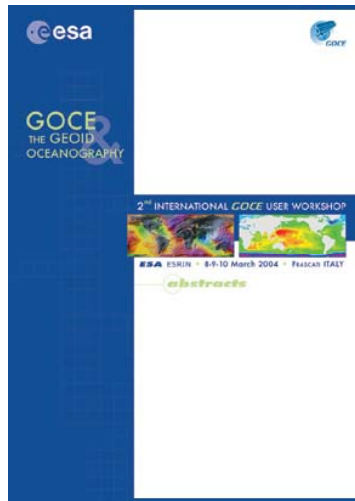Abstract Book and Workshop Programme

Second International GOCE User Workshop

"GOCE, The Geoid and Oceanography"

8-10 March 2004
ESA-ESRIN
Frascati
Italy

Organised by:
The European Space Agency

Feb 2004

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Foreword

Dear Colleagues,

On behalf of the organising committee, I am very pleased to welcome you to "GOCE, The Geoid and Oceanography", the Second International GOCE User Workshop, taking place from Monday 8 to Wednesday 10 March 2004 at ESA-ESRIN in Frascati, Italy.

GOCE, The Goid and Oceanography presents a unique opportunity to have first-hand information on latest developments and to discuss the use of GOCE products for scientific research and application. The Workshop environment offers the ideal opportunity to liase with ESA and allow for scientific exchange with your colleagues. As the Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission approaches its launch, this workshop is designed to provide a forum for presenting the technical and programmatic status of the GOCE Project and progress in development of the:

- o Satellite and its payload
- o Ground Segment up to Level 1
- o Level 1-2 Data Processing
- o Level 3 Data Product developments
- o GOCE Data Exploitation preparations
- o National and EC GOCE activities.

Preparations are underway in the international scientific community for exploitation of high-resolution GOCE gravity data along with other geodetic and oceanographic data sources. Resulting high-precision geoid data are expected to have an impact in Oceanography, Solid-Earth Physics, Geodesy, Glaciology and Climate-change research. The goal of the GOCE mission is to deliver a high-precision and high-resolution global gravity field model as well as global gridded geoid heights and gravity anomalies to the scientific community. ESA is presently co-ordinating efforts to produce a validated high-resolution gravity and geoid model. Various groups and consortia throughout Europe have also expressed an interest in development of either Level 2 or Level 3 products, and in pursuing GOCE-related research.

In particular, this Workshop will focus on oceanographic applications, such as derivation of absolute dynamic topography, of GOCE data in conjunction with other space-borne data, such as radar altimetry, and also in-situ data and models. This Workshop provides an opportunity to publicise these higher-level data processing, geophysical validation plans and to coordinate such activities.
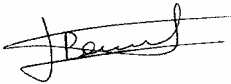
In order to avoid parallel sessions and to facilitate scientific discussion among the participants, the Workshop has been organised with dedicated plenary poster sessions. The poster area will remain open for the duration of the Workshop.

The "round table" discussions will be animated by two moderators and shall facilitate the discussion on the presentations.

The scientific committee, the session chairs and the session rapporteurs will stimulate the debates by preparing seed questions. The round tables shall also allow ESA to capture all your recommendations for the improvement of GOCE services and products and encourage proposals for new algorithms and products development, including a User Toolbox.

The final programme includes more than 60 presentations organised in 4 sessions and round table discussions. The Workshop papers will be published as an ESA SP formal publication and the various presentations, and session summaries shall also be made available via the Workshop web site.

I am Looking forward to a successful Second International GOCE User Workshop and to welcome you in Frascati.

Jérôme Benveniste
ESA-ESRIN
Earth Observation Science and Applications Department
Workshop Local Organiser

Draft Programme - Day 1, 8 March

08:30-09:00	Registration	
Opening Session		**Chair: Jérôme Benveniste**
09:00-09:10	Welcome	**José Achache**
09:10-09:20	Workshop Objectives and Organization	**Jérôme Benveniste**
The GOCE Mission		
09:20-10:20	**Development Status of the GOCE Project**	**Danilo Muzi**
10:20-10:40	**High Level Processing Facility for GOCE: Products and Processing Strategy**	**Reiner Rummel**
10:40-11:00	*Coffee Break*	
Oceanography and Synergy between Gravity and Altimetry (1)		**Chair: Keith Haines**
11:00-11:20	**The GRACE Mission: Status and Relevance to GOCE**	**Byron Tapley**
11:20-11:40	**The GOCINA project - an overview and status**	**Per Knudsen**
11:40-12:00	**Gravity field improvements in the North Atlantic region for the GOCINA project**	**Rene Forsberg**
12:00-12:20	**GOCINA developments of recommendations for using GOCE data in ocean analyses**	**Johnny Johannessen**
12:20-12:40	**Benefits of GOCE to studies of global sea level change**	**Philip Woodworth**
12:40-13:00	**Mass transports and mass distribution in the Earth system; filter methods for sea surface topography**	**Jakob Flury**
13:00-14:00	*Lunch*	
National Activities Presentations		
14:00-15:00	*Poster Session*	
	FROG: French Resources Organisation for GOCE	**Sébastien Deroussi**
	GOCE activities in the Netherlands	**Radboud Koop**
	Current and future GOCE activities in Canada	**Nico Sneeuw** (cancelled)
	GOCE Activities in Germany	**Jakob Flury**
	The GOCE End-To-End System Simulator	**Giuseppe Catastini**
Oceanography and Synergy between Gravity and Altimetry (2)		**Chair: Detlef Stammer**
15:00-15:20	**Multiscale Modelling of Ocean Circulation**	**Dominik Michel**
15:20-15:40	**Transports and sea level slopes in high resolution ocean models**	**Keith Haines**
15:40-16:00	**Application of GOCE to the Southern Ocean Circulation**	**Jens Schröter**
16:00-16:20	*Coffee Break*	
16:20-16:40	**Impact of geoid definition on the simulated strength of the equatorial undercurrent in a global data assimilation system**	**Femke Vossepoel**
16:40-17:00	**GOCE Data Product Verification in the Mediterranean Sea**	**C.K. Shum**
17:30-18:30	*Cocktail*	

Draft Programme - Day 2, 9 March

	Processing Algorithms up to the Geoid and Gravity Field (1)	**Chair: Erricos Pavlis**
9:00-9:20	**Recovery of the Earth's Gravity Field from GOCE Satellite Gravity Gradiometry: a Case Study**	**Oleg Abrikosov**
9:20-9:40	**GOCE Gravity Field Processing**	**Gernot Plank**
9:40-10:00	**Computation of Calibration Gradients and Methods for In-Orbit Validation of Gradiometric GOCE Data**	**Jürgen Müller**
10:00-10:20	**An enhanced space-wise simulation for GOCE data reduction**	**Federica Migliaccio**
10:20-10:40	*Coffee Break*	
10:40-11:00	**Effect of High-Frequency temporal aliasing on GOCE gravity field solution**	**C.K. Shum**
11:00-11:20	**GOCE: is aliening a cause for concern?**	**Philip Moore**
11:20-13:00	*Poster Session*	
	Numerical simulation of the gravity field recovery from GOCE mission data	**Sean Bruinsma**
	Gravity Gradients and Spherical Harmonics – A Need for Different GOCE Products?	**Johannes Bouman**
	GOCE Quick-Look Gravity Field Analysis	**Roland Pail**
	GOCESOFT: a software for GOCE data processing	**Pavel Ditmar**
	Validation Concepts for Gravity Field Models from New Satellite Missions	**Thomas Gruber**
	GOCE: dealing with large attitude variations in the conceptual structure of the space-wise approach	**Mirko Reguzzoni**
	Simulation results from combination of GOCE gridded SST and SGG data	**Christian Tscherning**
	Gravity field analysis from preprocessed and calibrated GOCE observations: the Delft Approach	**Pavel Ditmar**
	Is there a common future for GOCE and GRID?	**Keith Haines**
13:00-14:00	*Lunch*	
	Processing Algorithms up to the Geoid and Gravity Field (2)	**Chair: Thomas Gruber**
14:00-14:20	**Anisotropy in GRACE resolution: lessons for GOCE?**	**Walter Smith**
14:20-14:40	**Precise Orbit Determination and Cal/Val for GOCE**	**Henno Boomkamp**
14:40-15:00	**Multiscale Modeling from EIGEN-1S, EIGEN-2, EIGEN-GRACE01S, GGM01, UCPH2002_0.5, EGM96**	**Martin Gutting**
15:00-15:20	**Modeling the Earth's gravity field from precise satellite orbit data: the acceleration approach works!**	**Pavel Ditmar**

	Solid Earth	Chair: G. Balmino
15:20-15:40	**Effects of topographic and isostatic masses in satellite gravity gradiometry**	**Franziska Wild**
15:40-15:50	*Coffee Break*	
15:50-16:10	**A linear algorithm for computing the spherical harmonic coefficients of the potential from a constant-density polyhedron**	**Olivier Jamet**
16:10-16:30	**High-Harmonic Geoid Signatures due to Glacial Isostatic Adjustment, Subduction and Seismic Deformation**	**Bert Vermeersen**
16:30-16:50	**Gravity Field Determination Using Multiresolution Techniques**	**Michael Schmidt**
16:50-17:10	**The Use of GOCE Data for Detection and Classification of Mantle Plumes**	**Gabriele Marquart**
17:10-18:10	*Poster Session*	
	Kinematic and Dynamic Precise Orbit Determination of Low Earth Orbiters: Importance of the GPS Receiver Performance	**Drazen Svehla**
	The T5 Ion Propulsion Assembly for Drag Compensation on GOCE	**Clive Edwards**
	Comparison of some methods for modifying Stokes' formula in the GOCE era	**Jonas Aagren**
	Parameter Choice Strategies for Multiscale GOCE Modeling	**Martin Gutting**
	Non-linear computation of the gravity field of an aspherical planet	**Virginie Belleguic**
	GOCE gradients validation by the airborne gradiometer and grace measurements	**Janusz Zielinski**
	Calibration/Validation of GOCE Data over Antarctica	**C.K. Shum**
	Upward/downward continuation of gravity gradients for precise geoid determination	**Gyula Tóth**
	Static gravity model development: incorporation of GOCE data	**Erricos Pavlis**
	A Bayesian approach to invert GOCE gravity gradient	**Gwendoline Pajot**
	A wavelet based representation of the gravity field	**Isabelle Panet**
	Recovery of the gravity field signal due to a low viscosity crustal layer in GIA models from simulated GOCE data	**Hugo Schotman**
	Gravity and geoid in the Arctic region – the northern GOCE Polar gap filled	**Rene Forsberg**
19:30	*Dinner*	

Draft Programme - Day 3, 10 March

Oceanography and Synergy between Gravity and Altimetry		Chair: Ole Andersen
09:00-09:20	**Estimating the ocean circulation and the geoid through a combined analysis of altimetric and geoid information.**	**Detlef Stammer**
09:20-09:40	**Recent improvement in altimetry: how MSS and MDT can benefit from it in combination with a GOCE geoid?**	**Fabrice Hernandez**
09:40-10:00	**Combined use of altimetry, in-situ measurements and a geoid model to estimate a global mean dynamic topography impact of GRACE and GOCE data**	**Marie-Helene Rio**
10:00-10:20	**Use of GOCE for Operational Oceanography**	**Pierre-Yves Le Traon**
10:20-10:40	*Coffee Break*	
10:40 - 11:20	**Summary and recommendation from "Processing Algorithms up to the Geoid and Gravity Field"**	
	Round Table Discussion	
11:20 - 12:00	**Summary and recommendation from "Solid Earth"**	
	Round Table Discussion	
12:00 - 12:40	**Summary and recommendation from "Oceanography and Synergy between Gravity and Altimetry"**	
	Round Table Discussion	
12:40 - 13:00	**Workshop Summary and Closure**	**Jérôme Benveniste**

DEVELOPMENT STATUS OF THE GOCE PROJECT

Danilo Muzi[1], Alex Popescu[1], Rune Floberghagen[1], Franz-Josef Demond[1] and Pier Paolo Emanuelli[2]

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Abstract

Scheduled for launch in 2006, the **G**ravity Field and Steady State **O**cean **C**irculation **E**xplorer (**GOCE**) mission is the first of the Earth Explorer Core Missions planned as part of ESA's Earth Observation Envelope Programme.

The goal of the GOCE mission is to provide high-resolution and high-accuracy global models of the Earth's gravity field and derived quantities, such as the geoid, geoid slopes and gravity anomalies, along with their associated error measures. Such an advance in the knowledge of the Earth's gravity field will help to develop a deeper understanding of the physics of the Earth's interior, the interaction of the continents and the ocean circulation.

To achieve its objectives, the GOCE mission is designed to meet the following key requirements:

- uninterrupted tracking of the satellite in three spatial dimensions
- measurement and compensation of the effect of the non-gravitational forces
- orbital altitude as low as possible
- enhancing the strength of the high frequency components of the gravity field signal by differentiation (counteraction of attenuation with altitude)

These key requirements drive the design of the satellite, the choice of the orbit in all mission phases as well as the selection of the core payload.

The primary payload consists of a highly sophisticated three-axis electrostatic gradiometer and a geodetic-quality GPS receiver. In order to minimise atmospheric drag, the satellite has an elongated shape with a minimal cross-sectional area in the flight direction. A combined "drag-free" and attitude control system ensures the minimisation of residual non-conservative forces and torques acting on the spacecraft. The satellite is also aerodynamically stabilised by using small winglets to control the position of the centre-of-pressure with respect to the centre-of-mass. During gravity mapping the orbit altitude will be 250 km or lower, but still compatible with operational requirements.

The paper addresses key aspects of the GOCE mission and their development status, including:

- the programmatic status
- the space segment, including the performance of the satellite data
- the ground segment, including satellite operations and data processing

HIGH LEVEL PROCESSING FACILITY FOR GOCE: PRODUCTS AND PROCESSING STRATEGY

Reiner Rummel[1], Thomas Gruber[1] and Radboud Koop[2]

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(2) SRON National Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, Netherlands

Abstract

The High Level Processing Facility for GOCE (HPF) will produce systematically GOCE level 2 products, which are orbits and gravity field models of different kind. While so-called quick-look or rapid products mainly are of interest for the GOCE performance monitoring, the final and precise products will represent the official GOCE level 2 products, which further will be used for level 3 processing by the GOCE users (e.g. oceanographers, solid Earth scientists, geodesists and others). The paper summarizes the architecture of the HPF and provides an overview of the planned products and their characteristics.

THE GRACE MISSION: STATUS AND RELEVANCE TO GOCE

Byron Tapley[1]and Christoph Reigber[2]

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(2) GeoForschungZentrum Potsdam, Telegrafenberg A 17, D-14473 Potsdam, Germany

Abstract

The Gravity Recovery and Climate Experiment (GRACE) is a dedicated satellite mission whose objective is to map the global gravity field with unprecedented accuracy over a spectral range from 500 km to 40,000 km. The measurement precision will support gravity field solutions in this frequency range that are between 10 and 1000 times better than our current knowledge. The mission profile calls for a gravity field solution with this accuracy every thirty days. Accurate measurements, with both high spatial and temporal resolution, will allow capture the gravitational signals associated with the mass exchange between the Earths solid, ocean and atmospheric system components. The primary measurement provided by the High Accuracy Inter-satellite Ranging System (HAIRS) is the range change between two satellites orbiting one behind the other at an approximate distance of 220 km. The range change is measured with a precision better than 10 microns over a ten second averaging interval. A highly accurate three-axis accelerometer, located at the satellite mass center, will be used to measure the surface force and attitude control induced accelerations. Satellite GPS receivers will position the satellites over the earth with centimetre level accuracy. The two satellites were launched on March 17, 2002 and were designed to operate for a period of five years.

This presentation will review the mission status and describe the status of the early science results, including the efforts to identify the time varying signal. In particular, the contributions to oceanography and hydrology will be highlighted. Finally, the presentation will highlight possible contributions of the Grace Mission to the GOCE Mission objectives.

THE GOCINA PROJECT - AN OVERVIEW AND STATUS

Per Knudsen[1]

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Abstract

GOCINA is a shared cost project (contract EVG1-CT-2002-00077) co-funded by the Research DG of the European Commission within the RTD activities of a generic nature of the Environment and Sustainable Development sub- programme of the 5th Framework Programme.

The aim of the GOCINA project is to enhance European capacity in Earth observation technologies by promoting and developing methods for the joint exploitation of the approved European Space Agency ENVISAT (Radar Altimeter) and GOCE missions for ocean circulation studies and associated climate modelling and operational data assimilation.

A major task is to determine an accurate geoid in the region between Greenland and the UK and, thereby, create a platform for validation of future GOCE Level 2 data and higher order scientific products. The new and accurate geoid is used together with an accurate mean sea surface to determine the mean dynamic topography. The mean dynamic topography is used for improved analysis of the ocean circulation and transport through the straits between Greenland and the UK. Furthermore, GOCINA will develop recommendations for use of GOCE data in ocean analyses.

GRAVITY FIELD IMPROVEMENTS IN THE NORTH ATLANTIC REGION FOR THE GOCINA PROJECT

R. Forsberg[1], R. Hipkin[2], A. Olesen[3], D. Solheim[4] and A. L. Vest[3]

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(2) University of Edinburgh, Edinburgh, UK EH9 3JW, United Kingdom
(3) KMS, Rentemestervej 8, DK 2900 Copenhagen NV, Denmark
(4) Statens Kartverk, Monserudveien, N-3500 Honefoss, Norway

Abstract

An airborne gravity survey was carried out in the Greenland-Iceland- Faeroe-Scotland region in the summer of 2003 to collect high-quality airborne gravity data, as part of the GOCINA project. Together with data from earlier airborne surveys, and other new airborne measurements to the north in the Greenland and Norwegian Seas (collected in the OCTAS project), the airborne data will allow the correction of older ship data to create a uniform gravity field database of the North Atlantic region for improved geoid determination. Data from new satellite missions like CHAMP and GRACE will be used to enhance the long wavelengths of the field. As part of the GOCINA project the geoid processing will also identify problems related to data and methods, and highlight the potential improvements by GOCE data. The underlying data for the geoid will at the same time be able to serve as ground truth for computation of gravity gradient at the GOCE altitude, and thus provide independent calibration and validation data for GOCE.

GOCINA DEVELOPMENTS OF RECOMMENDATIONS FOR USING GOCE DATA IN OCEAN ANALYSES

Johnny Johannessen[1]

(1) Kort & Matrikelstyrelsen, Rentevestervej 8, 2400 Copenhagen NV, Denmark

Abstract

Many conditions for the success of GOCE lie at the level of the processing of its data, which for a large part is going to be new to everyone. This implies that special and dedicated care of the data processing be taken; to ensure that the best Earths gravity field model can be delivered to the scientific users. The GOCINA project will in particular support the mission in two distinct cases, namely (1) to educate and prepare the community in using GOCE data for oceanography including sea level and climate research as well as operational prediction; and (2) to develop methods for generating regional gravity fields and to use them to generate a best possible regional gravity field and geoid model for the North Atlantic that can be used in validation of the GOCE products.

BENEFITS OF GOCE TO STUDIES OF GLOBAL SEA LEVEL CHANGE

Philip Woodworth[1]

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Abstract

The Intergovernmental Panel on Climate Change Third Assessment Report (IPCC TAR) made very clear the scientific interest in, and practical importance of understanding better past and potential future sea level changes. Space gravity missions will provide major benefits to the understanding of the past, and, thereby, in the prediction of future, sea level changes in many ways. The 'Granada-2' proposal for the GOCE mission described well the improvements to be expected from improved gravity field and geoid models in oceanography (for example, in the measurement of the time-averaged, or 'steady state', ocean surface circulation and better estimation of ocean transports), in geophysics (in the improvement of geodynamic models for vertical land movements), in geodesy (in positioning of tide gauge data into the same reference frame as altimeter data, and in improvement of altimeter satellite orbits), and possibly in glaciology (in improved knowledge of bedrock topography and ice sheet mass fluxes). CHAMP and GRACE will also make important steps towards these "steady state" aim. This presentation will summarize several of these issues, pointing the way towards improved accuracy of prediction of future sea level change.

MASS TRANSPORTS AND MASS DISTRIBUTION IN THE EARTH SYSTEM; FILTER METHODS FOR SEA SURFACE TOPOGRAPHY

Jakob Flury[1]

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Abstract

The high quality gravity field data from CHAMP, GRACE and GOCE open a range of new applications to determine mass transports, mass distribution and mass balance in the Earth system. In Germany, at present a group of scientists is initiating a priority program for these research areas. An integrative approach and an intensive cooperation between geodesy, oceanography, hydrology, glaciology and solid Earth physics are essential for the program. For GOCE, the combination of the gravity field with geometry data from altimetry and with in situ data is a key point of interest, in particular for ocean circulation, but also for ice modelling. Another central theme of the program is the analysis of time variable gravity signals based on GRACE data, which is also of some interest for GOCE, e.g. for the computation of corrections to the observed gradients. Besides a summary of these activities, the paper addresses geodetic aspects of the determination of the quasistatic sea surface topography (SST) for ocean circulation modelling. Filter methods in spherical harmonics and in space domain are discussed. These are important due to the different data structure and resolution of the geoid, the altimetric sea surface and the ocean model grid. The spectral signal content of SST models is analysed in order to discuss methods to achieve solutions with maximum spatial resolution.

FROG: FRENCH RESOURCES ORGANISATION FOR GOCE

Sébastien Deroussi[1], Georges Balmino[2], Michel Diament[3] and Pascale Ultre-Guerard[2]

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(3) Laboratoire de Gravimétrie et Géodynamique, 4 Pl. Jussieu, 75252 Paris Cedex 5, France

Abstract

The expected impact of the GOCE project on the geosciences requires that the concerned communities get organised in order to make the best possible use of the data and models to be derived. The French geodesists, geophysists and oceanographers are going to cooperate at different levels of the mission and, for so doing, a transverse and informal structure, FROG, has been set up. Besides being a forum where scientists can exchange their views and interact in planning their activities, FROG will help providing new direction and even tools to help teams and especially young scientists in their research.

GOCE ACTIVITIES IN THE NETHERLANDS

Radboud Koop[1], Boudewijn Ambrosius[2], Avri Selig[1] and Pieter Visser[2]

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(2) Delft University of Technology, Kluyverweg 1, 2629 HS Delft, Netherlands

Abstract

Dutch groups and persons have been participating in GOCE activities from the early days of the project till now and are planning to stay involved until the goals of the mission will be realised. The activities, that actually go back all the way to the first ideas of the Aristoteles mission, have been evolving over many aspects of the mission, from instrument simulation via data processing to user applications. The groups now involved can rely on a long lasting expertise in the respective fields of interest: space geodesy, orbital mechanics, space research and technology, oceanography and geodynamics. In the context of GOCE, but also in related fields, the participating Dutch groups have established both national and international cooperation and reputation. A Dutch GOCE User Community is being established and this paper will present the ongoing and planned GOCE activities within this community. In this overview we will deal with issues of organisation, science, funding, cooperation and an outlook to the future after GOCE.

CURRENT AND FUTURE GOCE ACTIVITIES IN CANADA

Nico Sneeuw[1] and Michael Sideris[1]

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Abstract

This paper reports on several activities by the Canadian earth science community in preparation for GOCE. Canadian data sets of interest for cal/val purposes will be presented, in particular gravity, secular gravity changes, regional geoids and GPS/leveling benchmarks. Several projects related to the use of GOCE (and other gravity satellite missions) are currently underway, both at level 2 and at level 3. The presentation will emphasize a project on vertical datum definition in the presence of a strong post-glacial rebound signal. It will also outline plans on using gravity satellites for Earth monitoring purposes in Canada.

GOCE ACTIVITIES IN GERMANY

Jakob Flury[1] and Reiner Rummel[1]

(1) GOCE Project Bureau Germany, Technische Universität München, Arcisstr.21, 80290 Muenchen, Germany

Abstract

The poster gives an overview over the GOCE related activities in Germany on he various levels of data processing. German enterprises play an important role in the GOCE platform construction. German scientists are involved in the development of the GOCE Calibration and Monitoring Facility (CMF) and Payload Data Segment (PDS). Several German institutions are members of the European GOCE Gravity Consortium (EGG-C) for level 2 data generation. The GOCE gravity field analysis is supported by research projects in the frame of the national geo-scientific programme Geotechnologien, which is running for 2 years now. For applications of the GOCE gravity field in oceanography, solid Earth geophysics, and glaciology (level 3 products), at the moment there is a concentrated effort to realize a priority research programme funded by the Deutsche Forschungsgemeinschaft. The German activities are coordinated by the GOCE Project Bureau Germany in Munich, which organized in November 2003 a GOCE-CryoSat-Workshop (second German GOCE workshop) at EADS-Astrium in Friedrichshafen, together with the CryoSat user community.

THE GOCE END-TO-END SYSTEM SIMULATOR

G. Catastini[1], D. Andreis[2], S. Cesare[1], S. De Sanctis[1], M. Dumontel[1], R. Floberghagen[3], D. Lamarre[3], M. Parisch[1], M. Saponara[1] and G. Sechi[1]

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(2) Politecnico di Torino – Dipartimento di Automatica e Informatica
(3) European Space Agency, Noordwijk, The Netherlands

Abstract

The idea of an end-to-end simulator was conceived in the early stages of the GOCE programme, as an essential tool for assessing the satellite system performance, that cannot be tested in its globality on the ground. The simulator in its present form is under development at Alenia Spazio for ESA since the beginning of Phase B and is being used for checking the consistency of the spacecraft and of the payload specifications with the overall system requirements, supporting trade-off, sensitivity and worst-case analyses, and preparing and testing the on-ground and in-flight calibration concepts.

The software simulates the GOCE flight along an orbit resulting from the application of Earth's gravity field, non-conservative environmental disturbances (atmospheric drag, coupling with Earth's magnetic field, etc.) and control forces/torques. The drag free control forces as well as the attitude control torques are generated by the current design of the dedicated algorithms. Realistic sensor models (Star Tracker, GPS receiver and gravity gradiometer) feed the control algorithms and the commanded forces are applied through realistic thruster and magnetic torquer models. The output of this stage of the simulator is a time series of Level-0 data, namely the gradiometer raw voltages, star tracker quaternions and spacecraft ancillary data. The next stage of the simulator transforms Level-0 data into Level-1b (gravity gradient tensor) data, by implementing the following steps:

- transformation of raw voltages of each pair of accelerometers, including phase and gain correction, into common and differential accelerations
- calibration of the common and differential accelerations
- application of the post-facto algorithm to estimate the GOCE angular velocity and attitude
- computation of the Level-1b gravity gradient tensor from calibrated accelerations and estimated angular velocity in the gradiometer reference frame;
- computation of the spectral density of the error of the tensor diagonal components (measured gravity gradient minus input gravity gradient) in order to evaluate the scientific performance, i.e. the error of gravity gradient and the spectral density of the tensor trace within the measurement bandwidth
- processing of GPS observation for orbit reconstruction within the required 10m accuracy and for gradiometer measurement geolocation.

The current version of the end-to-end simulator includes the outcome of the redesign activity started in July 2003, which yielded to the identification of a new set of actuators (ITA and MTR) and to a major redesign of the DFAC control law. The current simulation scenarios are mainly focusing on the gradiometer payload (in flight calibration manoeuvre, scientific telemetry-like output, basic gradiometer transition) and the simulator is undergoing detailed testing based on a time span of 30 days of simulated flight.
The paper will describe the simulator's current status and will illustrate its capabilities for supporting the assessment of the quality of the scientific products resulting from the current spacecraft and payload design.

MULTISCALE MODELLING OF OCEAN CIRCULATION

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Abstract

In the future, it will be necessary to analyse oceanic currents in local environments, for example, the northern Atlantic Ocean for an analysis of the Gulf stream. In the last two decades, spherical spline- and wavelet-techniques have been developed by the Geomathematics Group in Kaiserslautern. For this task, lately applicated space localizing basis functions are of interest. So for an analysis of, e.g. the El Nino phenomena, only oceanic flow in the region around the western coast of South America would be necessary, neglecting all other data material, in particular from the northern Pacific and the Atlantic Ocean. This gives two major advantages over well-known Fourier expansions with globally defined basis functions. Foremost, local variations inflict only changes within small areas, reducing numerical costs and needed observables. This leads straightforward to the second point. Since all real data are error affected, needing only local (and therefore less) observables implies less influence of these errors.

In particular, our wavelet methods provide a multiscale analysis of the given data. Thereby we have at each scale a low-pass-filtered version of our signal. Depending on the details we need locally, we can zoom-in into regions under consideration. Especially high-frequent structures are explicitly observable with these methods.

Within the context of oceanography these methods will be used for a new model of ocean circulation, using the advantages of a local multiscale analysis to gain greater inside into phenomena with small spatial or temporal length. Further, due to the new localizing kernels, greater amounts of data can be handled to obtain new high-precision results.

TRANSPORTS AND SEA LEVEL SLOPES IN HIGH RESOLUTION OCEAN MODELS

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Abstract

One key objective of GOCE is to provide a geoid accurate enough to be helpful in determining the ocean dynamic topography and thereafter information of ocean mass and heat transports. The current best available Mean Dynamic Topographies (MDTs) are probably those provided by ocean circulation models with assimilated hydro graphic data, which have the effect of correcting the model biases. We have compared a number of different model/assimilation products as part of the EU GOCINA project, focussing on the NE Atlantic between Scotland and Greenland, with the models ranging from 1 degree to 1/9 degree spatial resolution. Very consistent results are found for the MDTs over this region giving some confidence that this is a good way of deriving MDT products. Comparisons at different length scales will be discussed.

The relationships between transports and sea surface slopes in these models is then examined, again in the GOCINA region of the NE Atlantic, to estimate how improved sea surface slopes give transport information. Considerable variability occurs in dynamic topography on multiannual timescales requiring the concept of a mean dynamic topography to specify a particular period. The relationship between slopes and transports at different locations and frequencies of variability will be reported. Work within the GOCINA project is aimed at quantifying the uncertainty in MDT estimates in order to use model derived MDTs in combination with altimetric sea level and geoid information to get the best possible consistent products.

APPLICATION OF GOCE TO THE SOUTHERN OCEAN CIRCULATION

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Abstract

The Southern Ocean is the connection that exchanges heat and trace substances between the Atlantic, Pacific and Indian Ocean. The dynamics of the Antarctic Circumpolar Current are not sufficiently understood due to lack of oceanic data and a lack of sea surface topography referenced to an accurate geoid.

In this area we expect GOCE to play a major role in determining the mean dynamics as well in improving our understanding of the interaction between the mean flow and transient eddies.

IMPACT OF GEOID DEFINITION ON THE SIMULATED STRENGTH OF THE EQUATORIAL UNDERCURRENT IN A GLOBAL DATA ASSIMILATION SYSTEM

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Abstract

The availability of gravity data from recent satellite missions (CHAMP, GRACE) and the future GOCE mission will improve our current knowledge of the Earth's geoid. An accurate description of the geoid is essential for a proper interpretation of altimetric sea level data, which can help us to better understand the ocean circulation. This study evaluates the sensitivity of an estimated ocean circulation to the definition of the geoid, using a global ocean circulation model (OGCM) and an advanced data assimilation technique.

In the analysis system, Topex/Poseidon altimetric sea level heights are related to modelled sea level. Instead of using sea level anomalies with respect to a long-term mean, which is the most common usage of altimetry, the absolute sea level minus the geoid estimate is assimilated. In the current study, we adopt TOPEX/Poseidon altimetry and incorporate the most recent geoid solutions based on satellite data (GRIM5-S1, EIGEN-2, GRACE).

The analysis system consists of the OPA OGCM, in which observations are being assimilated. The assimilation technique, the sequential importance resampling (SIR), is an ensemble-based method, that determines the optimal model trajectory by statistical evaluation of a number of perturbed model simulations. The implementation of this technique is especially efficient in a parallel computing environment.

Specific attention is being paid to the equatorial undercurrent in the Atlantic, Indian and Pacific Oceans. We evaluate the impact of the geoid definition on its strength and its variability, and discuss the implications of improving geoid accuracies for the estimation of ocean circulation.

GOCE DATA PRODUCT VERIFICATION IN THE MEDITERRANEAN SEA

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Abstract

ESA's General Ocean Circulation Experiment (GOCE) mission is anticipated to generate Level 2 data products such as global geopotential model with geoid undulation accuracy of 1 cm rms and a spatial resolution of 160 km or longer. We propose a calibration and validation effort to verify GOCE measurements and data products including the Level 2 geopotential model in the Mediterranean Sea, a water body of 4000 km by 1000 km area. Multiple altimetric determined mean sea surface model after removal of thermal effects will be used as one of the measurement types to construct an in situ geoid undulation model for valiating GOCE geopotential. Additional measurements required are XBT data, sea surface temperature and/or dynamic topography model computed using e.g., NODC 2001 data compiled by S. Levitus. These measurements will be used to compute steric (thermosteric and halosteric) components of the sea level which will be appropriately removed from altimetric/GPS mean sea surface to construction a geoid model in the Mediterranean. Appropriate upward (and downward) continuations of the Mediterranean geoid to the GOCE altitude to compare with GOCE measurements directly, in addition to comparing with the GOCE geopotential model with the appropriate resolution. This paper provides a description of the methodology and example applications using CHAMP and GRACE data products.

RECOVERY OF THE EARTH'S GRAVITY FIELD FROM GOCE SATELLITE GRAVITY GRADIOMETRY: A CASE STUDY

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Abstract

GOCE SGG data were simulated along a 28-day perturbed orbit with an initial semi-major axis of 6621 km, an inclination of 96.5°, and an eccentricity of 0.0045. Based on these data, we have estimated numerically the effects of various (static and time-varying) geopotential constituents on the components of the gravity gradient tensor referred to the RTN (radial – quasi-transversal – normal) local orbit system. We have seen that within the gradiometer's measurement bandwidth the recovery of harmonic coefficients may be not affected by temporal variations of the gravity field. In fact, the total signal of the sum of considered time-dependent constituents (solid Earth tides up to degree and order 4, ocean tides up to degree 50 and order 39, variable atmospheric potential up to degree and order 50) does not exceed 0.1% of the contribution of the Earth's static anomalous potential (GPM98CR gravity model up to degree 720). Even maximal amplitudes in the spectra of the gravity gradients generated by the sum of these time-dependent constituents were less than the anticipated measurement error of the diagonal components of the gravity gradient tensor. Therefore, in further simulation we take into account only the Earth's static potential. The computation of power spectral densities (PSD) of gravity gradients generated by spherical harmonics of various degrees has shown that the amplitudes of all harmonics of degree n>250 are less then the anticipated error of GOCE SGG data. Thus, the static anomalous potential is expected to be recoverable up to degree 250 from the GOCE gradiometry data processing. In order to de-correlate the gravity gradients affected by colored noise, several filter approaches were considered and numerically tested for different sampling rates and different spectral properties of measurement errors (including white noise and noise with PSD presumed for GOCE SGG data). As a result, we come to a simple non-recursive filter technique, which incorporates observation equations for SGG data within a floating time interval of fixed length comparable with the GOCE measurement bandwidth. We have examined this technique for the computation of the filter coefficients based on (1) the a priori given PSD of noise and (2) a PSD of noise estimated from the sum of measured diagonal components of the gradient tensor. Each case gives practically the same results after filtering and does not change the signal/noise ratio. Naturally, the second case is closer to real processing of GOCE SGG data. Independently on sampling rate, no more than 400 data samples are required for a stable computation of the filter coefficients. We have used the proposed filter technique for a least-squares estimation of spherical harmonic coefficients of the Earth's gravitational potential from 28-day simulated GOCE SGG data disturbed by colored noise. Finally the results of recovering spherical harmonic coefficients at various degrees are discussed.

GOCE GRAVITY FIELD PROCESSING

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Abstract

The dedicated satellite gravity mission, the first Core Mission of ESA's Living Planet Programme, strives for a high-accuracy, high-resolution global model of the Earth's gravity field. GOCE is based on a sensor fusion concept: satellite-to-satellite tracking in the high-low mode (hl-SST) using GPS, plus on-board satellite gravity gradiometry (SGG). The recovery of a full set of gravity field parameters (spherical harmonic coefficients) from these complementary data is a huge numerical and computational task. Therefore, parallel computing strategies have to be applied, which solve the fully occupied normal equation systems rigorously. The large matrices involved (e.g. 30 GB storage requirement for a system complete up to degree/order 300) have to be distributed over a Beowulf cluster. This distributed matrix has to be set up (each observation holds information which reflects onto the whole normal equations) and afterwards the system is solved to deliver the unknowns (harmonic coefficients) and the corresponding full variance - covariance information. Several numerical solution strategies and their combination for an optimum exploitation of the data are presented, assessed and compared both theoretically and on the basis of a realistic-as-possible numerical simulation, regarding the accuracy of the results as well as the computational effort. Special concern is given to the correct treatment of the coloured noise characteristics of the gradiometer as well as to the benefits which are achieved, from the data combination of the SGG and hl-SST component.

COMPUTATION OF CALIBRATION GRADIENTS AND METHODS FOR IN-ORBIT VALIDATION OF GRADIOMETRIC GOCE DATA

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Abstract

The accuracy planned for GOCE gravity gradiometry requires special independent concepts for calibration and validation of the measured gravitational gradients. Although the gradiometer will be calibrated internally on ground (pre- flight) and prior to the measurement phase itself in orbit (in-flight), further external calibration is obligatory to establish the relationship of the measurements to the earth's gravitational field at the required accuracy level. To keep the accuracy of the satellite data, a region with correspondingly well known gravity field parameters has to be selected for calibration. Central Europe has been identified as such a region where the Institut für Erdmessung has collected a database of 5' by 5' gridded gravity anomalies. For calibration and validation purposes, reference gravitational gradients at GOCE altitude are computed from these terrestrial gravity anomalies. The upward continuation is carried out by least squares collocation and integral formulas. The calibrated gravitational gradients have to pass a further quality assessment. Even without the availability of independent data, some conclusions on quality and consistency of the collected data can be drawn by comparing measurements in the same satellite position, i.e. satellite track cross-overs or repeat orbits. Unfortunately, due to the orbit characteristics of the mission, identical repeat positions are reached seldom throughout the mission lifetime, so one has to take into account satellite ground track cross-overs as well. For those, a reduction concept has to be applied to consider the differences caused by different satellite altitudes and orientations. It is shown here, that present global gravity field models meet the accuracy and resolution requirements of the reduction concept. This relative validation procedure obviously just allows the identification of parts of the possible errors. So a further validation step has to be integrated to obtain absolute differences between the calibrated measurements and the earth's real gravitational field. If this comparison is done with terrestrial data in the same well observed region mentioned above, it has to be performed in close coordination with the calibration step to avoid misinterpretation. But in contrast to the gradients' calibration, the absolute validation step can also be carried out after further processing of the measurements, e.g. based on new regional or global gravity field models or the use of oceanographic data.

AN ENHANCED SPACE-WISE SIMULATION FOR GOCE DATA REDUCTION

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Abstract

Polar gaps effects, gridding effects and noise propagation from GOCE Trr data into harmonic coefficients estimates, by the so called space-wise approach, have been extensively studied. Recently the conclusion has been drawn that a fast collocation approach must be considered superior to the simple quadrature approach, for this aim. Now several generalizations need to be implemented and integrated in order to come to a final architecture of the software. The integration of non-radial components and the effects of small rotations are presented in a parallel paper. In this work we aim at integrating the information coming from Trr, Tr and T data, in order to better understand the improvement in the low frequency band. To obtain this result, we simulated a realistic data grid on a spherical boundary, implementing a realistic (and close to optimal) grid step and including realistic polar gaps effects.

EFFECT OF HIGH-FREQUENCY TEMPORAL ALIASING ON GOCE GRAVITY FIELD SOLUTION

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Abstract

European Space Agency's GOCE space gradiometer mission is anticipated to produce the mean gravity field model of the Earth with an unprecedented geoid accuracy of 1 cm rms with wavelength at 160 km or longer. In a sun-synchronous near-polar orbit and at an orbital altitude of 200 km, GOCE senses more than mean gravitational forces including tides and other temporal gravity field signals, including gravitational perturbation due to atmospheric loading on solid Earth and ocean. In this study, we investigate the effect of high-frequency temporal gravity field errors or signals from ocean tides, atmosphere, hydrological, ocean and continental ice sheets, on the accurate estimation of GOCE Level 2 product of the geopotential model complete to degree 180. In particular, in addition to errors from temporal gravity field models, due to the orbital sampling characteristics, the effect of temporal aliasing could be critical to the recovery of the GOCE mean gravity field. We will conduct a simulation study with the objectives to quantify the temporal aliasing and model errors using current temporal gravity field models.

GOCE: IS ALIASING A CAUSE FOR CONCERN?

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Abstract

Several authors have considered the effects of short-term temporal variability in the Earth's gravity field on the inter-satellite range- rate measurements from GRACE and the associated aliasing of the monthly solutions leading to the possibility of spurious signals in the seasonal to annual signatures. Similarly, for GOCE aliasing may occur as the static gravity field solution will be time-averaged over two observation periods separated by a period of hibernation. In such a scenario it is conceivable that the time average of the annual gravity field signal will be non-zero. In consequence, this study discusses the possible aliasing of the static GOCE gravity field in the presence of temporal variability due to mass redistribution in the hydrosphere, atmosphere and oceans and attempts to quantify the magnitude of the aliasing in terms of the degree variances.

NUMERICAL SIMULATION OF THE GRAVITY FIELD RECOVERY FROM GOCE MISSION DATA

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Abstract

The feasibility of the gravity field recovery employing the classical, direct numerical method has been tested. This procedure consists in cumulating normal equations, which are generated on a per orbital arc basis, and subsequent inversion using Cholesky decomposition. The estimated parameters concern both the gravity field coefficients and arc dependent ones, such as state vector at epoch and (corrections to) accelerometer calibration parameters, for example. The precision of the computation as well as the necessary CPU time have been evaluated through restitution of a high-resolution static gravity field model in absence and presence of certain other perturbations. The gravity field model coefficients have been estimated using the Satellite-to-Satellite (SST) tracking data (in this study replaced by perturbed positions) and Satellite Gravity Gradients (SGG). A data rate of 0.2 Hz, which is adequate for this first simulation, has been adopted for both data types. The simulated data were generated using the EGM96 gravity field model up to degree and order 300 while the a-priori model in the adjustment procedure was GRIM5-S1. The simulation spans two months. The relative weighting of the SST and SGG normal equations has been investigated. The commission error has been evaluated as a function of the weighting and solution strategy.

GRAVITY GRADIENTS AND SPHERICAL HARMONICS – A NEED FOR DIFFERENT GOCE PRODUCTS?

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Abstract

GOCE will deliver level 2 products such as grids of geoid heights and gravity anomalies, along with a spherical harmonic model of the Earth's gravity field. Furthermore, level 1B calibrated gravity gradients will be available. The majority of these products may seem superfluous, as they are all linear functionals of one and the same quantity, the Earth's gravitational potential. We will show why both observed gravity gradients and derived spherical harmonics might be useful. Their different information content will be discussed as well as the difficulties that occur when one product is to be transformed into another product.

GOCE QUICK-LOOK GRAVITY FIELD ANALYSIS

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Abstract

The satellite mission GOCE, the first Core Mission of ESA's Living Planet Explorer Programme funded by ESA, is dedicated to the precise modeling of the Earth's gravity field from satellite gravity gradiometry (SGG) and high-low satellite-to-satellite tracking (hl-SST) observations. The mathematical models for its parameterisation are based on a series expansion into spherical harmonics, yielding a huge number of unknown coefficients, and efficient solution strategies are required to solve the corresponding large normal equation system. The Quick-Look Gravity Field Analysis (QL-GFA) tool is based on the semi-analytic method. The purpose of QL-GFA is to analyse partial and/or incomplete data sets of SGG and hl-SST data, in order to derive a fast diagnosis of the GOCE system performance, by detecting potential distortions of statistical significance (e.g. systematic errors) in the input data, and to give a fast feedback to the GOCE mission control (Payload Data Segment). This procedure includes the estimation of the noise characteristics of the SGG time series, which is checked against the gradiometer error PSD, and of hl-SST time series, as well as the fast analysis of the information content of these data on the level of the gravity field solution. By means of an iterative strategy, QL-GFA can overcome the negative effect of data gaps, partial data sets and non-repeat orbits. The feasibility of the method to fulfil the intended tasks is demonstrated on the basis of numerical simulations with a realistic GOCE configuration, and special concern given to a realistic noise modelling of SGG and SST data.

GOCESOFT: A SOFTWARE FOR GOCE DATA PROCESSING

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Abstract

The primary goal of the "GOCESOFT" software is the Earth's gravity field modeling on the basis of satellite-to-satellite and satellite gravity gradiometry data to be collected by the GOCE mission. The data can processed either separately or jointly. The necessary input information is: (i) observation points in the spherical geocentric coordinate system - they can be obtained directly from the reduced-dynamic orbit; (ii) the angles defining the orientation of the Local Orbital Reference Frame (LORF) at each observation point; (iii) gravity gradients in the LORF; (iv) average satellite accelerations in the LORF. The latter information is supposed to be obtained by the 3-point double differentiation of the kinematic orbit in an inertial frame. Importantly, both the gravity gradients and the satellite accelerations have to be pre-processed in order to remove: (i) signal from the reference static Earth's gravity field; (ii) signal from temporal gravity variations, e.g. related to tides; (iii) influence of non-gravitational effects, e.g. the atmospheric drag (if the drag-free control system fails to remove all such effects entirely). The result of the processing is a set of geopotential coefficients. These coefficients should be added to those describing the reference gravity field in order to obtain the final product: a model of the Earth's gravity field, which matches the GOCE data optimally. The GOCESOFT software can also be used to solve two other tasks: (i) simulation of gravity gradients or/and satellite accelerations on the basis of a static gravity field model; (ii) computation of the normal matrix and of the right-hand side vector in the system of normal equations in connection with gravity gradients or/and satellite accelerations. The results of the latter computation can be used: (i) to obtain the covariance matrix of the geopotential coefficients; (ii) to model the Earth's gravity field using both GOCE data and data from other sources jointly. At present, GOCESOFT has been adapted to and tested on: (i) Linux PC; (ii) multi-processor computer SGI Origin 3800; (iii) multi-processor computer SGI Altix 3700 (with Itanium-2 processors as the elementary base). We expect that GOCESOFT can also be used (as is or with minor modifications) on any other multi-processor platform with the Unix/Linux operating system; the only requirement is the presence of MPI and Lapack/Blas libraries.

We have put significant efforts in the optimisation of GOCESOFT both in terms of CPU time and computer memory. In particular, the memory requirements are of the order of 200 bytes per observation point for either type of data (in the gravity field modeling mode). This means that one would need only about 12 Gb of memory to process all the GOCE data (about 3×10^7 observation points). By the time GOCE flies, this amount can probably be achieved even on a plain PC. As far as the CPU time is concerned, it is of the order of 1 hour on the SGI Origin 3800 platform with 64 CPUs for a 1-year data set of either type with 1-s sampling, provided that the maximum degree/order is set equal to 300, and the optimal regularization parameter is known. GOCESOFT is also capable of finding the optimal regularization parameter automatically (by means of the generalized cross-validation method). The CPU time in this case, however, increases by about the factor 30 (which is still well within reasonable limits).

VALIDATION CONCEPTS FOR GRAVITY FIELD MODELS FROM NEW SATELLITE MISSIONS

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Abstract

The new satellite missions CHAMP, GRACE and GOCE will provide drastically improved global gravity field information in terms of quality and spatial resolution. In order to quantify independently from the estimation procedure the quality of these gravity field models, new concepts for validation using external information are necessary. Validation requires the processing of selected level 3 products, which further on can be compared to independent solutions. A typical example for such an approach is the determination of the stationary sea surface topography using the geometric approach (mean sea surface minus the geoid) and comparison to oceanographic derived solutions. The paper summarises procedures for validation of gravity field models on different data levels and provides samples of validation results for the latest CHAMP and GRACE fields. Further on an outlook to the requirements for validating GOCE gravity field models will be given.

GOCE: DEALING WITH LARGE ATTITUDE VARIATIONS IN THE CONCEPTUAL STRUCTURE OF THE SPACE-WISE APPROACH

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Abstract

The space-wise approach to the analysis of GOCE data utilizes a grid of convenient "geographic" second order derivatives on a boundary sphere at satellite altitude. These derivatives are to be predicted from actually observed data, which include second derivatives along instrumental axes; in fact the instrumental and geographic frames are not perfectly aligned (e.g. the z-axis is not radial). The prediction can be performed by collocation by exploiting the full covariance (and cross-covariance) of the second derivatives tensors in two arbitrarily rotated frames. This solution is being implemented by UCPH and it has to work only with local data for the well-known limitation in the numerical handling of collocation formula. Since the "radial" component Trr is the most informative component, we are particularly interested in the effect of the misalignment on the prediction of Trr. In this respect Tzz is the most important contributor because the z-axis is very close to the radial axis. In the paper we present a study on the possibility of performing this prediction by applying a Wiener filter along the orbit, exploiting the full spatial covariance structure of T, as it has been recently done by POLIMI, in a simpler context.

SIMULATION RESULTS FROM COMBINATION OF GOCE GRIDDED SST AND SGG DATA

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Abstract

EGM96 spherical harmonic coefficients from degree 25 to 300 has been used to produce grids of values of the anomalous potential,. T, the radial derivative, T_r, and various second order derivatives in an East, North, radial frame, (T_{rr} , T_{re} , T_{ee}, T_{nn})Various combinations of the data has been used to recover the potential coefficients using the method of Fast Spherical Collocation (FSC).

The simulation shows that using T_{re} , T_{ee}, T_{nn}, T_{rr} , and combining T_{re} , T_r, T_e nearly give the same result. That T_{nn} , T_{ee} , gives the same results, but combining T_{ee} with T_{nn} improves the results slightly. T_r , T_{rr} ,and combining T_{rr}, T_r also gives nearly the same results, while the results using the "horizontal" derivatives are up to a factor 2 worse per degree.

However, the different data types "aliases" back into degrees 2 – 24. Here T and T_r give the smallest aliasing.

GRAVITY FIELD ANALYSIS FROM PREPROCESSED AND CALIBRATED GOCE OBSERVATIONS. THE DELFT APPROACH

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Abstract

The current status of the Delft approach to the gravity field analysis of GOCE level 1b data is presented.

The goal of the research is to develop algorithms and software to obtain the optimal estimation of the Earth's gravit field from GOCE SGG and SST data. The philosophy behind the Delft approach can be summarized as follows: (a) no reduction, interpolation, re-sampling etc. of data at the pre-processing stage in order to preserve the stochastic properties of data noise and the information content in the data; (b) proper data weighting even in the presence of frequency-dependent noise and data gaps; (c) selection of a high maximum degree (300) to be solved for in order to recover all information contained in the data; (d) quality description in terms of the auto-covariance matrix of the estimated gravity field parameters in order to allow a proper interpretation and combination of the results with other gravity data.

The primary observations are the 4 components of the Eoetvoes tensor in the LORF and time-averaged satellite accelerations. The latter are to be derived from the precise kinematic GOCE orbit by a three-point differentiation scheme. The primary unknowns are the spherical harmonic coefficients of the residual gravitational potential complete to degree 300. A regularized least-squares solution is computed using a preconditioned conjugate gradient algorithm without the explicit computation of the design matrix and the normal matrix. Efficient block-diagonal pre-conditioners for gravity gradients and satellite accelerations reduce the number of iterations. Fast spherical harmonic synthesis and co-synthesis algorithms are used to apply the design matrix and its transpose to a vector. Data are accurately weighted according to their stochastic properties by a low-level preconditioned conjugate gradient method with ARMA filtering. First-order Tikhonov regularization is combined with the generalized cross-validation method to estimate the regularization parameter from the data. Column-by-column assembly of the normal matrix, based on the fast spherical harmonic synthesis and co-synthesis algorithms, is used to compute the auto-covariance matrix of the potential coefficients.

The results of extensive numerical computations are presented using a simulated 6-months GOCE data set consisting of gravity gradients and precise orbit information. Stand-alone and combined inversions of gravity gradients and precise orbit data will be presented for various sampling rates, colored noise scenarios including non-stationary noise, and data gaps of variable duration.

IS THERE A COMMON FUTURE FOR GOCE AND GRID?

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Abstract

Using Grid and Web services to manage distributed data and computing resources is becoming more common in a number of science fields both in the US and across Europe. It is an ideal time to start an early discussion about whether this technology will be useful for GOCE either for managing data within the ground segment and/or for working up the data towards level 2 and 3 gravity and geoid products. A presentation of the background to Grid and the Grid activities within ESA will be given followed by an invitation for discussion of what the possibilities are for investing in a GOCE data users Grid. Such a Grid might be used for managing and enabling more extensive research with GOCE data among user groups who otherwise may not have sufficient local computational resources to participate in such activities.

ANISOTROPY IN GRACE RESOLUTION: LESSONS FOR GOCE?

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Abstract

The 1997 U.S. National Research Council report "Satellite Gravity and the Geosphere" describes a number of science applications and estimates the resolution capabilities of satellite gravity mission designs similar to GRACE and GOCE. I participated in the 1997 NRC study. Since then, I have come to believe that the NRC report's treatment of the resolution calculations missed some important subtleties. The report assumed that error propagation could be treated as isotropic over the surface of a sphere, and that the resolution of a gradiometer mission could be characterized by considering only one component of the gradient, the second radial derivative. I believe that these assumptions may have led the NRC report to overestimate the resolution of a mission like GRACE and to underestimate the resolution of a mission like GOCE. The gravity field measurement scheme used by GRACE cannot distribute errors isotropically over the sphere. As GRACE measures the inter- satellite line-of-sight velocity perturbation in a polar orbital plane, it effectively measures only the north-south gradient of the gravity potential. If a gravity field model is fit to the GRACE data without some a priori constraint on the field smoothness, the result is a field with too much power in the east-west gradients at low to mid latitudes; this appears as north-south stripes in a map of the gravity anomaly. The problem can be cured but only with heavy smoothing of the field in the east-west direction at low latitudes; thus, the resolution of GRACE is strongly anisotropic over the latitude range where most of Earth's area lies. The NRC report ignored the fact that GOCE will measure along- and across- track second derivatives as well as radial second derivatives. The experience with GRACE suggests that the across-track components may be a particularly important measurement from GOCE. I suggest that the full resolution capabilities of GOCE should be studied with careful application of inverse theory, giving due consideration to all three components of the gradiometer.

PRECISE ORBIT DETERMINATION AND CAL/VAL FOR GOCE

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Abstract

In its position as IGS analysis centre, the ESOC Navigation Support Office has extensive expertise in the processing of GPS data for precise orbit determination purposes. On-going developments in this area include the gradual implementation of real-time processing, and the possible incorporation of GPS data from low Earth orbiting satellites in IGS product generation. From this position, and its close interaction with the operational orbit determination for GOCE at ESOC, the Navigation Office is well suited to provide precise orbit solutions for GOCE on a routine basis, in support of validation and processing of the level 1 and 2 products. Extrapolating recent improvements in GPS- based orbit determination for LEO satellites, it can be expected that near-real-time precise orbits for GOCE can be made available, which can for instance be of great value to the calibration and validation of the GOCE data. Some recent examples will be presented of GPS orbit determination results.

MULTISCALE MODELING FROM EIGEN-1S, EIGEN-2, EIGEN-GRACE01S, GGM01, UCPH2002_0.5, EGM96

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Abstract

Spherical wavelets have been developed by the Geomathematics Group Kaiserslautern for several years and have been successfully applied to georelevant problems. Wavelets can be considered as consecutive band-pass filters and allow local approximations due to their strong localizing properties. The wavelet transform can also be applied to spherical harmonic models of the Earth's gravitational field like the most up-to-date EIGEN-1S, EIGEN-2, EIGEN-GRACE01S, GGM01, UCPH2002_0.5, and the well-known EGM96. Thereby, wavelet coefficients arise and these have been made available to other interested groups. (They can be downloaded from our web page: http://www.mathematik.uni-kl.de/~wwwgeo/waveletmodels.html) These wavelet coefficients allow the reconstruction of the wavelet approximations. The resulting models show the strong approximating capacity of wavelets as well as their applicability to local problems, e.g. modeling locally the geostrophic flow. Different types of wavelets are considered: bandlimited wavelets, i.e. Shannon and Cubic Polynomial (CuP), as well as non-bandlimited ones, i.e. Abel-Poisson. For these types wavelet coefficients are computed and compared for the different spherical harmonic models. Moreover, wavelet variances are given in order to compare these quantities with the well-known degree variances. The presentation also includes the data format of the wavelet coefficients.

MODELLING THE EARTH'S GRAVITY FIELD FROM PRECISE SATELLITE ORBIT DATA: THE ACCELERATION APPROACH WORKS!

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Abstract

A technique has been developed for modeling the Earth's gravity field from precise satellite orbit data. The technique makes use of the orbit-derived accelerations, which can be related to the gravity field in compliance with Newton's second law. The goal of the presentation is to compare this technique with others in terms of the modeling accuracy and CPU time. We demonstrate that the general opinion about a poor performance of the acceleration approach is nothing but a myth. The key elements of the developed technique are as follows:

1) A clear distinction between the observations and the observation points. It is proposed to take the observation points from the reduced- dynamic satellite orbit and to derive the observations (satellite accelerations) from the kinematic orbit. The latter is motivated by the following considerations: (i) the kinematic orbit, contrary to the reduced-dynamic one, is not biased towards the reference model; (ii) the stochastic properties of the data can be estimated much easier.

2) Usage of a simple three-point differentiation scheme for deriving the satellite accelerations. Naturally, such accelerations cannot be treated as point-wise. The functional model, however, can be easily adapted to such data. The motivation for using the 3-point scheme: (i) fewer orbit data are lost at the vicinity of gaps and (ii) the noise propagation "orbit -> accelerations" is straightforward.

3) Exploitation of the pre-conditioned conjugate gradient (PCCG) method for computing the Earth's gravity field parameters (spherical harmonic coefficients) from the data. In this way, the explicit computation of the normal matrix can be avoided. Thanks to that, both the CPU time and the required computer memory is reduced.

4) Formation of the pre-conditioner on the basis of a block-diagonal approximation of the normal matrix, which is derived under the Colombo's assumptions about the satellite orbit. Thanks to that, the number of PCCG iterations is reduced to only a few (10 to 30).

5) Exact data weighting by means of a low-level conjugate gradient scheme (including the case of a data set with gaps). The following situations are distinguished: (i) noise in the accelerations is a propagated non-correlated non-stationary noise in the orbit data; (ii) noise in the accelerations is stationary and colored (such noise may be caused, e.g., by the accelerometer inaccuracies); (iii) noise in the acceleration is a combination of scenarios (i) and (ii).

The developed technique is compared analytically and numerically with: (i) the "classical" approach based on the integration of variational equations; (ii) the energy balance approach (EBA). It is shown that developed technique is as accurate as the classical one but is orders of magnitude faster. Furthermore, the developed technique is more accurate than the EBA. The latter is explained by the fact that the EBA is only sensitive to the along-track force component. The other force components, which may also contain valuable information about the Earth's gravity field, are ignored because they do no work and do not contribute to the energy balance.

EFFECTS OF TOPOGRAPHIC AND ISOSTATIC MASSES IN SATELLITE GRAVITY GRADIOMETRY

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Abstract

Gravity gradiometry is strongly sensitive to the gravity field induced by the topographic and isostatic masses of the Earth. Based on a simplified isostatic model, based on a generalization of Helmert's condensation method, the topographic-isostatic effects are calculated for a GOCE-like satellite orbit. The relationship between the depth of the condensation layer and the residual signal in the gravity gradient tensor is investigated in detail, providing interesting results concerning the smoothness of gravity field related quantities outside the Earth's surface.

A LINEAR ALGORITHM FOR COMPUTING THE SPHERICAL HARMONIC COEFFICIENTS OF THE POTENTIAL FROM A CONSTANT-DENSITY POLYHEDRON

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Abstract

The availability of gradiometric measurements along the tracks of the forthcoming low orbiting satellite GOCE will bring several new challenges to geodesists and geophysicists -- such as the integration of this new kind of measurements in the gravity field determination techniques, the inversion of medium scale geophysical phenomena (e.g. seamounts, rifts, fracture zones) from this new gravity data, etc. In this paper, we present a new computational method for the determination of the spherical harmonic coefficients of the contribution to the potential of a constant density polyhedron of arbitrary shape. Up to now, only one solution is known to this problem. It was proposed by R.A.Werner (1997). This solution has a complexity function of the square of the number of computed spherical harmonic coefficients. This rather high complexity prohibits the processing of realistic geologic models (polyhedra with tens of thousands of faces) at a degree and order compatible with GOCE accuracy (over 400). The complexity of the algorithm we developed is linear as a function of the number of spherical harmonic coefficients to be computed, and as a function of the complexity of the polyhedron (its number of edges). This low complexity will allow to produce simulated spherical harmonic developments of the potential at high degree and order, from realistic geological models. Such simulated models will be of great value for assessing the quality of geophysical inversion processes. We aim for instance at using a complete geological model of the crust (from surface down to Moho) over a 100km wide area for assessing the signature of several density discontinuities at GOCE altitude. We will present the principle of the algorithm and discuss the possible strategies for assessing the numerical accuracy of the computation.

Reference: R.A. Werner (1997) Spherical harmonic coefficients for the potential of a constant-density polyhedron, Computer & Geosciences, vol. 23, n. 10, pp. 1071-1077

HIGH-HARMONIC GEOID SIGNATURES DUE TO GLACIAL ISOSTATIC ADJUSTMENT, SUBDUCTION AND SEISMIC DEFORMATION

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Abstract

GOCE is expected to increase our knowledge of the higher spherical harmonics of the quasi-static geoid, with "higher" being in the range of about harmonic degree 50 (half-wavelength 400 km) to harmonic degree 250 (half-wavelength 80 km). One of the major challenges in interpreting these high-harmonic (regional-scale) geoid signatures in GOCE solutions will be to discriminate between various solid-earth contributions. Here, emphasis will be placed on three major contributors: remaining deviations from isostasy due to late-Pleistocene ice ages; shallow upper mantle subduction of oceanic lithosphere; and accumulated deformation due to sequences of large earthquakes. However, there are many more possible high-harmonic (shallow) solid-earth contributions, including uncertainties related to isostasy of a chemically and stratigraphically heterogeneous crust and lithosphere; tectonic processes like mounting building, continental plateau and oceanic basin formation; and high-harmonic signatures related to shallow mantle density variations and mantle-based processes as plumes. Discrimination between all these various causes might be accomplished by combining the geoid signal with other (space-)geodetic observables, geological data, seismic models and by 2-D pattern matching.

GRAVITY FIELD DETERMINATION USING MULTIRESOLUTION TECHNIQUES

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Abstract

The precise GOCE gradiometer measurements are anticipated to produce a geopotential model with 1 cm rms geoid accuracy and wavelengths longer than 160 km. We present results for modeling the Earth's gravitational field using spherical wavelets and applying methodologies for the estimation of the corresponding coefficients. The observation types in our techniques could either be gravity gradient tensor measurements from the GOCE gradiometer, or other gravity mapping mission data such as the GRACE low-low intersatellite KA-band range-rate, or CHAMP high-low intersatellite GPS phase data, or a combination of all the data types. Our approach combines a spherical harmonics part with an appropriate spherical wavelet representation. Using appropriate techniques for the solution of the resulting normal equation system, wavelet coefficients up to certain detail level can be estimated. Techniques for optimised downward continuations will be discussed with applications for local gravity signal enhancement as well as comparison with in situ data. Finally, we will provide a demonstration of the developed methodology using CHAMP data.

THE USE OF GOCE DATA FOR DETECTION AND CLASSIFICATION OF MANTLE PLUMES

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Abstract

Confined hot up welling of material in the Earth's mantle is known as a mantle plume. Plumes are believed to origin from the core-mantle thermal boundary layer and rise through the entire mantle driven by positive buoyancy forces. The gravity signal caused by such a mantle plume is given by the superposition of the effect of the hot anomaly itself and the effects of the upward deflected surface and internal phase boundaries. The strength and spectrum of the gravity signal depends on the position of the plume in the Earth's mantle, as well as on its temperature, size, and rise velocity, and on the mantle viscosity. With the use of numerical fluid dynamic modelling the gravity fields of different mantle plumes are studied and compared to the expected resolution of GOCE. The maximum gravity signal is on the order of 100 mgal and is found when the top of the plume reaches the base of the lithosphere. The gravity anomaly spectrum of a mantle plume, while rising through the mantle is significantly different from the gravity spectrum of an old plume, which is spreading below the lithosphere. While the gravity field of deep mantle plumes is mainly characterized by long wavelength signals, plumes encountering the lithosphere base and in an old stage of sp reading exhibit considerable energy in a shorter wavelength band related to the size of the plume head in the first case and to the thickness to the asthenosphere in the second case. The possibility to use GOCE data to classify known plumes and to detect plumes rising through the mantle is discussed.

KINEMATIC AND DYNAMIC PRECISE ORBIT DETERMINATION OF LOW EARTH ORBITERS: IMPORTANCE OF THE GPS RECEIVER PERFORMANCE

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Abstract

Thanks to the high performance of the BlackJack GPS receiver flying on CHAMP, kinematic precise orbit determination (POD) has turned out to be a new method in orbit determination for Low Earth Orbiters (LEO). Kinematic POD is based on GPS measurement and does not make use of information on force models. Therefore it is independent of orbit design (e.g. satellite altitude). From that point of view, kinematic orbits are very well suited for the Earth observation satellites at very low altitudes, where air-drag and gravity become more difficult to model. With highly accurate CHAMP kinematic positions, interesting new methods are being developed nowadays to e.g. determine gravity field parameters, validate dynamical models, or derive atmosphere density information.

In this paper we would like to show the latest results in orbit determination for today's geodetic missions like CHAMP, SAC-C, and JASON-1 and point out the importance of GPS receiver performance for kinematic and reduced-dynamic POD as well as for gravity field recovery from SST data. Receiver performance is especially critical for a satellite mission as complex as GOCE, flying at very low altitude, where accurate orbit determination is much more challenging. Since the accuracy of kinematic POD mainly depends on the quality of phase GPS measurements, this kinematic method in combination with a reduced-dynamic approach is very well suited to validate the performance of the spaceborne GPS receiver. We would like to show the large differences in quality of the estimated kinematic orbits among today's geodetic missions. The quality differs considerably because of L2-ramps in phase measurements, large data gaps, phase breaks, multipath, number of GPS satellites tracked, GPS antenna design and attitude characteristics. As an example, JASON-1 kinematic orbits are typically less accurate than those of CHAMP. To a great extent, this also stands for the reduced-dynamic (GPS-derived) orbits of these two satellites, although the forces acting on a satellite are much easier to model for the higher altitude of JASON-1. This apparent paradox in orbit determination is due to the performances of the GPS receiver. Problems similar to those of JASON-1 GPS receiver can also be identified in the early GPS data of the CHAMP mission. Under these circumstances, kinematic POD is very inaccurate as seen from SLR validation and the GPS data are not really suited for gravity field determination. The last two years of CHAMP GPS data allows for kinematic and reduced-dynamic orbit determination on the level of 1-3 cm.

THE T5 ION PROPULSION ASSEMBLY FOR DRAG COMPENSATION ON GOCE

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Abstract

Due to the nature of the gravity field measurements to be made by GOCE, the satellite must fly in a near-circular, sun-synchronous, dawn-dusk orbit at an altitude of around 250 km. At this altitude the residual air drag is significant, and must be actively compensated by onboard thrusters. In addition the gradiometer instrument is sensitive to linear acceleration, which must also be precisely compensated for by the thruster system.

The dominant component of the drag force is in the primary flight axis, requiring a system capable of continuous throttling between 1 and 20 mN, with a thrust resolution of 12 mN, a response rate up to 2.5 mN/s, and a thrust vector stability of better than ± 0.2 degrees. In addition to the drag compensation role, the thruster will also be operated at a fixed high thrust during orbit raising for the long eclipse season.

These stringent requirements can only realistically be met using a highly controllable ion thruster assembly (ITA). The QinetiQ T5 Kaufman- type thruster is ideally suited for this mission, having been designed for a nominal thrust of between 15 - 25 mN, and including solenoid magnets which allow the operating parameters to be efficiently and accurately controlled over the required thrust range. As such the T5 represents an enabling technology for the mission.

At the time of the workshop all pre-verification activities will have been completed, and formal qualification of the ITA will be well underway. This paper will present an overview of the pre-verification and qualification programmes, and is intended to provide the GOCE scientific users with an understanding of the technology, its performance, and the challenges which have been overcome to provide it. The presentation will also offer them an opportunity to clarify any issues linking the ion propulsion system to the performance of the gradiometer instrument.

COMPARISON OF SOME METHODS FOR MODIFYING STOKES' FORMULA IN THE GOCE ERA

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Abstract

The dedicated satellite gravity mission GOCE will drastically improve our knowledge of the long to medium wavelengths of the Earth's gravity field. In order to determine the finest details, however, we still have to utilise regional gravity data. It is the purpose of this paper to study three modifications of Stokes' formula numerically, using simulated standard errors for the GOCE potential coefficients. The methods tested are the standard remove-compute-restore, the least squares and the low-degree GOCE-only modifications. In the latter it is required that only GOCE information must influence the determination of the lowest degrees.

PARAMETER CHOICE STRATEGIES FOR MULTISCALE GOCE MODELING

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Abstract

The determination of the Earth's gravitational field from GOCE measurements is a exponentially ill-posed problem which requires adequate methods of regularization. Multiscale Tikhonov regularization, i.e. Tikhonov scaling functions and wavelets, has been suggested as a means for the solution of the SGG-Problem e.g. by Freeden (1999). It has already been successfully applied for CHAMP modeling by M. Fengler, W. Freeden and J. Kusche (2003). However, the main question in Tikhonov regularization is the choice of a suitable regularization parameter. Our intention is to present some different numerical tests for known methods for the choice of this parameter (such as L-curves, generalized cross validation) to simulated GOCE data. Moreover, we introduce techniques that have not yet been applied in GOCE modeling: quasi-optimality criterion and GOCE specific strategies from Freeden, Pereverzev (2000). All these different approaches are compared within a multiscale concept that allows not only global, but also local modeling of GOCE data.

NON-LINEAR COMPUTATION OF THE GRAVITY FIELD OF AN ASPHERICAL PLANET

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Abstract

GOCE will provide global gravity models of the Earth with an improvement of an order of magnitude, with a resolution in wavelength greater than 100 km. To take full advantage of these high-quality data in the determining the distribution of mass density, we need an accurate way to calculate the predicted gravity field caused by topography or internal structures and lateral variations in density. In addition, incorrect estimation of their contributions to the global field lead to misinterpretations of the gravity signal. The method presented here allows the computation of the global gravity field and its derivatives inside and outside a planet for models with lateral density variations as well as lateral variations of interfaces. So far, the global methods already developed are either based on the mass-sheet approximation, or allow only the evaluation of the gravity field at a single given altitude. In addition, these methods use Clebsch-Gordan coefficients for the computation of lateral variations effects and are thus computer intensive, allowing only the study of large scale structures. Our method is based on the propagation (and not a downward continuation) of a solution of Newton's equation from a given height, for example the observation point, toward the center of the planet. In order to reduce the computation time, all the lateral variational effects and the angular derivations are performed using Legendre transforms between the physical and spectral domains. Such an approach reduces by l^2 the amount of computation in angular order, thereby allowing non-linear modeling to be performed for models with high angular degrees. The computation is adapted to the modeling of gravity fields for models with lateral variations larger than 200 in angular orders and might therefore be used for a rapid modeling of the gravity fields of Mars, the Moon and the Earth at tectonic scales.

GOCE GRADIENTS VALIDATION BY THE AIRBORNE GRADIOMETER AND GRACE MEASUREMENTS

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Abstract

Validation of the GOCE gravity gradient product by comparison with measurements on low and high altitudes is discussed. As the low altitude case we can consider the application of the airborne gradiometer flying at the altitude of 40 - 30 km on the board of a stratospheric balloon. The measurements can be compared with satellite data. The post-mission validation is possible more directly than through the comparison with the ground truth gravity anomalies or geoid undulation. The low flying gradiometer is less sensitive, but thanks to the altitude difference, compatible in precision with the orbiting GOCE gradiometer. The high altitude data are generated by simulation of the GRACE mission converted to gravity gradients. It is interesting in particular for the middle part of the spectrum of the gravity field. Two procedures of the downward/upward continuation are presented: the least squares collocation and the Upward Continuation with the Reference Model. Comparison of these two methods shows some advantages and disadvantages of each of them. Numerical tests are presented using data simulated by the IAG Special Study Group "Gravity Field Missions".

CALIBRATION/VALIDATION OF GOCE DATA OVER ANTARCTICA

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Abstract

European Space Agency's GOCE space gradiometer mission is anticipated to produce the mean gravity field model of the Earth with an unprecedented geoid accuracy of 1 cm rms with wavelength at 160 km or longer. We propose an international effort for the calibration and validation of GOCE gravity gradient tensor measurements and Level 2 geopotential data product (1) over a blue ice region (100x50 km^2) south of Schirmacheroase glacier, Dronning Maud Land, E. Antarctica, and (2) at regions near the Soywa station, E. Antarctica. These two regions have been well surveyed by gravimeters, GPS traverse, tide gauge, and other instrumentations. They are currently participating or propose to participate in the calibration and validation of other spaceborne sensors, including GRACE, ICESAT and CRYOSAT. This paper reports the collaborative effort and plans for potential GOCE data product and measurement validation and description of approach for comparing in situ and other satellite data with GOCE data.

UPWARD/DOWNWARD CONTINUATION OF GRAVITY GRADIENTS FOR PRECISE GEOID DETERMINATION

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Abstract

The forthcoming GOCE mission will produce gravity gradient data at satellite altitude. There are different data processing strategies in order to obtain updated gravity field information from these measurements, but most of them are based on the spherical harmonic expansion of the gravity field. An alternative approach would be the direct use of the GOCE data in the space domain. In this case we need formulas for transferring gravity gradients and other gravity field information in spherical approximation between different height levels.

The upward/downward continuation problem of second vertical gravity gradients has been already solved by different authors. In this paper we discuss formulas for the other gravity gradients. The proposed approach is to use these gravity gradients in two combinations. The corresponding formulas are tested with synthetic gravity field information as well as with simulated GOCE measurements and conclusions on precise geoid determination and validation are drawn.

STATIC GRAVITY MODEL DEVELOPMENT: INCORPORATION OF GOCE DATA

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Abstract

JCET is contributing to current efforts to enhance the geopotential model underlying the World Geodetic System 84 (WGS 84), and in particular, with the incorporation of data from new missions such as CHAMP at present, and GRACE and GOCE in the future. One of the many enhancements that the new development incorporates is the modeling of temporal variations for the long wavelength components of the field, in order to avoid aliasing of these signals and a consequent degradation in the quality of the new model. Currently, and until we accumulate several years of GRACE data, the best data source for determining these variations are satellite laser ranged geodetic targets (such as the LAGEOS, ETALON, AJISAI, STARLETTE, STELLA, etc.). While the data from these satellites provide the definition of the underlying Terrestrial Reference Frame, its crust-fixed orientation, and the temporal variations in the long wavelength, the detailed components of the gravitational model will be primarily determined from the data of dedicated missions such as CHAMP, GRACE, and GOCE in the future. We will present preliminary results of a new analysis of our expanded data set using NASA Goddard's GEODYN/SOLVE II software, and our plans for incorporating the GOCE data in the future.

A BAYESIAN APPROACH TO INVERT GOCE GRAVITY GRADIENT

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Abstract

The measurements made by the gradiometer on board in the GOCE satellite are gravity gradients in three directions of space. The main goal of these data is to compute the Earth gravity field at global scale with improved accuracy and a spatial resolution. However, it is quite clear gradiometric data themselves might help to infer the inner structure of the Earth. The vertical gravity gradient has actually been successfully used to improve the inversion of gravity data for density, and the full gradiometric tensor is now measured in the oil and gas prospection for the imaging of subsurface structures, when seismic methods are not suitable. For those reasons, we propose to build an inversion method for gradiometric data, dedicated to geodynamical studies both at global and regional scales, since those scales of study are indeed allowed by GOCE data spatial distribution. We choose to use a bayesian approach, which is seldom applied in the field of gravity inversion, even though often mentioned. This type of approach is less consuming for heavy computations and then should allow us to deal more easily with a great among of data. We discuss here on the contribution of the FTG (Full Tensor Gradiometry) data.

A WAVELET BASED REPRESENTATION OF THE GRAVITY FIELD

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Abstract

GOCE will provide an unprecedented knowledge of the earth gravity field that will allow to realize geodynamic studies at various scales, ranging from the entire globe to the "local" scale. However in order to carry on this "local" studies it will be necessary to mix GOCE data with other ones, namely surface or airborne data in order to improve the short wavelengths resolution of the gravity anomalies that have to be interpreted for geodynamic purposes. For that aim, we developed a representation of the gravity field based on wavelets instead of the classically used spherical harmonics. We first tested several different bases, namely Shannon, De La Vallée Poussin and Abel-Poisson. We carried out our tests on the entire globe as on limited areas. We tested "perfect" data and noisy ones and we also investigated the possible effects of data distribution, from homogeneous distribution to very inhomogeneous ones. We present and discuss here our results that appear to be most promising.

RECOVERY OF THE GRAVITY FIELD SIGNAL DUE TO A LOW VISCOSITY CRUSTAL LAYER IN GIA MODELS FROM SIMULATED GOCE DATA

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Abstract

We model the glacial isostatic adjustment (GIA) process using a semi-analytical normal mode technique (Vermeersen & Sabadini 1997) and a pseudo-spectral sea level code (Mitrovica & Peltier 1991) to compute the response of a model Earth to a sea and ice load history. The results of these computations are 3-D displacements, free-air gravity anomalies and geoid heights.

In previous studies (Vermeersen (2003), van der Wal et al. (2003), Schotman et al. (2003)), we have investigated the influence on the high resolution gravity field signal of a ductile, low viscosity layer in the lower crust of the Earth, and the use of different sea and ice load histories. We have compared the results with the expected GOCE performance.

In this study, we use this forward model in the simulation of GOCE satellite gravity gradient (SSG) measurements. First, reference SSG measurements are simulated by an a priori gravity field model. Second, SSG measurements are simulated by extending the a priori gravity field model with the gravity signal due to a ductile crustal layer. The differences between these measurements or residues then show the effect of such a layer on GOCE measurements.

In the next step, the gravity field model is further extended by additional signals due to for example topography, and time-variable signals as the atmosphere. We recover the gravity field signal due to the ductile crustal layer from these measurements and estimate the inversion or aliasing error.

Our current Earth model can handle variations in the radial direction only. To make full use of the spatial high-resolution capabilities of GOCE, we are developing a regional finite element model to include lateral heterogeneities. To study the effect of these results on GOCE measurements, we consider investigating the use of a non-global inversion.

GRAVITY AND GEOID IN THE ARCTIC REGION - THE NORTHERN GOCE POLAR GAP FILLED

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Abstract

The GOCE satellite gravity field mission will leave "polar gaps", and to fill-in these gaps terrestrial and airborne gravity data will be essential. The Arctic Gravity Project, an international initiative involving eleven circumarctic countries, has recently completed the compilation of a gravity field on a 5x5'' grid of the entire Arctic region north of 64°N. The project incorporated major new airborne surveys of the US Naval Research Laboratory, Scandinavian, German and Russian sources, as well as extensive surface data coverage for the Russian sector of the Arctic Ocean (VNIIO, St. Petersburg). Other data sources included submarine data (SCICEX cruises) that provided detail over many of the high frequency features in the Arctic and enhanced satellite altimetry over ice-covered areas. In the poster we describe the methodology used in the final compilation including the downward continuation of airborne gravity, modelling of the terrain and bathymetry, merging and combination techniques, and final data analysis and selection. An accuracy assessment of the Arctic gravity field has been performed, including comparisons with available satellite mission data from CHAMP and GRACE geopotential models. The Arctic Gravity Project includes free-air gravity anomalies, updated elevation and bathymetry data, Bouguer anomalies, and a precise geoid. A similar effort with new airborne gravity survey should also be undertaken in Antarctica, especially for the central south pole region, ideally coordinated by bodies like SCAR and IAG.

ESTIMATING THE OCEAN CIRCULATION AND THE GEOID THROUGH A COMBINED ANALYSIS OF ALTIMETRIC AND GEOID INFORMATION

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Abstract

An ocean data assimilation framework will be presented which is designed to obtain a dynamically consistent picture of the changing flow field of the ocean by combining global ocean data set with a general circulation model (GCM). For the mean circulation a precise geoid describes the reference frame for dynamical signals in altimetric sea surface height observations. For a consistent estimate information about the prior geoid error covariance is essential and the results need to be consistent with estimated residuals in sea surface height and the prior error information. Data assimilation is one of the few quantitative consistency checks for anticipated new geoid measurements. Anticipated from the assimilation procedure is a best possible estimate of the dynamical sea surface height that when subtracted from altimetric observations can help improving geoid estimates them self.

RECENT IMPROVEMENT IN ALTIMETRY: HOW MSS AND MDT CAN BENEFIT FROM IT IN COMBINATION WITH A GOCE GEOID?

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Abstract

In the last three years, satellite altimetry has benefited from the addition of Jason-1, EnviSat and Geosat Follow On (GFO) dataset. Along track altimetric data, once averaged in time, provide an accurate value of the mean sea height, and therefore to the geoid undulations. In the past, Mean Sea Surface (MSS) have merged the different dataset to provide mean height accuracy of few centimetres for wavelength ~10-30km due to their particular spatial distribution. By cumulating in time more altimetric data, MSS are usually more precise in the open ocean, and furthermore in coastal areas and semi-enclosed seas. Besides, GFO and T/P data, into the new interleaved orbit, are also enhancing the accurate sampling of the ocean mean topography.

We show here the MSS improvements provided by these new dataset. Focusing on the northern north east Atlantic, the GOCINA area. The new MSS is compared to state-of-the-art global MSS (CLS01 and KMS02). MSS are used in combination of geoid to estimate Mean Dynamic Topography (MDT). In the context of the expected improved accuracy provided by GOCE (i.e., few centimetres at 50-100 km wavelength), we assess here the needed accuracy of MSS to reduce in equivalent way the MDT estimation errors. Both local tailored geoid (provided by the GOCINA project) and the global GRACE solutions are used here to analyse residual errors and evaluated the corresponding improvements.

In conclusion, we discuss the needed precision and spatial resolution of future altimetry (in the context of the Global High Resolution Sea Surface Topography program) to match GOCE outcome.

COMBINED USE OF ALTIMETRY, IN-SITU MEASUREMENTS AND A GEOID MODEL TO ESTIMATE A GLOBAL MEAN DYNAMIC TOPOGRAPHY: IMPACT OF GRACE AND GOCE DATA

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Abstract

New and fundamental insights are expected for oceanographic applications from the launch in 2006 of the Gravity Field and Steady- State Ocean Circulation Mission (GOCE) whose objective is to determine the geoid to 1 cm accuracy for spatial scales down to 100 km. The use of GOCE data together with altimetric measurements of the Sea Surface Height will finally allow retrieving with high accuracy the short wavelengths of the ocean dynamic topography whereas so far only its variable part can be deduced from altimetric heights. In order to reconstruct absolute sea level from altimetric sea level anomalies (SLA), the estimation of a realistic mean dynamic topography (MDT) consistent with altimetric SLA is a crucial issue. Also, estimating an accurate MDT will help the definition of future GOCE products for oceanographers and prepare for the calibration/validation of GOCE products. In that context, a method was developed to estimate globally the required MDT combining altimetric data, in-situ measurements and a geoid model. First, the geoid model EIGEN-2 is subtracted to the Mean Sea Surface Height CLS01 at spherical harmonics degree 30. The obtained field is used to improve the Levitus climatology at wavelengths longer than 660 km (major improvements are obtained at high latitudes) providing a first guess for the computation of the MDT. On the other hand, in situ measurements and altimetric data are combined using a synthetic method. This method consists in subtracting synoptically the altimetric sea level anomaly to in-situ measurements of the full dynamical signal so as to obtain local estimates of the mean field which are then used to improve the first guess using an inverse technique. The obtained combined MDT (CMDT) is compared to other existing MDT (like the Levitus climatology or mean fields issued from models). In particular, absolute dynamic topography values obtained referencing altimetric anomalies to the various solutions are compared to independent in situ measurements. RMS differences to the observations are significantly reduced when using the CMDT. In order to further understand the impact of future accurate geoid measurements, two particular points are then investigated. First, a focus is made on the Mediterranean Sea - whose mean circulation features short scales and is largely unknown- to better understand the future impact and limitation of GOCE data in areas where the mean circulation scales are expected to be inferior to GOCE resolution (i.e. ¡Ö100 km). Second, the impact of using the new GRACE geoid - whose error is close to 1 cm at 360 km resolution ¨C when estimating a CMDT is studied. GRACE information allows to significantly improve the MDT first guess, resulting in a more realistic CMDT in all areas where no in situ measurements were available.

USE OF GOCE FOR OPERATIONAL OCEANOGRAPHY

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Abstract

One of the main objectives of GOCE is to provide a sufficiently accurate geoid model to allow a precise estimation of absolute dynamic topography from altimetry. In practice the best procedure to get an estimation of the absolute dynamic topography from altimetry will be to estimate a mean dynamic topography from GOCE and altimetry and to add this mean dynamic topography to sea level anomaly derived from repeat- track analysis.

The product that oceanographers will need from GOCE will thus be a mean dynamic topography (and its error). Such a product will have a major contribution to oceanography and operational oceanography (see Woodworth et al., 1998; Le Provost et al., 1999; Le Traon et al., 2003). To benefit from the full potential of this mission, work should be carried out:

To define the best strategy to estimate a mean dynamic topography (MDT) and its error from GOCE (GRACE/CHAMP) and altimeter data (mean sea surface) to define the best methodologies to validate such MDTs and their errors (and corresponding ocean circulation). The comparison with MDTs derived from in-situ data and models will be very useful for the validation. The comparison of absolute dynamic topography derived from GOCE MDTs and altimeter SLA with in-situ data (drifters, Argo) should also be very powerful. •to combine these MDTs with those derived from in-situ measurements. The in-situ and GOCE/GRACE/CHAMP topographies will have very different error characteristics and will thus be complementary. It is likely that the in-situ data estimations will be very accurate in well-sampled regions and low variability regions. In other regions and also at high latitudes and in coastal regions (where the barotropic component will not be well estimated) they will be less useful. •to quantify the impact of these new MDTs in a global data assimilation system. This should be done both for analyses and forecasts.

CLS has been involved in some of these tasks as part of the French MERCATOR project and the ENACT and GOCINA EC projects. Main results and findings will be illustrated here. An overview of existing and future operational oceanography projects (GODAE, MERCATOR, MERSEA) will also be given as well as their plans for using GOCE products. In the longer run, our goal is to develop and validate a global MDT product from GOCE. This will allow us through the SSALTO/DUACS operational altimetry system to provide our altimeter and operational oceanography users with absolute dynamic topography measurements.