The Inter-Commission Committee on Theory of the International Association of Geodesy

Final Report

Period covered: 2007-2011

March 2011

Inter-Commission on Theory (ICCT)

http://icct.kma.zcu.cz

President: Nico Sneeuw (Germany)
Vice President: Pavel Novák (Czech Republic)

Structure

IC-SG1: Theory, Implementation and Quality Assessment of Geodetic Reference Frames
IC-SG2: Quality of Geodetic Multi-Sensor Systems and Networks
IC-SG3: Configuration Analysis of Earth Oriented Space Techniques
IC-SG4: Inverse Theory and Global Optimization
IC-SG5: Satellite Gravity Theory
IC-SG6: InSAR for Tectonophysics
IC-SG7: Temporal Variations of Deformation and Gravity
IC-SG8: Towards cm-accurate Geoid – Theories, Computational Methods and Validation
IC-SG9: Application of Time Series Analysis in Geodesy

Overview

The Inter-Commission Committee on Theory (ICCT) was formally approved and established after the IUGG XXI Assembly in Sapporo, 2003, to succeed the former IAG Section IV on General Theory and Methodology and, more importantly, to interact actively and directly with other IAG entities.

The main objectives of the ICCT are:
- to be the international focal point of theoretical geodesy,
- to encourage and initiate activities to further geodetic theory,
- to monitor research developments in geodetic modelling.

The structure of the ICCT is specified in the IAG by-laws. The ICCT Steering Committee consists of the President, the Vice-President and representatives from all IAG Commissions:

President: Nico Sneeuw (Germany)
Vice-President: Pavel Novák (Czech Republic)
Representatives:
Commission 1: Zuheir Altamimi (France)
Commission 2: Pieter Visser (The Netherlands)
Commission 3: Richard Gross (USA)
Commission 4: Sandra Verhagen (The Netherlands)

After the IUGG General Assembly in Perugia (held in July 2007), a structure of nine ICCT Study Groups was created. They are denoted as IC-SG1 to IC-SG9, see the list above. The new structure, terms of reference, objectives and program of activities for the 2007-2011 period were presented in the Geodesist's Handbook 2008 published in the *Journal of Geodesy* (J Geod 82: 783-792, November 2008).

Website of ICCT

During the fall of 2007, the new ICCT Website was also established at: http://icct.kma.zcu.cz. The website is located at the web server of the Department of Mathematics, University of West Bohemia in Pilsen, and is powered by the MediaWiki Engine (similar to that used for the Wikipedia, a free, web-based multilingual encyclopaedia project). Due to this setup, the content of the ICCT Website can easily be edited by any authorized personnel (members of the ICCT Steering Committee and Chairmen of the Study Groups). Thus, the website can be used by for fast and easy communication of ideas among the members of the Study Groups. During 2008 the latest Study Group was established (IC-SG9), i.e., there are currently nine active Study Groups within the ICCT.

Steering Committee

During the 2007-2009 period, the ICCT Steering Committee organized two meetings. The ICCT Splinter Meeting was held during the IAG International Symposium on *Gravity, Geoid and Earth Observation* in Chania (June 2008). The agenda of the meeting included these issues: the information of the ICCT President on the structure of the ICCT, organization of the Hotine-Marussi Symposium in 2009, the new website of the ICCT and short reports of the present chairmen of the ICCT Study Groups. The second meeting of the ICCT Steering Committee was organized during the VII Hotine-Marussi Symposium in Rome (July 2009). The committee was almost complete with the ICCT President, Vice-President, three of four commission representatives and six of nine Study Group Chairmen attending the meeting. The business meeting took place at the Academia Nazionale dei Lincei in Rome on July 8, just in the middle of the VII Hotine-Marussi Symposium. The program of the meeting included the evaluation of the first part of the Hotine-Marussi Symposium and the mid-term report of the ICCT to the IAG. The SG Chairmen attending the business meeting presented shortly reports of their Study Groups for the 2007-2009 period and outlined plans for the next two-year period (until 2011).

Hotine-Marussi Symposium 2009

The highlight of the ICCT activities in 2009 was the organization of the VII Hotine-Marussi Symposium in Rome, 6-10 July 2009. The conference was organized by the ICCT with the strong support from the local organizing committee under the leadership of Mattia Crespi, University La Sapienza in Rome. The five-day program of the Symposium consisted of eight sessions covering research areas of all nine ICCT Study Groups, namely:

- Geodetic sensor systems and sensor networks (Verhagen)
- Estimation and filtering theory, inverse problems (Kutterer, Kusche)
- Time series analysis and prediction of multi-dimensional signals (Kosek, Schmidt)
- Geodetic boundary-value problems and cm-geoid computational methods (Wang, Novák)
- Satellite gravity theory (Mayer-Gürr, Sneeuw)
- Earth-oriented space techniques and their benefit for Earth system studies (Seitz, Gross)
- Theory, implementation and quality assessment of geodetic reference frames (Dermanis, Altamimi)
- Temporal variations of deformation and gravity (Spada, Crespi, Wolf)

Additionally, a special session was organized at the Academia Nazionale in commemoration of Antonio Marussi (Sansò). The program of the conference consisted of 52 oral presentations

(12 of them invited) and approximately of 50 posters. In total, 112 participants from 20 countries attended the VII Hotine-Marussi Symposium.

Further Meetings

The Hotine-Marussi Symposium was not the only scientific meeting with the visible presence of the ICCT. At the last two EGU General Assemblies in Vienna (2008, 2009), sessions on recent developments in geodetic theory were co-organized and co-convened by the ICCT President. The ICCT Vice-President is a member of the Scientific Committee of the next IAG Scientific Meeting held in Buenos Aires, September 2009. The ICCT was also present through its Working Groups at other meetings, see their respective reports below. The Study Group 1 organized the IAG School on Reference Systems that was held for the period June 7 - 12, 2010 at the facilities of the Aegean University at Mytilene, Island of Lesvos, Greece. The Study Groups 2 and 3 jointly organized the 1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems (QuGOMS'11), 13–15 April 2011 in Munich.

Summary

The activities of the ICCT are related namely to the research carried out by members of its Study Groups. Their final reports specify the areas investigated by the members of the Study Groups, achieved results (publications and presentations) and plans for the future work. All the SG Chairmen (but two) submitted their reports that can be found at the following pages. Based on the content of the reports, it can be concluded that the Study Groups are active, although the level of mutual co-operation and/or interaction between its members is not necessarily the same for all the Study Groups.

IC-SG1: Theory, Implementation and Quality Assessment of Geodetic Reference Frames

Chair: A. Dermanis (Greece)

Introduction

This document presents a status report of the work undertaken by the ICCT Study Group IC-SG1 since its creation in 2007 after the IUGG General Assembly in Perugia. It is a joint Study Group of the ICCT, the IAG Commission 1 (Reference Frames) and the IERS (International Earth Rotation and Reference Systems Service).

Primary Objectives of the Study Group

The primary objectives of this SG have been the following:

- Study of models for time-continuous definitions of reference systems for discrete networks with a non-permanent set of points and their realization through discrete time series of station coordinate functions and related earth rotation parameters.
- Understanding the relation between such systems and reference systems implicitly introduced in theories of earth rotation and deformation.
- Extension of ITRF establishment procedures beyond the current linear (constant velocity) model, treatment of periodic and discontinuous station coordinate time series, understanding of their geophysical origins and related models.
- Understanding the models used for data treatment within each particular technique, identification of possible biases and systematic effects and study of their influence on the combined ITRF solution. Study and improvement of current procedures for the merging of data from various space techniques.
- Statistical aspects of reference frames, introduction and assessment of appropriate quality measures.

Current Membership Structure

A. Dermanis (Greece) – chair
Z. Altamimi (France)
L. Biagi (Italy)
G. Blewitt (USA)
C. Boucher (France)
X. Collilieux (France)
H. Drewes (Germany)
T. Herring (USA)
C. Kotsakis (Greece)
D. Lavallee (UK)
A. Nothnagel (Germany)
E. Pavlis (USA)
G. Petit (France)
J. Ray (USA)
F. Sansò (Italy)
P. Willis (France)

Activities of the Study Group

IAG School on Reference Systems

The main and most important activity of the Study Group has been the organization of the First IAG School on Reference Systems, on June 7-12 2010. The School was hosted by the Department of Geography of the Aegean University in Mytilene, Lesvos Island, Greece. The School has been realized thanks to the generous financial support of the School of Rural and Surveying Engineering, Faculty of Engineering, Aristotle University of Thessaloniki.

The scope of the School has been twofold: First, to introduce young researchers to the theoretical-methodological and operational problems within various aspects and techniques of establishing global reference frames. Secondly, to give the opportunity to more experienced researches working on a particular field within global reference frame establishment, to gain a more general perspective and deeper understanding of the various tools and aspects within neighboring research fields. Furthermore, the School aspired to provide a forum for discussion and exchange of experiences and ideas for researchers working on adjacent fields in order to facilitate a wider understanding of the various problems and peculiarities. This has been achieved by providing adequate time for discussion within the lectures.

The School was attended by 58 students from 19 countries. Some came from as far as Australia, North America and South Korea. The participation may be judged as unusually large in comparison to that of other IAG Schools, thus reflecting the great interest in the topic and the need for more Schools in the future, preferably in other parts of the world.

The topics covered were *"Basic Concepts of Reference Systems in Geodesy, Astronomy and Geophysics"* (A. Dermanis), *"SLR Data Analysis for Terrestrial Reference Frame Development"* (E. Pavlis), *"Models and Strategies for Global VLBI Networks"* (T. Herring), *"Models and Strategies for Global GNSS Networks"* (T. Herring), *"Models and Strategies for Global DORIS data analysis"* (P. Willis), *"Reference Frame Combination and Time Series Analysis"* (Z. Altamimi) and *"Height Systems"* (M. Sideris). In addition to the taught material the students had the opportunity of familiarization with software currently used for the analysis of data either within each particular space technique or for the implementation of the International Terrestrial Reference Frame.

More details of the School, including the program, a detailed description of each lecture, as well as the lecture notes and other distributed material can be found at the School web page: http://www.topo.auth.gr/IAG2010_RefSchool/

Meetings of the Study Group

Due to very limited overlap of the presence of members in the various scientific meetings no actual meeting of the study group has been realized.

Conference Sessions

- VII Hotine-Marussi Symposium, Rome July 06-10, 2009.
  Session 7: Theory, implementation and quality assessment of geodetic reference frames.
  Conveners: A. Dermanis, Z. Altamimi.
- IAG Commission 1 Symposium 2010, Reference Frames for Applications in Geosciences (REFAG2010), Paris 4-8 October 2010.

Session 1: Theory and realization of global terrestrial reference systems
Conveners: Claude Boucher, David Coulot.

Study Group Webpage

A web page of the study group has been established at: http://der.topo.auth.gr/sgrf. The web page contains the terms of reference, objectives, membership and program of activities of the study group.

Future Activities

A number of theoretical problems remain unsolved and can be the subject of future research. To mention a few:

- Inclusion of non-linear periodic terms in the ITRF coordinate model.
- Comparison of the various strategies for ITRF formulation, taking into account the non-validity of the Gauss-Markov model (systematic biases and colored noise).
- Development of efficient models for geophysical effects and the corresponding data reduction.

The most important activity though is the organization of IAG Schools on Reference Systems in a more-or-less regular basis.

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Willis P., Lemoine F., Soudarin L. (2007), Looking for systematic errors in scale from terrestrial reference frames derived from DORIS data, in Dynamic Planet - Monitoring and Understanding a Dynamic Planet with Geodetic and Oceanographic Tools, P. Tregoning, C. Rizos, (Eds.), IAG Symposium, 130:143-151. DOI: 10.1007/978-3-540-49350-1_23

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IC-SG2: Quality of Geodetic Multi-Sensor Systems and Networks

Chair: H. Kutterer (Germany)

Introduction and Primary Objectives of the Study Group

Modern geodetic observations are usually embedded in an integrated approach based on multi-sensor systems and networks. The fields of application are as manifold as the sensors in use. For example, total stations, GPS receivers and terrestrial laser scanners are applied in engineering geodesy for structural monitoring purposes together with permanently installed equipment. Geometric and physical space-geodetic sensors may serve as a second example since they are used for the determination of global reference frames. This report comprises some relevant research in theory (uncertainty modeling and propagation, recursive state-space filtering) and applications (design, implementation and validation of multi-sensor systems) which has been carried out during the last four years.

Membership Structure

H. Kutterer (Germany) – chair
O. Akyilmaz (Turkey)
H. Alkhatib (Germany)
A. Eichhorn (Germany)
I. Neumann (Germany)
V. Schwieger (Germany)
J. Wang (Australia)
Y. Yang (China)

Activities of the Study Group

The field of uncertainty modeling and propagation is of interest in many disciplines. It also concerns international standardization activities in the field of metrology. Here, an approach is broadly used which is based on stochastics – more or less on Bayesian theory in a very technical way (ISO, 1995; ISO, 2007). As this approach relies on a special interpretation of uncertainty – and is more or less restricted to uncertainty measures for scalar measurement results – alternative approaches are of increased interest. Alkhatib et al. (2009) consider the joint modeling and propagation of two major types of data uncertainty – random variability and imprecision – of vector quantities. For the modeling of random variability a Bayesian approach in combination with Monte-Carlo simulations is used. In contrast, imprecision is modeled using fuzzy theory which allows a more flexible concept of uncertainty propagation. The analysis of fuzzy data is described, e.g., in Viertl (1996); see Neumann (2009) for some recent developments in Geodesy. Note that Koch (2008a, b) studied uncertainty propagation in a rigorous Bayesian framework. Meanwhile, extended studies which are based on real data from Terrestrial Laser Scanning (TLS) revealed non-normality in observed TLS profile time series (Kutterer et al., 2010) which has to be modeled accordingly.

For state-space filtering recursive algorithms are of major interest as they provide the basis for real-time applications. The classical Kalman filter is the most prominent example. In order to take deviations from the normality and linearity assumptions into account, several extensions have been studied. Alkhatib et al. (2008) compare the so-called extended Kalman filter (use of functional 2^{nd} order terms), the unscented Kalman filter (use of so-called sigma points to approximate a non-normal distribution) and the particle filter (Monte-Carlo solution of a

Bayesian state-space filter). Meanwhile, this work has been extended with respect to both efficiency and the use of adaptive parameters in the system equations (Alkhatib et al., 2011). Vennegeerts and Kutterer (2009) consider efficiency issues of the algorithmic variance-covariance propagation of geometric mass data (3D point clouds) which are observed using a kinematic multi-sensor system (GPS, INS, terrestrial laser scanner). Work in the field of data-driven modeling of time-variable systems based on a Neuro-Fuzzy approach for application in Earth orientation prediction is presented by Akyilmaz et al. (2010).

Kutterer and Neumann (2009, 2010) develop a Kalman filter extension and a recursive least-squares estimation with respect to data imprecision. Here, the set-theoretical overestimation is the main problem as in recursive formulations some information on data dependencies gets lost. In case of fuzzy data – defining fuzzy vectors by the so-called minimum principle – this yields true supersets of the correct fuzzy state-space vectors. Hence, the obtained uncertainty measures are only upper bounds of the true ones. In linear estimation problems this problem is easily overcome if the observation data uncertainty is strictly referred to originally independent uncertain influence quantities. Hence, the same idea has been applied to state-space recursion which has consequently been resolved for the uncertainty propagation. In this case it is also possible to introduce adaptive system parameters.

The theoretical developments on uncertainty modeling and state-space filtering have been supported by R&D work on kinematic multi-sensor systems using a terrestrial laser scanner as the main sensing device (see, e.g., Paffenholz et al., 2010).

Ongoing Activities

Together with IC-SG3, IC-SG2 has been organizing QuGOMS 2011 (1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems) in Garching/Germany. This IAG-sponsored workshop will take place in 2011, April 13-15, and it is co-sponsored by FIG – IAG Springer proceedings are scheduled. Closely related methodological issues in engineering geodesy and Earth system observation will be addressed by ten invited speakers and about 40 contributed papers. Its main purpose is to gather experts in this field to stimulate new discussions on theory and methodology for geodetic observation and monitoring; requests from the applications are taken into account.

Study Group Webpage

The webpage of the group is http://icct.kma.zcu.cz/index.php/IC_SG2

Publications

Akyilmaz, O, Kutterer, H, Shum, CK, Ayan, T (2010) Fuzzy-wavelet based prediction of Earth rotation parameters. Applied Soft Computing, Elsevier (http://dx.doi.org/10.1016/j.asoc.2010.01.003).

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Kutterer, H, Alkhatib, H, Paffenholz, J-A, Vennegeerts, H (2010) Monte-Carlo Simulation of Profile Scans from Kinematic TLS. In: Proc. XXIV FIG International Congress 2010: Facing the Challenges – Building the Capacity. Sydney, Australia, April 2010.

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IC-SG3: Configuration Analysis of Earth Oriented Space Techniques

Chair: F. Seitz (Germany)

Introduction

This document presents a status report of the work undertaken by the ICCT Study Group IC-SG3 since its creation in 2007. Activities of the study group Configuration Analysis of Earth Oriented Space Techniques are focussed on the application and combination of modern space-based Earth observation systems for studies related to Earth system science. A multitude of simultaneously operating satellite systems with different objectives is available today. Various sensors offer a broad spectrum of information on geodynamic processes within and/or between individual components of the Earth system in different temporal resolutions and on different spatial scales. The general objective of this study group is the development of strategies how the available information from complementary and redundant observation systems can be combined and analysed in order to answer up-to-date scientific questions in the context of geodetic Earth system research.

Primary Objective of the Study Group

The observations of most space-based geodetic observation techniques are influenced by various dynamical processes in the Earth system that are involving transports and redistributions of masses as well as the exchange of energy and angular momentum. In order to separate the observations into contributions of individual processes, a combination of sensors that are unequally sensitive to different processes is indispensable. Based on this background the development of strategies for multi-sensor approaches is the primary goal of the study group. Investigations deal with the question in which way heterogeneous data sets can be combined in an optimal way in order to identify and quantify the contributions of particular processes. This way the study group aims on fostering and improving the understanding of the Earth system by creating more reliable information on processes and interactions in the subsystems of the Earth. This is especially necessary in view of studies related to global change.

Among the most important tasks are the compilation and assessment of background information for individual systems and sensors (mode of operation, sensitivity, accuracy, deficiencies) as well as theoretical studies, which (new) information on the Earth system can be gained from a combination of different observation methods. Furthermore the work comprises theoretical studies on combination strategies and parameter estimation. The study group provides a forum for researchers from various fields of space geodesy and geophysics in order to discuss theoretical and computational aspects of sensor combination. Special attention of the research is turned to methodology and data analysis.

Common research the study group is reflected by various common publications and presentations of its members (see below). The activities are also supported by third party funds in the form of two major projects: The Deutsche Forschungsgemeinschaft (DFG) and the International Graduate School of Science and Engineering (IGSSE) of the Technische Universität München support the research activities on the field of the study group with a total of four positions and scholarships for PhD students for periods between 2 and 3 years. These funds resulted from common project proposals of the SG members F. Seitz, M. Schmidt, F. Meyer and K. Hedman.

Current Membership Structure

F. Seitz (Germany) – chair
S. Abelen (Germany)
J. Dickey (USA)
K. Hedman (Sweden)
F. Meyer (USA)
M. Motagh (Germany)
M. Schmidt (Germany)
M. Seitz (Germany)
A. Singh (India)
X. Wang (Germany) – until 2009

Activities of the Study Group

Conference Contributions of SG Members

Abelen, S., K. Hedman, F. Seitz: Contributions from different Water Storage Compartments to total Storage Change from Multi-Sensor Analysis. *German Geodetic Week*, Cologne, Germany, 7.10.2010.

Abelen, S., F. Seitz, A. Güntner, M. Schmidt: Analysis of regional variations in soil moisture by means of remote sensing, satellite gravimetry and hydrological modeling. *IUGG XXV General Assembly*, Melbourne, Australia, 28.6.-7.7.2011.

Abelen, S., F. Seitz, A. Güntner, M. Schmidt: Signals of soil moisture variations in remote sensing and gravity field observations. *IUGG XXV General Assembly*, Melbourne, Australia, 28.6.-7.7.2011.

Abelen, S., F. Seitz, M. Schmidt, A. Güntner: An inter-comparison of soil moisture variations detected by satellite remote sensing, satellite gravimetry, and hydrological modeling. *EGU General Assembly*, Vienna, Austria, 3.-8.4.2011 (Poster).

Blossfeld M., Seitz M., Angermann D.: EOP from combined space geodetic techniques. *EGU General Assembly 2010,* Vienna, Austria, 2010 (Poster).

Dettmering , D. , Schmidt , M. , Heinkelmann , R.: Systematic differences of ionospheric parameters from various space-geodetic techniques. *EGU General Assembly*, Vienna, Austria, 2010 (Poster).

Dettmering D., Schmidt M., Zeilhofer C., Tsai L.C., Zhang J., Bosch W., Shum C.K., Tseng K.H.: Combination of different satellite observation data for ionosphere modelling. *EGU General Assembly*, Vienna, Austria, 2009 (Poster).

Dickey, J., S. Marcus: The Changing Cryosphere in Alaska: Results and Implications, *Western Pacific Geophysical Meeting,* 2008.

Dickey, J., S. Marcus, J. Willis: Ocean Cooling: Constraints from Time-Varying Gravity and Altimetry, *GRACE Science Team Meeting*, San Francisco, USA, 2008.

Drewes, H., W. Bosch, M. Schmidt, F. Seitz: Separation of mass signals by common inversion of gravimetric and geometric observations. *2nd Colloquium of the DFG-Priority Programme SPP1257 'Mass transport in the Earth System'*, Munich, 2008 (Poster).

Göttl, F., M. Schmidt: Earth rotation excitation mechanisms derived from geodetic space observations. *EGU General Assembly*, Vienna, Austria, 2009 (Poster).

Gozalpour, B, Motagh, M., Momeni, M.: The application of InSAR technique for investigating mass movement in Semirom, Southeast Iran, *AGU Fall Meeting*, San Francisco, USA, 2010 (Poster).

Khavaninzadeh, N., Motagh, M., Sharifi, M.A.: The potential of Envisat and ALOS Interferometry in monitoring slope instability in Taleghan, Iran. *ESC Conference,* Montpellier, France, 2010 (Poster).

Khavaninzadeh, N., Motagh, M., Sharifi, M.A., Alipour, S.: C-band and L-band InSAR for recognition and monitoring of landslides in Taleghan, Central Iran. *AGU Fall Meeting,* San Francisco, USA, 2010 (Poster).

Kutterer H., Schmidt M., Seitz F., Heiker A., Göttl F., Heller M., Kirschner S.: Combined analysis and validation of Earth rotation models and observations. *German Geodetic Week*, Cologne, Germany, 2010 (Poster).

Mateo M.L., Drewes H., Seitz M.: Análisis de la influencia de carga atmosférica sobre las variaciones en las alturas de las series temporales de la red SIRGAS-CON. *SIRGAS 2010 General Assembly*, Lima, Peru, 2010 (Poster).

Meyer, F.: Monitoring Landfast Ice Through L-band SAR Interferometry. *3rd ALOS PI Symposium*, Kona, Hawaii, USA, 2009.

Meyer, F.: Characteristics of Ionospheric Signals in L-band SAR/InSAR Data and Methods for Their Correction, *AGU Fall Meeting,* San Francisco, USA, 2009.

Meyer, F.: Performance Requirements for Correction of Ionospheric Signals in L-band SAR Data. *8th European Conference on Synthetic Aperture Radar (EUSAR)*, Aachen, Germany, 2010.

Meyer, F.: A Review of Ionospheric Effects in Low Frequency SAR Data – Signals, Correction Methods, and Performance Requirements. *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, Honolulu, Hawaii, USA, 2010.

Meyer, F.: Monitoring Arctic Landfast Ice Extent Through L-band SAR Interferometry. *AGU Fall Meeting,* San Francisco, USA, 2010 (Poster).

Motagh, M., Hooper, A., Walter, T.: The value of InSAR time-series analysis to investigate natural and anthropogenic processes. *AGU Spring Meeting*, Toronto, Canada, 2009.

Motagh, M.: The use of INSAR time-series analysis for long-term subsidence monitoring in plain aquifers of Iran. *15ARSPC Conference,* Alice Springs, Australia, 2010.

Motagh, M., Anderssohn, J., Krüger, F., Schurr, B., Walter, T.: Coseismic and early postseismic deformation of the 14 Mw=7.7 Tocopilla earthquake: Results from space-geodetic and seismological data. *AGU Fall Meeting*, San Francisco, USA, 2008 (Poster).

Motagh, M., Schurr, B., Anderssohn, J., Cailleau, B., Walter, T.R., Wang, R.: InSAR and seismological observations associated with the 14 November 2007, Mw 7.8 Tocopilla earthquake in Chile. *ESC Conference,* Montpellier, France, 2010.

Motagh, M., Schurr, B., Hooper, A.J., Anderssohn, J., Moreno, M., Wang, R.: Coseismic and postseismic deformation from the 14 November 2007 Mw 7.8 Tocopilla earthquake, as investigated by INSAR, and seismic observations, *AGU Fall Meeting,* San Francisco, USA, 2010 (Poster).

Motagh, M., Sharifi, M., Aipour, S., Akbari, V., Walter, T., Rajabi, M., Samadzadegan, F., Djamour, Y., Sedighi, M.: InSAR time-series analysis of land subsidence due to groundwater overexploitation in groundwater basins of central and northeast Iran. *AGU Fall Meeting,* San Francisco, USA, 2008 (Poster).

Pesian, N., Motagh, M., Sharifi, M.A.: The analysis of PALSAR and ENVISAT InSAR for mapping of water level changes in Anzali Mordab, North Iran, *ESC Conference*, September 6-10, Montpellier, France, 2010 (Poster).

Schmeer M., Bosch W., Drewes H., Schmidt M.: Analysis of Atmospheric Density Variations - MaSiS: Separation of Mass Signals by Common Inversion of Gravimetric and Geometric Observations, *Joint International GSTM and DFG SPP Symposium*, Potsdam, Germany, 2007 (Poster).

Schmeer M., Bosch W., Schmidt M.: Separation and estimation of oceanic and hydrological model parameters from simulated gravity observations. *EGU General Assembly*, Vienna, Austria, 2008 (Poster).

Schmidt M.: Spatio-temporal multi-resolution representation of the gravity field from satellite data. Goddard Space Filght Center, Seminar, Greenbelt, USA, 2008.

Schmidt M.: Towards a Multi-Resolution Analysis in Geodetic Applications. *EGU General Assembly*, Vienna, Austria, 2010.

Schmidt M., Dettmering D., Heinkelmann R., Bilitza D.: Regional ionophere modeling from the combination of different satellite observation techniques. *IRI 2009 Workshop*, Kagoshima, Japan, 2009. (Poster)

Schmidt M., Dettmering D.: Regional multi-dimensional modeling of the ionosphere from satellite data. *IGS Workshop/Vertical Rates Symposium*, Newcastle, UK, 2010.

Schmidt M., Dettmering D., Heinkelmann, R.: Multi-Scale Representation of the Ionosphere from the Combination of Space-geodetic Observations. *International Beacon Satellite Symposium,* Barcelona, Spain, 2010.

Schnitzer, S., A. Menzel, F. Seitz: Estimation of mass loss due to soil erosion in the Loess Plateau in China: A comparison of the erosion model RUSLE, multi-temporal DEMs and GRACE satellite gravimetry. *EGU General Assembly*, Vienna, Austria, 2011 (Poster).

Seitz, F.: Configuration analysis of Earth oriented space techniques: Status report of the study group IC-SG3 of IAG's Inter Commission Committee on Theory. *VII Hotine-Marussi Symposium*, Rome, Italy, 2009.

Seitz, F.: Multi-sensor space and in-situ observations for the separation of integral GRACE signals of continental water storage. *EGU General Assembly*, Vienna, Austria, 2011 (Poster).

Seitz, F., A. Güntner, M. Schmidt, W. Bosch: Mass variations in continental water storages from a combination of heterogeneous space and in-situ observations. 2nd Colloquium of the DFG-Priority Programme SPP1257 'Mass transport in the Earth System', Munich, 2008 (Poster).

Seitz, F., K. Hedman, C. Walter, F. Meyer, M. Schmidt: Towards the assessment of regional mass variations in continental surface water storages from a combination of heterogeneous space and in-situ observations. *ESA* Living Planet Symposium, Bergen, Norway, 2010 (Poster).

Seitz, F., S. Kirschner, D. Neubersch: Determination of physical Earth parameters from space geodetic observations - inverse dynamic model approaches and numerical results. *1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems (QuGOMS)*, Munich, Germany, 2011.

Seitz, F., H. Kutterer, M. Schmidt, S. Kirschner, A. Heiker, F. Göttl: Estimation of Earth rotation and gravity field parameters, separated excitation mechanisms and physical Earth parameters from geometric and gravimetric space observations. *EGU General Assembly*, Vienna, Austria, 2011.

Seitz, F., M. Motagh: Geodetic methods for monitoring water overexploitation: Results from geometric and gravimetric observation techniques. *AGU 2009 Fall Meeting*, San Francisco, USA, 2009 (Poster).

Seitz, F., M. Motagh, C. Lubitz: Application of INSAR and GRACE observations for the assessment of groundwater storage depletion. *IUGG XXV General Assembly*, Melbourne, Australia, 2011 (Poster).

Seitz, F., M. Schmidt, C.K. Shum, K. Hedman, H. Lee, F. Meyer: Multi-sensor space and in-situ monitoring of extreme hydrological conditions in the Amazon region. *IUGG XXV General Assembly*, Melbourne, Australia, 2011.

Seitz M., Angermann D., Drewes H.; Accuracy assessment of ITRF2008D. *IAG Commission 1 Symposium 2010 (REFAG 2010)*, Marne-La-Vallee, France, 2010.

Seitz M., Blossfeld M., Sánchez L., Seitz F.: Understanding and treating seasonal signals of station positions in the ITRF computation. *EGU General Assembly 2010,* Vienna, Austria, 2010 (Poster)

Seitz M., Heinkelmann R., Blossfeld M.: Combination of VLBI and GPS in order to improve TRF and EOP solutions. *Workshop VLBI and GNSS: New Zealand and Australian perspectives*, Auckland, New Zealand, 2010.

Singh, A., F. Seitz, Ch. Schwatke, M. Schmidt, A. Güntner: Changing hydrology of the Aral Sea: Results from satellite altimetry, GRACE satellite gravimetry and hydrological modeling. *EGU General Assembly*, Vienna, Austria, 2011 (Poster).

Wang, X., Peters, T.: Determination of mass transport in the Earth system from satellite constellation flights . *IAG International Symposium on Gravity, Geoid and Earth Observation 2008*, Chania, Greece, 2008 (Poster).

Study Group Webpage

The webpage of the group is http://icct.kma.zcu.cz/index.php/IC_SG3

Meetings of the Study Group

- International Seminar on Signals of Climate Variability on Continental Hydrology from Multi-Sensor Space and In-situ Observations and Hydrological Modeling (CLIVAR-Hydro), TU München, Munich, Germany, 11-12.10.2010 (Organizer: F. Seitz)

- The 1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems (QuGOMS), TU München, Munich, Germany, 13-15.4.2011. Co-organized by IC-SG2 and IC-SG3 (Organizers: H. Kutterer, F. Seitz)

Conference Sessions

- German Geodetic Week, Bremen, Germany, 2.10.2008:
  Session 5: GGOS – Global Geodetic Observing System (Convenor: F. Seitz)

- VII Hotine-Marussi Symposium, Rome, Italy, 6-10.7.2009:
  Session 6: Earth oriented space techniques and their benefit for Earth system studies (Convenors: F. Seitz, R. Gross)

- IEEE International Geoscience and Remote Sensing Symposium, Cape Town, South Africa, 12.-17.7.2009:
  Sessions: Sessions: Ionospheric Effects In Polarimetric and Interferometric SAR Imagery I and II; Interferometry – Moving Targets (Convenor: F. Meyer)

- German Geodetic Week, Karlsruhe, Germany, 24.9.2009:
  Session 5: GGOS – Global Geodetic Observing System (Convenor: F. Seitz)

- 3rd ALOS PI Symposium, Kona, Hawaii, USA, 9.-13.11.2009:
  Session: Ionosphere (Convenor: F. Meyer)

- EGU General Assembly 2010, Vienna, Austria, 4.5.2010:
  Session G12: Observing and Understanding Earth Rotation and its Geophysical Excitation (Convenors: A. Brzezinski, F. Seitz, D. Salstein,)

- EGU General Assembly 2010, Vienna, Austria, 5.5.2010:
  Session G2: The Global Geodetic Observing System: Tying and Integrating Geodetic Techniques for Research and Applications (Convenors: P. Sarti, R. Gross, E. Pavlis, M. Seitz)

- EGU General Assembly 2010, Vienna, Austria, 6.5.2010:
  Session G6: Space geodetic techniques and the Earth's atmosphere (Conveners: M Schmidt, R. Pacione , M. Karslioglu , A. Martellucci)

- German Geodetic Week, Cologne, Germany, 7.10.2010:
  Session 5: GGOS – Global Geodetic Observing System (Convenor: F. Seitz)

- IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Honolulu, Hawaii, USA, 26.-30.7.2010:
  Sessions: Ionospheric Effects In Polarimetric and Interferometric SAR Imagery I and II (Convenor: F. Meyer)

- Committee on Earth Observing Sensors (CEOS) Synthetic Aperture Radar Calibration/Validation Workshop, Zurich, Switzerland, 23-27.8.2010:
  Session : Calibration Methods (Convenor: F. Meyer)

- EGU General Assembly 2011, Vienna, Austria, 5.4.2011
  Session G5.1: Monitoring and modelling of the ionosphere from space-geodetic techniques (Conveners: M Schmidt, M. Karslioglu , A. Krankowski, D. Dettmering , P. Wielgosz)

- EGU General Assembly 2011, Vienna, Austria, 6.4.2011:
  Session G2.3: Observing and Understanding Earth Rotation and its Geophysical Excitation (Convenors: F. Seitz, D. Salstein, A. Brzezinski)

- EGU General Assembly 2011, Vienna, Austria, 7.4.2011
  Session G2.2: The Global Geodetic Observing System: Tying and Integrating Geodetic Techniques for Research and Applications (Convenors: R. Gross, E. Pavlis, M. Seitz, D. Behrend)

Future Activities

All members of the SG intend to continue their common activities on the field of Earth observation by means of multi-satellite in the upcoming years. It is intended to propose further projects in order to raise funds for PhD positions on the basis of the common work. It is also planned to organize a summer school in which all collaborating PhD students at the institutions of the SG members shall participate. Furthermore it is intended to repeat the successful Workshop on the Quality of Geodetic Observation and Monitoring Systems (QuGOMS) that has been organized jointly by SG2 and SG3 in Munich in April 2011, in regular intervals. The results of the SG activities shall be published in highly-ranked scientific journals.

Publications

Abelen, S., Seitz, F., Schmidt, M., Güntner, A. (2011): Analysis of regional variations in soil moisture by means of remote sensing, satellite gravimetry and hydrological modelling. IAHS Red Book Series, in press.

Anderssohn, J., Wetzel, H.U., Walter, T.R., Motagh, M., Djamour, Y., Kaufmann, H., (2008). Land subsidence pattern controlled by old alpine basement faults in the Kashmar Valley, northeast Iran: Results from InSAR and leveling. *Geophysical Journal International*, 174, 1, 287-294.

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IC-SG4: Inverse Theory and Global Optimization

Chair: C. Kotsakis (Greece)

[no final study group report available at time of writing]

IC-SG5: Satellite Gravity Theory

Chair: T. Mayer-Gürr (Germany)

[no final study group report available at time of writing]

IC-SG6: InSAR for Tectonophysics

Chair: M. Furuya (Japan)

Introduction

This document is a summary report of the work undertaken by the ICCT Study Group "InSAR for Tectonophysics" since its creation in 2007. Against a backdrop of a series of SAR satellite missions, ERS1/2, JERS, Envisat/ASAR, ALOS/PALSAR, Radarsat-1/2, TerraSAR/X, and planned future missions (e.g. Sentinel-1 and DESDyni), many interesting and exciting results have been presented from this SSG as illustrated in the publication list. Those results include the following research areas, related to geodetic measurement and analysis of SAR/InSAR data and their application to tectonophysical problems: (1) SAR/InSAR data analysis for tectonophysics, (2) retrieval and separation of atmospheric and crustal deformation signal, (3) modeling and interpretation of SAR/InSAR data, (4) combination of InSAR data with other measurement sources.

Primary Objectives of the Study Group

The primary objective of this SG has been to be a focus of activities related to geodetic measurement and analysis of SAR/InSAR data and their application to tectonophysical problems.

Current Membership Structure

M. Furuya (Japan) - chair
F. Amelung (USA)
A. Donnellan (USA)
Y. Fukushima (Japan)
R. Hanssen (Netherlands)
B. Heck (Germany)
S. Jónsson (Iceland)
Z. Li (UK)
D. Sandwell (USA)
T. Wright (UK)

Activities of the Study Group

Conference Contributions of SG Members

Each of the SC members have presented their papers at a number of international meetings, which include American Geophysical Union, European Geoscience Union, Asia Oceania Geosciences Society, IEEE International Geoscience and Remote Sensing, the ESA's FRINGE and Envisat workshop, ALOS-PI meeting and the IAG's 2008 GGEO meeting.

Conference Sessions

Earth Observation by Satellite Altimetry and InSAR at GGEO 2008 meeting.

Study Group Webpage

The webpage of the group is http://icct.kma.zcu.cz/index.php/IC_SG6

Future Activities

New satellite-based SAR missions, C-band Sentinel-1 by ESA and L-band ALOS2 by JAXA, are approved to be launched in ~2013. Exploiting these new data as well as archived data, we will further be able to develop advanced analysis techniques and acquire more exciting scientific results. We plan to hold conference sessions in future international meetings.

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IC-SG7: Temporal Variations of Deformation and Gravity

Chair: D. Wolf (Germany)

[no final study group report available at time of writing]

IC-SG8: Towards cm-accurate Geoid – Theories, Computational Methods and Validation

Chair: Y.M. Wang (USA)

Introduction

This document presents a status report of the work undertaken by the ICCT Study Group 8 since its creation in 2007.

Primary Objectives of the Study Group

The Inter-Commission Study Group (SG 8) focuses on the theories and computation methods for cm-accurate geoid. Geoid computation is a sophisticated process which involves the fundamental theory (geodetic boundary values problem), computation methods and data acquisition. The geoid accuracy depends on a precise theory, adequate computation methods and high quality data. Since the creation of the SG, the focus has been placed on the following topics:

- Optimal combination of global gravity models with local gravity data.
- Rigorous calculation of the topographic effects on gravity and the geoid, refinement of the topographic and gravity reductions.
- Studies on harmonic downward continuations.
- Non-linear effect of the geodetic boundary value problems on geoid determination.
- The effect of topographic density variations on the Earth's gravity field, especially the geoid.
- Effect of time varying gravity on the geoid

Current Membership Structure

Y.M. Wang (USA) – chair
W. Featherstone (Australia)
N. Kühtreiber (Austria)
H. Moritz (Austria)
M.G. Sideris (Canada)
M. Véronneau (Canada)
J. Huang (Canada)
M. Santos (Canada)
J.C. Li, (China)
D.B. Cao (China)
W.B. Shen (China)
Z. Martinec (Czech Republic)
R. Forsberg (Denmark)
O. Anderson (Denmark)
H. Abd-Elmotaal (Egypt)
H. Denker (Germany)
B. Heck (Germany)
K. Seitz (Germany)
W. Freeden (Germany)

E. Grafarend (Germany)
J. H. Kwon (South Korea)
L. Sjöberg (Sweden)
P. Dumrongcha (Thailand)
D. Roman (USA)
J. Saleh (USA)
D. Smith (USA)

Activities of the Study Group

This document presents the status report of IC-SG 8 since its creation in 2007. During the period 2007-11 the SG established its terms of reference, organized its membership structure, adopted an Internet site, and proposed focus items. There are many activities within as well as outside the SG, this report can only cover the main activities of SG members. The material presented here has been compiled from information and feedback obtained from individual SG members. Important developments by research outside the SG are also included.

Moritz (2011) outlined the contemporary perspective of the height anomaly determination assuming the Earth's surface is known. In the approach, the gravity anomaly is replaced by gravity disturbance, and Hotine/Koch's formula takes place of the Stokes's integral.

Flury and Rummel (2009) refined the formulation for the separation between the quasigeoid and geoid. They showed that the refinement may improve the geoid by a decimeter dm in high mountainous region. From a different angle, Sjöberg (2010) developed a strict formula for the separation.

Grafarend et al (2010, 2011) investigated the application of the ellipsoidal harmonics in modelling the Earth's gravity field. Sjöberg (2008, 2009) continues his research in the topographic effects on geoid computations. He has questioned the usefulness of the terrain correction in geoid computations. His conclusion induces an interesting discussion between the author and Vermeer (2007).

Heck and Seitz (2007) presented solutions of the inverse Stokes and inverse Hotine problems to order of f^2 for an ellipsoid boundary. Heck (2009, 2011) also presented solutions of fixed and internal geodetic boundary value problems. Wild and Heck (2008) also studied the topographic and isostatic reductions for satellite gradiometry.

Huang and Novák (2008) revisited their one step geoid computation that combines the Stokes integral and the harmonic downward continuation, aimed to avoid the step function caused by computation blocks. Huang et al (2009) also computed a gravimetric geoid in combination with mean see surface height to determine the Labrador Current. Regarding the geoid modeling, Huang and Véronneau (2010) develop the three different methods of combining the satellite and terrestrial gravity data using the Stokes kernel kernel modification techniques. Ince et al. (2010) compare CGG05, EGM08 and US2009 geoid models over the Great lakes region and conclude the accuracy of the three geoid models is about 5 cm in this region.

Abd-Elmotaal and Kühtreiber (2007a, b) compared the method of Stokes kernel modification and the window technique used in geoid computation. The optimal combination of surface gravity data with a global coefficient model is also investigated (Abd-Elmotaal and Kühtreiber (2008). The method of optimal combination of the deflections of the vertical and the surface gravity anomaly is also proposed by Kühtreiber and Abd-Elmotaal (2007).

Ellmann (2009) showed a large difference (9 cm standard deviation) between the geoids computed by using different kernel modifications. The difference is almost one order larger than the cm-geoid requirement. Similar results are obtained by other researchers. This draws attention to how to use the kernel modification methods properly in geoid computations. Li and Wang (2011) investigated the stability of the modified Stokes kernels to different computation cup size and modification degrees using Alaska as a test area. They found that some methods are more stable than others.

Modeling the topographic potential using the high degree spherical harmonic series has been in progress since the publication of EGM08. Novák (2009) and Wang (2009) presented their topographic potential in spherical harmonic series to degree and order 2700 under the spherical approximation. The coefficients models are used in geoid determinations (Wang et al., 2010).

Effect of varying topographic density to geoid has been one of the important aspects of the cm-geoid determination. Investigation by Kingdon et al (2007, 2008, 2009, and 2010) is an example of this effort. More research along this line is expected, when more accurate density profiles become available.

Kwon and Jekeli (2009), Hong et al (2009) assessed data requirements for precise geoid computation using gravity and topographic data in South Korea. By using 30" elevation model of the North America, Wang (2009) studied omission error due to limited grid size used in geoid computations. He concluded that the omission error is below 1 cm for extreme cases, if 1' grid size is used. However, the omission error in gravity may reach in tens of mGals.

Local geoid computations over various countries and regions are as follows, but not limited to: Featherstone (2007,2010); Claessens et al (2011); Amos et al (2009); Huang and Veronneau (2010), Ince et al (2010); Biltzkow et al. (2008); Avalos et al (2008); Abd-Elmotaal (2008); Wang et al (2010). The geoids serve directly and indirectly as vertical datums in many countries.

To validate relative accuracy of the geoid, Smith et al (2010) proposed a plan using all possible means of survey gravity, vertical gravity gradient, GPS/leveling, deflections of the vertical along a line in Texas. The survey is planned to complete in the summer of 2011.

Meetings of the Study Group

During the period covered the SG had one meeting during the IAG Science Assembly, Geodesy for Planet Earth, Buenos Aires, August 31-September 3, 2009.

Conference Sessions

During the period covered the SG had one conference session during The VII Hotine-Marussi Symposium: Geodetic boundary value problems and cm-geoid computational methods, Rome, July 6-10, 2009.

Study Group Webpage

The webpage of the group is http://icct.kma.zcu.cz/index.php/IC_SG8

Future Activities

The Earth's surface is measured by remote-sensing technology in high resolution with high accuracy, so that the foundation of geoid determination is changing from the free-boundary problems to the much easier fixed-boundary values problems. It is the time to replace the gravity anomaly by gravity disturbance, to use the Hotine/Koch formula instead of Stokes's integral, and to use the ellipsoid, rather than the geoid as the reference surface in geoid computations. The SG plans to have a meeting at IUGG 2011 in Melbourne, Australia to discuss whether we should encourage group member to advocate the changes.

Publications

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IC-SG9: Application of Time-series Analysis in geodesy

Chair: W. Kosiek (Poland)

Introduction

This report presents a status report of the work undertaken by the ICCT Study Group 9 since its creation in 2009.

Primary Objectives of the Study Group

The primary objectives of this study group are as follows:

- Study of the nature of geodetic time series to choose optimum time series analysis methods for filtering, spectral analysis, time frequency analysis and prediction.
- Study of Earth rotation and gravity field variations and their geophysical causes in different frequency bands.
- Evaluation of appropriate covariance matrices for the time series by applying the law of error propagation to the original measurements, including weighting schemes, regularization, etc.
- Determination of the statistical significance levels of the results obtained by different time series analysis methods and algorithms applied to geodetic time series.
- Comparison of different time series analysis methods in order to point out their advantages and disadvantages.
- Recommendations of different time series analysis methods for solving problems concerning specific geodetic time series.

Current Membership Structure

W. Kosek (Poland) – chair
M. Schmidt (Germany)
J. Vondrák (Czech Republic)
W. Popinski (Poland)
T. Niedzielski (Poland)
J. Boehm (Austria)
D. Zheng (China)
Y. Zhou (China)
M.O. Karslioglu (Turkey)
O. Akyilmaz (Turkey)
L. Fernandez (Argentina)
R. Gross (USA)
O. de Viron (France)
S. Petrov (Russia)
M. van Camp (Belgium)
H. Neuner (Germany)

Study Group Webpage

The webpage of the group is http://www.cbk.waw.pl/~kosek/ICSG9.

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