SATELLITE-TRACKING AND EARTH-DYNAMICS
RESEARCH PROGRAMS

Grant Number NGR 09-015-002

Semiannual Progress Report No. 29

1 July to 31 December 1973

Project Director: Dr. G. C. Weiffenbach

(NASA-CR-138161) SATELLITE-TRACKING AND EARTH-DYNAMICS RESEARCH PROGRAMS Semiannual Progress Report, 1 Jul. - 31 Dec. 1973 (Smithsonian Astrophysical Observatory) 41 p HC $5.25 CSCL 22C G3/30

N74-22441

Unclas 36840

Prepared for

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

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
are members of the
Center for Astrophysics

SATELLITE-TRACKING AND EARTH-DYNAMICS RESEARCH PROGRAMS

Grant Number NGR 09-015-002

Semiannual Progress Report No. 29

1 July to 31 December 1973

Project Director: Dr. G. C. Weiffenbach

Prepared for

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

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
are members of the
Center for Astrophysics

404-060

TABLE OF CONTENTS

SATELLITE-TRACKING AND EARTH-DYNAMICS

RESEARCH PROGRAMS

Semiannual Progress Report No. 29

1. INTRODUCTION

This report covers the following activities in Smithsonian Astrophysical Observatory's (SAO) earth-dynamics programs:

A. Satellite-tracking network operations (NASA/OTDA) (see Section 2).

B. Satellite geodesy and geophysics programs (NASA/OA) (Section 3).

C. Atmospheric research (NASA/OSS) (Section 4).

The following paragraphs outline some of the highlights of our program activities during the reporting period.

During the last 6 months of 1973, approximately 46,000 successful range measurements were acquired by the SAO laser stations in Peru, South Africa, Brazil, and Arizona; this constitutes a 50% increase over the comparable period of 1972.

The Peole satellite-tracking campaign conducted in conjunction with the Centre National d'Etudes Spatiales (CNES) was completed in August 1973. Tracking of Peole began in April and continued after the D5B launch vehicle failed. During the campaign, the SAO network obtained 4482 validated returns of 310 arcs of Peole. This is an impressive figure, compared to only 1178 Peole returns on 195 arcs acquired during the International Satellite Geodesy Experiment (ISAGEX) and the Earth Physics Satellite Observation Campaign (EPSOC). This improvement is attributed to new prediction software and new operating techniques. These data are of particular value for obtaining more accurate gravity-field and zonal-harmonics coefficients.

Work continued on the design and early construction phase of the prototype pulse digitizing system, which presents, in digital form, the outgoing and return pulses from each laser tracking system. We plan to install a pulse digitizing system at each SAO laser station in order to improve ranging accuracy in preparation for Geos C.

The Analytical Satellite Geophysics Department began work on the Research and Technology Operating Plans (RTOPs) assigned to SAO in support of the Earth and Ocean Physics Applications Program (EOPAP). These are discussed more fully in Section 3.

The first half of Fiscal Year 1974 constituted a transition from efforts supporting the National Geodetic Satellite Program (NGSP) to those for EOPAP. In addition, a number of NGSP activities were completed. SAO's contribution to the NGSP, which also comprises the 1973 Smithsonian Standard Earth (III) (SE III) (Gaposchkin, 1973), was submitted to the American Geophysical Union and will be published as Chapter 9 in the NGSP Final Report. A comparative study of all NGSP contributions is now under way. The preliminary results of this comparison indicate that geocentric coordinates have quoted accuracies that are optimistic by factors of 2 to 5. Even so, independent estimates of coordinates agree with each other to within 10 m, the NGSP goal.

The results obtained from work on some of the RTOPs are being used as supporting material in preparing SAO's proposal to OTDA for upgrading SAO's laser systems.

SAO participated in a number of Lageos activities during this period. This included a review meeting on Lageos program objectives and scientific and technical features at National Aeronautics and Space Administration (NASA) Headquarters on 11 October, followed by subsequent meetings both at NASA Headquarters and at Marshall Space Flight Center (MSFC) in Huntsville, Alabama. Discussions covered various views concerning the orbit altitude, orbit inclination, and the satellite size and mass required for the specification of the Lageos system. From these data, NASA will compile the Phase B definition study. A number of memoranda were provided to NASA/OA as a result of analyses performed by SAO – e.g., one by Dr. E. M. Gaposchkin entitled "LAGEOS Orbit Specifications," dated 10 December 1973, and others on the Lageos retroreflector-array requirements, by Dr. M. R. Pearlman and Mr. D. Arnold.

Dr. L. G. Jacchia's attempts to model the variations in thermospheric composition as observed by satellite mass spectrometers, and to reconcile these variations with doppler temperature data and total densities from satellite drag, have scored remarkable success. Two simple formulas have been found to represent the observed seasonal-latitudinal variations in composition and the diurnal variations of the individual atmospheric constituents at any given location and height. Each equation contains a single numerical constant. Attempts are also being made to find a way to represent the global variations of temperature and composition with geomagnetic activity.

A study of the effect of radiation pressure and atmospheric drag on the balloon satellite 1963 30D has been completed. Mr. J. Slowey has found that by using a single value of the reflection parameter, it is possible to model perturbations due to direct radiation pressure in all the elements.

Slowey has begun work on the determination of atmospheric rotation from the secular decrease in the inclination of satellite orbits. Most of the necessary programming has been completed, and the first results were being obtained at the end of the reporting period.

2. SATELLITE-TRACKING NETWORK OPERATIONS (STADAD)

2.1 Satellite Observing Campaigns

SAO continues to track Geos 1, Geos 2, and BE-C in support of its ongoing NASA-supported research programs in geophysics. The data acquired during the last 2 years on these satellites are now being analyzed by SAO's Analytical Satellite Geophysics Department to measure the motion of the earth's pole (Chandler motion) and to refine geodetic parameters in preparation for Geos C.

The Peole satellite-tracking campaign, initiated 11 April 1973 in conjunction with the CNES, was completed on 7 August 1973. Tracking of Peole began during the pre-launch phase of a proposed D5B tracking program and continued after the failure of the D5B launch vehicle. During the campaign, 4482 validated returns on 310 arcs of Peole were obtained by the SAO network. In comparison, only 1178 Peole returns on 195 arcs were acquired during ISAGEX and EPSOC. This improvement is attributed to new prediction software and new operating techniques. These data are of particular interest for obtaining more accurate gravity-field and zonal-harmonics coefficients.

2.2 Laser Data

During the reporting period, nearly 46,000 successful range measurements were acquired by the SAO laser stations in Peru, South Africa, Brazil, and Mt. Hopkins (see Table 1). This represents a 50% increase over the last 6 months of 1972. The Geos 1, Geos 2, and BE-C satellites were tracked 7 days a week until September, when the laser schedule was reduced to 6 days for operational reasons.

After their summer rainy season, the Tokyo Astronomical Observatory (TAO) began operating its laser system again in November with a modified prediction format. An increase in data has been seen.

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

Month	South Africa (02)	Peru (07)	Brazil (29)	Mt. Hopkins (21)	Total SAO
July	3098 (124)	6994 (298)	1689 (102)	342 (16)	12, 123 (540)
August	1586 (86)	3695 (190)	1214 (98)	731 (35)	7, 226 (409)
September	1492 (80)	2452 (126)	655 (53)	1937 (86)	6, 536 (345)
October	886 (39)	2875 (144)	1029 (78)	2572 (94)	7, 362 (355)
November	538 (32)	868 (62)	1182 (59)	3255 (131)	6, 443 (284)
December	391 (21)	1786 (104)	1165 (74)	2693 (103)	6, 035 (302)
Totals	7991 (382)	18, 670 (924)	6934 (464)	12, 130 (465)	45, 725 (2235)

Cooperating stations, July to December 1973:

Japan 388 (37)

A new coudé laser mount was purchased by the National Technical University (NTU) in Athens. It was temporarily set up for testing at the former Baker-Nunn site while the laser building was being modified to accommodate the coudé mount. In October, the laser and electronics were sent to Othoni, an island northwest of Corfu, to obtain range measurements between Corfu, Othoni, and Italy. The purpose of these measurements was to obtain a more accurate geodetic tie between Greece and Italy and, in turn, to establish a more accurate geodetic location for Greece in the European datum. Preliminary results indicate that the project was a success.

The laser system in Ethiopia, on loan from CNES, was not operational during the reporting period. Persistent electronics and supply problems have plagued that system. At a meeting held with a representative of CNES in December, it was decided that the system would not be operated without a commitment of engineering support from CNES. SAO has now suspended the laser operations activity in Ethiopia with the understanding that the French may provide support for special observing periods in Calendar Year 1974.

2.3 Baker-Nunn Camera

Ten Baker-Nunn cameras operated by SAO and its cooperating agencies made over 8000 successful observations of 22 satellites (see Table 2). The cameras provided routine observations to support the generation of pointing predictions for the lasers belonging to SAO and its cooperating agencies.

Table 2. Total number of Baker-Nunn observations by month.

Month	Number of observations
July	1561
August	1542
September	1539
October	1445
November	982
December	934
Total	8003

The network made over 2400 successful observations of the five atmospheric satellites in support of NASA-sponsored research by Jacchia (see Table 3). Special support was also provided by tracking the Cosmos 382 rocket body for geodetic research for Mr. Carl A. Wagner of Goddard Space Flight Center (GSFC). We stopped tracking the object on 15 December at the request of NASA. Tracking support continued on 1971 54A for Dr. Desmond King-Hele of the Royal Aircraft Establishment for his study of 15th-order resonance. In addition, special photographic support on satellite 1972 37A was provided for the Air Force.

Table 3. Baker-Nunn data on atmospheric satellites, July to December 1973.

Satellite	Number of observations
Vanguard 2	350
Explorer 8	445
Explorer 19	703
Explorer 32	323
Explorer 39	662
Total	2483

The Baker-Nunn camera in Australia remains in storage, awaiting construction of a building at a new site in Orroral Valley.

The twelfth Baker-Nunn camera, operated by the CNES in Upper Volta, was dismantled in October, and the mirror was sent to be resilvered in preparation for the launch of the French satellite Starlette.

The network began nightly observations of Comet Kohoutek on 20 November, and by the end of December, 78 successful photographic sequences had been obtained by eight stations (see Table 4).

Table 4. Sequences of Comet Kohoutek made from 21 November to 14 December 1973.

	Spain	India	Hawaii	Mt. Hopkins	Peru
November	4	6	0	3	2
December	7	4	3	11	6
	11	10	3	14	8

	South Africa	Ethiopia	Brazil	Total
November	2	3	0	20
December	6	15	6	58
	8	18	6	78

2.4 Engineering

The second half of 1973 has been devoted to the design and early construction phase of a prototype system to digitize the outgoing and return pulses of the laser tracking system. This system is being built to improve the laser ranging accuracy in preparation for Geos C.

Various system components, such as the digitizer, paper-tape perforator, and pulse processing devices, were selected and purchased during the summer. In the fall, SAO built an intercoupler to handle the system flow and to format the data from the digitizer, the laser system clock, and the range counter.

The intercoupler was operational by December, and system integration has already begun. The entire system will undergo shakedown and calibration tests early in 1974, after which it will be installed at Mt. Hopkins for field testing.

Work continues on the software development for the minicomputers for the field stations. The full prediction program that runs from orbital elements is now nearly complete. Comparisons with predictions generated on the CDC 6400 computer show no differences. Present efforts are being applied to the input/output software and to other operational support routines (see Section 3).

2.5 Communications

Experiments with direct communications between SAO and Mt. Hopkins were conducted in November by using acoustic couplers with the FTS phone lines. Initial problems were solved, and the direct link has been established, thus relieving the Mt. Hopkins staff of a 20-mile drive to retrieve laser and Baker-Nunn predictions.

A direct link was established between STADAD offices and the SAO Communications Center to speed passage of administrative traffic.

The radio TTY link with Peru and Brazil operated routinely during the reporting period; predictions were transmitted for approximately 140,000 points on 3000 arcs, and nearly 26,000 points of data were received.

Under the auspices of the NASA Kohoutek project, the Communications Center began total coverage in December in support of Comet Kohoutek. This round-the-clock operation will continue until February 1974.

2.6 Data Services

The Data Services Division provided pointing predictions for four retroreflector satellites, BE-C, Geos 1, Geos 2, and Peole (this last satellite was covered during July and August only), for the laser sites at Mt. Hopkins, Brazil, Peru, South Africa, the NTU at Dionysos, and TAO. Orbital elements were routinely provided to Air Force Cambridge Research Laboratories, CNES, and the Institut für Angewandte Geodäsie, in Germany, for use in generating laser predictions. Camera predictions were generated and sent to 10 Baker-Nunn stations. Table 5 lists the satellites observed.

Table 5. Satellites tracked from 1 July through 31 December 1973.

Satellite	Name
Tracked on request from NASA	
1963 53A	Explorer 19
1965 89A	Geos 1*
1968 2A	Geos 2*
1970 103B	Cosmos 382 rocket body
Tracked for geodesy and earth physics	
1961 αδ1	Midas 4
1964 64A	BE-B
1965 32A	BE-C*
1965 89A	Geos 1
1968 2A	Geos 2
1970 109A	Peole*
Special requests	
1971 54A	Thor burner 2 rocket
1972 37A	Molniya 2
1972 69A	Triad
Tracked for long-period perturbations	
1959 α1	Vanguard 2
1960 ι2	Echo 1 rocket body
1964 64A	BE-B
1965 89A	Geos 1
Tracked for atmospheric investigations	
1959 α1	Vanguard 2
1960 ξ1	Explorer 8
1963 53A	Explorer 19
1966 44A	Explorer 32
1968 66A	Explorer 39

*Tracked by both lasers and cameras during this period.

Orbits and predictions were provided to the Baker-Nunn sites for satellite 1971 54A in support of Dr. King-Hele's research and for satellite 1972 69A (Triad) to help evaluate the surface-force compensation system DISCOS as a future technique for gravity-field measurements.

Local predictions were computed for Skylab for public information.

Final validation of SAO laser data was completed for Fiscal Year 1973 and made available to the Analytic Satellite Geophysics Department for analysis.

The film-control section received and cataloged 8476 observations on 7812 films from the Baker-Nunn stations. During this period, the practice of spooling three observations on one roll was started in order to conserve space and film cans. We received 840 films from the Air Force sites.

Table 6 lists the 1520 precise reductions of satellite positions completed, which brings the number of all reductions as of 31 December 1973 to 242,085. Of these, 92 were provided by the group at the Instituto di Geodesia, Bologna, Italy, in cooperation with SAO.

Photographs of 280 laser pulses were precisely reduced.

Table 6. Reductions completed 1 July through 31 December 1973.

Object	Period	Number of images	Investigator
Vanguard 2	20 July to 20 August 1972	52	Jacchia
Explorer 19	20 July to 20 August 1972	212	Jacchia
Explorer 32	20 July to 20 August 1972	103	Jacchia
Explorer 39	20 July to 20 August 1972	42	Jacchia
Explorer 19	June through October 1972	505	Jacchia
Explorer 39	11–31 July 1968	92	Jacchia
Pageos (selected observations)	March 1967 to January 1970	514	Dr. I. Mueller
Total		1520	

3. SATELLITE GEODESY AND GEOPHYSICS PROGRAMS

3.1 Introduction

During the period 1 July to 31 December 1973, we began working on the 10 RTOPs assigned to SAO in support of EOPAP. These include studies of satellite dynamics to improve satellite ephemerides; use of existing satellite-tracking data for determination of geophysical parameters, such as the gravity field, earth tides, polar motion, and station location; evaluation of SE III; reduction and analysis of geodimeter measurements to determine local movements of the earth's crust; and studies to establish requirements for satellite-tracking equipment, network distribution, and satellite design.

This period was one of transition from work supporting the NGSP to that for EOPAP. A number of NGSP activities were completed. The SAO contribution to the NGSP, based on SE III (Gaposchkin, 1973), was submitted to the American Geophysical Union and will be published as Chapter 9 in the NGSP Final Report. A comparative study of all NGSP contributions is now under way. Preliminary results of this comparison indicate that geocentric coordinates have quoted accuracies optimistic by factors of 2 to 5. Even so, independent estimates of coordinates agree with each other to within 10 m, the NGSP goal.

The scientific work related to individual RTOPs is discussed in the following subsections.

3.2 Geophysical Data Base

Under RTOP 369-01-04, Dr. M. R. Williamson and Gaposchkin have begun the development of computer software to manage a geophysical data base, which will be computer-accessible, through an interactive terminal if required. The data base is planned to have 10^7 characters initially and to be expanded to 10^9 or 10^{10} characters.

The software being developed in FORTRAN for this data base is a set of user subroutines; these routines will manage a data set within the data base and are the same routines the agent who maintains the data base will use. Therefore, the user can create his own private data sets. The format and ordering of each data set is arbitrary, subject to the limit of about 100,000 units of data in each set. Each unit can be arbitrarily large.

The principal storage medium is a magnetic tape. A separate directory of information is maintained on disk. With this facility, it is easy to update and expand a data set or the data base and retain old data if desired. In fact, a user can determine quickly what data are in the data base and in each data set without actually compiling subsets. Therefore, a user can retrieve a wide variety of data sets, or subsets, depending on the contents of the data base. For example, for a data set of topographic heights, a subset can be requested containing all gravity and heat-flow measurements, where both are available, from places with a topographic height of > -1 km. Finally, the facility was planned for the convenience of scientists; therefore, a working knowledge of FORTRAN programing is sufficient to use these subroutines.

The first version of these subroutines is virtually complete. The subroutines are written in FORTRAN except for the random-access facility, and they can be transferred to another computer if a suitable random-access facility is available. A set of weather data are currently being incorporated into the data base.

3.3 Orbit-Computation Techniques

RTOP 161-05-05, on orbit-computation techniques, encompasses two main activities: 1) theory and computation of satellite motion and 2) development of minicomputer software for field stations.

3.3.1 Nongravitational perturbations

The effects of direct solar radiation pressure and albedo radiation pressure on satellite ephemerides have been studied. While semianalytical developments for both these forces have been used for some years, the short-period effects have virtually been ignored until now, owing to their small amplitude. Because the EOPAP program requires centimeter accuracies, we have been reexamining the adequacy of existing theories. The analysis to date has been for spherical satellites having small or modest eccentricity, with particular attention given to Lageos. The Pageos satellite is being used to test this formulation, as it has an area-to-mass ratio 10^5 times larger than Lageos's.

Dr. D. A. Lautman has developed a theory for albedo perturbations that includes short-period effects. These formulas are now being incorporated into the orbit-computation program. Table 7 shows the approximate amplitudes of the albedo perturbations of Pageos and Lageos expressed in linear units. The two orbits have the same sun–node angle and the same argument of perigee. The large magnitude of the along-track secular change arises from the perturbation in the mean motion. A theory is being developed to account for latitudinal variations in the albedo.

Table 7. Theoretical calculation of albedo radiation-pressure perturbations.

Parameter	Pageos	Lageos
a	1.66 a_e	1.9 a_e
e	0.06	0.02
I	86°.9	90°
A/M (cgs)	136.0	0.004
Albedo	0.4	0.4
Cross-track short-period perturbation	10 m	0.05 cm
Along-track short-period perturbation	150 m	1.5 cm
Cross-track secular perturbation	100 m day^{-1}	0.25 cm day^{-1}
Along-track secular perturbation	3600 m day^{-1}	25 cm day^{-1}

The treatment of the direct effect of solar radiation has been revised by Dr. K. Aksnes to include an analytic formulation for both long- and short-period perturbations. This revision agrees well both with numerical integration and with the semianalytical formulation currently in use and is more efficient in terms of computer resources. These formulas will be tested in the orbit-computation program, and extension of the development is being considered for satellites with variable aspects.

3.3.2 Gravitational perturbations

Aksnes has completed a review of the analytical theory for gravitational perturbations. A development of the earth's potential in spherical harmonics assumes the following form:

$$V = \frac{GM}{r} \left[1 - \sum_{\ell=2}^{\infty} J_\ell \left(\frac{R}{r}\right)^\ell P_\ell(\sin\theta) + \sum_{\ell=2}^{\infty} \sum_{m=1}^{\ell} J_{\ell,m} \left(\frac{R}{r}\right)^\ell P_{\ell,m}(\sin\theta) \cos(\lambda - \lambda_{\ell,m}) \right] , \tag{1}$$

where the dominating zonal coefficients are

$$J_2 = 1.08 \times 10^{-3} \quad , \quad J_3 = -2.4 \times 10^{-6} \quad , \quad J_4 = -1.7 \times 10^{-6} \quad . \tag{2}$$

The higher order zonal coefficients J_1 and the tesseral coefficients $J_{\ell,m}$ are all of the second order in J_2 or smaller. However, the perturbing effect of the corresponding harmonics on high satellites of geodetic interest diminishes rapidly with increasing values of ℓ because of the quotient $(R/r)^\ell$. For high satellites, therefore, it is reasonable to assume that an orbit theory is adequate if it incorporates the first-order perturbations due to all the known harmonics and the second-order perturbations arising from J_2, J_3, and J_4. Furthermore, those tesseral harmonics that give rise to resonances in the motion of a given satellite also require a special nonlinear treatment.

As a first step in testing the above supposition, Aksnes compared his second-order analytic theory (J_2, J_3, and J_4 only) with a theory of special perturbations (numerical integration). Complete to $O(J_2^2)$, the analytic theory must account for all the following terms, most of which arise through interaction with J_2:

First order: J_2, J_3/J_2, J_4/J_2

Second order: J_2^2, J_3, J_3^2/J_2^2, J_4, J_4^2/J_2^2, J_3, J_4/J_2^2.

The results of such a comparison are shown in Table 8 for Pageos (in orbit) and Lageos (to be launched). From column 5, we see that for both satellites the maximum residual (≈ the error of the analytic theory) after 1 day of motion is about 20 cm, while after 1 revolution (column 6), it varies from 3 to 13 cm. During both intervals, the residuals vary roughly as sin 2u (u = argument of latitude) and do not appear to increase rapidly with time. To find out which of the three harmonics contributed most to the error, two additional comparisons (last two columns) were made for Lageos. Apparently, J_3 holds this distinction.

Table 8. Comparison of theory and numerical integration.

Satellite	a (Mm)	e	i	Δ (cm day^{-1})*	Δ (cm rev^{-1})*	Δ (cm rev^{-1})†	Δ (cm rev^{-1})‡
Pageos	10.6	0.06	86°9	19	4.1	–	–
Lageos	10.13	0.02	60	20	13	1.5	0.13
Lageos	10.13	0.02	90	21	3.3	1.2	0.72

Note: Δ = "integrated" minus "analytic" position.
*J_2, J_3, and J_4 included.
†J_2 and J_4 included.
‡J_2 included.

The above is in agreement with the so-called d'Alembert characteristics, according to which the perturbations in, for example, r must take the form

$$\delta r = \sum_{j,k} r_{j,k}(a, e, i)\; e^{|k|} \sin^{|j|} i \; \frac{\sin}{\cos} (ju + kf) \quad . \tag{3}$$

When e is small, as in equation (3), terms with k = 0 must dominate. We conclude that an accuracy better than 20 cm requires the inclusion of third-order terms due to J_3 in the analytic theory. For orbits with low eccentricity, only a few such terms are needed. An alternative to a third-order analytic development is to introduce some empirical terms of the form just shown.

Of course, it remains to be demonstrated what accuracies are achievable if the higher order zonal and the tesseral harmonics are also incorporated into the theory (as well as into the numerical integration) in the manner already indicated. Most of these perturbations have already been included in our precision orbit-computation program.

Satellite resonance has been studied by Ms. B. A. Romanowicz. Her development attempts to find a unified treatment for resonance that includes the resonant gravity-field coefficient and J_2 by the Lie-Hori method. A first-order solution in elliptic integrals has been found. The formulation is being put into final form, and extension to second order is being investigated.

3.3.3 Tides

Dr. Y. Kozai's revised theory for perturbations due to the sun and the moon (Kozai, 1973) has been incorporated into the precision orbit-computation program. This theory includes parallactic and short-period terms and makes no assumptions about the motion of the sun or moon. The body tide and the associated phase angle are treated separately for the sun and the moon. At the same time, minor corrections to the perturbations due to the moving equator of the earth have been made.

3.3.4 Numerical integration

Williamson has converted the numerical-integration program previously used to verify the analytical formulas to an Adams method, a method far more efficient than that of Runga-Kutta-Gill. Investigation of the accuracy of this version continues. The program has been expanded to include an arbitrary gravity field expressed in spherical harmonics. Modifications are in progress to include a surface-layer density model and the albedo radiation pressure in the force field. The integration program is being modified to be incorporated into the precision orbit-computation program in place of the analytical theory. This will provide a further comparative test with real data of the analytical treatment.

3.3.5 Minicomputer development

Mr. J. R. Cherniack has continued directing the development of minicomputer software for the Data General Nova 1200 in support of field operations. Using orbital elements, the Nova computer field software has generated predictions that agree with the main computing-center predictions to $0.^{\circ}001$. The programing required to achieve this agreement included the following:

A. Assimilation of floating-point processors into FORTRAN.

B. Incorporation of lunisolar perturbations.

C. Incorporation of tesseral and zonal-harmonics perturbations by using a medium-sized field (16×16 plus resonant terms).

D. Inclusion of estimated signal-strength computation.

The programing was unusually difficult because of the limited memory size of the minicomputer, the lack of peripheral devices, and the absence of a decent operating system. These difficulties persuaded the research group not to use FORTRAN for subsequent field software.

Additional software, which has been defined and is now being designed, will permit the following:

A. Control of the laser mount in real time.

B. Rejection of spurious data.

C. Handling of pass summaries, report writing, etc.

We decided to use FORTH (not to be confused with FORTRAN H or any other FORTRAN) for all the new software described above. A version of FORTH received from the National Radio Astronomy Observatory was upgraded in the following areas:

A. Floating-point operations.

B. Diagnostics and debugging.

C. Addition of arrays.

D. Mathematical library.

E. Soft restart following power failures.

Specifications and requirements for field minicomputers have been established and documented (see SAO Proposal P 425-5-73, Supplement No. 1). Installations in the field will begin when authorized by NASA/OTDA.

3.4 Selection of Fundamental Sites

The analysis of ground-systems requirements and plans for a fundamental EOPAP network under RTOP 161-01-03 began. Assuming the number of stations and their distribution among the major plates are known, the criteria to be used for site selection have been established and a particular site has been evaluated. These criteria are discussed in the following sections.

3.4.1 Geological and geophysical environment

The geological and geophysical environment is critical. A fundamental satellite-tracking site should be in a tectonically inactive region; that is, places where local deformation is occurring should be avoided. Local deformation can be studied more easily with other methods and will corrupt analysis of global motions. The principal types of information considered in choosing a site are as follows:

A. Geological record.

B. Seismicity of the area.

C. Distance from the oceans.

The geological record indicates the long-term (millions of years) evolution of a region, for example, by the existence of fault zones or uplift. Furthermore, old (Precambrian basement) rocks have recently been tectonically quiet. The seismicity of a region indicates the amount of strain release currently going on and, by implication, the amount of deformation. However, anomalous earthquakes can occur in relatively quiet areas. Therefore, there is no foolproof method of selecting quiet sites, but the chances are best in an old craton or shield with no observed seismicity.

Ocean tidal loading is a significant signal, which can be modeled only approximately today. To minimize this effect, it is preferable for a site to be located several hundred kilometers from an ocean.

3.4.2 Atmospheric environment

The principal consideration in selecting sites is the amount of cloud cover, as clouds are the main reason for loss of data. Global cloud-cover maps are available (see, e.g., Kravtsova, 1972; Landsberg et al., 1965; Army-Air Force, 1942), and these can be used to identify good regions. More detailed information is then requested from local weather bureaus. In the future, the amount of relative humidity will dictate the accuracy of the refraction corrections.

3.4.3 Orbital coverage

Accurate orbit determination requires complete orbital coverage. Continuous observation is not necessary, but it is desirable that each section of the orbit be observed at least once in the interval of orbit computation. Orbital coverage depends on the distribution of stations, the satellite height, and the orbital inclination.

Our station complement currently is such that satellite orbits are covered adequately in the northern and equatorial latitudes and inadequately in the southern hemisphere. The critical parameter is the geocentric angle in the orbital plane delimiting the region of geometrical unobservability. The smaller the unobservable orbit-plane angle is, the better. This angle is a function of the southernmost station's latitude; we give its values in Table 9 for several satellites, for several choices of southernmost station, and for two assumptions about the minimum observable instrument elevation angle.

At 5690 km, Lageos, with an inclination of 70°, will require a station latitude of 25°.7 for 15° elevation angle and of 29°.8 for 20° elevation angle. Therefore, complete Lageos orbital coverage is possible with any of the stations in Table 9.

3.4.4 Communications and logistics

Communications and logistics considerations require that stations be in inhabited regions and have communications. Further, it is desirable that the regions have commercial power and telephones and political stability.

Table 9. Southern unobservable orbit-plane angle in degrees.

Satellite	Inclination	South Africa $\phi = 26°$	Gold Mine, Australia $\phi = -31°$	Orroral Valley, Australia $\phi = -35°$	Comodoro Rivadavia, Argentina $\phi = -46°$	
Geos C	115	86	73.6	63	28.3	
Starlette	54	73	56.3	40	0	
Geos 2	105	86	75	66	40.5	20° elevation angle
Geos 1	59	60	42.6	24	0	
BE-B	80	96	85	77	53.7	
Geos C	115	79	66.3	55.5	12	
Starlette	54	65	46.5	26	0	
Geos 2	105	79.5	68.5	59.5	32.5	15° elevation angle
Geos 1	59	49	28.1	0	0	
BE-B	80	89	79.3	71	47.5	

3.4.5 Summary and recommendations

Gaposchkin, Pearlman, and Dr. P. A. Mohr are collecting weather data and geological, tectonic, and seismic maps by regions. With more detailed data, they will investigate the number and distribution of the tectonic plates among a complex of stations.

The necessity of moving the laser station 7902 out of South Africa provides an opportunity to apply these considerations. Because of its advantageous latitude, Australia has been studied in some detail, and two sites are documented here. Geological and seismic maps of Australia are presented in Figures 1 and 2 (McElhinny, 1973). The first site studied is in Orroral Valley, where there is an existing NASA facility and a lunar laser system. However, Orroral Valley is not suitable as a long-term EOPAP station, because it is directly on a seismic zone in the midst of a Paleozoic orogenic region. Since South Africa is considered to be a good station for observing, we compare its cloud-cover data (Figure 3) and its data loss due to cloud cover (Figure 4) with those for Orroral Valley (Figure 5) (Morgan and Miller, 1973). It is clear that there would be a significant loss of data due to cloud cover in Orroral Valley, yet from Table 9, we can see that the orbital coverage for that region is an improvement over that in South Africa.

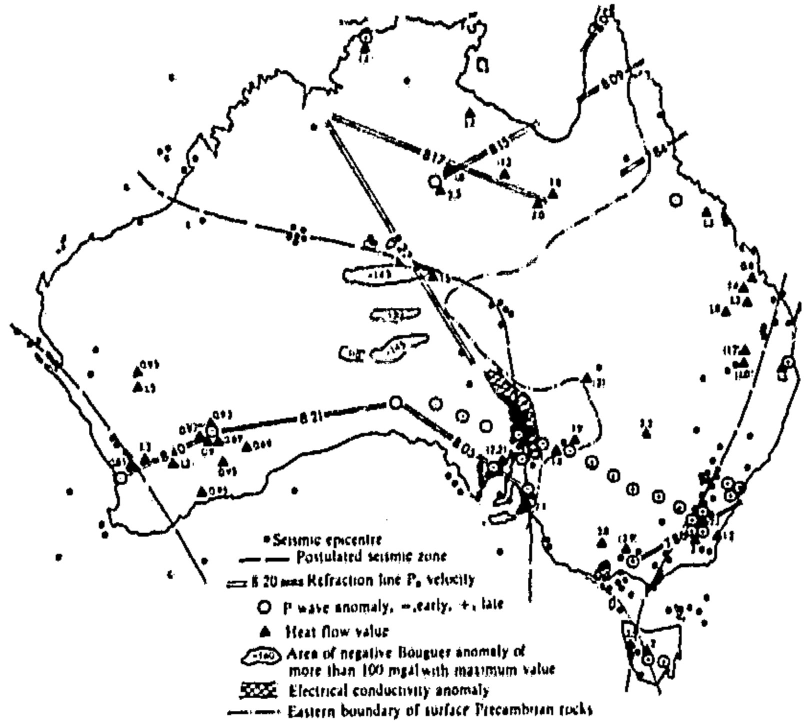

Figure 1. Seismic map of Australia.

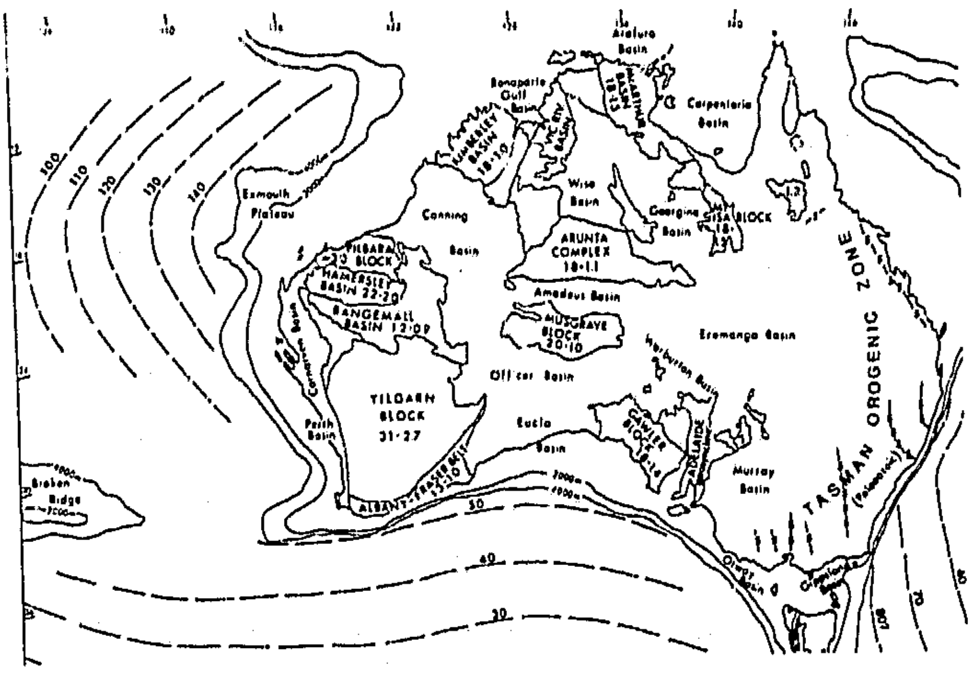

Figure 2. Geologic map of Australia.

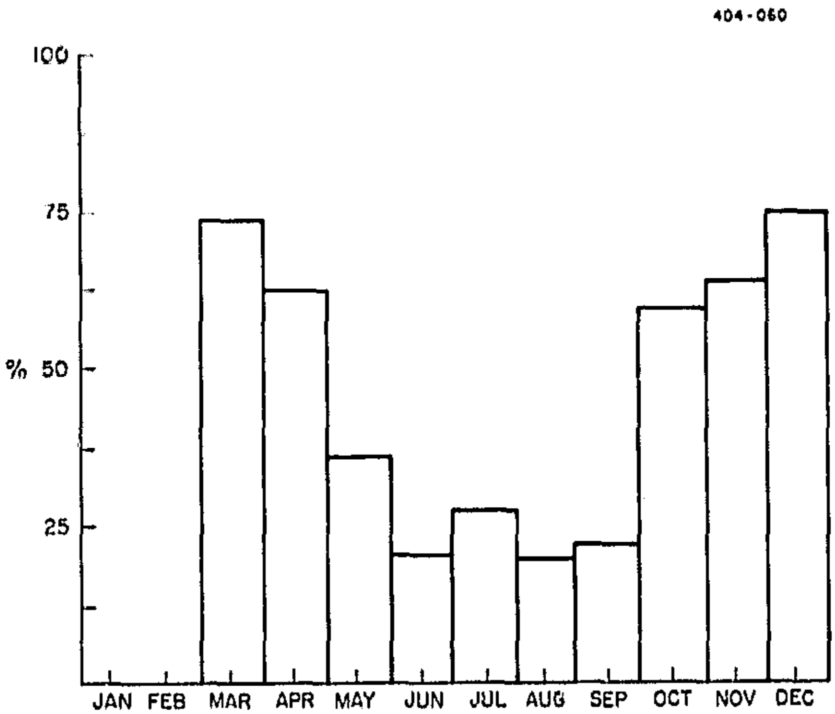

Figure 3. Mean cloudiness, South Africa.

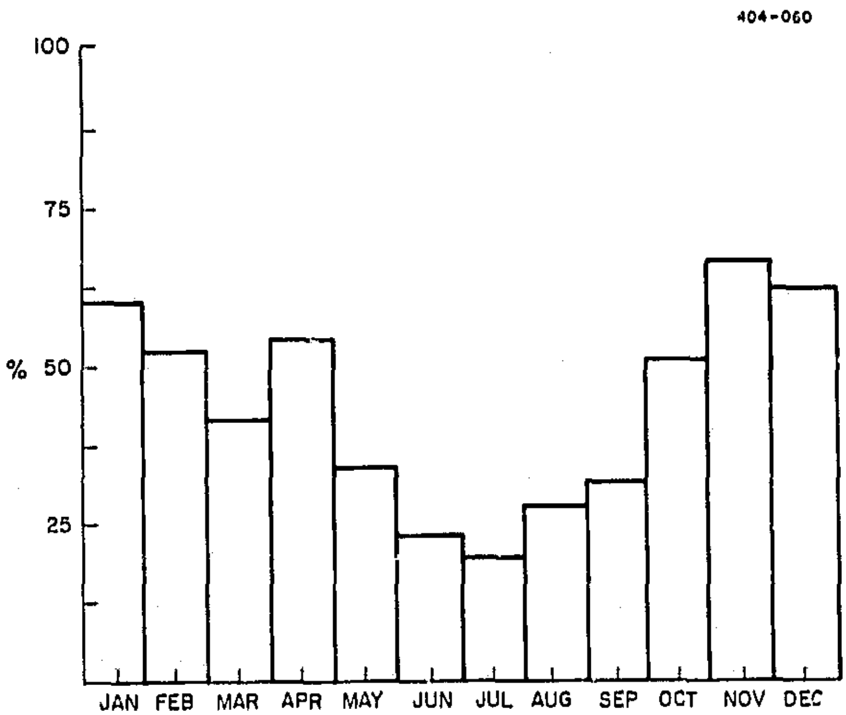

Figure 4. Baker-Nunn data loss, South Africa.

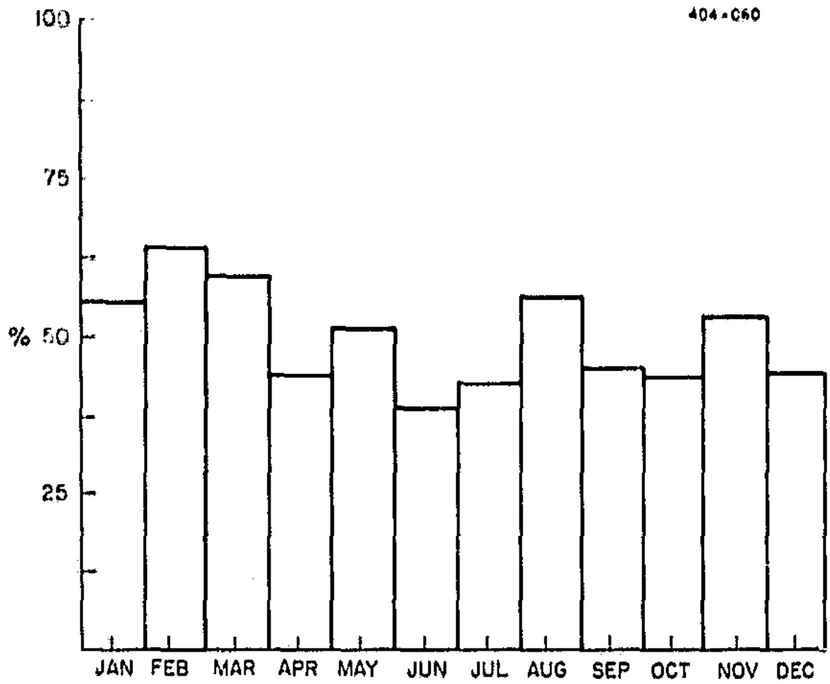

Figure 5. Mean cloudiness, Orroral Valley.

The region around Kalgoorlie in southwest Australia is the second site studied. Figures 6 and 7 show the local cloud cover for a typical Eastern seacoast area of Australia near Orroral Valley (Sydney) and for the southwestern inland region near Kalgoorlie (Lawlers). The weather is far superior in both these areas to that in South Africa and in Orroral Valley. From geological and seismic maps, it is apparent that this region is located on one of the oldest Precambrian basement rocks known ($\approx$3 billion years) and has no seismicity. Because of gold mining in that region, good communications exist there. In addition, the mines provide the opportunity to establish stations to monitor earth tides. Finally, the orbital coverage offered by this site is acceptable. Gaposchkin, Pearlman, and Mohr are obtaining detailed geological and tectonic maps, other geophysical information, and local weather data of this region. Tentatively, however, it appears that locating a laser tracking station in the Kalgoorlie region would be ideal for EOPAP from the scientific point of view.

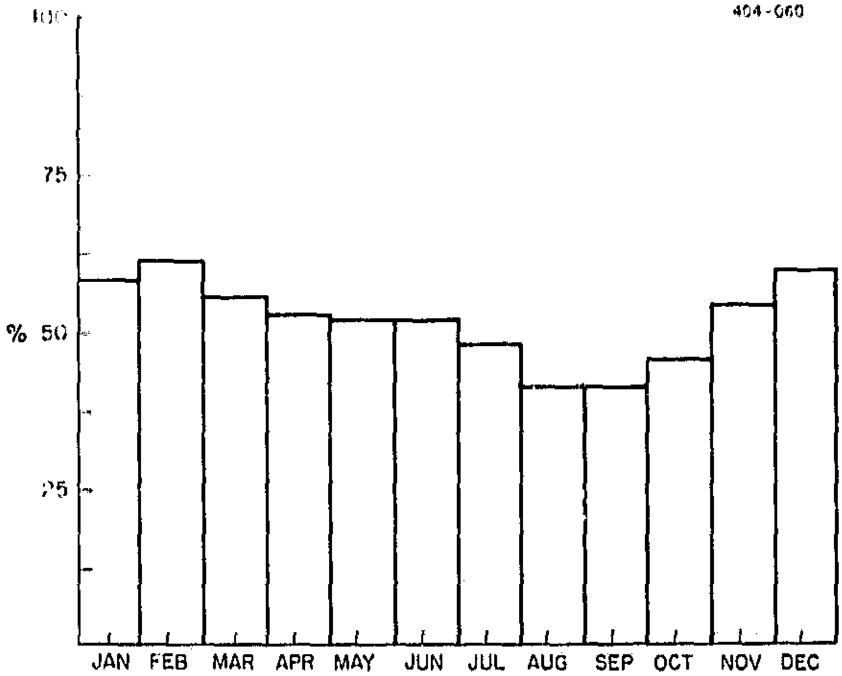

Figure 6. Mean cloudiness, Sydney, Australia.

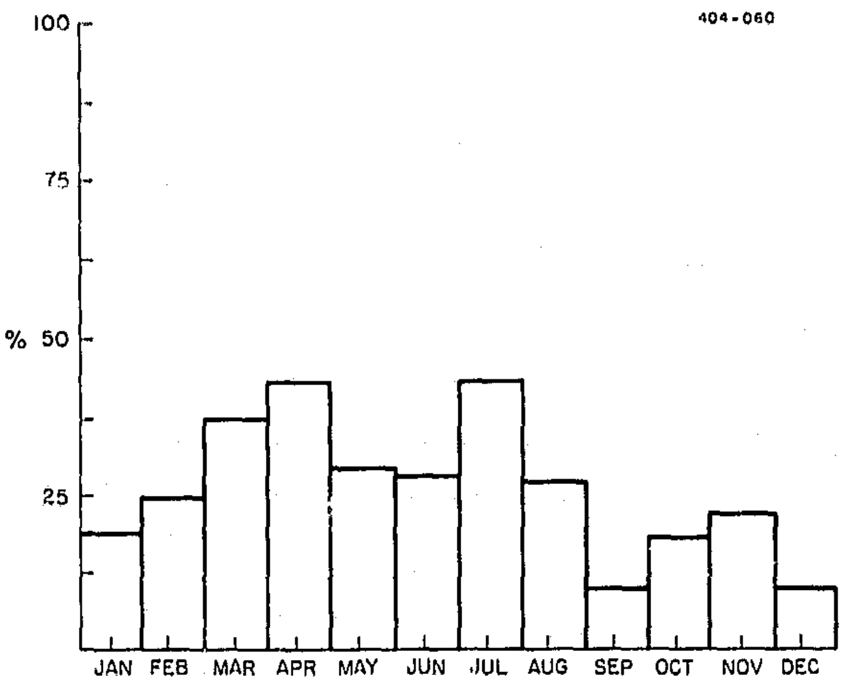

Figure 7. Mean cloudiness, Lawlers, Australia.

3.5 Gravity Field

Work on the earth's gravity field, under RTOP 369-02-03, has been concerned with the analysis of long-term effects. Gaposchkin and Ms. G. Mendes have recomputed a long series of orbits for Geos 1 and Geos 2 by using Baker-Nunn data. These series have been examined for the following:

A. To test the lunar, solar, tidal-radiation-pressure, reference-system, and long-period gravitational-perturbation theories.

B. To evaluate the internal coherence of mean elements.

C. To provide reduced mean elements for the determination of those harmonics in the gravity field that give rise to long-period perturbations.

The internal consistency of mean elements depends on the averaging time – the number of days covered by each orbit. With Baker-Nunn data, the low density of observations precludes calculating orbits coherent to 10^{-5} with 2 days of data. A 4-day span of data will give 10^{-5} to 10^{-6}, and except for unusually poor distribution, an 8-day span will give a, e, and I consistent to 10^{-6}.

The reference-system correction, tides, and parallactic terms in the lunar and solar perturbations all have the same amplitude and frequency. By using Love number k_2 compensated for the ocean tide, these perturbations seem to be treated properly.

Residual long-term variations in a, e, and I remain unexplained. The series of data is being extended to a full year. These residuals could be due to the as-yet-unmodeled albedo radiation (RTOP 161-05-05) or to the anisotropic reflectivity and variable cross section of the satellite. Both possibilities are under investigation.

From this analysis, an unexplained long-period effect in the eccentricity related to the odd zonal harmonics has been observed. This effect cannot be due to tides or reference systems, as these do not influence the eccentricity. The neglected second-order terms in J_3/J_2 in the gravitation theory are currently being examined (RTOP 161-05-05) as a possible explanation.

3.6 Station-Coordinate Determination

Under RTOP 369-02-01, two activities concerning tectonic plate and fault motion have been started:

A. The use of data from the ISAGEX program to determine the geocentric coordinates of individual stations.

B. The design and development of a general simulation program.

ISAGEX laser data on Geos 1 and Geos 2 have been used to determine the station coordinates of Dakar (7820) and Haute Provence (7809). The coordinates were determined in the same computation with the orbit in the precision orbit-determination calculation.

The ISAGEX data for Dakar did not give a satisfactory solution for the station coordinates in SE III. The coordinates determined in SE III disagreed with the height of mean sea level and with the coordinates from the nearby BC-4 station by more than 40 m. We thought this subsequent investigation would provide acceptable coordinates and indicate what problems existed with the data. The study was also extended to Haute Provence because we have reasonable confidence in the coordinates and laser data from that station. The results using current data, geodetic parameters, and analytical models with nine arcs of data can be summarized as follows:

A. Only single-pass determinations were possible from 7820 owing to a paucity of data.

B. The mean of these independent determinations agreed with the "best" global solution to within 15 m for station 7809 and 23 m for 7820.

C. The independent determinations of coordinates differed from the "best" global solution by as much as 121 m for station 7820 and 44 m for 7809.

D. The amplification of errors is evident from the study. The overall accuracy of these 4-day ISAGEX orbits is about 7 m. Single-pass station determinations used for data screening and preliminary simulations consistently give a factor-of-10 amplification (RTOP 161-05-02).

It is evident that adding more arcs to the average will result in a better global solution.

The use of existing data has raised a number of questions that Gaposchkin and Mr. J. Latimer are now examining through a simulation study. For example, they plan to study the effects on station-coordinate determination of known gravity-field model errors, the distribution and errors of station coordinates, the number of stations and known errors in their data (such as refraction, retroreflector-array distortion, and signal strength), polar motion, mean orbital elements, and the gravity field. The first use of the simulation will be to establish the number of stations needed to measure plate motions. The program being constructed will employ the precision geodesy program for all analyses. The simulation consists of defining the universe, gravity-field station coordinates, tides, drag, radiation pressure, and system errors and generating corresponding data. These data can be corrupted (e.g., by loss due to weather, system biases, poor station distribution) and used to compute geophysical and geodetic parameters. Shortly, it will be possible to perturb each system parameter separately. The influence of critical errors – such as station distribution, orbit configuration, gravity-field uncertainty, and refraction errors – can be determined in this way.

3.7 Surface Surveys

Under RTOP 161-05-06, Mohr and Mr. A. Girnius have made further analyses of all the Ethiopian geodimeter surveys to date (Mohr, 1974). The precision of the survey lines has been improved by the derivation and application of an empirical formula for ground-radiation effects, to be applied to the atmospheric-density correction. This precision is now ±5 to 6 mm. However, under stable atmospheric conditions, the precision may improve to ±3 mm, and, thus, crustal deformation of this magnitude should be detectable.

The new analysis reveals progressive crustal extension in the western sector of the northern network at a rate of 1.0 cm yr^{-1}. This extension acts perpendicular to the rift trend, as expected from geological considerations. The central Ethiopian rift network has suffered progressive deformation at a rate of about 0.5 cm yr^{-1}, again perpendicular to the rift trend. The southern network has not been significantly deformed. The northern network also reveals possible rift-trend zones of no extension and even of compression; the application of a homogeneous strain field, commonly assumed in analyses of geodimeter surveys of the San Andreas fault region, California, appears unjustifiable for a grid-faulted rift valley.

The deformation rates obtained from the Ethiopian geodimeter surveys are not inconsistent with estimates Mohr has made from measurements of the magnitude of rift faulting and from radiometric ages of the rocks cut by the faulting (Mohr, 1973). Mohr concludes that the rate of crustal extension at the African rift plate boundary has quickened during the Quaternary, and that the zone affected by extension has progressively narrowed to its present 5- to 10-km width within the rift floor.

Working with a survey team from Dartmouth College and the University of Iceland, Mohr has remeasured geodimeter lines across the Eastern active zone of Iceland. Previous surveys revealed an extension rate of 2 cm yr^{-1} for this zone, in precise agreement with plate-tectonic studies of the North Atlantic (Decker et al., 1971). But the 1973 resurvey showed a more complex picture: Sectors that had extended from 1967 to 1970 tended to shorten again between 1970 and 1973. This indicates that rift deformation on a scale of years only is unlikely to match integrated plate-tectonic rates. It is hoped that in this new field, precise geodetic surveys will suggest the manner and cause of plate separation.

3.8 Polar Motion and Earth Rotation

The study of polar motion and earth rotation, RTOP 161-02-02, is concerned with determining the accuracy of mean elements (RTOPs 369-02-03 and 161-05-05) and the preparation of EPSOC data for analysis (see Section 2.1).

By using 8-day averages of Baker-Nunn camera data, the mean inclination of Geos 1 and Geos 2 can be computed with a consistency of 10^{-6}. The EPSOC data for Fiscal Year 1973 are now preprocessed and can be used to determine mean elements. The success in improving the accuracy of mean elements in general and the mean inclination in particular depends on the proper treatment of perturbing effects and on the accuracy of tracking data. Of particular importance now are the effects of photon pressure and body and ocean tides (RTOPs 369-02-03 and 161-05-05). The EPSOC data will be more consistent and of greater accuracy and reliability than any laser data used before. Preliminary orbits are now being computed.

The theoretical model of polar motion by Dr. G. Colombo is progressing. This deterministic model is based on nonlinear coupling between the core and mantle to provide a means for transmitting the excitation energy for the Chandler motion. The effects that earthquakes have on the Chandler motion are currently being investigated, not as a source of excitation energy, but as a source of random changes in the inertia tensor. The spectral characteristic of the Chandler motion excited by core-mantle coupling and perturbed by earthquakes is being compared with the observed spectrum obtained by the maximum-entropy method. The preliminary results are very encouraging.

3.9 Laser Techniques

Under RTOP 161-05-02, the first draft of a detailed description of the techniques used by SAO to compute retroreflector-array transfer functions has been completed by Arnold and will soon be published as an SAO Special Report. The text includes methods to account for cube-corner size, shape, and optical properties, as well as discussions on the influences of interference and diffraction. A copy of the draft was furnished to GSFC for their review and use. Preliminary retroreflector-array transfer functions were calculated for Geos C and Starlette during Fiscal Year 1973. The final transfer functions will be computed as soon as complete spacecraft designs have been provided by the Applied Physics Laboratory and CNES.

Several analyses have been carried out by Arnold and Pearlman in support of the Lageos program. Simulations based on the retroreflector-array transfer functions were used to investigate a number of spacecraft designs and orbital parameters to ensure that Lageos will satisfy program requirements and yet be compatible with projected laser capabilities. Simulations and field experiments were also used to study the ability of the Baker-Nunn camera to track Lageos with a number of different spacecraft and orbital parameters. Tracking with the Baker-Nunn camera will be required for routine orbital maintenance and for laser pointing predictions. The results of the SAO analyses have been furnished to Dr. J. Siry and Mr. R. Spenser of NASA Headquarters and to Mr. J. Randell of NASA/MSFC.

System simulations were performed on models of the SAO laser systems to evaluate specific designs for laser upgrading for Geos C. These simulations indicated that pulse digitizing techniques would reduce bias errors introduced by the present leading edge, fixed-threshold detection techniques to less than 10 cm. These analyses were basic support in the SAO proposal to OTDA for laser upgrading.

In accordance with a plan to achieve increased range accuracy for Geos C measurements, a study of the systematic and random errors of the SAO laser systems in their current configuration has been made by Mr. C. G. Lehr and Pearlman. In their present configuration, the SAO systems determine range from readings of a time-interval counter that is started and stopped at threshold points on the leading edges of the transmitted and received pulses, respectively. Since the counter's resolution (0.1 or 1 nsec) is considerably less than the laser's pulse width (20 to 25 nsec), the counter readings are sensitive to the variations in the size and shape of the returned pulses. A random error of 75 cm is typical; but of greater concern is the systematic error, which is insensitive to statistical averaging. Figure 8 shows how this systematic error varied during a transit of Geos 1 at Arequipa, Peru. The correction for the systematic error is largest near culmination of the satellite, because at this time the signal's amplitude is greatest and consequently the counter's threshold level is relatively farther down the pulse's leading edge. The correction curve of Figure 8 was obtained by measuring oscilloscope photographs of return pulses. Since these photographs capture the amplitude variations within the pulse, they can be used to compute the time between threshold crossing and pulse center. Both the effects of intensity variations from pulse to pulse and the quantal irregularities within pulses are accounted for by this procedure.

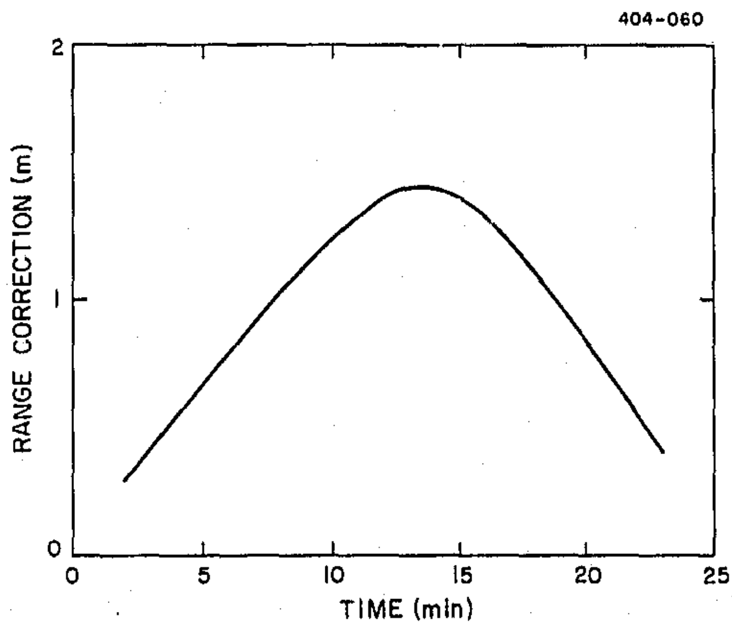

Figure 8. Example of systematic range correction, taken on Geos 1 transit, 9 June 1973 from Arequipa, Peru.

The photographic method is not efficient at a high data rate but is very useful for system analysis on selected transits. Investigations based on pulse photography were used in the development of SAO's plan for laser system upgrading for Geos C. A waveform digitizer, soon to be installed at the Mt. Hopkins observing station, will take data automatically and correct for irregularities in pulse shape and size.

In a program to understand the operation of individual system components and to identify any unsuspected errors, measured and calculated values of the numbers of photoelectrons were compared for return pulses obtained from satellites and fixed reflectors. It was found that the photomultiplier tubes show saturation effects at about 1000 photoelectrons. As part of this investigation, receiver efficiencies were measured by using stellar photometry. The values (expressed as photoelectrons emitted by the photomultiplier tube divided by photons entering the receiver aperture) are listed in Table 10.

Table 10. Receiver efficiency measurements.

Station number	Location	Receiver efficiency (%)
7902	South Africa	1.9
7907	Peru	0.6
7921	Arizona	1.1
7929	Brazil	3.2

3.10 Other RTOPs

Work on analytical models of earth motions, RTOP 161-02-07, will begin in the next few months. Satellite self-tracking by use of altimetry data, RTOP 161-03-07, will be combined with the Geos C sea-surface topography program. Work on the Geos C program is expected to begin during the last part of Fiscal Year 1974, by which time the NASA/Wallops contract for Geos C will have been received by SAO.

4. ATMOSPHERIC RESEARCH

Jacchia's attempts to model the variations in thermospheric composition as observed by mass spectrometers on the OGO 6 and ESRO 4 satellites and to reconcile them with the doppler temperature data from OGO 6 and total densities from satellite drag have scored remarkable success (Jacchia, 1973). Two simple formulas have been found to represent the observed seasonal-latitudinal variations in composition and the diurnal variation of the individual atmospheric constituents at any given location and height. Each of the equations contains a single numerical constant.

Work is in progress to determine with greater accuracy the numerical value of the constants. Also, attempts are being made to find a way to represent the global variations of temperature and composition with geomagnetic activity. In the latter project, a collaboration is envisaged with a group at the Physics Department of Bonn University, West Germany, which is analyzing the ESRO 4 composition data.

A study of the effects of radiation pressure and atmospheric drag on the balloon satellite 1963 30D has been completed (Slowey, 1974). Slowey has found that by using a single value of the reflection parameter, it is possible to model the perturbations due to direct radiation pressure in all the elements. This is contrary to the earlier findings of other workers and is thought to be due primarily to the more accurate treatment given to terrestrial radiation pressure. The reflection parameter was found to change very little from the beginning to the end of the 7-yr lifetime. A very small increase was detected, however, which may be related to a slight change in the character of the surface. Another interesting result was the success achieved in modeling the "anomalous" perturbations that now seem clearly associated with the effect of direct radiation pressure on the aspherical figure of the satellite. These perturbations are quite noticeable in the orbital acceleration and were also clearly detected in the eccentricity. A rotating component of force, transverse to the solar direction, was found to reproduce the effects extremely well. The magnitude of this force was only about 3% of the total force due to direct radiation pressure. It, too, remained essentially constant over the lifetime, although the period of rotation changed considerably.

Terrestrial radiation pressure can make a significant contribution to the total acceleration of satellites at greater heights in the earth's atmosphere. The success attained using the Tiros model of the earth's albedo in the case of 1963 30D led the atmospheric research group to apply the model to the orbits of other high satellites for the determination of atmospheric drag. At the same time, a more precise assessment of the effects of direct radiation pressure on these satellites was made. As a result, a catalog giving more accurate densities from five balloon satellites will be published in the near future. Work has now begun to utilize these results in new studies of the hydrogen and helium concentrations and of the oxygen interface. Much of this, of course, is related to the determination of constants in Jacchia's new model for the seasonal-latitudinal variations of all atmospheric constituents, a project that is just beginning.

Slowey has begun work on the determination of atmospheric rotation from the secular decrease in the inclination of satellite orbits. Most of the necessary programming has been completed, and the first results were being obtained at the end of the reporting period. The initial work uses the periods of orbital decay for four balloon satellites. Results indicate that significant values of the rotation can be achieved from 2 to 3 months of data in these cases. The values obtained apply to heights where few other data are available, and these values are quite important to an understanding of the rotation. If the method is successful, it is planned to use six or seven ordinary satellites in lower orbits to obtain mean values of the rotation.

Normally, work would have continued on the determination of atmospheric densities from the drag on six or seven artificial satellites with perigee heights ranging from 130 to 800 km. However, funding restraints, particularly in the areas of personnel and computing time, greatly impeded this study during the reporting period. It is hoped that we can find a way to sustain the density determinations on a reasonably up-to-date basis. Assuming that this can be accomplished, the upper atmospheric research group would like to perform correlative studies by using extreme-ultraviolet data from the Atmospheric Explorer satellite and global density data from drag on a variety of satellites at different heights and under different conditions.

5. REFERENCES

ARMY-AIR FORCE

1942. Preliminary cloud cover map of the world. Spec. Series 1, Head, Army-Air Force Director of Weather.

DECKER, R. W., EINARSSON, PÁLL, and MOHR, P. A.

1971. Rifting in Iceland: New geodetic evidence. Science, vol. 173, pp. 530-533.

GAPOSCHKIN, E. M., editor

1973. 1973 Smithsonian Standard Earth (III). Smithsonian Astrophys. Obs. Spec. Rep. No. 353.

JACCHIA, L. G.

1973. Variations in thermospheric composition: A model based on mass-spectrometer and satellite-drag data. Smithsonian Astrophys. Obs. Spec. Rep. No. 354.

KOZAI, Y.

1973. A new method to compute lunisolar perturbations in satellite motions. Smithsonian Astrophys. Obs. Spec. Rep. No. 349.

KRAVTSOVA, L. M.

1972. World Surface Cloudiness Climatic Maps for January and July IGY Period. Moscow Hydrometeorological Service (provided through Natl. Climatic Center, Ashville, N. C.).

LANDSBERG, H. E., LIPPMAN, H., PAFFEN, K. H., and TROLL, C.

1965. World Maps of Climatology. Springer-Verlag, New York.

McELHINNY, W. W.

1973. Earth sciences and the Australian continent. Nature, vol. 246, pp. 264-268.

MOHR, P. A.

1973. Crustal deformation rate and the evolution of the Ethiopian rift. In Implications of Continental Drift to the Earth Sciences, ed. by D. H. Tarling and S. K. Runcorn, Academic Press, London, pp. 767-776.

MOHR, P. A.

1974. 1973 Ethiopian-rift geodimeter survey. Smithsonian Astrophys. Obs. Spec. Rep. No. 358.

MORGAN, P., and MILLER, L.

1973. The national mapping lunar laser programme. Presented at the International Geophysical Union, Sydney, Australia, December.

SLOWEY, J.

1974. Radiation-pressure and air-drag effects on the orbit of the balloon satellite 1963 30D. Smithsonian Astrophys. Obs. Spec. Rep. No. 356.