Department of Geodetic Science and Surveying

BASIC RESEARCH FOR THE GEODYNAMICS PROGRAM

Eleventh Semiannual Status Report
Research Grant No. NSG 5265
OSURF Project No. 711055

Period Covered: April 1 - September, 1983

Prepared for

NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

The Ohio State University
Research Foundation
Columbus, Ohio 43212

November, 1983

PREFACE

This project is under the supervision of Professor Ivan I. Mueller, Department of Geodetic Science and Surveying, The Ohio State University. The Science Advisor is Dr. David E. Smith, Code 921, Geodynamics Branch, and the Technical Officer is Mr. Jean Welker, Code 903, Technology Applications Center, both at Goddard Space Flight Center, Greenbelt, Maryland 20771.

TABLE OF CONTENTS

Page

1. CURRENT TECHNICAL OBJECTIVES 1

2. ACTIVITIES

2.1 The Effect of Earth Orientation Errors in Baseline Determination 2

2.2 Utilization of Range-Difference Observations in Geodynamics. 3

2.3 Earth Rotation Parameter Determination from Different Space Geodetic Measurements. 13

3. PERSONNEL. 19

4. TRAVEL 19

5. REPORTS PUBLISHED TO DATE 20

1. CURRENT TECHNICAL OBJECTIVES

1. Optimal Utilization of Laser and VLBI Observations for Reference Frames for Geodynamics

2. Utilization of Range Difference Observations in Geodynamics

2. ACTIVITIES

2.1 The Effect of Earth Orientation Errors in Baseline Determination

The results of this investigation were published in Bulletin Geodesique, Vol. 53, No. 3, pp. 272-282 (1983) as "The Effect of Earth Orientation Errors in Baseline Determination" by E.C. Pavlis and I.I. Mueller.

2.2 Utilization of Range-Difference Observations in Geodynamics

Introduction

Laser systems currently deployed in satellite tracking have been upgraded to accuracy levels where biases from systematic unmodelled effects constitute the basic factor that prohibits the extraction of the full amount of information contained in the observations. Taking into consideration that the quality of the instrument advances at a faster pace compared to our understanding and modeling of the physical processes involved, one can foresee that in the near future when NASA replaces all its lasers with third-generation ones the limiting factor for the estimated accuracies will be the aforementioned biases.

Therefore, for the reduction of the observations new methods should be deployed in such a way that the effect of the biases will be kept well below the noise level. Such a method has been proposed and studied in (Pavlis, 1983).

This method consists of using the coobserved part of the satellite pass and converting the laser ranges into range-differences in hopes that they will be less affected by biases in the orbital models, the reference system, and the observations themselves. Since it is quite improbable if not impossible to obtain exactly simultaneous laser observations from two ground stations to a satellite, it is required to generate simultaneous ranges from an interpolation of the recorded range observations. This interpolation of the range observations is required only for one of the stations at the epochs which the alternate station has observed. Therefore it is chosen to interpolate the ranges from the station with the best data distribution in order to keep approximation errors as small as possible. Using these interpolated ranges from the one station and the actual observations of the alternate station, the simultaneous range differences are generated (see Fig. 1). These quasi-observables are then analyzed to obtain the minimum variance estimate of the baseline length (ibid.). Since there was no data taken specifically for this type of reduction technique, the study of the above method was mainly based on simulated data.

The advantages of using co-observed satellite passes in baseline determinations are now well established through the above proposed method and

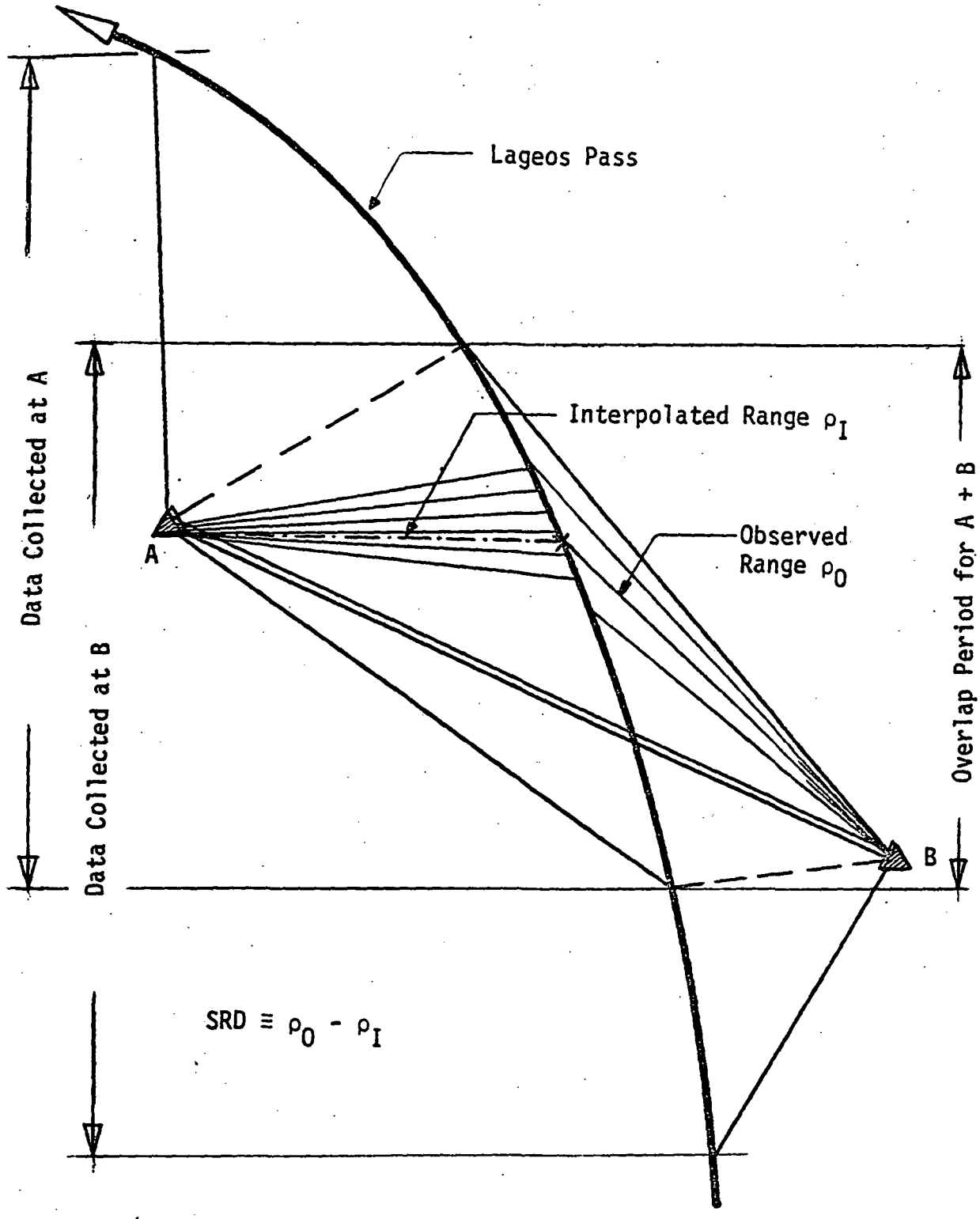

Fig. 1 Simultaneous range-differencing. (from (Pavlis, 1982)).

through other investigations undertaken at the Goddard Geodynamics Branch (Christodoulidis and Smith, 1981). In light of these advantages, an increasingly successful effort is being made by all the observing stations to collect as much simultaneous data as possible. Using this simultaneous data, an investigation of the above method is performed based purely on real data.

The Data Set

The data set used for this investigation contains all the range observations to Lageos as collected by NASA's stations (see Table 1) during the year 1982.

This data set along with relevant catalog and format information has been kindly released to us on four magnetic tapes by NASA/Goddard Space Flight Center (Henry G. Linder).

The data set as supplied by NASA is the so-called "preprocessed data" which comprise the actual observations with certain corrections applied, and with other corrections having been computed but not applied. The latter are included in the disseminated data set with appropriate indicators that inform the analyst of what has been included already in terms of corrections and what yet remains to be applied (Linder, 1981). The corrections that need to be applied to the observed ranges are:

--fixed threshold to peak (return) signal offset
--instrumental calibration correction
--satellite center-of-mass offset correction
--atmospheric refraction correction

Data Preprocessing

The data as received on magnetic tapes are arranged in files, one for each month of the period covered. Within each file the data is sorted by time. The last file of each magnetic tape contains a catalog showing the observing station ID's together with the number of observed passes and the number of observations per pass. This catalog contains also a pass-by-pass breakdown of the data along with the beginning and ending epochs for each station having observed a certain pass. On the basis of this catalog and the known geographical location of the observing stations, the station pairs

Table 1 Catalog of NASA Laser Observations, 1982

LOCATION	STATION(NAME)	STATION(I.D.)	# OF PASSES	# OF OBSERVATIONS
	TAPE # 1			
AREQUIPA PERU	ARELAS	7907	101	28157
HALEAKALA HAW.	HOLLAS	7210	23	21268
YARRAGADEE, AST.	ML0502	7090	23	38285
PLATEVILLE, COL.	ML0212	7112	21	7595
GREENBELT, MD.	ML0703	7105	20	28782
MONUMENT, PEAK.	ML0308	7110	20	9637
VERNAL, UTAH	TL0112	7892	11	3752
QUINCY, CALIF.	ML0804	7109	18	25454
	TAPE # 2			
AREQUIPA, PERU	ARELAS	7907	93	23524
HALEAKALA HAW.	HOLLAS	7210	48	43676
GREENBELT, MD.	ML0801	7101	1	7144
YARAGADEE, AST.	ML0502	7090	48	52342
PLATEVILLE, COL	ML0212	7112	27	6946
GREENBELT, MD.	ML0703	7105	24	33608
MONUMENT, PEAK	ML0308	7110	27	14788
VERNAL, UTAH	TL0112	7892	16	12185
QUINCY, CALIF.	ML0804	7109	51	55674
	TAPE # 3			
METSAHOVI, FIN.	FINLAS	7805	72	2489
KOOTWIJK, HOLLAND	KOOLAS	7833	181	17734
WETZELL, GERMANY	WETZEL	7834	271	159917
FRANCE	GRASSE	7835	111	18810
	TAPE # 4			
AREQUIPA, PERU	ARELAS	7907	55	9817
HALEAKALA, HAW.	HOLLAS	7210	29	24960
GREENBELT, MD.	ML0402	7102	6	4077
GREENBELT, MD.	ML0601	7103	32	51920
YARAGADEE, AST.	ML0502	7090	46	66335
PLATEVILLE, COL	ML0212	7112	40	20184
GREENBELT, MD.	ML0703	7105	50	59006
MONUMENT PEAK	ML0308	7110	41	25991
QUINCY, CALIF.	ML0804	7109	47	194129

which are likely to have sufficient number of observations on the same portion of a satellite pass are determined.

The next step is the actual determination of the overlapping observational periods and the number of observations collected by each station pair over those periods. This is done by processing the data with the OVERLAP software (see OVERLAP documentation). Due to equipment failures, occasionally a pass is interrupted by gaps as a result of the missing data. These gaps result in an uneven data distribution over the pass and will cause problems at the later stages when simultaneous ranges are to be interpolated. To overcome this problem the OVERLAP program checks the duration of these gaps and if they are larger than a pre-specified value the pass is broken down into subsets of data. A 60-second maximum gap has proven to be reasonable in a sense that does not cause problems in interpolation and at the same time does not result in extremely small subsets that would be impossible to interpolate due to insufficient data points.

At this point the output of the OVERLAP program is examined in terms of data content and distribution; overlapping passes with less than 200 data points are rejected and so are the data from stations pairs that have no significant total amount of observations over the period that the corresponding baselines are to be estimated.

The following step is the examination of the relative orientation between the baselines to be estimated and the satellite passes. As it has been already demonstrated (Pavlis 1979, 1983), the satellite passes parallel to the estimated baseline should be preferred to those which cross it at almost a right angle. In reality, though, the satellite passes are neither parallel nor perpendicular to the estimated baseline. Therefore, at this point a close and careful investigation of this relative orientation should be conducted. A 30° maximum intersection angle between the satellite groundtracks and the estimated baseline has proven reasonable as it does not cause problems in the baseline estimation. Passes not being in favor of the above geometry are rejected.

The periods of the remaining satellite passes are now used to select the actual observations out of the original data set. This is accomplished through the SLCTOVER program. The selected observations are then corrected by the program CHKTPR according to the indicators included in the disseminated

data set (see section: The Data Set). These corrected observations are processed through the COMBOS program. The output of this program consists of two files, one containing the selected observations and one containing the data station directory. This directory contains the endpoint epochs for each batch of data constituting a pass or a portion of it, the identification numbers of the stations co-observing the pass, and an indicator that determines for which of the stations the ranges will be interpolated and for which the actual observations will be used (see Introduction). These two files are fed into either a cubic-spline or Chebyshev polynomial interpolator and ranges for the station with the most observations are obtained at the epochs which the alternate station has observed. These ranges then are differenced to produce the range-difference data input for the final adjustment program GEOSPP81. The software used for the cubic-spline and the Chebyshev-polynomial interpolation are named SIMURNGS and CHEBYNOM respectively. Figs. 2 and 3 depict the data distribution for two sample passes of Lageos. The bars indicate the epochs when the actual observations occurred, and the curve joining their centers is the spline fit (Fig. 2) with good data distribution and (Fig. 3) with a not good enough one.

The next step, not completed yet, is to process these quasi-observables (simultaneous range-differences) through the final adjustment program (GEOSPP81). Once this step has been completed the monthly baseline estimates will be compared with the corresponding ones as determined by the GEODYN program at Goddard Geodynamics Branch. As it is well known, GEODYN employs the single station satellite range mode. This comparison will demonstrate the consistency and the accuracy (apart from biases) for each of the above methods. Here it should be mentioned that consistency and accuracy (not precision) in the baseline determinations are very important for crustal movement investigations.

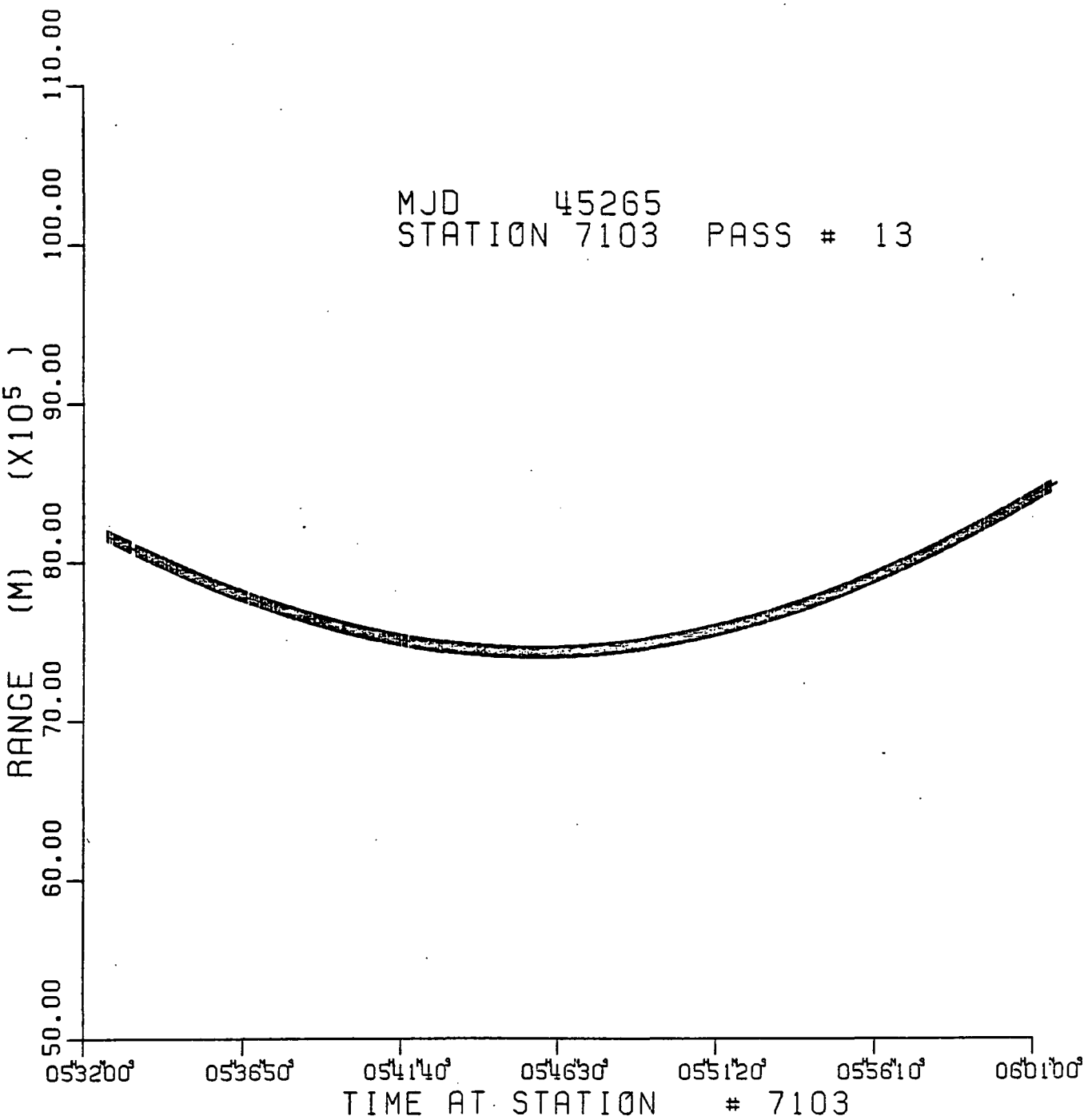

Fig. 2 Laser range versus time for good data distribution.

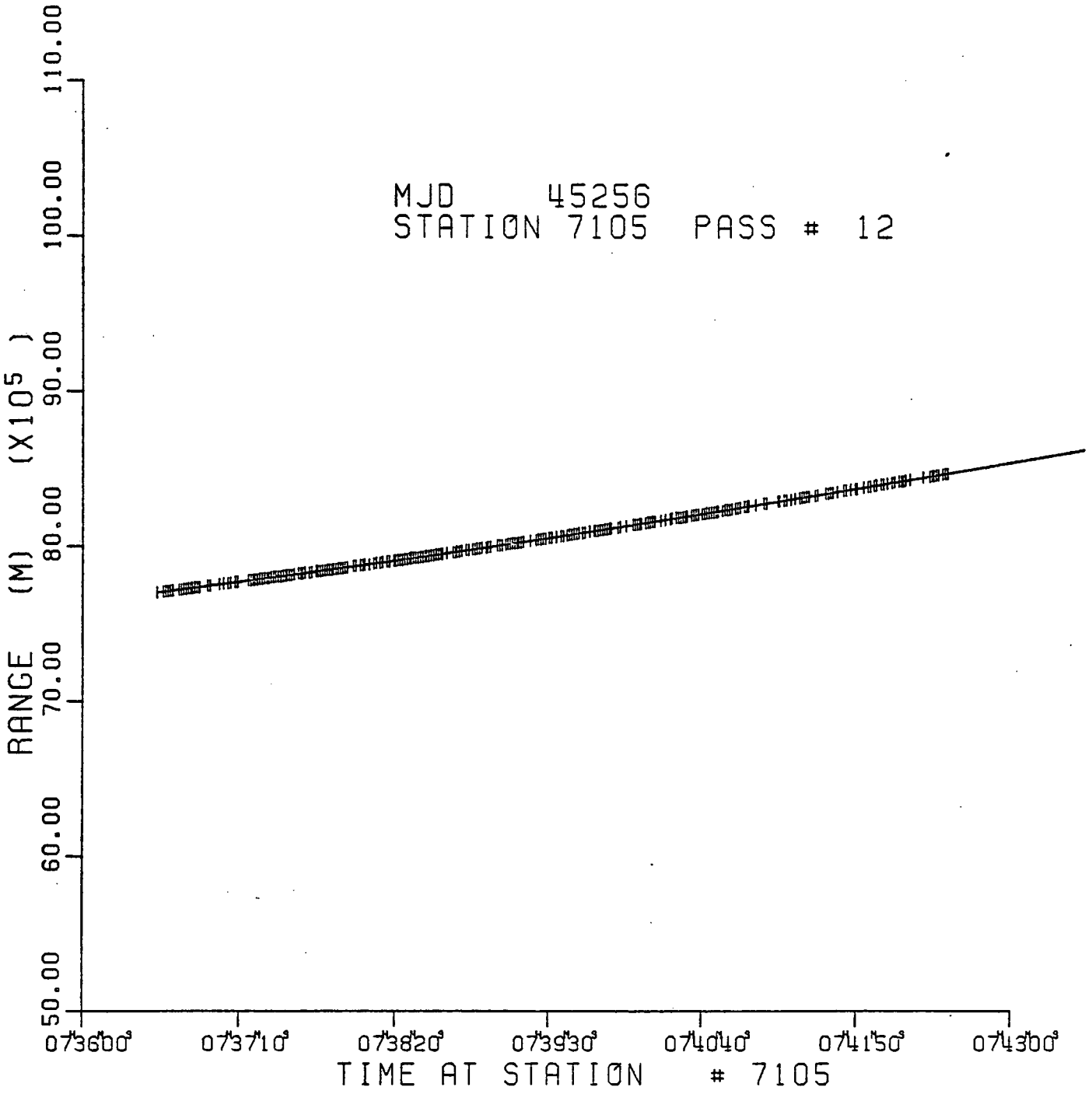

Fig. 3 Laser range versus time for sparse data distribution.

References

Christodoulidis, D.C. and D.E. Smith (1981) "Prospects for TLRS Baseline Accuracies in the Western USA Using Lageos," NASA Technical Memorandum 82133, Goddard Space Flight Center, Greenbelt, MD 20771.

Linder, H.G. (1981) "Data Management Plan for Crustal Dynamics Project," NASA Technical Memorandum X-931-81-18, Goddard Space Flight Center, Greenbelt, MD 20771.

Pavlis, E.C. (1979) "Error Analysis for a Spaceborne Laser Ranging System," Dept. of Geodetic Science and Surveying Rep. 290, Ohio State Univ., Columbus.

Pavlis, E.C. (1982) "On the Geodetic Applications of Simultaneous Range-Differencing to Lageos," Dept. of Geodetic Science and Surveying Rep. 338, Ohio State Univ., Columbus.

Page intentionally left blank

Page intentionally left blank

2.3 Earth Rotation Parameter Determination from Different Space Geodetic Measurements

Introduction

Currently data from several "space-"based systems are being used to determine Earth Rotation Parameters (ERP) (including the change in the earth's rotation rate $\Delta UT1$, and the polar motion parameters Δx_p, Δy_p). These systems include VLBI methods, satellite laser ranging (SLR), lunar laser ranging (LLR), Doppler tracking of the Navy Navigation Satellite System (NNSS), and various methods of tracking the satellites of the Global Positioning System (GPS). "Final" ERP values are actually computed by the BIH by taking weighted averages of the ERP values computed individually by the various systems (along with values obtained via classical astrometric methods) (Feissel, 1980).

A question that has been raised is whether there is some better way of determining the "final" ERP values than simply taking weighted means of the individual values. Various alternatives have been proposed, such as:

(1) combining the raw data in one massive adjustment, and solving for the final ERP,

(2) combining the normal equations of the various individual solutions and then solving for the final ERP;

(3) taking weighted averages of the parameters <u>with</u> their variance-covariance matrices as determined by the different systems;

(4) and/or in addition use variance component estimation theory to determine the variance-covariance matrices of the individual ERP estimates, before combining them (Schaffrin, 1983).

Another way to realistically ask the above question is "<u>How much information is being lost by determining the ERP for each system separately</u>?" And would the extra computational and data transmission work be justified by a significant increase in the accuracy of ERP determination?

A simulation study is being undertaken to partially answer the above questions. Specifically, the possibility of combining raw data or normal equations from various systems will be considered to see if it will provide significant increases in the ERP accuracies. This is along the lines of (1) and (2) given above.

The simulation will include the realistic simulation of ERP parameters (so that they will be known a priori), and simulation of raw or normal point data from VLBI, SLR to Lageos, and LLR systems, with various expected station configurations. The following solutions for ERP could then be computed:

(1) individual solutions for the various systems,

(2) a combined solution using all the data in one adjustment,

(3) a combined solution using the normal equations from the solutions in (1),

(4) a combined solution using weighted means of the parameters obtained in (1) (using a method similar to that of the BIH (Feissel, 1980)).

The parameters and statistics of these solutions could then be compared directly to the a priori ERP values and a realistic estimate of the improvement of one method over another be made.

The following sections discuss some of the details involved in the simulation. However, it should be realized that this information is still quite preliminary, with much more study necessary, especially of the available computer software.

Simulation of Earth Rotation Parameters

The earth rotation parameters themselves are simulated so that they may be assumed known exactly when compared with the parameters computed from the data simulation and adjustment. Indeed, the primary objection to using real data in this study (other than computational problems) is that the earth's true ERP are never known a priori. Some type of model for the parameters (an nth-degree polynomial?) must be assumed, using real ERP's and their short period fluctuations as a guide. A method of computing discrete (averaged) parameters should also be available. This will be necessary since the parameters being solved for in the simulation will actually be for specific periods, e.g., 1, 5, and 10-day intervals, as is done in reality by the BIH, USNO and others. One-half day intervals might also be used since at least VLBI data may have such resolution. The choice of which of these periods to use for most of the investigations is another problem yet to be decided.

The length of time for which these parameters (and the data) are to be simulated is also still under consideration. Initial considerations would indicate that a period of two to three weeks appears optimal, since it would

cover all short-period fluctuations in the ERP's fairly well (semidiurnal, diurnal, weekly and possibly fortnightly) and indicate trends of longer periods (monthly or semiannually). The computer time involved is an important factor here, since if true-rate data will be simulated, anything beyond a few days of simulation may use very large amounts of computer time. Therefore, the initial simulation tests will be over a period of a few days, and final tests probably within the two to three week time frame. If it then seems warranted and if funds are available, a longer period could be considered. It may also be possible to get by with "normal point" data of some type in order to reduce expenses.

Simulation and Adjustment of Data

Assumed Errors in Simulated Data and Reference Frames.

The simulated data (ranges for SLR and LLR, delay rates for VLBI) will obviously have random noise added to it, with a variance approximately that of the expected precision of these systems. This will also be the case for the station coordinates (which define a Conventional Terrestrial System (CTS)) and the various Conventional Inertial Systems (CIS's) involved (i.e., Lageos ephemeris for SLR, a lunar ephemeris for LLR, and a radio source catalog for VLBI). It will likely be assumed that the CTS is rigid and not undergoing internal motion, since for the short period involved this assumption is quite valid. One of the CIS's will be held fixed (probably the radio source catalog, as it is the closest to being "inertial") and transformation parameters to the other two CIS's will be solved for (e.g., at least a Z-axis rotation). The CIS-CTS connection will also be assumed known (including precession and nutation), probably with appropriate standard deviations.

The introduction of systematic errors into the simulated data of any of these systems will require further study as it is likely that they (along with the CIS orientation errors) are primarily responsible for the differences in the ERP's of different systems. VLBI and LLR systematic error sources seem to be well known, but the possible systematic errors in SLR have been more difficult to track down. At first glance, it would appear that if a possible systematic error is ignored when simulating the data <u>and</u> when adjusting that data, there should be no problem. But the mismodeling of some systematic errors in

the adjustment of real data may be precisely the cause of ERP differences in different systems. Therefore, this remains an important problem to be settled before the simulation is done.

Station Locations.

The stations chosen will be as realistic as possible to reflect stations expected to be operational during the MERIT campaign and the mid-1980's. This implies that for SLR a set or various sets of currently active (mostly NASA) stations; for LLR, the three or four stations expected to soon be in operation; and for VLBI, the NGS Polaris 3 station network possibly supplemented with other stations will all be used. The current "best" possible coordinates and (as mentioned above) reasonable standard deviations for them will be used in simulating and adjusting the data. The collocation of some stations, as is now being done as part of the MERIT campaign, will also be considered.

Computer Software.

An important problem to be solved before attempting any simulation is whether adequate computer software is available. A quick survey revealed that the following software was available or accessible for the simulation of the data:

SLR - NASA's GEODYN or Pavlis' GEOSPP81 (Pavlis, 1983)
LLR - University of Texas, or MIT programs? GEODYN?
VLBI - Bock's VIP (Bock, 1980) or Ma's CALC 4.0 or possibly CALC 5.0, GEODYN?

A quick survey also indicated that a program capable of adjusting all three types of data would have to be either written, possibly obtained from MIT, or be an advanced version of GEODYN.

Further consideration revealed that GEOSPP81, VIP, CALC 4.0 and CALC 5.0 might all be useable programs now available here, except that additional parameters would likely need to be added to each of these in order to account for various systematic errors. Further, the programs will need to be examined carefully to determine if systematic differences exist in the models. E.g., CALC 4.0 uses the "old" system of astronomical constants and 1950.0 epoch, while CALC 5.0 uses the new (1984) system and the J2000.0 epoch.

In contrast to this, it was also learned that the GEODYN program (version 8210) can now handle and has been thoroughly tested with SLR and VLBI data. It is also expected that it will be able to handle LLR data early

next year, albeit not as well tested as with the other data types. Additionally, another program, "SOLVE," is available which will accept normal equations created by GEODYN and perform solutions with various parameters optionally eliminated, added or constrained.

GEODYN also has the advantage of being an already written, thoroughly tested program in use by several groups with generally adequate documentation and assistance available and capable of operation on OSU's Amdahl V-8 computer. Considering these advantages and the fact that the same program used for simulation may be used for the adjustments, it is tentatively the choice for the data processing. The disadvantages that exist include:

(1) The program is computationally expensive.
(2) Some of the documentation is out of date (but personnel are available at GSFC to answer questions about it).
(3) The LLR portion of the program will not be ready for several months.
(4) Some systematic error parameters may not be available.
(5) The program still uses the "old" system of astronomical constants and the 1950.0 epoch.

Most of these problems would not greatly affect the proposed study. Work with SLR and VLBI would proceed until the LLR capability is ready, <u>although it will be required</u> to obtain the most meaningful results from this study. The specific systematic error parameters available may or may not be important, depending on their effect. This will have to be looked into. The fact that the old astronomical system is in use should not be of much concern, since this is a simulation. It would be a possible problem only if real data were to be processed.

Therefore, since we currently have a slightly older version of GEODYN (8202.3), the newest version has been requested (8210). We have also already received (October 19, 1983) an updated version of Volume III (input and operation instructions) of the GEODYN manual, which includes instructions for version 8210 specifically.

It should finally be noted here that other software will have to be obtained or most likely written here to

(1) simulate the ERP,
(2) compare the results of the various solutions (graphically?), and
(3) compute the normal weighted mean ERP values for comparison purposes (using methods similar to that of the BIH).

An obvious extension of this study (which could be done as a follow-up here at OSU) would be an identical comparison using real data. By the time this study itself is complete, not only will it (thereby) be possible to estimate possible gains in the accuracy of the ERP, but software for processing real data will be available, and a great amount of very useful collocated data from various systems will be available from the MERIT main campaign now underway.

References

Bock, Yehuda (1980) "A VLBI Variance-Covariance Analysis Interactive Computer Program," Dept. of Geodetic Science and Surveying Rep. 298, Ohio State Univ., Columbus

Feissel, Martine (1980) "Determination of the Earth Rotation Parameters by the Bureau International de l'Heure, 1962-1979," Bull. Geodesique, 54, 81-102.

Pavlis, Erricos (1983) "On the Geodetic Applications of Simultaneous Range Differencing to Lageos," Dept. of Geodetic Science and Surveying Rep. 338, Ohio State Univ., Columbus.

Schaffrin, Burkhard (1983) "Model Choice and Adjustment Techniques in the Presence of Prior Information," Dept. of Geodetic Science and Surveying Rep. 351, Ohio State Univ., Columbus.

3. PERSONNEL

Ivan I. Mueller, Project Supervisor, part time

Brent Archinal, Graduate Research Associate, part time

George Dedes, Graduate Research Associate, part time

Erricos C. Pavlis, Graduate Research Associate, part time through 6-10-83

Irene B. Tesfai, Secretary, part time

4. TRAVEL

Ivan I. Mueller
Airlie, Virginia February 15-18, 1983
To attend NASA Geodynamics Workshop. Also MERIT meeting on February 19 in Washington, D.C.

Ivan I. Mueller
Royal Greenwich Observatory
Sussex, England May 13-21, 1983
To attend Second MERIT Workshop as Vice-Chairman, and to conduct meetings of COTES as its chairman.

5. REPORTS PUBLISHED TO DATE

OSU Department of Geodetic Science Reports published

262 The Observability of the Celestial Pole and Its Nutations
by Alfred Leick
June, 1978

263 Earth Orientation from Lunar Laser Range-Differencing
by Alfred Leick
June, 1978

284 Estimability and Simple Dynamical Analyses of Range (Range-Rate and Range-Difference) Observations to Artificial Satellites
by Boudewijn H.W. van Gelder
December, 1978

289 Investigations on the Hierarchy of Reference Frames in Geodesy and Geodynamics
by Erik W. Grafarend, Ivan I. Mueller, Haim B. Papo, Burghard Richter
August, 1979

290 Error Analysis for a Spaceborne Laser Ranging System
by Erricos C. Pavlis
September, 1979

298 A VLBI Variance-Covariance Analysis Interactive Computer Program
by Yehuda Bock
May, 1980

299 Geodetic Positioning Using a Global Positioning System of Satellites
by Patrick J. Fell
June, 1980

302 Reference Coordinate Systems for Earth Dynamics: A Preview
by Ivan I. Mueller
August, 1980

320 Prediction of Earth Rotation and Polar Motion
by Sheng-Yuan Zhu
September, 1981

329 Reference Frame Requirements and the MERIT Campaign
by Ivan I. Mueller, Sheng-Yuan Zhu and Yehuda Bock
June, 1982

337 The Use of Baseline Measurements and Geophysical Models for the Estimation of Crustal Deformations and the Terrestrial Reference System
by Yehuda Bock
December, 1982

338 On the Geodetic Applications of Simultaneous Range-Differencing to LAGEOS
by Erricos C. Pavlis
December, 1982

348 On the Time Delay Weight Matrix in VLBI Geodetic Parameter Estimation
by Yehuda Bock
July, 1983

351 Model Choice and Adjustment Techniques in the Presence of Prior Information
by Burkhard Schaffrin
September, 1983

The following papers were presented at various professional meetings and/or published:

"Concept for Reference Frames in Geodesy and Geodynamics"
AGU Spring Meeting, Miami Beach, Florida, April 17-21, 1978
IAU Symposium No. 82, Cadiz, Spain, May 8-12, 1978
7th Symposium on Mathematical Geodesy, Assisi, Italy, June 8-10, 1978
"Concepts for Reference Frames in Geodesy and Geodynamics: The Reference Directions," Bulletin Geodesique, 53 (1979), No. 3, pp. 195-213.

"What Have We Learned from Satellite Geodesy?
2nd International Symposium on Use of Artificial Satellites for Geodesy and Geodynamics, Lagonissi, Greece, May 30 - June 3, 1978

"Parameter Estimation from VLBI and Laser Ranging"
IAG Special Study Group 4.45 Meeting on Structure of the Gravity Field
Lagonissi, Greece, June 5-6, 1978

"Estimable Parameters from Spaceborne Laser Ranging"
SGRS Workshop, Austin, Texas, July 18-23, 1978

"Defining the Celestial Pole," manuscripta geodaetica, 4 (1979), No. 2 pp. 149-183.

"Three-Dimensional Geodetic Techniques"
Technology Exchange Week, Inter-American Geodetic Survey
Fort Clayton, Canal Zone, May 14-19, 1979
published in Spanish as "Tecnicas Geodesicas Tridimensionales," Memoria de la Semana de Intercambio Tecnologico, Panama, Rep. de Panama, pp. 400-426.

"On the VLBI-Satellite Laser Ranging 'Iron Triangle' Intercomparison Experiment," Meeting on Radio Interferometry Techniques for Geodesy, Massachusetts Institute of Technology, Cambridge, June 19-21, 1979

"Space Geodesy for Geodynamics, A Research Plan for the Next Decade"
Sonderforschungsbereich - Satellitengeodäsie - SFB 78
Colloquium in Viechtach, FRG, October 23-24, 1979

"Concept of Reference Frames for Geodesy and Geophysics"
seminar given at University of Stuttgart, West Germany, June 19, 1980

"Space Geodesy and Geodynamics,"
seminar given at University of Stuttgart, West Germany, June 26, 1980

"Geodetic Applications of the Global Positioning System of Satellites and Radio Interferometry," seminar given at University of Stuttgart, West Germany, July 3, 1980

"Reference Coordinate Systems for Earth Dynamics: A Preview,"
Proc. of IAU Colloquium 56 on Reference Coordinate Systems for Earth Dynamics," September 8-12, 1980, Warsaw, Poland, E.M. Gaposchkin and B. Kołaczek, eds., D. Reidel. Presented at AGU, San Francisco, December, 1980.

"Comments on Conventional Terrestrial and Quasi-inertial Reference Systems," with J. Kovalevsky, Proc. of IAU Colloquium 56 on Reference Coordinate Systems for Earth Dynamics, September 8-12, 1980, Warsaw, Poland, E.M. Gaposchkin and B. Kołaczek, eds., D. Reidel.

"Precise Positioning with GPS"
seminar given at Deutsche Geodätische Forschungsinstitut, Munich, West Germany, September 18, 1980

"Tecnicas Geodesicas Tridimensionales"
(translated from English by IAGS), ASIA Journal (Asociacion Salvadorena de Ingenieros y Arquitectos) San Salvador, No. 61, Oct. 80, pp. 40-51; cont'd in No. 62, Dec. 80, pp. 31-39.

"Space Geodetic Techniques and Geodynamics"
Proc. 1st International Symposium on Crustal Movements in Africa Addis Ababa, Ethiopia, May 5-16, 1981

"Comparison of Polar Motion Data from the 1980 Project MERIT Short Campaign" Proc. of IAU Colloquium 63 on "High Precision Earth Rotation and Earth-Moon Dynamics: Lunar Distances and Related Observations," May 22-27, 1981, Grasse France, D. Reidel (I.I. Mueller, B.S. Rajal and S.Y. Zhu)

"Geodesy and the Global Positioning System"
Proc. of IAG Symposium on Geodetic Networks and Computations, Aug. 31-Sept. 5, 1981, Munich (I.I. Mueller and B. Archinal)

"The Future of Space Techniques in Geodesy and Geodynamics," 2nd Symp. on Geodesy in Africa, Nairobi, November 9-20, 1982.

"Use of Simultaneous Doppler-Derived Ranges in the Geometric Mode," Proc. of 3rd International Geodetic Symp. on Satellite Doppler Positioning, Las Cruces, New Mexico, Feb. 8-12, 1982 (R. Schneeberger, D. Pavlis and I.I. Mueller).

"Glacial Movement Measurements in Greenland by Satellite Doppler Geodetic Receivers," Third Symp. on the Study of Movements in Engineering Surveys, August 25-27, 1982, Budapest, Hungary (Alice Drew, Ivan I. Mueller and Ian Whillans).

"On the Establishment and Maintenance of a Modern Conventional Terrestrial Reference System," Proc. of Symp. No. 5: Geodetic Applications of Radio Interferometry, IAG, Tokyo, May 7-8, 1982, NOAA Technical Rep. NOS 95 NGS 24, pp. 36-45 (Y. Bock and S.Y. Zhu).

"Comments on 'Frequency Modulation of the Chandlerian Component of Polar Motion' by William E. Carter," JGR, 87(B13), Dec. 10, 1982 (S.Y. Zhu).

"Effects of Adopting New Precession, Nutation and Equinox Corrections on the Terrestrial Reference Frame," XVIII General Assembly of the IAU, Patras, Greece, August, 1982. Bulletin Geodesique, 57, 1 (1983) (Sheng-Yuan Zhu and Ivan I. Mueller).

"Lectures on the Terrestrial Reference Frame," Third International Summer School in the Mountains on Geodesy and Global Geodynamics, Admont, Austria, Aug. 30 - Sept. 10, 1982

"Geometric Adjustment of Simultaneous Doppler-Derived Range Differences," Third International Symp. on the Use of Artificial Satellites for Geodesy and Geodynamics, Porto Hydra, Greece, Sept. 20-25 (C. Zhang and I.I. Mueller).

"The Effect of Earth Orientation Errors in Baseline Determination," Annual Fall Meeting of the American Geophysical Union, San Francisco, Dec. 7-15, 1982, and Fifth Annual NASA Geodynamics Program Conference and Crustal Dynamics Project Review, Washington, D.C., Jan. 24-28, 1983; Bulletin Geodesique, 57, 3 (1983) (Erricos C. Pavlis and Ivan I. Mueller).

"Estimating Crustal Deformations from a Combination of Baseline Measurements and Geophysical Models," Bulletin Geodesique, 57, 3, (1983) (Yehuda Bock).