS

Jan. - June 1964

Satellite		No. of Observations Received
1963	C	21
	E	1
	50A	29
	B	6
	52B	2
	53A	256
	B	6
	E	1
	F	24
	G	1
	54A	10
	B	2
	55B	4
1964	1A	22
	B	6
	C	2
	D	14
	E	11
	2A	6
	3A	11
	B	14
	4A	438
	B	119
	C	17
	D	22
	E	54
	5A	148
	B	1
	6A	100
	B	3
	C	3
	D	6
	7A	1
	10A	11
	B	19
	D	1
	11A	12
	13A	6
	B	5
	15A	9
	B	7
	17B	3
	19B	5
	21A	3
	B	4
	23A	3
	B	3
	25A	2
	26D	1
	28A	11
	B	20
	29A	1
	B	1
	30A	2
	31C	5
	33A	5
	B	4
	34A	1
1964		
First Quarter		2208
Second "		2120
TOTAL		60,291

COMMUNICATIONS

This division now handles more than 3,000,000 words per month; most of this traffic consists of satellite information. It also continues close liaison with the tracking systems of NASA and NORAD, all types of satellite data being mutually exchanged.

New services and equipment

In April, the NASA Communications network converted to the fully automatic switching complex, the Univac 490, Real-Time Communications Processor. This system will eventually afford much greater speed in communications between Cambridge and the Baker-Nunn camera stations in Argentina, Australia, Peru and South Africa.

For more efficient operations, new model-28 teletypewriter machines were installed in February to replace model-19 equipment.

Backup radio-teletype equipment has been installed at the station in Argentina, from which regular schedules are conducted with Lima, Peru, and special schedules with Argentine Space Commission in Buenos Aires.

Publications

The Division continues to issue the monthly satellite situation report, which shows the status of all objects launched and gives a summary of recent space activity.

Plans

We may exchange another model-19 teletype machine for the more reliable model-28, and increase all in-house circuit speeds to 100 words per minute. The latter step will make all off-line machines compatible with one another, and with the military, NASA, and Spacetrack circuits.

DATA PROCESSING

DATA DIVISION

This Division computes predictions of satellite positions for the various satellite tracking stations; derives orbits from observations made by Baker-Nunn, Moonwatch, or other tracking systems; prepares smoothed and mean orbits (from both field-reduced and photoreduced data) for publication in SAO Special Reports; records information that may affect research on satellite orbital data; publishes predictions, orbital elements, and equator crossings; and handles the routine technical correspondence of the Satellite Tracking Program. The Division is also responsible for preparing and publishing the SAO Star Catalog.

One hundred and ninety-one nominal and revised early-tracking predictions for the Baker-Nunn cameras were derived for the six NASA launches made during this period.

We processed Baker-Nunn, Moonwatch and other observations and derived orbits each week by means of the Differential Orbit Improvement Program. Employing SCROGE, Ephemeris II and Ephemeris IV programs, we then used these orbits to produce predictions for the Baker-Nunn stations and selected Moonwatch sites (see Tables 1 and 2).

We completed the analysis of SAO contributions to Centaur AC-2 and Echo II projects, issued Special Report 156 on AC-2, and communicated the Echo material to the project office. Support of Centaur project continued for AC-3, and preparations are under way for AC-4.

The network regularly tracked as many as 27 satellites, and tracked other objects for launch backup and for special purposes.

We derived and published in Special Report 156 the mean and smoothed orbital elements for Centaur AC-2 and a preliminary analysis of the film of Syncom-II fourth-stage firing; and published observations of the satellites in the reports listed in Table 4.

We also prepared special predictions for objects of particular interest to SAO scientists and to other requesting agencies; these included Imp I, SA-6, Telstar II mirror reflections, and objects expected to re-enter the earth's atmosphere. In further accordance with the terms of the satellite tracking grant, we also prepared predictions and orbital elements of such objects as SA-5, Echo I, and Echo II, and the other balloon satellites for tracking agencies requesting them. The predictions usually took the form of look-angles. Among the recipients were Mitre Corporation, MIT Lincoln Laboratory, the Air Force Cambridge Research Laboratory, Coast and Geodetic Survey, Raytheon, Bell Telephone Laboratory, and State University of Iowa.

The new program for decoding, checking, and punching observations for computer use was introduced during this period. It has enabled us to handle the 14% increase in observations with greater efficiency and with no increase in personnel costs.

Table 4

PUBLISHED SATELLITE OBSERVATIONS

Satellite	Special Report Number
1958 Alpha (Explorer I)	153
1959 Alpha 1 (Vanguard II)	148, 153
1959 Eta (Vanguard III)	148, 153
1959 Iota 1 (Explorer VII)	153
1960 Beta 1 (Tiros I Rocket)	147
1960 Beta 2 (Tiros I)	147
1960 Iota 1 (Echo I)	154
1960 Iota 2 (Echo I Rocket)	148, 154
1960 Xi 1 (Explorer VIII)	154
1961 Delta 1 (Explorer IX)	148, 154
1961 Omicron 1 (Transit 4A)	147, 155
1961 Omicron 2 (Injun Solar Radiation 3)	147, 155
1961 Alpha Delta 1 (Midas 4)	148
1962 Alpha Epsilon 1 (Telstar I)	148, 155
1962 Beta Mu 1 (Anna 1B)	155
1962 Beta Tau 2 (Injun 3)	155
1962 Beta Upsilon 1 (Relay I)	155
1963 9A (Explorer XVII)	155
1963 13A (Telstar 2)	155

The star catalog

With the Star Catalog now available in tape form and soon to be issued in printed form, this seems an appropriate time to review both the production and the content of the work.

When the Observatory began to make precision reductions of the Baker-Nunn films, it became obvious that a computer-accessible catalog of accurate star positions would substantially lessen the time required for the preparation of each satellite position. SAO therefore initiated a project to gather together the best catalogs available, reduce them all to the same equinox (1950), refer them to the same positional system (FK-3), and obtain proper motions for each star. The result of this compilation is the SAO Star Catalog, which contains positions, proper motions, magnitudes, etc. for more than a quarter of a million stars. As a final step, the catalog was referred to the more recent system of FK-4.

All catalogs were processed on an electronic computer and the reduced data stored on magnetic tapes in several binary formats. (See the section on Computations for a description of these formats.)

In the period of this report, the various formats of the tapes were completed and consolidated, and a set of special tapes produced for the preparation of microfilm to be used for the printed version of the catalog and for a microfilm format of the catalog itself. The Government Printing Office in Washington is now processing this set of tapes for the display of the information on a cathode /ray tube that will be photographed as a step in making the plates for printing.

The introduction to the Star Catalog, published as Special Report No. 151, includes information and statistics of general interest.

Tests and samples of work from several data plotters have continued in a search for the best means of preparing the star charts from tapes.

New work begun or in progress includes a bibliography and evaluation of the various star catalogs, a catalog of radio sources (with computation of galactic coordinates) and a list of artificial satellites with characteristics and orbital elements. Programming for all of these projects was provided by the Computations Division.

PHOTOREDUCTION DIVISION

In this period, the Division determined 16,362 precise satellite positions, reduced to A1 time. Regular reduction of observations increased 22.4% over the previous report period. During the fiscal year 1964, we determined 29,725 precise satellite positions, reduced to A_1 time, an increase of 6,569 (28.4%) over the previous year. The total number of precise positions, reduced to A1 time, completed through June 30, 1964 is 85,055.

Included in the total for this report period were 808 precisely reduced positions of satellite Midas IV (Object 61281) photographed on Baker-Nunn film in October and November 1963. These positions were determined in accordance with the simultaneous observing project in which most of the Smithsonian stations have participated.

ANNA IB--The Astrometric Section, assigned to produce precise reductions of the geodetic satellite ANNA 1B, completed 489 precise positions determined by measurement of flashes of the satellite photographed on Baker-Nunn film. The total number of such positions completed since the beginning of the project is 1,224. (Because of the complexity of the procedures used, the time required for preparing and reducing each flash is three or four that expended on the images of other satellites.)

ECHO I films--In accordance with a request from the Echo Project Office (Goddard Space Flight Center), we have recieved through that office 29 Russian films of Echo II, including several different types taken by a variety of cameras. Twenty-six of the films were taken on January 25 and 26, 1963; three others on January 28, 1963. We have prepared 67 evaluated positions in an attempt to provide more data that may explain the satellite's anomalous behavior in the period just after the balloon inflation.

Routine operations

The film control section received and catalogued approximately 22,000 films from the Baker-Nunn stations. Of these, over 14,000 were evaluated for precise reduction. Our Cambridge storage facility now contains over 133,000 films.

We have continued close participation in the Cambridge phase of Baker-Nunn station observer training. During the period of this report ten trainees spent a total of 85 work days with members of the Division staff, who instructed them in the necessary techniques of precision measuring and reduction.

COMPUTATIONS DIVISION

The Computations Division is responsible for the development of computer programs for all phases of the satellite program, for the operation of existing computer programs, and for development work in applied mathematics required to execute these objectives. The computer programs are run on the Harvard University IBM-7094.

Projects completed

Dataplotter package--A general routine was written for the IBM-7094 to enable programmers to put out results from that computer in a mode that permits a wide flexibility in the use of the EAI Dataplotter. Two vivid examples of the use of this program are the map of the equipotentials of gravitation obtained from the Tesseral Harmonics program, and the contours of equal temperature obtained from the Heat Flow program. The latter are plotted with the continent contours described in Progress Report No. 9.

Star Catalog--The Star Catalog tape set was completed during the past six months. All information is now in the FK-4 system. The set of tapes includes the following:

1. Two tapes, with nine words/star. These are the basic tapes with information in the epoch of the original star catalogs, but corrected for precession.

2. Two tapes, one for each hemisphere, with 11 words/star, i.e., the nine words/star for the basic tape plus coordinates in the 1950 epoch.

3. One tape with two words/star of epoch 1963.5 for those stars used in the reduction of data on satellite positions.

4. One tape with three words/star for star charts. Cards will be punched from this tape to produce the star charts on the Dataplotter.

5. Four BCD tapes for input to the SC-4020 microfilm processor. These tapes were produced from the input of 11 word/star tapes for the SC-4020. The microfilm output will be enlarged and photographed by the Government Printing Office to produce the printed version of the Catalog.

Although the tape set is now complete, modifications such as change of epoch may be desired in the future. Coordinates of stars not now included on the tapes will be added, and eventually further editions of the catalogue will be printed. These changes, which will be implemented easily with the programs generated for the present catalog, are the following:

1. A program for each original input catalog to produce from input cards the 9 word/star binary tape in the FK-4 system, which correction for precession.

2. A program to produce an 11 words/star binary tape with the present nine words/star, plus the star position in the 1950 epoch.

3. A program to produce a two words/star tape with an arbitrary epoch for the set of stars used in the reduction of satellite position data.

4. A program to produce, from the 9 words/star tape, a binary tape for epoch 1950, sorted into 156 sky segments, of star position and magnitude, and indices to indicate whether the star is binary, or variable, or whether proper motion has been applied.

5. A program to produce cards for the Dataplotter from the binary star-chart tape.

6. A program to produce the input tapes for the SC-4020 from the 11 words/star tape.

Automatic processing of observations--This program, described in the previous semiannual report, has been in operation for six months. It has significantly increased the efficiency of conversion of Baker-Nunn teletype data to input acceptable to the DOI. A program was completed and is now in operation to convert Minitrack teletype data in a similar manner.

Projects continued

Since the beginning of the Satellite Tracking Program in 1957, a large number of computer programs have been developed to increase the efficiency in the routine operation of the Baker-Nunn stations, and to analyze the precise data from observations at those stations. These programs are continually undergoing change in varying degrees to improve efficiency of station operation and economy of computer calculations.

*The preparation program--For increased efficiency, we recently converted it to run with BESYS 4 system.

*The Reduction Program--Small modifications made in the past six months have improved the flexibility of data read in and increased the information printed out.

*Differential orbit improvement program--The tesseral harmonics were added to the orbit calculations in the program. To facilitate this and future additions, we rewrote the DOI program in relocatable computer language.

*Matched-track prediction program (SCROGE)--We made routine modifications to improve the printed output.

Tesseral harmonics--We completed the changes that permit this program to run under BESYS 4, and to accept as input the tape output from DOI.

Simultaneous observations--We finished the subroutines that determine the correction in the chord between two stations from simultaneous observations of satellites by a number of stations of which the two are a subset; and that determine the adjustments of a three station network using simultaneous observations by a number of stations of which the three are a subset.

*This program is in maintenance status.

These subroutines use the Reduction of Observation Data and Least-Square section of the Simultaneous Observation program described in a number of previous reports. We also completed an independent routine to reduce observation data with corrections for parallactic refraction and planetary aberration, and with a Lagrangian interpolation to determine the mean time of simultaneity.

Planetary disturbing function--There is a continuing project to improve computer methods for calculating the functions and coefficients appearing in the planetary disturbing function. As part of this effort, SAO is developing a general program to compute as many as possible of these special functions. A Newcomb Operator program written at MIT was adapted into the FORTRAN Monitor System of SAO; to it were added the following:

1. A program that computes the outer operators to yield the combined Newcomb operators;

2. A Laplace coefficient program from which the Jacobi coefficients were derived. From this enlarged program one can obtain the coefficients of the four-fold Fourier expansion of the disturbing function. The mathematical details are given in Special Report 140.

Geophysical calculations--A routine was written to determine the correlation of the coefficients of the spherical harmonics describing the heat flow from the surface of the earth with the coefficients of the spherical harmonics describing the gravitational potential of the earth. Routines are being written to calculate the parameter of geophysical models that are compatible with the observational data on the heat-flow and gravitational potential.

System programming--We have modified the FORTRAN Monitor System and BESYS 4 to use the automatic double precision instructions in the IBM-7094 hardware in FORTRAN compilations, rather than the time consuming subroutines previously used. This work, begun in the previous report period, was continued to remove some inadequacies in the system. A filing system for the program library is being organized to permit easy access and cross-referencing of information in abstracts.

New projects

Ephemeris 7--We have developed a routine for the Moonwatch program to compute from standard orbital elements the time and direction information of successive perigee crossings of a satellite, and the time of entry into and exit from shadow of satellites and subsatellite points. Derivatives of these quantities are printed to provide Moonwatch observers with sufficient data to make position calculations. When field testing is completed, Ephemeris 7 will replace Ephemeris 6, which is based on time and longitude of equatorial crossings.

Publications

During the reporting period the Computations Division issued 3 program write-ups.

Kulvinskas, V., AZALT--Satellite Orbit Parameters, January, 1964.

Hauck, R., 1401 Fortran Preprocessor (Memorandum), January 8, 1964.

Gingerich, O., REREAD--Input Routine, March 18, 1964.

DATA UTILIZATION

RESEARCH AND ANALYSIS

Continuing his work in the field of satellite geodesy, Imre G. Izsak investigated methods by which the results he previously obtained for the gravitational field of the Earth and the positions of the Baker-Nunn camera stations could be improved. First, it seems advisable to solve for more unknowns simultaneously in a single computer run, the typical case being twelve stations and harmonics up to the fourth degree (52 unknowns). Second, the technique of iterating previous solutions seems to yield promising results. The third, and perhaps most important, is to recompute orbits with already improved station coordinates and the inclusion of some low-degree tesseral harmonics. These generalizations of the relevant computer programs will soon be used for a refined analysis of the data.

The planetary disturbing function project is near completion. Preliminary runs of the program, written by Benno Benima and Sara B. Mills, show very satisfactory agreement with the classical development of Leverrier for the planets Jupiter and Saturn.

To allow (a) more unknowns in the tesseral harmonics program, and (b) a more efficient DOI program, E. M. Gaposchkin changed the Kaula subroutines to speed and shorten them. He worked with Page Nelson to make the so-called iteration version of the tesseral harmonics work and to treat weighting correctly in the calculation of improvement factors. Mr. Gaposchkin also incorporated the tesseral harmonics subroutines into the DOI program. This new version, now in production status, is referred to as DOI3.4. The results of orbit improvement using these perturbations are encouraging. He is now working on the construction of a new DOI (DOI4.1) based on the Izsak second-order orbit theory; it will process all the observational material that SAO now uses and the range rate data that SAO hopes to acquire in the near future.

W. Köhnlein continued his studies of the geometrical structure of the earth's outer gravitational field and is now evaluating the numerical results. Of particular interest are the shapes of the surfaces of constant potential and of constant gravity, their gaussian and mean curvature, the figure of the latitude and longitude curves, the deflection of the verticals, the curvature and torsion of the plumblines, etc. These numerical results will be finally plotted as level curves for different sections of the outer space.

In another project W. Köhnlein devised several computer programs for the adjustment computation of space triangulations. They are needed for the connection of the American and European triangulation systems and for the determination of the coordinates of the satellite tracking stations. By using the correlation of already adjusted coordinate values, he has combined a pure geometrical method and a dynamical method (as developed by I. Izsak) for a joint adjustment computation of the station coordinates.

Morton Davies has assisted Dr. Jacchia in the determination of good orbits for Satellite 1961 Delta 1. Since many observations of high precision exist for this object, it is desirable to obtain maximum efficiency in the computed orbits. The effect of the tesseral harmonics in the earth's gravitational field is now being included directly in the orbit determinations, a refinement that was investigated by Mr. Davies under the direction of Mr. Izsak, and that was programmed into the D.O.I. by Mr. Gaposchkin. Mr. Davies has also made a more general study of the methods of analysis of dynamical systems.

Theoretical studies on the correlation between the satellite-geoid given by Izsak and the heat-flow distribution on the surface of the earth have justified the hypothesis that the irregular differences of the satellite-geoid from that of a best-fitting ellipsoid of revolution is caused by inhomogeneous thermal expansion in the interior of the earth, resulting from some uneven heating processes by certain distributions of heat-sources. Chi-Yuen Wang has suggested that this inhomogeneous distribution of heat-source has existed since the formation of the crust and the upper mantle and is concentrated near the top of the mantle. He has computed corresponding variations of temperature for sources distributed according to several proposed models. The best model has an inhomogeneous layer about 100 to 200 kilometers thick; variations of temperature have amplitudes of about 100° degrees centigrade. Computations of the corresponding concentration of heat-sources suggest that the upper mantle may have a composition similar to that of basalt or eclogite. This conclusion is consistent with considerations of some of the other geophysical phenomena, such as the physical state of the mantle and the mean rate of heat-flow.

Because of the unique capabilities of the station network and of individual stations, the Observatory receives occasional requests for special observing assistance. These requests involve no significant additional costs; give the field staff practice in special techniques; and provide scientific data that would not otherwise be available. Therefore, we find it advantageous to cooperate in these special studies, some of which are described below.

Flare star observations

During four months, station operations attempted 260 hours of photography on 4 stars, in cooperation with radio telescopes at Jodrell Bank, CSIRO (Sydney) and Arecibo. Forty-five hours of films were obtained, including several small events, not yet analyzed. Analysis of film from previous report periods continues, and several major flares during October 1963 were analyzed. Results to date show at least two types of flare activity, and give an upper limit of 1 part in a million to any difference in velocity between radio and optical radiation. Work on this project continues.

Comets

Comets Tomita-Gerber-Honda and Encke were observed during this period for tail-structure and total brightness studies. The number of films received was 45 of T-G-H and 10 of Encke. A preliminary orbit of T-G-H was computed by Data Division, and a program is being written to do this for future comets. Another program, to supply Baker-Nunn camera settings for sidereal tracking is also being written.

The Photoreduction Division determined 80 precise positions of Comet Peyreyra, photographed on Baker-Nunn film in the period September 17 through 30, 1963. Positions of the head and position angles of the tail of the comet were precisely measured (but not reduced to A_1 time); the purpose was to determine the magnitude and period of the Comet tail oscillation. This work was carried out in conjunction with the project under the direction of Mr. Daniel Malaise. The Division also intends to participate in a program involving comet photometry, as outlined in the Preliminary Prospectus for Photographic Photometry of Comets with the Baker-Nunn Cameras (SAO, April, 1964) by R. B. Southworth. Densitometry equipment has been ordered and will arrive shortly.

The Computations Division began work on several routines to compute information on comet orbits. Among them were routines to compute the distribution of semimajor axes of comet orbits, to compute the orbital elements of the comet from three observations, and to prepare predictions for the Baker-Nunn stations for observations of the comet.

Micrometeorites project

Drs. Colombo and Lautman of SAO and Dr. Shapiro of the MIT Lincoln Laboratory have continued their study of the concentration of cosmic dust near the earth. The completion of the computer program DUSTY BALLS by Mr. Cherniack and the modification of the Lincoln Laboratory is GENERAL PERTURBATION PROGRAM have led to greatly increased accuracy and reliability of the results. The research has shown that long-lifetime orbits of particles ejected from the moon do not contributed significantly to the dust cloud.

Underway is an investigation of the optical characteristics of dust particles so that the effective area-mass ratios of very small particles may be established.

Other projects

Photoreduction also completed U.S. Air Force Contract, AF 19(623)-3360. A total of 183 precise positions, reduced to A_1 time (a single frame from each successfully evaluated film), of Object 62394 covering the period August 25 to October 14, 1963 were determined, as well as 102 precise position, reduced to A_1 time of Object 62491, covering the period October 15 to 31, 1963.

In accordance with a request from the Echo Project Office, NASA Goddard Space Flight Center, we determined 294 precise positions, reduced to A_1 time, of Echo II (Objects 64041, 64042, 64043, 64044).

The airborne-observing study begun during the last report resulted in the publication of SAO Special Report No. 146. Continuation of this study will cover available forecasting capability and practicable aircraft instrumentation. From this analysis we expect to determine both the operational costs and the usefulness of the program.

EDITORIAL AND PUBLICATIONS

The Satellite Tracking Program issued the following Special Reports during this six-month period:

No. 140 -- Construction of Newcomb Operators on a Digital Computer by I. Izsak, J. M. Gerard, R. Efimba, and M. P. Barnett.

No. 141 -- Satellite Orbital Data No. E-3 by I. G. Izsak.

No. 142 -- Satellite Orbital Data by I. G. Izsak.

No. 143 -- Inhomogeneous Distribution of the Radioactive Heat Sources I. Theory by C. Y. Wang.

No. 144 -- Geodetics on an Equipotential Surface of Revolution by W. Kohnlein.

No. 145 -- On the Luminous Efficiency of Meteors by F. Verniani.

No. 146 -- On the Visual Tracking of Two Bright Satellites from C-130-Type Aircraft by R. C. Vanderburgh.

No. 147 -- Catalog of Precisely Reduced Observations No. P-11 compiled by P. Stern.

No. 148 -- Catalog of Precisely Reduced Observations No. P-12 compiled by P. Stern.

No. 149 -- Long-Period Effects in Nearly Commensurable Cases of the Restricted Three-Body Problem by J. Schubart.

No. 150 -- The Temperature Above the Thermopause by L. G. Jacchia.

No. 151 -- A Catalog of Positions and Proper Motions of 258 997 Stars for the Epoch and Equinox of 1950.0 by SAO staff.

No. 152 -- Temperature Variations in the Upper Atmosphere During Geomagnetically Quiet Intervals by L. G. Jacchia and J. Slowey.

No. 153 -- Catalog of Satellite Observations No. C-37 prepared by B. Miller.

No. 154 -- Catalog of Satellite Observations No. C-38 prepared by B. Miller.

No. 155 -- Catalog of Satellite Observations No. C-39 prepared by B. Miller.

No. 156 -- Baker-Nunn Photography of the Syncom II Fourth-Stage Ignition by R. Citron and L. H. Solomon.

Tracking of Centaur (AC-2) by L. H. Solomon.