Abstract Book

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The GOCE Mission I:
Satellite Payload and Performance

GOCE Mission Objectives and Requirements

Mark Drinkwater[1] and Roger Haagmans[2]

[1] ESA/ESTEC, EOP-SMO, 2201AZ Noordwijk ZH, Netherlands
[2] ESA/ESTEC, EOP-SME, 2201AZ Noordwijk ZH, Netherlands

Abstract

ESA's first Core Earth Explorer mission within the Living Planet Programme is the Gravity field and steady-state Ocean Circulation Explorer (GOCE). GOCE shall play an important role in this 'geopotential decade' by acquiring a high quality, high spatial resolution gravity field and geoid for future scientific applications. GOCE combines an innovative new three-axis gravity gradiometer (EGG) instrument (comprising three x, y, z pairs of accelerometers with a baseline separation of 0.5 m) with a drag-compensating ion-propulsion system to measure for the first time the full gravity gradient tensor along its orbit at around 250 km altitude. GOCE will carry a GPS satellite-to-satellite tracking navigation system for 3-dimensional positioning, star trackers for precise pointing knowledge, and a laser retroreflector for ground laser tracking. The primary mission objective is for GOCE to make accurate and precise measurements of the Earth's stationary gravity field and gravity anomalies. Various applications in the fields of oceanography, solid-earth physics and geodesy require data to be acquired within specific ranges of accuracy and spatial resolution. This presentation will focus on the origin of the key GOCE mission requirements to obtain a gravity field accurate to 1 mGal at high spatial resolution 100 km, as well as a global geoid model to 1-2 cm accuracy.

Mission Development Status

Danilo Muzi[1]

[1] ESA/ESTEC, Keplerlaan 1, 2200 AG Noordwijk, Netherlands

Abstract

The current status of development and recent advances in work on the GOCE payload and platform will be presented.

Spacecraft Attributes

Alex Popescu[1]

[1] ESA/ESTEC, Keplerlaan 1, 2200 AG Noordwijk, Netherlands

Abstract

The unique attributes of this dedicated gravity field spacecraft will be presented.

Mission Performance

Rune Floberghagen[1]

[1] *ESA/ESTEC, Keplerlaan 1, 2200 AG Noordwijk, Netherlands*

Abstract

The expected performance of the GOCE Mission will be detailed.

The Accelerometers of the GOCE Mission Design, Integration and Tests

TEAM GOCE GA&E[1], Jean-Pierre Marque[1], Christophe Bruno[1], Françoise Liorzou[1], Dominique Horrière[1], Guillaume Bodovillé[1], Jean Guérard[1], Vincent Lebat[1], Bernard Foulon[1], Pierre Leseur[1], Dominique Chauvin[1] and Yann Alonso[1]

[1] *ONERA, BP-72, 29 Avenue de la Division Leclerc, 92322 Chatillon, France*

Abstract

Main attributes of the GOCE accelerometers in term of design, performance budget and test plans will be presented.

The Accelerometers of the GOCE Mission Objective milli Eötvös

TEAM GOCE GA&E[1], Jean-Pierre Marque[1], Bruno Christophe[1], Françoise Liorzou[1], Dominique Horrière[1], Guillaume Bodovillé[1], Jean Guérard[1], Vincent Lebat[1], Bernard Foulon[1], Pierre Leseur[1], Dominique Chauvin[1] and Yann Alonso[1]

[1] *ONERA, BP-72, 29 Avenue de la Division Leclerc, 92322 Chatillon, France*

Abstract

The major expected performances of the Accelerometers, as issued from the main analysis and test results performed during the integration and testing phases, will be presented.

Alcatel Alenia Space-France's (AAS-F) Contribution to GOCE

Max Bard & and AAS-F Gradiometer Team[1]

[1] *Alcatel Alenia Space, 100 Boulevard du Midi, BP99 06322, Cannes, France*

Abstract

The poster will detail the contribution of Alcatel Alenia Space-France (AAS-F) to the GOCE Gradiometer instrument.

Session 2

National, EC and ESA Project Activities

Predictions of the GOCE in-flight performances with the End-to-End System Simulator

Giuseppe Catastini(1), Stefano Cesare(1), Simona De Sanctis(1), Massimo Dumontel(1), Manlio Parisch(1) and Gianfranco Sechi(1)

(1) *AAS-I, Strada Antica di Collegno, 253, 10146 Torino, Italy*

Abstract

The Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) satellite is now at about one year from the launch (planned for the second half of 2007). The GOCE payload (constituted by a 3-axis gradiometer and by a 12-channel GPS receiver) has been implemented and characterized to the maximum possible extent on ground. The results of the characterisation tests have been used to complete the high-fidelity models of the GOCE instruments which are included in the GOCE End-to-End (E2E) System Simulator. The E2E Simulator, set up since the early stages of the GOCE programme and continuously updated according to the project evolution, includes in addition accurate models of the satellite linear and angular dynamics and of its perturbations, of the Drag-Free and Attitude Control System and of the orbit environment (Earth gravity and magnetic field, atmosphere density and winds at satellite altitude, Sun/Earth radiation, GPS satellite constellation). This tool allows simulating the in-flight dynamics behaviour of the satellite in various mission phases and the behaviour/output of the payload instruments during initial set up, calibration and science modes. A post-processing module elaborated the raw measurements using the Payload Data Ground Segment algorithms and provides the Level 1b products of the mission, among which the components of the gravity gradient tensor in the Gradiometer Reference Frame and the GPS receiver measurements, derived positions and reconstituted satellite orbit in Earth-fixed reference frame.

The GOCE E2E System Simulator is the tool utilized for producing the most reliable prediction of the GOCE in-flight performances on the measurement of the gravity gradient tensor and on the observables from which the precise orbit determination is performed. These performances are the result of factors that cannot be fully tested on ground (for the impossibility of reproducing the orbit gravitational environment) and can be treated analytically only in a simplified way (for their complexity), like the intrinsic noise of the gradiometer accelerometers, the behaviour of the Drag-Free and Attitude Control System of the platform, the functioning of the gradiometer in-flight calibration procedure. This paper will present the results of the last simulation of the gradiometer in-flight calibration and of the successive mission measurement phase carried out with an E2E Simulator fully representative of the as-built satellite and payload. The resulting performances on the Level 1b product of the GOCE mission will be provided.

GOCE research in Germany: from sensor analysis to Earth system science

Reiner Rummel[(1)], Jakob Flury[(1)] and Thomas Gruber[(1)]

[(1)] Technical University Munich, Arcisstr. 21, 80290 München, Germany

Abstract

GOCE Level 2 research in Germany is focussed on various gravity field estimation approaches, on calibration and validation of GOCE gravity field gradients and gravity field models using terrestrial gravity field observations and marine data. Research on these fields is supported by the federal Geotechnologien research programme. GOCE Level 3 research is focussed in the new priority research programme of the German Research Foundation "Mass Transport and Mass Distribution in the Earth System". The programme (starting in autumn 2006) aims at an interdisciplinary effort on the study of mass related processes and signals based on data from CHAMP, GRACE, GOCE and satellite altimetry. It includes projects on global and regional ocean circulation, on structure and dynamics of mantle and crust (using GOCE data) as well as GRACE related research on temporal mass variability and mass exchange. From the viewpoint of GOCE users, the integration into Earth system research is particularly attractive. The GOCE project bureau Germany at Technische Universität München is engaged in coordination of these level 2 and level 3 activities. Workshops and round tables have been organized on themes such as GOCE gravity field analysis, inverse problems, on mass transport and mass distribution in the Earth system, and on future perspectives for satellite gravimetry. The paper summarizes the current status and research activities on these fields. Additional information in German language can be found at http://www.goce-projektbuero.de.

Combination of spaceborne, airborne and surface gravity in support of Arctic Ocean sea-ice and MDT mapping

Rene Forsberg[(1)], Henriette Skourup[(1)], Ole Andersen[(1)], Seymour Laxon[(2)], Andy Ridout[(2)], Alex Braun[(3)], Johnny Johannessen[(4)], Frank Siegismund[(4)], Carl C. Tscherning[(5)] and Per Knudsen[(1)]

[(1)] Danish National Space Center, Juliane Maries Vej 30, DK-2100 Copenhagen Oe, Denmark
[(2)] University College London, Gover St, London WC1E 6BT, United Kingdom
[(3)] University of Calgary, 2500 University Dr, Calgary T2N 1N4, Canada
[(4)] Nansen Environmental and Remote Sensing Center, Thormolensgate 47, N 5006 Bergen, Norway
[(5)] University of Copenhagen, Juliane Maries Vej 30, DK-2100 Copenhagen Oe, Denmark

Abstract

Improved knowledge of the gravity field in the Arctic is a key to the utilization of satellite altimetry to determine sea-ice thickness and mean dynamic topography (MDT). In the paper we outline the construction of a new gravity field of the Arctic Ocean region, combining new GRACE and ICESat observations with earlier compilations of airborne, surface, and submarine gravity data from the Arctic Gravity Project. We compare the corresponding geoid model to a mean sea surface (MSS) model derived from ICESat lowest-level filtered laser altimetry and retracked radar altimetry, to allow for a consistent estimate of the Arctic Ocean MDT. Results are compared to oceanographic models, and show an overall absolute consistency is achieved at the decimeter-level. Arctic Ocean sea ice freeboard heights (and thus ice thickness) are an integral part of these investigations, and ICESat-derived freeboard heights show a good correlation to multi-year ice distribution as determined from Quikscat. The investigations represent the core of the ongoing ESA project “ArcGICE”. One of its major objectives is to provide a practical algorithm for the estimation of sea surface heights including the associated errors. These parameters can further be used for example as a reference for Cryosat-2 measurements of sea ice freeboard. The ArcGICE study includes detailed error estimates and covariance studies, and it is clear that the inclusion of GOCE data will significantly enhance ice thickness and MDT mapping from e.g. CryoSat-2.

The OCTAS project, the geoid, the mean sea surface and the mean dynamic topography

Dag Solheim(1), Ove C. D. Omang(1), Addisu Hunegnaw(1), Helge Drange(2), Johnny Johannessen(2), Frank Siegismund(2), Hossein Nahavandchi(3), Kourosh Ghazavi(3), Bjørn Ragnvald Pettersen(4), Dagny Lysaker(4), Arne Gidskehaug(5) and Hans-Peter Plag(6)

(1) Norwegian Mapping Authority, Kartverksveien, NO-3507 Honefoss, Norway
(2) Nansen Environmental and Remote Sensing Center, Edvard Griegsvei 3a, NO-5059 Berge, Norway
(3) NTNU, Høgskoleringen 7G, NO-7491 Trondheim, Norway
(4) Norwegian University of Life Sciences, Postboks 5003, NO-1432 Ås, Norway
(5) University of Bergen, Allégt. 41, NO-5007 Bergen, Norway
(6) University of Nevada, Mail Stop 178, Nevada 89557-0088, United States

Abstract

The OCTAS project, funded by the Norwegian Research Council, is a multidisciplinary project combining geodesy, satellite altimetry and oceanography. The main objective is to enhance the Norwegian capacity in Earth observation technologies through determining the ocean circulation and transport by using satellite techniques in combination with geodesy. The primary study area is the Fram Strait between Svalbard and Greenland.

A vital objective is the determination of a high precision gravimetric geoid for the OCTAS study area. This requires an error free high quality gravimetric dataset. The process of establishing such a data set by adjusting older marine data through comparison with modern airborne and marine gravity data sets is described. Combining this updated gravity data set with data from the CHAMP and GRACE satellites an OCTAS geoid has been computed. The updated gravity field and the derived geoid may be used in validating the GOCE products.

The challenges and efforts undertaken in deriving a high precision mean sea surface in a region with an abundance of sea ice and limited number of altimetric satellites is described. The derived geoid and mean sea surface is combined to form the mean dynamic topography, MDT. These MDT's are assessed by intercomparing with oceanographically derived MDT models.

The status and an overview of the project is given including identification of challenges that must be addressed in order to achieve the project objectives.

Integration of Altimetry and GOCE geoid for Ocean Modeling: Results from the GOCINA project

Per Knudsen(1) and the GOCINA Team(1)

(1) Danish National Space Center, Juliane Maries Vej 30, 2100 Copenhagen, Denmark

Abstract

One of the major goals of the recently completed EU project GOCINA (Geoid and Ocean Circulation In the North Atlantic) was to determine the following three quantities; an accurate mean dynamic topography model, an accurate mean sea surface and an accurate geoid for the GOCINA region between Greenland and the UK and to use the common relationship between the three quantities for mutual improvement. The improved determination of the mean circulation will advance the understanding of the role of the ocean mass and heat transport in climate change. To calculate the best possible synthetic mean dynamic topographies a new mean sea surface (KMS04) has been derived from nine years of altimetric data (1993-2001). The regional geoid has furthermore being updated using GRACE and gravimetric data from a recent airborne survey. Subsequently, an integrated approach has been used to compute MDTs from joint inversions of data from the various sources. Then the optimally estimated MDT was used for the assimilation of altimetry into the FOAM, MERCATOR, and the TOPAZ model systems. The results demonstrated that the use of the improved MDT improved the modeling of the transports and increased the agreement with observations. The modeling of the heat transport through the straits was changed accordingly, showing the importance of including proper MDTs in climate predictions. Hence, the potential of GOCE to improve future global ocean and climate modeling is evident.

Session 3

Scientific Exploitation of Data Products: Oceanography

How well do we know the mean ocean dynamic topography?

Femke Vossepoel[1,2], Peter Jan Van Leeuwen[1] and Radboud Koop[2]

[1] IMAU, Princetonplein 5, NL-3584 CC Utrecht, Netherlands
[2] SRON, Sorbonnelaan 2, NL-3584 CA Utrecht, Netherlands

Abstract

After more than 10 years of satellite altimetry, a spatially homogeneous, continuous data set of sea level has become available. Together with increasingly accurate estimates of the geoid, the altimeter data can be used to improve observational estimates of the mean dynamic topography (MDT) of the ocean. At the same time, advanced mixing schemes and increased resolution of numerical ocean models have led to realistic model estimates of MDT. In this study we investigate the present-day accuracy of MDT estimates from both models and observations, and quantify their mutual differences. A comparison of four observational estimates illustrates that rms differences in MDT vary from 4 to 19 cm at spatial scales of one degree, reducing to 3-8 cm for larger scales. Differences in data sources (geoid model, in-situ data) are mostly visible in the small-scale oceanic features, while differences in processing (filtering, inverse modelling techniques) are reflected at larger scales. The MDT estimates of seven different numerical ocean models are compared. Model estimates differ mostly in western boundary currents and in the Antarctic Circumpolar Current. These differences can be attributed to differences in wind-stress forcing, parameterization of sub-grid-scale processes, and spatial resolution. Rms differences between modeled and observed MDT are at best 19 cm at spatial scales of 1 degree, and reduce to a 5 cm level for spatial scales of 24 degrees. A comparison of low-pass filtered MDTs demonstrates that differences between MDT estimates reduce with increasing spatial scales. This reduction is smaller than expected, and suggests that GOCE will not only improve MDT estimates at small spatial scales, but also at the larger scales.

Quantifications of Ocean Mass Variation and Steric Sea Level Using GRACE and Satellite Altimetry

Chung-Yen Kuo[1], C.K. Shum[2], Y. Tony Song[3] and Yuchan Yi[4]

[1] National Cheng Kung University, No. 1, Ta-Hsueh Road, Tainan 701, Taiwan
[2] Ohio State University, 2070 Neil Avenue, Columbus 43210, United States
[3] Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, California 91109, United States
[4] Ohio State University, 2070 Neil Avenue, columbus 43210, United States

Abstract

Sea level rise has been widely recognized as a measurable signal as one of the consequences of possible anthropogenic effect of global climate change. The small rate of sea level rise signal, at 1-2 mm/yr during the last century, at present could only be partially explained by a number of competing geophysical processes, each of which is a complex process within the Earth atmosphere-ocean-cryosphere hydrosphere system. The NASA/GFZ Gravity Recovery and Climate Experiment (GRACE) mission is designed to measure small mass changes over a large spatial scale and in the form of time-varying gravity field. Satellite radar altimetry with a cluster of spaceborne instruments measuring sea surface height changes for ~20 years since the launch of GEOSAT in 1984 and the highly successful TOPEX/POSEIDON in 1992, has been widely accepted to be a viable tool for monitoring contemporary and future global sea level changes. The anticipated accuracy of a mean gravity field with a resolution of 150 km or longer and with an accuracy of 1 cm rms in geoid undulations could be measured by GOCE, which would provide an unprecedented accuracy, combining with GRACE and satellite altimetry and in situ measurements of steric sea level (e.g., ARGO), to measure the absolute circulation and sea level variations and separate the steric and the mass variation components. Advances in general global ocean circulation modeling for topography-following, non-Boussinesq model allows one to validate observations, and physics-based interpolation/prediction of sea level and ocean circulations. We will present results using GRACE, satellite altimetry, steric data and the non-Boussinesq ocean model to quantify sea level variations, with a focus in the Southern Ocean, which is traditionally lack of in situ data.

Use of oceanographic in-situ measurements and altimetry to assess the accuracy of present (GRACE) and future (GOCE) geoid models. Impact for the estimation of the ocean Mean Dynamic Topography

Marie-Hélène Rio[(1)], Philippe Schaeffer[(1)], Jean-Michel Lemoine[(2)], Gilles Larnicol[(1)] and Fabrice Hernandez[(3)]

[(1)] CLS, 8-10 rue Hermes, 31256 Ramonville Saint Agne, France
[(2)] GRGS, 14 avenue Edouard Belin, 31400 Toulouse, France
[(3)] IRD-MERCATOR, 8-10 rue Hermes, 31256 Ramonville saint agne, France

Abstract

The accurate knowledge of the geoid at all spatial scales (and thus, by subtraction from an altimetric Mean Sea Surface, of the ocean Mean Dynamic Topography) is a crucial issue for the correct assimilation of altimetric measurement into operational forecasting systems. At the time the first results of the GOCE mission will be available, the French system MERCATOR will be operating routinely the PSY3v2 protoype, providing on a global ¼° grid forecasts and analysis of the ocean state through the joint assimilation of altimetric data and in-situ measurements. The integration in the system of the information brought by GOCE will be highly valuable provided an accurate knowledge of the error level of all information entering the system (MDT, altimetry data, in-situ measurements) is accurately known and overall consistent. A method has been developed to compare the MDT obtained by direct subtraction between a geoid model and an altimetric Mean Sea Surface ('direct' MDT) to independent synthetic estimates of the MDT. Synthetic estimates are obtained from the combined use of altimetric Sea Level Anomalies and in-situ measurements of the ocean absolute dynamic topography (or related geostrophic circulation). Both the direct and synthetic MDTs are filtered to various spatial resolutions (from 133 km to 1000 km) and a thorough analysis of the different error contribution (including the comission and omission errors of the geoid model, as well as the altimetric and in-situ data measurement and processing errors) is done to make sure that all signal are consistent in the range of their error bar. The method is applied on the latest geoid models available based on GRACE data. The models are found to be accurate for oceanographic use at scales longer than 400 km. The better accuracy of combined solution compared to satellite-only solutions is also characterized as well as the strong impact of using two years of GRACE data compared to one year only for the geoid model computation. The shortest scales contained in the synthetic estimates are finally combined to the largest scales of the GRACE direct MDT to obtain a full resolution MDT estimate.

Calibration/Validation of GOCE Measured Mediterranean Sea level Using Satellite Altimetry and GRACE

Juan Jose Martinez-Benjamin[(1)], Alexander Braun[(2)], C.K. Shum[(3)], Chung-Yen Kuo[(3)], Shin-Chan Han[(3)], Yuchan Yi[(3)], Y. Tony Song[(4)], Marina Martinez-Garcia[(1)] and Gema Rodriguez-Velasco[(5)]

[(1)] Technical University of Catalonia, Campus South, bldg. P, 08028 Barcelona, Spain
[(2)] University of Calgary, 2500 University Drive NW, Calgary, Canada
[(3)] The Ohio State University, 2070 Neil Avenue, 43210-1275, Columbus, United States
[(4)] Jet Propulsion Laboratory, 4800 Oak Grove Drive, 91109 , Pasadena, United States
[(5)] Complutense University of Madrid, Avda. Complutense, s/n, 28040 Madrid, Spain

Abstract

European Space Agency (ESA)'s Gravity field and steady state Ocean Circulation Explorer (GOCE) mission is planned to launch in 2007 for a 20- month time period to primarily measure the Earth's mean gravity field. In a sun-synchronous orbit and at an altitude of 250 km, the GOCE onboard space gravity gradiometer (SGG) will measure primarily 4 components (3 diagonals and 1 off-diagonal) of the gravity gradient tensor field of the Earth. One of GOCE's primary high-level data products is the global gravity model with an anticipated geoid accuracy

of 1 cm RMS and a spatial resolution of 130 km or longer. The Mediterranean Sea is a semi-enclosed 'true' ocean. Recent Mediterranean circulation and sea level studies using various observations (multi-mission altimetry, tide gauge, thermosteric sea level from WOA01, and to a lesser extent, GRACE) and ocean circulation models (e.g., JPL's ECCO and non-Boussinesq models) show good coherence and agreement. The satellite altimetry and tide gauge observed and model predicted sea level show good coherent with correlation coefficient of 0.6. The barotropic pressure response accounts for about 66% of the Mediterranean sea level rise (1948–2001). The estimated sea level trend (1.54±0.75 mm/yr) using decadal altimetry (1985–2001) after correcting the interannual/decadal signals reconstructed using tide gauge data, agrees well with the long term trend (1948–2001) estimated using tide gauges (1.43±0.09 mm/yr) in the Mediterranean Sea, and is in better agreement than before with the global long-term sea level trend (1.7–1.8 mm/yr). Finally, multiple altimetry sea level measurements are being calibrated in dedicated campaigns to quantify the error characteristics. This study makes use of all of the above knowledge in a simulation study to show that the GOCE data (gravity gradient tensors) and data product (GOCE geoid in the Mediterranean), after correcting for temporal variability (e.g., from GRACE to potentially account for hydrologic fluxes), could be validated in the Mediterranean Sea.

Estimation of the ocean Mean Dynamic Topography in the Mediterranean and Black Seas by combination of altimetry and GRACE/GOCE geoids

Luciana Fenoglio-Marc[(1)], Juergen Kusche[(2)], Matthias Becker[(1)] and Emil Stanev[(3)]

[(1)] Darmstadt University of Technology, Petersenstrasse 13, 64287, Germany
[(2)] Delft University of Technology, Kluyverweg 1, 2600, Netherlands
[(3)] Oldenburg University, Carl-von-Ossietzky Str. 9-11, 2503, Germany

Abstract

For the combination of satellite altimetry with the new gravity missions of GRACE and GOCE, the Mediterranean – Black sea region represents an interesting field for modelling and validation.

We investigate the importance of using GRACE and GOCE data regionally in areas dominated by continental shelf and steep topography breaks, were the ocean Mean Dynamic Topography (MDT) is characterised by scales shorter than 50-100 km.

In a first step we study the contribution of the most recent satellite-only gravity field model (EIGEN-GL04S1) for estimating the ocean MDT. This gravity model, derived from GRACE and LAGEOS data, should greatly improve the estimate of the MDT at scales larger than 300 km. The MDT is obtained by subtracting the EIGEN-GL04S1 geoid from a regional altimetric Mean Sea Level Surface over 1993-2005 and by filtering the shorter scales. We compare this synthetic MDT estimates with the mean dynamic topography outputs from regional ocean models. The short scales missing in EIGEN-GL04S1 and in the synthetic MDT are investigated by comparing the short scales of the altimetric MSS and of the mean dynamic topography outputs of ocean models .

In a later step, we will make use of the static high resolution GOCE gravity field and of altimetric sea level heights to derive absolute dynamic ocean topography and to assess the performance of the regional oceanographic models. With simulations and analyses we especially aim at the improvement of the shelf circulation ocean modelling using GOCE data and assimilation of the low resolution MDT. Turbulent eddy kinetic energy simulated in the ocean models with and without assimilation will be considered. The time-varying and mean near-shore transport in regions with different topographic controls (deep sea, slope area, continental shelf) and the water, heat and salt transport along the continental shelf break and shelf regions will be evaluated.

We will use GOCE Level 2 spherical harmonic models as input. Investigations will focus towards the error assessment in the three data sets (gravity models, altimetry, regional oceanographic models) and the combination procedure.

New Geoid and Mean Sea surface for ocean circulation

Ole Andersen[1] and Per Knudsen[1]

[1] *Danish National Space Center, Juliane Maries Vej 30, DK-2100 Copenhagen Oe, Denmark*

Abstract

Satellite altimetry is one of the key elements in global high resolution models of the mean sea surface and the global gravitational models. In this presentation we will focus on the latest development in the accuracy and processing of satellite altimetry. The latest version (DNSC06) of the formerly KMS global marine gravity fields and mean sea surfaces (MSS) will be presented. Both the DNSC06 gravity field and the DNSC06 mean sea surface have been derived with a spatial resolution of 1 minute by 1 minute and cover all marine regions of the world including the Arctic Ocean up to the North Pole.

Amongst the improvement in satellite altimetry are retracking of the entire ERS-1 GM mission using a highly advanced expert based system of multiple retrackers to gain data from both the open sea surface and from all ice-covered regions within the coverage of the ERS-1, in order to derive products with higher accuracy that are presently available.

The Mean Dynamic Topography is the quantity that bridges the geoid and the MSS and the impact of these new quantities with respect to an accurate determination of the Mean Dynamic Topography will be investigated.

VANIMEDAT Project: Decadal and Interdecadal Sea-Level Variability in the Mediterranean Sea and Northeastern Atlantic Ocean

Ananda Pascual[1], Simon Ruiz[2], Marta Marcos[3], Damià Gomis[1], Sebastià Monserrat[1], Enrique Alvarez-Fanjul[4], Begoña Pérez[4], Marcos García Sotillo[4], Gilles Larnicol[5] and Mikis Tsimplis[3]

[1] *IMEDEA (CSIC-UIB), Universitat de les Illes Balears, 07122 Palma de Mallorca, Spain*
[2] *IMEDEA (CSIC-UIB), C/Miquel Marquès, 21, 07190 Esporles, Spain*
[3] *NOCS, Empress Dock, SO14 3ZH Southhampton, United Kingdom*
[4] *Puertos del Estado, Avda. del Partenón, 10, 28042 Madrid, Spain*
[5] *CLS Space Oceanography Division, Parc technologique du canal, 31520 Ramonville St-Agne, France*

Abstract

VANIMEDAT is a 3 year project funded in the last Call for R+D projects of the Spanish National Program. The general objective of the VANIMEDAT project is to study the decadal and interdecadal sea-level variability in the seas surrounding the Iberian peninsula. The project will make use of long tide gauge records, improved altimetric data sets and 44 years (1958-2001) of data derived from the HIPOCAS project (a downscaled re-analysis of meteorological and oceanographic fields). The project has several specific objectives. The first one is to determine the spatial and temporal sea-level variability, devoting special attention to the consistency between coastal and open sea observations. To do this, we take advantage of the complementariness of the data sets: while the altimetry reports the open sea variability with a convenient spatial resolution, tide gauge records mainly correspond to coastal sites and provide the time length requested to study the variability at decadal and interdecadal scales. The second objective is to quantify the contribution, at a regional level, of the different mechanisms that drive sea-level variability. This will be achieved basing mainly on the results of numerical modelling. Namely, we aim at: i) quantifying the effect of atmospheric pressure and wind forcing on sea level from the analysis of sea-level residuals produced by the model HAMSOM. ii) Quantifying the contribution of the steric component from the results produced by a 3D baroclinic model forced by HIPOCAS heat fluxes. The third objective iii) will be to estimate the ocean mass increase as the difference between total sea level and the two contributions previously determined. Results will be compared with data from the GRACE and, hopefully, GOCE gravimetric mission.

Combining high resolution GOCINA topography with ARGO float data

Dmitrii Sidorenko[(1)]

[(1)] *AWI, Postfach 120161, 27515 Bremerhaven, Germany*

Abstract

We report on impact of the GOCINA dynamic topography and newly available ARGO float data on estimates of the circulation in the North Atlantic. An inverse Finite Element Ocean circulation model is used which seeks for a stationary solution which approaches both types of data and respects equations of motion. The questions we seek to answer are what are the impacts of individual and combined data sets on the circulation. The modelled ocean velocities are compared to the observed float velocities.

Estimation of the ocean Mean Dynamic Topography by optimal combination of a geoid model and along-track altimetric mean profiles

Philippe Schaeffer[(1)] and Marie-Hélène Rio[(1)]

[(1)] *CLS, 8-10 rue hermes, 31526 Ramonville saint agne, France*

Abstract

Sea Level Anomalies (SLA) are computed from altimetric measurements with a few centimetre accuracy using the repeat-track method. In order to compute from altimetric SLA the absolute value of the ocean dynamic topography, which is the signal of interest for oceanographers, the missing component is the Mean Dynamic Topography. The ocean Mean Dynamic Topography can be simply computed by directly subtracting a geoid model from an altimetric Mean Sea Surface (this is the so-called direct method). The altimetric Mean Sea Surface CLS01 is computed on a high resolution regular grid (1/30°) using along-track mean profiles from different altimetric satellites and the associated errors as input to an objective analysis. However, while altimetric Mean Sea Surfaces are known at the centimetric error level for spatial resolutions down to 10-20 km, up-to-date geoid models, based on GRACE data, reach this precision at scales no shorter than 400 km. This implies that both surfaces are correctly and consistently filtered before being combined. Practically, difficulties arise along the coasts or in strong subduction areas, where strong gradients present in the MSS (but not resolved in the geoid models) are not totally filtered by classical spatial filters resulting in unrealistic circulation features in the final Mean Dynamic Topography. Also, the errors associated to the geoid and the MSS are not taken into account in this direct method. A technique is presented here where both the geoid heights and the along-track altimetric mean profiles are combined through an objective analysis taking into account the variance and covariance error characteristics of both fields. The method is applied on the latest satellite-only geoid models based on GRACE data (EIGEN-GRACEGL04S) and the obtained MDT is compared to the direct MSS-Geoid solution.

Gravity improvement of continental slope and shelf ocean modelling

Eric Jeansou[(1)], Georges Balmino[(1)], Chris Hughes[(2)], Isabel Andreu-Burillo[(2)], Florent Lyard[(3)], Muriel Lux[(1)], Laurent Roblou[(1)], Pierre De Mey[(3)], Enrique Alvarez-Fanjul[(4)], Guilhem Moreaux[(1)], John Huthnance[(2)], Marcos García Sotillo[(4)], Roger Proctor[(2)], Begoña Pérez[(4)], Helge Rebhan[(5)], Mark Drinkwater[(5)] and Roger Haagmans[(5)]

(1) NOVELTIS, 2 avenue de l'Europe, 31520 Ramonville Saint Agne, France
(2) Proudman Oceanographic Laboratory, 6 Brownlow Street, Liverpool, L3 5DA, United Kingdom
(3) Pôle d'Océanographie Côtière, 14 avenue Edouard Belin, 31400 Toulouse, France
(4) Puertos del Estado, Avda. del Partenón 10, 28042 Madrid, Spain
(5) ESA/ESTEC, P.O. Box 299, 2200 AG Noordwijk, Netherlands

Abstract

This ESA-funded study aims to assess the capabilities and the limits of the use of the GOCE geoid to improve modelling of shelf and coastal ocean low-frequency circulations. The approach consists in using techniques of data assimilation into hydrodynamic models to estimate the present and future benefit of altimetric data use. Assimilation allows control of dynamical simulations and estimates of model and data error covariances.

Components of the project are:

• Review of the state of the art (character of processes and circulation in this context, character and status of models, present knowledge of gravity fields);

• Deciding which models, domains, forcing, tide models, validation data and model performance metrics are to be used in the project;

• Runs of models over the respective domains without and with assimilation of altimetry;

• Analysis of model output, comparison with measurements, identification of scales of variability, effects of assimilating altimetry;

• Assessing expected impact of GOCE, with model runs and data to yield mean dynamic topography, filtering to GRACE and GOCE resolution, relating model skill to length scale;

• GOCE performance impact studies with runs of models over the respective domains, without and with assimilation of altimetry, without and with GOCE ("perfect" and degraded), including computation of the expected point-to-point covariance of the GOCE geoid height.

Conclusions from the review are that:

• Along-slope currents, tides, wind-driven circulation and storm surges, surface wave statistics and seasonal heating scale with the shelf or slope width and have time-scales f-1 or longer. Their surface elevation represents sub-surface pressure and near-surface flow.

• We expect improved knowledge of the geoid to be useful, for (i) absolute mean transports – models may be used to determine the spatial distribution of the transport in the vertical and with finer horizontal resolution than the geoid, (ii) open boundary conditions for limited-area models, especially the overall pressure difference applied across the extent of the model and thereby (iii) for model estimation of ocean-boundary and slope currents, associated secondary ocean-shelf exchanges and eddies, tides, wind-driven circulation, along-front and coastal currents.

• Good knowledge of tidal elevations is necessary to process "raw" altimetric data, and of tidal currents for good model friction and mixing. This knowledge is available.

• Well established models are effectively operational for the three proposed areas of study: Gulf of Lions, Iberian shelf and Biscay, North-west European shelf. However, there is little practice of assimilating altimetric data over such shelf-and-slope seas at present.

• R.m.s. geoid uncertainties (differences between models) over the study areas are presently O(0.2 m) which is larger than typical non-tidal surface elevations in shelf seas.

• The GOCINA project successfully used locally dense and precise gravity measurements to improve geoid model quality locally.

Global Eddy-Mean-Flow Interaction From High-Resolution Altimetry and Geoid

Lee-Lueng Fu[(1)]

[(1)] *Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, United States*

Abstract

Analysis of the combined altimeter data from TOPEX/Poseidon and ERS/ENVISAT revealed detailed patterns of the propagation of ocean eddies in the global oceans. These patterns show high correlation with the mean flow of the global ocean circulation. The spatial scales of the eddy propagation variability are often shorter than the resolution of the current geoid produced by the GRACE Mission. Therefore, the resolution of the mean flow determined from altimetry and existing geoid cannot address the eddy-mean-flow problem, which is a critical issue for understanding the dynamics of ocean eddies and their role in ocean general circulation. The eddy propagation velocity in various dynamically interesting regions (Gulf Stream, North Atlantic Subpolar Gyre, Kuroshio, Antarctic Circumpolar Current, etc.) and their relations to the mean flow determined from numerical models and in-situ observations will be presented. The potential value of high-resolution geoid from GOCE will be discussed.

GOCE Validation via Ocean State Estimation

Vanya Romanova[(1)]**, Armin Koehl,**[(1)] **Detlef Stammer**[(1)] **and Frank Siegismund**[(1)]

[(1)] *Universitaet Hamburg, Bundesstr. 53, 20146 Hamburg, Germany*

Abstract

This poster will summarize ongoing ocean syntheses that brings together altimetric and geoid fields, in situ data and a numerical model using data assimilation and its use for geoid validation efforts. Over the last decade, ocean data assimilation has made a remarkable progress, to the point that it is now feasible to perform mathematically rigorous global ocean data synthesis in a routine manner as a core strategy for climate research. In analogy to atmospheric re-analysis, this effort sometimes is referred to as reanalysis. However, in the absence of analyses in the ocean, the term data synthesis seems more appropriate.

To date, several ocean syntheses are being run routinely over the period 1992 through present. Applications of syntheses range from mesoscale and coastal ocean state estimates to the ocean as part in climate system with applications ranging from estimating ocean transports, mixing, surface fluxes to impacts on biogeochemistry.

Results will be presented that illustrate the use of ocean data assimilation in testing the consistency of existing geoid information and their error bars. We will also show recent results that illustrate the impact of modern GRACE geoid fields in improving estimates of the ocean mean and time-varying circulation. Resulting fields will be compared with existing bottom pressure time series to investigate the quality of the estimation results, to investigate the possible impact of new geoid fields for ocean state estimation, and to discuss the impact of ocean state estimation for geoid validation efforts.

Session 4

Scientific Exploitation of Data Products: Geodesy, Orbits and Inertial Navigation

Satellite to Satellite Tracking Instrument (SSTI): Design and Performance

Alberto Zin[1], Stefano Landenna[1] and Alessandro Conti[1]

[1] *Alcatel Alenia Space Italy, Via Malpensa, 1, 20157 Milan, Italy*

Abstract

The aim of the presentation is to provide an overview of the GPS receiver on board GOCE, GOCE SSTI, manufactured by AAS-I, Milan plant. In particular the design of the instrument is addressed in the first part of the presentation and some performance aspects (real-time navigation, measurement accuracy, robustness against ionospheric scintillation) are described later on.

A past experience of a precursor of SSTI (ENEIDE) that was flown in 2005 on the International Space Station is also briefly presented as a flight experience.

Broad-band gravity field mapping by GOCE and airborne gravity

Rene Forsberg[1] and Arne Olesen[1]

[1] *Danish National Space Center, Juliane Maries Vej 30, DK-2100 Copenhagen Oe, Denmark*

Abstract

Airborne gravity, together with existing high-quality surface data and satellite altimetry gravity in the open ocean, may supplement GOCE to make a consistent high resolution global gravity field models up to very high resolutions (10 km or less). Current airborne gravity accuracies for long-range geodetic surveys are at the 1-2 mgal level, with no biases if properly processed and careful attention to base ties and instrument corrections. Airborne gravity may therefore extend the resolution of GOCE-derived gravity field models, and at the same time be most useful for checking and correcting errors in existing land and marine surface data. Coordinated airborne gravity surveys will also be a key to filling in the polar gaps of GOCE, especially in Antarctica, but also in parts of the Arctic where current gravity compilations still have systematic errors. In the paper we outline some recent results on large-scale continental and marine airborne gravity surveys, and illustrate errors in different wavelength bands by a.o. comparisons to GRACE data

On a strategy for the use of GOCE gradiometer data for the development of a geopotential model by LSC

Arabelos Dimitrios[(1)] and Carl C. Tscherning[(2)]

[(1)] *University of Thessaloniki, Box XX, Thessaloniki, Greece*
[(2)] *University of Copenhagen, Juliane Maries Vej 30, DK-2100 Copenhagen Oe, Denmark*

Abstract

For the development of a spherical harmonic expansion of the Earth's gravity field using point data such as gravity gradient components from GOCE mission, data with a global coverage are needed. For a satisfactory representation of the gravity field in an area using point data of a relevant quantity, the number of the data needed depends on the variance of the gravity field in this area. Therefore, for global coverage, using a proper data distribution it is possible to achieve a good approximation of the gravity field without increasing unnecessarily the number of data, using more data in areas with rugged gravity field and fewer data in areas where the gravity field is smoother. This is essential for methods such as the method of Least Squares Collocation (LSC) where a system of linear equations is to be solved having a number of unknowns equal to the number of input data. The aim of this paper is to suggest a strategy for the collection of point data on real GOCE orbits, leading to optimal LSC determination of spherical harmonic coefficients, with the minimum number of data points. Numerical experiments for the determination of harmonic coefficients were carried out, using noise-free or noisy simulated data with different distributions. The suggested strategy is based on the comparison between computed and true coefficients, the collocation error estimate of the coefficients and the comparison of the original data with data generated by the computed coefficients.

Regional solutions from GOCE orbit information and gradiometry measurements considering topographic-isostatic models

Annette Eicker[(1)], Atef Makhloof[(1)], Torsten Mayer-Gürr[(1)] and Karl-Heinz Ilk[(1)]

[(1)] *University of Bonn, Nussallee 17, 53115 Bonn, Germany*

Abstract

The satellite mission GOCE promises an improvement of the static gravity field with unprecedented accuracy and resolution. To exploit the signal information present in the satellite and sensor data to full content, it seems reasonable to improve global solutions by regional recovery strategies. Especially in the high frequency part of the spectrum the gravity field features differ in different geographical areas. Therefore the recovery procedure should be adapted according to the characteristics in the respective area. For the GOCE mission this aspect is of particular interest due to its strength in recovering the high resolution part of the gravity field. In the approach presented here in a first step a global gravity field represented by a spherical harmonic expansion up to a moderate degree has to be derived from a combination of orbit information and gradiometry measurements. It is then refined by regionally adapted high resolution refinements being parameterized by splines as space localizing base functions. To smooth the signal and to simplify the downward continuation process, information originating from topographic-isostatic models is subtracted from the data according to a remove-restore step. Additionally in a last step those tailored regional solutions are merged to a global representation, from which a parameterization by global base functions such as spherical harmonics can be derived by means of quadrature methods as well. The approach is demonstrated by a simulation example.

Session 5

The GOCE Mission II:
Ground Segment, Level I Products, Calibration

GOCE Payload Data Ground Segment Overview

Eric Monjoux[1]

[1] *ESA/ESRIN, Via Galieo Galilei, 00044 Frascati, Italy*

Abstract

A brief introduction to the Payload Data Ground Segment services and some hints on the PDGS architecture and on the GOCE product access through the Multimission User Services.

From Telemetry to Level 1b: Architecture and Processing Strategy

Diana De Candia[1]**, Teresa Geminale**[1]**, Pierluca Mantovani**[1] **and Carlo Zelli**[1]

[1] *Advanced Computer Systems ACS SpA., Via della Bufalotta 378, 00139 Rome, Italy*

Abstract

This presentation provides an overview of the Processing Facility Infrastructure and of its processors designed by ACS for the GOCE Mission of ESA.

GOCE is the Gravimetry mission of ESA scheduled for launch in 2007 as part of the Earth Explorers Programme. GOCE Level 1b processing, which actually encompasses science processing to transform telemetry in to engineering calibrated values, calibration processing for gradiometer and GPS instruments, monitoring processing for attitude control and gradiometer, is performed in the PDS within a hosting environment named IPF (Instrument Processing Facility). The generation of the full set of Level 1b products is actually not a simple matter, since several types of products shall be created and there exist strong interrelations among the various products giving rise to a fairly complex data flow. Additionally, there are different types of latency requirements for the products: the Nominal Level 1b products will be generated on orbit basis, while Calibration products may require exploitations of long sequences of data (even more than a single orbit). As a consequence of these requirements, the IPF architecture has been designed to be flexible (in order to cope with various types of processors and product types to be generated) as well as open to the hosting of several types of processors, not excluding the possibility of co-existence in the infrastructure of different versions of the same basic processor due to the highly experimental nature of the mission. At the same time, the IPF shall be available for the plugging of totally new processors which may generate new products in addition to the existing ones. The design of the IPF which will be reviewed in this paper has been deeply based on the well proven architecture designed and developed by ACS for CRYOSAT and currently in use also for the ADM-Aeolus PDS infrastructures. Some innovations have been introduced to cope with the specific requirements of GOCE. This architecture will be presented in this paper together with the products, Data Flow and the resulting processing strategy.

From Telemetry to Level 1b: Processing Flow and Products

Alessandra Tassa[1], Alessandra Buongiorno[2], Eric Monjoux[2] and GOCE PDGS Support Team[1]

[1] SERCO-DATAMAT Consortium c/o ESA/ESRIN, V. G. Galilei, 00044 Frascati, Italy
[2] ESA/ESRIN, V. G. Galilei, 00044 Frascati, Italy

Abstract

Telemetry data from the Electrostatic Gravity Gradiometer (EGG) and from the Satellite-to-Satellite Tracking Instrument (SSTI) are automatically processed at ESA up to level 1b.

All intermediate processing results are stored within the final products.

The main product from EGG is called EGG_NOM_1b and it contains several data sets, corresponding to differents degrees of processing (from the accelerometers control voltages to the gravity gradients).

The main product from SSTI is called SST_NOM_1b and, like the EGG_NOM_1b, it is composed by several data sets that correspond to differents degrees of processing (from raw pseudoranges and carrier phases, including inter-channel and interf-frequency biases, and up to the computation of GOCE orbit).

The main processing steps will be presented in the paper, together with a description of products format and content.

Degradation in accuracy of gravity variations from CHAMP, GRACE, and GOCE

Jaroslav Klokocnik[1] and Jan Kostelecky[2]

[1] Astronomical Institute Czech Acad. Sci., Fricova 1, 251 65, Czech Republic
[2] Research Institute of Geodesy, Ondrejov 244, 251 65 Ondrejov, Czech Republic

Abstract

Due to orbit resonance 61/4 of GRACE, accuracy of the monthly solutions for gravity field variations significantly decreased. This was already discussed elsewhere, also by the authors of this presentation. Our new analysis show the problem of the degradation in the accuracy in more general light, as a product of orbit evolution (encountering various resonances and inevitable decrease of density of ground tracks) and as a function of latitude (with unexpected behaviour for GRACE). We summarize our results for CHAMP and GRACE and comment on GOCE orbit as a warning for future analysis of data from this mission. Although the situation is very different with GOCE than with CHAMP and GRACE, the latitudinal dependence of the density of ground tracks and the effects of the ‘tail” of 16/1 resonance and lower resonances for different orbit scenarios should be studied in a detail.

Evaluation of a GOCE combination model

Sean Bruinsma[1], Jean-Charles Marty[1], Georges Balmino[1], Oleg Abrikosov[2], Christoph Förste[2] and Markus Rothacher[2]

[1] CNES, 18, avenue E. Belin, 31401 Toulouse, France
[2] GFZ, Telegrafenberg A17, 14473 Potsdam, Germany

Abstract

Numerical simulations of the gravity field parameter recovery using the direct method, with satellite positions as pseudo observations instead of simulated GPS Satellite-to-Satellite (SST) tracking data, and with gravity gradients

(SGG data), were done and are ongoing in the framework of the European GOCE Gravity Consortium test and validation plan for GOCE mission data processing. The pseudo-GPS observations, containing the long wavelength gravity field signal, and the SGG measurements are processed separately because of the coloured noise in the latter. Due to this instrumental behaviour, the SGG observation equations must be filtered in order to retain only the precise information contained in the measurement bandwidth. The GOCE processing yields SST and high resolution SGG normal equations. These matrices are subsequently combined for the GOCE gravity field model adjustment and solved using Cholesky decomposition. However, the GOCE solution suffers from the polar gap in the data distribution due to the orbit inclination of 96 deg. Two general solution strategies exist to redress the model error that results from this lack of information: we may apply a regularization to the solution, or we add pertinent external data, such as GRACE and/or surface gravity data. Gravity field model solutions are computed using the simulated GOCE normal equations and either regularization is applied or additional external data (also simulated) are used. The resulting solutions are compared and evaluated.

Contribution of modern satellite tracking data to GOCE-based gravity solutions

Oleg Abrikosov[1], Frank Flechtner[1], Christoph Förste[1], Ulrich Meyer[1], Markus Rothacher[1] and Roland Schmidt[1]

[1] *GeoForschungzZentrum Potsdam, Telegrafenberg A17, 14473, Germany*

Abstract

On the basis of GOCE data simulated along perturbed orbits of different lengths and contaminated by a realistic noise, we have derived gravity field solutions from (1) 4 components of the gravity gradient tensor that are expected to be measured with a high accuracy during the GOCE mission, (2) GOCE positions used as pseudo-observations and processed by means of the direct approach based on numerical integration, (3) accelerations derived from the GOCE positions by means of the numerical differentiation. All the GOCE-only results suffer from the polar gaps and the uneven distribution of the data over altitude. To suppress the corresponding errors in the gravity field recovery, we were forced to apply regularization methods. Also, gravity field combined solutions were derived from the simulated GOCE and GRACE data. The impact of all mentioned data sets and their different combinations on the quality of the satellite-derived gravity models has been analyzed.

Gravity gradients from mean sea level – data for validation and downward continuation of GOCE gravity fields

Wolfgang Bosch[1]

[1] *DGFI, Alfons-Goppel-Strasse 11, 80539 München, Germany*

Abstract

Combining Laplace Differential Equation and Bruns formula yields to a well known relationship between geometry and gravity: Gravity gradients of an equipotential surface are related to the mean curvature. It is shown that – in the present context – the deviation between geoid and mean sea level, known as sea surface topography, can be neglected and that the mean curvature of the geoid can be approximated by the mean curvature of the mean sea level. Consequently, models of mean sea surface heights are used to derive gravity gradients. As the spatial resolution of GOCE-only gravity fields will be restricted by band limited spherical harmonics (developed up to degree and order 250) the gravity gradients are smoothed correspondingly and – as long as GOCE models are not yet available – compared with the most recent gravity field from GRACE. Gravity gradients from mean sea level are gravity data on the Earth surface – as close as possible to the gravitating masses. Therefore this data should allow to strengthen the downward continuation of GOCE observation. It is investigated to what extend the normal equations of satellite-only gravity fields are stabilized by gravity gradients derived from mean sea level.

Downward continuation of satellite gradiometry data

Juraj Janak[(1)], Karol Mikula[(1)] and Michal Sprlak[(1)]

[(1)] *Slovak University of Technology, Radlinskeho 11, 81368 Bratislava, Slovakia*

Abstract

The purpose of this contribution is to estimate the accuracy of the downward continuation of satellite gradiometry data from the GOCE orbit to the surface of the Earth. Input and output values are generated from the Earth synthetic model. The numerical stabilisation by means of topographic reduction of input data, suggested by (Heck and Wild, 2005), is applied before the downward continuation itself. Iterative procedure is performed to solve the Poisson's downward continuation. Comparison of downward continued data with data generated from synthetic model gives us an estimate of the accuracy of presented downward continuation procedure. Results are discussed and some conclusions are posed.

Some Practical Issues of Upward / Downward Continuation of Gravity Gradients

Gyula Tóth[(1)], Lóránt Földváry[(1)] and Ilias N. Tziavos[(2)]

[(1)] *Budapest University of Technology and Economics, Muegyetem rkp. 3. Kmf 16., H-1111 Budapest, Hungary*
[(2)] *Aristotle University of Thessaloniki, Univ. Box 440, 54 124 Thessaloniki, Greece*

Abstract

The GOCE mission will produce gravity gradient data at satellite altitude and consequently contribute to more accurate determination of the gravity field. In a previous paper we discussed formulae for the upward/downward continuation problem of second gravity gradients. The proposed approach was to use these gravity gradients in two combinations with special kernel functions. These kernel functions are infinite sums of Legendre functions of orders 0, 1 and 2.

As a continuation of our previous study, several practical aspects of the proposed approach are addressed. First, the practical use of formulae in gravity field determination makes it necessary to evaluate these kernel functions in a band-limited setup. Second, the integration radius of gravity gradient data depends on the particular data combination, bandpass filter and altitude. Third, the upward/downward continuation problem can be extended to other gravity field functionals with appropriate kernel functions. These issues are investigated in the present paper in the context of GOCE.

Multi-resolution representation of the gravity field from a combination of GOCE and GRACE data

Michael Schmidt[1], C.K. Shum[2], Shin-Chan Han[2] and Juergen Kusche[3]

[1] DGFI, Alfons-Goppel-Strasse 11, 80539 Muenchen, Germany
[2] The Ohio State University, 275 Mendenhall, Columbus, OH 43210-1308, United States
[3] DEOS, Kluyverweg 1, 2600 GB Delft, Netherlands

Abstract

The GOCE mission will allow the determination of the Earth's static gravity field down to features less than 100km w.r.t. the spatial resolution. Traditionally in satellite gravity recovery problems the global gravity field of the Earth has been modeled as a spherical harmonic expansion. Recently, regional modeling techniques have been successfully applied to GRACE data and provide new insights in gravity field determination. In our approach a multi-resolution representation, i.e. the decomposition of the gravity field into constituents or levels of different spatial resolution, has been realized using spherical scaling functions and spherical wavelets.

The combination of GRACE and GOCE is a particular challenging area of research. A combined time-averaged mean field will benefit from GOCE gradiometry in the high degrees - the higher resolution levels in our approach - and GRACE POD and K-band tracking in the lower degrees or resolution levels, with a time-variable parameterization of the lower degrees absorbing time-variable signals. In our concept, the time-variable representation of the lower resolution levels, i.e. one-dimensional series expansions for the corresponding scaling and wavelet coefficients, will be estimated jointly with the static higher resolution levels that benefit from GOCE, leading to optimal estimates for all field constituents.

Earth Explorer Missions Payload Data Segments: GOCE

Daniela Bencivenni[1], Roberto Medri[1], M. Pastori[1], V.D. Spaventa[1], Paolo Spera[1] and Antonio Vollono[1]

[1] ACS, Via della Bufalotta, 378, 00139 Roma, Italy

Abstract

In the frame of two European tender competitions, Advanced Computer Systems SpA has been awarded by ESA of the contracts for the design and development of the Payload Data Segment (PDS) and of the Instrument Processing Facility (IPF) of the first two Earth Explorer Missions, CRYOSAT and GOCE.

Following the design and development activities, the GOCE Operational PDS/IPF system has been successfully deployed in Frascati (ITALY) during June 2006 and it is now ready to support the mission operations in view of the satellite launch planned for the next coming year.

The PDS/IPF System is characterised by several innovative and powerful features. The main one is the infrastructure design and the overall architecture of the Processing subsystem. The Core of the PDS is the Storage Archive, represented by an integrated collaboration of a DBMS and a Hierarchical Storage Management system (HSM) completely designed and developed by ACS. The HSM, designed originally for the management of very large multimedia archives (500 TBytes of the RAI digital audio archive), has been for the EO systems usage completely wrapped by a DBMS-based facility, designed to support and allow a Data Driven access to EO data, both for ingesting and processing systems.

Although it can be seen as an hybrid solution between an Event Driven and a Data Driven System, for its natural way of activating, carrying on parallel actions, distributing the intelligence rather than centralising it, it is surely not belonging to a classical Event Driven system and is to be regarded instead much closer to a Data Driven System. In brief it allows:

• Distributed architecture against centralised decisions

• No Time-programmed actions have to be designed. Scheduling policy based on tasks allocation made by each available node, rather than on predefined assignment of nodes to a predefined task

• Shortened latency (i.e. sub-elements wake up immediately in the moment new input data is available)

• Easy to be integrated as interfaces are simple and often ASCII based (XML)

• Easy to expand to heterogeneous elements (e.g. other processing chains have to be integrated with minimum effort)

• Light control on each facility but deep and effective monitoring

• Priority processing to manage systematic and on demand production orders in the various modalities foreseen

Aim of this paper is to provide an overview of the design and of the developed infrastructure of the PDS for these two Missions. The Data driven approach will be discussed against the Event Driven one, showing its advantages, demonstrating the high level of optimisation reachable by systems based upon its data management philosophy. Moreover the PDS modern and innovative design will be detailed, being it an "hybrid" solution between Data Driven and Event Driven, taking benefits by both approaches advantages and mitigating their weak points.

GOCE Level 1 products format presentation

GOCE PDGS Support Team[2], Alessandra Buongiorno[1] and Eric Monjoux[1]

[1] ESA/ESRIN, V. G. Galilei, 00044 Frascati, Italy
[2] SERCO-DATAMAT Consortium c/o ESA/ESRIN, V. G. Galilei, 00044 Frascati, Italy

Abstract

GOCE L1b products are in ASCII and follow the XML (eXtensible Mark-up Language) representation or the RINEX format. While the latter format is common within the GPS community, the use of XML format for scientific data represents somehow an innovation. In fact, up to now, in ESA Ground Segment, XML has been widely used for configuration and auxiliary files, but not for the full products description. Such a language is characterized by helpful tagging that allows immediate validation against existing format descriptions (XML schemes). Another advantage of XML is that for this language automatic handling tools (parsers) are widely available on the WEB. According to identified needs, ESA is developing libraries and tools to facilitate GOCE products handling.

The poster describes in detail:

- The XML products structure and composition;

- XML schemes for product validation and reading;

- Simple tools available for quick data parsing and visualization.

Organisation of GOCE Cal/Val and Product Quality Assurance Activities

Rune Floberghagen[1], Mark Drinkwater[2], Roger Haagmans[2], Michael Kern[2], Danilo Muzi[1], Gernot Plank [2] and Alex Popescu[1]

(1) ESA/ESTEC, EOP-PG, 2200 AG, Noordwijk, Netherlands
(2) ESA/ESTEC, EOP-SMO, 2200 AG, Noordwijk, Netherlands

Abstract

While the details of the various GOCE calibration and validation (Cal/Val) activities are presented in a number of workshop presentations and posters, the present paper will focus on the overall organisation of the Cal/Val activities performed. Ideally, such procedures should lead to an optimal quality assurance of all scientific products from the mission, i.e. both for Level 1b data and for Level 2 data. The procedures and timeframes for the Cal/Val of these two classes of products are obviously different, and require tailored approaches. First, the Cal/Val activities performed on Level 1b data are put in place in order to determine and verify the quality of the Level 1b products as input to the Level 2 processing. Moreover, given the short operational liftetime of the mission, it is

crucially important to achieve a rapid validation of the Level 1b products in order to swiftly be able to handle problems related to the satellite and/or payload hardware. On the other hand, the Cal/Val of Level 2 data will be performed on the basis of several orbit and gravity field solutions generated from independent processing methodologies. Such independent processing schemes offers the possibility of cross-comparing various steps of the processing. Additionally, a synthesis step at the end of the Level 2 processing chain is introduced in order to compare GOCE gravity field and orbit solutions with a huge number of available external data sets.

The Basic Principles of the GOCE Gradiometer In-Flight Calibration

Daniel Lamarre[(1)]

[(1)] *ESA/ESTEC, Keplerlaan 1, 2201 AZ Noordwijk, Netherlands*

Abstract

The GOCE gradiometer is comprised of six accelerometers arranged in 3 pairs, mounted in the so-called ‘diamond’ configuration. To achieve the required accuracy in the retrieval of the diagonal terms of the gravity gradient, a nominally performing gradiometer requires two characterization operations to be done in flight:

1) Measurement of the quadratic factor of the response of each accelerometer, & 2) Measurement of relative misalignments and scale factors between accelerometers

1) The working principle of the GOCE accelerometers is based on a levitating proof mass maintained at a constant position in the accelerometer reference frame, by application of forces through electrostatic actuators. The voltages applied by the control loops then constitute the outputs and are related to the accelerations experienced by the proof mass in a nearly linear manner. However, second order terms due to manufacturing dissimilarities are not negligible and need to be measured (and then adjusted physically to be minimized). The innovation in the measurement of the quadratic factor consists in the introduction of a train of pulses inside the control loop of each accelerometer. These pulses can be seen as a modulated carrier. The frequency of modulation rests within the control bandwidth of the accelerometer, while the carrier frequency lies outside. The result is a beat appearing at the accelerometer output, which frequency follows the pulse rate, and which amplitude is proportional to the quadratic factor. 2) The main objective of the gradiometer calibration is to reject common mode accelerations. This translates into the need to determine with high accuracy the relative responses and misalignments of accelerometers between themselves, rather than their common characteristics. To achieve this, it is not necessary to apply known accelerations to the gradiometer, since the main goal is to null the common signal contributions in the gravity gradient measurements. This principle is the basis of this innovative calibration where pseudo-random linear and angular accelerations are applied to the spacecraft through simple on/off cold gas thrusters. Through an empirical iterative algorithm, only the signals from the gradiometer itself and the star tracker are used to retrieve the gradiometer parameters.

Session 6

Calibration and Validation

GOCE gravity gradients for use in Earth sciences

Johannes Bouman[(1)], Sietse Rispens[(1)] and Radboud Koop[(1)]

[(1)] SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, Netherlands

Abstract

One of the most interesting Level 1b products derived from the GOCE observations are the gravity gradients (GG). These GG are provided in the so-called Gradiometer Reference Frame (GRF) and are internally calibrated ('in-flight calibration', by comparison with artificial but known signals). In order to use these GG for application in Earth sciences some additional pre-processing needs to be done, including external calibration (by comparison with existing external gravity field information), corrections for temporal gravity field signals (in order to isolate the static gravity field part), and additional screening for outliers.

These three steps, outlier detection and/or data gap interpolation, corrections for temporal gravity field variations and external calibration are part of the GOCE GG pre-processing, one of the tasks of the GOCE High-level Processing Facility (HPF). In our presentation this pre-processing is discussed with emphasis on those characteristics of the GG that are most important for end users who want to use the GG in scientific applications. The GOCE gradiometer has been designed such that the GG error characteristics are optimal in the so-called MBW (measurement bandwidth) between 0.005 and 0.1 Hz, exactly corresponding to the medium to high wavelength gravity field features that are to be resolved from the novel gradiometer instrument on GOCE. Below the MBW the error PSD is expected to show a dominant 1/f behaviour. For use of the final GOCE gravity field models the very high quality SST data will complement this degraded long-wavelength error behaviour of the GG, but a direct comparison of the GG with existing external gravity data, which is used in the outlier detection and external calibration, will become more cumbersome. The pre-processing algorithms that overcome this problem are presented.

The pre-processed GG, or Level 2 gradients, can be used in gravity field analysis, that is, a global gravity field model may be derived from these gradients also in combination with satellite-to-satellite tracking data. In addition, the Level 2 gradients themselves may be directly used in Earth sciences, typically for local and regional applications focusing on the smaller wavelengths. Since the GG are given in the GRF, which is not directly linked to the Earth, a derived product provided from the pre-processing facility is, therefore, GG in an Earth-fixed reference frame (EFRF). If all Level 2 gradients would have a comparable accuracy, then the transformation from the GRF to the EFRF would be straightforward. However, four out of the six gradients have a high accuracy in the MBW, whereas the other two are not very accurate in the MBW. A direct rotation from the GRF to EFRF would project the larger errors of the two inaccurate gradients to all gradients, which is undesirable. Therefore least-squares collocation (LSC) will be used to do the GRF – EFRF transformation and the accuracy of the gravity gradients in the EFRF will not be severely degraded as compared to the accuracy in the GRF. We will present our processing strategy which should result in accurate gravity gradients in the EFRF for further use in geophysical and oceanographic applications.

In-flight validation and monitoring of gradiometric GOCE data

Michael Kern[(1)], Haagmans Roger[(1)], Gernot Plank[(1)], Rune Floberghagen[(1)] and Mark Drinkwater[(1)]

[(1)] ESA/ESTEC, Keplerlaan 1, 2200 AG Noordwijk ZH, Netherlands

Abstract

The European Space Agency's Gravity field and steady-state Ocean Circulation Explorer (GOCE) Mission will be the first of ESA’s Core Earth Explorer satellite missions. Mission goals are to determine the Earth’s gravity field and its anomalies with an accuracy better than 1 mGal, and the global geoid with an accuracy better than 1-2 cm at a spatial resolution of 100 km or better. To meet these goals, the satellite instruments will undergo a series of calibration procedures before launch and in flight. In flight, the gradiometer will be calibrated prior to the measurement phases by the so-called in-flight calibration, which makes use of a unique satellite and proof mass shaking set-up and calibration techniques. Ultimately, the gradiometric measurements are externally calibrated using external gravity information over well-survey areas and global gravity field models.

This paper studies novel concepts to monitor and validate the quality of the gradiometer data in flight. This may be done by using satellite-only information, but could also involve external information (global gravity field models and alike). The concepts should provide a quick quality assessment of the gradiometric components. Special emphasis will be placed on the issues and inherent assumptions for such algorithms. An outlook will be given and numerical examples will be shown that demonstrate the potential of the proposed concepts.

A regional GOCE validation and combination experiment based on absolute gravity, deflections of the vertical and GPS/levelling data

Nina Lux[(1)], Christian Voigt[(2)], J. Ihde[(1)] and H. Denker[(2)]

[(1)] Bundesamt für Kartographie und Geodäsie (BKG), Richard-Strauss-Allee 11, D-60598 Frankfurt, Germany
[(2)] Institut fuer Erdmessung(IfE) Universität Hannover, Schneiderberg 50, D-30167 Hannover, Germany

Abstract

Within the framework of the GOCE-GRAND II project (GRavitationsfeldANalyse Deutschland), a regional GOCE validation and combination experiment is realized in Germany, where absolute gravity observations, deflections of the vertical and GPS/levelling data are employed as independent data sets. About 100 new absolute gravity stations are planned as spot-checks of the existing gravity data base, aiming at the validation and detection of possibly existing offsets or other systematic errors in the existing gravity data base that is used for geoid modelling. For this purpose, the new and recently developed portable absolute gravimeter A 10 is used, which is the only absolute gravity instrument suitable for field operation. In addition, deflections of the vertical are observed with a transportable digital zenith camera (TZK2-D) in profiles, traversing through all nearby GPS/levelling stations and thus allowing a cross validation of both data sets. After filtering the surface data to remove high frequencies not included in the GOCE models, all terrestrial data sets are employed in the validation of the global GOCE geopotential models.

Besides the validation of the GOCE products, the second major issue of the project is the combination of the (revised) terrestrial gravity field data with the global models from the GOCE mission in order to compute geoid or quasigeoid models which provide the complete spectrum (all wavelengths) with an accuracy at the centimeter level. The combination shall be carried out in a remove-restore procedure using a spectral combination technique (IfE) and the method of point mass modelling (BKG). The combination solutions will again be evaluated by independent data, i.e., GPS/levelling and deflection of the vertical data.

The paper will describe the project background and aims. Then the field experiences obtained so far with the absolute gravimeter A 10 and the transportable digital zenith camera TZK2-D including instrumental enhancements will be described. The accomplished part of the field campaigns will be documented and first results will be presented. An outlook will be given on further proceeding, which includes the determination of the geoid models from the combination of terrestrial and satellite gravity field models.

GOCE-GRAND II is supported under grant 03F0422A BMBF/DFG Research and Development Programme "Geotechnologien".

Improved kHz-SLR Tracking Techniques and Orbit Quality Analysis for LEO-Missions

Walter Hausleitner[(1)], Georg Kirchner[(2)], Roland Pail[(3)] and Helmut Goiginger[(3)]

[(1)] *Austrian Academy of Sciences, Schmiedlstrasse 6, 8042 Graz, Austria*
[(2)] *Austrian Academy of Sciences, Lustbühelstrasse 46, 8042 Graz, Austria*
[(3)] *Graz University of Technology, Steyrergasse 30, 8010 Graz, Austria*

Abstract

The Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) is a low Earth orbiting (LEO) satellite dedicated to sensing the Earth's gravity field with a very high spatial resolution. Much effort will have to be spent on the precise determination of the complex orbit in order to gain maximum accuracy for the data products. The precise orbit information of low Earth orbiting gravity field missions currently in orbit is mainly provided by GPS/SST, which is operated in high-low (CHAMP) or in a low-low (GRACE) configuration. All these spacecraft have in common, that they carry laser retro-reflectors on board. This points out the importance of Satellite Laser Ranging (SLR) as an independent external tracking instrument.

SLR is a method to measure distances between the SLR ground station and the satellite by means of very short laser pulses. The SLR technique can very efficiently be used for the calibration and validation of low Earth gravity mission products, i.e. to assess the quality of GPS orbits and gravity field solutions, respectively. Since October 2003 the Space Research Institute of the Austrian Academy of Sciences (AAS/SG) runs a new kHz-SLR system at the observatory Graz/Lustbuehel. This system is capable of performing ranging measurements at a 2 kHz rate compared to the commonly used 5-10 Hz rate. However, it is assumed that hardly any SLR station will be able to provide ranging observations to very low orbiting spacecraft such as GOCE. For the purpose of raising the laser tracking efficiency a project applied by AAS/SG and TUG/INAS was approved and will be funded by a national organisation. The project aims on the one hand to the implementation of optimized kHz-SLR tracking techniques in order to improve the tracking efficiency of LEO satellites, and on the other hand to the establishment of quality assessment tools for LEO orbits and derived gravity field solutions.

The activities focus on a number of hardware upgrades and methodical improvements in order to achieve a faster target acquisition. This increases the number of observations per pass and further improves the normal point accuracy as well as the overall system stability. The quality assessment process considers two aspects: GPS/SST derived orbits will be evaluated using orbital arcs generated from the global set of SLR data in a kinematic and a dynamic mode. Quick-look gravity field solutions (QL-GFA) from SST and SGG data will be provided by TUG/INAS in the frame of the operational GOCE data processing. The quality of these can be assessed by analyzing the residuals resulting from orbit adjustments using the corresponding coefficients.

GOCE GPS data processing at ESOC

Henno Boomkamp[1] and John Dow[1]

[1] *ESA/ESOC, Robert-Bosch-Strasse 5, D64293 Darmstadt, Germany*

Abstract

The majority of GOCE studies and mission proposals are related to applications of the gradiometer data to gravity field and oceanography studies. However, for accurate positioning of the gradiometer instrument relative to the gravity field that it is measuring, the satellite depends entirely on GPS information. This presentation will discuss some aspects of precise GPS data processing that can be offered by ESOC, capitalizing on experience in routine GPS data processing at its IGS Analysis Centre.

The first area of interest is near real-time quality assessment and validation of the GOCE GPS data, based on independent orbit predictions for GOCE and for the GPS constellation. This can be integrated with the operational activities of the recently inaugurated Navigation Facility at ESOC, taking advantage of its stable operational infrastructure.

A second topic is accurate calibration of the GOCE GPS antenna phase pattern, to remove the related systematic errors in the GPS tracking data. Accurate antenna phase patterns can be determined a posteriori from processed GPS data, and can then be used to improve the GOCE products in a reprocessing stage.

The third area in which ESOC can contribute to the GOCE analysis is by independent assessment of the GOCE gradiometer reference frame, which is realized by means of the GPS orbits that are used in GOCE orbit determination. To relate the gradiometer data to the actual Earth models of IERS, ESOC can provide a direct link between the GOCE orbit reference frame and the ITRF via simultaneous solutions for the GOCE orbit, the GPS satellite orbits and a substantial network of ITRF ground stations. The perfect internal consistency that such a solution offers between a GOCE orbit and an ITRF realization can be used to produce time series of transformation parameters between the GOCE science orbit, based on fixed a priori GPS products, and the ITRF.

GOCE Calibration and Monitoring Facility (CMF)

Jose Antonio Gonzalez Abeytua[1], Andres Canales[1] and Eduardo Lopez Hazas[1]

[1] *DEIMOS Space, Ronda de Poniente, 19. Edificio Fiteni VI,Portal2, 28760 Tres Cantos, Spain*

Abstract

The CMF is responsible for the calibration (the nominal calibration is done in PDS/IPF1, but the CMF is responsible for the assessment and approval of the calibration products) and the monitoring of the space segment, as well as the monitoring of the performance of the PDS products, in particular the calibration products.

The CMF consists of a combination of generic and specific functionality. Generic tools are such that they can be applied to any type of data time series (i.e. both science and HK products) while specific toolboxes shall be developed for the analysis of GOCE products. These specific toolboxes include: Gradiometer Instrument Monitoring Functions, Satellite-to-Satellite Tracking Instrument Monitoring Functions, Drag-Free and Attitude Control System Monitoring Functions and Gradiometer In-Flight Calibration Monitoring Functions. It is required to have the capability to add further toolboxes during mission operations.

The different tools of the CMF run in either automatic or interactive mode. When in automatic mode the tools are used for systematic quality analysis of the calibration data and products. When in interactive mode, the tool is run by an operator and by the Calibration and Monitoring (CM) team having the required experience to analyse the data of the PDS and to propose modifications to the mission planning (extra calibration, downlink of diagnostic HK parameter, etc.).

Quick Validation of GOCE Gradients

Focke Jarecki[1], Karen Insa Wolf[1] and Jürgen Müller[1]

[1] *University of Hanover, Schneiderberg 50, 30167 Hannover, Germany*

Abstract

Contributing to ESA's calibration and validation activities (Cal/Val Team) for the GOCE mission, this paper presents two quick validation methods for GOCE gradients: a cross-over procedure for an internal quality check and the comparison with external reference data in the time and frequency domain.

The cross-over approach includes adequate reduction procedures to deal with altitude and attitude differences for the immediate comparison of the gradient tensor components in satellite track cross-over points. Simulated gravity gradiometry data sets based on different error assumptions are processed. The cross-over validation, as a relative approach, proves to be capable to detect gross errors, data gaps and long term drift parameters well, whereas geographically fixed error phenomena and constant biases remain undiscovered. Combining selected data from different epochs, drift behaviour and short-term biases are very well identified through cross-over validation.

The second part of the paper deals with the computation of external reference gradients with sufficient accuracy in the measurement bandwidth of the gradiometer. Therefore geopotential models are combined with terrestrial gravity and terrain data to improve the high frequency information of the upward continued gradients. Pre-calculated reference gradients from high quality data over Europe are produced. Beyond this, the errors of the computed gradients are studied based on closed-loop calculations with synthetic data including noise and on statistical error estimations. The propagated errors of the upward continued gradients are shown in time and frequency space to evaluate the quality of the gradients in the measurement bandwidth of the GOCE gradiometer.

Dealing just with subsets of the original SGG measurements both methods offer the opportunity to do a quick validation, already on the Level-1B data processing step.

Session 7

GOCE, Grace, Gravity Field Models

Synergy of the GOCE and GRACE satellite missions

Pavel Ditmar[(1)], Xianglin Liu[(1)] and Roland Klees[(1)]

[(1)] *Delft University of Technology, Kluyverweg 1, 2629 HS Delft, Netherlands*

Abstract

GRACE and GOCE missions exploit different measurement concepts to map the Earth's gravity field. The GRACE k-band data are not sensitive to the cross-track gravity field component, and, therefore, result in a very anisotropic error behavior. On the other hand, the GOCE gravity gradiometer will measure all the diagonal components of the gravity gradient tensor, so that the error behavior will be much more isotropic. Finally, for both satellite missions accurate GPS tracking data are available, which can be used to compute precise kinematic satellite orbits and, ultimately, the Earth's gravity field. A viable research question, therefore, is how these two satellite missions may complement each other and how the result of a joint data processing would differ from those obtained from the two missions separately. To answer this question, a numerical study has been performed. The following data sets have been generated: (i) a set of GOCE accelerations that can be derived from a satellite orbit by a three-point numerical differentiation; (ii) similar sets of accelerations for both GRACE satellites; (iii) a set of GOCE gravity gradiometer data; and (iv) a set of range-rate linear combinations that can be derived from GRACE range-rate data. Importantly, all the considered data types can be directly related to parameters of the Earth's gravity field. Each of the data sets is contaminated by a realistic frequency-dependent noise. Furthermore, noise in GRACE data is scaled in such a way that the accuracy of the gravity field model derived from it is close to the accuracy of state-of-the-art GRACE models. The simulation shows that the mean gravity field model obtained by a joint processing of GOCE and GRACE data is much more accurate in a wide range of spherical harmonic degrees than models obtained on the basis of data from only one satellite. We explain this by the fact that errors in each stand-alone solution are unevenly distributed over the orders. Due to the anisotropic error pattern in GRACE data, the least accurately determined harmonics in the corresponding models are the nearly-sectorial ones. On the other hand, the most inaccurate harmonics in GOCE-based solutions are the nearly-zonal ones, which can be attributed to the extended polar gap in GOCE data. Thus, GOCE and GRACE data contain complementary information. To fully exploit this complementarity, we recommend to process GRACE and GOCE data jointly whenever possible.

The Slepian approach revisited: dealing with the polar gap in satellite based geopotential recovery

Nico Sneeuw[(1)] and Oliver Baur[(1)]

[(1)] *Universität Stuttgart, Geschwister-Scholl-Str. 24D, 70174 Stuttgart, Germany*

Abstract

Gravity field modelling is typically based on spherical harmonic expansion of the potential function. Surface spherical harmonics are globally defined and satisfy the orthogonality relations on the sphere. However, satellite ground tracks often leave out polar areas. Especially regarding the GOCE mission, a double polar cap with a radius of more than six degrees will not be covered by observation data. Conventionally, this problem is tackled by adjusting the data situation to the model, e.g. by introducing terrestrial measurements. As an alternative we investigate the adaptation of the geopotential modelling to the observations. In particular we introduce band limited base functions that are optimally concentrated within the spherical belt. This approach goes back to David Slepian who referred them to as prolate spheroidal wave functions. Already in Albertella et al. (1999) the method has been applied in satellite geodesy. However, they only succeeded in the calculation of random band limited functions. Recently an analytical expression has been found for the unique transformation to the Slepian base when neglecting an axisymmetric double polar cap. We apply that approach to a simulated GOCE data set to investigate its benefit for geopotential recovery.

Status of GRACE mission

Byron Tapley[(1)], Srinivas Bettadpur[(1)] and Christoph Reigber[(2)]

[(1)] The University of Texas at Austin, 3925 W. Braker Lane, Suite 200, Texas 78759-5321, United States
[(2)] GeoForschungsZentrum Potsdam (GFZ), Telegrafenberg A 17, 14473 Potsdam, Germany

Abstract

The NASA/DLR Gravity Recovery And Climate Experiment (GRACE) is in its fifth year of operation. At this time, routine and continuous collection of gravity and radio occultation science data is being carried out. The Level-1 (tracking data) and Level-2 (gravity field) data products are being routinely made available to the user public.

This paper will summarize the status of the GRACE project, including plans for the mission extension. The status of the science results, and the data products will be presented. The relevance of GRACE during the period of common operation with GOCE will be addressed as well.

Global Mean Gravity Field Models from Combination of Satellite Mission and Altimetry/Gravimetry Surface Data

Christoph Förste[(1)], Frank Flechtner[(2)], Roland Schmidt[(2)], Rolf König[(2)], Ulrich Meyer[(2)], Richard Stubenvoll[(1)], Markus Rothacher[(1)], Franz Barthelmes[(1)], Hans Neumayer[(2)], Richard Biancale[(3)], Sean Bruinsma[(3)], Jean-Michel Lemoine[(3)] and Sylvain Loyer[(3)]

[(1)] GeoForschungsZentrum Potsdam, Telegrafenberg A17, D-14473 Potsdam, Germany
[(2)] GeoForschungsZentrum Potsdam, c/o DLR Oberpfaffenhofen, D-82234 Wessling, Germany
[(3)] Groupe de Recherche de Geodesie Spaciale, 18, avenue Edouard Belin, F-31055 Toulouse, France

Abstract

Precise high-resolution global mean gravity field models are needed in various geodetic-geophysical applications such as e.g. precise orbit determination of Earth satellites at all altitudes, GPS levelling, determination of ocean surface currents from altimetry or geotectonic/geodynamic interpretation and modelling. Traditionally, such models are derived from the combination of satellite tracking data describing the long -wavelength components and surface gravity data providing the short-wavelength. With the modern high precision and homogeneous data from CHAMP and GRACE a new class of high-resolution global mean gravity field models can be derived.

At GFZ Potsdam and GRGS Toulouse, such advanced global gravity models are routinely produced in the framework of the EIGEN processing activities (EIGEN = European Improved Gravity model of the Earth by New techniques). In this contribution we highlight the latest results of the EIGEN gravity model products, labeled EIGEN-04 and EIGEN-05, and compare with outcomes of former analyses. Among other features like partially newly processed surface gravity data a special band-limited combination technique was applied to get a smooth transition from the long- to the short-wavelength bands. The obtained Earth gravity field parameters are an update of former EIGEN models of a resolution corresponding to a half-wavelength of 55 km and degree/order 360, respectively. The high quality value of these new models was recently appreciated by adopting the EIGEN-GL04C model as a standard for the reprocessing of Jason and TOPEX/Poseidon data, indicating the potential benefit of even further improved EIGEN combination models for the upcoming GOCE mission.

Session 8

Scientific Exploitation of Data Products: Solid Earth

How to combine GOCE and ground data?

Isabelle Panet[1], Michel Diament[2], Matthias Holschneider[3] and Olivier Jamet[4]

[1] IGN/IPGP, 4, Place Jussieu, 75252 Paris, France
[2] IPGP, 4, Place Jussieu, 75252 Paris, France
[3] Universität Potsdam, Postfach 60 15 53, D-14415 Potsdam, Germany
[4] IGN, 6 et 8, avenue Blaise-Pascal, Cité Descartes, F-77455 MARNE-LA-VALLÉE Cedex 2, France

Abstract

With the advent of satellite gravity, new datasets of unprecedented precision become available and require the development of efficient methods of representation and analysis in spherical geometry. Wavelets are especially interesting because they allow to merge low resolution, satellite data with local, high resolution data within combined representations, and because they offer possibilities of analysis in a wide range of spatial scales. We discuss here a new way to compute a discrete wavelet representation of the gravity field through a regularized least-squares inversion of gravity data and we apply this method to some examples.

Exploitation of GOCE Data for a Local Estimate of Gravity Field and Geoid in the Regione Piemonte Area (Northern Italy)

Riccardo Conte[1], Fernando Sansò[2] and Filomena Solitro[3]

[1] Protezione Civile Regione Piemonte, Corso Marche, 79, 10146, Italy
[2] Politecnico di Milano, Piazza Leonardo da Vinci, 32, 20133, Italy
[3] ALTEC S.p.A., Corso Marche, 79, 10146, Italy

Abstract

This poster describes the activities carried out by a working group, including the Civil Protection department of Regione Piemonte, Altec S.p.A. (Advanced Logistic Technology Engineering Center) and Politecnico di Milano, regarding the exploitation of GOCE data for a local estimate of gravity field and geoid in the Regione Piemonte area.

The idea of the project was conceived in July 2004; within it, the different groups operate as follows: · Altec is prime contractor of the project and responsible for the coordination of the work, development of the demonstrative and/or operative products, analysis of the user requirements; · Politecnico di Milano is responsible for the technical and scientific analysis and the development of specific algorithms needed for the modelling of the local gravity field and the geoid; · Civil Protection of Regione Piemonte is interested in gravimetric and seismic applications (new gravity field map of Regione Piemonte and evaluation of solid earth processes – geodynamics).

The "GOCE Data for Civil Protection" Project started in February 2005 and will last until July 2007. The main activities of the project are the following: · analysis of the requirements of Civil Protection of Regione Piemonte; · collection of gravimetric data and data validation at ground level; · definition of technical procedures to estimate the gravity field and to evaluate the actual impact of GOCE data in the local geoid estimation procedure; · integration of GOCE simulated data for the Piemonte area with gravimetric data at ground level; · development of a product operative demonstrator (a sort of "tool box" for the specific applications of the project), based on the exploitation of data collected over the area of interest and on software specifically developed with the aim of data updating, of evaluating project products, and possibly of identifying new potential applications (training, education, product promotion, etc).

Most of the scheduled activities have been already carried out successfully. In particular, the scientific approach has demonstrated the positive impact of the GOCE information on the local geoid estimation using simulated data. Besides, the "tool box" is well under construction and can now be used to estimate the gravitational field and the geoid in the Piemonte area, and to compute point-wise values of them and of other functionals of the gravity potential. When the project will be completed, in the frame of a specific GIS, it will be possible to integrate a new gravimetric map of Regione Piemonte with other data and also to combine the Piemonte geological map with the gravimetric data.

Comparison of the modelling of topographic and isostatic masses in the space and the frequency domain for use in satellite gravity gradiometry

Franziska Wild[1] and Bernhard Heck[1]

[1] University of Karlsruhe, Englerstr. 7, 76128 Karlsruhe, Germany

Abstract

In terrestrial and airborne gravity field determination the formulae for the gravitational potential and its first order derivatives have been evaluated, while second order derivatives are related to the analysis of upcoming satellite gravity gradiometry missions of GOCE type. Especially there, the reduction of topographic and isostatic effects within the remove-restore concept is important to produce a smooth gravity field suitable for downward continuation. Another application of topographic and isostatic reductions consists in the external calibration of the GOCE gravity gradiometer. In this presentation, the modelling in the space domain is opposed to the modelling in the frequency domain. In the space domain the gravitational effects of volumetric mass elements can be presented by prisms, point masses, mass layers and tesseroids. The volume integrals are analytically solvable for all mentioned mass elements, except the tesseroid. Approximate solutions of the elliptic integrals related to the tesseroid can be produced by semi-analytical or purely numerical methods. Based on different isostatic models the topographic-isostatic effects are calculated for a GOCE-like satellite orbit, and the computation methods in the space and frequency domain are compared.

Mascon solutions with GRACE and GOCE for Time-Variable Gravity Recovery

Frank Lemoine[1], Scott Luthcke[1], David Rowlands[1], Richard Ray[1], Despina Pavlis[2], John McCarthy[2], Steve Klosko[2], Douglas Chinn[2], Sean Bruinsma[3] and Jean-Charles Marty[3]

[1] NASA GSFC, Code 698, Greenbelt, MD 20771, United States
[2] SGT Inc., Greenbelt Road, Greenbelt, MD 20770, United States
[3] CNES, 18, Avenue Edouard Belin, Toulouse, 31401 Cedex 09, France

Abstract

The GRACE and GOCE gravity missions provide unique and complementary sensitivity into the gravity spectrum. The GRACE data so far have been used to provide an order of magnitude improvement in the static gravity field, and a window into the mass variations on time scales as short as ten days and on spatial scales as short as 400 km. The localized nature of the GRACE inter-satellite measurement lends itself to localized solutions with mascons (mass concentrations) that offer unique advantages over solutions obtained using spherical harmonics. We review the latest mascon solutions from GRACE, and investigate the feasibility of integrating the data from both GRACE and GOCE in a complementary fashion to enhance the time-variable gravity recovery. In addition we describe the signal and information content of GRACE and GOCE gravity solutions compared with the signal spectrum from time-variable signals such as land hydrology, ocean tides, and surface ice mass variations.

Geophysical and Petrological Applications of New-Generation Satellite-Derived Gravity data With a Focus on Hazardous and Frontier Regions

Ron Hackney[(1)], Romain Bousquet[(2)], Hans-Jürgen Götze[(1)], Rezene Mahatsente[(1)], Thomas Jahr[(3)], Gerhard Jentzsch[(3)] and Roland Oberhänsli[(2)]

[(1)] Universitaet Kiel, Otto-Hahn-Platz 1, 24118 Kiel, Germany
[(2)] Universitaet Potsdam, Karl Liebknecht str. 24-27, 14476 Potsdam, Germany
[(3)] Universität Jena, Burgweg 11, 07749 Jena, Germany

Abstract

As part of the Germany Priority Program "Mass Transport and Mass Distribution and in the Earth System", we are proposing to take advantage of new-generation satellite-derived gravity and gradient data from CHAMP, GRACE and, in particular, GOCE for studies of the crust and upper mantle in hazardous and frontier regions. These new models provide gravity information (1) for areas previously lacking data and (2) that is continuous and consistent across natural and artificial boundaries. We will develop and test methods for dealing with the new satellite gravity and gradient data in geophysical applications (computation of Bouguer anomalies, satellite gravity data for regional–residual field separation). In order to ascertain the degree to which the satellite data resolve lithospheric structures, we will also compare the satellite data to gravity and gradients predicted from existing 3D density models. New petrologically- and thermodynamically-based methods will be used to constrain density independently of gravity data. These methods will be tested against satellite gravity data and used in our models of frontier regions and subduction zones. In selected frontier regions, new gravity models constrained by satellite data will extend existing interpretations and demonstrate the use of the new-generation satellite gravity data in geophysical applications. In subduction zones, we will integrate static density modelling and finite-element modelling to study asperities and to examine the temporal variation of the gravity field in response to fore-arc deformation.

Coseismic Deformation Studies Using GRACE and GOCE

C.K. Shum[(1)], Shin-Chan Han[(1)] and Chung-Yen Kuo[(2)]

[(1)] Ohio State University, 125 S Oval Mall, Columbus, Ohio 43210, United States
[(2)] National Cheng Kung University, 1 University Road, Tainan, Taiwan

Abstract

Satellite gravimetry in GRACE and gradiometry in GOCE are distinctly different measurement types with GRACE primarily more accurate in the long-wavelength and GOCE more accurate in the high-frequency components of the gravity field. It has been demonstrated that GRACE is capable of observing coseismic deformation in the form of gravity changes (primarily crust density change) of a large undersea subduction earthquake (the Great 26 December 2004 Sumatra-Andaman earthquake, Mw=9.3). This paper provides a study of the feasibility of GOCE gravity gradient tensor measurements to be able to observe coeismic deformation of earthquakes potentially of significantly smaller earthquakes than the Sumatra-Andaman earthquake.

Constraints on Shallow Low-Viscosity Earth Layers from Future GOCE Data

Hugo Schotman[1,2], Bert Vermeersen[1] and Pieter Visser[1]

[1] *Delft University of Technology, Kluyverweg 1, 2629 HS Delft, Netherlands*
[2] *SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, Netherlands*

Abstract

In previous papers (Schotman and Vermeersen, Earth Planet. Sci. Lett. 236 (2005), Schotman, Vermeersen and Visser, Proc. IAG (2006, in press)) we have shown that geoid heights due to shallow, laterally homogeneous low-viscosity earth layers are above the performance of GOCE, and that GOCE is especially sensitive to the properties of crustal low-viscosity layers and uncertainties in the ice-load history. Here we will try to recover properties of crustal low-viscosity layers from synthetic GOCE data, in the presence of error sources. We will group these error sources in model errors and noise.

Model errors include errors in the background models (e.g. the GIA earth and ice model combination), unmodelled medium- to short-wavelength (harmonic degree above 20) solid-earth features related to subduction, passive margins and topography, time-dependent mass variations in the oceans and atmosphere, and errors in the recovery of the gravity field from simulated gravity gradients. Noise consists of random mass inhomogeneities in the shallow earth and realistic gradiometer measurement noise.

We will focus on a region where other solid-earth aspects contribute to the static gravity field, and use a combined spectral-spatial domain approach to separate the different contributions. We will give an estimate of how well homogeneous crustal low-viscosity layers can be constrained by GOCE data and shortly expatiate on the validity of our conclusions for laterally heterogeneous low-viscosity layers.

Session 9

The GOCE Mission III: Mission Operations, Level 2 Products and User Services

GOCE Flight Operations

Pier Paolo Emanuelli[(1)]

[(1)] *ESA/ESOC, Robert-Bosch-Strasse 5, 64293 Darmstadt, Germany*

Abstract

To achieve its objectives of providing provide high-resolution and high-accuracy global models of the Earth's gravity field, the GOCE mission will rely heavily on its space segment. The current status of GOCE Flight Operations will be presented as well as their expected support of GOCE scientific objectives.

The Status of the GOCE High-level Processing Facility (HPF)

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

[(1)] *SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, Netherlands*
[(2)] *IAPG, Arcisstrasse 21, D-80333 Munchen, Germany*

Abstract

The GOCE High-level Processing Facility (HPF) is the part of the GOCE Ground Segment which is dedicated to the scientific processing of the GOCE observations and the production of the final gravity field products provided to the end users. The HPF is currently in the final stage of its development. During and shortly after the operational phase of the GOCE mission the HPF will systematically produce GOCE level 2 end products such as orbits and gravity field models of different kinds, derived from the novel and highly precise GOCE gradiometry observations, GPS high-low satellite-to-satellite tracking data and additional measurements. Ten European university institutes and research facilities, having complementary expertise in gravity and geodesy related science fields, together have formed the European GOCE Gravity Consortium (EGG-C), which has been contracted by ESA to develop, implement and operate the HPF throughout the whole GOCE mission lifetime.

The HPF is designed and developed with the capabilities to produce on a regular basis so-called quick-look or rapid products, that are mainly of interest for the GOCE performance monitoring, as well as final and precise products, representing the official ESA GOCE level 2 products that will become available to end-users. A unique feature of the HPF is that it will implement and operate three different gravity field analysis techniques in parallel, complemented with dedicated scientific pre-processing techniques and a thorough validation procedure for the derived gravity field models before the official ESA solution will be selected out of them. In this way (scientific) users of GOCE products (e.g. oceanographers, solid Earth scientists, geodesists and others) will benefit from the optimal exploitation of the GOCE data. The paper presents an overview of the architecture of the HPF, the status of its development and an outlook to the operational phase.

HPF Overview and How to Use GOCE Level 2 Products

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

[(1)] *Technical University Munich, Arcisstrasse 21, 80333 Muenchen, Germany*
[(2)] *SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, Netherlands*

Abstract

The GOCE High-level Processing Facility (HPF) is in charge of the production of the following final level 2 products: Calibrated and corrected gravity gradients, precise science orbits and global gravity field models. These products represent the main input to all further applications of GOCE. In order to correctly apply these products the user has to know the definitions, conventions and standards adopted for their generation. The underlying assumptions are described in detail in two documents, which will be released together with the data products. These are the GOCE Standards and the GOCE Product Data Handbook. The standards provide detailed information about the reference systems, the transformations between the reference systems and the adopted geometrical and the dynamical models. The data handbook is intended to provide to the users all required information for the correct use of the products. It includes an overview of the mission and products, general definitions, mathematical and geophysical conventions as well as a description of formats. The paper summarizes the applied standards and conventions and introduces in detail the content of the global gravity field product.

GOCE Data Announcement of Opportunity

Jérôme Benveniste[(1)]

[(1)] *ESA/ESRIN, Via Galileo Galilei, 00044 Frascati, Italy*

Abstract

The Gravity field and steady-state Ocean Circulation (GOCE) mission is scheduled for launch in 2007, and will be ESA's first Earth Explorer Core mission. The primary objective of the GOCE mission is to provide global and regional models of the Earth gravity field and the geoid, its reference equipotential surface, with high spatial resolution and accuracy. The high resolution static gravity field and gravimetric geoid measured by GOCE will stimulate research in a wide range of disciplines spanning studies of ocean circulation, cryosphere, solid-earth physics, natural hazards, geodesy and surveying. When used in combination with existing sensors on ESA and Third Party Missions, GOCE data will stimulate a rich variety of value-added research. Moreover, GOCE data will facilitate important advances in the use of historical altimetry and other such datasets when referenced to a precise geoid. The dedicated GOCE Data AO aims at promoting pre-launch preparations for use and exploitation of GOCE standard data products in conjunction with data from other missions (such as Envisat, ERS, and Third Party Missions).

Proposals should be submitted for evaluation via the dedicated Web site http://eopi.esa.int/GOCE. The submission deadline is on 8 December 2006. Proposals will be evaluated by a scientific committee according to the criteria described in the GOCE AO document found on the eopi web site mentioned above. Following approval of the proposed project by ESA, access to data sets necessary to execute the projects will be provided free of charge to the selected Principal Investigators, within the limits of the quota assigned to the proposal.

The following data sets will be made available:

- GOCE calibrated and validated Level 1B and Level 2 data products

- ERS, ENVISAT and ESA Third Party Missions products

This presentation will describe in detail the AO submission and selection processes and the duties of the future Principal Investigator.

Session 10

Towards GOCE Level 2 Products

Rapid and Precise Orbit Determination for the GOCE Satellite

Pieter Visser[(1)], Jose Van Den IJssel[(1)], Tom Van Helleputte[(1)], H. Bock[(2)], A. Jaeggi[(2)], G. Beutler[(2)], U. Hugentobler[(2)] and Drazen Svehla[(3)]

[(1)] Delft University of Technology, Kluyverweg 1, 2629 HS Delft, Netherlands
[(2)] University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland
[(3)] Technical University Munich, Arcisstrasse 21, D-80290, Munich, Germany

Abstract

The ESA GOCE Core Explorer Mission will carry a 12-channel, dual-frequency GPS receiver for high-accuracy precise orbit determination. Precise GOCE orbit solutions will be used to accurately geolocate the observations taken by the primary science instrument, the gradiometer, that aims at collecting medium to short wavelength gravity information. In addition, the orbit solutions will provide complementary information for the long-wavelength gravity field part.

Precise orbit determination is an integral part of the GOCE High-Level Processing Facility (HPF) that aims at producing the best gravity field model products possible. A rapid (RSO) and precise science orbit (PSO) determination chain will be implemented at respectively DEOS and AIUB with typical latencies of 1 day and 1-2 weeks. Additional orbit analysis, such as comparisons of different solutions and quality checks will be conducted by IAPG. The RSO chain will support the operations of the GOCE satellite allowing quick checks of the scientific data streams and quick-look gravity field solutions. The PSO chain will provide the most accurate GOCE orbit solutions possible for use in the final gravity field determinations.

An overview will be given of the adopted orbit determination strategies, RSO and PSO product contents and quality control.

The latest test of the space-wise approach for GOCE data analysis

Federica Migliaccio[(1)], Mirko Reguzzoni[(2)], Fernando Sansò[(3)], Nikolaos Tselfes[(3)], Carl C. Tscherning[(4)] and Martin Veicherts[(4)]

[(1)] Politecnico di Milano, Piazza Leonardo da Vinci, 32, 20133 Milano, Italy
[(2)] OGS - c/o Politecnico di Milano, Via Valleggio, 11, 22100 Como, Italy
[(3)] Politecnico di Milano, Via Valleggio, 11, 22100 Como, Italy
[(4)] University of Copenhagen, Juliane Maries Vej 30, 2100 Copenhagen, Denmark

Abstract

A new set of E2E (end-to-end) simulated data for the GOCE mission has been recently produced by the European Space Agency and used for extensive testing of the procedures for the estimation of the gravity field. These data set spans 60 days and includes the satellite state vector data and orientation parameters, the measured gravity gradients and the measured non gravitational accelerations. These data have been contaminated by realistic in-flight calibration noise and other systematic effects, like biases, which make the analysis more difficult but also representative of the real case and meaningful.

The space-wise solution procedure has been applied to the E2E data with very promising results. However some routines of the procedure had to undergo further tuning with respect to previous experiments. In fact, calibration methods have been used to estimate biases for the common-mode accelerations and long wavelength effects for the gravity gradients, before these data could enter the basic processing chain. In this experiment for the first time a real combination of the energy integration solution and the gradiometry solution has been achieved, which permits also the accurate estimation of low degree coefficients. Moreover it has been found that the information of the GOCE data can be used to resolve for coefficients beyond degree 200 with a commission geoid error of the order of centimetres.

The final step of the space-wise approach, which is the estimation of the gravitational potential coefficients from gridded data, has been performed by three different methods: collocation, integration and exact Fourier analysis.

The results are presented here and the choice of the method is justified via the results of the simulation. The theoretical justification of this choice is discussed in another paper.

GOCE Gravity Field Analysis in the Framework of HPF: Operational Software System and Simulation Results

Roland Pail[(1)], Wolf-Dieter Schuh[(3)], Hamza Alkhatib[(3)], Christian Boxhammer[(3)], Christian Siemes[(3)], Thomas Badura[(1)], Barbara Lackner[(1)], Martin Wermuth[(4)], Bernhard Metzler[(1)], Thomas Preimesberger[(1)] and Eduard Hoeck[(2)]

[(1)] *Graz University of Technology, Steyrergasse 30, 8010 Graz, Austria*
[(2)] *Austrian Academy of Sciences, Schmiedlstraße 6, 8042 Graz, Austria*
[(3)] *University of Bonn, Nussallee 17, 53115 Bonn, Germany*
[(4)] *Technical University Munich, Arcisstrasse 21, 8033 Munich, Germany*

Abstract

In the framework of the ESA-funded project “GOCE High-level Processing Facility”, an operational hardware and software system for the scientific processing (Level 1B to Level 2) of GOCE data has been set up by the European GOCE Gravity Consortium EGG-C. One key component of this software system is the processing of a spherical harmonic Earth’s gravity field model and the corresponding full variance-covariance matrix from the precise GOCE orbit and satellite gravity gradiometry (SGG) data.

In the framework of the time-wise approach a combination of several processing strategies for the optimum exploitation of the information content of the GOCE data has been set up: The Quick-Look Gravity Field Analysis is applied to derive a fast diagnosis of the GOCE system performance and to monitor the quality of the input data. In the Core Solver processing a rigorous high-precision solution of the very large normal equation systems is derived by applying parallel processing techniques on a PC cluster.

The presentation gives an overview of the operational software system. On the basis of a realistic numerical case study, which is based on the data of an ESA GOCE end-to-end simulation, the key components of the processing architecture are presented, and several aspects of the involved functional and stochastic models are addressed.

Special emphasis is put to the filtering of the SGG observations, which is performed by means of an optimum stochastic model representing the actual noise behaviour of the GOCE gradiometer, the optimum combination of the two normal equation systems related to the precise GOCE orbit and SGG, as well as the optimum treatment of the polar gap problem by means of a regularization strategy which is tailored to this problem.

Correlations, Variances, Covariances --- From GOCE Signals to GOCE Products

Wolf-Dieter Schuh[(1)], Hamza Alkhatib[(1)], Christian Boxhammer[(1)], Boris Kargoll[(1)] and Christian Siemes[(1)]

[(1)] *University Bonn, Nussallee 17, D-53115 Bonn, Germany*

Abstract

The great amount of data generated by the satellite mission GOCE will allow for a precise determination of the Earth's garvity field in terms of spherical harmonic parameters and their variances/covariances. To capture the detailed correlation structures present in the SGG signals, complex stochastic models must be built. Such models are implemented in an efficient manner by means of digital filters with tailored stop and band-pass regions. Unfortunately, the computational costs grow considerably when the filter captures more and more details. The first question to be addressed in this talk will be, whether the quality of the parameter estimates justifies the use of an exact filter.

The second topic of this talk is about the use of the variances and covariances of the estimated gravity field parameters for deriving secondary GOCE products such as Earth process models.The variance- covariance matrix of the parameters, which is equivalent to the inverse normal equation matrix, is a very large, fully populated, and numerically instable matrix. To make this data easier to manage, in particular easier to integrate into Earth process models, it is necessary to reduce the amount of data and to improve the stability of the variance-covariance information. For this purpose, alternative ways of representating the variance-covariance matrix by means of sparse matrices or Monte-Carlo samples will be discussed. Finally, the relationship between the parameter accuracies of such Earth process models and the rate of data compression is investigated.

Error propagation of large GOCE normal equation systems: The impact of covariances

Eduard Hoeck[(1)], Roland Pail[(2)] and Bernhard Metzler[(2)]

[(1)] Austrian Academy of Sciences, Schmiedlstraße 6, 8042 Graz, Austria
[(2)] Graz University of Technology, Steyrergasse 30, 8010 Graz, Austria

Abstract

The rigorous error propagation, based on large and full variance-covariance matrices related to a spherical harmonic Earth’s gravity field model (with a square dimension in the order of 70,000 parameters), to derived gravity field quantities such as geoid heights, gravity anomalies, geoid slopes etc. is a huge numerical task. Although nowadays such a processing task is manageable by applying parallel processing techniques on clusters or massive-parallel machines, in practice frequently alternative approximate techniques (e.g. based on Monte-Carlo algorithms) are applied.

Due to the large computational effort, usually only the variances (or standard deviations) of the derived quantity are processed, but the covariances and thus the correlations among the derived quantities defined at discrete spatial locations (e.g. geoid heights on a global or regional grid) are disregarded. In this presentation, also the covariances of a rigorous covariance propagation shall be analyzed. This numerical simulation is based on a full variance-covariance matrix, which is output of a GOCE gravity field processing from realistically simulated precise GOCE orbit and satellite gravity gradiometry (SGG) data, and thus can be considered as representative for the real GOCE gravity field solution.

Additionally, the impact of neglecting the covariances of the derived quantities (e.g. geoid heights), defined on a regional grid, if they are used as an input for further (Level 2 or level 3) processing steps, shall be evaluated. Thus, the contents of the presentation are also relevant for oceanography, geophysics, and all applications where the covariance information of the GOCE gravity field products and derived products will be used.

Session 11

Tools and Algorithms

The GOCE User Toolbox

Jérôme Benveniste[(1)] and Per Knudsen & the GUTS Team[(2)]

[(1)] ESA/ESRIN, via Galieo Galilei, 00044 Frascati, Italy
[(2)] Danish National Space Center, Juliane Maries Vej 30, DK-2100 København Ø, Denmark

Abstract

Data from the ESA GOCE mission are of fundamental importance to the geodesy, solid Earth and oceanographic community. It is expected that in conjunction with altimetric observations, gravity data from the ESA GOCE Mission will - for the first time in history - allow access to the absolute ocean dynamic surface topography and to compute the absolute ocean surface geostrophic currents at spatial scales down to about 100 km. Despite their importance for oceanographic studies, the processing and analysis of gravity mission data has proven to be complicated to the point that the lack of proper processing software is hampering progress in the use of those data. Success in the exploitation of Spaceborne Gravity data therefore seems to depend fundamentally on the proper knowledge of several steps of the detailed gravity data processing procedure in terms of spherical harmonics, their implicit consistent normalization factors, filtering and error data, among others. To facilitate the easy use of GOCE products for geodesists, solid Earth scientitsts, oceanographers and to support the needs of specific applications, the development of a user toolbox (GOCE user toolbox study = GUTS) was identified as an urgent step at the Second International GOCE User Workshop.

Such a toolbox is required to guarantee optimal use of the existing and future gravity data acquired from GRACE and GOCE. In particular it is recognized and accepted that software packages are required that allow the gravity field data, in conjunction and consistent with any other auxiliary data sets, to be pre-processed by users not intimately familiar with gravity field processing procedure, for scientific application, both regionally and globally.

The final Level 2 products consist of: the precise orbit of GOCE, the gravity field in terms of spherical harmonic coefficients, the corrected, calibrated and geo-located gravity gradients, a map of the gravity anomalies and a map of the geoid. This effort will be an essential element in the entire GOCE data stream. However, no ocean circulation products are planned to be delivered as Level-2 products so that a strong need exists for GUTS to deliver oceanographers with additional information and tools that can turn the Level 2 products into application-dependent fields by further processing the GOCE Level-2 geoid and merging it with Radar Altimetry and other auxiliary data.

Among the fields that are important is the geoid error covariance function. For many applications it is required in geographic coordinates or at specific locations. The toolbox therefore needs to perform this and other extra functions that are essential for using the GOCE geoid fields efficiently and for testing it in geoid validation studied.

The GUTS working group is an open group, gathering the European Scientists around a study aimed at writing the specification of the GOCE User Toolbox (GUT), after a user requirement and algorithm trade-off study.

Elementary Algorithms for Determining the Ocean Dynamic Topography From Altimetric and Gravity Data

Rory Bingham[(1)], Keith Haines[(2)] and Hughes Chris[(1)]

[(1)] Proudman Oceanographic Laboratory, 6 Brownlow Street, Liverpool, L19 0NT, United Kingdom
[(2)] University of Reading, 3 Earley Gate, Reading, RG6 6AL, United Kingdom

Abstract

A key quantity in oceanography is the ocean's dynamic topography. While satellite altimetry has provided the oceanographic community with a good picture of the time variable dynamic topography for some time now, direct determination of the mean dynamic topography (MDT), which is simply the difference between the mean sea-surface and the geoid, has been restricted by the lack of a sufficiently accurate geoid. From an oceanography perspective the primary benefit from GOCE will be the resolution of this problem. However, because of the contrasting representations of the constituent surfaces, and their differing error characteristics, care is needed in

the choice of algorithms used to derive the MDT. The objective of this paper is to assess a number of elementary approaches for computing and filtering the MDT. For the GOCE User Toolbox (GUT) determination of good elementary procedures is important since, compared with more sophisticed methods, such procedures are less computationally expensive, and are easier for a user to understand and implement. Two main computational algorithms are considered: conventional differencing of the mean sea-surface height and geoid height anomaly in the geographical domain, and differencing in the spectral domain. It is shown how the latter approach significantly reduces numerical artifacts in the resulting MDT. We also consider simple methods of filtering the MDT to remove noise. The problems of naive filtering, including coastal artifacts and the attenuation of oceanographic signals are considered, and methods to resolve these issues without incurring a high computational burden are presented.

Optimal filtering of mean dynamic topography models

Per Knudsen[(1)], Ole Andersen[(1)] and Toke Beck Andersson[(1)]

[(1)] *Danish National Space Center, Juliane Maries Vej 30, 2100 Copenhagen, Denmark*

Abstract

Least squares collocation is an estimation technique where discretely located observations of different kinds can be integrated. The technique allows a rigorous description of the full covariance associated with signal, the errors as well as the estimated quantities. In this presentation error covariances associated with the ocean dynamic topography are analysed and described. The multi-disciplinary project "Geoid and Ocean Circulation in the North Atlantic (GOCINA)" aims at enhancing the capacity in Earth observation using data from the European Space Agency missions ENVISAT and GOCE. In this study the techniques are applied to enhance the estimation of the Mean Dynamic Topography using the high resolution Mean Sea Surface KMS04 and the geoid model GGM02S from GRACE. Especially, for modeling marine quantities with incomplete global coverage the methods have its advantages compared to a regular expansion into spherical harmonic functions. Furthermore, the full spectrum error covariances may be derived.

Consolidating User Requirements for the GOCE User Toolbox

Per Knudsen[(1)] and the GUTS Team[(1)]

[(1)] *Danish National Space Center, Juliane Maries Vej 30, 2100 Copenhagen, Denmark*

Abstract

No ocean circulation products are planned to be delivered as level-2 products as part of the GOCE project so that a strong need exists, for oceanographers, to further process the GOCE level-2 geoid and merge it with Radar Altimetry. This need, and subsequent recommendations for optimal use of GOCE data by oceanographers, was explicitly expressed during the second International GOCE Workshop, which was held in ESRIN from 8-10 March 2004. A synthesis of the main recommendations has been published in the GOCE workshop proceedings. The primary requirement of oceanographers is to have access to a geoid and its error covariance at the highest spatial resolution and accuracy possible, although required resolution depends on application. For effective use of the geoid data, knowledge of the error covariance is mandatory so that the two previous geoid products have to be delivered with their corresponding covariance matrices. Within the GUTS project the user requirements for GOCE User Toolbox associated with geodetic, oceanographic and solid earth applications are consolidated.

GOCE User Toolbox Specification (GUTS) - System Specification and Architectural Design

Keith Haines[(1)] and Daniel Bretherton[(1)]

[(1)] *Reading University, Harry Pitt Building, 3 Earley Gate, Reading, RG6 6AL, United Kingdom*

Abstract

The GUTS project has been inter-comparing algorithms for translation of GOCE HPF data for use in the fields of oceanography and solid Earth science. The system specification and architectural design for GUTS include the following information:

* Design of all user interfaces and description of file formats for input and output. * Design of the logical model of the software functionality. * Complete specification of output, including data products, reports and logs.

Within this project the designs and specifications are limited to a logical description of the toolbox architecture and data flow, and do not include software design details. The purpose is to provide the link between scientists in the toolbox design team and the software engineers who will implement the toolbox.

The toolbox will be composed of a collection of executable tools, sets of auxiliary data and a programming interface, with dedicated plug-in points to allow for easy integration of new algorithms, new data and the GOCE HPF product files. The architecture of the toolbox will allow any user to substitute their own auxiliary data or to integrate extra modules to extend the toolbox for individual applications. The ancillary data will include Mean Sea Surface Height data from altimetry and Dynamic Topography data from models or other oceanographic measurements, as well as a priori non-GOCE geoid information. Good documentation will be necessary in order to facilitate communication between the various user communities. The software will be developed on an Open Source basis, to allow the flexible use and development of the toolbox by the science community.

This paper will present the current design plans for the Toolbox, the final version of which is due to be delivered at the end of 2006.

The GOCE User Toolbox: Toward a first prototype

Marie-Hélène Rio[(1)]

[(1)] *CLS, 8-10 rue hermes, 31526 Ramonville Saint Agne, France*

Abstract

Data from the ESA GOCE mission are of fundamental importance to the oceanographic community since they will finally allow, in conjunction with altimetry, to access the absolute ocean dynamic topography with a centimetric accuracy at spatial scales down to 100 km, whereas for the moment, only the variable part of the sea level, and thus the geostrophic currents, can be inferred from altimetric heights with sufficient accuracy. Despite their importance for oceanographic studies, the processing and analysis of gravity mission data has proven to be complicated to the point that the lack of proper processing software is hampering progress in the use of those data. To facilitate the easy use of GOCE products for oceanographers and to support the needs of specific applications, the development of a user toolbox was identified as an urgent step at the Second International GOCE User Workshop and the GOCE user toolbox study (=GUTS) begun in January 2006 with the objective of producing algorithms and input and output specification for the subsequent generation of a user toolbox. The scope of this paper is to present a synthesis of what has been achieved so far in the framework of the GUT study and in particular to introduce the first toolbox prototype as well as the complementary Tutorial Toolbox Description that can serve first pilot users as an instruction and that can help later software engineers to construct the toolbox subsequently in a user friendly manner.

GOCE User Toolbox Specification: Scientific trade off study and algorithm specification

Frank Siegismund[(1)], Helen Snaith[(2)] and Per Knudsen & the GUTS Team[(3)]

[(1)] *Nansen Environmental and Remote Sensing Center, Thormøhlensgate 47, N-5006 Bergen, Norway*
[(2)] *National Oceanography Centre, Southampton, 254/33 European Way, Southampton SO14 3ZH, UK*
[(3)] *Danish National Space Center, Juliane Maries Vej 30, DK-2100 København Ø, Denmark*

Abstract

As part of the GOCE User Toolbox Specification project (GUTS), the GUTS team will carry out a scientific trade-off study, to select the best algorithms to fulfil the user requirements for the toolbox. In some cases the selection is straightforward. However, in other cases, the choice will depend on scientific applications as well as the algorithm efficiency and more practical considerations. Studies need to be performed to demonstrate the best possible algorithm. Examples include the selection of filtering functions and the choice of interpolation schemes used in calculation of a mean dynamic topography from combined GOCE and satellite altimeter data. The trade-off study will also select the functionality of the toolbox, given the user requirements and the recommended algorithms. In this poster we will present the expected functionality of the toolbox, and the most important algorithm selections. As part of the scientific trade-off, a pilot application is investigating validation of mean dynamic topography, generated from pseudo observations using proposed toolbox algorithms, against ocean model data. The study will also include results from research into methods of calculation of mean dynamic topography and filtering methods presented at this workshop.

Session 12

GOCE Level 2 Data Processing

Status of the GOCE High-level Processing Facility (HPF)

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

[(1)] SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, Netherlands
[(2)] IAPG, Arcisstrasse 21, D-80333 Munchen, Germany

Abstract

This poster aims at presenting a detailed overview of the architecture of the HPF, as well as the status of its development and a look ahead to the operational phase.

In brief, the GOCE High-level Processing Facility (HPF) is the part of the GOCE Ground Segment which is dedicated to the scientific processing of the GOCE observations and the production of the final gravity field products provided to the end users. The HPF is currently in the final stage of its development. During and shortly after the operational phase of the GOCE mission the HPF will systematically produce GOCE level 2 end products such as orbits and gravity field models of different kinds, derived from the novel and highly precise GOCE gradiometry observations, GPS high-low satellite-to-satellite tracking data and additional measurements. Ten European university institutes and research facilities, having complementary expertise in gravity and geodesy related science fields, together have formed the European GOCE Gravity Consortium (EGG-C), which has been contracted by ESA to develop, implement and operate the HPF throughout the whole GOCE mission lifetime. The HPF is designed and developed with the capabilities to produce on a regular basis so-called quick-look or rapid products, that are mainly of interest for the GOCE performance monitoring, as well as final and precise products, representing the official ESA GOCE level 2 products that will become available to end-users. A unique feature of the HPF is that it will implement and operate three different gravity field analysis techniques in parallel, complemented with dedicated scientific pre-processing techniques and a thorough validation procedure for the derived gravity field models before the official ESA solution will be selected out of them. In this way (scientific) users of GOCE products (e.g. oceanographers, solid Earth scientists, geodesists and others) will benefit from the optimal exploitation of the GOCE data.

On the use of gridded data to estimate potential coefficients

Federica Migliaccio[(1)], Mirko Reguzzoni[(2)], Fernando Sansò[(3)] and Nikolaos Tselfes[(3)]

[(1)] Politecnico di Milano, Piazza Leonardo da Vinci, 32, 20133, Italy
[(2)] OGS - c/o Politecnico di Milano, Via Valleggio, 11, 22100 Como, Italy
[(3)] Politecnico di Milano, Via Valleggio, 11, 22100, Italy

Abstract

In the framework of the space-wise approach for the GOCE data analysis an intermediate step of prediction of functionals of the gravitational potential on a regular spherical grid has to be performed. The scope of this procedure is to filter the observations in a space-wise sense. The gridding procedure is made by collocation over local patches of observations, while a global collocation would be numerically unfeasible because of the large number of data. The gridded values are then used for the estimation of the spherical harmonic coefficients of the gravitational potential.

Once such a procedure is envisaged, several questions arise. Is there loss of information within this step-wise procedure, with respect to a direct collocation estimate of the coefficients from the original data? What should the size of the grid be and which intermediate functional should be predicted? What is the impact of the local application of collocation? These questions, connected to the concept of sufficient statistics, are studied. Some of them (the simplest ones) are answered from the theoretical point of view, while others are investigated numerically.

A realistic GOCE simulation scenario is also used for numerical tests, since the final scope is to identify the optimal procedure with respect to the space-wise approach performance. One of the results of these tests is that the error in the final estimate of the coefficients is almost invariant with respect to the choice of the intermediate functional. Moreover the specific features of the final coefficients estimation step, i.e. by collocation versus exact spherical Fourier analysis, are demonstrated and the results are discussed.

Investigation of Velocities derived from Satellite Positions

Helmut Goiginger[1] and Roland Pail[1]

[1] *Graz University of Technology, Steyrergasse 30, 8053 Graz, Austria*

Abstract

In the context of the analysis of the GOCE orbit data and the computation of the Earth's gravity field applying the energy integral approach, it is necessary to derive the velocities from the kinematic orbit positions of the satellite. Since the accuracy of the velocities is directly proportional to the accuracy of the satellite positions it is important to be aware of the behaviour of the differentiators. One of the main tasks is to investigate which differentiation method delivers appropriate ouput data. Furthermore the input parameter of several differentiation techniques play a key role in dependance on the resolution of the gravity field. In reality one always has to deal with noise on data which normally is not known until real data - in this case satellite positions - is available. Therefore, a noise has to be modelled and applied on the satellite positions to study the influence on the derived velocities. In this investigation two different numerical differentation strategies are compared and their impact on the gained gravity field model is analysed.

GOCE Quick-Look Gravity Field Analysis (QL-GFA) in the Framework of HPF

Roland Pail[1], Barbara Lackner[1], Bernhard Metzler[1], Thomas Preimesberger[1] and Martin Wermuth[2]

[1] *Graz University of Technology, Steyrergasse 30, 8010 Graz, Austria*
[2] *Technical University Munich, Arcisstrasse 21, 8033 Munich, Germany*

Abstract

The Quick-Look Gravity Field Analysis is a component of the Routine & Rapid Processing Facilities in the framework of the ESA-funded project “GOCE High-level Processing Facility”, an operational hardware and software system for the scientific processing (Level 1B to Level 2) of GOCE data, in order to derive a spherical harmonic Earth’s gravity field model from the precise GOCE orbit based on satellite-to-satellite tracking (SST) in high-low mode, and satellite gravity gradiometry (SGG) data.

The purpose of the QL-GFA is to analyze partial and/or incomplete sets of SGG and SST data, in order to derive a fast diagnosis of the GOCE system performance in parallel to the mission.

Key products of QL-GFA are: • Quick-look gravity field models (SGG only, SST only, combined SST+SGG): They are computed for a fast analysis of the information content of the input data on the level of the gravity field solution. • Estimates of the gradiometer error PSD (power spectral density): These are computed from the residuals of a SGG-only gravity field analysis. Previously defined statistical hypothesis test strategies in time and frequency domain are applied in order to answer the question whether the a priori gradiometer error model, and thus the stochastic model of the parameter adjustment, is realistic.

The poster gives an overview of the operational QL-GFA software system. On the basis of a realistic numerical case study, which is based on the data of an ESA GOCE end-to-end simulation, the key components of the QL-GFA processing architecture are addressed, and the information content of all relevant output products is presented and discussed.

Spherical Cap Regularization of GOCE normal equation systems

Bernhard Metzler[(1)] and Roland Pail[(1)]

[(1)] *Graz University of Technology, Steyrergasse 30, 8010 Graz, Austria*

Abstract

Due to the special configuration of the satellite orbit, the least-squares estimation of a gravity field model represented in spherical harmonic functions based on GOCE measurements is an ill-posed problem. Since the primary reason for the ill-posedness are the missing data on the poles, the spherical cap regularization approach has been introduced. In principle, a stabilizing function which is restricted to the regions where no measurements are available is used to stabilize the system.

Besides the regularization parameter that controls the power of the regularization the choice of an appropriate stabilizing function is essential. The better the stabilizing function fits the measurement data, the stronger the regularization can be applied without producing harmfuls effects. Too strong a regularization can lead to Gibbs phenomenon in the transition zone around 83.5° latitude where the measured data coincides with the stabilizing function.

The extent of the Gibbs phenomenon depends on the one hand on the power of the regularization and on the other hand on the differences between the stabilizing function and the measured data at 83.5° latitude. The larger the differences and the larger the regularization parameter, the larger the oszillations in the transition zone will be. In order to avoid the occurrance of this phenomenon several strategies have been investigated, that allow a smooth transition from the measured data to the introduced function. Consequently, a strong regularization is possible even with a function that does not fit the measurements perfectly.

Validation of GOCE Gravity Field Models

Thomas Gruber[(1)], Christian Ackermann[(1)], Martin Wermuth[(1)] and Pieter Visser[(2)]

[(1)] *Technical University Munich, Arcisstrasse 21, 80333 Muenchen, Germany*
[(2)] *Delft University of Technology, Kluyverweg 1, 2629 HS, Delft, Netherlands*

Abstract

The GOCE High-level Processing Facility (HPF) will systematically generate global gravity field models from GOCE data applying different approaches. In order to identify the best performing solutions and in order to determine the overall quality of the final solutions an extensive validation of these models is performed before they will be released to the users as final GOCE level 2 products. For this a separate processing chain has been set up inside the HPF. The following techniques are applied for estimating the quality of the gravity field models: Orbit computation performance; Comparison to external gravity field information like geoid heights at GPS-levelling points or gravity anomalies; Comparisons of errors to signals on coefficient and degree variances level; Error propagation of full variance-covariance matrix to geoid height errors. All results of these test procedures are finally collected in a report attached to the final products. The paper provides examples for the test procedures showing results for simulated solutions as well as GRACE gravity field models.

Data product validation by HPF's Central Processing Facility

Sander de Witte[1], Richard Van Hees[1], Sietse Rispens[1] and Radboud Koop[1]

[1] *SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, Netherlands*

Abstract

The High-level Processing Facility (HPF) is part of the GOCE Ground Segment and is developed under ESA contract by the European GOCE Gravity consortium (EGG-c). The HPF is set up as a distributed facility consisting of several sub-processing centers for scientific pre-processing, orbit determination, gravity field analysis and validation. The sub-processing facilities are connected through a kind of internal HPF-network through a central node which is called the Central Processing Facility (CPF). This CPF is the single point of interface between HPF and ESA's Ground Segment (for the latter this is the Payload Data Center (PDS)). The tasks of the CPF are: to collect all data necessary for high-level processing, this includes Level 1b data products from the PDS and auxiliary data products from external data providers; to convert these input data to a dedicated internal HPF format; to distribute these data, and Level 2 intermediate and final products, within the HPF using a full-fledged data base facility; to formally check all L2 products on format, validity and content; to monitor the whole data distribution chain; and to distribute all L2 data to ESA for storage and archiving and use by end users. This poster will illustrate the design and operation of the CPF in its HPF context and indicate the specific monitoring, validation and control activities the CPF performs to support the quality of the final data products.

GOCE Rapid Science Orbit Determination

Jose Van Den IJssel[1], Pieter Visser[1] and Tom Van Helleputte[1]

[1] *Delft University of Technology, Kluyverweg 1, 2629 HS Delft, Netherlands*

Abstract

For the GOCE satellite a Rapid Science Orbit (RSO) chain will be implemented to produce daily orbits with a 1-day latency and an accuracy of better than 50 cm, in order to support satellite operations. The RSO will be used as input for external calibration and geodetic pre-processing of the gradiometer data and for quick-look gravity field modeling.

The RSO chain provides as a baseline two orbit products, a reduced-dynamic and a kinematic solution. The reduced-dynamic solution is computed using the NASA/GSFC Geodyn s/w package and is based on a triple differenced approach, using ionospheric-free GPS phase measurements along with rapid GPS orbits computed by the International GNSS Service. The kinematic RSO solution is computed using the DLR GHOST s/w package, and is based on a zero differenced approach, using rapid GPS orbits and 30-seconds clocks computed by the Center for Orbit Determination in Europe. Both POD strategies have been extensively tested with CHAMP and GRACE data and have shown good performance.

In this paper a detailed overview will be given of both RSO POD strategies, showing results obtained with simulated GOCE receiver data. Special attention will be given to modifications that have been made for the GOCE mission, like e.g. the handling of the clock behaviour of the GOCE GPS receiver, which might show large drifts. In addition, a phase unwrapping procedure needs to be applied to the GPS observables. Finally, the reduced-dynamic POD has been tuned to take into account the anticipated behaviour of the drag-free system.

Generation and Validation of Orbit Products for the GOCE Mission

Drazen Svehla[(1)]

[(1)] *Technical University Munich, Arcisstrasse 21, 80333 Munich, Germany*

Abstract

The ESA GOCE Core Explorer Mission will be equipped with a dual-frequency GPS receiver for precise orbit determination and with a SLR reflector for orbit validation. The final GOCE orbit will be jointly computed by the AIUB in Bern and the IAPG at the TU München on a daily routine basis as an integrated part of the GOCE High-Level Processing Facility (HPF). In addition, the IAPG is responsible for the re-processing of the final kinematic and reduced-dynamic GOCE orbit.

We perform the generation and validation of the orbit products including the final GOCE precise kinematic orbit with the variance-covariance matrix and the GOCE precise reduced-dynamic orbits. Both types of orbits will be accompanied with the quality information and orbit validation reports including performance of the GOCE GPS receiver. We present an algorithm to compute the variance-covariance information for the GOCE kinematic orbit and the way by which it is defined as a product. In order to provide information about the Earth rotation and transformation between the Earth-fixed and inertial system we present the algorithm and the use of the Earth orientation quaternions. Finally, we address the role and present the chain for reprocessing the final GOCE kinematic and reduced-dynamic orbits. We give an overview of various orbit determination strategies developed for the GOCE mission starting from the purely kinematic, reduced-kinematic, reduced-dynamic to fully dynamic methods based on numerical integration.

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The GOCE Mission: Operational Support Facilities

GOCE Reference Planning Facility (RPF)

Jose Antonio Gonzalez Abeytua[1] and Patricia Talaverano[1]

[1] *DEIMOS Space, Ronda de Poniente, 19. Edificio Fiteni VI,Portal2, 28760 Tres Cantos, Spain*

Abstract

The RPF is a tool in charge of generating inputs for mission planning to the FOS and/or PDS. The RPF will generate, on operator request, mission-planning data in the form of computer files using inputs received from the CMF and the Mission Management.

RPF generated files are stored under configuration and control in the RPF storage area and transferred to the FOS or the PDS through a computer network using the FTP protocol.

The RPF will retrieve calibration data from the CMF to be used as input for the generation of mission planning files and it plays an essential role in the planning of the DFACS Data Recording.

The RPF consists of a combination of a system infrastructure and specific functions. The infrastructure was built from the CryoSat Reference Planning Facility, by extracting all the common elements and creating an RPF core mission independent. This core is the first step towards a truly Multi-Mission Reference Planning Facility.

GOCE Performance Monitoring Facility (PMF)

Jose Antonio Gonzalez Abeytua[1], Diego Lozano[1] and Borja Lopez[1]

[1] *DEIMOS Space, Ronda de Poniente,19. Edificio Fiteni VI, Portal 2, 28760 Tres Cantos, Spain*

Abstract

The PMF is the facility responsible for monitoring the performances of the GOCE GS Facilities. It detects anomalies in the instrument processors, product archiving, and product dissemination. It monitors the product generation dataflow from the acquisition to the processing and to the dissemination to the user services. To do this, it gets the input and output data from the GS facilities. It calculates the expected outputs according to a model of each facility and compares them to the actual outputs for obtaining the deviation (anomalies).

The PMF will always provide clear performance measures against a given baseline (i.e. verifying the real production against the mission plan). Based on the detection of anomalies, the PMF will raise anomalies to inform about the detected problem, publishing dedicated reports via Web or e-mail. The Gantt-tool can also be used to visualise the problems.

The PMF is developed fully using QUARC capabilities.

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