Preface

This is the second volume of the book series of Sciences of Geodesy. This series of reference books describes different, but complementary fields involving geodesy in seven chapters. Each chapter describes the history, theory, objectives, technology, development and highlights of the research and applications of the individual field. In addition, challenges and future directions are discussed. The subjects covered by this reference book include Computation of Green's Functions for Ocean Tide Loading, General Relativity and Space Geodesy, Global Terrestrial Reference Systems and their Realisations, Photogravimetry, Regional Gravity Field Modelling, Regularisation and Adjustment, and Very Long Baseline Interferometry for Geodesy and Astronomy.

The first volume in this series contains chapters that detail the subjects: Absolute and Relative Gravimetry, Adaptively Robust Kalman Filters with Applications in Navigation, Airborne Gravity Field Determination, Analytic Orbit Theory, Deformation and Tectonics, Earth Rotation, Equivalence of GPS Algorithms and Its Inference, Marine Geodesy, Satellite Laser Ranging, Superconducting Gravimetry and Synthetic Aperture Radar Interferometry.

The above mentioned fields cover the most active areas related to geodesy. These individual subjects are, for the first time, combined in a two-volume series thereby providing a comprehensive overview of the multi-disciplinary nature of geodesy. The series serves as a reference for teaching and learning the basic principles of many subjects related to geodesy. The material is suitable for high-level geodetic researchers, educators as well as engineers and students. Some of the chapters are written to fill voids in the current literature of the related areas. Most chapters are written by international scientists, well known in their specific field of expertise.

The chapters are arranged in alphabetical order of their titles. Summaries of the individual chapters and introductions of their authors and co-authors are as follows:

Chapter 1 "Computation of Green's Functions for Ocean Tide Loading" describes the theory and the methods of the point load problem for a radially symmetric, elastic Earth. A researcher or Ph.D. student who wants to learn more about this classic topic will find in this chapter a good starting point where all assumptions are clearly explained and where enough details are given to implement the equations into a computer program. First, the differential equations for the gravitational elastic deformations are derived from first principles. Then the boundary conditions to solve these equations are presented, and analytical solutions and numerical values of Love numbers for two simple Earth models are discussed. This chapter also contemplates the problem related to periodic loading of a model Earth with a fluid core as the period goes to infinity, the so-called Longman paradox. The degree-1 deformation, the centre-of-mass centre-of-reference problem, receives special attention. Next, several numerical methods to solve the equations are explained. Finally, the formulas for computing Green's functions are listed.

The author and co-authors of Chap. 1 are Dr. Machiel Bos and Dr. Hans-Georg Scherneck.

Machiel Bos studied Aerospace Engineering at Delft University of Technology, The Netherlands. After his graduation in 1996 he performed his Ph.D. research at Proudman Oceanographic Laboratory, Liverpool, United Kingdom. In 2001 he spent 7 months as postdoc at Onsala Space Observatory, Sweden. From 2001 to 2003 he worked as a postdoc at the Faculty of Geodesy of Delft University of Technology. From 2003 to 2008 he held a postdoc position at the Astronomical Observatory of Porto, Portugal and since 2008 he has been working at CIIMAR (Centre of Marine and Environmental Research of the University of Porto). His scientific interests include ocean tide loading, GPS time-series analysis and the geoid.

Hans-Georg Scherneck studied Physics and Geophysics at J. W. Goethe University in Frankfurt/M., Germany. He received a Ph.D. degree in geodesy from Uppsala University in 1986. In 1993 he joined the Department of Earth and Space Science at Chalmers University of Technology, Gothenburg, Sweden. He holds a Docent degree (associate professor) in geodynamic measurement techniques and occupies a position as a Lecturer. His major research interests are the use of gravity and space geodetic techniques in application to solid earth deformation, most prominently Glacial Isostatic Adjustment.

Chapter 2 "General Relativity and Space Geodesy" introduces the general and special relativity theory as it is applied to space geodesy. Section 1 sketches some basic implications of GRT for space geodesy and the need to incorporate GRT in all high accuracy space geodetic applications. Section 2 discusses GRT implications for satellite laser ranging, specifically the Shapiro delay and accelerations as described by the Schwarzschild field, Lense–Thirring precession (frame dragging) and de Sitter (geodesic) precession. A short discussion on using SLR to test the effects of GRT is included and Sect. 2 is concluded with sections on lunar laser ranging and interplanetary laser ranging. Special and general relativity theory considerations for GPS are discussed in some detail in Sect. 3, including reference frame issues, effects on GPS satellites' clocks and how GRT corrections are incorporated. Section 4 consists of a short overview of VLBI estimates of parameterised post-Newtonian parameter Gamma.

The author of Chap. 2 is Dr. Ludwig Combrinck of the Hartebeesthoek Radio Astronomy Observatory (HartRAO) located near Krugersdorp, South Africa, a facility of the National Research Foundation (NRF). Ludwig Combrinck was awarded a Ph.D. by the University of Cape Town in 2000; his thesis focussed on GNSS applications for precise positioning. He is responsible for the Space Geodesy Programme at HartRAO, which includes the NASA satellite laser ranging station, MOBLAS-6. In 2009 he was appointed as Professor-extraordinaire at the University of Pretoria. His main research interests currently include applications of space geodetic techniques, specifically related to tests of general relativity theory, reference frame development for Africa and the development of a new high accuracy satellite and lunar laser ranger for South Africa. His diverse interests in the applications of space geodesy have resulted in the establishment of geodetic stations throughout Africa, Marion Island and Antarctica, in collaboration with international partners.

Chapter 3 is entitled "Global Terrestrial Reference Systems and their Realizations". It is organised in six parts. In Sect. 1 the authors give an introduction and address the key role of geodetic reference systems and frames for measuring the surface structure, the rotation and the gravity field of the Earth along with its variations in time, which is a prerequisite for Earth system studies and for the monitoring of physical processes of global change. The next section provides some basic concepts and fundamentals for the definition and realisation of reference systems. Section 3 deals with the International Terrestrial Reference System (ITRS), its definition and the conventional modelling of station positions and displacements of reference points, which materialise the system. The next two sections focus on its realisation, the International Terrestrial Reference Frame (ITRF), which is the key topic of this chapter. Thereby Sect. 4 provides some general information and gives an overview about the history and the latest developments in the field of global terrestrial reference frame realisations. Section 5 deals with the latest realisation, the ITRF2008, which has been computed from a combination of time series of station positions and Earth orientation parameters from VLBI, SLR, GPS and DORIS observations. In the last section, the present status of the terrestrial reference frame computations is discussed and challenges for future improvements are provided.

The author and co-authors of Chap. 3 are Dr. Detlef Angermann, Dr. Manueal Seitz and Prof. Dr. Hermann Drewes.

Detlef Angermann has been senior research scientist at Deutsches Geodätisches Forschungsinstitut (DGFI) in Munich since 1999. He graduated in geodesy from University Hannover in 1985 and received his Ph.D. from Technical University in Berlin in 1991. He occupied the following positions: Scientific Assistant at Technical University in Berlin (1985–1990); research scientist at DGFI (1990–1992); senior scientist at GeoForschungsZentrum (GFZ) Potsdam (1992–1999); senior scientist at DGFI (since 1999), where he has been head of the research field "Earth system observations" since 2002. Major areas of scientific interests are GNSS and SLR data analysis for geodetic research and geodynamics, the combination of space geodetic techniques and the realisation of geodetic reference systems. He served as chair and as a member in various sub-commissions and working groups of the International Association of Geodesy (IAG) and as a principal investigator of various research projects at DGFI. In 2009, he was nominated as the Secretary of the GGOS Bureau for Standards and Conventions and took over the responsibility of the Director in 2011.

Manuela Seitz studied Geodesy at the Technische Universität Dresden (TUD). After her graduation in 2001 she joined the Deutsches Geodätisches Forschungsinstitut (DGFI) in Munich, where she collaborated on various projects in the field of combination of space geodetic techniques for the realisation of reference systems. She developed strategies for the realisation of the International Terrestrial Reference System (ITRS) on the basis of normal equations for which she obtained her doctorate from TUD in 2008. In addition to her research activities she was strongly involved in the computation of the DGFI solution of the International Terrestrial Reference Frame ITRF2005 and was responsible for the computation of the recent realisation DTRF2008. Her main scientific interests are the global as well as regional realisation of the ITRS as well as the consistent realisation of terrestrial and celestial reference systems. Her focus of attention also comprises the development of combination strategies for the generation of other combined geodetic products, e.g., Earth orientation parameter or tropospheric parameter series.

Hermann Drewes is the Secretary General of the IAG and the past Director of the German Geodetic Research Institute (Deutsches Geodätisches Forschungsinstitut, DGFI), Munich, Germany. He graduated (Dipl.-Ing.) and received his doctor's degree (Dr.-Ing.) from Technische Universität Hannover, Germany, where he worked as assistant professor and chief engineer. From 1977 to 1979 he was a professor at Universidad del Zulia in Maracaibo, Venezuela. His scientific work concentrated at that time on precise gravimetry and geoid determination. In 1979 he moved to DGFI and changed the field of research to geodynamics and geodetic reference systems. In parallel he got a lectureship at Technische Universität München (TUM) and at Universität der Bundeswehr, München. In 1994 he became the Director of DGFI and received an honorary professorship at TUM. From 1995 to 2003 he was at first the Secretary and then the President of the IAG/COSPAR Commission on Space Techniques for Geodesy and Geodynamics (CSTG), and from 2003 to 2007 the President of the IAG Commission on Reference Frames. Since 1994 he has been the IAG representative to the Sistema de Referencia Geocéntrico para las Américas (SIRGAS), and since 2003 the representative of IUGG to the Pan-American Institute for Geography and History (PAIGH). In 2007 he became the IAG Secretary General. In the same year he was awarded the Order of Merit of the Federal Republic of Germany.

Chapter 4 "Photogrammetry" gives an overview about the methods and applications of aerial photogrammetry, focusing on those for geoinformation acquisition. After a short introduction in Sect. 1, three sections follow: Image Acquisition, Image Georeferencing and Image Processing. Large format analogue and digital aerial cameras are described in Sect. 2, as well as the aspects to consider when planning a photo flight. Section 3 deals with several strategies for establishing a georeference for aerial images considering the cases of frame and line scanner images. Spatial resection, ground and GNSS supported triangulation and GPS/IMU supported photo flights are presented in this section. Section 4 describes the most important photogrammetric products and how they are obtained today: line maps, 3-D elevation models, 3-D urban models, orthophotos and realistic virtual models.

The author of Chap. 4 is Prof. Dr. Paula Redweik. She is an Assistant Professor at the Faculty of Sciences of the University of Lisbon, Portugal, in the Department of Geographic Engineering, Geophysics and Energy. She is also a researcher at the Centre of Geology of the same faculty. After obtaining a B.Sc. in Mathematics in 1983 and a degree in Geographic Engineering from the University of Lisbon in 1985, she worked as a researcher in the Institut für Photogrammetrie und Ingenieurvermessungen (IPI) of the University of Hannover, Germany, where during 1993 she obtained a Ph.D. in Photogrammetry. Since 1993 she has been responsible for the education in photogrammetry in several bachelor and master courses at the University of Lisbon; currently, she is the coordinator of the Geographic Engineering bachelor course. She worked in projects for modelling coastal retreat and has supervised M.Sc. theses and co-supervised Ph.D. theses in this subject. She is co-author of one book (two volumes) about topography and several papers on different applications of photogrammetry.

Chapter 5 "Regional Gravity Field Modeling: Theory and Practical Results" gives an overview of high-precision gravity field modelling on a provincial to national and continental scale. In this context, the geoid and quasigeoid are of major interest, e.g., for the transformation between the purely geometric GNSS (Global Navigation Satellite System) ellipsoidal heights and physical heights in geodesy, for the modelling of dynamic ocean topography, as well as for geophysical applications, requiring accuracies at the level of about 1 cm or even below. After the motivation, some fundamentals of physical geodesy are provided, including reference systems, basic gravity field properties, the geoid and height systems, the normal gravity field, as well as some remarks about temporal gravity field variations, tidal systems and atmospheric effects; the intention of this section is to provide the basics for regional gravity field modelling with as few approximations as possible. The next section covers the methodology of gravity field modelling, where the disturbing potential is the primary quantity of interest; in particular, geodetic boundary value problems, the linearisation of the boundary conditions (observation equations), the spherical and constant radius approximations and the associated classical integral formulas of Poisson, Hotine and Stokes, solutions of Molodensky's and Stokes's boundary value problem, the spectral combination approach, least squares collocation, astronomical leveling, as well as the remove-compute-restore technique are described, the latter providing the basis for regional computations. The subsequent section gives some practical results related to the European geoid and quasigeoid calculations carried out at the Institut für Erdmessung (IfE), Leibniz Universität Hannover (LUH), Germany; the data requirements, the collected gravity field data sets and the development and evaluation of the European Gravimetric (Quasi) Geoid model EGG2008 are discussed. Finally, a short summary of the results and an outlook are given.

The author of Chap. 5 is Dr. Heiner Denker, a senior scientist employed at the Leibniz Universität Hannover (LUH), Germany. His major areas of scientific interest are regional and global gravity field modelling (especially geoid and quasigeoid), including the combination of terrestrial and satellite data, vertical reference systems and height determination, as well as geodynamics research. Heiner Denker graduated in 1984 from Universität Hannover (now LUH) and received a Ph.D. in 1988, also from Universität Hannover. In 1989 he was employed as a researcher at The Ohio State University, Columbus, U.S.A., where he investigated the global analysis of satellite altimeter data for dynamic ocean topography estimation. At the end of 1989, Heiner Denker returned to Universität Hannover on a permanent position, where he specialised in gravity field modelling and has given lectures since 1996, covering the areas of physical geodesy, advanced physical geodesy, geometric geodesy and signal analysis. Since 1990, Heiner Denker has been responsible for the computation of the geoid and quasigeoid in Europe, a task supported by the International Association of Geodesy (IAG) in different ways, presently as IAG Sub-Commission 2.4a "Gravity and Geoid in Europe" (Chair: H. Denker). Furthermore, he chaired an IAG Special Study Group, has been a member of several special study groups as well as the advisory boards of some IAG bodies, and since 2008 he has served as Associate Editor for "Geodetic Theory and Applications" of the scientific journal "Marine Geodesy".

Chapter 6 "Regularization and Adjustment" consists of two parts. The first part focuses on regularised solutions for ill-posed problems, while the second provides an overview of the adjustment theory. Following a brief introduction in the first part of the chapter, unstable and ill-posed problems, regularisation algorithms and determination of the regularisation parameters (including suitable examples) are discussed. In the second part, least squares adjustment, sequential application of least squares adjustment via accumulation, sequential least squares adjustment, conditional least squares adjustment, a sequential application of conditional least squares adjustment, block-wise least squares adjustment and a sequential application of block-wise least squares adjustment are described. In addition, an equivalent algorithm to form the eliminated observation equation system and the algorithm to diagonalise the normal equation and equivalent observation equation, a priori constrained adjustment, a priori datum method and a quasi-stable datum method are discussed, before a short summary.

The author and co-author of Chap. 6 are Prof. Dr. Yunzhong Shen and Dr. Guochang Xu.

Yunzhong Shen is a professor in the Department of Surveying and Geo-informatics Engineering of Tongji University where he was the dean from 2003 to 2006. He graduated from Tongji University with a bachelor's degree in Surveying Engineering in 1983, and obtained his master's degree in Geodetic Data Processing in 1986 and a Ph.D. degree in Geophysical Geodesy in 2001 from the Institute of Geodesy and Geophysics. He is an editor of "Acta Geodetica et Cartographica Sinica". His main research interests are theory of geodetic data processing, satellite positioning and satellite gravimetry. He was a visiting member of the staff of Stuttgart University in Germany (1999–2000), visiting scientist of

GeoForschunsZentrum GFZ Potsdam (8.-11.2006), research fellow of Hong Kong Polytechnic University (5.-6.2008) and professorial visiting staff in Queensland University of Technology (5.-6.2009). In the past 5 years, he has published more than 40 refereed journal papers in geophysical geodesy, GNSS theory and application, geodetic data processing theory, of which six papers have appeared in Journal of Geodesy, four in GPS Solutions, and the others in J Surveying Engineering, Chinese Science Bulletin etc.

After graduating in Mathematics and Geodesy from Wuhan University and the Chinese Academy of Sciences (CAS) in 1982 and 1984 respectively, I, Guochang Xu, obtained the Dr.-Ing. degree from the Technical University (TU) Berlin in 1992. Having worked as a research associate at the TU Berlin from 1986 to 1993, as a scientist at the GFZ Potsdam from 1993 to 1998 and as a senior scientist at the National Survey and Cadastre, Denmark, from 1998 to 1999, I returned to GFZ as a senior scientist in 1999. I have authored and co-authored several scientific books and software and acted as supervisor of several Ph.D. and post-doctoral studies. From 2003 to 2008 I was an overseas assessor, adjunct professor, and winner of an overseas outstanding scholar fund of CAS. I have been an overseas communication assessor of Education Ministry China since 2005, adjunct professor of Chang'an University since 2005, National Time Service Center, CAS, Neubrandenburg University of Applied Sciences since 2009, and National Distinguished Expert of Chinese Academy of Space Technology since 2010. In 2011 I was honoured by an appointment as an honorary professor by the South-west Jiaotong University.

Chapter 7 entitled "Very Long Baseline Interferometry for Geodesy and Astrometry" provides an overview of this space geodetic technique which is essential for the determination of the complete set of Earth orientation parameters as well as for the celestial reference frame. After an introduction in Sect. 1 with information about the concept of VLBI and the historical and technological developments, the computation of the delays is discussed in detail in Sect. 2. It covers all models necessary to reach mm-accuracy of the theoretical delays. Section 3 deals with the least squares adjustment which is widely used for the estimation of geodetic parameters in VLBI analysis, such as the Earth orientation parameters, the celestial reference frame expressed by radio source coordinates, or the terrestrial reference frame realized by station coordinates. VLBI observations are coordinated globally by the International VLBI Service for Geodesy and Astrometry (IVS; Sect. 4), and ideas and plans for VLBI2010, the next generation VLBI system, are given in Sect. 5.

The author and co-author of Chap. 7 are Prof. Dr. Harald Schuh and Prof. Dr. Johannes Böhm.

Harald Schuh is a full professor and Director of the Institute of Geodesy and Geophysics, Vienna University of Technology, Austria. Major areas of scientific interest are Very Long Baseline Interferometry (VLBI), Earth rotation, investigations of the troposphere and ionosphere. He graduated in 1979 from Bonn University, Germany and received his Ph.D. in 1986. He occupied the following positions: Scientific assistant and associate professor at Bonn University (1980–1988); program scientist at the German Air and Space Agency (1989–1995), senior scientist and head of the Earth Rotation Division at DGFI, Munich (1995–2000); Chair of the IVS Directing Board since 2007; President of IAU (International Astronomical Union) Commission 19 “Rotation of the Earth” (2009–2012); President of the Austrian Geodetic Commission since 2008 and President of the Austrian National Committee of the IUGG since 2009; Vice-President of the IAG (International Association of Geodesy) since 2011; member of various directing and governing boards; editorial board of the Journal of Geodesy (2003–2007), and served as president, chair, member or consultant of various commissions, sub-commissions and working groups in geodesy (IAG) and astronomy (IAU); coordinator of the German Research Group on Earth Rotation (1999–2003); supervisor, co-supervisor, or examinator of more than 25 dissertations. In 2009 Harald Schuh received the degree of a doctor honoris causa (Dr. h.c.) and in 2011 the Vening-Meinesz Medal of the European Geosciences Union.

Johannes Böhm is associate professor at the Institute of Geodesy and Geophysics, Vienna University of Technology, Austria, where atmospheric effects in space geodesy and very long baseline interferometry (VLBI) are his main fields of interest and research. In 1999 he graduated from the Vienna University of Technology with a thesis about modern geopotential models and received his Ph.D. in 2004 with a dissertation on troposphere delays in VLBI. Troposphere delay modelling for all space geodetic techniques at radio wavelengths with the application of numerical weather models was the topic of his habilitation thesis in 2008. Johannes Böhm is President of IAG Sub-Commission 1.4 “Interaction of Celestial and Terrestrial Reference Frames”, and he has been chair or member of various working groups of the IVS and the IAG. He has been on the editorial board of Journal of Geodesy since 2007 and has been leading various research projects related to VLBI at the Vienna University of Technology. Johannes Böhm received the Guy Bomford Prize of the IAG in 2011.

The book has been subjected to an individual review of chapters. I am grateful to reviewers Prof. Trevor Baker of the Proudman Oceanographic Laboratory in the United Kingdom, Dr. Bert Vermeersen of Technical University Delft, Dr. Roberto Peron of the Institute of Physics of Planetary Space (IFSI-INAF) in Rome, Prof. Zhiping Lü and Dr. Xiguang Zhang of Zhengzhou Institute of Surveying and Mapping (ISM), Prof. Shulong Zhu of Zhengzhou ISM, Prof. Rene Forsberg of Danish Space Centre, Dr. Karsten Jacobsen, Dr. Ludger Timmen of the University Hannover, Prof. Wolfgang Torge and Dipl.-Ing. Christian Voigt of the Leibniz Universität Hannover, Prof. Bernhard Heck of Karlsruher Institut für Technologie, Prof. Guigen Ni of the Information Engineering University (IEU) in Zhengzhou, Prof. Yuanxi Yang and Dr. Tianhe Xu of the Institute of Surveying and Mapping (ISM) in Xi’an, Dr. Axel Nothnagel of the University Bonn, Prof. Ludwig Combrinck of the Hartebeesthoek Radio Astronomy Observatory (HartRAO), Dr. Svetozar Petrovic, Dr. Monika Korte, and Dr. Matthias Förster of GFZ. As editor I made a general review of the whole book. A grammatical check of technical English writing has been performed by Springer Heidelberg.

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