A STUDY PROGRAM FOR GEODETIC SATELLITE APPLICATIONS

Final Report

Grant NGR 09-015-002

Principal Investigator

Dr. Michael R. Pearlman

October 1972

Prepared for

National Aeronautics and Space Administration

Washington, D. C. 20546

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

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A STUDY PROGRAM FOR GEODETIC SATELLITE APPLICATIONS

Final Report

1. INTRODUCTION

The Smithsonian Astrophysical Observatory (SAO) was awarded supplement 35 to grant NGR 09-015-002 for the period 1 February to 31 October 1971 for a study program in geodetic satellite applications. The work, under the auspices of the Office of Geodetic Satellites, was in support of such program as GEOS-C and the National Geodetic Satellite Program (NGSP) and in support of the development of an Earth Physics Program. The grant was extended through 30 June 1972 by supplements 38 and 42, primarily owing to the delay in the GEOS-C schedule and to the work still required to complete the plan for the Earth and Ocean Physics Applications Program. The work statement appears as Appendix 1.

During the period of performance, the Principal Investigator, Dr. Michael Pearlman of SAO, worked at NASA Headquarters with the acting Geodetic Satellites Program Managers, Mr. Jerome Rosenberg (February 1971 to March 1972) and Mr. Benjamin Milwitzky (March to June 1972). The facilities and personnel of SAO provided such support as Dr. Pearlman required.

2. PROJECT PARTICIPATION

2.1 GEOS-C

Background. In FY 1969, Congress authorized the GEOS-C project. The third in a series of specialized satellites for geometric and gravimetric geodesy, it was intended to be the final satellite for the NGSP, and its low-inclination (22°) orbit was selected to fill a gap in the array of existing laser retroreflector satellites. It was to be launched sometime between 1971 and 1973. The initial objectives of the project were the following:

1) To support the acquisition of the data required to complete the objectives of the NGSP (highest priority).

2) To demonstrate the feasibility of using a satellite radar altimeter to measure the geometry of the ocean surface and then to acquire altimeter observations for applications in geodesy and oceanography (if possible).

3) To demonstrate the capability of satellite-to-satellite tracking (SST) for geodetic and gravimetric applications.

4) To support intercomparison experiments with the altimeter, satellite-to-satellite tracking, lasers, Unified S-Band (USB), C-band radars, GRARR, doppler, and flashing lights for evaluation as future geodetic tools.

In December 1970, GEOS-C was deleted from the FY 1972 NASA budget submission for fiscal reasons of the agency but with the understanding that it was being deferred, not canceled. The decision was made to complete the NGSP without an additional satellite.

Description of Activity. In February 1971, the DOD and DOC (NOAA) approached NASA with specific requirements for a GEOS-C satellite and requested that NASA reconsider the launch. When grant supplement 35 was awarded to SAO in January, the Office of Geodetic Satellites had already begun to orient the project more toward earth and ocean physics, which had higher priority than did geodesy and which was very desirable from the point of view of the other agencies. With significant modification, the project was approved by NASA headquarters in July 1971. Since then, additional important modifications have been made to the project and to the spacecraft design.

During the period of performance, we worked with the Office of Geodetic Satellites to restructure the mission. Some of the key items are listed below:

1) Highest priority was given to the satellite altimeter, in recognition of the fact that it would be an indispensable tool in earth and ocean physics investigations of the future and that GEOS-C would offer a critical testbed for this system. With the cooperation and support of NOAA and DOD, the capability of the radar altimeter was improved with the addition of a high-resolution mode that will permit measurements of immediate interest to the oceanographic community. These measurements include topographic and sea-state features to a resolution of several decimeters.

2) High priority was given to the satellite-to-satellite tracking experiment with ATS-F in the recognition that precision long-arc tracking would be required to support altimetry for both solid-earth and oceanographic investigations.

3) The orbital inclination was increased to 65°. With the relaxation of the original NGSP requirement, this new inclination was selected as a compromise between a high inclination, which is required for global coverage, and an intermediate-to-low inclination, which reduces problems of tracking coverage. The new inclination was also selected to fill for gravimetry purposes the inclination gap among existing retroreflector satellites.

4) The design of the retroreflector array was modified to support laser ranging of decimeter accuracy. The array is now symmetrically placed around the yaw axis to permit an accurate extrapolation of range measurements to the spacecraft center of mass.

5) The flashing lights were given lowest priority; they were subsequently deleted owing to weight constraints on the spacecraft.

6) The memory was deleted because of budgetary constraints.

7) The launch date was delayed until July 1974 owing to scheduling and program constraints.

8) The functions of the SST were included with the USB, and the GRARR system was deleted for instrumentation and operational simplicity.

During this period, we worked with NASA Headquarters, Wallops Station, GSFC, NOAA, and DOD to formulate mission parameters and design goals. This coordination was undertaken to ensure that the GEOS-C mission would satisfy as much as possible the program requirements of NASA as well as the individual needs of the other agencies and that optimum utilization would be made of available resources. We assisted in the writing of project-related documents such as the Project Summary Document, the Project Plan, and the Support Instrumentation Requirements Document. We worked with Wallops Station, GSFC, and the Applied Physics Laboratory (APL) during the formulation of mission and system specifications and during the planning and design phases of the mission, and we reported on the project status to the Associate Administrator at the monthly reviews. We kept the international geodetic community abreast of the GEOS-C status at meetings of COSPAR and the IUGG and explored avenues of possible cooperation. A proposal has already been submitted by the French for data analysis.

A paper on GEOS-C presented at IUGG (1971) appears as Appendix 2. Additional details of discussions pertaining to GEOS-C are included in the trip reports in Appendix 3.

2.2 NGSP

Background. The NGSP is a joint NASA/DOD/DOC program to acquire and analyze geodetic satellite data. Its objectives are to develop (1) a worldwide geodetic reference system consisting of a global network of precisely located stations (±10 m) and (2) a detailed description of the earth's gravity field. The program was initiated in 1964 and has since involved numerous international participants who have played an active role (among them, France, USSR, Greece, Japan, and Australia); others have allowed the US to operate tracking stations on their soil.

NASA manages the NGSP and will publish a final document when the program is completed in FY 1974. This document will contain the latest geodetic and gravimetric solutions produced by NASA, NOAA, SAO, and Ohio State University and present the results of systems intercomparison tests and some additional geophysical results derived from satellite geodetic data.

Description of Activity. As of June 1972, all data to be used in the NGSP final solutions had been acquired, and each participant was performing his own analyses. We worked with the Office of Geodetic Satellites of NASA to facilitate the exchange and distribution of the BC-4 camera data and to coordinate the work being performed by each of the investigators. We assisted the Geodetic Satellites Program Office to develop a format and schedule for the NGSP final document acceptable to all participants and to initiate plans to have the document edited by the AGU.

2.3 EOPAP

Background. For several years, NASA has been supporting earth physics investigations at a low level under SR&T. These investigations have relied to a great extent on techniques that were developed under the Geodetic Satellites Program, and the SR&T line item was intended to help sponsor the development of a basis and a plan for an Earth Physics Program.

Description of Activity. During the period of performance, we worked with NASA Headquarters, GSFC, Wallops Station, JPL, SAO, NOAA, and other participants to prepare a plan for an Earth and Ocean Physics Applications Program (EOPAP) as a candidate for a new start in FY 1974. The EOPAP plan is now under consideration by NASA management. We assisted in the initial planning and structuring of EOPAP and its program document and in the development of the rationale and the implementation plan required to make it a viable program. We helped to coordinate the work of each of the contributors to ensure an integrated plan, and we worked with individuals from NOAA and the U. S. Geological Survey to ensure that EOPAP would fulfill the specific requirements of their agencies.

EOPAP as now structured would support investigations of the nature of solid-earth and ocean dynamics as they pertain to specific applications such as the following: earthquake hazard assessment and alleviation; the search and management of mineral resources; and problems in ocean pollution, climate, ocean-resources management, ocean navigation, and transient ocean phenomena such as storm surges and tsunamis. The principal tools of the program include the following: laser ranging to satellites, satellite altimetry, satellite-to-satellite tracking, and very long-baseline interferometry (VLBI), all of which were developed initially under the auspices of the Geodetic Satellites Program or are currently under development in the GEOS-C Project. A summary of the Program Plan is included in Appendix 4.

2.4 TIMATION III

Background. The U.S. Navy plans to launch a high-orbiting (14,000 km) gravity-gradient stabilized navigation satellite, TIMATION III, by the middle of FY 1974. This satellite, if equipped with laser retroreflectors, would provide an ideal tool with which to begin measuring dynamic properties of the earth, such as polar motion, tectonic-plate motion, and earth rotation (UT1). Measurements of this type are the critical bases of EOPAP.

Description of Activity. We worked with the Naval Research Laboratory and GSFC on plans to include a NASA-furnished laser retroreflector array on TIMATION III. The facility would support earth-dynamics measurements of interest to NASA and assist the Navy by providing an independent tracking technique with which to test a new satellite navigation system. Several retroreflector configurations were proposed and evaluated. NASA has allotted funds to procure the array. The Navy's final approval of this joint venture is anticipated sometime this fall.

3. INTERNATIONAL COOPERATION

3.1 ISAGEX

Background. During the period January to August 1971, CNES of France organized and coordinated the International Satellite Geodesy Experiment (ISAGEX). The experiment was the first geodetic satellite experiment to place highest priority on laser data and was centered around the launch of the French satellite PEOLE into an orbit of 14° inclination. From the standpoint of dynamical geodesy with lasers, the major participants were GSFC, SAO, and CNES.

Geometric geodesy with cameras was given second priority, and the USSR was among the major participants in this activity. Other participants included Greece, Japan, Czechoslovakia, and Poland, as well as a few minor ones.

Description of Activity. We assisted the Program Office in coordinating the NASA participation in ISAGEX. We worked with GSFC at the ISAGEX committee meetings at COSPAR (1971, 1972) and IUGG (1971) in discussions involving scientific analysis, data handling and distribution, schedules, publications, and future programs. Details are included in the trip reports in Appendix 3.

3.2 Information Exchange

Many countries throughout the world are actively participating in international geodesy programs. Up-to-date information on the geodesy-related activities in each of these countries is important from the standpoint of NASA's future planning, and access by these countries to information on NASA programs is crucial for effective international cooperation.

During the tenure of the contract, we attended the meetings already noted and visited CNES in France, the Zvenigorod Observatory in the USSR, and the Ondřejov Observatory and the Faculty for Nuclear and Physical Engineering (Technical University) in Czechoslovakia. Details are included in the trip reports in Appendix 3.

APPENDIX 1

STATEMENT OF WORK

STATEMENT OF WORK

During the period of performance, the following work will be undertaken:

A. We will continue to refine the objectives of the Geos C program with the realization that Geos C must represent a smooth transition between the on-going NGSP and the emerging Earth-Physics Program and that the Geos C program must be cognizant of the requirements of the other NGSP members: the DOD and the DOC. In addition, these objectives must be compatible with the appropriate state of the art and with the time and financial resources available.

B. We will continue to define and evaluate parameters for the Geos C satellite and its associated systems. This will be carried out to ensure that the satellite characteristics are compatible with the mission objectives and to make certain that the mission hardware is physically realized within the time and financial constraints imposed on the program.

C. We will define the NGSP and Geos C requirements to be placed on the Office of Tracking and Data Aquisition. This will be carried out to ensure that appropriate data are acquired to support the scientific objectives of the NGSP and the Geos C satellite program.

D. We will define and evaluate the data-analysis plans for the Geos C mission. This will be carried out to ensure that appropriate and timely preparations are made for the data analysis in the Geos C program.

E. We will further define the scientific program for analysis of the data obtained during ISAGEX. The results from this experiment will contribute significantly to the NGSP results and will generate important input to the Geos C program. Included in this analysis should be an improved gravity field and an improved set of station coordinates. The tracking data collected during the ISAGEX campaign, centered on the low-inclination PEOLE satellite, are a valuable contribution in the refinement of the low-order, low-degree harmonics of the gravity field. In fact, this campaign has allowed NASA to relax the original low-inclination geodetic requirement on Geos C and has permitted the restructuring of the Geos C program around the Earth-Physics requirements.

F. We will continue to define and evaluate geodetic satellite programs to occupy the period between ISAGEX and the Geos C launch. We have already defined a 14-month, low-level, interim tracking campaign, EPSOC, which will provide long-term continuous coverage for the observation of geophysical phenomena such as polar motion and earth tides. In addition, EPSOC will directly support the Geos C program by providing a refinement in the gravity field and in station locations. The geodetic satellite programs during this period may emphasize improvement of present observational techniques and analytic tools in preparation for the Geos C program.

G. We will continue to explore avenues of international cooperation in the Geos C and other NGSP satellite programs. Contact has already been made with groups in France, Japan, Switzerland, West Germany, Finland, Czechoslovakia, and the Soviet Union. All are interested in participating in Geos C and other tracking campaigns. Each has lasers in operation now or plans to have them in time for the Geos C program.

H. We will continue to work with GSFC to refine the present Earth and Ocean Dynamics Satellite Program and to assist in assembling it into a viable Earth-Physics Program for NASA.

APPENDIX 2

GEOS-C SUMMARY DESCRIPTION

GEOS-C

Summary Description

The [redacted] GEOS-C Program has been restructured to increase the emphasis on the radar altimeter and the satellite-to-satellite tracking. These experiments have particular significance at this time, as it is anticipated that measurements of these type will form the basis of future satellite Earth and Ocean Dynamics Studies Programs.

Mission Objectives

The spacecraft will carry the first true altimeter system which will be capable of mapping the ocean surface height on a synoptic basis to an accuracy of 2-5 meters. With this information, significant improvements can be made in the determination of the intermediate and short-scale terms in the geoid over the ocean regions of the earth. The GEOS-C altimeter data will also be used to investigate ocean surface features such as; tides, surface waves, ridges, and trenches; and to determine sea slope over as much of the oceans as is feasible.

GEOS-C will be provided with a satellite-to-satellite tracking link with ATS-F. This system will be used to perform long arc tracking of GEOS-C in order to evaluate the technique as a means for precision orbit determination, and to secure adequate tracking over regions such as the mid-oceans, which are remote from ground tracking coverage. The data will also be used to refine existing gravity field models and to seek evidence of gravity field anomalies and mass concentrations.

The GEOS-C satellite will also be equipped with the more "conventional" tracking systems which will be used to furnish ground truth and verification for the principal experiments and perform systems intercomparison among all candidate tracking techniques for future missions. In addition, the mission will furnish a spaceborne coherent C-band transponder for the calibration of ground station radar systems. It is expected that an inclination can be chosen to support the acquisition of data to augment the gravimetric results of the National Geodetic Satellite Program (NGSP).

The experiments to go aboard GEOS-C have been discussed in detail by Dr. F. Vonbun[1] of Goddard Space Flight Center and H. R. Stanley and N. A. Roy of Wallops Station.[2]

Mission Description

GEOS-C will be built from the backup structure of GEOS-2 and will be launched in the second half of 1973. The instrumentation aboard GEOS-C will include; a radar altimeter, C-band transponder, Goddard Range and Range Rate (GRARR) transponder, GEOS GRARR/ATS-F relay transmitter amplifier, laser retroreflector array, 162/324 MHz radio Doppler beacon, Manned Space Flight Network (MSFN) USB transponder, and probably flashing optical beacons.

The tentative orbital parameters for the mission are; an inclination of 40-70°, an eccentricity of .01, and a mean altitude of about 700 km. The specific inclination will be selected to insure a reasonable coverage for the altimeter and the C-band and USB transponders. The eccentricity and altitude were selected to be consistent with reasonable altimeter specifications from the standpoint of system range tracking capability and adequate signal return. The spacecraft will be stabilized to 1.3° and will weigh approximately 525 pounds.

Principal Mission Experiments

Altimeter: The radar altimeter as envisioned will have an instrumental accuracy of about 2 meters and, with present orbital tracking capabilities, will be able to map ocean surface features to between 2 and 5 meters, depending upon the region of interest and the tracking coverage. The altimeter will have an operating frequency of 13.6 GHz, a pulse repetition rate of 1,000 per sec, an integration time of .5 seconds, and an antenna beam width of about 2.6°. The altimeter will have a synoptic mode with a pulse width in the neighborhood of 100-300 nsec which would be capable of taking one full orbit of data at a time, storing the data, and transmitting them back to earth when the spacecraft next passes an appropriate STADAN site. The system will have a footprint of about 10 km. Power constraints will limit the use of the altimeter to one or two of these full orbit cycles or the equivalent (time) per day. It is planned to turn the instrument off over land. We are also considering adding a high resolution mode which, using techniques of pulse compression, would give a system resolution of about 50 cm.

Satellite-to-Satellite Tracking: The satellite-to-satellite tracking system between GEOS-C and ATS-F will use the S-band GRARR transponder, a special relay amplifier, and an upward viewing antenna system aboard GEOS-C. The mode of operation is to transmit a signal from the ATS ground station to ATS; then, have it coherently changed in frequency and transmitted to GEOS-C where it would be received and returned back along the same path. The measurements will be those of total range and range rate along the two-satellite path. The use of other tracking systems and the diverse nature of the two orbits will permit the two orbital contributions to be isolated. The system aboard GEOS-C will have a tracking accuracy of better than 1.0mm/sec for integration times of 10 to 50 seconds.

Project Management

The GEOS-C Project will be managed from the NASA field center at Wallops Station. The Wallops Station will also provide the altimeter investigator and act as the focal point for the C-band radar calibration mission. Goddard Space Flight Center will provide the subsystem management for the satellite-to-satellite and other tracking experiments. The Applied Physics Laboratory will build the spacecraft and assemble the experimental payload.

References

[1] Vonbun, F. O., Geodetic Satellite Mission and Spacecraft (GEOS-C), presented at the XIII Plenary Meeting of COSPAR, at Leningrad, May 1970.

[2] Stanley, H. R., Roy, N. A., Global Geoid Mapping Using Satellite Altimetry, presented at the Third International Symposium on the Use of Artificial Satellites for Geodesy, Washington, D. C., April 1971.

NASA-HQ

APPENDIX 3

TRIP REPORTS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO ATTN OF: SC(ERP:dmn)

July 13, 1971

MEMORANDUM

TO: SC/Director, Communications Programs

FROM: SAO/Visiting Scientist, Geodetic Satellites

SUBJECT: Highlights of COSPAR Meeting

I attended the COSPAR Meeting in Seattle during the period June 23 to June 29. I was concerned primarily with the sessions and business meetings of Working Group I on Tracking, Telemetry and Dynamics.

Open Sessions

The open sessions of Working Group I dealt primarily with Lunar Ranging Instrumentation. It had been previously agreed that data analysis would be deferred for the IUGG in Moscow, whereas, operational details would be discussed in Seattle. Each of the active groups in the area presented a status report on their laser systems.

Dr. D. Eckhardt from AFCRL described their system on Mt. Lemmon in Arizona. Although they had received a number of returns from the Apollo 11 retro-reflector array, they had focussing difficulty with the 60-inch metal primary that they were using in their telescope. They are now making preparations to install a cervit mirror and hope to be back on the air sometime in early 1972.

The Japanese described a system that members of the Tokyo Astronomical Observatory and the Hitachi Company built from components supplied by Hitachi. The system was located at Okayama Observatory of the Tokyo Astronomical Observatory. After considerable instrumental difficulties they got some confirmed returns on the Apollo 11 array, but the instrumentation had to be returned and the operation is presently at a standstill. They are planning to build a dedicated system for lunar ranging, but operation of this system is at least 1 or 2 years off. Dr. Kozai gave a brief summary of their data collection and evaluation.

C. Lehr of the Smithsonian Astrophysical Observatory (SAO) described their system which should be in operation by the fall. The interesting point here is that their ranging system* does not require a large telescope to collimate the transmitted laser beam. They are using a Nd^+ glass laser instead of the ruby lasers that others have been using. Their laser is nearly diffraction limited and 8-inch optics are sufficient to get down to the atmospheric limit. They still require a large collector, but their transmitter can be co-located with any available large telescope.

Dr. Kokurin from the Soviet Union described in detail their system which is located in the Crimea. They have received a fair number of returns from the French retro-array which is located on the Russian "Lunokhod I."

Dr. Rösch from the French Observatory at Pic du Midi described the system that they used to get returns from the "Lunokhod I" array. They also report returns from the Apollo 11 array. He also discussed modifications that they intend to put in their system. Of particular interest here is a program to build a large, effective receiver from an array of smaller collectors. They will use fiber optics to collect the individual light contributions.

Dr. Silverberg described the McDonald Observatory system in detail. They appear to have accuracies in the decimeter range using a cavity dumped ruby laser. They have had over 150 acquisitions; each acquisition is a 50 shot sequence during which they got lunar returns. They average about ten returns during this sequence. They have been able to acquire the Apollo reflectors but not the one on "Lunokhod I."

The interesting point here is that only the French have reported success in acquiring both the U. S. and the French/Russian arrays. The problem is partially one of confusion in coordinates; some discussions were held during the COSPAR meeting to try to iron this difficulty out.

Several groups gave papers on the technical details of corner cubes and retroreflector arrays. Dr. Faller from Wesleyan University (he is a member of University of Maryland investigating team) discussed the characteristics and performance of the Apollo 14 and 15 corner cube arrays. The array to go on Apollo 15 will be three times larger than those flown on previous missions. They have also contoured the well in which each corner cube sits in order to increase returns for off normal incidence.

Faller also discussed a multi-element collector that they are building for a future, more elaborate lunar ranging system. He also philosophized on the future of lunar ranging and the importance of a large cooperative effort.

3.

Dr. Chang from Maryland presented analyses and experimental data on the properties of corner cubes. He dealt mainly with those that had been placed on the moon by the Apollo flights. He also discussed possible modifications such as back-silvering and changes in dimensions that could increase signal returns.

Dr. Fournet from France described the French/Russian retroreflector array that is on Lunokhod 1.

In summary, the U. S. corner cubes have round faces and are totally internal reflecting (unsilvered). They are recessed into their support housing. This design was chosen to minimize thermal degradation and to enable the facility to be used during both lunar day and night. The array consists of 100 (300 on Apollo 15) cubes. In the French/Russian array the corner cubes are triangular, silvered on the back, and mounted flush with the top of their housing. Their system cannot be used during lunar day because of thermal degradation, but they require far fewer corner cubes for a return comparable to that from the U. S. array.

Dr. Currie from the University of Maryland related future plans of the Maryland/McDonald group to build a second installation in Hawaii. He intends to use a mode locked laser, probably ruby, to get down to centimeter accuracies. He also discussed some ideas to refine system calibration to a level consistent with these new lasers.

At the same session, Michelini from the Smithsonian described preliminary VLBI results that they had from L-band observations of ATS-5 in 1970. They were able to get fringes and make rough determinations of satellite-baseline geometry. Dr. Ramasastry discussed briefly the ATS-1 and 3 VLBI experiment that GSFC and SAO had just completed. The data analysis is now underway.

The third session of Working Group I dealth with refraction errors in satellite tracking. Several talks were given each on the ionosphere and atmosphere effects. One of the more interesting of the talks was given by Dr. Hoppfield* of APL, whose analyses now show that optical refractive corrections for range measurements near zenith can be made to better than a centimeter using ground based meteorological data.

Business Meeting

An open business meeting was held in an attempt to foster a working relationship between separate groups doing lunar ranging. The session was chaired by Dr. Alley of the University of Maryland.

Dr. Alley discussed the endorsement that he has received from the IAU and COSPAR for an international program of cooperation and data sharing. Interest has been expressed by essentially all of the groups involved in lunar ranging. Dr. Alley expects that the IUGG will adopt a resolution in support of his program of cooperation this August in Moscow.

The working group reviewed the progress of lunar ranging summarizing the efforts and accomplishments of each of the participating groups. Dr. Mulholland of the University of Texas presented a draft of standards to be used for documentation of lunar ranging data. A number of comments were forthcoming from the audience, and Dr. Mulholland will revise his draft incorporating the comments.

A second open business meeting covered the ISAGEX campaign (earlier closed meetings were held at COSPAR on this topic, but these were preliminary in nature, and I was not permitted to attend). GSFC reported that they had shot 500 passes with their 2 lasers since January. Their systems appeared to have a noise level of about 50 cm. They have detected a significant error (250 meters) in the position of Guam. More complete data analyses will be required to finalize these new coordinates. GSFC had some difficulty in fitting data of other organizations in with their own; this shift in the coordinates of Guam may well be the reason.

The group at CNES reported that they had shot 300 passes with their three lasers. They are extending the ISAGEX campaign two more months into the summer to make up for the poor start in January and February. Timing and station location problems that had been found in the French data were discussed.

SAO reported that it had data from about 750 passes with its 5 laser systems. From preliminary analysis, they thought that their data looked good. They had a noise level of about 50 cm. They discussed some difficulties that they had in predictions for some of the satellites, mainly PEOLE, which is subjected to considerable air drag because of its low altitude. SAO had the responsibility of providing predictions for some of the participating organizations.

The principal investigators for ISAGEX from the Astronomical Council of the Academy of Sciences of the USSR did not attend the COSPAR meeting and sent Dr. Kukuran as a representative. He was not well informed about the status of the Soviet data collection with their camera network, and could not report. The French announced that they were aware of at least 150 AFU 75 photographs that were taken during the first few months of the campaign. The lack of information and the absence of their personnel meant that discussions on data distribution which were slated to be held at COSPAR had to be delayed until IUGG in Moscow.

Some tentative guidelines were established, however. All laser data would be submitted to the Data Bank at CNES by January 1, 1972, and all camera data for simultaneous observations would be submitted by January 1, 1973. Only the principal investigators would be entitled to the data, and then only in their field of investigation. This meant that GSFC, SAO, and CNES would obtain all of the data since they are investigators in Dynamical Geodesy and the Russians who are investigators in Geometric Geodesy would receive only the simultaneous observations (cameras and lasers). Special requests for data from other groups would be handled on an individual basis. It is intended to complete ISAGEX by about January 1, 1974, and then release all data. The problem here is that the Russians expect some data with which to begin a program in Dynamical Geodesy, and the other investigators are quite leary about giving up even just their simultaneous laser data before seeing some of the Russian data (with the help of Dave Williamson we are formulating a position to be conveyed to CNES, the organizers of the campaign, before the IUGG meeting.)

SAO announced that it will be undertaking a low key tracking campaign with their lasers and cameras during the next year in order to study phenomena such as; polar motion and earth tides, and to refine station coordinates and the earth's gravity field. They invite other groups to join and have offered to act as the central organizing agency. They passed out a short document outlining their plans for such a program. GSFC and CNES expressed their interest and their intention to join the campaign. Kozai stated that the Japanese would have a satellite tracking laser in operation by the end of the summer and would like to join in also. The campaign will give new camera and laser stations in Switzerland, Japan, Germany and other countries a chance to determine their coordinates in the world geodetic reference system. It is anticipated that some geometric geodesy will also be done during this campaign.

The French announced that an AFU 75 camera is going to be in operation in French Guiana and will be operated by a French crew.

The open business meeting also addressed the reorganization of Working Group I. Kovalevsky (France) the Chairman of the Working Group proposed a schema by which Working Group I would be reduced in size from its present fifty or so members. The panels would exist with some reorganization, but only chairman, co-chairman and a small number of members would be members of the Working Group. The argument here was that a smaller group could act more effectively.

6.

There was a ground-swell of opposition and a second revised schema was adopted. All members of the panels would be included in Working Group I. Each panel would be temporary in nature. Each is intended to handle special problems and can be dissolved (or established) by Working Group I. A steering committee consisting of the Working Group Chairman and Co-Chairman, the panel chairman and co-chairman, and a small number of members would help facilitate working group activities. The exact role of this steering committee is not clearly defined. The new proposed panels and their proposed chairmen and co-chairmen are:

1a. Tracking Instrumentation and Procedures

Weiffenbach	(USA)
LaPushka	(USSR)

1b. Frequency Allocation and Radio Transmissions

Rawer	(FRG)
Kreplin	(USA)

1c. Satellite Geodesy and Geodynamics

1d. Lunar Laser Randing

Alley	(USA)
Kokurin	(USSR)

Kovalevsky will act as temporary chairman of panel 1c for at least a year. At that time a chairman and co-chairman will be chosen. Other members of the steering committee include: Kozai (Japan), Massevitch (USSR), Veis (Greece), Vonbun (USA). This schema for proposed reorganization will be submitted to the Executive Board of COSPAR.

Working Group I recommended that COSPAR support international cooperation for a Soviet program in geometric geodesy. The object of this program is to measure large arc terrestrial chords linking the Arctic and Antarctic.

We presented a brief sketch of the tentative GEOS-C program and discussed the possibility of retroreflectors on ATS-F. There was considerable interest on both.

7.

SAO described its proposed Cannonball satellite for an Earth Physics Program. The satellite would be a large solid metal sphere completely covered with laser corner cubes. This configuration would allow precise laser ranging (10 cm. or better) to a satellite with a large enough mass to area ratio that air drag is minimal and orbits can be accurately maintained.

Other topics such as the status of the Central Bureau for Satellite Geodesy, frequency allocation, and the relevancy of astrodynamics were discussed briefly.

MRP

Michael Pearlman

* Funded by NASA

SAO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO ATTN OF: SAO(MRP:vrt)

August 24, 1971

MEMORANDUM FOR THE RECORD

FROM: SAO/Visiting Scientist, Geodetic Satellites
Office of Space Science and Applications

SUBJECT: Trip Report - August 1971

I. France

A. Visit to CNES

George Weiffenbach and I met with Gerald Brachet of CNES for discussions on present operations and future plans in geodesy and earth physics.

1. Missions

In March of 1973 the French will launch two satellites (piggyback) into a 300 x 1,500 km orbit at 20° inclination.

a. D5A will carry an electrostatic accelerometer (concentric spheres) which will have the capability of detecting 10^{-9}g. The accelerometer has already been tested out by rocket flight in Argentina. The data will be available on a cooperative basis in exchange for assistance in tracking. The spacecraft will perform three principal experiments:

Air Density Measurements - the low perigee lends itself to a good air drag experiment with the accelerometer. They are interested in studying the equatorial region.

Geodesy - the spacecraft will carry laser retroreflectors for tracking and geodetic purposes.

Micrometeorites - the accelerometer will be used to look for micrometeorites (actually mini-meteorites).

The satellite will have a variable measurement integration time of 3-20 seconds. A memory aboard the spacecraft will be capable of storing approximately 1,300 measurements.

b. D5B will carry a hydrozine propulsion experiment to test the capability to maneuver a satellite in orbit. The hydrozine system creates too much propulsion for the drag free application.

2. Status of the French Laser Systems

a. Dakar - this system will be shipped to Addis Ababa, Ethiopia to be maintained by an Italian crew. The laser is old, having been built in 1964, and although it has been operational this past year, the French expect considerable instrumentation problems.

b. San Fernando - after ISAGEX, this system will be sent to Britany for modifications, including the addition of a saturable dye cell for pulse narrowing, a better counter (1-.1 nsec) and pulse height digitizing equipment for improved accuracy. In October CNES will meet with the Russians to discuss a loan of this laser system. The loan would be a six-month program with the systems being placed at Ushgorod, probably in January 1972. A Russian crew would operate the equipment with a French manager and possibly technicians overseeing the operation. The data would naturally be available to the Russians.

If this Russian loan does not pan out, CNES is considering a request by Aardom from Holland for a loan under similar conditions. In January CNES will get together with SAO to decide on long term plans for the equipment. It has already been suggested that a low latitude site such as Haiti or Hawaii would be a good site for the 1973-1974 tracking effort (GEOS-C, D5A, etc.).

c. Haux Provence - this system is owned by the Office National Etudes et de Recherches Aerospatiales (ONERA). This is a military organization; CNES must contract them to operate. They have no immediate interest of their own, but Brachet is approaching them to continue operations. The facility also has a larger long-mode laser which has been used to illuminate satellites for photographic purposes. They have not reported any data as far as we know.

3. Change in Organization

CNES and other agencies have been funding several organizations to do geodesy and related astronomical work. These organizations include the Institute de Geographique National, Observertoire de Paris, Bureau des Longitudes and the orbit computation group within CNES itself. In an attempt to streamline the operation, CNES requested that interested groups within these organizations form a single research group. The result has been the formation of the Groupe de Recherches de Geodesie Spatiale (GRGS) from small groups within these larger organizations. Naturally these groups still remain part of their parent organizations. The GRGS is headed by Dr. Kovalevsky from the Bureau de Longitudes. The structure looks like the chart on the following page.

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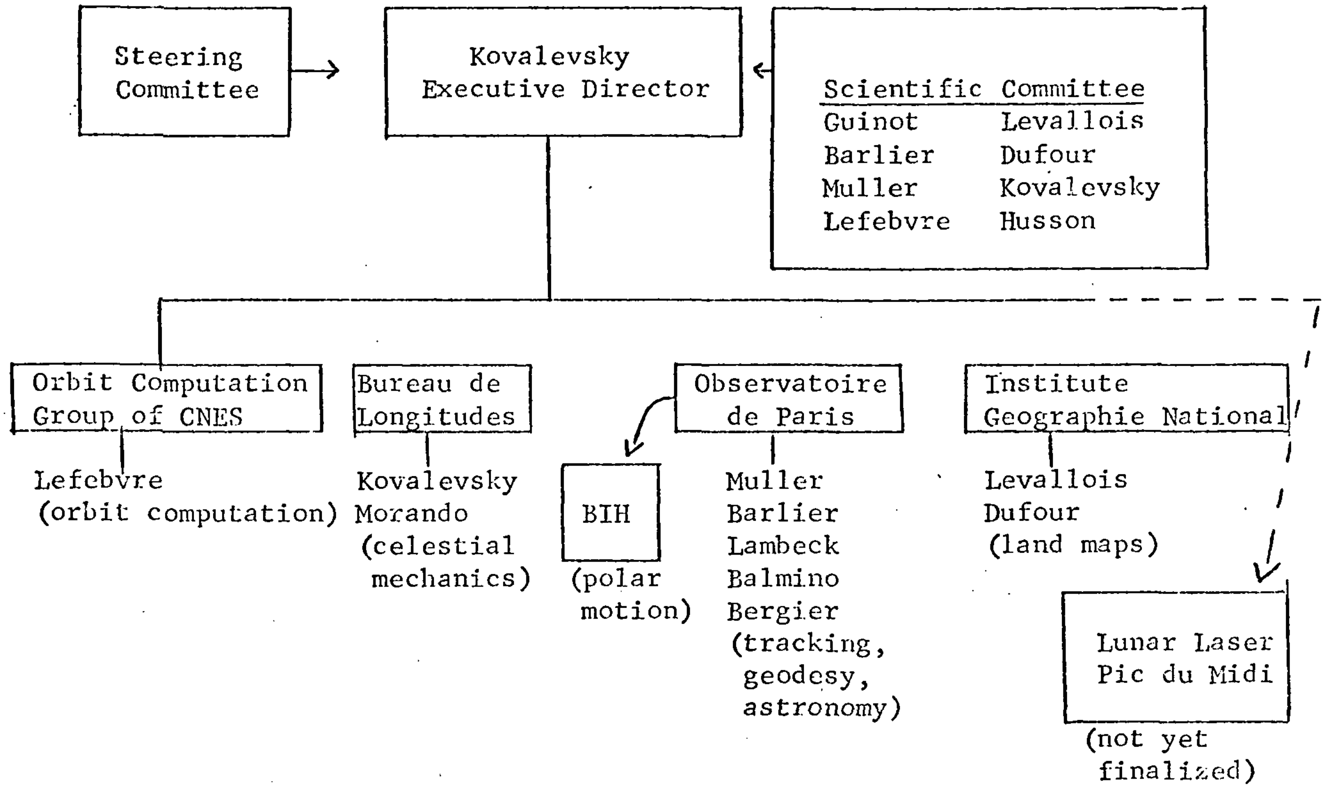

The French are further planning a merger of organizations such as GRGS into a larger: Centre de Etudes Recherche de Geodesie et Astronomie (CERGA). This organization would require two to five years to be set up properly. It appears that the GRGS and many of the pertinent groups at CNES will be relocated to Nice in the South of France at the time or prior to the joining of GRGS into the CERGA.

Within the GRGS group, they have made some informal plans for an Earth Physics Program. They want very much to supplement the program that NASA is going to embark upon and do not want to duplicate our efforts.

CNES has sent out requests for satellite missions which could be launched should a vehicle become available. GRGS has responded with suggested missions which would be of value to an Earth Physics Program, but they remain very flexible and would like to play an integral part in at least a bilateral program with NASA.

4. Additional Tracking System Information

Baker-Nunn from Dakar will be going into Ouagadougou in Upper Volta. Fortunately, from the standpoint of a fixed world reference network, this will be a long term site. The French continue to get interferometer data from PEOLE. They would like to know if NASA can supply Minitrack data on GEOS-2. They could supply data themselves, but with several other satellites being launched this year, their limited facilities would make it very difficult.

An AFU 75 camera is now in the Kerguelen Island in the Indian Ocean. It is operated by a [illegible]ssian crew.

B. Meeting on Laser Systems Improvement

We had a meeting with people at CNES to discuss their plans for future generation laser systems. They now want to go to a system that does not require visual tracking so that it can be used for daytime and unilluminated nightime passes. They are considering two possible alternatives:

1. Build a system with a 20 cm accuracy using Nd^+ glass or ruby. This system would have a 4 joule, 3 nsec pulse and a repetition rate of 1/sec. The beam divergence would be 1 mrad at the laser. They would use a .1 nsec counter and a 1m collecting area. The mount would be a coudé design (stationary laser) with a 10 arcsec tracking capability and would have a computer for tracking purposes. The Nd^+ laser with their specs appears to be very costly and they would probably go to ruby.

2. Go directly to a third generation system with a 2-4 cm capability using a Nd^+ Yag laser. With this system they would have a pulse of less than 400 psec and a repetition rate of 100/sec. Although these lasers are available, they are still state-of-the-art, and it may be impractical to go this route now.

CNES appears to be having some difficulty in satisfying its laser requirements for both of these options and is seriously considering American manufacturers for their transmitter. They are awaiting the outcome of the ATS-F reflector decision to obtain corner cube specs to use as an input for their final decision.

Attendance

Mr. de Lamare, Director adjoint des programmes
Mr. J. C. Husson, Chief de la division des programmes scientifiques
A. W. Stoefner, REIAI, equivalent to our International Affairs Office
A. Goebbels, Section optique division equipment
G. Brachet, Manager of the ISAGEX Program

C. Seminars on On-Going Programs

We presented seminars on the Smithsonian Programs and the GEOS-C Program and were given a presentation on the GEOLE Project by Mr. Thieriet.

The GEOLE satellites will interrogate small, automatic transponders at sites on the ground to get range and range rate information. The system will look at a whole array of ground stations, interrogating them one at a time. CNES envisions a system which could get down to the meter level within a few passes. The satellite will relay the information to ground. This could be used as a traffic management system for ships or planes. The downlink will be operated at 2,000 MHz; the uplink will be 2,000 MHz and 400 MHz in order to make an adequate ionospheric connection. The transponder will be coherent.

A tentative initial flight is slated for early 1975. It would carry no memory and would be purely a test of the instrumentation and software. A more developed system would follow in or about 1977. This project is an outgrowth of the EOLE Project presently underway for tracking meteorological balloons. The satellite in 1975 would have corner cubes.

Operational Notes

- Accuracy: 1 pass - 10 meters
  1 day - 1-2 meters
- Orbit: 3,500 km circular, 60° inclination
- The system will require 5-10 seconds per observation and would make several observations of a given site per pass.

Experiments for 1975

- Intercomparison with laser tracking
- Resolution of 5 station locations in tetrahedral geometry
- Locate both fixed and moving targets

With range and range rate they will be able to get speed and heading for a traffic control system. The specific technology to be utilized in this satellite has not been decided upon.

II. Russia

A. IUGG Meeting

I attended the IAG sessions of the IUGG meeting in Moscow.

1. Satellite Geodesy Section - this section dealt mainly with tracking by cameras. There were sessions that were concerning primarily plate reduction, timing and the star catalogues.

Kovalevsky discussed the ISAGEX results, pointing out that there were over 2,000 laser passes taken. The number of geometric observations were very small and probably will not be very significant. It will no doubt be necessary to continue such observations in order to complete present programs in geometric geodesy. He is confident that the ISAGEX data will give evidence of polar motion, but none has been seen in the data so far.

Mrs. Massevitch gave a description of the Soviet camera systems. She described the AFU 75 and the "new" larger VAU camera. She gave a brief rundown of the Soviet program to connect the arctic and antarctic with large arc observations. Dr. Lefebvre discussed the laser results obtained by the French during ISAGEX.

I gave a description of the newer SAO laser systems and described some of the results from recent experiments. I also gave a briefing on GEOS-C. Dr. Weiffenbach gave a paper on the Cannonball Satellite, which appeared to generate considerable interest.

In the General Assembly, George Veis was chosen as the Chairman of this section for the next term.

2. Lunar Ranging Sessions

In this session Kaula and others discussed the implications of lunar ranging in the study of the earth and the earth-moon system. The items discussed included; polar motion and its possible connection with earthquakes, continental drift, variations in the earth's rotation, the shape of the earth, and the general earth-moon interaction. There was naturally a general conclusion to broaden and expand this type of program. There was a status report on the AFCRL lunar ephemeris program. The McDonald team gave a general status report on the lunar ranging effort being carried by each of the groups and the geophysical results that they would anticipate from a worldwide cooperative program. This was a reiteration and a reemphasis of the international cooperative program that Dr. Alley had proposed previously.

3. Oceanographic Geodesy

There were only a few good papers in this session. The most interesting from our standpoint was one by Von Arx and Harlow on geoid measurements made on the ocean surface in the Pacific. They chose what they considered to be a relative flat region, and still found a tremendous amount of short scale structure. If their results are correct, we can expect a good deal of structure on our satellite altimeter measurements. Von Arx's scheduled paper on an Oceanographic Satellite was not given.

4. Study Group on Laser Ranging

A Study Group on Laser Ranging has been formed under the Section on Satellite Geodesy. Dr. Weiffenbach is the Chairman. This group will concern itself with the dissemination of information about laser systems in use, and will attempt to promote the development and/or purchase of laser systems for satellite tracking by new groups. It will attempt to coordinate tracking efforts of those stations already in use. This study group is taking the immediate responsibility of duplicating and sending out any and all system and operations literature that participating parties can supply.

The first meeting was attended by individuals from many countries, including France, USA, Soviet Union, the Netherlands, Germany, Switzerland and Japan. Others expressed interest, but could not attend.

In addition to the laser systems already in operation by groups in the USA and France, other countries reported having laser programs in progress.

The Swiss reported having their laser system at Zimmerwald in operation. They have already had satellite returns, but are having some difficulty with pointing accuracy and predictions. The Germans announced that their system at Wettzel will be in operation in 1972, and the Japanese announced that their satellite ranging system would be operating within the next year. Information on the Czech laser, which will be operational at the beginning of 1972, had been given to several of the attendees earlier. Representatives from Belgium and Holland stated that programs being initiated in their countries should produce operational laser tracking systems by 1973-4.

B. ISAGEX Meeting

We had an informal meeting on the ISAGEX program. The Seattle document on ISAGEX was found quite acceptable by the Soviets, who were not present at COSPAR. This satisfies the conditions stipulated by Dr. Vonbun in his last telegram to Kovalevski with regard to data handling. This means that all parties appear to agree that the Jan. 1, 1972 and Jan. 1, 1973, are acceptable dates for the deposit of all laser and camera data, respectively, and that the Russians would be principal investigators only in the geometrical geodesy and entitled only to that portion of the data. It was agreed that requests by non-principal investigators would be dealt with by unanimous decision of the ISAGEX Scientific Council and that the Russian request for dynamical data would fall under this category.

Mrs. Massevitch expressed some concern about the tardiness of data exchange in some previous experiments. Her reference was to a French agreement to exchange camera data for a campaign that took place several years ago. The French admitted that they have been late in supplying their data and that the Russians have already kept their part of the agreement.

We suggested that a milestone date sometime in mid-1972 be set, at which time a set portion of the camera data would become available for initial evaluation. It was agreed that by July 1, 1972, the small amount of simultaneous camera data and one-fourth of the total camera data for dynamical observations would be available for analysis. At that milestone, the data would be released. The amendment to the ISAGEX document must be agreed to by NASA's representative, Dr. Vonbun, before it becomes an official amendment to the Seattle document.

C. Discussions on Bilateral Agreement

While at the IUGG meeting, I was approached by Mrs. Massevitch to see if NASA would be interested in bilateral agreements in satellite tracking with the Soviet Academy of Science. She is interested in adding such agreements to the present Bilateral Agreements being ironed out in the field of Space Science. She feels that cooperative tracking campaigns could be put together in a fairly straight forward manner and are the type of thing that could show results in a very short time. This would be in contrast to the more complicated long term programs that are now being discussed. A follow-up memo is to be forwarded to Naugle.

In particular, Mrs. Massevitch is interested in two programs.

1. The first is to have NASA and probably SAO cooperate with

cameras in the large arc program to connect the arctic and antarctic. At present the Soviets are working on one arc through Europe and Africa and would like some help from stations in South Africa and probably Ethiopia and Greece. They would also like to expand the program to include a second arc through the Western Pacific which could include Japan, Australia and any other cameras in the area.

2. The second is the EPSOC campaign that SAO plans. The Soviets will probably have the French laser at Ushgorod and the Czech's should have their system going. In addition, the Eastern Bloc has a considerable number of cameras available. They have already approached SAO for information about this low level tracking campaign.

D. Visit to Zvenogorad

We visited the tracking station at Zvenogorad We were given briefings on the AFU 75 camera, the Zeiss tracking camera, and the VAU camera. We have photographs of all three. The VAU camera was the only one that I was not previously aware of. The mount and camera stand about 20 feet high and should have a capability comparable to the Baker Nunn. They estimate that their system should be able to see some satellites in synchronous orbit (13 mag).

We saw some of the newer Russian photoreduction equipment. It appeared to be at least comparable, if not better, than those machines that we are using.

III. Czechoslovakia

A. Visit to Astronomical Institute

We visited Dr. Sehnal of the Astronomical Institute and his co-workers in Czechoslovakia for general discussions on laser systems for satellite tracking. We gave them a briefing on the Smithsonian Laser System for satellite ranging and they briefed us on the status of their program.

A Laser Ranging System

Sehnal has been chosen as the head of the Eastern Bloc effort in this field. As far as we can see, his group appears to be the only group with enough capability and interest to see this work through.

The laser satellite group is made up of members of the Astronomical Institute such as Sehnal and Lala who are interested primarily in the orbital dynamics and geophysics, and members of the Faculty of Nuclear and Physical Engineering at the Technical High School who are interested in lasers. Workers at the Research Institute of Geodesy are also cooperating. Those present at our discussion were:

Dr. L. Sehnal, Dr. P. Lala, Mr. P. Navara of the Astronomical Institute.

Mr. K. Hamel, Mr. T Daricek, Mr. A. Novotny, Technical High School, (actually Institute of Technology)

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The group, under Mr. Hamel, is very competent in lasers. They have built both ruby and Nd^+ glass lasers and are doing state-of-the-art work in short-pulse mode-locked systems. This group has had to build most of its own components including laser flash lamps. Other groups in Czechoslovakia have been supplying them with ruby rods, but their principal source of Nd^+ glass has been the Schott Company in West Germany.

The Technical High School has supplied a ruby laser for preliminary ranging experiment to clouds and satellites which took place last year. The laser was a 5 joule oscillator-amplifier configuration similar to some built in the USA. They mounted the laser on the Zeiss satellite tracking camera at the Research Institute of Geodesy facility in Ondrejov. Although they had no time interval counter, they did photograph returns from an oscilloscope trace. The preliminary experiment has been published in the Bulletin of the Astronomical Institute of Czechoslovakia.

The Russians will be supplying Sehnal's group with a mount for laser ranging. The mount will be similar to that used in the AFU 75 except that it will not have the sidereal tracking capability. The delivery is slated for November 1971. A group in Poland has built a 10 nsec time interval counter which could be used for this system, but the Czech's await the U. S. response to their request for a 1 nsec instrument. They require an answer soon, as the sale must be completed before December 31, 1971, after which their funds will not be available.

This laser ranging system which should be on the air in Ondrejov, Czechoslovakia by the beginning of 1972 will probably be the prototype of the systems to be used in the Eastern Bloc countries. There is a strong possibility that this laser will eventually be sent to Ulan Bator in Mongolia which would represent an ideal location from the standpoint of global distribution and excellent weather.

The Czech's informed us that they and the other Eastern Bloc countries (including the USSR) would like to increase cooperation with the West in tracking programs. Now that they will have lasers, they feel that more meaningful well balanced international programs can be conducted.

B. Visit to Tracking Stations

We visited the Astronomical Institute's tracking station at Ondrejov to see the AFU 75 camera. We also visited the Institute of Geodesy's site at Ondrejov to see the Zeiss camera. The general specifications of both instruments are in the literature. There is a possibility that the AFU 75 may be moved to Yugoslovia next year. In any event, the Czech's will be running a training session for the Yugoslavs.

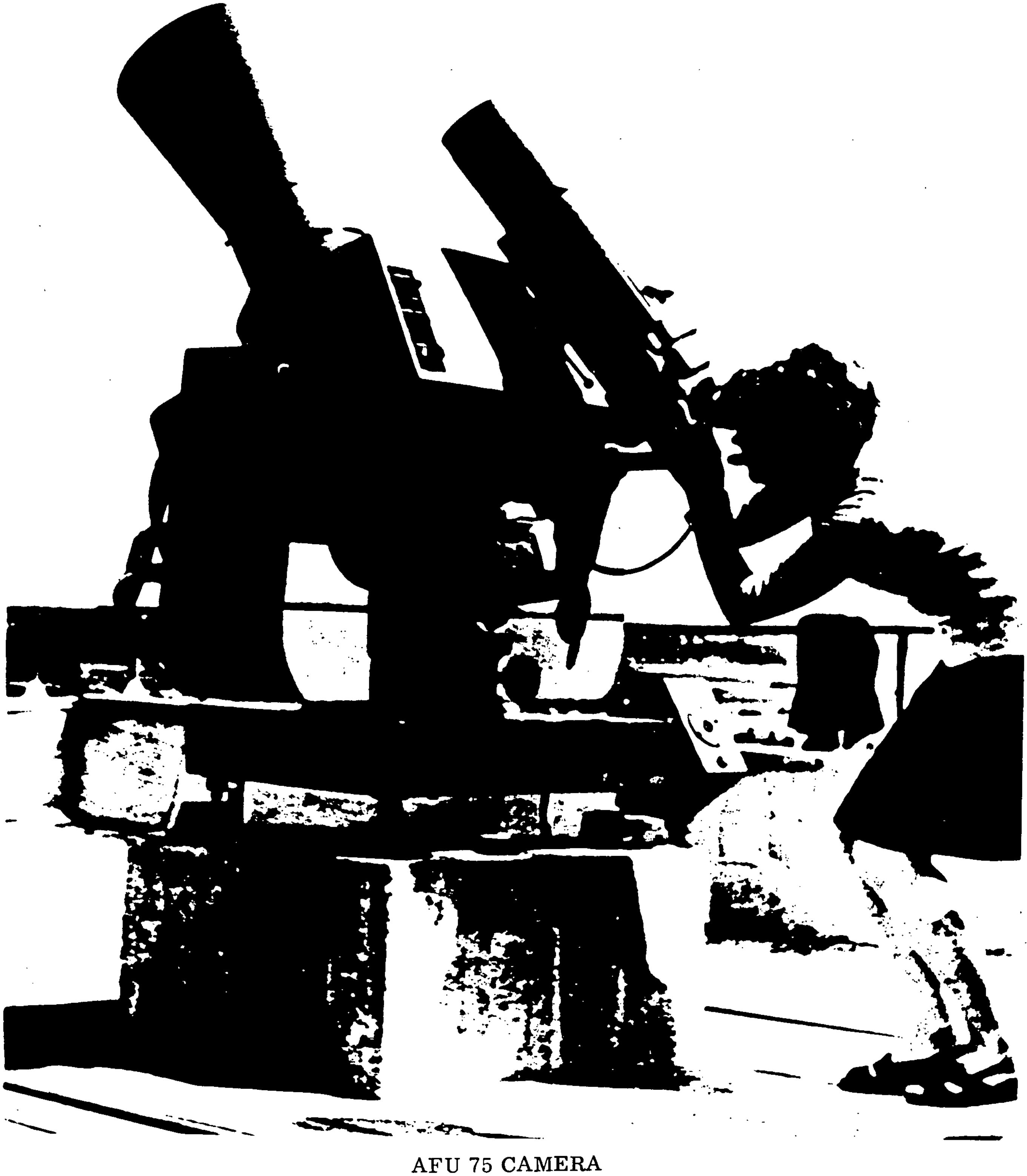
C. Cannonball

Dr. Sehnal is performing solar and albeido radiation pressure calculations for the Smithsonian proposed cannonball satellite. He will require some satellite cloud cover data for his calculations.

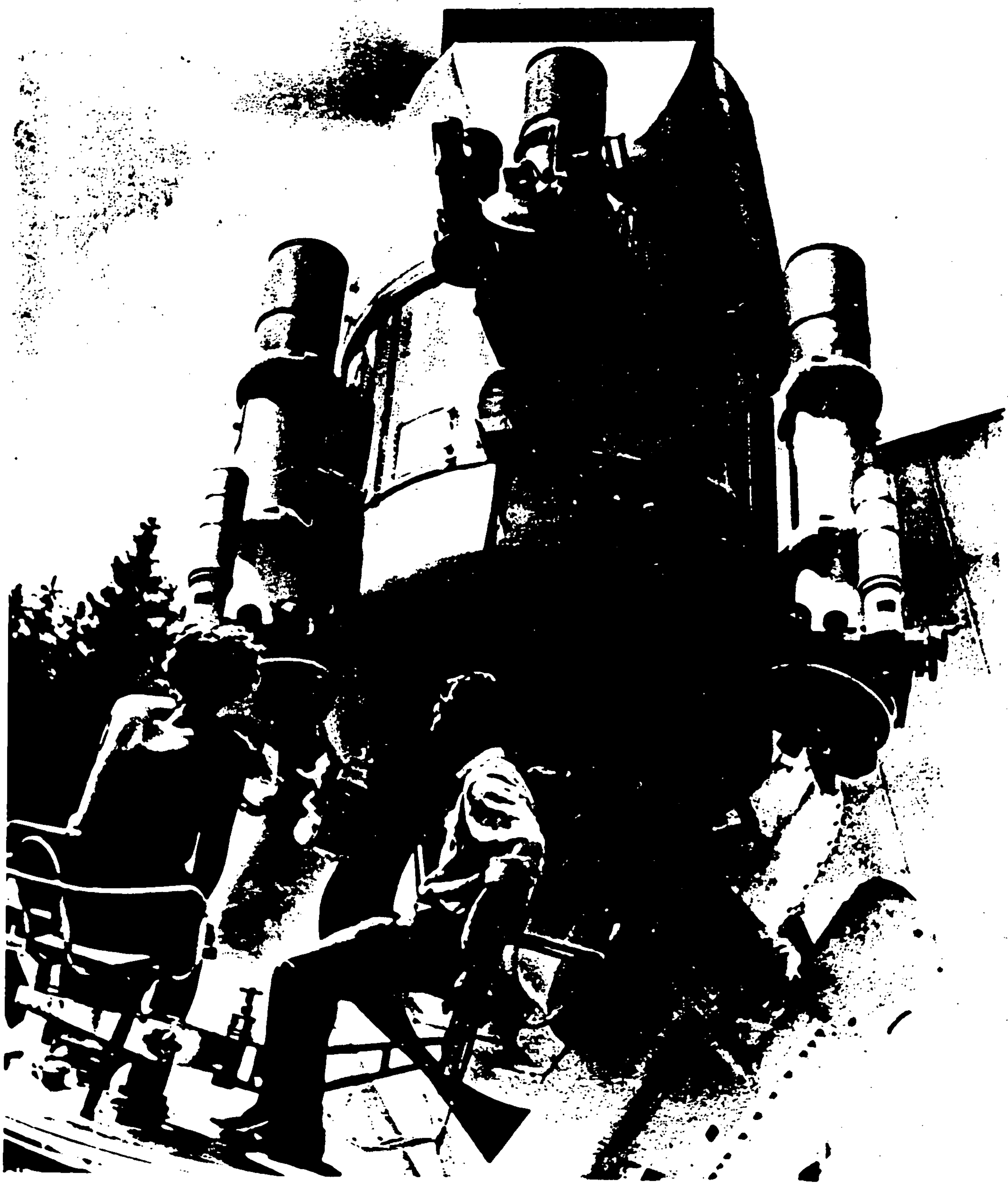
Michael R Pearlman

Michael R. Pearlman

cc: SCD/Rosenberg
DoC/Townsend
DoC/Jones
DoD/McGough
DoD/Frederick
SA/Jaffe
AAA/Williamson
SAO/Weiffenbach
DOA/Mancini



AFU 75 CAMERA



VAU CAMERA

VAU CAMERA AND BUILDING

24 JUL 1972

MEMORANDUM FOR THE RECORD

FROM: ES/Dr. Michael R. Pearlman

SUBJECT: Trip Report, COSPAR 1972, Madrid

I. COSPAR

A. Business Meeting--Working Group I

Dr. Kovalevsky of France resigned as Chairman of WG I. The working group's recommendation for a replacement was Dr. Sehnal of Czechoslovakia (former Co-Chairman). Dr. Veis from Greece was recommended as the new Co-Chairman. Final approval by COSPAR should be routine.

At the business meeting many of the groups which are active in satellite geodesy and geophysics were given an opportunity to brief the others on recent work:

The laser in Ondrejov, Czechoslovakia is now operating with a 4 nsec counter built in one of the Eastern Bloc countries. A second satellite ranging laser system is also going into operation at the Technical University in Prague. A laser system is being tested at Wettzel in Germany and plans are being made to build either a satellite tracking laser or a lunar laser in the United Kingdom.

The Central Bureau for Geodesy was reported to be in better financial shape than it was last year. Consideration is still being given for a quarterly publication for Satellite Geodesy.

SAO discussed the status of the Earth Physics Satellite Observation Campaign (EPSOC) which is being extended until July 1973. Only a limited amount of data has been taken so far. No analysis has yet been undertaken and no arrangements have yet been made for data exchange.

The Arctic/Antarctic Long Arc Program of the USSR was discussed. Some data was acquired during ISAGEX, but many more observations are required and the USSR has invited other groups to join the effort. The ISAGEX data, taken with the Soviet Camera network, has permited considerable refinement in the station position in Cairo (15m). Additional

ISAGEX data from other countries will be required to define this station position further. A French laser is now in Ushgorod and should be operational momentarily with a mixed French/Soviet crew.

The French described their doppler and astronomical results for earth rotation measurements and satellite orbit determination. They described their micrometer accelerometer satellite D5B slated for launch in 1973. An international tracking campaign associated with this satellite, which will have retroreflectors was suggested. The French mentioned some ideas that they had on future missions including: a drag-compensated satellite, an altimeter satellite, and a geodetic satellite based on the Eole tracking system.

NASA gave brief descriptions of GEOS-C, recent VLBI experiments, and SAFE. The Earth and Ocean Physics Applications Program was described as a candidate FY 1974 New Start.

Closer cooperation between work group I and the Geodynamics project was strongly urged. Drs. Kaula and Lundquist were selected as liaison individuals between the WG I/IAG Commission and the Geodynamics Project to help alleviate the communications gap that appears to exist.

A revised list of the Panel Memberships is now being prepared by COSPAR and will be available shortly. This list will include the new IAG members who have been appointed to the WG I/IAG Joint Commission.

B. Business Meeting--Working Group I/Panel C

Dr. Kovelevsky from France was selected by the General Assembly as Chairman of the newly formed Panel 1C/IAG Commission.

The Commission's role in assisting small countries to develop programs in satellite geodesy was discussed in some detail. The Soviets recommended that countries consider grouping themselves together or forming "cooperative aggregates" to pool their resources in satellite geodesy for economic and operational reasons.

There was a discussion on the principles of data exchange. Most members felt that all satellite geodesy data should be available to any country that is cooperating in: tracking, data reduction, or analyses. This discussion will be continued next year with a possible recommendation. (This is an area to watch.)

There were some questions on GEOS-C. Some individuals at the meeting were aware that the memory on GEOS-C was in jeopardy and expressed concern for the impact on the ocean geoid determination.

International cooperative projects in hardware, spacecraft, and analysis were suggested as a possible means to give general encouragement to programs in satellite geophysics.

C. Business Meeting--Working Group I/Panel A

The first meeting of the newly formed Panel on Tracking Instrumentation was held under the Chairmanship of Dr. Weiffenbach. The meeting dealt primarily with organizational matters. The objectives of the Panel as stated by the Chairman are to provide a forum for discussions pertaining to:

1. Present and future tracking campaigns.

2. Logistics to support present and future tracking campaigns.

3. Development of tracking systems and calibration procedures.

4. Fostering international cooperation in tracking and dissemination of pertinent technical information.

A resolution for COSPAR approval was drafted for the support of programs to develop Laser Retroreflector Satellites and supporting analytical work. This resolution was modified and passed by WG I.

D. Open Session--Working Group I

At the open session, papers were given on some of the major tracking techniques that may play a role in future geodynamics investigations including: laser satellite tracking, lunar ranging, VLBI, and doppler systems. Several papers on lunar ranging were given by groups including the French, the Soviets, and the LURE team. Recent advances in both hardware and analyses were discussed. Dr. Mulholland presented lunar ranging results with residuals of order 10 meters, a recent improvement of 1-2 orders of magnitude. A paper given by Dr. Ivan Mueller of Ohio State University, based on computer simulations, questioned the application of lunar ranging for measurements of crustal motion on the earth's surface. A lengthy discussion followed with the expressed general feeling that this required further investigation. Most of those who expressed their opinion, however, did not feel that lunar ranging could compete with satellite tracking and VLBI.

Dr. Weiffenbach gave his views on the future tracking requirements that will be necessary to support earth and ocean physics investigations. These are the same kinds of requirements that are discussed in the EOPAP plan. Dr. Sehnal gave a detailed presentation on the Ondrejov laser. The mount, a modified AFV 75 mount, has been delivered by the USSR and is in operation. Mrs. Massevitch mentioned that several additional lasers based on this design will be built by the Eastern Bloc countries in the near future. Dr. Moran from SAO presented a paper on UT1 determination by VLBI. More than an order of magnitude improvement over the present 2-5 nsec capability appears to be possible with available VLBI techniques.

Dr. Smith presented some of his preliminary results on his gravity field work. Lefebvre from France discussed an idea for a new scheme for the dissemination of precise time using a satellite-borne laser detector and the presently available satellite tracking laser system. Dr. King-Hele (U.K.) presented an interesting paper on the improved determination of specific terms in the gravity field through satellite resonance analysis. Dr. Regan (U.S. Geological Survey) presented a paper (co-authored by Dr. Cain/GSFC) on the results of satellite magnetometer experiments.

II. ISAGEX MEETING

The members of the ISAGEX scientific committee and some observers met to discuss the status of the data exchange, to set priorities for future data reduction, and to consider additional requests for data.

A. Present Agreements

At the last ISAGEX Meeting in Moscow in August 1971 the scientific committee members set the following goals:

1. All laser data would be in the ISAGEX Data Bank and would be exchanged by January 1972 (NASA, SAO, the French).

2. All available optical observations would be quality evaluated (as to their measurability) with the information being sent to the French by January 1972 for tabulation in a catalogue to be available at COSPAR 1972. (SAO, French, USSR)

3. Photo-reduction of: all simultaneous optical observations (highest priority), PEOLE observations, and a few passes of GEOS 1 and 2 would be carried out by July 1972 with results sent to the ISAGEX Data Bank (SAO, French, USSR).

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B. Present Status

1. All laser data from NASA, SAO, and the French has been exchanged between NASA, SAO, and the French. This includes:

   NASA -- 600 passes
   SAO -- 870 passes
   French -- 500 passes

   A total of 10 laser stations (NASA-2, SAO-5, French-3) participated actively in the program. The amount of data collected on PEOLE was a bit disappointing due in part to weather and difficulty in prediction. The three investigations for dynamical geodesy (NASA, SAO, French) have begun their analyses.

2. Nearly all of the optical data has been quality evaluated and catalogued on a preliminary basis. A special updated catalogue of the simultaneous observations was presented to the scientific committee at this meeting. An evaluation of the remaining observations, including a small number now in transit from some SAO stations and some general updating from the other participants, should be available for a new catalogue by July 1972. A total of 48 cameras participated in the campaign.

3. Each of the participants is in the process of meeting the July 1972 goal:

   a. SAO has reduced 80% of its simultaneous optical observations. All of the PEOLE observations have been sent to the data bank. Some observations are still in transit from the SAO stations, and photo-reduction continues. An additional 100 observations, many of which are being reduced for SAO by the U.S. Air Force by agreement, should be in the data bank by July 1972.

   b. The French have reduced essentially all of their simultaneous and PEOLE Observations. About 120 observations are already in the data bank. Another 100 observations will be in the data bank by July 1972. Reduction continues on GEOS-1, 2 observations.

c. The Soviets reported that they had reduced all of their simultaneous observations, and that approximately 150 observations are on route to the ISAGEX data bank. Some 15-20 have already been received. Photo-reduction continues on GEOS-1, 2 passes.

d. The Czechoslovakians have reduced and submitted approximately half of their 80 optical observations. The remainder will be submitted by July 1972.

e. About 50 camera observations have been reduced and submitted by additional European countries.

f. NASA made no camera observations for ISAGEX.

It appears that each of the principle participants is making every effort to meet his commitment for July 1972.

C. Future Priorities

The members agreed on the following priorities for photo-reduction in the future.

1. SAO

a. Remaining simultaneous observations.

b. Observations of MIDAS to support dynamic solution of Soviets for location of Kerguelen Island. (See data requests below.)

c. GEOS, 2 observations.

2. USSR

a. GEOS 1, 2 observations to support NASA/SAO/ rench dynamic solutions.

3. French

a. GEOS 1, 2 observations.

b. Small number of MIDAS observations (no significance to order here).

In addition, each was reminded to clean up his present obligation as soon as practicable.

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D. Additional Data Requests

1. USSR requested camera observations from the Mediterranean area and from South Africa to support "near simultaneous" solutions for Helwan, Kerguelen, and Mirny. This is actually a geometric solution with near simultaneous observations. The request includes:

San Fernando	44 observations (SAO, French)
Athens	25 observations (SAO, Greece)
South Africa	54 observations (SAO)

The Soviets will provide the following data:

Helwan	69 observations
Kerguelen and Mirny	35 observations

The committee agreed to provide these data by the end of the calendar year.

2. The Polish Academy of Science requested data for two successive satellite passes over an individual station in which simultaneous observations with any combination of stations were taken. No such case is known to exist in the ISAGEX data.

   They also requested some simultaneous observations from the Soviet Union, who will satisfy the request.

3. Great Britain had earlier requested a small amount of data on orbital elements. Orbital elements from the public ISAGEX documents are available to fulfill this request.

4. Japan requested orbital elements. These are available through the ISAGEX public reports.

5. Germany requested data from a large number of long arcs with dense coverage. This request was denied since Germany did not contribute any data to ISAGEX and since no results have been published with data given them from previous campaigns.

6. Bulgaria requested orbital elements. These will be fulfilled from the ISAGEX public reports.

7. Czechoslovakia requested laser data from shorts arcs (30 minutes) with dense coverage (2-3 station passes). The data are to be used for investigations of short period, non-gravitational perturbations (air drag and solar radiation pressure) by Dr. Sehnal. Their total request included approximately 80 station passes mainly from the SAO and French lasers over a period of 6 months. (The data requested was insufficient and too poorly distributed for any geodetic work.) Since the Czechoslovakians were active participants in the ISAGEX, and since Sehnal's results in the past has been published, it was agreed to give them one-half of their data request (approximately 2% of the 2000 ISAGEX laser passes) once all of their optical observations were in the ISAGEX data bank.

8. Holland requested GEOS-2 flash observations taken from the European Cameras. The Committee agreed to fulfill this request from available data. No special reductions will be undertaken.

E. Preliminary Results

The ISAGEX data has already been used to develop at least an order of magnitude improvement in the locations of Guam, Dakar, Mirny, and Helwan. Similar improvement is expected for Kerguelen Island and Mirny. Preliminary analyses have made general improvements on the locations of many of the stations in the world geodetic system and significant improvement is anticipated with the Soviet data from Oshgorod, Ulan Bator, and Sakalinsk. The decision on the final disposition and publishing of the ISAGEX data was left for the next ISAGEX Meeting in COSPAR 1973. The present plan is to release the data for public use in Calendar 1974.

III. MEETING WITH ITALIANS ON MINI-LASER RETROREFLECTOR SATELLITE

While in Madrid, Dr. George Weiffenbach and I were approached by Drs. A. Marussi and G. Manzoni from the Institute of Geodesy and Geophysics at the University of Trieste about the possibility of the Italians launching a mini Laser Retroreflector Satellite (LRS) as part of an overall international effort in geodesy and earth physics. Dr. Marussi is the President of the Italian Geodetic Commission.

Dr. Marussi is proposing that the Italians build a 24cm diameter, dense passive satellite, completely covered with laser retroreflectors, and launch it from the San Marco launch site as early as 1974. The satellite would be used to refine the large and intermediate scale terms of the earth's geoid and would be placed into an orbit agreed to by the Geodetic and Geophysics Community (Working Group I/IAG Commission). The Italians would pay the cost for operations and launch if NASA could supply the launch vehicle, a Scout D. Marussi feels that the project has a 99% chance of approval if NASA supplies the launch vehicle free of charge, and about a 40% chance of approval if the Italians have to purchase the vehicle from NASA. Slightly less desirable options in terms of orbit and payload size could be carried out with smaller (older) versions of the Scout vehicle.

The Italians are presently striving to consolidate their efforts in Satellite Geodesy and to develop a program which could be an integral part of an international effort. They have some tracking cameras that are quite old and are, as far as we know, not in use at the moment. They are presently operating the French satellite tracking laser in Ethiopia and are involved with precision photo-reduction of Baker Nunn Camera films for the Smithsonian. They are considering the possibility of putting a laser station of their own at the San Marco site.

The Italians have experience at launching Scout vehicles from San Marco. This satellite is particularly simple to fabricate and to integrate into the Scout vehicle.

Dr. Marussi would like an indication from us as to whether he should pursue this idea at home and with NASA. He would like to submit a proposal to us for such a venture.

Small LRS satellites were included in early versions of the Earth and Ocean Physics Applications Program Plan. These satellites were to be launched into orbits of different inclinations and altitudes (several hundred kilometers) to be used in the development of the long and intermediate scale terms in the geoid and for geometric determination of crustal motion on a regional basis. Although these satellites were recognized as an important tool in both crustal dynamics (Earthquake Hazard Assessment and Alleviation) and Geoid determination (Ocean Dynamics), they had to be deleted from the Program Plan for economic and scheduling reasons.

IV. MEETING WITH DR. SEHNAL ON THE CZECHOSLOVAKIAN REQUEST FOR A COUNTER

While at the COSPAR meeting in Madrid, Dr. Lundquist of SAO and I met with Dr. Sehnal from the Ondrejov Observatory in Prague to discuss the status of his request to purchase a 1 nsec counter from the Eldorado Company. Dr. Sehnal is now very concerned that resources to make his purchase will not be available after December 31, 1972. This means that, unless he receives an affirmative answer very shortly, he will be forced to look elsewhere for the counter. He has had contact with the Takeda Riken Company whose model TR-5599 1 nsec counter can, according to Sehnal, be delivered to Eastern Bloc countries with no difficulty. The interface between the Japanese counter and the Czech laser system is considerably more complicated than with the Eldorado unit, and the Czechs would much rather go with a counter (the Eldorado) that has already been used extensively in this particular application.

International programs for tracking and data exchange involving the Czechs will probably develop whether or not we sell them the counter. The counter will, however, help them in developing their satellite geodesy program. The Czechs have played an active role in ISAGEX with their tracking camera. About half of their 80 or so optical observations have already been reduced and have been submitted to the ISAGEX data bank; the other half are promised for July 1972. The laser at Ondrejov is now operating and visits to the site have been unrestricted to foreigners.

The 1 nsec counter is the same type as has been used by NASA, SAO, and the French. NASA has recently instrumented its laser stations with 1 nsec counters (Sehnal's original request); the SAO and the French are planning to similarly update their systems this coming year. The counter that we would be selling the Czechs would not be as sophisticated as the ones in use by NASA, SAO, and the French in the 1974 time frame.

Two years have now passed since the Czechoslovakians made their original reservations. Sehnal is waiting for some advice on what action to take. He needs an answer by July 1, 1972.

Michael R. Pearlman

Michael R. Pearlman

APPENDIX 4

EARTH AND OCEAN PHYSICS APPLICATIONS PROGRAM

EARTH AND OCEAN PHYSICS APPLICATIONS PROGRAM

1. INTRODUCTION

The Earth and Ocean Physics Applications Program (EOPAP) is an applications program based on the discipline of earth and ocean dynamics. Its primary goals are to identify, develop, and demonstrate relevant space techniques that will contribute significantly to the development and validation of predictive models for earthquake-hazard alleviation, ocean-surface conditions, and ocean circulation.

The discipline of earth dynamics embraces phenomena that are of immense practical importance. Solid-earth dynamics is concerned with the physical motions and distortions of the solid earth that are responsible for earthquakes, tidal waves, volcanic eruptions, mineral differentiation, mountain building, etc. Ocean dynamics is concerned with ocean circulation and the physical state of the ocean surface, which are clearly of direct and great concern both to ships at sea and to population centers bordering the oceans that must extract food from the sea and dispose of pollutants. Further, ocean dynamics is intimately related to climate and weather in all parts of the world. Clearly, a thorough understanding of earth and ocean dynamics is fundamental to intelligent management of the earth.

The importance of earth and ocean dynamics is reflected in the vigorous efforts now being applied to various aspects of this discipline by a large number of agencies both in this country and abroad, and in the organization of large-scale cooperative programs such as the International Decade of Ocean Exploration (IDOE) and the Geodynamics Project.

It is the central theme of EOPAP that it provides a forum for a broad cooperative effort for the development of practical tools – predictive models and observational systems – that can ultimately be used by operating agencies such as the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS) to provide applications outputs of social benefit to this nation and, indeed, to the whole world.

The objectives of the Earth and Ocean Physics Applications Program fall naturally into two major categories: (Solid) Earth-Dynamics Applications and Ocean-Dynamics Applications. To facilitate discussion and the development of implementation plans, the program has been divided into these two major areas (see Figure 1-1). However, since the geophysics and the measurement techniques are largely the same, a combined implementation plan has been developed that encompasses both areas.

The EOPAP is directed to the following major applications objectives:

- Development and validation of methods leading to Earthquake-Hazard Assessment and Alleviation Models to predict probable time, location, and intensity of earthquakes.
- Development and validation of means for predicting the general ocean circulation, surface currents, and their transport of mass, heat, and nutrients.
- Development and validation of methods for synoptic monitoring and predicting of transient surface phenomena, including the magnitudes and geographical distributions of sea state, storm surges, swell, surface winds, etc., with emphasis on identifying existing and potential hazards.
- Refinement of the global geoid, extension of geodetic control to inaccessible areas including the ocean floors, and improvement of knowledge of the geomagnetic field for mapping and geophysical applications, to satisfy stated user requirements.

The more closely we examine the problems of environmental management and the alleviation of natural disasters, the more evident it becomes that progress in solving these problems will be quite limited until we have a deep understanding of the physical forces at work and the physical mechanisms that respond to these forces. The realization is also growing that understanding will not come easily if we restrict our vision to limited geographic areas or to isolated phenomena. Earth dynamics is a subject of enormous complexity, involving as it does strong interactions among events in different parts of the globe and among phenomena in the atmosphere, oceans, and solid earth.

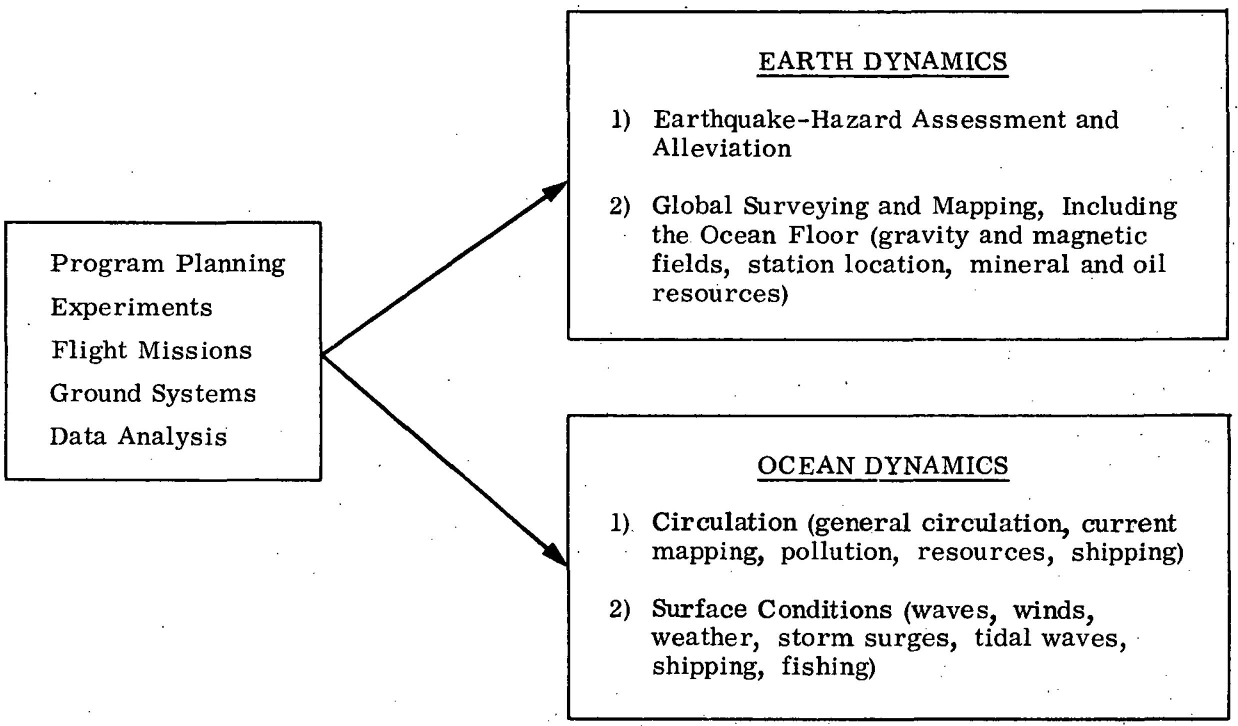

Figure 1-1. Earth and Ocean Physics Applications Program elements.

The complexity of earth dynamics precludes any possibility of finding solutions in terms of simple theoretical descriptions. Predictions of earthquakes, storm surges, and other natural catastrophic events will almost certainly be based on strongly empirical numerical computer models that will require as operational inputs very large numbers of very recent synoptic data from large geographic areas. The implication for the operational predictive systems is clear: An integral component of the operational apparatus must be an observational subsystem that can rapidly acquire and report measurements from large geographic areas.

Further, extraordinary measuring accuracies will be needed to detect such things as motions of the crust in fault zones, which are of the order of a few centimeters per year at most. And these accuracies must be attained not just as a one-time laboratory _tour de force_, but routinely in remote and sometimes inhospitable regions of the world.

There is no question that surface-based measurements are absolutely necessary to an earth-dynamics program, nor that ongoing programs are essential and must be continued. It is also abundantly evident that substantial progress has already been achieved within these existing programs in many sectors of earth dynamics. On the other hand, it is difficult to conceive of an effective operational system for reporting sea state, as an example, that does not require frequent and prompt reporting of sea-state observations from all parts of the world ocean. This, we believe, is feasible only by means of satellites – both for making observations and for collecting data from _in situ_ sensors.

The EOPAP is based on the fact that satellites and space techniques can provide a large body of new data, not otherwise obtainable, required for the solutions of significant problems in earth and ocean dynamics. Some particular characteristics of space techniques that establish this unique role are as follows:

1) Space techniques provide access to a stable inertial reference (the star background) or to quasi-inertial references (the moon and artificial satellites), which is essential for determining the earth's rotation and polar motion and is of great importance in sorting out the complex motions of points on the earth relative to one another.

2) Artificial satellites, the moon, and the stars can serve as geometric references visible simultaneously from points on the earth that are widely separated geographically.

3) Satellites provide rapid and repeated global coverage; for example, a satellite in a polar orbit will see every point on the earth's surface at least once each day.

4) Satellites are the most stable and most accurately positioned mobile platforms available for observations over large geographic areas, as demonstrated by the applicability of satellites to navigation and astronomy.

5) Space observations have minimum path length in the atmosphere, thereby minimizing atmospheric-propagation errors, the basic limitation to all high-precision distance and angle measurements.

Earthquake-Hazard Assessment and Alleviation is a key element of the Earth-Dynamics Applications area. The practical implications of a workable Earthquake-Hazard Assessment (EHA) Model are clear. Predictions of probable time, location, and intensity of earthquakes could lead to enormous savings in lives and property. The generally accepted modern theory of fault motion and plate tectonics takes the view that the outer portion of the earth consists of a number of major floating tectonic plates. These plates move at a rate of a few centimeters per year relative to one another, with spreading, colliding, underthrusting, and slipping occurring at their boundaries. In many regions, the plate interfaces remain locked for an appreciable period of time, forcing local strains to build up. The sudden fracture of a locked boundary, when the critical stress is exceeded, releases the stored energy and produces earthquakes. There is some evidence that perturbations in the motion of the earth's pole and in the earth's rotation rate may give a forewarning of earthquake activity. Space techniques, principally laser ranging and Very Long-Baseline Interferometry (VLBI), will permit close monitoring of plate and crustal motions, polar motion, and earth rotation-rate variation. Mapping of the earth's gravity and magnetic fields by satellite techniques will play a basic role in improving our understanding of the mechanisms involved in tectonic plate motions.

Space surveying methods will allow the extension of global geodetic control to remote areas, including the ocean floor, to an accuracy of 1.0 m vertically and 10 m horizontally. Exploitation of continental-shelf areas, for example, will be facilitated through the use of this capability.

Mapping of the large-scale features of the earth's gravitational and magnetic fields, which can be conducted most effectively from space, will be of use in several ways. Reference models of the gravitational field will be useful in connection with surveying and geophysical studies, and information about the fine structure of the earth's gravity field may help in the search for mineral resources, particularly in continental-shelf regions. Reference models of the magnetic field, which changes with time (westward drift for instance), have traditionally been used in navigation.

The oceans have always been a major source of man's nutrients and a sink for his garbage. Fish follow the currents in the oceans, and discharged material is pushed along by the general ocean circulation. At the moment, we cannot observe and predict the day-to-day meanderings of even such well-charted and major ocean currents as the Gulf Stream. Similarly, we lack the ability to maintain surveillance of and predict sea state and surface-wind conditions over the world ocean. If an oil spill occurs on the high seas, we have little idea if and where the oil may come ashore. Accurate modeling of deep-ocean currents throughout the world ocean is of further importance in predicting where radioactive waste may some day appear. This may have serious future implications.

Ocean circulation plays a major role in the control of global climate and weather owing to the immense oceanic heat transport. The general circulation patterns are responsible for the marked differences in climate between regions at the same latitude, such as Labrador and Great Britain.

Monitoring of sea state and surface winds is important from the standpoint of weather determination and ocean traffic. Satellite-borne radar altimeters, scatterometers and radiometers, and satellite-tracked buoys offer the capability for quick monitoring of the dynamical processes of the oceans on a synoptic and repetitive basis and for prompt reporting of the needed information.

The motivation for including this broad scope of applications in one program arises from the significant amount of fundamental geophysical information and understanding that are common to all, as well as the commonality of technology, systems, measurements, and spacecraft required. To address the problem of understanding earthquakes and finding means to alleviate earthquake hazards, the geophysicist will require a global network of precisely monitored station positions in order to measure accurately the very slow motions of the earth's crust, variations in the earth's rotation and polar motion, and a detailed definition of the gravity field. The oceanographer requires a network of precision station locations as a reference from which to measure the orbits of the altimeter satellites that will be used to measure the topography of the ocean surface. The oceanographer also requires an accurate and detailed geoid so that geoidal undulations can be separated from the measured ocean topography, thereby enabling oceanographic effects on the topography to be identified.

The development of many of the basic techniques to be used in this program was initiated under the National Geodetic Satellite Program (NGSP), a major interagency program in geodesy, and under other NASA programs. It was recognized quite early that techniques such as laser ranging systems, VLBI, radar altimeters, and satellite-to-satellite tracking could achieve precisions necessary for probing the dynamic processes of the earth.

The fundamental tools available for EOPAP are laser ranging to satellites and the moon, VLBI, satellite altimetry, scatterometry and radiometry, and satellite-to-satellite tracking. For earthquake-hazard assessment and alleviation, laser ranging and VLBI can be used to measure tectonic plate motion, regional strain buildup, polar motion, and UT1. The refined geoid can be developed with the assistance of satellite-to-satellite tracking and satellite altimetry, and the magnetic field will be mapped in detail with satellite-borne vector magnetometers.

Under the Ocean-Dynamics Applications, the topography of the ocean surface will be mapped by means of satellite altimetry to give critical data on ocean currents and circulation and on transient phenomena such as storm surges, barometric effects, and possibly tsunamis. The satellite-to-satellite and ground tracking systems will support the altimetry missions by providing the required precision orbit determination. Satellite-borne thermal sensors and tracking of ocean buoys can provide additional information about ocean circulation and currents. Satellite altimetry, scatterometry, and radiometry will be applied to the acquisition of surface-roughness and surface-wind data.

It is very likely that the observing techniques chosen to implement the operational systems that may emerge from EOPAP will be selected from those listed above.

All the required space techniques have been implemented with two exceptions — satellite altimetry and scatterometry, which will soon be tested experimentally, and satellite-borne gravity gradiometry. Large quantities of experimental data have been analyzed, and the significant error sources identified. Moreover, many corrective measures have already been demonstrated experimentally, such as two-wavelength optical correction for tropospheric propagation and two-frequency r.f. correction for ionospheric effects. There are, of course, many developmental tasks in the area of technology and increased measurement accuracy, but these are largely concerned with more precise experimental determination of various error sources, with experimental evaluation of corrective methods, and with the design of efficient operational systems.

This program is intended to augment activities now under way in other agencies. It has been developed in consultation with these other agencies and is structured to provide critical information that can be uniquely supplied by space techniques. In carrying out this program, strong interagency coordination and cooperative efforts are contemplated. In the field of earthquake research, NOAA and USGS are engaged in local ground-based surveying and seismic monitoring programs to measure localized crustal motions and strain buildup over small regional areas. Under EOPAP, on the other hand, stations several hundred or even thousands of kilometers apart can be measured to an accuracy that will yield critical data about the tectonic plate motions and regional strain fields that give rise to earthquakes. The program will also provide crucial information on polar motion, earth rotation, and earth tides, all of which are thought to be related to earthquakes. An experiment using NASA satellite-tracking lasers in cooperation with NOAA, USGS, and the Lamont-Doherty Geological Observatory is being undertaken in the San Andreas region of California to help determine the stored energy of the fault. In the field of ocean dynamics, both NOAA and the Naval Research Laboratory (NRL) have been working closely with NASA; both were consulted in many aspects of the planning for EOPAP. Representatives from NOAA participated in the writing of the Ocean-Dynamics Applications portion of the program.

In 1969, NASA sponsored the Williamstown Conference (Kaula, 1970a) on Terrestrial Environment: Solid-Earth and Ocean Physics to give the agency some guidance on how to apply available capabilities toward meaningful objectives in the geophysical sciences. Although the attendees were primarily from the scientific community, they formed many of their recommendations around potential results of practical benefit, such as better understanding of those mechanisms involved in earthquakes and ocean dynamics. This program incorporates many of the recommendations from that Conference.

EOPAP offers an excellent opportunity for international cooperation. In fact, a meaningful NASA Earth and Ocean Physics Applications Program requires, at a minimum, cooperation from other countries in tracking support or tracking-site locations. Our experience in the past has demonstrated that other countries are eager to participate actively in cooperative programs in geophysics. Two pertinent examples of this are the cooperation in satellite geodesy (ISAGEX) and the U.S./USSR bilateral exchange on the earth's magnetic-field survey. There is every indication that this cooperation will not only continue, but increase in scope as the program gets under way.