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SMITHSONIAN INSTITUTION
ASTROPHYSICAL OBSERVATORY

# SATELLITE-TRACKING AND EARTH-DYNAMICS RESEARCH PROGRAMS



Grant Number NGR 09-015-002

Semiannual Progress Report No. 27

1 July to 31 December 1972

Project Director: Dr. G. C. Weiffenbach

Prepared for

National Aeronautics and Space Administration
Washington, D.C. 20546

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# INTRODUCTION

Highlights of program activities during this report period were the following:

The accuracy of tracking predictions was significantly improved, and a new method of data validation was instituted.

Progress continues in writing useful programs in preparation for acquiring and installing a minicomputer at an SAO laser station. Stand-alone software has been developed for orbit computation using a $J_2$ gravity model and is now being tested at SAO headquarters.

Scientists at SAO continued to participate in developing the scientific and program planning portions of NASA's Earth and Ocean Physics Applications Program (EOPAP). This included definition of requirements for new satellites, such as Lageos, which will be needed in this earth-dynamics program.

At the fall meeting of the AGU, Drs. M. Williamson and E. M. Gaposchkin presented a paper describing the results of research on estimation of $1° \times 1°$ gravity anomalies.

In analyzing the relation between solar activity and upper atmosphere temperature, Dr. L. Jacchia and his group found that for the interval 1958 to 1971, the solar flux at 2300 MHz was a better indicator of the ultraviolet heat source than were the Ca II-plage data before 1969. The analysis is being retested by using only data since 1969.

Effective 2 October 1972, an SAO Earth-Dynamics Program (EDP) was established in recognition that new measuring techniques have opened up possibilities in earth-dynamics research that extend far beyond our previous goals in satellite geodesy. The adoption of these more advanced and more difficult objectives is in step with the planned completion of the NASA Geodesy Program and the proposed initiation of the NASA Earth and Ocean Physics Applications Program.

The SAO Earth-Dynamics Program involves research in basic and applied science directed toward developing fundamental information on the kinematics of the earth.

In addition to the continuing program of upper atmosphere research, the primary objectives of EDP are

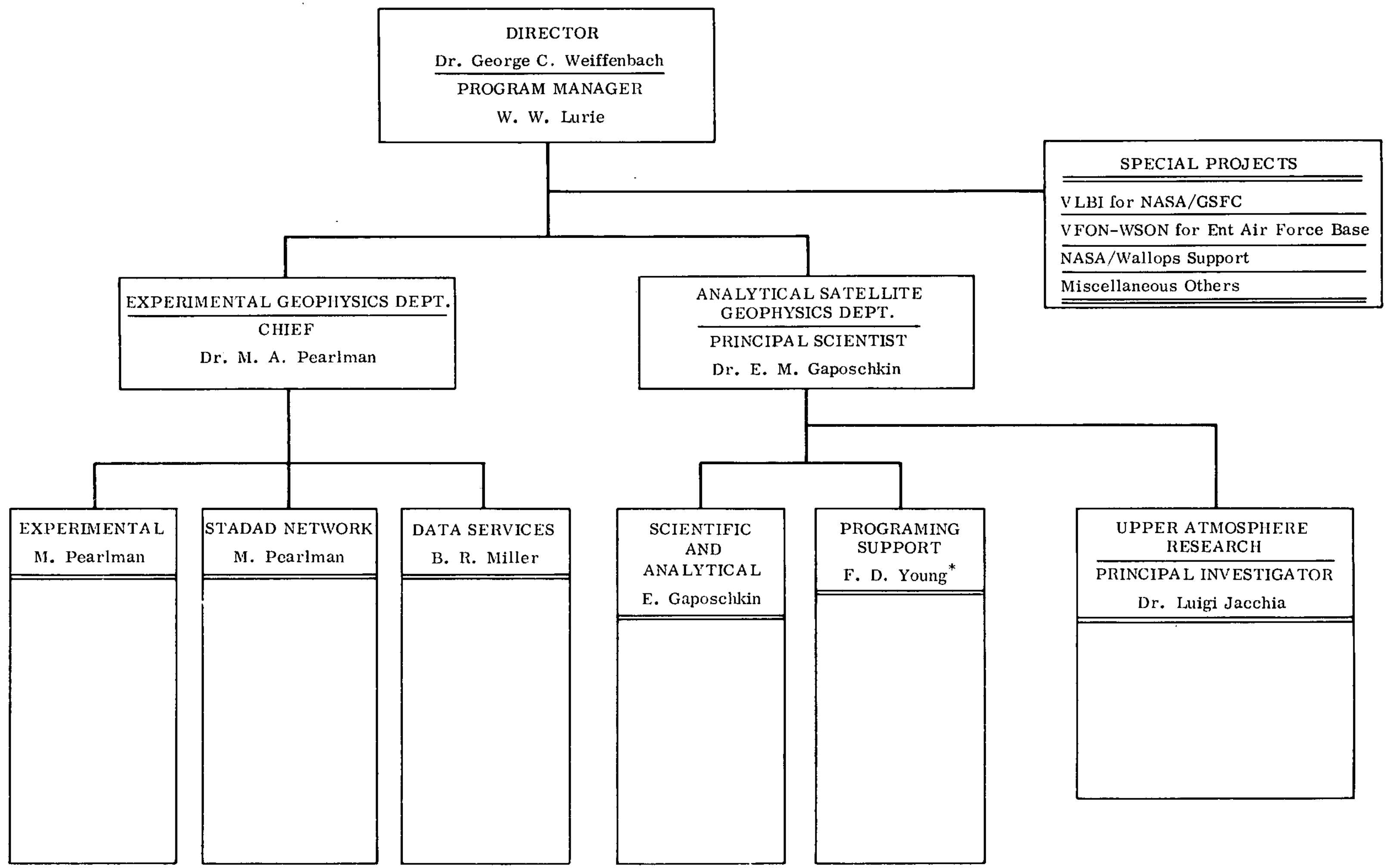
1. To develop theoretical models and improved understanding of the kinematics, internal structure, and mechanics of the earth.

2. To apply the results to such geophysical problems as earthquake prediction.

A basic task implicit in the successful execution of this program is the development of means for reaching a laser ranging accuracy of 2 cm or better.

The demanding requirements and ambitious goals of this program have necessitated a realignment so that the organization can function as a single instrument. The new and fundamental emphasis on the developmental aspects of data acquisition is the motive for establishing the Experimental Geophysics Department, which combines, in a single organizational unit, the satellite-tracking and data-acquisition network with scientific, engineering, and data-evaluation groups. Research and analysis activities in earth dynamics and upper atmospherics will be conducted within the Analytical Satellite Geophysics Department, as in the past.

Figure 1 details the new organization.




*Administratively reports to manager, Data-Processing Department.

Figure 1. Earth-Dynamics Program Office – Functional Organization.

# RESEARCH PROGRAMS

## GEODETIC AND GEOPHYSICAL INVESTIGATIONS

The major effort of the Analytical Satellite Geophysics Department during the first half of FY 1973 has been Standard Earth III. Computation of the gravity field is nearly finished. Only a final combination solution evolving from five independent solutions for station coordinates remains to be completed.

Dr. Gaposchkin, assisted by Ms. G. Mendes, Mr. A. Girnius, Mr. J. Latimer, and Dr. G. Veis, has determined tesseral-harmonic coefficients in the potential expansion complete to degree and order 18. Twelve pairs of higher degree coefficients are also defined. Coordinates for 90 independent stations have been obtained.

The effects of terrestrial gravimetry data are included in the final tesseral-harmonic coefficients of Standard Earth III. These data are important in determining the high-frequency features of the gravity field. From a set of gravity anomalies (obtained from Aeronautical Chart and Information Center, Woods Hole Oceanographic Institute, and R. Mather) that are substantially better than those used in Standard Earth II, Williamson and Gaposchkin have used a block covariance function to estimate $5° \times 5°$ gravity anomalies from $1° \times 1°$ ones. Preliminary results of comparisons between the block covariance function and other methods disclosed that the former was suitable for this purpose. Williamson and Gaposchkin described the results of this research at the fall AGU meeting.

The five subsolutions that will compose the final combination solution for station coordinates have developed from a mixture of laser (some from collocated instruments) and Baker-Nunn data. These subsolutions are used separately to determine subsets of geodetic parameters. The optimum set of geodetic parameters is established from a suitable combination of these data, as it provides a superior solution with a higher degree of accuracy.

One of the most important of the five is the SAO dynamical solution. This is based on satellite-perturbation analysis of laser and camera data obtained from 28 independent station groups. The inclusion of the large number of precision laser data has increased the accuracy of the solution.

Also of major importance are the three geometrical subsolutions. That of SAO utilizes data collected from 27 independent station groups of Baker-Nunn and independent European instruments. The 5200 pairs of simultaneous observations used yield 72 weighted interstation directions. The BC-4 geometrical subsolution is composed of observations of the Pageos satellite (1966 56A) taken by 47 independent National Oceanic and Atmospheric Administration observing stations. The subsolution of the Jet Propulsion Laboratory (JPL) deep-space network is based on observations of several Mariner probes to Mars and is composed of data taken from eight independent stations. These three subsolutions have an accuracy of 2 to 3 m for the fundamental laser stations and 3 to 6 m for the fundamental camera stations.

The last subsolution relates surface survey information for 36 stations from the previous four groups. These stations were selected because links could be established among neighboring stations on the same geodetic datum.

Normal equations from these five subsolutions were weighted, and the resulting matrix was inverted to produce the combination solution.

Mr. J. Cherniack has finished work on the second- and third-order lunar perturbation theories. In turn, he and Gaposchkin have incorporated the earth's tidal parameters into these theories. The results have been verified and included in the geodetic research program and are reflected in Standard Earth III.

To increase the accuracy of future geoidal studies, further research is being done on a numerical integration program to be used for determining resonant and zonal harmonics, for recovering the earth's tidal parameters, and for defining the effects of radiation-pressure coefficients. Dr. K. Aksnes has been experimenting with different types of integration methods to increase further the capabilities of the current integrating program. The most promising method appears to be a multiorder, multistep method developed by F. T. Krough at JPL. Test results on orbits of earth satellites indicate this method to be fast, reliable, and well suited for numerical integration of lunar and radiation-pressure perturbations on satellites.

Reduction of MK8 laser geodimeter data taken during the period 1970 to 1971 in Addis Ababa, Ethiopia, has been completed. Dr. P. Mohr finds that the work has demonstrated crustal extension and possibly transcurrent movement. This work has been submitted for publication in Ethiopia.

The Ethiopian Rift will be resurveyed in the spring of this fiscal year. The apparent increments of distance within the networks will be evaluated, and a regional strain pattern will be established. With current improvements in satellite-tracking accuracy, the ground-deformation data from this geodimeter work will become important in analyses concerning precise studies of the geoid.

Mohr and Girnius are continuing to refine more recent studies made with the MK8 laser geodimeter. During the FY 1972 expedition, additional lines were measured to form a closed figure in order to provide a mathematical check.

Research on the Data General Nova 1200 minicomputer has progressed. A LINC tape system with a single drive and expansion chassis has been added to the existing hardware as a form of secondary storage. Such an addition will improve the performance of computations and, in turn, the accuracy of predictions for tracking satellites.

Now that most of the preliminary research essential to the performance of the minicomputer in the field has been completed, tentative plans are being made for field installations; most probably, the first will be at Mt. Hopkins.

Independent software for orbit computation on the Nova 1200 has been developed by using a $J_2$ gravity mode. Cherniack and Gaposchkin suspect that this level of prediction accuracy is sufficient to satisfy the requirements of the Analytical Satellite Geophysics Department. Latimer and Cherniack are now testing this assumption.

The cooperative project with SAO's Computer Center to use the minicomputer as a concentrator for time sharing on the CDC 6400 is finished, and Mr. P. Collins is adapting this software to interface the two computers.

## ATMOSPHERIC RESEARCH USING SATELLITE DRAG DATA

To determine atmospheric densities, Dr. Jacchia, assisted by Mr. J. W. Slowey and Mr. I. G. Campbell, has continued routine analysis of the orbits of 1959 Alpha (Vanguard 2), 1960 $\xi 1$ (Explorer 8), 1963 53A (Explorer 19), 1966 44A (Explorer 32), 1966 70A (OV3-3), and 1968 66A (Explorer 39). For the drag determinations, positions derived from photographs with the Baker-Nunn cameras, as well as radar data supplied to us by the 14th Aerospace Force, were used. Atmospheric densities were determined from the drag of 1971 67C (Cannonball 2), which was launched in August 1971 and decayed on 31 January 1972, and of 1963 30D.

A catalog of densities obtained from nine different satellites, covering an average of 3.5 years and based on results from field-reduced Baker-Nunn and radar observations taken through 14 January 1970, is being prepared for publication.

Work has also begun on Cannonball 2, a satellite of short lifetime. With a perigee height of about 130 km, it should yield some interesting data concerning the atmospheric variations correlated with geomagnetic activity.

Jacchia and his assistants have continued analyzing the relation between solar activity and upper atmospheric temperature. They have found that in the interval 1958 to 1971, the solar flux at 2300 MHz was a better indicator of the ultraviolet heat source than were the Ca II plage data before 1969. That is, the solar flux is more perfectly correlated with the atmospheric variations that have been determined from satellite drag and that are rather clearly associated with the variations in ultraviolet radiation that accompany variations in solar activity. With coefficients determined empirically by least-squares to fit all the densities from satellite drag, models of the solar-activity variations were constructed in various ways by using both the solar flux and the Ca II plage data as indices of the atmospheric heating associated with solar activity. In every case, the standard deviations were significantly smaller when the solar flux was used to represent both the long-range variation associated with the solar cycle and the short-range variation associated with the solar rotation. The analysis is being retested by using only data since 1969. The variation in height of the amplitude of the diurnal temperature variations derived from densities by use of static models is a byproduct of the retesting.

After analyzing the acceleration of the balloon satellite 1963 30D (Dash 2) from Baker-Nunn and radar observations, the group discovered that the accelerations observed when the orbit was partly in shadow could be reproduced quite well by introducing a small force due to solar radiation pressure at right angles to the solar direction and allowing this to rotate. The observed accelerations of this satellite had long been a mystery. Their interpretation is based on the assumptions that the satellite is slightly spheroidal in shape – hence, the component of force is at right angles to the solar direction – and that it is spinning with a precession of the spin axis about the solar direction. This is entirely similar to the situation of Pageos as deduced from photometric observations. Excellent results suggesting precession with nutation have been obtained by using the Baker-Nunn data taken in the early life of this satellite. The magnitude of the right-angle component remains essentially constant, at about 3% of the total force, over the more than 6-year interval in the earlier part of the satellite's lifetime, when the effect was not buried in atmospheric drag.

Dash 2 is also interesting because the effects of earth radiation pressure are readily discernible in the earlier portion of its life, when the perigee height was well over 1000 km and the effects of air drag were relatively small. Somewhat more sophisticated models of the earth's albedo and infrared radiations are being developed in order to fit the observed accelerations more closely. Most earlier attempts to evaluate quantitatively the effects of earth radiation on satellite orbits assumed constant mean values over the whole earth for both the albedo and the infrared components. Calculations using both a mean model and one developed from data reported from Tiros observations that include latitudinal and seasonal variations have now been performed. They clearly indicate that the mean model is inadequate for the determination of atmospheric densities. Whether or not even more detailed models are required remains to be seen. The results of this work will have important application to studies of the accelerations of the Explorer balloon satellites to determine atmospheric densities.

The balloon satellite 1963 30D also probed the earth's upper atmosphere over a tremendous range in height. Density results from the final year of its lifetime, when the height went from over 1000 to about 300 km, are in good agreement with existing atmospheric models if only a slight adjustment of the assumed area/mass ratio is made. Densities from the earlier portions at heights where hydrogen is the major atmospheric constituent indicate hydrogen densities at solar minimum of 2 to 3 times the model values. However, this result depends somewhat on the solution for earth radiation pressure, which is not yet final.

# SATELLITE-TRACKING NETWORK FUNCTIONS

# AND

# SUPPORT GROUPS

## NETWORK OPERATIONS (STADAD)

### Satellite Observing Campaign

The Earth Physics Satellite Observation Campaign (EPSOC), which began in September 1971, continued through the last half of 1972. The EPSOC simultaneous observing campaign, begun in early 1972, continued with Smithsonian stations in Athens (Greece), San Fernando (Spain), and Debre Zeit (Ethiopia) cooperating with sites in San Vito (Italy), Ouagadougou (Upper Volta), Nice (France), and Uzhogorod (USSR).

### Lasers

The SAO network of four static-pointing systems – in South Africa, Peru, Brazil, and Mt. Hopkins – and the two visually aided tracking systems at Athens (Greece) and Dodaira (Japan) obtained over 30,000 successful range measurements from more than 1700 separate satellite arcs (see Table 1). Geos 1, Geos 2, and BE-C were in saturation tracking mode for the 6-month period; D1D and BE-B were tracked for only part of this period.

### Predictions

During this reporting period, the accuracy of predictions was significantly improved. Pointings that had along-track errors of 1 sec by the end of the prediction week are now essentially on time for the whole week. A new method of data validation was instituted, whereby all laser range measurements are plotted and inspected before new predictions are generated from those data. By the use of only validated points, the accuracy of laser predictions has noticeably improved, and the data rate has increased. As a by-product, the plots are sent to each field station to provide them fast feedback on data quality and system operation.

Table 1. Successful laser range measurements. (The numbers in parentheses indicate successful arcs.)

| Month | South Africa | Peru | Brazil | Mt. Hopkins | Greece | Japan | Total |
|---|---|---|---|---|---|---|---|
| July | 967(60) | 3952(223) | 167(14) | 0(0)* | 20(12) | 0(0) | 5106(309) |
| August | 1339(75) | 3968(255) | 216(31) | 0(0)* | 12(6) | 0(0) | 5535(367) |
| September | 1299(48) | 3099(151) | 478(52) | 0(0)* | 0(0) | 0(0) | 4876(251) |
| October | 1458(50) | 5207(224) | 880(85) | 0(0)* | 5(4) | 0(0) | 7550(363) |
| November | 412(20) | 1647(85) | 617(51) | 1471(75) | 159(34) | 16(3) | 4322(268) |
| December | 379(23) | 1704(80) | 385(49) | 741(41) | 0(0) | 70(14) | 3279(207) |
| Total | 5854(276) | 19, 577(1018) | 2743(282) | 2212(116) | 196(56) | 86(17) | 30, 668(1765) |

*Prototype system was being refurbished during this period.

A number of small changes were made to the orbit generation and prediction routines to enhance their capabilities. The programs now provide the stations with estimates of return-signal strength so that the operators can adjust system parameters to accommodate larger signal dynamic ranges. The geometry of the satellite array, the satellite range, and the atmospheric extinction are used to calculate, in decibels, the expected amplitude, which is then employed by the observer to set system controls. With this programed capability, we are better able to delete predictions for which satellite and orbit geometry are unfavorable.

## Baker-Nunn Cameras

The 11 Baker-Nunn camera sites operated by or in conjunction with the Smithsonian made over 12,500 successful observations of 16 satellites during the second half of 1972 (see Table 2). There were 129 successful simultaneous observations made for geodetic analysis (see Table 3). Over 2500 observations were made on the atmospheric satellites (see Table 4). Special tracking support was provided of 1970 103B for Mr. Carl A. Wagner of the Goddard Space Flight Center. During November and December, 1971 54A was tracked for Dr. Desmond King-Hele of the Royal Aircraft Establishment in Farnborough, Hants, England, who is studying the 15th-order resonance.

Table 2. Baker-Nunn observations.

| | |
|---|---|
| July | 2011 |
| August | 2060 |
| September | 2187 |
| October | 2088 |
| November | 2269 |
| December | 1799 |
| Total | 12,578 |

Table 3. Simultaneous observations (July through December 1972).

| Baseline | Number of Observation Pairs |
|---|---|
| Spain to Greece | 71 |
| Peru to Brazil | 39 |
| Spain to Brazil | 4 |
| Spain to India | 1 |
| Greece to India | 4 |
| Ethiopia to India | 6 |
| Ethiopia to Greece | 2 |
| South Africa to Ethiopia | 2 |
| Total | 129 |

Table 4. Baker-Nunn data – atmospheric satellites (July through December 1972)

| Satellite | Number of Observations |
|---|---|
| Vanguard 2 (1959 Alpha) | 651 |
| Explorer 8 (1960 $\xi$1) | 468 |
| Explorer 19 (1963 53A) | 634 |
| Explorer 32 (1966 44A) | 489 |
| Explorer 39 (1968 66A) | 348 |
| Total | 2590 |

## Engineering

From July to October, the Mt. Hopkins prototype laser system was refurbished to provide more reliability, as well as more compatibility with the three other operating laser systems. This laser, now essentially the same as the other three, is fully environmentalized for the field and is already providing considerably enhanced reliability for the operation at the Mt. Hopkins station. The pedestal, previously a hand-operated, static-pointing system, was rebuilt and motorized, and electronics were provided to allow automatic pointing from punched paper-tape input. This automation has permitted an increase in data rate to 4 ppm; even faster rates are possible with this equipment. The output of the data system is now automatically punched on paper tape; those data include not only the range time but also the epoch time of the observations. Previously, this information was punched by hand. The improvements to the range gate consisted of special simplified electronics incorporated with the present counter to enhance system reliability. In November, the first operating month for the refurbished system, the data yield broke all previous records for that station.

From 1 July through 31 December 1972, timing at all stations was maintained to better than ±100 μsec of UTC (USNO), with laser station timing traceable to ±50 μsec. Most tracking stations have now converted from a monthly summary of time corrections and uncertainties to a graphic display of drift for the month, so that a unique correction for each observation can be made; timing uncertainty is thus lower.

On 31 December, a leap second was applied to UTC (USNO). All stations successfully retarded their station clocks by 1 sec to conform to this time step.

## COMMUNICATIONS

Regular radio and radio TTY communications have been in operation to Peru and Brazil for a year. This system has been very reliable and has provided us with real-time communications for operational and maintenance problems.

A 10-kw radio transmitter plus a 1-kw transmitter are being prepared for incorporation into our communications system. This system will alleviate the occasional operational problems due to adverse atmospheric conditions and permit simultaneous transmission of separate predictions to both Peru and Brazil. This duplex operation will reduce considerably the time required for communications to South America.

A new communications route was established in India. In the past, predictions were mailed a month in advance; now they are sent to the American Embassy in New Delhi and then by messenger to the observing station in Naini Tal. New predictions, run from new orbits, are sent each week. The additional cost of this service is being paid by excess currency funds. This new communications channel now gives us 1-day turn-around time for operational problems.

## DATA-SERVICES DIVISION

During this 6-month period, pointings were generated for five retroreflector-equipped satellites for the SAO laser stations at Mt. Hopkins, Natal, Arequipa, and Olifantsfontein (South Africa) and for the National Technical University laser at Dionysos (Greece). Predictions were computed for 16 Baker-Nunn sites, including 5 Air Force cameras. Table 5 lists the satellites tracked.

Predictions on satellites being used for study of long-period perturbations and of the atmosphere were generated for the Baker-Nunn observing sites.

Special predictions were generated on Vanguard 1 to reassess the capability of the Baker-Nunn camera.

Predictions on 1971 54A were computed for Baker-Nunn sites at a request from Dr. King-Hele.

The cooperative program with the Western European Satellite Triangulation (WEST) network was continued through 14 July 1972, with observations being made of Explorer 19, Explorer 39, and Pageos.

The Data-Services Division continued to provide weekly orbital elements on seven laser satellites and Midas 4 to all agencies cooperating in EPSOC. To compute the most precise orbital elements, observations were processed from as many stations as possible, including optical, radio, and laser sites. Simultaneous predictions between collocated camera and laser tracking systems were generated for EPSOC.

The validation of laser data has been further improved by use of a routine in which the range residuals of each laser point are plotted by the computer. By visual inspection of the general trend of the residuals, noise points become apparent. The data are now processed weekly.

Table 5. Satellites tracked from 1 July through 31 December 1972.

| Satellite | Name |
|---|---|
| | Tracked on Request from NASA |
| 1963 53A | Explorer 19 |
| 1965 89A | Geos 1* |
| 1967 11A | D1C |
| 1967 14A | D1D* |
| 1968 2A | Geos 2* |
| 1968 66A | Explorer 39 |
| 1970 103B | Cosmos 382 Rocket Body |
| 1972 96A | Apollo 17 |
| | Tracked for Geodesy and Earth Physics |
| 1961 1 | Midas 4 |
| 1964 64A | BE-B* |
| 1965 32A | BE-C |
| 1965 89A | Geos 1 |
| 1966 56A | Pageos |
| 1967 11A | D1C |
| 1967 14A | D1D |
| 1968 2A | Geos 2 |
| 1970 109A | Peole |
| | Long-Period Perturbations |
| 1959 1 | Vanguard 2 |
| 1960 2 | Echo 1 Rocket Body |
| 1964 64A | Explorer 22 |
| 1965 89A | Geos 1 |
| | Tracked for Atmospheric Investigations |
| 1959 1 | Vanguard 2 |
| 1960 1 | Explorer 8 |
| 1963 53A | Explorer 19 |
| 1966 44A | Explorer 32 |
| 1968 66A | Explorer 39 |
| | Special Requests |
| 1958 2 | Vanguard 1 |
| 1971 54A | Cosmos |
| 1972 72A | Cosmos 520 (Air Force cooperation) |

*Satellites ranged by lasers during this 6-month period.

The Film Control Section received and cataloged 11, 870 films from the SAO stations and 1517 from the Air Force Baker-Nunn stations.

A total of 1379 precise reductions of satellite positions was completed, which brings the number of all reductions to 239, 455 as of 31 December 1972. Table 6 gives a breakdown of the satellite reductions made during the current period.

Inquiries concerning tape distribution of the SAO Star Catalog continue to be handled routinely.

Table 6. Reductions completed 1 July to 31 December 1972.

| Object | Period | Number of Images |
|---|---|---|
| Midas 4 | March 1971 | 64 |
| Explorer 27 | 8–31 August 1971 | 76 |
| D1C | 5–30 June 1971 | 138 |
| Geos 1 | 16 December 1971 | 30 |
| Geos 2 | 25 March–15 April 1971 | 173 |
| | 14–31 July 1971 | 34 |
| | 11–31 August 1971 | 180 |
| Selected Simultaneous Observations | February–August 1971 | 646 |
| Selected WEST Observations | October 1966–June 1969 | 38 |
| | Total | 1379 |

# MOONWATCH

Moonwatch stations with registered site numbers total 150. An additional 30 stations were called on to observe satellite reentries and other nonroutine phenomena. During this period, stations reported more than 14,000 positional and 11,500 optical-signature observations.

Special look-angle predictions were calculated for selected observers whose capabilities and geographic locations enabled them to make observations to help determine air density and its variations and the rotational speed of the atmosphere. Selected optical observations were used by Dr. King-Hele in determining zonal harmonics in the earth's gravitational field. Further, optical observations were utilized in "finding" orbits for laser satellites on their emergence from periods of invisibility. Data from observations of satellites having research applications went into data banks of SAO and other scientific organizations and are available to all investigators.

During this period, there were 147 satellite decays, of which 50 were predicted by NORAD. For these 50, Moonwatch calculated specific look-angle data and telegraphed this information to stations having possible visibility. Observations were made during reentry of satellite pieces associated with five Cosmos and two Molniya launches from USSR, as well as debris from the US Titan 3 C-8 and Explorer 44.

Ephemerides were calculated for all stations, including approximately 200 cooperating observatories, covering the final Apollo 17 mission.

A last attempt was made to observe the lunar impact point of the SIVB rocket, either optically or in the infrared. No successes were reported.

Special tasks for Moonwatch observers included the tracking of selected satellites in highly elliptical, high-apogee orbits, as well as of the UK 4 satellite for establishing its orientation in space by determining its spin axis.

Moonwatch maintained close contact with the NORAD Space Defense Center (SDC) and continued to administer the Volunteer Flight Officer Network (VFON) under an Air Force contract. The VFON now encompasses 120 airlines with the active involvement of over 56,550 flight crew members located in 58 countries and covering over 4 million unduplicated air miles.

Airmail and national and international telephone and teletype continue as the major communication links between Headquarters and the Moonwatch worldwide network of stations. Also, cooperating amateur (volunteer) radio links have been routinely operational between Moonwatch headquarters and certain South American observers for the timely exchange of satellite-tracking data. This additional mode of communications was developed because conventional airmail and teletype into these countries have not been able to function within our time and budgetary constraints.

Procedures were developed to help identify observed but unpredicted satellite decays. These procedures involve keeping orbital-element sets on file for every satellite piece nearing decay. The SDC, through their network of satellite sensing devices, attempts to keep close track of only major satellite components just before and during decay.

Many of our ground-based and airborne observers report all unusual atmospheric events they see. Those reports that, by their description (direction and angle of tracking, length of observation, color, etc.) could possibly be of satellite origin are then considered for possible satellite-decay correlations. Should a correlation appear feasible, orbital elements covering all possible decays during that approximate period are assembled. These elements are then entered into a computer program developed to predict the location of the orbit plane in the correct place and time. If a close correlation can be made, it is assumed that the several aspects of a satellite reentry would probably remove most elements of chance from the identification and that a reentry observation of a specific satellite piece had been made.

## PROGRAMING GROUP

The Programing Group is responsible for the development of computer programs for all phases of the satellite-tracking program, for the operation of existing computer programs, and for development work in applied mathematics required to achieve these objectives. The computer programers now use almost exclusively a Control Data 6400 and a Data General 1200.

Staffing has remained approximately constant over the past 6 months; it still allows for maintenance of operational programs and for a limited amount of support for research.

### CDC 6400 Programs

SCROGE: This program is in a maintenance stage.

GRIPE: New expressions for lunisolar perturbations on earth satellites have been incorporated into GRIPE. These expressions were developed in FORTRAN format via SPASM and then processed by a SNOBOL program that, by calls to arithmetic statement functions, recognized and replaced occurrences of similar but not identical expressions. This reduced the resultant code for the lunisolar expressions by about 80%.

DOI: Some significant bugs were located and corrected in DOI; it can now consistently utilize range observations correctly.

AIMLAZR: Numerous corrections and improvements have been incorporated into AIMLAZR as a result of its continued use and maintenance. However, AIMLAZR should soon be replaced by SLAPP for regular satellite predictions.

SLAPP (Smithsonian Laser Prediction Program): This new prediction program was written primarily to obtain a close interface with GRIPE and therefore to take advantage of GRIPE's expanded capabilities. SLAPP is now being tested and debugged.

SPASM: Two new subroutines have been incorporated into SPASM; one makes Hansen-type substitutions, the other factors expressions of specific types. These are two of the chief tools used in developing the lunisolar expressions for GRIPE.

DG 1200 Programs

1. In November, LINC tapes were acquired for the 1200. This facility provides disk-like magnetic-tape storage for the minicomputer users. Shortly thereafter, the following were accomplished:

   a. The LINC-tape bootstrap procedure was modified to make it less laborious to use.
   b. The LINC-tape operating system (LTOS) was modified to allow more files per tape.
   c. The paper-tape prediction program developed for field use was converted to a LINC-tape-accessible format that is now operational.

2. A Hold-and-Forward Concentrator program was written to assist in the development of interactive computing.

3. An interface for a program to transmit data from the DG 1200 to the CDC 6400 was adapted from the concentrator code. Eventually, this should lead to the use of the 6400 high-speed peripherals by the 1200.

Miscellaneous

1. SLAVE, RESONT, and several other programs were organized to create a new SLAVE program library.

2. REFRCT and REFRCT2 were developed to evaluate atmospheric refraction for various temperatures and vapor pressures.

## Plans for Near Future

1. SLAPP will be adjusted and improved as it comes into routine use.

2. A program that uses precise laser ranges to solve for shifts in station positions will be written.

3. A new theory of lunar perturbations by Dr. Y. Kozai will be verified by SPASM and extended by Aksnes.

4. The 1200 prediction program will be expanded, with AIMLAZR as the model.

5. The LINC tape operating system will be revised so that the LINC tapes can be used in conjunction with FORTRAN.

6. A second version of the 1200 concentrator program will include an automatic answering facility.