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ORIGINAL ARTICLE

The GeoForschungsZentrum Potsdam/Groupe de Recherche de Gèodésie Spatiale satellite-only and combined gravity field models: EIGEN-GL04S1 and EIGEN-GL04C

Christoph Förste · Roland Schmidt · Richard Stubenvoll · Frank Flechtner · Ulrich Meyer · Rolf König · Hans Neumayer · Richard Biancale · Jean-Michel Lemoine · Sean Bruinsma · Sylvain Loyer · Franz Barthelmes · Saskia Esselborn

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Abstract The recent improvements in the Gravity Recovery And Climate Experiment (GRACE) tracking data processing at GeoForschungsZentrum Potsdam (GFZ) and Groupe de Recherche de Géodésie Spatiale (GRGS) Toulouse, the availability of newer surface gravity data sets in the Arctic, Antarctica and North-America, and the availability of a new mean sea surface height model from altimetry processing at GFZ gave rise to the generation of two new global gravity field models. The first, EIGEN-GL04S1, a satellite-only model complete to degree and order 150 in terms of spherical harmonics, was derived by combination of the latest GFZ Potsdam GRACE-only (EIGEN-GRACE04S) and GRGS Toulouse GRACE/LAGEOS (EIGEN-GL04S) mean field solutions. The second, EIGEN-GL04S1 was combined with surface gravity data from altimetry over the oceans and gravimetry over the continents to derive a new high-resolution global gravity field model called EIGEN-GL04C. This model is complete to degree and order 360 and thus resolves geoid and gravity anomalies at half-wavelengths of 55 km at the equator. A degree-dependent combination method has been applied in order to preserve the high accuracy from the GRACE satellite data in the lower frequency band of the geopotential and to form a smooth transition to the high-frequency information coming from the surface data. Compared to pre-CHAMP global high-resolution models, the accuracy was improved at a spatial resolution of 200 km (half-wavelength) by one order of magnitude to 3 cm in terms of geoid heights. The accuracy of this model

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C. Förste (✉) · R. Schmidt · R. Stubenvoll · F. Barthelmes · S. Esselborn
GeoForschungsZentrum Potsdam (GFZ), Department 1 ‘Geodesy and Remote Sensing’, Telegrafenberg A17, 14473 Potsdam, Germany
e-mail: foer@gfz-potsdam.de

R. Schmidt
e-mail: rschmidt@gfz-potsdam.de

F. Barthelmes
e-mail: bar@gfz-potsdam.de

S. Esselborn
e-mail: essel@gfz-potsdam.de

F. Flechtner · U. Meyer · R. König · H. Neumayer
Department 1 ‘Geodesy and Remote Sensing’, GeoForschungsZentrum Potsdam (GFZ), c/o DLR Oberpfaffenhofen, 82234 Weßling, Germany
e-mail: flechtne@gfz-potsdam.de

U. Meyer
e-mail: meyeru@gfz-potsdam.de

R. König
e-mail: koenigr@gfz-potsdam.de

H. Neumayer
e-mail: neumayer@gfz-potsdam.de

R. Biancale · J.-M. Lemoine · S. Bruinsma · S. Loyer
Groupe de Recherche de Géodésie Spatiale (GRGS), 18 Avenue Edouard Belin, 31401 Toulouse, France
e-mail: richard.biancale@cnes.fr

J.-M. Lemoine
e-mail: jean-michel.lemoine@cnes.fr

S. Bruinsma
e-mail: sean.bruinsma@cnes.fr

S. Loyer
Collecte Localisation Satellites (CLS), 8-10 rue Hermès, 31520 Ramonville Saint-Agne, France
e-mail: sylvain.loyer@cls.fr

(i.e. the commission error) at its full spatial resolution is estimated to be 15 cm. The model shows a reduced artificial meridional striping and an increased correlation of EIGEN-GL04C-derived geostrophic meridional currents with World Ocean Atlas 2001 (WOA01) data. These improvements have led to select EIGEN-GL04C for JASON-1 satellite altimeter data reprocessing.

Keywords Earth gravity field model · Global gravity field recovery · GRACE · LAGEOS · Surface gravity data

1 Introduction

High-resolution global gravity field models can be inferred from satellite tracking measurements and surface gravity data (e.g. Lemoine et al. 1998 or Gruber et al. 2000a). In the past, data from a large number of satellites, at different altitudes and inclinations, had to be processed in order to generate the so-called satellite-only solutions (e.g. Reigber et al. 2005), but the twin-satellite mission Gravity Recovery and Climate Experiment (GRACE; Tapley et al. 2004) with its objective to map the global gravity field of the Earth on a monthly basis made a compilation from satellite ensembles superfluous.

The GRACE satellites, jointly managed by National Aeronautics and Space Administration (NASA) and Deutsches Zentrum für Luft- und Raumfahrt (DLR) were launched on March 17, 2002 in a near-circular orbit at about 500 km altitude. They are separated from each other by approximately 220 km along-track, and this distance and its rate of change are measured using a K-band microwave ranging system. Furthermore, the science payload of each satellite consists of a Global Positioning System (GPS) receiver, laser retro-reflector, star sensors, and a high precision three-axis accelerometer. Gravity field models derived from the GRACE mission and the precursory CHAMP mission are much more accurate than any other precursor satellite-only model derived from dozens of spacecraft and analyzing tracking data from more than 10 years (e.g. Reigber et al. 2003b), except for the very-low degrees, especially for C_{20} (e.g. Eanes et al. 2005; Biancale et al. 2004). Thus, additional LAGEOS data should be used in order to estimate C_{20} accurately.

Since the launch of GRACE, a number of satellite-only gravity field models from different Analysis Centers have become available. They all claim to resolve the geoid with an accuracy of 1 cm for half-wavelengths down to approximately 270 km (e.g. EIGEN-GRACE02S, Reigber et al. 2005; GGM02S, Tapley et al. 2005; ITG-GRACE02s, Mayer-Gürr et al. 2006). This is an accuracy improvement of more than two orders of magnitude compared to the latest pre-CHAMP satellite-only model GRIM5-S1 (Biancale et al. 2000). The most recent European Improved Gravity model of the Earth by New techniques (EIGEN) models generated at the GeoForschungsZentrum Potsdam (GFZ) and the Groupe de Recherche de Géodésie Spatiale Toulouse (GRGS) are EIGEN-GRACE04S (an update of EIGEN-GRACE02S; Schmidt et al. 2007) and EIGEN-GL04S (Lemoine et al. 2007). The EIGEN as well as the preceding GRIM (GRGS and German geodetic research Institute Munich) gravity field solutions were produced jointly by GFZ Potsdam (resp. the earlier GRIM-models by DGFI Munich = Deutsches Geodätisches Forschungsinstitut) and GRGS Toulouse. Both groups operate equivalent and harmonized data reduction software packages, called Earth Parameter and Orbit System (EPOS, e.g. Schmidt 2007), and Géodésie par Intégrations Numériques Simultanées (GINS, e.g. Schwintzer et al. 1991), allowing a shared data processing at the level of normal equations. The dynamic approach based on the analysis of orbit perturbations (e.g. Reigber 1989) is used in the processing of GRACE and LAGEOS observations. In this way the long- to medium-wavelength features of the Earth's gravity field are derived from GRACE satellite data, whereas the shorter wavelengths must be inferred from surface gravity data. These data, compiled from satellite altimetry, ship- and airborne gravimetry over the oceans, and airborne and terrestrial gravimetry over land, provide—except for Antarctica—an almost complete global coverage if condensed to block mean values of a regular equal-angular $30' \times 30'$ grid. Due to inconsistencies between the various data sets (e.g. in the vertical datum, see Heck 1990), and accuracies varying regionally, the surface data do not contain precise long- to medium-wavelength gravity information. However, if properly combined with satellite-only gravity field models (on the basis of normal equations), the resolution of the global model can be extended down to 55 km half-wavelength. Such a combination, based on the pre-CHAMP satellite-only model EGM96S, resulted in the broadly used model EGM96 (Lemoine et al. 1998).

In this paper, a new GRACE- and LAGEOS-based satellite-only model (EIGEN-GL04S1), and a new high-resolution combination gravity field model (EIGEN-GL04C) are presented. The latter model, when compared to EGM96 and GGM02C (Tapley et al. 2005), benefits in its long- to medium-wavelength part from the unprecedented performance and improved processing of the GRACE data, whereas at higher frequencies it is slightly more accurate thanks to the assimilation of a more complete and updated surface data compilation.

Section 2 depicts the processing of the satellite tracking data and the satellite-only model, whereas Sect. 3 describes the preparation and processing of the surface gravity data. The combination solution strategy and the resulting EIGEN-GL04C model are described in Sect. 4, followed by a section concerning the model evaluation.