

Cambridge University Press

978-1-107-02413-7 - Acquisition and Analysis of Terrestrial Gravity Data

Leland Timothy Long and Ronald Douglas Kaufmann

Frontmatter

[More information](#)

Acquisition and Analysis of Terrestrial Gravity Data

Gravity surveys, detecting minute variations of the gravitational field at the Earth's surface, have a huge range of applications, indicating density variations in the subsurface, identifying man-made structures, characterizing local changes of rock type, or even mapping deep-seated structures at the crust/mantle boundary. This important one-stop book combines an introductory manual of practical procedures with a full explanation of analysis techniques, enabling students, geophysicists, geologists, and engineers to fully understand the methodology, applications, and limitations of a gravity survey.

Filled with examples from a wide variety of acquisition problems, the book instructs students in avoiding common mistakes and misconceptions. The authors also explore the increasing near-surface geophysical applications being opened up by improvements in instrumentation, and provide some more advanced-level material to give a useful introduction to potential theory.

Springing from the authors' extensive teaching experience and professional participation in a wide range of engineering applications, this book shares their considerable insight into data-acquisition procedures and analysis techniques. A key text for graduate students of geophysics, this is also an invaluable resource for professionals using gravity surveys, from civil engineers and archaeologists, to oil and mineral prospectors and geophysicists seeking to learn more about the Earth's deep interior.

Leland Timothy Long is Emeritus Professor of Geophysics at the Georgia Institute of Technology, where he has taught geophysics for more than 40 years, on topics including exploration geophysics, potential theory, seismology, data analysis, and earth science. He is also a licensed Professional Geologist in Georgia and consults on topics of gravity data interpretation, seismic hazard, and blast vibration. Professor Long's research interests in potential methods include the interpretation of regional crustal structures for seismic hazards, deflections of the vertical, statistical properties of gravity fields, and microgravity for the detection of sinkholes. His research interests in seismology have emphasized seismicity, seismic networks, induced seismology, many aspects of theoretical seismology related to scattering and scattering inversion, and near-surface surface wave analysis. In 2006, Professor Long was awarded the Jesuit Seismological Association Award honouring outstanding contributions to observational seismology.

Ronald (Ron) Kaufmann is President of Spotlight Geophysical Services in Doral, Florida and has more than 19 years of geophysical consulting experience, including positions of Vice President and Senior Geophysicist at Technos, Inc. He is a licensed Professional Geophysicist in California and a Professional Geologist in Tennessee. Mr Kaufmann is an expert in the use of microgravity for karst and geologic hazard investigations and has personally acquired gravity measurements at more than 20,000 stations for a variety of near-surface investigations. He has led geophysical projects for environmental, geotechnical, and groundwater applications across the US and Latin America, including several comprehensive geophysical investigations for the Panama Canal Third Set of Locks Project. Mr Kaufmann is on the Board of Directors for the Environmental and Engineering Geophysical Society and is a Section Officer for the Association of Environmental and Engineering Geologists.

Cambridge University Press
978-1-107-02413-7 - Acquisition and Analysis of Terrestrial Gravity Data
Leland Timothy Long and Ronald Douglas Kaufmann
Frontmatter
[More information](#)

Cambridge University Press
978-1-107-02413-7 - Acquisition and Analysis of Terrestrial Gravity Data
Leland Timothy Long and Ronald Douglas Kaufmann
Frontmatter
[More information](#)

Acquisition and Analysis of Terrestrial Gravity Data

LELAND TIMOTHY LONG

Professor Emeritus, Georgia Institute of Technology

RONALD DOUGLAS KAUFMANN

President, Spotlight Geophysical Services



CAMBRIDGE
UNIVERSITY PRESS

Cambridge University Press
978-1-107-02413-7 - Acquisition and Analysis of Terrestrial Gravity Data
Leland Timothy Long and Ronald Douglas Kaufmann
Frontmatter
[More information](#)

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town,
Singapore, São Paulo, Delhi, Mexico City
Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK
Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9781107024137

© Leland Timothy Long and Ronald Douglas Kaufmann 2013

This publication is in copyright. Subject to statutory exception and
to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without
the written permission of Cambridge University Press.

First published 2013
Printed and bound in the United Kingdom by the MPG Books Group
A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing in Publication data
Long, L. T. (Leland Timothy)
Acquisition and analysis of terrestrial gravity data / Leland Timothy Long, Professor Emeritus,
Georgia Institute of Technology; Ronald Douglas Kaufmann, Spotlight Geophysical Services.
pages cm

Includes bibliographical references and index.
ISBN 978-1-107-02413-7
1. Gravity anomalies – Measurement. 2. Geophysical surveys. 3. Earth – Crust.
I. Kaufmann, Ronald Douglas. II. Title.
QB337.L66 2013
526'.7 – dc23 2012030766

ISBN 978-1-107-02413-7 Hardback

Cambridge University Press has no responsibility for the persistence or
accuracy of URLs for external or third-party internet websites referred to
in this publication, and does not guarantee that any content on such
websites is, or will remain, accurate or appropriate.

Cambridge University Press
978-1-107-02413-7 - Acquisition and Analysis of Terrestrial Gravity Data
Leland Timothy Long and Ronald Douglas Kaufmann
Frontmatter
[More information](#)

Dedicated to our mentors and students.

**In particular to Dr. Alan R. Sanford who instilled the importance of examining problems in
revolving detail, to Dr. Joseph W. Berg for his enthusiasm for new ideas and
participation in the science community, and to the many students who
participated in the acquisition and analysis of gravity data while at Georgia Tech
and who have continued these virtues in their work, teaching, and life.**

Cambridge University Press
978-1-107-02413-7 - Acquisition and Analysis of Terrestrial Gravity Data
Leland Timothy Long and Ronald Douglas Kaufmann
Frontmatter
[More information](#)

Contents

<i>Preface</i>	<i>page x</i>
1 Gravitational attraction	1
1.1 Universal gravitational attraction	1
1.2 Gravitational acceleration	3
1.3 Gravitational potential of a point mass	4
1.4 Gravitational potential of a solid body	5
1.5 Surface potential	7
1.6 Attraction of a sphere	8
1.7 Units of acceleration	9
2 Instruments and data reduction	10
2.1 The gravitational constant	10
2.2 Absolute measurements	11
2.3 Relative measurements	13
2.4 Instruments for gravity-gradient measurements	16
2.5 Data reduction	17
2.6 Variation with latitude	21
2.7 Atmospheric correction	24
2.8 Free air correction	24
2.9 The simple Bouguer correction	27
2.10 Terrain corrections	29
2.11 Isostatic anomaly	32
2.12 Characteristics of the different reductions	38
3 Field acquisition of gravity data	41
3.1 Introduction	41
3.2 Planning the survey	42
3.3 Suggested documentation	43
3.4 Base station network	44
3.5 Monitoring meter drift	45
3.6 Same-day data reduction	46
4 Graphical representation of the anomalous field	48
4.1 Map scale and implied accuracy	48
4.2 Map projections	51

4.3	The accuracy of gravity data measurements	52
4.4	Observational determination of precision	54
4.5	Linear interpolation of gravity data	55
4.6	Accuracy of linear interpolation	57
4.7	Optimal linear interpolation	60
4.8	Accuracy of the gravity gradient	62
4.9	Precision of a gravity map	63
4.10	The correlation and covariance functions	63
4.11	Computation of the autocovariance function	66
5	Manipulation of the gravity field	69
5.1	Objective of gravity field manipulation	69
5.2	Anomalies: regional, local, and noise	70
5.3	Smoothing	71
5.4	Examination of a three-point smoothing operator	74
5.5	Orthogonal function decomposition	76
5.6	The discrete Fourier transform	78
5.7	Least squares criteria for fitting data	86
5.8	Polynomials	87
5.9	Upward continuation	87
5.10	Numerical integration of upward continuation	91
5.11	Fourier transform continuation	92
5.12	Finite-difference methods	93
5.13	Analytical continuation	94
6	Interpretation of density structure	99
6.1	Introduction	99
6.2	Densities of rocks	100
6.3	Nettleton’s method for determination of reduction density	104
6.4	Seismic velocity as a constraint for rock density	106
6.5	Gravity anomalies from spherical density structures	107
6.6	The attraction of a thin rod	112
6.7	Attraction of a horizontal cylinder of finite length	114
6.8	The two-dimensional potential	116
6.9	Vertical sheet	117
6.10	Horizontal half-sheet	119
6.11	Two-dimensional polygonal-shaped bodies	121
6.12	Polygons of attracting mass in a horizontal sheet	125
7	The inversion of gravity data	129
7.1	Introduction	129
7.2	Depth of a basin as layer thicknesses	131
7.3	Depth in a basin as an overdetermined inverse problem	133
7.4	Stripping by layers	136

7.5	Formulation of an underdetermined inverse problem	138
7.6	The minimum length solution of the underdetermined inverse problem	138
7.7	Seismic velocity as a constraint	142
7.8	Maximum likelihood inversion	143
8	Experimental isostasy	149
8.1	The isostatic reduction	149
8.2	The isostatic response function	149
8.3	Determination of the isostatic response function	151
8.4	Interpretation of the isostatic response function	155
8.5	Example computation of the admittance and isostatic response functions	156
8.6	Isostasy in coastal plain sediments	158
	<i>Appendix A. Common definitions and equations in potential theory</i>	161
	<i>Appendix B. Glossary of symbols</i>	165
	<i>References</i>	167
	<i>Index</i>	170

Preface

Gravity data acquisition and analysis is most often presented in outline form as one of the smaller chapters in books on general geophysical exploration methods. This limited description means that the details of field techniques and data analysis are lost or greatly abbreviated and left to the individual to learn through experience. The objective of this book is to offer a detailed presentation of gravity data acquisition and analysis in a single package. The examples are taken from geophysical engineering problems as well as the analysis of regional and global data.

The objective is to completely cover the information needed for a novice to understand how and why gravity data are acquired and analyzed. A student completing a course using this text could easily acquire gravity data and would be prepared to initiate independent research on the analysis of potential data. A consulting geophysicist will find a base of both theoretical- and application-oriented information in this text, while a geologist or engineer can use this book to better understand the advantages and limitations of the gravity method. The general approach of this text has evolved over the past 20 years through experience gained from the acquisition of more than 40,000 values of gravity and in teaching courses in potential methods.

The text is intended for a wide range of users. It is written so that the basic applications are easily understood by those with limited training in mathematics. At the same time, the text occasionally introduces more advanced topics from potential theory for those with greater skills in mathematics. The text does not present extensive equations for the many possible specific models. Some simple shapes lead to complex equations that are computationally intense and generally of little practical use. Instead, the text presents the simpler models as a means of illustrating concepts or as a method of approximating structures. Sufficient background is presented in the equations and analysis techniques for those wishing to create their own more detailed models. In general, methods that allow automatic modeling of the gravity fields using approximations will be emphasized. Inversion methods are presented for the geophysicists needing more advanced analysis techniques for larger datasets.

Most texts are lacking on advice for data acquisition and the quality control needed to prevent corruption of the data. This text presents important aspects of data acquisition and provides organizational tools needed to carry out a successful survey. The text draws on examples from a wide variety of acquisition problems. They range from environmental and engineering problems, such as locating sink holes, to examples from crustal structure analysis and global gravity fields.

This book is a user's manual for those wishing to obtain and use gravity data, as well as a textbook for the introduction to more advanced concepts in tectonics and geodesy.