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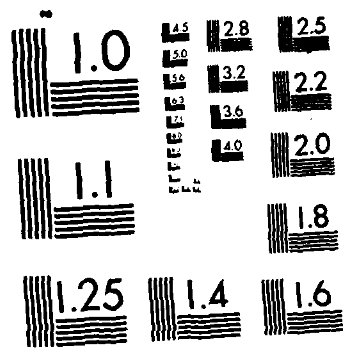

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THE STUDY OF GRAVITY FIELD ESTIMATION PROCEDURES

Richard H. Rapp

The Ohio State University
Research Foundation
Columbus, Ohio 43212

Final Report
22 December 1981 - 30 June 1985

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This report is the final report of the project. It briefly summarizes the research described in detail in ten scientific reports. The research described includes the use of high degree potential coefficient expansions, vertical datum corrections, improved gravity fields from satellite altimetry, the computation of the gravity vector in space and the use of digital terrain models for gravimetric computations.

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FOREWORD

This report was prepared by Richard H. Rapp, Professor, Department of Geodetic Science and Surveying, The Ohio State University under Air Force Contract No. F19628-82-K-0022, The Ohio State University Research Foundation Project No. 714274. This report is the final report of the contract that started December 22, 1981 and ended June 30, 1985. This project has been administered by the Air Force Geophysics Laboratory, Air Force Systems Command, Hanscom AFB, Massachusetts, with Dr. Christopher Jekeli, Contract Manager.

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1. Introduction

This final report covers the period of contract No. F19628-82-K-0022 from December 22, 1981 thru June 30, 1985. The research conducted under this contract has been carried out under the general theme of the project which was The Study of Gravity Field Estimation Procedures. The results of the research have been reported in 10 scientific reports and numerous papers and presentations. The scientific reports have been prepared by post doctoral researchers, graduate students, and the principal investigator. One of the reports was submitted to the Graduate School as a Master of Science thesis and one was submitted as a PhD dissertation.

A complete list of reports is given in Section 4. A list of papers and presentations may be found in Section 5 and the list of personnel associated with this project is given in Section 3.

The details of the research activity are best found through reading the individual reports. In the following section a brief discussion of the various reports is given.

2. Report Discussion

Scientific Report 1 (by Rapp) describes the theory and development of a computer program to calculate several quantities from a high degree spherical harmonic expansion. The specific quantities calculated were the geoid undulation, gravity anomaly, gravity disturbance, and the and components of the deflection of the vertical. This program calculates the quantities on a point by point basis as opposed to a grid computation. The program has been used with developments up to degree 200.

Scientific Report 2 (by Rummel) describes a technique for estimation of quantities such as geoid undulations from gravity anomalies using the actual point data. The technique attempts to implement a collocation type of estimation but retaining the advantages of a Stokes' type of integration. Preliminary (and successful) tests were made to recover gravity anomalies from Geos-3 altimeter data with the new methods.

Scientific Report 3 (by Hajela) was the first of two reports dealing with the vertical datum definition and connection question. The report by Hajela determines the expected accuracy of the determination of the potential difference between Western Europe and the United States. The data included in the computation was the laser ranging network whose coordinates have been accurately determined through the observations of Lageos. In addition a high degree spherical harmonic expansion and gravity data in caps about the tracking stations were used. With realistic accuracy estimates the potential difference between the two vertical datums was 58 mgal·cm. This accuracy estimate is not much better than what one would determine from knowledge of sea surface topography. In order to improve this accuracy estimate, a substantial improvement in the low degree spherical harmonic potential coefficients is needed.

The second report dealing with the vertical datum question is Scientific Report 4 by Laskowski. In this report the author considers two basic questions. First, what are the distortions caused in the North American Vertical Datum 29 by fixing the elevation of all tide gauge stations at zero. The second question studied relates to the errors caused in the computation of gravimetric quantities by inconsistent vertical datums. The reason for inconsistency is due to the effects of sea surface topography. Various models of SST were used to study the error in such quantities as geoid undulations and deflections of the vertical. The estimated error in geoid undulation determination caused by SST was on the order of 7 to 19 cm when gravity data in a cap about a station was used.

Scientific Report 5 (by Forsberg) examined the role of topography and terrain reductions in gravimetric computations. Forsberg's report discussed many topics in gravity field modeling related to the terrain and the use of digital terrain models. He shows how Fourier techniques can be used for the computation of terrain corrections and he introduces the concept of a residual terrain model (RTM) based on a high degree (180) spherical harmonic expansion of the topography. One of the important practical results of this report is a Fortran program, TC, that uses digital terrain models to compute the various terrain reduction effects. This program can compute: 1) the direct topographic effect of all masses above sea-level; or 2) a topographic/isostatic reduction with an Airy model; or 3) a gravimetric terrain correction; or 4) a residual terrain model effect, on the following quantities; gravity disturbance, deflections of the vertical, and height anomaly. This program has proved quite useful for computations performed for the contract and described in several reports.

In Scientific Report 6, Forsberg continued his studies of local gravity field behavior. In this report power spectrums of various anomalous densities were developed through Fourier techniques. There spectrums were related to the isotropic covariances. Of special interest for later research was the development of a relationship between the power spectrums of geoid undulations or gravity anomalies and the degree variances of the spherical harmonic expansion of the earth's gravitational potential. Various spectra, potential coefficient behavior, and anisotropic covariance functions were developed for regions in Ohio, Colorado, California and New Mexico. The computations were made on gravity anomalies for which topographic effects have been removed using a residual terrain model (RTM). The RTM involves the use of terrain corrected Bouguer anomalies and degree 180 spherical harmonic developments of the earth's potential and topography. The potential coefficient behavior can be studied by these techniques up to very high degree depending on the spacing of the gravity data being studied.

The techniques for improved spherical harmonic expansions is discussed by Hajela in Scientific Report 7. In this study Hajela has extended the work and computer programs of Colombo so that optimal estimation of the potential coefficients can be made from 1°x1° gravity anomalies. The importance of this study is to show how potential coefficients beyond degree 180 can be obtained in an optimal way from 1° anomaly data.

Scientific Report 8, by Cruz and Laskowski, described a variety of methods that could be used for the computation of gravity anomalies in space given surface gravity anomalies. Of special interest in this study is the manner in which the terrain is considered for computations where the elevation of the computation is small (3 to 50 km) above the topographic surface. This study applied the program TC developed by Forsberg (Scientific Report 5) and used high degree expansions of the gravity field and topography for reference field purposes. The technique developed in this report were used with actual data to compute gravity at points associated with the balloon-borne gravity measuring project that is being coordinated by the Air Force Geophysics Laboratory. The computations done at Ohio State were provided to AFGL on a computer tape. Finally a program is given in the appendix to the report that can be used for the upward continuation of gravity anomalies using a Fourier transform procedure.

Rapp (Scientific Report 9) described sea surface height and gravity anomaly computations made with a combined Geos-3/Seasat altimeter data set. Extensive tests were carried out for this report to compare predicted gravity anomalies from altimetry with surface ship data. These tests led to production procedures for the prediction of point gravity anomalies and sea surface heights. Before the production runs were made selected arcs were readjusted to remove orbit error that was not satisfactorily removed before. Even then it was necessary to provide edit procedure during each prediction sequence. Approximately 2.2 million useful predictions were made of point values which were also formed into $0\overset{\circ}{.}5 \times 0\overset{\circ}{.}5$ and $1^\circ \times 1^\circ$ mean values for comparison with terrestrial data. Various analyses were carried out with this data set including the computation of spectra that show potential coefficient behavior at degrees up to about 900. The actual spacing of the predictions was $0\overset{\circ}{.}125$ which is slightly too small based on a spectral analysis of the predicted quantities. We did conclude that the gravity field in the oceans is clearly smoother than land areas.

An extensive discussion of the computation of the gravity vector in space from surface gravity anomalies was prepared by Cruz for Scientific Report 10. Cruz studied the three components of the gravitational vector considering spherical harmonic expansions, surface gravity data and digital terrain data. Computational techniques considered include the use of integration procedures; collocation models; and Dirac approaches. The methods considered were applied in a rugged area of New Mexico. Cruz gives as an Appendix to his report a specific set of recommendations on what procedures should be followed for the computation of the gravity vector in space with special attention given to the treatment of the terrain.

3. Personnel

The following Graduate Research Associates were employed under this project: J. Cruz, C. Liang, T. Engelis, and P. Laskowski. The following served as senior research associates: R. Rummel, R. Forsberg, D. Hajela. L. Brumfield and T. Runyon provided secretarial support. Richard H. Rapp was the principal investigator and project supervisor.

4. The Scientific Reports Produced Under the Contract

Sci. Rpt. No.

1 Rapp, R.H., A Fortran Program for the Computation of Gravimetric Quantities from High Degree Spherical Harmonic Expansions, DOGS Report No. 334, AFGL-TR-82-0272, ADA123406, 26 pages, September 1982.

2 Rummel, R., Gravity Parameter Estimation from Large Data Sets Using Stabilized Integral Formulas and a Numerical Integration Based on Discrete Point Data, DOGS Report No. 339, AFGL-TR-82-0295, ADA123397, 35 pages, September 1982.

3 Hajela, D.P., Accuracy Estimates of Gravity Potential Differences Between Western Europe and United States Through Lageos Satellite Laser Ranging Networks, DOGS Report No. 345, AFGL-TR-83-0132, ADA131838, 74 pages, February 1983.

4 Laskowski, P., The Effect of Vertical Datum Inconsistencies on the Determination of Gravity Related Quantities, DOGS Report No. 349, AFGL-TR-83-0228, ADA137881, 92 pages, August 1983.

5 Forsberg, R., A Study of Terrain Reductions, Density Anomalies and Geophysical Inversion Methods in Gravity Field Modeling, DOGS Report No. 355, AFGL-TR-84-0174, ADA150788, 134 pages, April 1984.

6 Forsberg, R., Local Covariance Functions and Density Distributions, DOGS Report No. 356, AFGL-TR-84-0214, ADA150792, 57 pages, June 1984.

7 Hajela D.P., Optimal Estimation of High Degree Gravity Field from a Global Set of 1°x1° Anomalies to Degree and Order 259, DOGS Report No. 358, AFGL-TR-84-0263, ADA156008, 65 pages, August 1984.

8 Cruz J. and Laskowski, P., Upward Continuation of Surface Gravity Anomalies, DOGS Report No. 360, AFGL-TR-84-0331, ADA154973, 116 pages, December 1984.

9 Rapp, R.H., Detailed Gravity Anomalies and Sea Surface Heights Derived from GEOS-3/SEASAT Altimeter Data, DOGS Report No. 365, AFGL-TR-85-0191, 135 pages, August 1985.

10 Cruz, J., Disturbance Vector in Space from Surface Gravity Anomalies Using Complementary Models, DOGS Report No. 366, AFGL-TR-85-0209, 147 pages, August 1985.

5. Papers and Presentations

The research described in the following list was support fully, or in part, by this project.

Lachapelle and Rapp, "Estimation of Disturbing Potential Compor ents with Emphasis on North America", presented at the CIS Centennial Convention, Ottawa, Canada, April 1982.

Rapp, R.H., "Aspects of Geoid Definition and Determination", presented at the IAG General Meeting in Tokyo, May 1982; (in Proceedings).

Rapp, R.H., Goad, C., and Tscherning, C., "A Comparison of Methods for Computing Gravimetric Quantities from High Degree Spherical Harmonic Expansions", manuscipta geodaetica.

Forsberg, René, "Gravity Field Modeling Using Known Density Anomalies and Geophysical Inversion Techniques", presented at the Workshop on Geoid and Gravity Modeling on a Local Basis, The Ohio State University, October 1983.

Forsberg, René, "Local Covariance Functions for Gravity and Topography", presented at the Workshop on Geoid and Gravity Modeling on a Local Basis, The Ohio State University, October 1983.

Rapp, Richard, "Problems in the Development of Improved High Degree Spherical Harmonic Expansions of the Gravity Field", presented at the Workshop on Geoid and Gravity Modeling on a Local Basis, The Ohio State University, October 1983.

Rapp, Richard, "Use of Altimeter Data for Local Gravity Field Recovery", presented at the Workshop on Geoid and Gravity Modeling on a Local Basis, The Ohio State University, October 1983.

Hajela, D.P., "Tests for Optimal Estimation of High Degree and Order Gravity Fields", presented at the Workshop on Geoid and Gravity Modeling on a Local Basis, The Ohio State University, October 1983.

Cruz, J., "Truncation Theory for Spatial Disturbance Computations", presented at the Workshop on Geoid and Gravity Modeling on a Local Basis, The Ohio State University, October 1983.

Rapp, R.H., "Gravity Field Products from Ocean Altimeter Data", presented at AIAA Guidance and Control Conference in Seattle and in conference proceedings, August 1984.

Cruz, J. "Filters for Data Noise, Problem Stabilization, and Data Combination in Physical Geodesy", presented at the American Geophysical Union Meeting in Cincinnati, May 1984, (abstract EOS, Vol. 65, No. 16, April 17, 1984).

Rapp, R.H., "A Detailed Sea Surface Height and Gravity Anomaly Data Base from Geos-3 and Seasat Altimeter Data", presented at Fall AGU Meeting, San Fransicso, December 1984, (abstract, EOS, Vol. 65, No. 45, p. 816, November 6, 1984).

Rapp, R.H., "Detailed Gravity Anomaly Fields from Satellite Altimetry", invited paper, Spring AGU Meeting, Baltimore, 1985, (abstract, EOS Vol. 66, No. 18, p. 242, April 30, 1985).

Rapp, R.H., "Gravity Anomalies and Sea Surface Heights Derived from a Combined Geos-3/Seasat Altimeter Data Set", submitted to the Journal of Geophysical Research, August 1985.

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