Deutsches Geodätisches Forschungsinstitut

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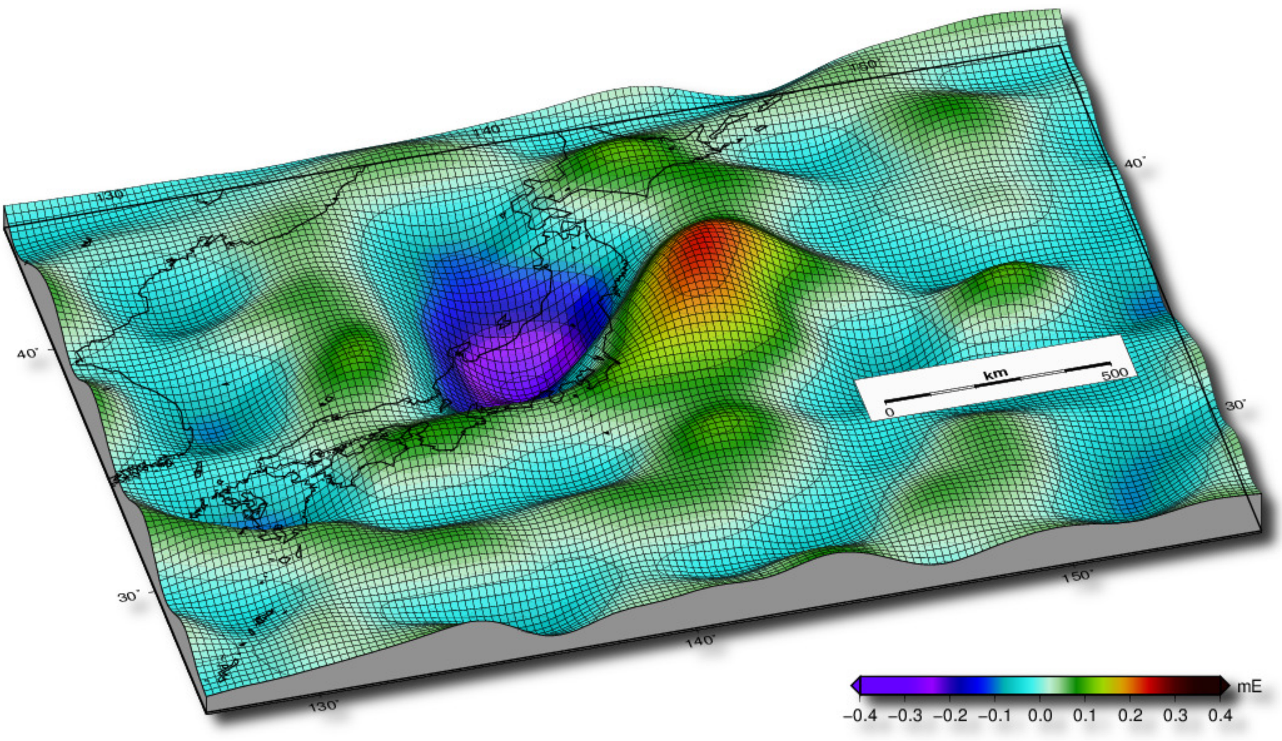

The Japan Tohoku-Oki earthquake occurred on March 11, 2011. The release of stress that had accumulated over hundreds of years left characteristic signatures in the Earth's gravity field. A combination of GRACE and GOCE information mapped this megathrust event with unprecedented accuracy. The figure shows the change in the vertical gravity gradient at GOCE orbital height. It can be related to the subsidence and the uplift of the Pacific and Eurasian plate, respectively.

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The Institute

60 years of geodetic research at DGFI

In 2012, DGFI celebrated the 60th anniversary of its foundation. The institute was established in 1952 based on a decision of the German Geodetic Commission (DGK) at the Bavarian Academy of Sciences (BAdW) in Munich. Since many years the institute has been fully funded by the Free State of Bavaria, it is nowadays affiliated to the section Erdmessung of DGK and regularly supervised by an international scientific council. DGFI acts as an autonomous research institute and has taken over various functions in international scientific bodies.

During the past decades the institute has performed notable and internationally recognised basic geodetic research, and today DGFI is a well-known acronym in the geoscientific community all over the world. During the first decades after the foundation of DGFI, outstanding results were achieved particularly in the fields of geodetic-astronomical observations and electro-optical distance measurements for the determination of the German and European triangulation as well as in gravimetric surveys for gravity networks. DGFI was involved in the first worldwide network of satellite triangulation and played an important role in the development of dynamical methods of satellite geodesy for precise orbit determination, point positioning and gravity field modelling. A key aspect of DGFI's research has always been the realisation of global and regional horizontal and vertical terrestrial reference systems and of the celestial reference system. Today, DGFI possesses unique competence on several research fields (e.g., the realisation of reference systems or satellite altimetry) and is internationally among the leading institutions in gravity field modelling and geodetic Earth system research.

DGFI has continuously been involved in various national and international activities and delivers indispensable contributions. Intensive collaborations exist predominantly in the frame of the international scientific organisations IUGG (International Union of Geodesy and Geophysics) and IAG (International Association of Geodesy). DGFI recognises the outstanding role of the IAG services for science and practice, and co-operates in these services as data, analysis and research centre. Scientists of DGFI have taken leading positions and supporting functions in IAG's Commissions, Services, Projects, Working and Study Groups, and in the Global Geodetic Observing System (GGOS). Furthermore, DGFI staff is prominently involved in the management of international scientific organisations, e.g., in the European Geosciences Union (EGU) and in the International Astronomical Union (IAU). DGFI also participates in research programmes and bodies of the European Union (EU) and the European Space Agency (ESA). It co-operates in several United Nations' (UN) and intergovernmental institutions and activities. On national level, DGFI has been a member of the Forschungsgruppe Satellitengeodäsie (FGS) since many years. The FGS is a follow-on co-operation of the former DFG-Sonderforschungsbereich SFB 78, closely affiliated with the Geodetic Observatory Wettzell in the Bavarian Forest. In the frame of FGS, DGFI is co-operating with the TU München (Institut für Astronomische und Physikalische Geodäsie [IAPG], Forschungseinrichtung Satellitengeodäsie [FESG]), the Bundesamt für Kartographie und Geodäsie, Frankfurt/Main (BKG) and the Institut für Geodäsie und Geoinformation of the University of Bonn (IGG).

Special occasions in 2012

On the occasion of its 60th anniversary DGFI organised a colloquium at the BAdW on June 25, 2012. The topic was "From Triangulation to Geodetic Earth System Research". During the first part of the celebration former institute directors commemorated the development of DGFI over the last six decades and recalled the most important milestones. Afterwards current employees presented recent scientific activities in four presentations on global and regional reference frames, gravity field research, ionosphere modelling, and satellite altimetry. The celebration ended with a festive banquet in the rooms of the BAdW. The colloquium provided a good opportunity for DGFI to present itself to the geodetic community and the public. The successful celebration was acknowledged with very positive resonance.

Fig. 1: *Poster of the 60th anniversary*

A very important date for the institute was the visit of a board of referees in the frame of the evaluation StrukBY in May 2012, performed on behalf of the Bavarian State Ministry of Sciences, Research and the Arts (StMWFK). All employees of DGFI were involved in the preparations of the evaluation and in conversations during the visit. In several discussions on different levels (directorate, scientists, doctoral candidates, co-operation partners) the structure and the research activities of DGFI were presented and evaluated. Also national and international collaborations were discussed.

DGFI – a member of the CGE

Since the year 2010, DGFI is connected with IAPG, FESG, and the section "Erdmessung" of BAdW's Kommission für Erdmessung und Glaziologie (KEG) in the frame of the Centre of Geodetic Earth System Research (CGE). Since 2011 the institutions of CGE work together according to a joint research and development programme, guided by the vision that geodesy can provide a high-precision, consistent and long-term valid metric for Earth system sciences.

The CGE programme is organised into the research areas (1) Geometric Techniques, (2) Gravity Field, (3) Geodetic Earth System Modelling, (4) Methodological Foundations and (5) New Technologies. Research activities within CGE are coordinated by scientists of the contributing partners. In 2012 the research and development programme was realised by scientific collaborations across the institutions, joint proposals for third-party funded projects have been submitted and future work and co-operations were discussed on a two-day retreat. Already within the first years of its existence, CGE has reached good visibility on national and international level.

Beside the work under the joint research and development programme, the co-operation between DGFI and TU München has been intensified in 2012 through the joint appointment of Prof. Dr.-Ing. Florian Seitz as the new director of DGFI in August 2012. At the same time he was appointed professor for TUM's newly established Chair of Geodetic Geodynamics where he is involved in teaching in the field of Earth system dynamics. Besides, also several other scientists of DGFI are involved in teaching at the TUM. In total, DGFI staff contributes 15 weekly hours to different study programmes. Especially, DGFI is deeply involved in the international master's course M.Sc. ESPACE (Earth Oriented Space Science and Technology). For his engagement in the education of students in the programmes M.Sc. ESPACE and M.Sc. Geodesy and Geoinformation over many years, Dr.-Ing. habil. Michael Schmidt was appointed extracurricular professor (apl. Prof.) of the TUM in March 2012.

DGFI research programme

The scientific activities of DGFI are oriented towards basic geodetic research. They are embedded in the overall topic "Geodetic Earth System Research" of the CGE. The research areas of DGFI according to its current research programme are consistent with the research areas (1) to (4) of the CGE programme:

1. Geometric Techniques
2. Gravity Field
3. Geodetic Earth System Modelling
4. Methodological Foundations

The DGFI research programme has been set up for the period 2011–2014 and was evaluated and approved by an international scientific council (Wissenschaftlicher Beirat) in November 2010.

Dynamic processes and interactions within and between individual components of the Earth system (e.g., atmosphere, hydrosphere, solid Earth) map into temporal variations of geodetic parameters that describe the rotation, the gravity field and the surface geometry of the Earth. Thus, the analysis of time series resulting from the analysis and combination of geodetic observations delivers important information and contributes to Earth system research. On the one side, geodetic research at DGFI aims at a further improvement of accuracy and consistency of geodetic parameters related to the Earth's geometry (research area 1) and its gravity field (research area 2). This work is related to and benefits strongly from DGFI's activities in international services. On the other side, DGFI aims at the interpretation of geodetic parameters and their application in Earth system research in interdisciplinary co-operations. Accordingly, research area 3 is dedicated to geodetic contributions to Earth system science. One of the main tasks in research area 3 is the application of geodetic data in order to enhance the understanding of dynamical processes in the Earth system and to develop and improve respective empirical and physical models. In particular, the data analysed and provided by DGFI (which is to a very large extent based on global satellite observations) contributes information about those components of the Earth system in which processes are acting on large spatial scales. The geodetic observations allow for conclusions with respect to large-scale mass redistributions and exchange processes of angular momentum that involve temporal changes of gravity field, surface geometry and rotation of the Earth. Furthermore, by suitable combination of observation techniques with different sensitivity for different processes and numerical models DGFI aims at the separation of integral parameters into contributions of individual system components and underlying dynamical processes. Finally, the cross-cutting research area 4 provides methodological foundations and support to the other research areas by the development and provision of tools, common standards and the necessary infrastructure.

1 Geometric Techniques

The space geodetic observation techniques Very Long Baseline Interferometry (VLBI), Satellite and Lunar Laser Ranging (SLR/LLR), Global Navigation Satellite Systems (GNSS) with the techniques GPS, GLONASS and in future Galileo, Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) as well as satellite altimetry provide the data basis for the work within this research field. These observation techniques allow a highly precise and continuous determination of the figure of the Earth and its orientation in space along with their temporal variations.

This research field is primarily concerned with the analysis and combination of the space geodetic observations mentioned above in order to determine geometric parameters describing the shape and orientation of the Earth as well as the low degree spherical harmonic coefficients of the Earth's gravity field.. The tasks cover the full processing chain from the original observations to the generation of geodetic results and products. They are divided into four major themes:

1.1 Observation systems, data acquisition and provision
1.2 Model development and analysis of the space geodetic observations
1.3 Analysis and refinement of combination methods
1.4 Computation of global and regional reference frames

The work in this research field benefits from a significant engagement of the DGFI in international scientific services of the International Association of Geodesy (IAG). The institute operates - mostly by long-term commitments - data centres, analysis centres, and combination centres and takes over various responsibilities and functions. The following activities are closely related to the research field "Geometric Techniques":

- *IGS Regional Network Associate Analysis Centre for SIRGAS (RNAAC-SIR)*
- *IGS Tide Gauge Benchmark Monitoring Analysis Centre (TIGA)*
- *IGS Antenna Working Group (Chair)*
- *ILRS Data and Operations Centre*
- *ILRS Analysis Centre*
- *IVS Analysis Centre*
- *IVS Combination Centre (jointly with BKG, Frankfurt/Main)*
- *ITRS Combination Centre within the International Earth Rotation and Reference Systems Service (IERS)*
- *Joint IAG Commission 1/IERS Working Group "Strategies for epoch reference frames" (Chair)*
- *IERS Working Group on Combination at the Observation Level (Co-chair)*

The scientific outcome of these international service activities enters directly into the basic research and there is a close link between DGFI's investigations and the activities within the services. Moreover, the participation in the IAG Services ensures the direct access to the original data of the space geodetic techniques and to the products generated by the scientific services. This is on the one hand of great benefit for the research activities in this field, and on the other hand the basic research performed at the institute ensures a high-quality generation of products. Thus, the engagement in the IAG Services is a backbone of this research field.

1.1 Observation systems, data acquisition and provision

DGFI has installed and operates about 15 GNSS stations in various regions of the world. The data of these stations are archived at DGFI and distributed to the processing centres. Within the European

Union's initiative (INTERREG III) Alpine Space Project (ALPS-GPS QUAKENET), DGFI has installed and operates five permanent GNSS stations. Although the project ended in 2007, the operation of these stations in the German part of the Alps is continued by DGFI. The other stations operated by DGFI (mostly in cooperation with local institutions) contribute to various international projects, such as the IGS Tide Gauge Monitoring (TIGA) and the regional densification of the ITRF, the Latin American reference frame, SIRGAS (see Sect. 1.4), for which DGFI also acts as a Regional Data Centre. Within the International Laser Ranging Service (ILRS), the institute took over the responsibility as a Global Data Centre and as an Operations Centre (see below).

ILRS Global Data and Operations Centre

Since the foundation of the International Laser Ranging Service (ILRS) in 1998, the EUROLAS Data Center (EDC) acts as one of two global ILRS data centres, the EDC at DGFI and the Crustal Dynamics Data Information System (CDDIS) at NASA.

In 2009, the EDC became an ILRS Operations Centre (OC) after the implementation of the so-called Consolidated Ranging Data (CRD) format. The OC has the function to ensure a correct conversion between the old CSTG format and the new CRD format. The final transition to the new CRD format (as the only official format of the ILRS) took place at May 2, 2012.

The EDC is running several mail exploders for the exchange of information, data and results within the ILRS. The Consolidated Prediction Format (CPF) files (36535 in 2012) of 71 satellites are exploded automatically on a daily and sub-daily basis and stored at the FTP server (ftp://edc.dgfi.badw.de). The following mailing lists are maintained by the EDC:

- SLR-Mail (99 messages in 2012)
- SLR-Report (1394 messages in 2012)
- Urgent-Mail (47 messages in 2012)
- Rapid-Service-Mail (27 messages in 2012)

In 2012, 36 SLR stations observed 70 satellites. There were 9 new satellite missions tracked by the SLR stations, namely Compass-G1, Compass-I3, Compass-I4, Compass-I5, Compass-M3, Galileo-103, Galileo-104, GLONASS-127, Lares, and ZY-3.

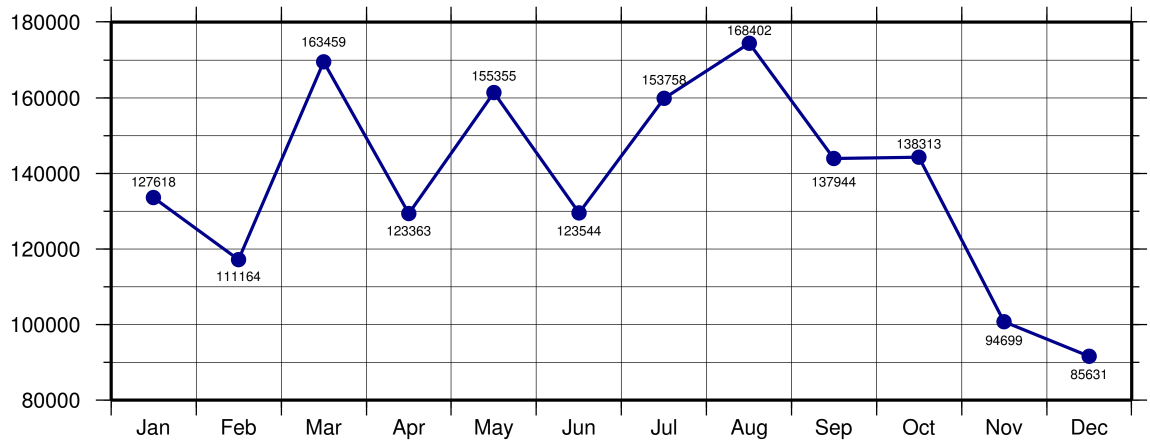

Fig. 1.1: *The blue line represents the number of monthly valid normal points in CRD format.*

1.2 Model development and analysis of the space geodetic observations

DGFI took over long-term commitments in its function as an Analysis Centre within the International Laser Ranging Service (ILRS) and the International VLBI Service for Geodesy and Astrometry (IVS). These responsibilities require a continuous analysis of SLR and VLBI data and the timely generation of geodetic products for these two services on a regular basis (e.g., daily or weekly). The obtained observation and parameter time series serve also as the basis for various research activities at DGFI, e.g., the combination of space geodetic observations (see Sect. 1.3) and the computation of geodetic reference frames (see Sect. 1.4). The activities also include a regular update of the software packages (DOGS-OC for SLR; DOGS-RI for VLBI) according to the processing standards specified by the ILRS and IVS and to the latest version of the IERS Conventions. Two highlights in 2012 were a) the computation of DGFI's first SLR multi-satellite solution (including 10 satellites with different altitude and inclination) and b) the progress concerning the harmonization and calibration of satellite altimetry data from various missions (see below).

The work within this theme was supported by two scientists funded by the International Bureau of the Federal Ministry of Education and Research (IB-BMBF) for a Chilean and German cooperation project from November 2010 until October 2012. Major tasks were the transfer of technology and the provision of software (including manuals and documentation) and experience for the processing of SLR and VLBI observations. The primary goal of the project was to enable the University of Concepcion (Chile) to analyse SLR and VLBI observations and to combine these results with GPS observations, which are analysed at the Instituto Geografico Militar (IGM) in Santiago de Chile.

SLR multi-satellite solution

Satellite Laser Ranging (SLR) is the only technique to determine station coordinates, Earth orientation parameters (EOP) and Stokes coefficients of the Earth's gravity field in one common adjustment. Recent software improvements of DOGS (see Sect. 4.4) allow to include beside the satellites LAGEOS 1/2 and ETALON 1/2 (ILRS standard solution) also LRA (laser retroreflector array) equipped satellites with an altitude below 2000 km such as STARLETTE, STELLA, AJISAI, LARETS, LARES and BLITS. All satellites included in the multi-satellite solution are shown in Fig. 1.2. Their satellite- and orbit-specific parameters are summarized in Tab. 1.1.

Table 1.1: *Satellite- and orbit-specific parameters of the ten considered spherical satellites. AMR is the abbreviation for area-to-mass ratio.*

satellite	mass [kg]	diameter [m]	AMR [m^2/kg]	altitude [km]	inclination [deg]	rev.-period [h]
LAGEOS 1	406.97	0.600	$6.947 \cdot 10^{-4}$	5850	109.90	3.76
LAGEOS 2	405.38	0.600	$6.975 \cdot 10^{-4}$	5625	52.70	3.76
ETALON 1	1415.00	1.294	$0.294 \cdot 10^{-4}$	19105	65.00	11.26
ETALON 2	1415.00	1.294	$9.294 \cdot 10^{-4}$	19135	64.40	11.26
STARLETTE	47.30	0.240	$9.564 \cdot 10^{-4}$	815	49.80	1.74
STELLA	47.00	0.240	$9.625 \cdot 10^{-4}$	800	98.60	1.69
AJISAI	685.00	2.150	$53.000 \cdot 10^{-4}$	1485	50.00	1.93
LARETS	23.28	0.210	$14.880 \cdot 10^{-4}$	691	98.20	1.64
LARES	386.80	0.364	$2.690 \cdot 10^{-4}$	1450	69.50	1.91
BLITS	7.53	0.170	$30.140 \cdot 10^{-4}$	832	98.77	1.68

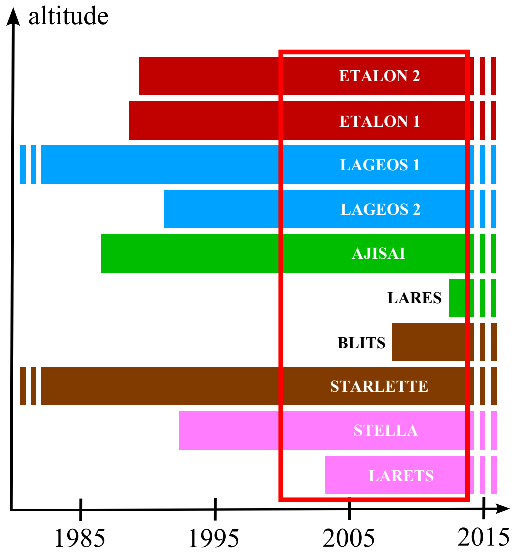

Fig. 1.2: Mission duration of the ten considered satellites. The red box shows the combination interval between 2000.0 and 2012.5.

The benefit of combining different satellites with different orbit characteristics (e.g., inclination, altitude) is a decorrelation of orbit and gravity field parameters and a stabilization of the SLR solution. Due to the inclusion of some satellites with low altitude the sensitivity for the estimated gravity field coefficients increases in the combined solution.

The satellites are combined on the level of normal equations (NEQs), and a variance component estimation (VCE) is used for the relative weighting of the NEQs. Besides the station coordinates, also the terrestrial pole coordinates, ΔUT1 and the Stokes coefficients up to degree six are estimated on a weekly basis. The differences between the obtained gravity field solutions and the EIGEN-6S model are displayed together with the geographic location of the processed observations exemplarily for GPS week 1542 in Fig. 1.3. The differences of the geoid heights are always below 1 cm. At maximum, geoid height differences of 6 cm occur in GPS week 1296 with poor SLR data coverage.

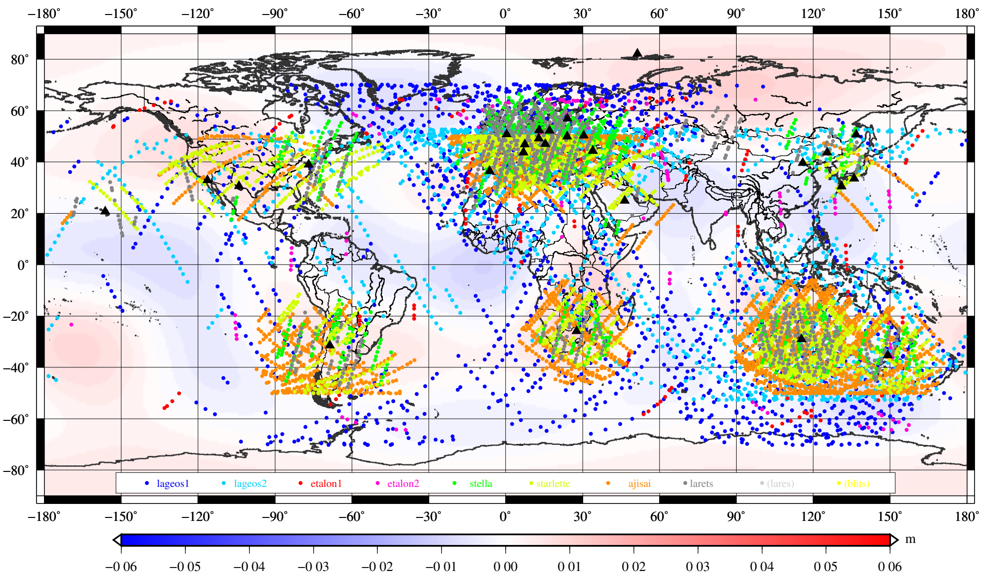

Fig. 1.3: SLR gravity field (GPS week 1542) w.r.t. the EIGEN-6S model. Both gravity fields are evaluated up to degree/order six. The geoid height differences are below 1 cm for this weekly solution. Additionally, the geographic location of the observations (coloured dots) and the observing stations (black triangles) are displayed.

Harmonization and calibration of satellite altimeter measurements

The combination of different altimeter missions is necessary in order to perform sea level mapping and modelling with high spatial and temporal resolution. At DGFI, this combination is done by a multi-mission cross-calibration (MMXO) allowing to correct for radial errors of single missions and to extract information on sea level variations which are based on multi-mission altimetry.

In order to ensure a precise and up-to-date database it is necessary to include current mission data on a regular basis as well as to update the used models and corrections. In 2012, the Jason-1 satellite was shifted to a new orbit with a very long repeat track cycle of about 168 days (GM – geodetic mission phase) and Envisat was decommissioned. For Jason-2, we could integrate reprocessed Jason-2 data (GDR-D – Geophysical Data Record, version D) and Cryosat-2 data from ESA were switched from Baseline A to Baseline B data. In addition we included new orbits for the ESA missions ERS-1, ERS-2, and Envisat which have been computed by GFZ within the ESA-funded Sea Level Project of the ESA Climate Change Initiative (SLCCI)[1].

Quality assessment of SLCCI orbits for ERS and Envisat

An analysis of MMXO results is able to reveal inconsistencies of data from different altimeter missions and can be used to get an impression of the data quality. We used this method to investigate the quality of different SLCCI orbit solutions for ERS-1, ERS-2, and Envisat which have been provided by GFZ. The solutions mainly vary in the consideration of time variable gravity effects. We computed radial errors for all three missions using all orbit solutions, as well as geographically correlated error (GCE) patterns and differences in the centre-of-origin realization (with respect to TOPEX and Jason-1, respectively).

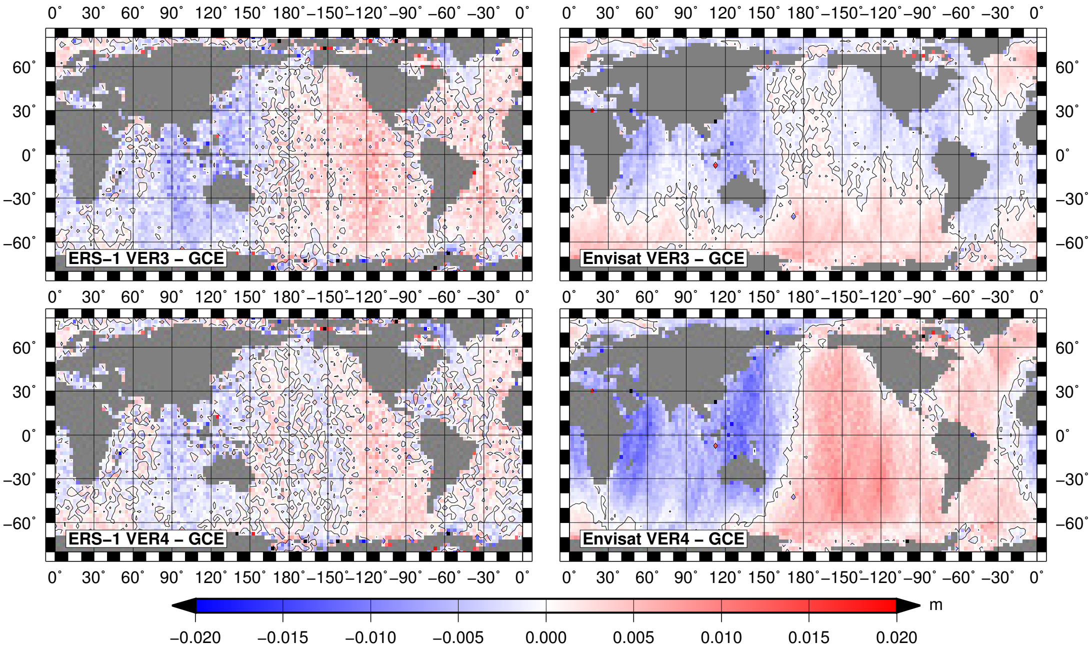

Fig. 1.4: *Geographically correlated errors for ERS-1 (left) and Envisat (right) based on two different orbit solutions: VER3 (top) with time variable gravity and VER4 (bottom) with static gravity field, both EIGEN-6S.*

Our investigations clearly show the impact of using different solutions for the time variable gravity field. If no drift terms for geopotential coefficients are used (VER4), the orbits show significant differences in the y-component of the centre-of-origin realization leading to an East-West pattern in geographically correlated errors and to East-West differences in regional sea level trends, mainly for time periods after 2008, i.e. for Envisat. This can be seen in the lower right plot of Fig. 1.4. ERS-1 GCE shows no East-West pattern for this orbit solution (lower left plot). On the contrary, using drift terms (VER3) yields better results for current time periods (thus for Envisat) but performs worse for time periods before 1998 (ERS) as can be seen in the upper plots of Fig. 1.4. It seems that the drift terms of the EIGEN-6S geopotential coefficients determined from GRACE covering the time interval 2003-2008 should not be used for POD before or after that time interval (e.g., for ERS-1).

[1]For more information see "Influence of time varying geopotential models and ITRF realizations on precise orbits of altimetry satellites and derived mean sea level" by S. Rudenko et al., presented at OSTST2012, Venice, Italy

1.3 Analysis and refinement of combination methods

The combination of space geodetic observation techniques is a major research topic at DGFI since several years. The combinations are performed on the level of datum-free normal equations with the DGFI software DOGS-CS. This software is continuously updated to enable the implementation of refined methodologies (e.g., epoch combinations, handling of non-linear station motions). The work within this theme provides the basis for the computation of global and regional reference frames (see Sect. 1.4) and for the contribution to various IAG services and working groups. Since many years, DGFI acts as an ITRS Combination Centre within the International Earth Rotation and Reference Systems Service (IERS) and as an IVS Combination Centre (jointly with BKG). DGFI acts as chair for the Joint Working Group 1.4 of IAG Commission 1 and the IERS "Strategies for epoch reference frames" and as co-chair for the IERS Working Group "Combination at the Observation Level". Several DGFI scientists actively contributed to the activities of these working groups. Since 2012, this theme is supported by two scientists funded within the Research Unit (FOR 1503) "Space-time reference systems for monitoring global change and for precise navigation in space" of the German Research Foundation DFG.

DFG Research Unit "Reference Systems"

The Research Unit "Space-time reference systems for monitoring global change and for precise navigation in space" (FOR 1503) has been granted by the German Research Foundation (DFG) in October 2011. Altogether, the research unit consists of six projects with 10.5 scientific positions in total. In 2012, two positions could be filled at DGFI: one position in project PN5 "Consistent celestial and terrestrial reference frames by improved modelling and combination" and the second one in PN6 "Consistent dynamic satellite reference frames and terrestrial geodetic datum parameters".

PN5 is a joint project of DGFI and BKG. The goal of this project is to deliver consistent terrestrial and quasi-inertial celestial reference frames based on a common set of parameters. The reference frames will be generated by combining time series of homogeneously processed VLBI, SLR and GNSS observations. For this purpose a unified set of processing standards has been defined. The analysis of SLR and VLBI observations (see Sect. 1.2) directly contributes to this project. The processing of GNSS observations is performed by BKG and TUM (see PN6).

The project PN6 is jointly conducted by TUM and DGFI. The aim of the project is to develop novel concepts for geodetic datum definition by exploiting the benefit from the available high and low orbiting satellites for the realization of a dynamic reference frame. Major tasks are to investigate different satellites (different orbit heights, inclinations, tracking techniques, and thus different sensitivities w.r.t. several datum parameters) to realise a dynamic reference frame with high accuracy, long-term stability and reliability. The processing of SLR observations to various satellites (see Sect. 1.2) provides a valuable basis for these tasks. Another topic of PN6 is the interaction between subdaily Earth rotation parameters and GPS orbits in order to improve GPS based subdaily tidal EOP models.

Combination methods for epoch reference frames

Recent realizations of global reference frames (multi-year reference frame MRF) used a constant velocity to describe the motion of a station position (after geophysical models had been applied). In this classical approach, non-linear station motions which are not considered by the geophysical correction models are forced into the observation residuals or, even worse, the parameter estimates. Since 2010, DGFI investigates an alternative type of parameterization called epoch reference frame (ERF). Therein, the station positions are estimated frequently in a regular time interval (e.g., weekly). The work was supported by the project "Integration of Earth rotation, geometry and the Earth's gravity field from observations of geodetic space techniques", funded within the DFG Research Unit "Earth rotation and global dynamic processes". In this project the effects of the different station parameterizations on consistently estimated parameters such as EOP are investigated.

Being the only technique which is sensitive to the centre of mass of the Earth *CM*, SLR plays a fundamental role in reference frame computations. GPS is also sensitive to the *CM*, but due to technique-specific model uncertainties, there are singularities w.r.t. the origin and the scale. To study the effect of different station parameterizations for GPS-only and SLR-only reference frames on the terrestrial pole coordinates, two different types of ERFs were computed for each technique and compared to the respective MRF:

(A) The station coordinates are estimated epoch-by-epoch. The orientation of the weekly reference frames is realized by applying a NNR condition on a subset of stable stations. All EOP except for the terrestrial pole coordinates (ΔUT1, celestial pole coordinates) are fixed to their respective a priori values at the mid-epoch of the week. This solution is the standard ERF solution.

(B) Neither the station coordinates (fixed to the MRF) nor the celestial pole coordinates or ΔUT1 are estimated. Solely the terrestrial pole coordinates are estimated. This solution is an epoch-wise reconstruction of the MRF.

Figure 1.5 shows the amplitude spectra of the terrestrial pole coordinate differences between the MRF and the ERFs of type (A) and (B) for the GPS-only (left plots) and the SLR-only solution (right plots). As expected, ERFs of type (B) show no clear pole differences for both the GPS and the SLR solution, whereas for solution (A), significant differences between the MRF pole and the ERF pole are visible.

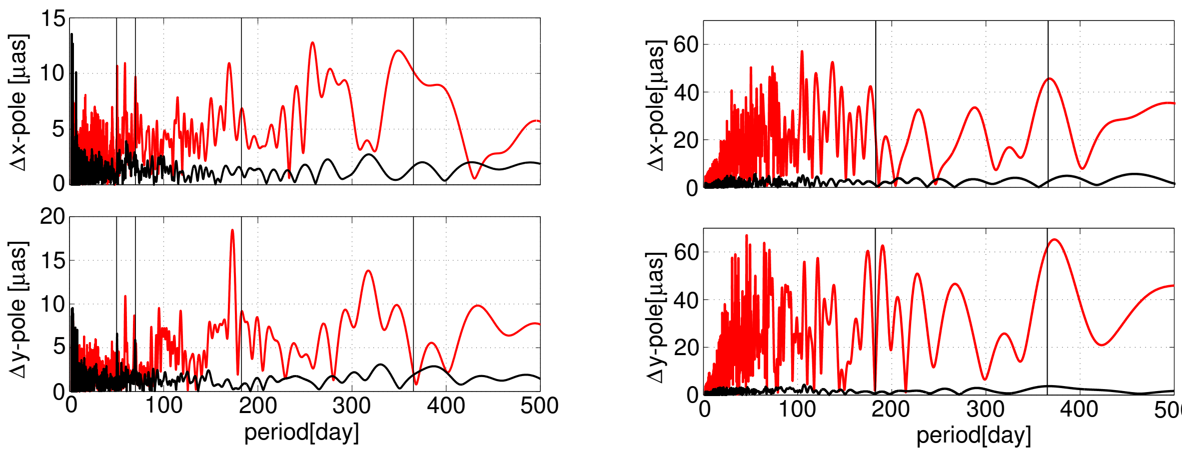

Fig. 1.5: *Amplitude spectra of the time series of differential pole coordinates of the GPS-only ERFs w.r.t. the GPS-only MRF (left plots) and of the SLR-only ERFs w.r.t. the SLR-only MRF (right plots). The spectra of x-pole differences are shown in the upper plots whereas the lower plots show spectra of the differences of the y-pole. The red lines denote solution (A), the black lines denote solution (B).*

Neglected atmospheric and hydrological mass variations cause translations common to all stations. In the case of the GPS-only solution, the artificially created singularities absorb this common translation. In case of SLR, the unconsidered common translation can propagate into the network orientation due to correlations between translation and orientation. The latter are caused by the sparse distribution of the weekly SLR networks. Together with the orientation also the pole coordinates as the parameters complementary to the network rotation are affected. This explains why in the SLR-only spectra clear annual periods can be identified with a maximum amplitude of 65.3 μas (2.0 mm at the Earth surface) in the y-pole. The other induced frequencies which can be seen in the four spectra are caused by individual station motions.

1.4 Computation of global and regional reference frames

DGFI has a long-term commitment to act as an ITRS Combination Centre within the IERS. In this function it is responsible for a regular computation of global terrestrial reference frame solutions. The latest computations were finalized in 2010/11 resulting in the DTRF2008 solutions (Seitz et al., 2012). The preparations and computations for the next realization, the ITRF2013, will start in 2013. During 2012, the global reference frame computations focussed on a common adjustment of the celestial and terrestrial reference frame together with the EOP (see below) and the development of combination strategies for the computation of epoch reference frames (see Sect. 1.3).

Since many years, DGFI is active in the field of regional reference frame computations, such as the processing of GPS stations within the IGS Tide Gauge Monitoring (TIGA) Working Group and for the Latin American reference frame, SIRGAS. The IGS Regional Network Associate Analysis Centre for SIRGAS (IGS RNAAC SIR) was installed in June 1996 under the responsibility of DGFI. The SIRGAS reference frame was regularly computed by DGFI alone until August 31, 2008 (GPS week 1495). Afterwards, due to the increasing number of stations, different sub-networks were defined and, at present, the SIRGAS computations are based on a distributed processing by various SIRGAS analysis centres (see below).

Simultaneous realization of ITRS and ICRS

Motivation

So far, the celestial and terrestrial reference systems, the ICRS and ITRS, are realized in different processing procedures performed by different institutions with different software packages. Thus, the two realizations, the ICRF and ITRF, are not consistent, even if an effort is made to reach consistency. The remaining inconsistencies are:

- The ITRF is derived from a combination of VLBI, SLR, GNSS and DORIS observations, whereas the ICRF is based on VLBI data only. The TRF estimated simultaneously with the ICRF is a VLBI-only reference frame (VTRF). This leads to inconsistencies w.r.t. the geodetic datum because the scale is realized by SLR and VLBI observations within the ITRF and by VLBI only within the VTRF. Additionally, there are small differences in the network geometry: (1) for the ITRF computation the combined IVS product is used, whereas the ICRF is computed by the data of one analysis centre, namely the AC at the Goddard Space Flight Center; (2) the combination of the different techniques changes the network geometry slightly.
- The Earth orientation parameters (EOP) resulting from both realizations are different: the ITRF solution includes the combined EOP series, in which the UT1-UTC and nutation parameters (can be derived in an absolute sense from VLBI only) are obtained from the combined IVS products, while in case of ICRF the EOP series is based on the products of one IVS AC only.

Fully consistent realizations of ITRS and ICRS can only be reached by a simultaneous estimation of both frames and the linking EOP series (CRF-TRF solution). Furthermore, it can be expected that all the estimated parameters (TRF, EOP and CRF) benefit from a combination of different techniques. Although radio sources are observed by VLBI only, in particular the combination of the EOP is assumed to have an effect also on the CRF.

CRF-TRF solution set-up

Input data are long time series of normal equations resulting from VLBI, SLR and GNSS analyses (see DGFI Annual Report 2011), which are homogenized w.r.t. models and parameterization. The parameter space comprises station positions and velocities, source positions and the EOP (terrestrial pole, UT1-UTC and nutation). The geodetic datum is realized following ITRF and ICRF standards: the origin is realized from SLR observations, the scale as a mean scale of SLR and VLBI, the orientation of the TRF by using no-net-rotation (NNR) conditions w.r.t. ITRF2008 and the orientation of the CRF by applying an NNR condition w.r.t. ICRF2.

Effect on the CRF – standard deviations

The EOP series resulting from a simultaneous realization of ITRS and ICRS show smaller standard deviations than the VLBI-only EOP series. The consequence is that also the standard deviations of the source positions decrease. This is particularly the case for so-called VCS sources which are observed by one regional VCS (VLBA Calibrator Survey) session only, which applies to more than 60 % of the sources. Figure 1.6 shows the decrease of source standard deviations w.r.t. a VLBI-only CRF. About 90 % of the effect results from the combination of the terrestrial pole.

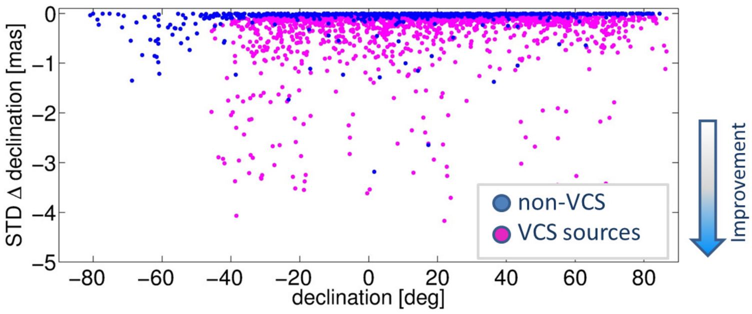

Fig. 1.6: *Change of standard deviations of declination angles due to the combination (combined minus VLBI-only solution). Non-VCS sources are observed by global station networks, VCS sources by the VLBA network in so-called VCS sessions only (mostly in only one session).*

Effect on the CRF – source positions

The combination of the station networks but even more the combination of the EOP has an impact on the source positions. Figure 1.7 displays the position differences between the CRF-TRF and the VLBI-only solutions. In particular the VCS sources show differences of up to 1 mas w.r.t. the VLBI-only CRF. In case of the right ascension (RA) even a systematic effect for some of the VCS sources with a declination (DE) between -40 deg and +30 deg could be detected. This effect applies to 108 VCS sources observed in 21 VCS sessions. It is mainly induced by the combination of LOD as shown in Fig. 1.8. However, the overall WRMS is small, it is only 6.7 μas for the declination and 9.0 μas for the right ascension.

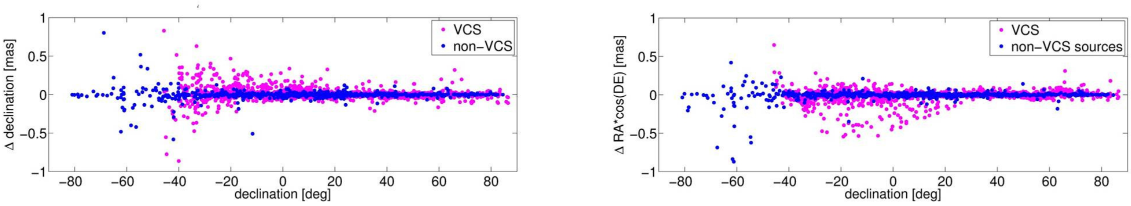

Fig. 1.7: *Position differences of radio sources from a combined TRF-CRF solution w.r.t. a VLBI-only CRF: (left) declination (DE), (right) right ascension (RA).*

Summary

The first solutions of a simultaneous realization of ITRS and ICRS provide promising results and they demonstrate the advantages of such an approach. In future, the effect of the combination on the CRF has to be investigated in more detail. In particular, it will be necessary to find strategies which allow to prove the benefit for the CRF from a common realization.

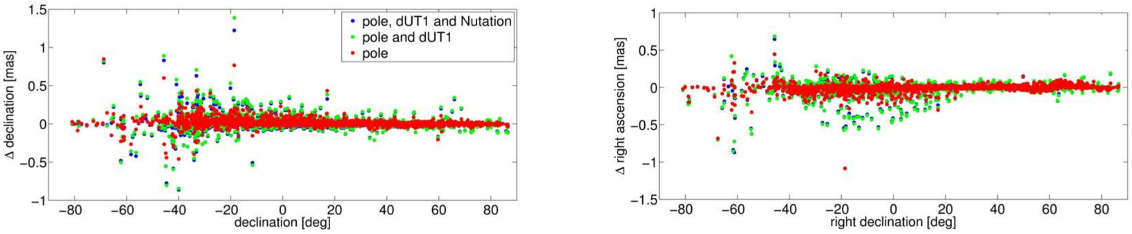

Fig. 1.8: Position differences of radio sources for three combined TRF-CRF solutions w.r.t. a VLBI-only CRF: (left) declination (DE), (right) right ascension (RA). The EOP are combined step by step: (red) only the terrestrial pole is combined, (green) terrestrial pole and UT1-UTC/LOD are combined, (blue) terrestrial pole, UT1-UTC/LOD and nutation are combined.

SIRGAS reference frame computations

At present, the SIRGAS reference frame in Latin America comprises about 300 continuously operating GNSS stations (see Fig. 1.9). The activities of DGFI as an IGS Regional Network Associate Analysis Centre for SIRGAS (IGS RNAAC SIR) concentrate on:

- The computation of loosely constrained weekly solutions for further combinations of the network (e.g. integration into the IGS polyhedron, computation of cumulative solutions, etc.). These solutions are delivered weekly to the IGS in SINEX format to be combined together with those generated by the other IGS Global and Regional Analysis Centres.
- Weekly station positions aligned to the IGS reference frame, i.e. the frame in which the IGS orbits are given. These positions are applied as reference values for surveying applications in Latin America.
- Multi-year solutions providing station positions and velocities to estimate the kinematics of the reference frame and to support applications requiring time-dependent coordinates.

The Bernese GPS Software 5.0 is used for the observation data analysis as well as for the combination of weekly data. The analysis strategy for the SIRGAS reference frame computations is based on the combination of individual solutions including: a) one core network with about 120 stations distributed over the whole continent, and b) different densification sub-networks distributed regionally on the northern, middle, and southern part of the continent (see Fig. 1.9).

The SIRGAS core network provides a direct densification of the ITRF in Latin America and the regional sub-networks improve the geographical density of the core network. The different networks are individually processed by certain SIRGAS Analysis Centres: the core network is computed by DGFI, the sub-networks by the SIRGAS Local Processing Centres: CEPGE (Ecuador), CIMA (Argentina), CPAGS-LUZ (Venezuela), IBGE (Brazil), IGAC (Colombia), IGM (Chile), IGN (Argentina), INEGI (Mexico), and SGM (Uruguay). DGFI directly supported, through capacity building activities, the installation of the processing centres in Colombia, Ecuador, Uruguay, and most recently in Chile. Bernese GPS Software 5.0 is applied by all these centres. The processing centres deliver loosely constrained weekly solutions for the assigned SIRGAS sub-networks. In these solutions, satellite orbits, satellite clock offsets, and Earth orientation parameters are fixed to the IGS final products, and positions for all sites are constrained to ±1 m. The individual contributions are integrated into a unified solution by the SIRGAS Combination Centres: DGFI and IBGE. Figure 1.10 shows the data flow within the SIRGAS processing.

DGFI is now responsible for a) processing the SIRGAS core network; b) combining this core network with the densification sub-networks; and c) making available the SIRGAS products, i.e.: loosely constrained weekly solutions, weekly station positions aligned to the ITRF, and multi-year solutions describing the kinematics of the reference frame. In addition to these routine SIRGAS activities, DGFI took the initiative: (i) to analyse and model the seasonal variations within the reference frame computation to increase the reliability and long-term stability of regional reference frames; (ii) to determine the best

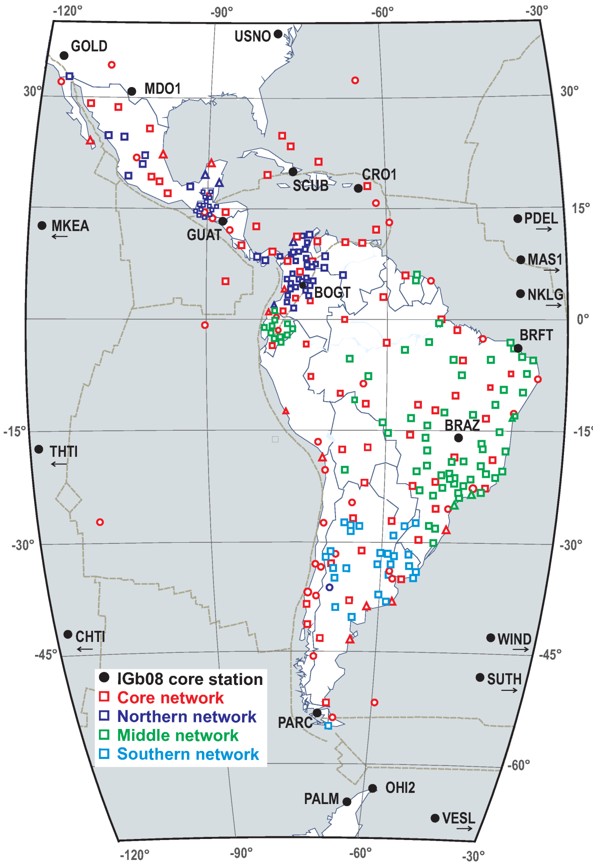

Fig. 1.9: SIRGAS tracking network (status 2013-01-15).

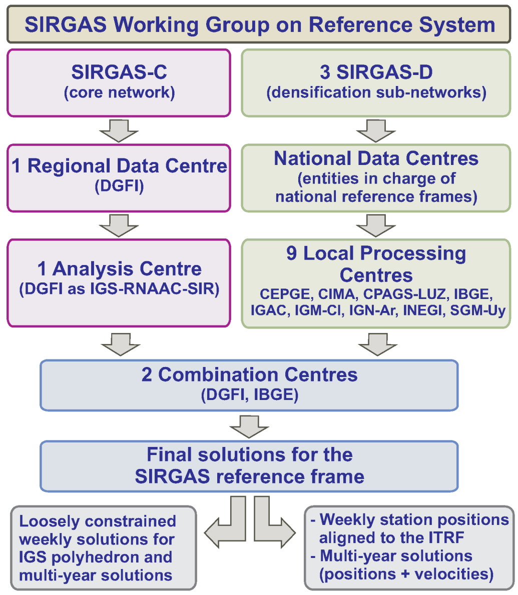

Fig. 1.10: Data flow within the weekly analysis of the SIRGAS Reference Frame.

possible strategy for the computation of deformation models that allow the appropriate transformation of station positions between pre- and post-seismic (deformed) reference frames; (iii) to prepare a second reprocessing campaign of all SIRGAS observations available based on the new generation of IGS products (IG2).

Datum definition and SIRGAS multi-year solution

The analysis of the SIRGAS reference frame as a regional densification of the ITRF is based on the IGS final products. Consequently, the SIRGAS weekly solutions are given in the same reference frame as the one applied by the IGS for the calculation of its products; namely, the IGS05 until GPS week 1631 and the IGS08 since week 1632. The geodetic datum of the weekly solutions is defined by constraining the coordinates of the IGS reference stations (see Fig. 1.9) to their positions computed within the IGS weekly combinations. The constraints guarantee that the coordinates of the IGS reference stations do not change more than ± 1.5 mm within the SIRGAS adjustment.

The kinematics of the SIRGAS reference frame is estimated by means of cumulative (multi-year) solutions, providing epoch positions and constant velocities for stations operating longer than two years. The coordinates of the multi-year solutions refer to the latest ITRF realization and to a specified epoch, e.g. the most recent SIRGAS-CON multi-year solution SIR11P01 refers to ITRF2008, epoch 2005.0. However, since the switch to the IGS08 reference frame causes a discontinuity of some mm in the station position time series, the computation of a new multi-year solution demands the reprocessing of all previous weekly solutions using the IGS08 frame and the phase centre correction model igs08.atx. Therefore, it is necessary to wait until the IGS has generated the corresponding IGS08-related products (e.g. satellite orbits, EOPs, terrestrial reference station positions, etc.).

Improvement of the IGS station coverage in Latin America

The large earthquake ($M = 8.8$) of February 2010 in the Chilean region Maule caused large displacements between 5 m at the Pacific coast and 2 cm at the Atlantic coast in Argentina and Uruguay. Additional movements due to the post-seismic relaxation during the first months after the main earthquake and its aftershocks are also evident in the station position time series. As a consequence, the reliability of the recently released IGS08 reference frame decreased considerably in South America; and the affected stations are no longer usable as a basis for the GNSS data analysis or to guarantee the long-term stability of the ITRF in this region. Taking into account the evolving regional reference frame SIRGAS and the planned second reprocessing campaign of the global IGS network, a set of continuously operating SIRGAS stations was proposed to be included in this reprocessing with the main objective of improving the IGS station coverage in Latin America. Initially, about 70 SIRGAS stations, which satisfied the IGS requirements, were selected by DGFI and the responsible national organizations in the Latin American countries. This selection was evaluated by the IGS Reference Frame Working Group, and after some interaction with the IGS Global Analysis Centres, it was decided to include 40 SIRGAS stations not only in the IGS reprocessing but also in the present routine IGS processing. DGFI provided the IGS data centres with the metadata and all existing observations (historical data) of the selected stations. The present data are directly provided by the responsible Latin American agencies to the IGS.

Acknowledgements

The operational infrastructure and results described in this report are possible thanks to the active participation of many Latin American and Caribbean colleagues, who not only make the measurements of the stations available, but also operate SIRGAS Analysis Centres processing the observational data on a routine basis. The achievements of SIRGAS are a consequence of a successful international geodetic cooperation not only following and meeting concrete objectives, but also becoming a permanent and self-sustaining geodetic community to guarantee quality, reliability, and long-term stability of the SIRGAS Reference Frame. The SIRGAS activities are strongly supported by IAG and the Pan-American Institute for Geography and History (PAIGH). More details about the activities and new challenges of SIRGAS can be found at www.sirgas.org.

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2 Gravity Field

The Earth's gravitational field serves on the one hand as a reference surface for many dynamic processes in the Earth system, while on the other hand the observation of the gravitational field itself and its variations in time characterize mass distribution and mass transport, which in turn describe geophysical processes. Typical examples of research areas where the gravitational field is of importance are geodesy, geophysics, oceanography and navigation. A central theme is therefore the observation, modelling and determination of the Earth's mean and time-variable gravitational field at all temporal and spatial scales.

In 2012 we focussed on three main topics related to the gravitational field. The first topic was the preprocessing and regional analysis of the Gravity field and steady-state Ocean Circulation Explorer (GOCE) gravity gradients, also in combination with satellite altimeter data. Another topic was height systems and their application. A final topic was the study of the time-variable gravity field in both the GOCE gravity gradients and the Gravity Recovery And Climate Experiment (GRACE) L1B data. Highlights of these three topics are discussed below.

2.1 Regional gravity fields

Using the full tensor of GOCE gravity gradients

The GOCE 3-axis gradiometer delivers tensor information of the Earth's gravity field, which promises a great benefit for geophysical applications as they contain information on radial as well as on lateral gravity variations. The GOCE gradients are given in the gradiometer reference frame (GRF) along the orbit with varying height and variable along-track and cross-track sampling. Their use in geophysical applications is therefore not straightforward, and the computation of gradient grids in the local north-oriented frame (LNOF) at mean orbital altitude is one of the main tasks within the ESA GOCE+ GeoExplore project. The aim is to use the *full* tensor of original GOCE gravity gradients. One of the regional study areas is the North-East Atlantic Margin (NEA) with a size of $23^\circ \times 24^\circ$ containing on- and offshore areas with mountainous regions, a strongly varying bathymetry and, thus, large gravity anomaly variations. The mean orbit height with respect to WGS84 is 270 km.

We use 16 months of data of the latest release of GOCE Level-2 gradients. Four steps are performed in the regional gravity field modelling approach: 1) Preprocessing of the GOCE data set; 2) Subtraction of a background model; 3) Analysis: series expansion in terms of reproducing kernels; and 4) Synthesis: series expansion in scaling functions. The *preprocessing* consists of high-pass filtering the GOCE Level-2 products to keep the measurement bandwidth (MBW) above 5 mHz, which is the range of the frequency spectrum with the highest gradiometer sensitivity. The long wavelengths below the MBW are filled up with model information from the GOCO03S model which is complete up to spherical harmonic degree and order 250. A procedure developed in-house is used to flag outliers and data before and after jumps. The use of a *background model* (V_{back}) has two aspects: (i) The well-known long wavelength part is removed so that regional gravity field features can be modelled from the remaining signal; (ii) The background model serves as prior information and avoids rank deficiencies in the estimation process. Also here the complete GOCO03S model is used.

In the *analysis step* we set up a functional model that describes the relationship between the measured GOCE gravity gradients and the mathematical expression for the second derivatives of the gravitational potential. In the regional gravity field modelling approach we use base functions that are strongly band-limited, and the frequency spectrum is split into several levels j, which are related to specific frequency bands. We implemented the regional gravity field modelling approach at level 9 (up to spherical harmonic degree $l = 511$). The unknown coefficients d_j for level $j = 9$ are estimated within a Gauss-Markov model,

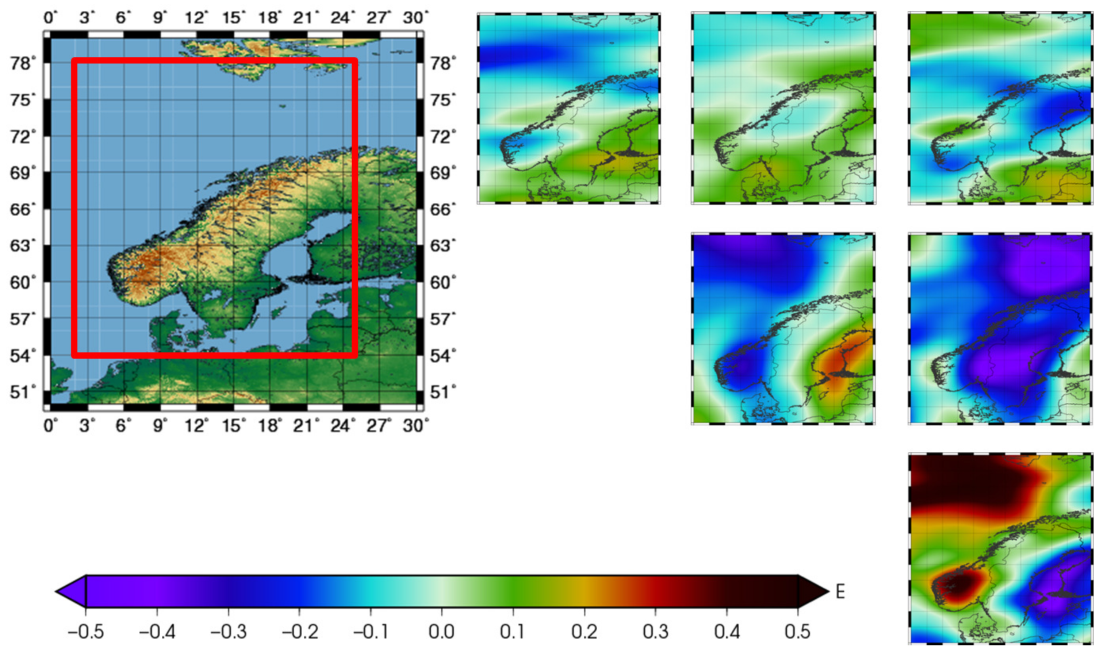

Fig. 2.1: *Final gravity signal from GOCE gravity gradients T_{ij} arranged according to the xyz tensor for the test area NEA. The grids (resolution $0.2°$) are generated for level $j = 9$ (up to $l = 511$) at a mean orbit height of 270 km. The weights of the observations are estimated by VCE.*

Table 2.1: *Relative weighting of observations by estimated (a) and manually fixed (b) variance components (VC) and statistics of the differences between the corresponding output gravity gradients of level 9 (up to $l = 511$) and the GOCO03S model (d/o 250) for the test area NEA.*

Input	Relative weighting		Output	$\Delta T_{ij} = T_{ij,\text{GOCE}} - T_{ij,\text{GOCO03S}}$	
observation	(a) VC est	(b) VC fix	$T_{ij,\text{GOCE}}$	(a) mean $\pm$ std [mE]	(b) mean $\pm$ std [mE]
V_{xx}	10^{-16}	10^{-16}	T_{xx}	0.01 ± 0.10	0.01 ± 0.10
V_{xy}	10^{-14}	10^{-01}	T_{xy}	0.00 ± 0.05	0.00 ± 0.06
V_{xz}	10^{-13}	10^{-14}	T_{xz}	0.00 ± 0.12	0.00 ± 0.14
V_{yy}	10^{-16}	10^{-11}	T_{yy}	0.00 ± 0.09	0.00 ± 0.11
V_{yz}	10^{-11}	10^{-01}	T_{yz}	0.00 ± 0.11	0.00 ± 0.13
V_{zz}	10^{-17}	10^{-16}	T_{zz}	0.00 ± 0.18	0.00 ± 0.21
V_{back}	10^{-15}	10^{-14}			

where the weighting of the different gravity gradients is realized by variance component estimation (VCE). The estimated coefficients $\hat{d}_9$ from the analysis step are then used to model the regional gravity signal on pre-defined grids (*synthesis*). Subtracting the normal potential gives gravity gradients of the disturbing potential: $T_{xx}, T_{xy}, T_{xz}, T_{yy}, T_{yz}, T_{zz}$.

Figure 2.1 shows the final signals of these 6 components at a mean orbit height of 270 km for level 9 (degree 511) according to the 3×3 tensor arrangement. The maximum signal variation is ±0.5 E for T_{zz}, which is oriented in the radial direction. We further compared these output grids with gravity gradients computed from the GOCO03S model up to degree and order 250 at the same mean orbit height. The differences $T_{ij,\text{GOCE}} - T_{ij,\text{GOCO03S}}$ are shown in Fig. 2.2. From the corresponding statistics (a) in Tab. 2.1 it can be seen that the standard deviations are generally small: $0.05 - 0.18$ mE. These statistics are based on VCE (VC est). But in polar regions the additional effect of systematic errors on the GOCE V_{yy} component may reduce the accuracy of V_{yy}. We therefore defined the relative weighting of the different gradients manually by setting a lower weight (i.e. a higher variance component VC) for V_{yy}. The standard deviations of the differences (b) between the GOCE grids generated by fixed weights (VC

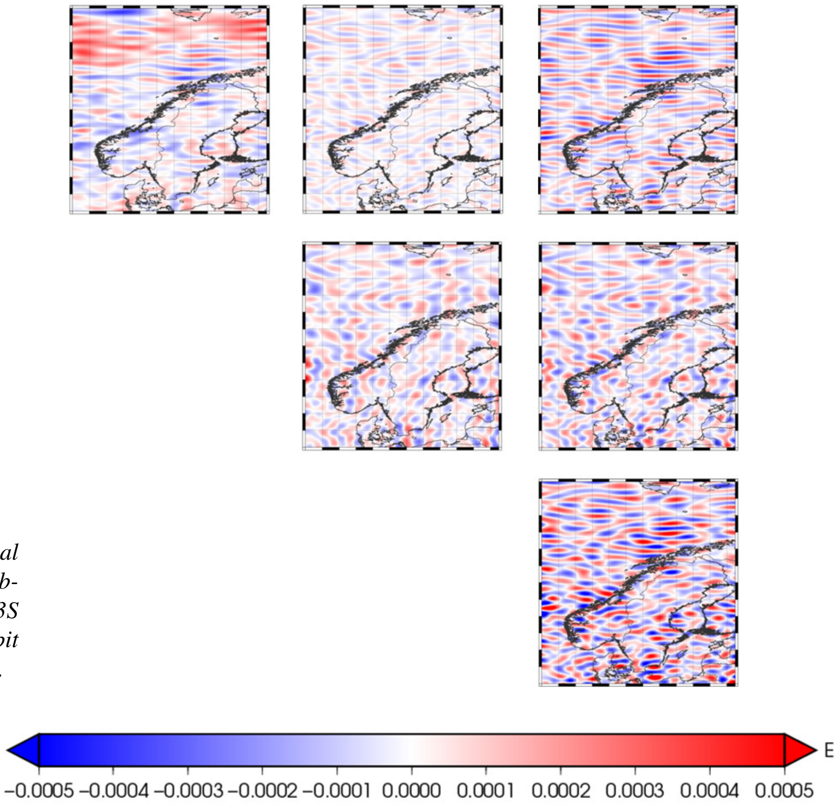

Fig. 2.2: *Differences between the final gravity signals ($j = 9$, up to $l = 511$) obtained from GOCE and the GOCO03S model (up to d/o 250) at a mean orbit height of 270 km for the test area NEA.*

fix) and GOCO03S vary between 0.06 and 0.21 mE. These statistical values correspond to the results obtained from estimated VCs, but the structure of the difference plots is different: especially the positive residuals detected in the T_{xx} component in the northern part of the NEA test area nearly disappear in the solutions based on fixed VCs. This could be an effect of the reduced influence of the less accurate V_{yy} gradients. Further improvements as regards the relative weighting of the observations are planned as well as detailed studies on the significance of the level-9 signal obtained from the GOCE gravity gradients compared with GOCO03S.

Regional gravity field modelling with altimeter data

After more than 10 years of mission lifetime, the Jason-1 satellite started its end-of-life (EOL) scenario at the end of April 2012. The satellite was moved from its repeat orbit to a new geodetic orbit with a cycle duration of 406 days leading to a very dense observation distribution on the ground. In addition, the Cryosat-2 mission provides data with a ground track separation of about 8 km at the equator (repeat cycle of 369 days) since 2010. Although not part of the basic mission objectives, these data sets allow improving the resolution and accuracy of the marine gravity field, as precise altimetry profiles with high spatial resolution are available for great parts of the globe for the first time since 1995 (geodetic mission phase of ERS-1).

We investigated the benefit of these two new data sets for marine gravity modelling. We used sea surface height (SSH) profiles from different altimeter missions to compute high resolution regional gravity models over the ocean. In combination with sea surface topography information (DGFI iDOT profiles computed in the framework of the GEO-TOP project, see Sections 3.4 and 6.1) the SSH is used to extract gravity potential information serving as input data for the estimation of the unknown model coefficients. The model approach is based on series expansions in spherical base functions, i.e. spherical scaling and wavelet functions in order to derive corrections w.r.t. a given background model (in this case GOCO02S up to spherical harmonic degree and order 180). In addition, it comprises a multi-resolution representation (MRR) of the gravity field that allows the decomposition of the signal in a number of detail signals.

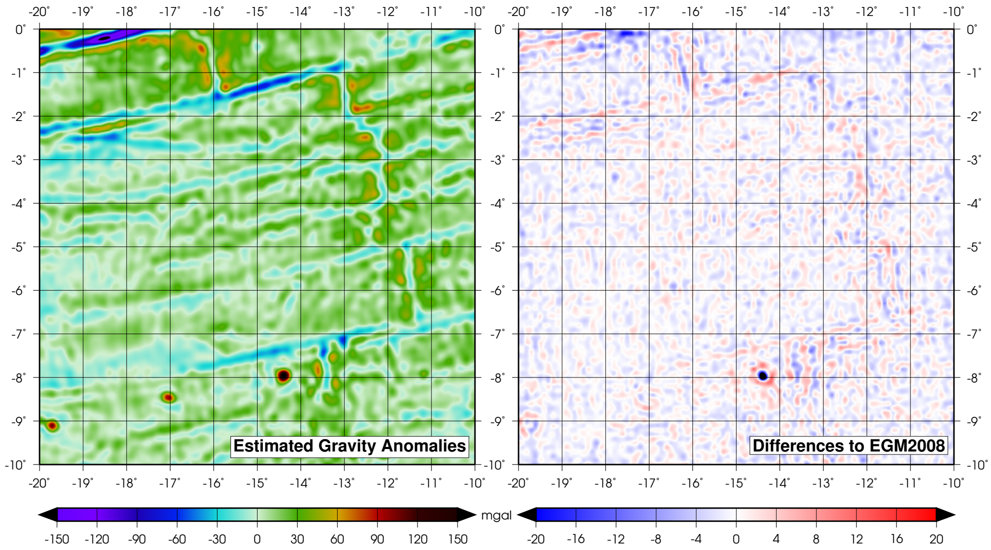

Fig. 2.3: *Estimated gravity anomalies from altimetry data sets (left) and differences w.r.t. EGM2008 (right). The RMS of the differences is 2.5 mGal.*

We used 20 months of retracked 1 Hz Cryosat-2 LRM (low resolution mode) data from the RADS (radar altimeter database system) database, as the ESA level 2 product shows unintentional effects and errors, which are not present in the RADS level 2 processing. For Jason-1 EOL only preliminary IGDR (interim product available in near real-time) data could be used (appr. 3.5 months, 1 Hz), as the GDR data were not available at the time of processing. In addition to these two new missions, data from the ERS-1 geodetic mission phase (GM, about 12 months) were used for the investigations. All data were cross-calibrated beforehand within a multi-mission crossover analysis (MMXO, see Sect. 1.2) to ensure a consistent input data set. A test region of 10° by 10° in the South Atlantic has been used, located directly above the Mid-Atlantic Ridge. As model resolution we chose Level 11 and 12, corresponding to spherical harmonic degree and order 2047 and 4095, respectively.

The weighting of the different missions (and of the reference model) is done automatically by means of VCE. The results of the VCE (given in Table 2.2) are an indication for the quality of the different data sets as regards the estimation of gravity field coefficients. As shown in the Table, Jason-1 EOL reaches the same level of accuracy as ERS-1. Cryosat-2 is more accurate by a factor of about 6. Probably, the quality of Jason-1 will improve when using GDR data instead of the interim product.

Table 2.2: *Variance components for the different input data (missions) and the background model (Level 11).*

	Variance Factor [-]
Jason-1 EOL (IGDR)	$0.41 \cdot 10^{-12}$
Cryosat-2 LRM	$0.06 \cdot 10^{-12}$
ERS-1 GM	$0.35 \cdot 10^{-12}$
Background model	$0.51 \cdot 10^{-10}$

Table 2.3: *Comparison of estimated gravity anomalies with ship-borne data along one track.*

	correlation [-] to ship-borne data	RMS [mGal] of differences
L11 model	0.984	4.3
L12 model	0.992	3.1
EGM2008	0.992	3.1

Figure 2.3 shows the estimated gravity anomalies in the test area (left plot) together with the differences w.r.t. EGM2008 (right plot). The RMS of the differences of about 2.5 mGal is very small. Maximum discrepancies occur around a small island where no valid altimeter data are available. Comparisons with single ship-borne measurement tracks prove the quality of our modelling, which is comparable with

EGM2008. Figure 2.4 shows the data along one track (top) together with the differences to the ship-borne data (bottom). Table 2.3 gives the RMS values of the differences and the correlation between the different tracks. Probably, the inclusion of larger data sets with enhanced quality (Jason-1 GDR data) and the choice of a higher spatial resolution will further improve the model.

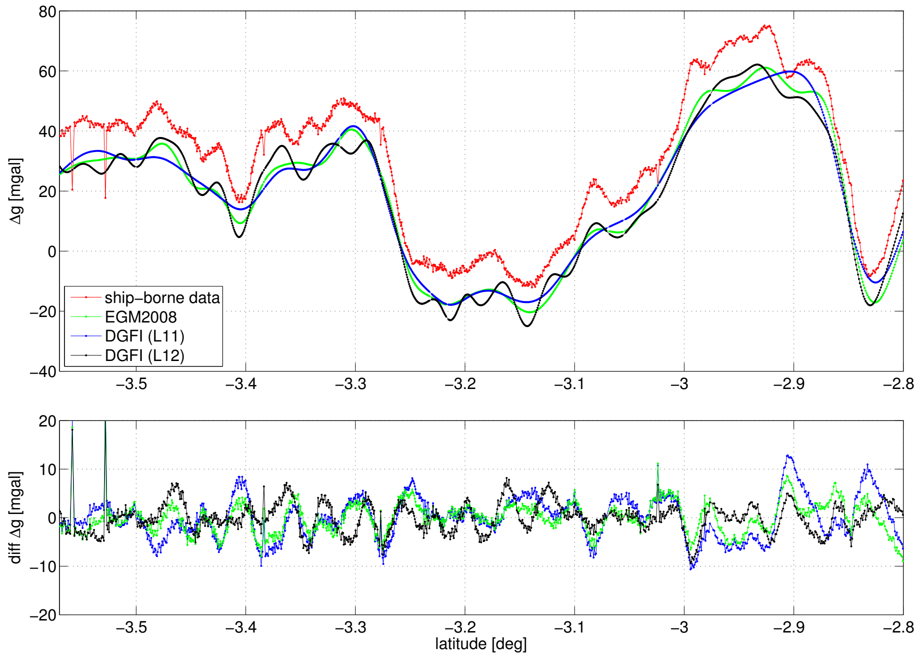

Fig. 2.4: Comparison with ship-borne data (Survey ID RC2806, partly, data source: NOAA NGDC). The top plot shows the gravity anomalies along the ship track. The ship measurements are plotted in red, EGM2008 in green, and the two DGFI solutions (with different spatial resolution) in blue and black. The bottom plot illustrates the differences w.r.t. the ship-borne data (mean value subtracted).

2.2 Height systems

The primary approach proposed by DGFI for the definition of a global vertical reference system is based on a geometric and a physical component in order to support the precise determination and reliable combination of both kinds of heights, i.e. geometric (ellipsoidal) and physical (orthometric or normal) heights. To guarantee that such a vertical reference system is suited for the estimation of orthometric as well as normal heights, this initial definition was refined indicating that the physical component shall be given in terms of geopotential quantities, i.e. geopotential numbers as vertical coordinates, and an absolute geopotential value (W_0) as the reference level. The spatial representation of the equipotential surface defined by W_0 (i.e. the geoid determination) and the transformation of geopotential numbers into physical heights are then understood as part of the realization of the reference system.

According to this definition, the activities initially faced by DGFI w.r.t. this topic are

a) the estimation of a global W_0 value,
b) a proposal for the realization of the global vertical reference system (i.e. the global vertical reference frame), and
c) the identification of the most appropriate strategy for the integration of the existing height systems into the global one.

The W_0 estimates obtained by DGFI present differences of about $2\,m^2s^{-2}$ with respect to previous computations, in particular with respect to the W_0 value included in the IERS Conventions. Other estimates applying a wide range of strategies and models recently computed by other groups are close to the DGFI results (Fig. 2.5); however, although these estimates are very similar, the discrepancies between the final W_0 values are larger than the expected realisation accuracy of the reference level, i.e. > 10 cm (or $1\,m^2s^{-2}$), in particular with respect to the W_0 value included in the IERS Conventions.

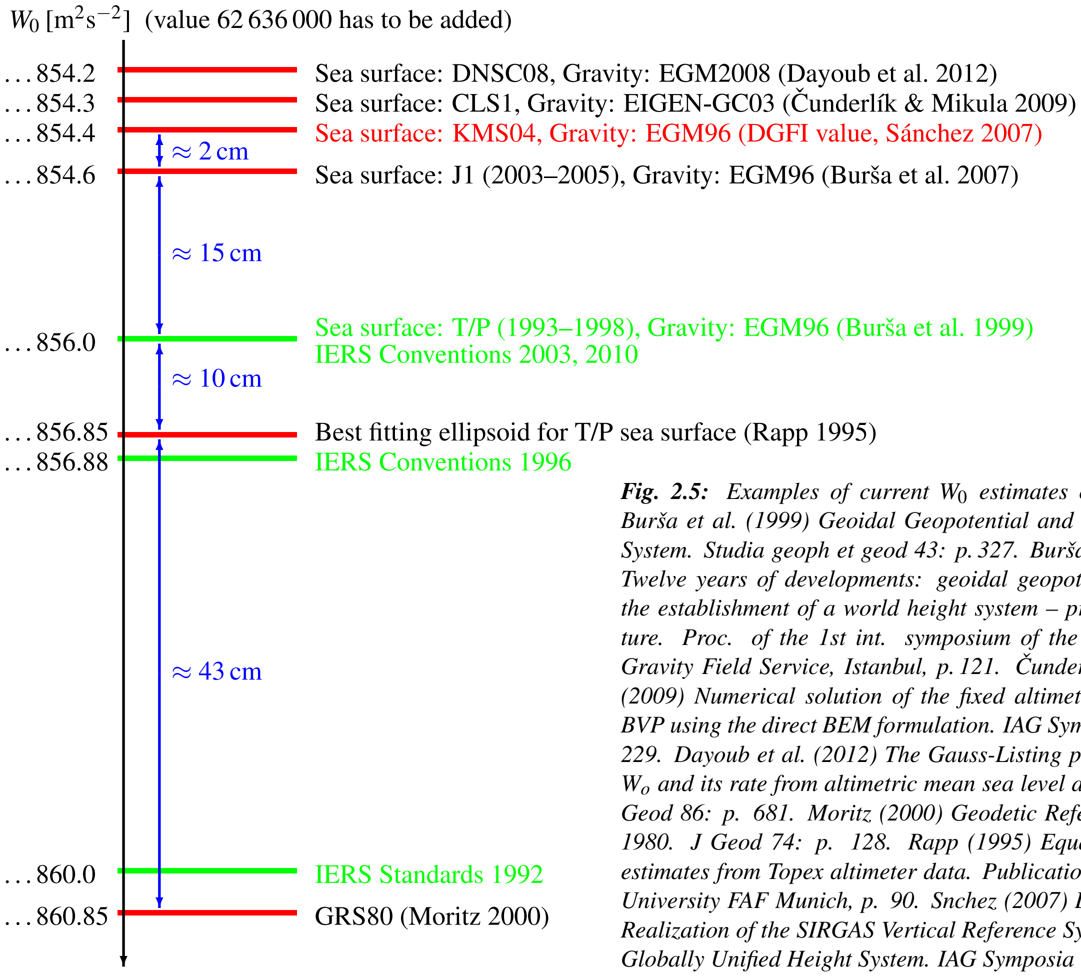

Fig. 2.5: *Examples of current W_0 estimates computed by: Burša et al. (1999) Geoidal Geopotential and World Height System. Studia geoph et geod 43: p. 327. Burša et al. (2007) Twelve years of developments: geoidal geopotential W_o for the establishment of a world height system – present and future. Proc. of the 1st int. symposium of the International Gravity Field Service, Istanbul, p. 121. Čunderlík & Mikula (2009) Numerical solution of the fixed altimetry-gravimetry BVP using the direct BEM formulation. IAG Symposia 133: p. 229. Dayoub et al. (2012) The Gauss-Listing potential value W_o and its rate from altimetric mean sea level and GRACE. J Geod 86: p. 681. Moritz (2000) Geodetic Reference System 1980. J Geod 74: p. 128. Rapp (1995) Equatorial radius estimates from Topex altimeter data. Publication of the IfEN, University FAF Munich, p. 90. Snchez (2007) Definition and Realization of the SIRGAS Vertical Reference System within a Globally Unified Height System. IAG Symposia 130: p. 638.*

Although any W_0 value could arbitrarily be chosen as a reference level for the global vertical reference system, this value should be consistent with other defining parameters of geometric and physical models of the Earth. Consequently, DGFI concentrates at present in joining efforts with colleagues working on the same topic at international level in order to:

a) Coordinate individual initiatives for a unified W_0 determination: At present there are at least four groups working on the estimation of a global W_0 value. It was possible to bring these groups together in 2012 to elaborate an inventory describing individual methodologies, conventions, standards, and models presently applied to compute W_0.

b) Refine the W_0 estimation: each group performs a new W_0 computation following its own methodologies, but applying the most recent geodetic models (e.g. GOCE/GRACE gravity models, sea surface models derived from calibrated and combined satellite altimetry observations, etc.). For this purpose, the recommendations given by the different IAG components in the respective fields of expertise are taken into account.

c) Make a proposal for a formal IAG/GGOS convention about W_0: It is expected that results obtained from applying the different methodologies considered in the previous item will be very similar. In this way, after a rigorous reliability evaluation, the best estimate of W_0 will be proposed as an

IAG/GGOS official convention. This procedure will be supported by a document containing the detailed computation of the recommended value.

d) Provide a standard about the usage of W_0 in the vertical datum unification: a document describing the most appropriate strategy to connect (unify, transform) any local height system with the global W_0 reference level is being written.

e) Promote the recommended W_0 value as a defining parameter for the computation of an improved mean Earth ellipsoid and as a reference value for the computation of the constant $L_G = W_0/c^2$, with c the speed of light, within the IERS Conventions. L_G is required for the realization of the relativistic atomic time scale, i.e. the transformation between Terrestrial Time (TT) and Geocentric Coordinate Time (GCT).

During the last decade, DGFI has been strongly involved in international activities oriented to the definition and realization of a global unified height system. The first undertakings were focused on the unification of the South American height datums under the umbrella of the SIRGAS Working Group III "Vertical Datum". Between 2003 and 2011, DGFI participated in the IAG Inter-Commission Project 1.2 (IAG ICP1.2) "Vertical Reference Frames", whose tasks are now continued by the GGOS Theme 1 "Unified Height System". DGFI supports this GGOS initiative by coordinating for the term 2011–2015 the Working Group "Vertical Datum Standardization", which directly depends on the GGOS Theme 1 and is supported by the IAG Commissions 1 (Reference Frames) and 2 (Gravity Field), as well as by the International Gravity Field Service (IGFS).

2.3 Time-variable gravity field

Case-study: Resolving time-variable processes using GOCE gravity gradients

In the framework of the GOCE+ Time-Variations study of the STSE (Support To Science Element) supported by ESA, the possibility to determine signals of Earth's time-variable gravity field using data of the GOCE mission has been evaluated. Together with the project partners of TU Delft two main goals have been defined: It is studied whether 1) the signal due to ice mass loss of Greenland, and 2) signals due to mass displacement of large earthquakes, such as the Chile February 2010 earthquake and the Japan-Tohoku earthquake 2011, are detectable using GOCE measurements.

Since its launch in March 2009 GOCE delivers highly accurate products denoted as gravity gradients given in the gradiometer reference frame. GOCE's main purpose is to measure Earth's fine-scale gravity field information with unprecedented accuracy. Compared with the GRACE mission the sensitivity of GOCE is lower at large spatial scales, but GOCE could deliver unique information for temporal short wavelengths in case the sensitivity of time-variable processes is being reached. A global analysis of the GOCE gravity gradients shows that assuming a Gaussian distributed noise behaviour of band-limited gradients, filtered to the measurement bandwidth of 5-100 mHz, reaches the theoretical limit of time-variable processes (which occur likely below about 0.2 mE).

The relation between signal sensitivity and resolution depends thereby on the gradient quality and the averaging interval. The GOCE gradiometer sensitivity at long wavelengths is small, whereas most time-variable signals are connected to these wavelengths. Consequently, the focus of this study is on the exploration of time-variable processes that have most energies at small spatial scales and signals that remain present at long integration periods. In case of an earthquake primarily an abrupt change in the static gravity field occurs. Therefore, the analysed time periods can be split in a pre- and post-earthquake scenario, neglecting the post-seismic gravitational change. In the case of "mega-thrust" earthquakes the co-seismic geoid change is typically at the cm level and usually at spatial scales around 400 km, which is in the scope of GOCE gravity gradiometry. Nevertheless a long integration period of GOCE data is necessary to reach sensitivity with respect to the predicted gravity gradient signal. In contrast the amount of GOCE data for investigation of the Chile 2010 earthquake shows that the pre-earthquake scene only

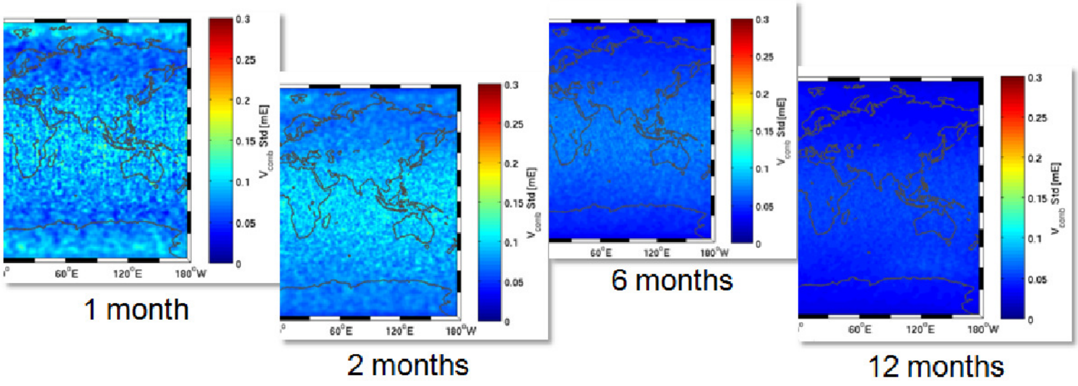

Fig. 2.6: Standard deviation of the mean for averaged gravity gradients of V_{zz} for time intervals of 1 to 12 months (left to right) applying a 84 km Gaussian smoothing kernel. In the case an averaging period of 1 month satellite tracks are clearly visible which results from an incomplete orbital repeat cycle of 61 days.

covers a data period of approximately three months. For change detection of pre- to post-earthquake differences the data availability limits the required accuracy where also compared to the Japan-Tohoku-Oki earthquake the gradient signals are approximately half.

For the Japan-Tohoku earthquake 12 months of pre- and post-earthquake data are available, which allows to reach the sensitivity predicted by forward computations. For the Japan-Tohoku earthquake the gravitational change results in a geoid change of approximately 1 cm, which is equivalent with a 0.6 mE change in the radial gravity gradient component (see Fig. 2.7).

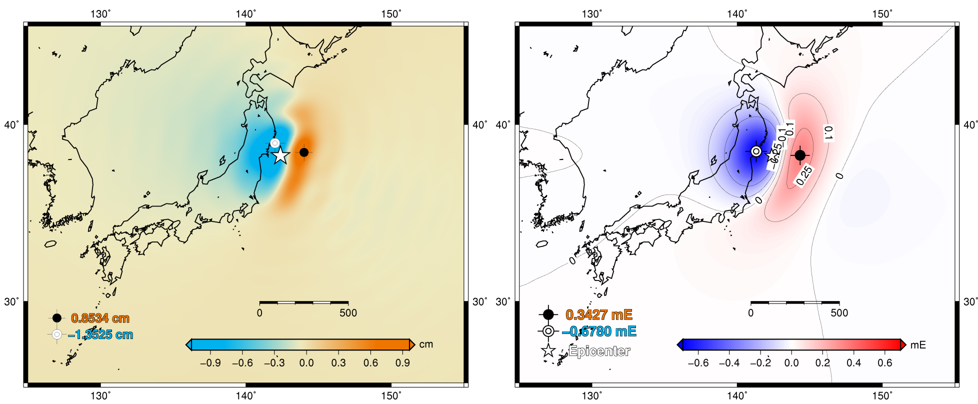

Fig. 2.7: Modelled V_{zz} gravity gradient (left) and the change in geoid height (right) for the Japan-Tohoku earthquake. The spherical harmonic coefficient set has been provided by T. Broerse, TU Delft.

The highest sensitivity of the GOCE gravity gradients is in the measurement bandwidth, whereas at lower wavelengths the $1/f$ noise dominates the measurements. For a more dedicated analysis we use a Wiener filter approach, which maximizes the filter bandwidth with respect to the forward modelled signal and the global noise behaviour of the combined V_{zz} component. The combined V_{zz} component is the average of the single diagonal components of the GOCE gradient tensor where the Laplace criterion is used. Averaging the gradients in this way leads to a noise reduction of approximately 30% compared with the original V_{zz} component. In addition, the reference model GOCO03s [1] has been subtracted from the point wise measurements. This model includes to a high extent pre-earthquake GOCE data besides SLR and GRACE data. The same procedure has been applied track-wise to the computed gradients from the forward model and compared with the original measured gradients afterwards.

In Fig. 2.8 a pre- to post-earthquake difference is clearly visible. A similar signature is also predicted by the forward modelled signal depicted on the right. Using the pure band-limited information provided by

[1] Mayer-Gürr T. et al. (2012): The new combined satellite only model GOCO03S. GGHS2012, Venice (Poster)

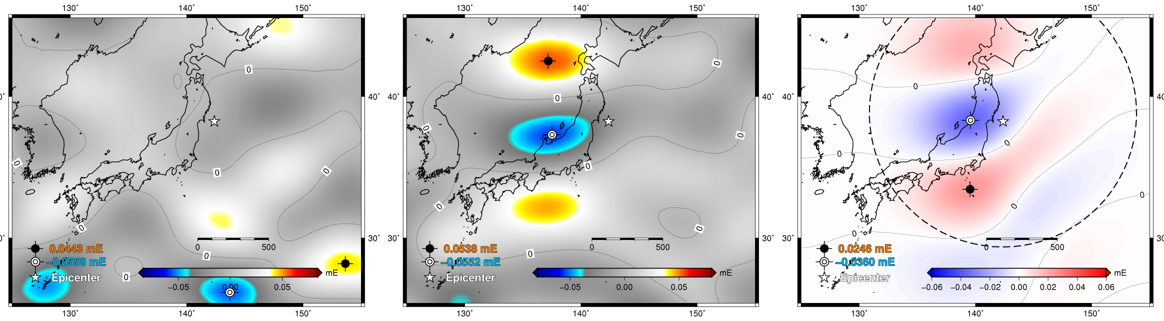

Fig. 2.8: GOCE derived V_{zz} gravity gradient component before (left) and after (middle) the earthquake, as well as the band limited forward computation of the simulated gradients (right).

GOCE the Japan-Tohoku earthquake is visible in the GOCE gravity gradients.

Since the earthquake signal is close to the measurement accuracy of the GOCE mission, a careful conditioning of the measurements must be made over a long integration period (at least 12 months of data) considering an appropriate resolution. Especially a combination of GRACE and GOCE measurements might increase the sensitivity at small scales which could provide new insights for the understanding of such a mega-thrust event. Further analysis will be made using the detected gravitational change in a geophysical interpretation where the difference between the forward model and the measurements are being evaluated.

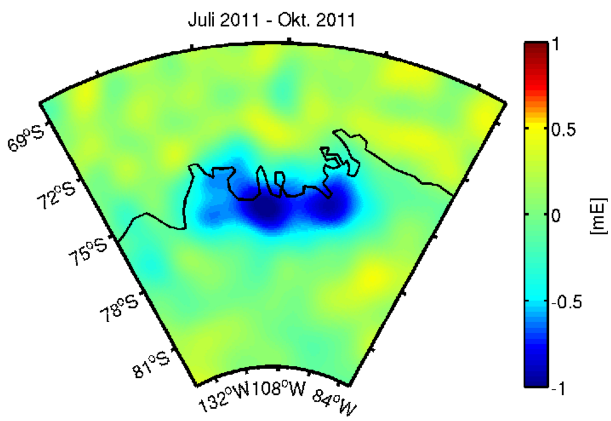

Fig. 2.9: GOCE derived V_{zz} gravity gradient for the time period July 2011 to October 2011 w.r.t. the reference model GOCO03S. The ice mass loss of the Pine Island glacier (right local minimum) and the Smith and Thwaites glaciers (left local minimum) are visible.

For the region of Greenland, the data quality of the GOCE gradients is degraded due to an anomalous signal in the V_{yy} component. A first quality assessment revealed that using the pure GOCE gradients does not reach solid sensitivity of the temporal gravitational signal as computed by forward models. The gradient quality in the West Antarctic area, in contrast, is quite good. The total ice mass loss in the West Antarctic might be smaller than in Greenland but it is very spatially focused. Besides a good gradient quality the forward modelled and the GRACE monthly solutions predict a gradient signal which is in the same order as the GOCE measurement accuracy for a four months time period. In addition, the track coverage of GOCE for high latitudes is quite dense.

First tests showed that differences w.r.t. the reference gravity field model GOCO03S show signatures related to geographical features of prominent ice mass loss (see Fig. 2.9). Thereby the spatial resolution provided by GOCE gravity gradients would even allow to separate neighbouring glaciers. Nevertheless the GOCE information must be integrated at least over a time span of 4 months which has limited relevance for temporal interpretations.

2.4 GRACE L1B processing

GRACE is a joint satellite mission of NASA and DLR, launched in 2002. Its aim is to deliver information about the Earth's gravity field and its time variations, caused by changes in e.g. hydrology and glaciology. To fulfil this task, a K-band-ranging system (KBR) measures the distance ρ between the twin satellites with an accuracy of 10^{-6} m. Besides the range measurement, its derivatives range-rate $\dot{\rho}$

and range-acceleration $\ddot{\rho}$ are provided. Further important sensors are the accelerometers to determine non-gravitational forces, star cameras for the attitude of the satellites and GPS receivers to compute orbits.

At DGFI we use the integral equation approach (IEA; Mayer-Gürr, 2008)[2] to derive gravity models from GRACE KBR data. The IEA has the advantage that the observable does not combine accurate KBR measurements and less accurate GPS orbits. Instead, GPS satellite positions are only used to compute approximate values. Besides, the IEA does not depend on satellite velocities derived from GPS measurements. Our observable is the range-rate $\dot{\rho}$ to avoid additional offsets.

We implemented an algorithm to estimate coefficients of a spherical harmonic series to obtain a global model. All observations are grouped in arcs of 30 min length and processed in parallel. To validate the algorithm, we used a data set of simulated GRACE orbits and measurements. The simulation was based on a given gravity field, additional corrections are not considered. First results are shown in Fig. 2.10.

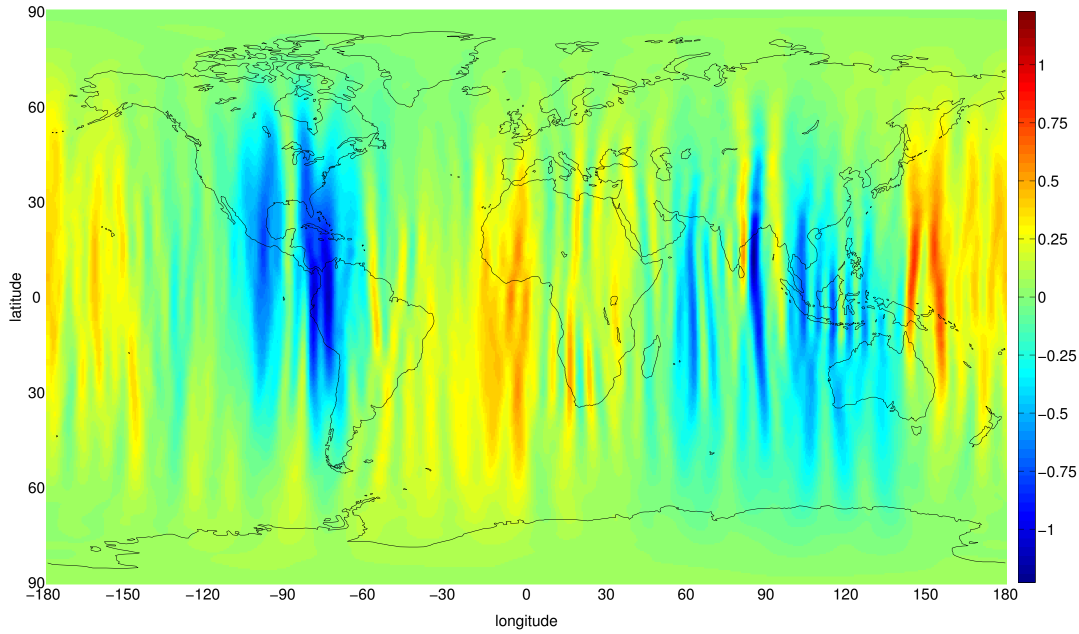

Fig. 2.10: *Absolute errors of our estimated spherical harmonic coefficients compared to given values and expressed in geoid heights [mm].*

Several corrections need to be applied when processing real data. We computed a set of corrections for ocean tides, solid earth tides and pole tides according to IERS 2010 Conventions. The comparison between our computations and a validation data set provided by M. Weigelt (University of Luxembourg) shows that the differences are small.

Related publications

Bouman J., Fuchs M.: GOCE gravity gradients versus global gravity field models. Geophysical Journal International, Volume 189, Issue 2, pp 846–850, doi: 10.1111/j.1365-246X.2012.05428.x, 2012

Bouman J., Fuchs M., Broerse T., Vermeersen B., Visser P., Schrama E., Schmidt M.: Modelling and observing the Mw 8.8 Chile 2010 and Mw 9.0 Japan 2011 Earthquakes using GOCE. International Association of Geodesy Symposia (accepted), 2012

[2] Mayer-Gürr T.: Gravitationsfeldbestimmung aus der Analyse kurzer Bahnbögen am Beispiel der Satellitenmissionen CHAMP und GRACE, Schriftenreihe des Instituts für Geodäsie und Geoinformation der Rheinischen Friedrich-Wilhelms-Universität Bonn, Heft 9, Bonn 2008

Bouman J., Ebbing J., Fuchs M.J.: Reference frame transformation of satellite gravity gradients and topographic mass reduction. J. Geophys. Res., doi:10.1029/2012JB009747, in press, 2012

Bouman J.: Relation between geoidal undulation, deflection of the vertical and vertical gravity gradient revisited. Journal of Geodesy, Volume 86, Issue 4, pp 287–304, DOI: 10.1007/s00190-011-0520-9, 2012

Ebbing J., Bouman J., Götze H.J., Haagmans R., Fuchs M., Meekes S., Fattah R.A.: Use of GOCE satellite gradient gravity data for forward and inverse modeling of the NE Atlantic Margin. 74th EAGE Conference & Exhibition incorporating SPE EUROPEC 2012, Copenhagen, Denmark, 4–7 June, 2012

Hirt C., Kuhn M., Featherstone W.E., Göttl F.: Topographic/isostatic evaluation of new-generation GOCE gravity field models. Journal of Geophysical Research, 117, B5, doi:10.1029/2011JB008878, 2012

3 Geodetic Earth System Modelling

The main components of the Earth system are the atmosphere (containing the subcomponents neutrosphere and the ionosphere), the hydrosphere (consisting of the oceans and the continental hydrology), the geosphere, i.e. the solid Earth, the cryosphere and the biosphere. The topics of this research field aim on improving the understanding of the dynamic processes and their interactions within these components observed by geodetic measurement techniques. Due to the close connection to other geoscience disciplines, such as geophysics, meteorology, oceanography or hydrology, complementary data from other sensors are integrated into the modelling process. The combination of all data allows for a reliable estimation of the dynamic processes, which are of great importance for monitoring climate change.

In 2012 we focussed on the estimation of oceanic polar motion excitations from the combination of time series, e.g. derived from GRACE gravity fields or sea level anomalies. We further dealt with the use of DORIS data for ionosphere modelling, we improved the modelling approaches for describing electron density variations within the ionosphere and for parameters of the WaterGAP Hydrology Model (WGHM). Furthermore, we determined lake level variations from satellite altimetry missions, we improved the ocean tides in shallow water and could provide new profiles of the instantaneous dynamic ocean topography (iDOT).

3.1 Earth system models

Estimation of oceanic polar motion excitations

Whereas the integral effect of mass displacements and motions on the Earth rotation is precisely known from geometric observation techniques such as GNSS, SLR and VLBI, the separation of contributions from particular geodynamic processes is still a challenge. The oceanic mass effect on the Earth rotation can be derived from both time variable gravity field solutions from GRACE and sea level anomalies (SLA) observed by satellite altimetry missions. Details on the preprocessing strategies were presented in last year's annual report and in Göttl (2012). Here, we compare the equatorial excitation functions $\chi_1(t)$ and $\chi_2(t)$ derived from five approaches, namely

(1) time variable gravity fields (GFZ, CSR, JPL, IGG Bonn, GRGS),
(2) sea level anomalies (AVISO, DGFI),
(3) combination of the time series used for the approaches (1) and (2),
(4) geophysical angular momenta (ECCO, OMCT), and
(5) geodetic polar motion time series EOP 08 C04 reduced by atmospheric, oceanic and hydrological mass effects and by atmospheric motion effects.

For the numerical evaluation of the first three approaches we set-up an adjustment model with a deterministic part containing the mass term $\chi_j^{\text{oceanic, mass}}(t_k)$ of monthly oceanic excitation function values with $j = 1,2$ for a total of 72 time moments t_k with $k = 1,\ldots,72$. A detailed description of the stochastic model part can be found in Göttl et al. (2012). Figure 3.1 shows the estimated results of the combination approach (3) in comparison with the excitation functions derived from the geophysical model ECCO and from the reduced polar motion time series according to the approaches (4) and (5).

Table 3.1 shows the RMS differences and correlation coefficients of the combination solutions (1), (2) and (3) as well as of the two model results (4) with respect to the reduced polar motion excitation functions following approach (5). Whereas the RMS differences are relatively large, the correlations are reasonably high. Obviously, the combination approaches as well as the ocean model results (4) agree

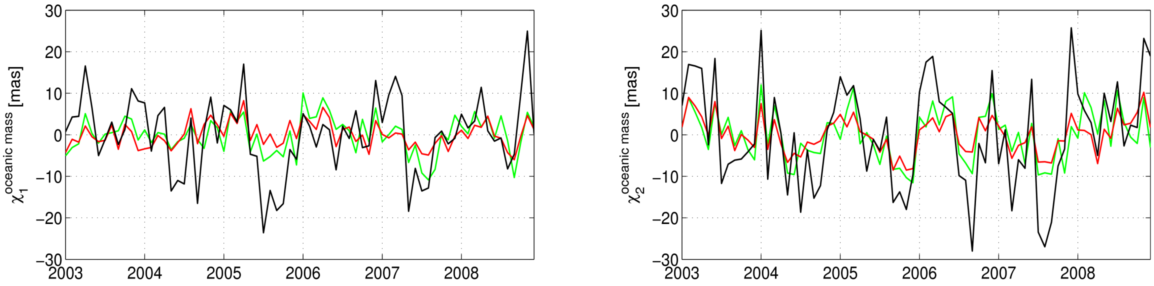

Fig. 3.1: Monthly oceanic excitation functions $\chi_j^{oceanic,\ mass}(t_k)$: Combined solution (red, (3)), model solution ECCO (green, (4)) and reduced polar motion (removed by atmospheric effects (NCEP), oceanic motion effect (ECCO) and hydrological mass effect (GLDAS) (black, (5)); offset and linear trends are removed (see Göttl et al., 2012).

Table 3.1: RMS differences and correlation coefficients between the combined solutions (1), (2), (3) and model solutions (4) w.r.t. the reduced geodetic excitation functions (5).

	χ_1 rms [mas]	χ_1 corr.	χ_2 rms [mas]	χ_2 corr.
comb. (1)	7.21	0.63	9.38	0.77
comb. (2)	9.07	0.21	9.74	0.70
comb. (3)	7.88	0.52	9.26	0.83
ECCO (4)	7.51	0.59	9.14	0.70
OMCT (4)	7.81	0.51	9.66	0.67

much better with each other than with the reduced geodetic excitations (5). As demonstrated in Fig. 3.1 the oceanic mass effect is overestimated by the reduced geodetic estimations. This is due to suffering from the geophysical model inaccuracies especially for the continental hydrosphere. Finally, it is worth mentioning that the reduced geodetic excitation functions (5) are about three times less accurate than the combined solution (3); for more details see Göttl et al. (2012).

3.2 Ionosphere

Using DORIS data for regional ionospheric VTEC modelling

Since several years, DGFI works on the combination of different space geodetic mission data for ionosphere modelling. In 2012, for the first time, we investigated the usefulness of DORIS data for modelling the vertical total electron content (VTEC). DORIS was primarily designed for precise orbit determination (POD) of satellites and is, therefore, on board of many low Earth orbiters (LEO) such as Envisat, Jason-1 and Jason-2. The satellite receivers collect Doppler measurements of signals from a worldwide network of ground-based beacons. As DORIS measures with two different frequencies, the signals can be used to extract information on the electron density distribution.

Older DORIS receivers (e.g. on board of Jason-1) only provide relative TEC data (temporal derivatives) since the main observations are Doppler measurements. However, the new DORIS receiver type DGXX (on board of Jason-2, Cryosat-2, and HY-2A) directly provides phase measurements which are very similar to GNSS measurements. We used data from Jason-2 for a test period of two weeks in 2008 (CONT08) to include them in our regional ionosphere model. As a test region we used Hawaii and combined the DORIS data from station Kauai (KOKB) with data from terrestrial GNSS, COSMIC, VLBI, and altimeter measurements from Jason-1 and Jason-2 (see Fig. 3.2).

Before being included in the ionosphere model, some preprocessing steps have to be performed to derive VTEC values from the DORIS measurements. Most of them are very similar to the preprocessing of terrestrial GNSS measurements, such as the computation of STEC (slant TEC) values from ionospheric delay and the mapping of STEC to VTEC. However, as the DORIS pseudo-range measurements are not usable for ambiguity fixing, the absolute level of the DORIS ionospheric effect must be adjusted by

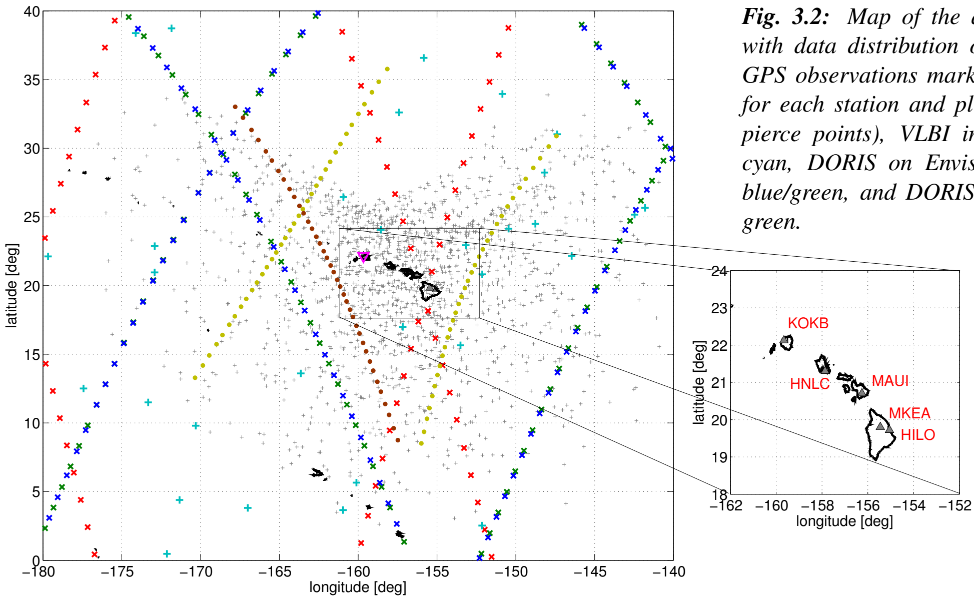

Fig. 3.2: *Map of the area under investigation with data distribution over 24 h (2008-08-24). GPS observations marked in grey (one triangle for each station and plus signs for ionospheric pierce points), VLBI in magenta, COSMIC in cyan, DORIS on Envisat in red, Jason-1/2 in blue/green, and DORIS asc/desc in brown/light green.*

means of external information. We used Global ionospheric maps (GIM) of IGS for this purpose. The preprocessed (and leveled) DORIS VTEC shows differences w.r.t. IGS maps of less than 1 TECU (RMS) for ascending passes (night time) and 1 to 2 TECU for descending passes (around noon). The differences w.r.t. other models are slightly higher, particularly for descending passes as shown in Fig. 3.3.

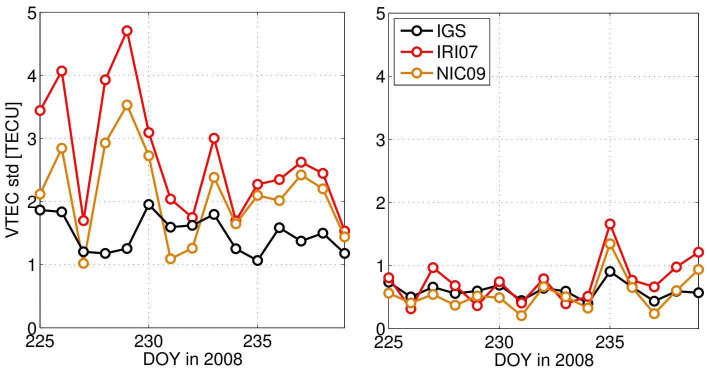

Fig. 3.3: *Standard deviations of VTEC differences between DORIS VTEC and three VTEC models for ascending (left) and descending DORIS passes (right).*

Our regional VTEC model uses a variance component estimation (VCE) to automatically weight the data of the various space geodetic techniques. In order to get an impression of the sensitivity of the different observations for ionosphere parameter estimation, the VCE results were analyzed. The estimated variance components (VC) for the different data groups are shown in Fig. 3.4. A small factor indicates high accuracy of the data set and leads to a high weight within the iterative parameter estimation. It can be seen that the factors for DORIS are smallest, followed by GPS.

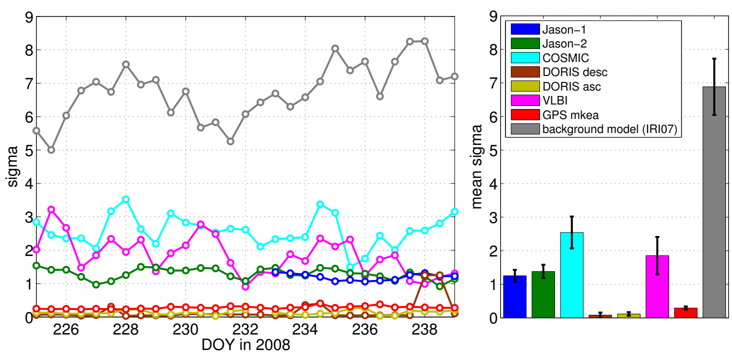

Fig. 3.4: *Estimated VCE results: standard deviation factors $\widehat{\sigma}_i$. The left panel shows the 15 days time series for each observation group and the right panel the mean standard deviation factors for the whole period. The factors have no unit and must be interpreted together with the weight matrices.*

The DORIS data of ascending passes are superior to those of descending passes. An example for a

VTEC map for the region under investigation is shown in Fig. 3.5 together with the formal errors and the background model. More details on the processing and evaluation of DORIS data for ionosphere parameters can be found in Dettmering et al. (2012). Since these first tests have been very promising we will continue our activities on DORIS, especially for including these measurements into DGFI's 4-dimensional model approaches.

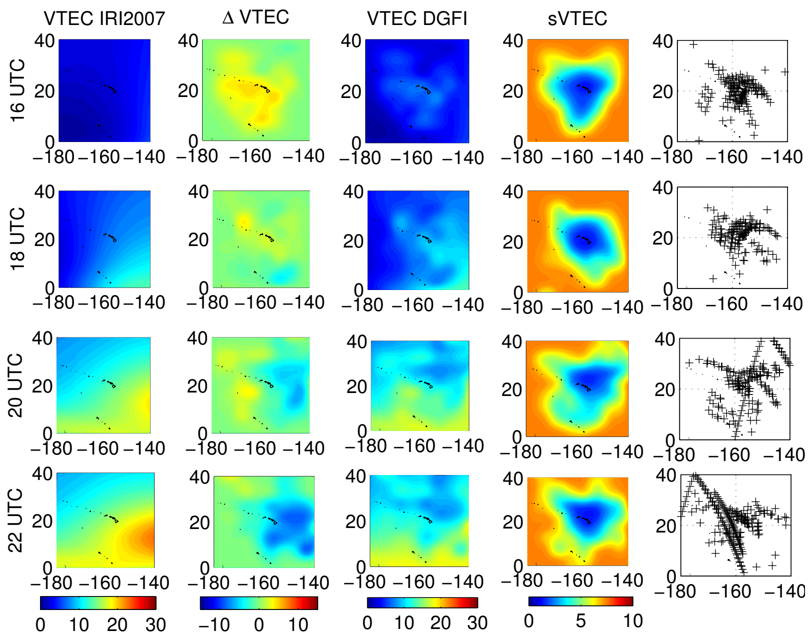

Fig. 3.5: Estimated VTEC for four epochs on August 24, 2008 (one row per epoch). The first column shows the background VTEC from IRI-2007, the second column the estimated ΔVTEC, the third column the DGFI VTEC (i.e. the sum of the first two columns), and the fourth column the standard deviations of the estimated VTEC, all values in [TECU]. In the last column the distribution of the input data is shown.

Multi-dimensional ionosphere model from the combination of space geodetic techniques (MuSIK)

Since 2011 a physics-motivated 4-D modelling approach has been developed within the DFG project MuSIK by a cooperation with the Institut für Astronomische und Physikalische Geodäsie (IAPG) of the Technische Universität München (TUM) and the German Aerospace Center (DLR) in Neustrelitz.

In our model, the vertical distribution of the electron density $N_e^{F2}(h)$ is described by a Chapman function for the ionospheric F2-layer and an additional plasmasphere term $N_e^P(h)$ according to

$$\begin{aligned} N_e(h) &= N_e^{F2}(h) + N_e^P(h) \\ &= N_m^{F2} \cdot \exp\left[0.5 \cdot \left(1 - z - \exp(-z)\right)\right] + N_0^P \cdot \exp\left[-|h - h_m^{F2}|/H^P\right] \end{aligned} \tag{3.1}$$

with $z = (h - h_m^{F2})/H^{F2}$ and $H^P = 10$ km for $h < h_m^{F2}$. As already described in last year's annual report, each of the key parameters (the F2 peak electron density N_m^{F2}, the corresponding peak height h_m^{F2}, the scale height H^{F2}, the plasmasphere basis density N_0^P and the plasmasphere scale height H^P) is decomposed into a background model part and an unknown correction term. The latter is modeled as a series expansion in terms of tensor products of three one-dimensional B-spline functions depending on longitude, latitude and time, respectively; the corresponding series coefficients are the unknowns of our approach. Since one of the features of the project is to transfer the results into a multi-scale representation (MSR), the coefficients have to be introduced into the pyramid algorithm for generating the MSR (see e.g. Schmidt, 2012). For the linearization of the electron density profile (Eq. 3.1) regarding h_m^{F2} and H^{F2}, a background model is used to calculate the initial values of the coefficients. Next, the unknown corrections to the series coefficients are estimated iteratively.

In 2012 several issues have been studied in detail by using simulated observations for the area of South America which covers the equatorial anomaly, e.g. the

(1) convergency as regards the estimation of the key parameters N_m^{F2}, h_m^{F2} and H^{F2},

(2) performance of the model using different noise levels for the observations,
(3) correlations between the key parameters N_m^{F2}, h_m^{F2} and H^{F2},
(4) handling of data gaps.

In the following we point out some details related to this list. In order to verify the performance of our model, we simulated homogeneously distributed hourly STEC observations and added random noise; for that purpose we use "true values" for the key parameters derived from the International Reference Ionosphere (IRI-2007). Related to the time interval between 6:00 h and 7:00 h at July 1, 2002 (high solar activity) the scale height values H^{F2} are restricted to $H^{F2} \in [63.69, 76.71]$ km. Next we estimated the B-spline coefficients of the series expansions for the selected key parameter H^{F2}. Figure 3.6 (top left panel) shows the deviations between the estimated scale height $\widehat{H}^{F2}$ and the "true" model values for 6:30 h. In this example the standard deviation of the added noise is 1% of the mean value of the total simulated STEC data set within the scenario. Relatively large deviations occur in the south-eastern part. If we look at the corresponding IRI-2007 VTEC map at the same time (bottom left panel), it can be seen that in the south-eastern part the VTEC values are smaller. Since the standard deviation of the random noise is based on the total signal, the noise-to-signal ratio of the simulated ray paths in the south-eastern part is larger as in the other regions and causes the larger deviations between the estimation and the "truth". To verify this assumption we chose a second example for the time interval between 13:00 h and 14:00 h on July 1, 2008 (low solar activity). In this case larger deviations occur in the south-western part, because in this area the signal is weaker than in the other parts of the area under investigation. Consequently, using simulated STEC observations with 1% signal dependent noise, the results show that the problems are not existent anymore, which also supports our conclusion.

The accuracy of our model using simulated STEC observations with a noise level of 1% of the total

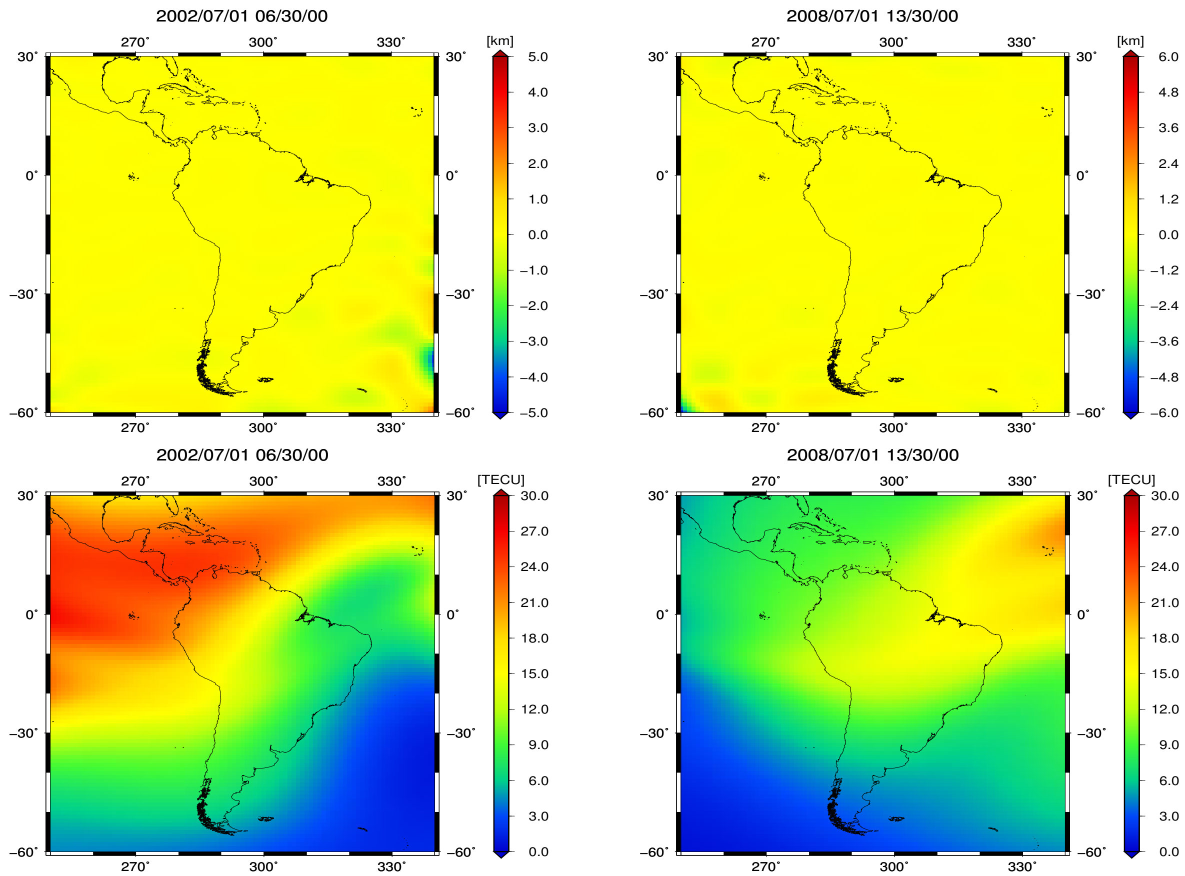

Fig. 3.6: Deviations of the estimated scale height $\widehat{H}^{F2}$ and the "true" values H^{F2} for 6:30 UT on July 1st, 2002 (top left panel) and for 13:30 UT on July 1, 2008 (top right panel), and VTEC from IRI-2007 (the corresponding bottom panels), $1\,TECU = 10^{16}\mathrm{el/m^3}$.

signal as regards the estimation of one or more key parameters are shown in Table 3.2. The estimated standard deviations $\widehat{\sigma}$ of the STEC observations are consistent with the noise level (since the mean value of the total simulated STEC observations is around 21 TECU, the a priori standard deviation amounts to $1\% \cdot 21$ TECU $= 0.21$ TECU).

Table 3.2: *Accuracies of the B-spline model as regards different key parameters estimated from simulated STEC observations with 1% noise level; RMS values are computed from the deviations w.r.t. the "true" values; $\widehat{\sigma}$ values are the estimated standard deviations of the observations.*

selected key parameters	RMS of N_m^{F2} deviations [el/m^3]	RMS of h_m^{F2} deviations [km]	RMS of H^{F2} deviations [km]	est. std. dev. of obs. $\widehat{\sigma}$ [TECU]
h_m^{F2}	–	1.238	–	0.208
H^{F2}	–	–	0.263	0.207
N_m^{F2}, h_m^{F2}	$6.498 \cdot 10^8$	2.255	–	0.208
h_m^{F2}, H^{F2}	–	1.981	0.355	0.208

Since H^{F2} can be approximated by the ionospheric slab thickness τ ($H^{F2} = \tau/4.13$) and $\tau = \text{VTEC}/N_m^{F2}$, the relation $H^{F2} = \text{VTEC}/4.13 \cdot N_m^{F2}$ holds. Obviously a strong negative correlation exists between N_m^{F2} and H^{F2}; accordingly high correlations and large noise-to-signal ratios cause a convergence problem.

Since ground-based GNSS observations provide the integrated ionospheric information in terms of STEC according to STEC $= \int_R^S N_e ds$, the stability of the model can be balanced by measurements of electron density profiles. In addition to the procedure derived above for one single observation technique, the routine has been extended to a multi-technique approach which allows to introduce multiple observation techniques. The unknown B-spline coefficients are then determined by a variance component estimation (VCE) which accounts for the relative weighting of the observation techniques as well as for the accuracies of the key parameters. First investigations have been accomplished by using electron density profiles of GRACE and CHAMP to determine the key parameters by our project co-worker Marco Limberger (TUM). Figure 3.7 shows the location of electron density profiles from radio occultation data as well as ground tracks for GNSS.

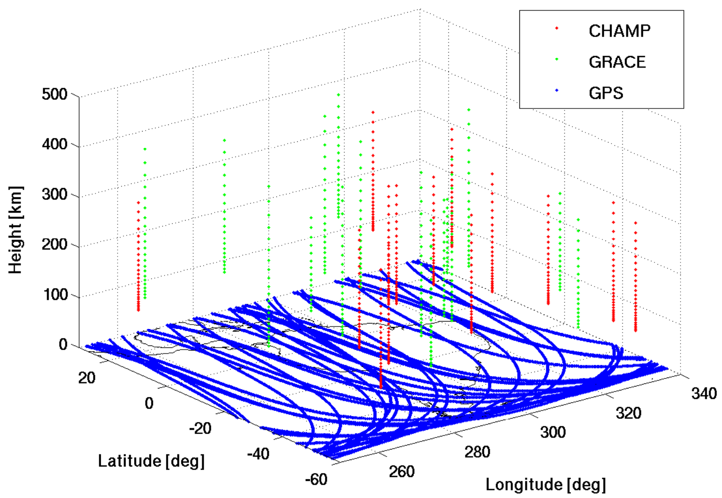

Fig. 3.7: *Distribution of real observations in South America for July 1, 2008. The ground tracks of GPS observations received from the SIRGAS network (blue lines), the vertical profiles from CHAMP (red points) and from GRACE (green points).*

3.3 Continental hydrology

Improvement of WGHM model parameters

The total continental water storage is composed of a variety of storage compartments, including surface water such as rivers, wetlands, lakes and man-made reservoirs, soil moisture, snow, ice and groundwater. According to the Intergovernmental Panel on Climate Change (IPCC) 2007 report the continental hydrology is still the most uncertain part of the global water cycle.

Hydrological models suffer from uncertainties with regard to model structure, input data and model parameters. The modern satellite missions can be used to improve selected model parameters. Within the DFG SPP1257 project 'Consistent estimation of water mass variations in different continental storage compartments by combined inversion of a global hydrological model with time-variable gravity and complementary observation data (CEMIG)' which is a cooperation of DGFI and GFZ the Water Global analysis and prognosis Hydrological Model (WGHM) was selected. WGHM is a conceptual water balance model with a spatial resolution of $0.5^\circ \times 0.5^\circ$ and a temporal resolution of 24 hours which simulates the continental water cycle by using conceptual formulations for the most important hydrological processes. A procedure for improving WGHM model parameters from satellite data is investigated in this project.

There are series of calibration parameters for WGHM, e.g., the runoff coefficient γ, the Priestley-Taylor (PT) coefficient α or the river velocity. The PT coefficient was identified by a sensitivity analysis as one of the most sensitive parameters. In the standard WGHM approach α is set to 1.26 and 1.74 in humid and arid regions, respectively. It is used to calculate the potential evapotranspiration in WGHM based on the approach of Priestley and Taylor in 1972[1]. Figure 3.8 shows the sensitivity of α related to two WGHM model outputs, namely the actual evapotranspiration (AET) and the total water storage (TWS) deviation.

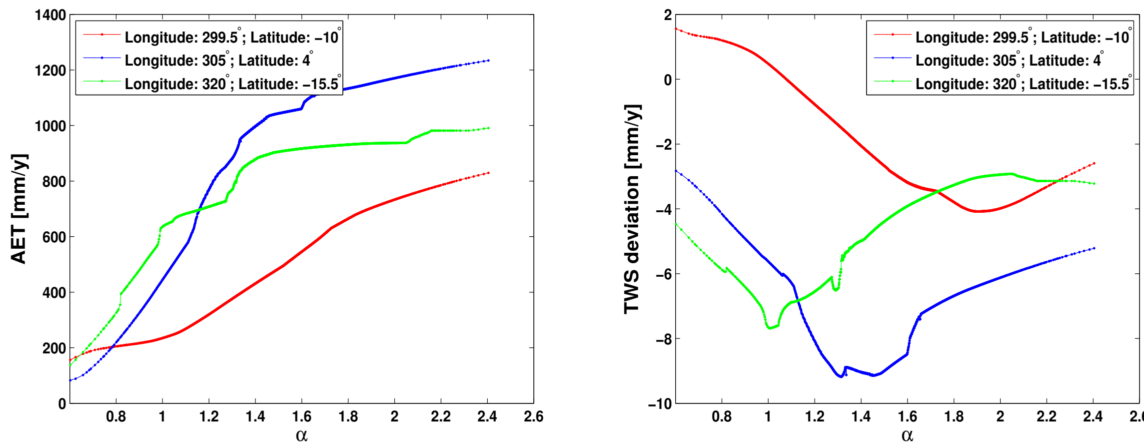

Fig. 3.8: Variations of the WGHM outputs AET (left) and TWS deviation (right) depending on the PT coefficient α for selected locations in the Amazon Basin.

Due to the variations of these two outputs w.r.t. α, the limitation to only two different α values is not appropriate. Therefore, we introduce a representation of α as a series expansion

$$\alpha(\boldsymbol{d}) \;=\; \sum_{k_1=0}^{K_1-1} \sum_{k_2=0}^{K_2-1} d_{k_1,k_2}\, \phi_{k_1}(\lambda)\, \phi_{k_2}(\varphi)$$

in terms of tensor products of two one-dimensional B-spline functions ϕ_k depending on the geographical longitude λ and latitude φ, respectively. The unknown series coefficients d_{k_1,k_2}, collected in the vector $\boldsymbol{d} = (d_{k_1,k_2})$ can be estimated from MODIS-based (Moderate Resolution Imaging Spectroradiometer)

[1] Priestley C.B.H. and R.J. Taylor: *On the assessment of surface heat flux and evaporation using large-scale parameters*. Monthly Weather Review, 100, 81-92, 1972.

AET products and GRACE TWS variations. Since the relations between the WGHM outputs and α are non-linear, a Monte Carlo simulation with 2000 runs with stratified sampling of α from a truncated normal distribution with a mean of 1.5 and a standard deviation of 0.3 was performed by Martin Wattenbach, co-worker of the project CEMIG at GFZ. We established a linearized observation equation system by using Taylor expansion. The first derivatives of WGHM w.r.t. α within the Taylor expansion are derived by the finite difference method from the 2000 model runs. Due to the linearization, the unknown series coefficients have to be estimated by an appropriate parameter estimation procedure using an iterative algorithm. The general estimation procedure from AET observations is shown in Fig. 3.9.

In order to verify the performance of the derived method we simulated AET observations according to defined random α values (i.e., the "true" values) from the 2000 model runs (see the left panel of Fig. 3.10) and added normally distributed random noise. We assume α as the mean value of the 2000 α samples, i.e., the average of the standard values 1.26 and 1.74 which is used to calculate the initial coefficients α_0. The final estimated $\widehat{\alpha}$ map using AET observations with a noise level of 10% of the total signal is shown in the right panel of Fig. 3.10. The RMS of $\widehat{\alpha}$ deviations w.r.t. the "true" values of α over the continent amounts to 0.056. The estimated standard deviation $\hat{\sigma}$ of AET observations is around 48 mm, which is

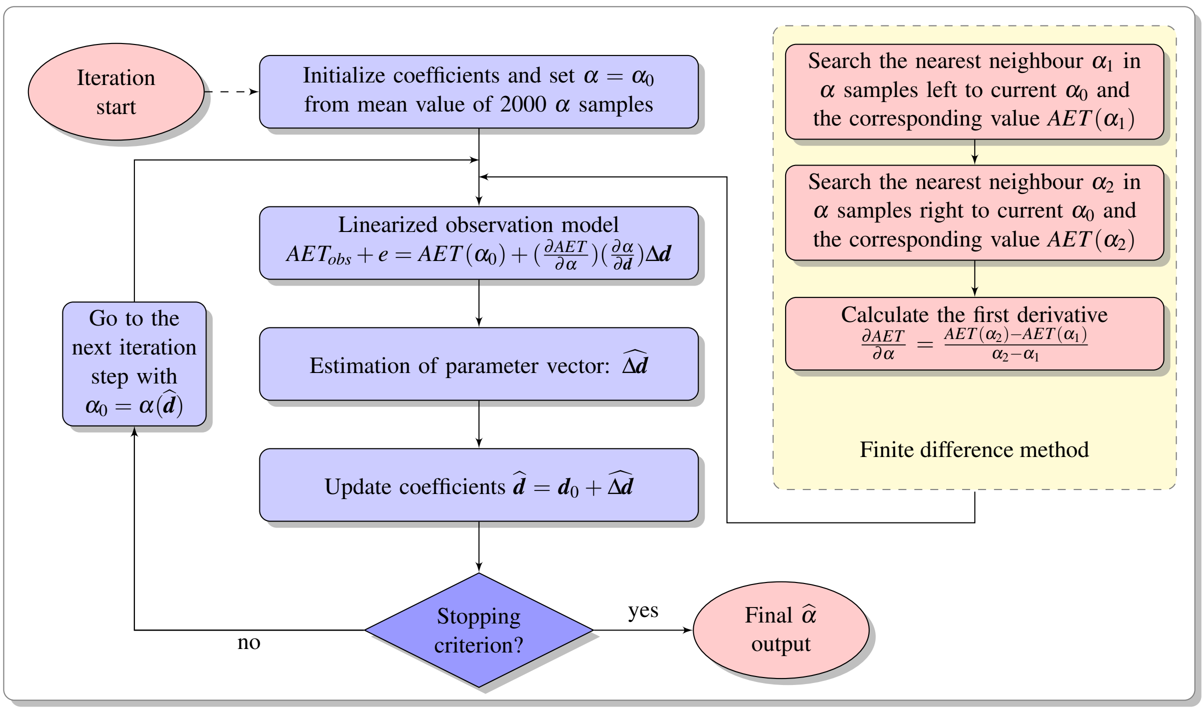

Fig. 3.9: Iterative algorithm for the α estimation (left) from AET observations and finite difference (here central difference) method for the estimation of the first derivative of WGHM w.r.t. α within the Taylor expansion (right).

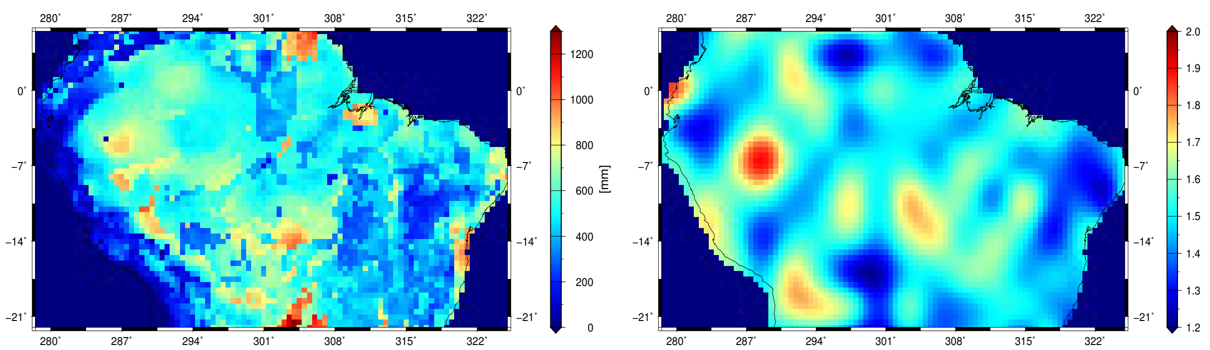

Fig. 3.10: Simulated AET observations from WGHM without considering noise for 2003 within the area of investigation (left) and the final estimated $\widehat{\alpha}$ map (right).

comparable to the noise level (the mean value of the total simulated AET is around 492 mm, the standard deviation of the noise is 10%·492 = 49.2 mm).

Determination of lake levels by using satellite altimetry

Satellite altimetry originally designed for ocean applications has been proven to be also a valuable technology for monitoring coastal zones and inland water. However, close to the shore or over inland water the altimeter waveforms do not have the typical ocean-like shape. The contamination of the radar signal by land areas leads to waveforms which are peaky and noisy and require dedicated retracking algorithms. Knowing the shape of the waveform allows to decide which is the best suited retracking algorithm. In the following we explain our method for classifying radar echos, retracking waveforms and determining lake levels using a Kalman filter.

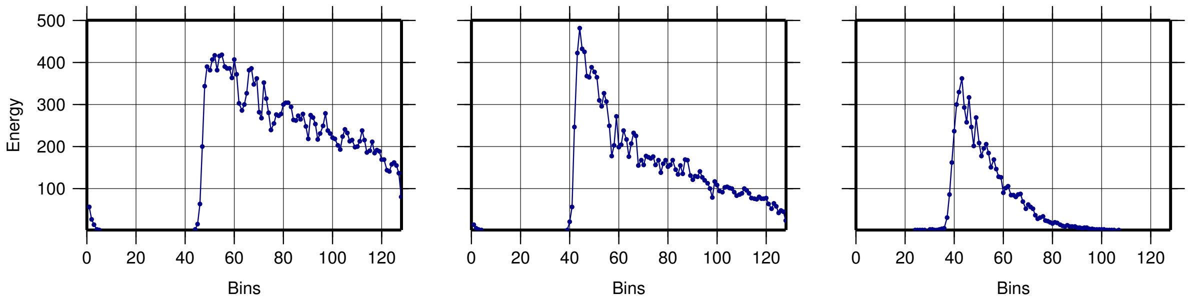

Fig. 3.11: Examples of radar echos over oceans ('Brown linear';left) and coastal zones/inland water ('peak Brown' (mid) and 'Brown exponential' (right)).

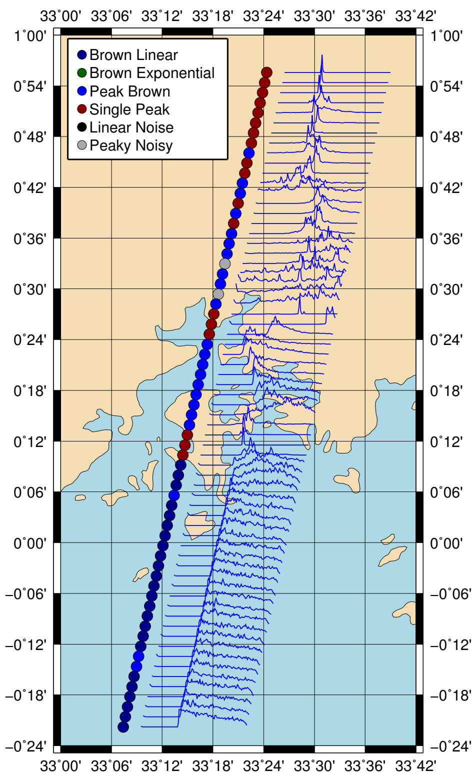

Fig. 3.12: Classification of an altimeter track for the land-water transition over Lake Victoria. Each waveform is assigned to one class.

The Support Vector Machine (SVM) is an algorithm used for the classification of radar altimeter waveforms to decide which retracking algorithm has to be applied. The SVM is a mathematical method of pattern recognition which divides objects into classes by using features. The classification is performed in two steps, the training and the prediction step. The objective of the SVM is to separate classes by a hyperplane where the width of the hyperplane is maximized. In our case the class is a type of waveform characterized by the shape, which can be for example 'Brown linear', 'peak Brown' or 'Brown exponential' (see Fig. 3.11), etc. For the distinction between classes suitable features such as kurtosis, skewness, peakiness, maximum power, etc. have to be selected.

The following methodology of SVM for classifying altimeter waveforms was used. In the first step training sets have to be created which means that waveforms are assigned manually to specific waveform classes. The resulting training sets are the input data for the SVM training step where a SVM model is computed which contains a decision function to assign each input waveform to exact one class with respect to the features of each class. In the prediction step this method was applied to an unknown data set of waveforms to classify each of them. The resulting information about the shape of the waveform is used to select a suitable retracking algorithm in the next step (see Fig. 3.12).

The objective of a retracking algorithm is to estimate the range of the altimeter measurement by analyzing the returned radar echo. Therefore we implemented some of the well-know retracking algorithms such as (1) the Beta-parameter Retracker, (2) the Offset Centre of Gravity Retracker (OCOG), and (3) the Maximum Likelihood Estimator (MLE). Each waveform has its own strength in retracking a special shape of waveform where the accuracy is very high. For ocean-like waveforms the Beta-parameter and MLE retracker achieve very good accuracies. However, in coastal zones these retrackers are often not able to analyze those waveforms due to the non-ocean-like shapes. In this case other retrackers such as the robust OCOG retracker show good results for peaky waveforms. In our studies different retracking algorithms were used to improve official ranges over rivers and lakes.

For the estimation of gridded orthometric lake heights we use the method of Kalman filtering. This algorithm uses time-dependent altimeter measurements as input data. We utilize altimeter data from all available missions such as Envisat, GFO, Topex, Jason-1, etc. All missions are cross-calibrated which enables us to use them as single altimeter systems. Depending on the extent of the investigated water body we use 1 Hz, high-frequent or retracked altimeter data.

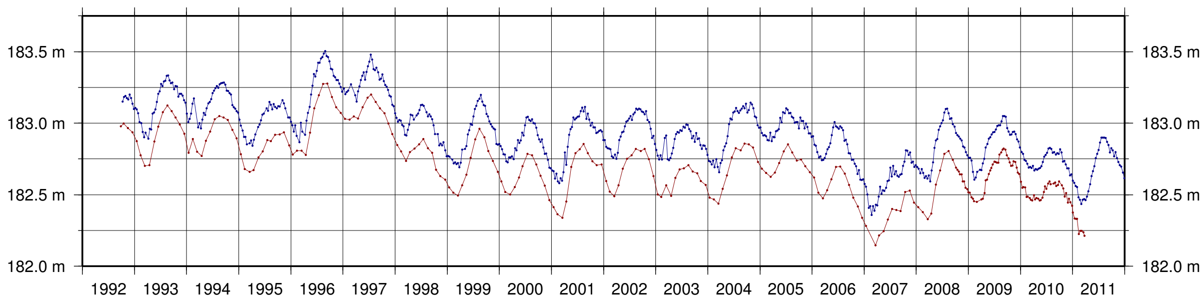

Fig. 3.13: *Orthometric heights of Lake Superior derived with Kalman filter approach (blue) and official LEGOS time series (red) from 1992–2011*

The resulting time series for Lake Superior (see Fig. 3.13) reflects the seasonal variations and trends very well. A comparison with time series from the LEGOS hydroweb shows also a very good agreement. The remaining height offset can be explained by different geoid models (we are using a GOCE-based and LEGOS uses a GRACE-based model). The estimated correlation coefficient for the time series of Lake Superior of 0.989 shows a very good agreement.

3.4 Ocean

Tides in shallow water

Modern global tide models exhibit a high accuracy over the deep ocean but are still to be improved in shallow water. On the one hand the accuracy and resolution of the astronomic tides must be increased. On the other hand the tidal regime is complicated and non-linear tides and long period modulations of astronomic tides become significant. Dedicated analyses proved that the length and accuracy of the combined multi-mission altimeter time series allows insight into weak non-linear effects. The approach accumulates normal equation matrices on the nodes of a geographical grid considering correlations between the measurements of one pass. The weighting was controlled by means of a Gaussian function with varying half width. Due to the ground track density we did not go below a half width of 0.25°. For diurnal tides the most appropriate half width is 0.5°. Half of this is adequate for the semi-, quarter- and sixth-diurnal tides. Due to the weaknesses of signals of other species a stronger smoothing must be applied to mitigate the noise of altimeter data. Thus, the optimal half width has to be between 0.33° and 0.75°. The best total accuracy of particular solutions is achievable if the smallest smoothing is applied. The seasonal modulations of the semidiurnal M_2-tide (with the annual periodicity of the Sun's longitude subtracted, MA_2, or added, MB_2, see Fig. 3.14) are difficult to validate because such estimates cannot be derived from bottom pressure data. However, the agreement with the constants from coastal tide gauge data, indicated by coinciding colours between ocean surface (altimetry analysis) and triangles (tide analysis) is rather good.

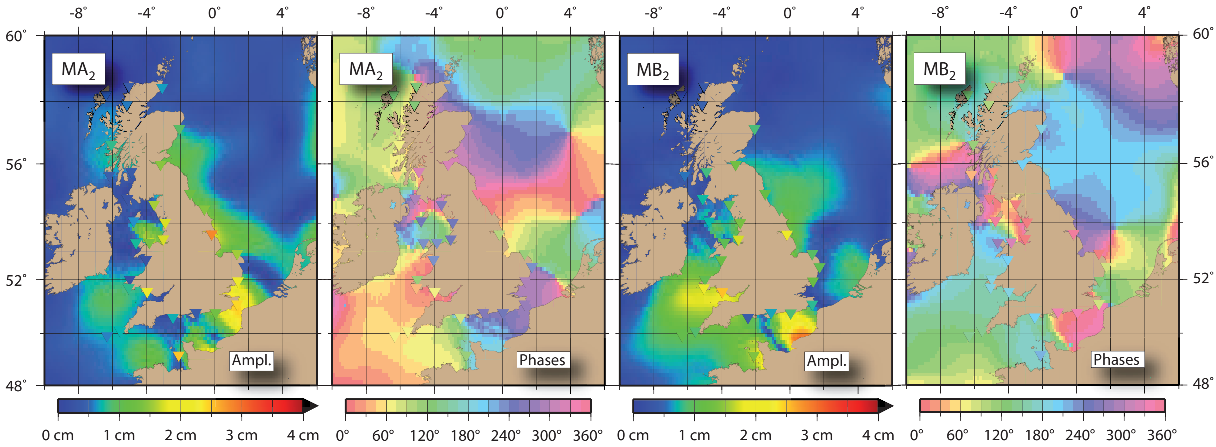

Fig. 3.14: *Seasonal modulations of M_2 (MA_2 and MB_2 correspond to Doodson numbers 254.555 and 256.555, resp.). The tidal constants from tide gauges of the UK tide gauge network are shown by means of inverted triangles.*

Dynamic ocean topography

The profile approach adopted by DGFI for the estimation of the dynamic ocean topography (DOT) was proven to be a powerful tool which can be applied as close to the coast as data availability allows. In contrast to alternative approaches the profile approach provides instantaneous DOT (iDOT) profiles which can be used to study the temporal evolution of the ocean topography and of the associated circulation pattern. The recently published gravity field GOCO03 based on GRACE and GOCE data was used for a reprocessing of iDOT profiles for nearly the complete holdings maintained by the OpenADB altimeter data base. A Gaussian filter with the length of 70 km was found to be appropriate for smoothing the altimeter height profiles and for the removal of unreliable high-degree components in the geoid while maintaining meso-scale features like eddies.

Figure 3.15 shows an application of a sequence of iDOT profiles in the north-west Atlantic. In this area, track 50 of Jason-1 crosses the meandering Gulf Stream at about 37° North (left panel). The colour code in Fig. 3.15 (right panel) indicates that the Gulf Stream position is varying seasonally with the most southern position in winter and the most northern position in late summer; the figure shows results related to a time span of about two years. Moreover, the mean slope of the iDOT profiles at 37° amounts to some $9 \cdot 10^{-6}$ rad (1 m dynamic height differences over a latitude distance of 1° or 110 km). This corresponds to a mean cross-track velocity of some 1 m/s – typical for the strong western boundary currents. The new iDOT profiles of the most important altimeter missions are provided on DGFI's anonymous ftp server (ftp://ftp.dgfi.badw.de/pub/iDOT/).

Related publications

Bosch W., Savcenko R., Dettmering D., Schwatke C.: *A two decade time series of eddy-resolving dynamic ocean topography (iDOT)*. Proceedings of 20 years of Progress in Radar Altimetry Symposium, Venice, Italy, ESA SP-710, ESA/ESTEC (accepted), 2012

Dettmering D., Schmidt M., Limberger M.: Contributions of DORIS to ionosphere modeling. Proceedings of 20 years of Progress in Radar Altimetry Symposium, IDS Workshop, Venice, Italy, ESA SP-710, ESA/ESTEC (accepted), 2012

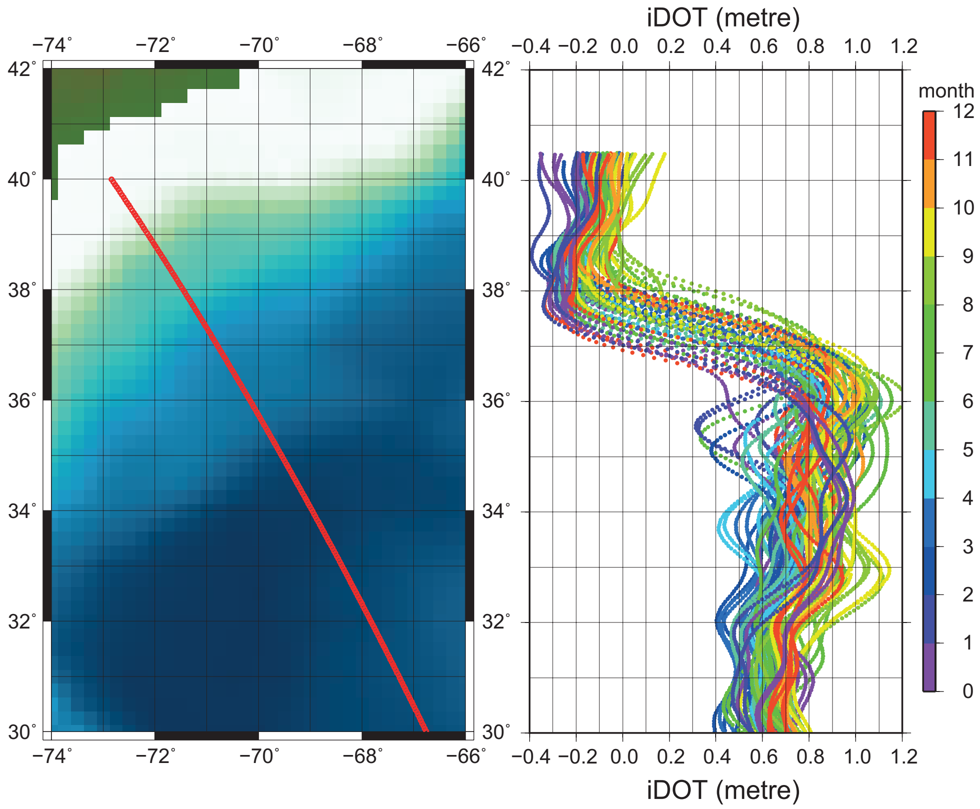

Fig. 3.15: *Jason-1 track 50 crossing the Gulf stream (left); sequence of iDOT profiles for a time period of about two years along track 50 (right).*

Göttl F.: *Kombination geodätischer Raumbeobachtungen zur Bestimmung von geophysikalischen Anregungsmechanismen der Polbewegung*. PhD thesis, Technische Universität München, http://nbn-resolving.de/urn/resolver.pl?urn:nbn:de:bvb:91-diss-20120806-1100728-0-0, 2012

Göttl F., Schmidt M., Heinkelmann R., Savcenko R., and Bouman J.: Combination of gravimetric and altimetric space observations for estimating oceanic polar motion excitations, J. Geophys. Res., 117, C10022, doi:10.1029/2012JC007915, 2012

Schmeer M., Schmidt M., Bosch W., Seitz F.: Separation of mass signals within GRACE monthly gravity field models by means of empirical orthogonal functions. Journal of Geodynamics 59-60, 124-132, Elsevier, DOI 10.1016/j.jog.2012.03.001, 2012

Schmidt M.: *Towards a Multi-Scale Representation of Multi-Dimensional Signals*. Sneeuw N. et al. (Eds.), ”VII Hotine-Marussi Symposium on Mathematical Geodesy”, IAG Symposia, 137:119-127, DOI: 10.1007/978-3-642-22078-4_18, 2012

Schmidt M., Göttl F., and Heinkelmann R.: *Towards the combination of data sets from various observation techniques*. Proceedings of the 1st Int. Workshop on the Quality of Geodetic Observation and Monitoring Systems (QuGOMS) 2011, Munich (accepted) , 2012

4 Methodological Foundations

Research on methodology has been identified as a cross-sectional field of activities serving all other research areas. This includes the development of generic methods and algorithms, to be implemented in a numerically efficient way, to be tested, documented and maintained such that its application leads to robust results in short time allowing sound decisions in research and development. In addition, acquisition, backup, documentation and long-term storage of primary data must be taken into account in order to provide the longest possible time series of observations related to a reproducible geodetic reference frame for reliable findings in Global Change studies. Also, current analysis methods are to be reviewed, the validity of their assumptions is to be verified in order to identify deficits or inconsistencies in the modelling and to deduce recommendations for an improved parameterisation.

In 2012, four topics have been considered in detail. The analysis and exploitation of data from the GOCE gradiometer mission is faced with the problem that two out of six tensor elements are observed with degraded accuracy. Numerical methods and parameter estimation were developed to avoid that, by tensor rotation, errors of these two elements are smeared up to other elements. By the GGOS Bureau for Standards and Conventions (BSC) a product-based inventory has been performed to review existing conventions and to identify inconsistencies. Besides, a stable algorithm for the computation of derivatives of Legendre polynomials has been coded. It is based on a recurrence relation, which can be applied repeatedly to obtain, e.g., second order derivatives. Finally, DGFI's software for orbit and geodetic parameter estimation (DOGS) has been extended by a DOGS-RI component dedicated to the interferometric observation of astronomic radio sources at terrestrial stations. For satellite laser ranging several models for atmospheric and oceanic loading effects were implemented.

4.1 Numerical methods and parameter estimation

The Gravity field and steady-state Ocean Circulation Explorer (GOCE) is the ESA's gravity satellite that delivers valuable new gravity field information. GOCE is the first satellite ever to measure the complete gravity gradient tensor even though two of the off-diagonal gradients are measured with a much lower accuracy than the other gradients. The former components are about a factor of 100 less accurate than the latter and in practice the measurement of the gravity gradient tensor is incomplete. In addition, the GOCE gravity gradients are given in the Gradiometer Reference Frame (GRF), which is an instrument frame that rotates with respect to the Earth. In order to relate the gradients to an Earth-fixed frame the tensor needs to be rotated. A direct rotation from the GRF to any other frame would project the error of the less accurate gradients onto the other gradients, which is undesirable. Consequently, the direct use of GOCE gravity gradients is not straightforward.

Here we discuss the estimation of the less accurate gradients V_{XY} and V_{YZ} from the accurate gradients V_{XX}, V_{YY}, V_{ZZ} and V_{XZ}. The idea is that in orbit crossovers the gradient tensors of ascending and descending tracks are equal when rotated to a common reference frame. The accurate gradients are considered as the observations, whereas the less accurate gradients are the unknowns. The advantage would be that one obtains V_{XY} and V_{YZ} gradients with a much better accuracy, which would allow a direct rotation from the GRF to other reference frames, or e.g. the computation of gravity gradient tensor invariants.

Figure 4.1 shows the estimated standard deviation of the V_{XY} and V_{YZ} gradients relative to the standard deviation of V_{XX} in GOCE orbit crossovers. We used one month of data, filtered to the measurement bandwith (MBW) where the GOCE gradients have the highest accuracy. In general, the standard deviation is largest close to the equator and decreases towards the poles. Singularities for V_{XY} occur around 80 degree latitude because ascending and descending tracks are perpendicular there and the system of observation equations becomes singular. Also close to the poles singularities occur as the angle between

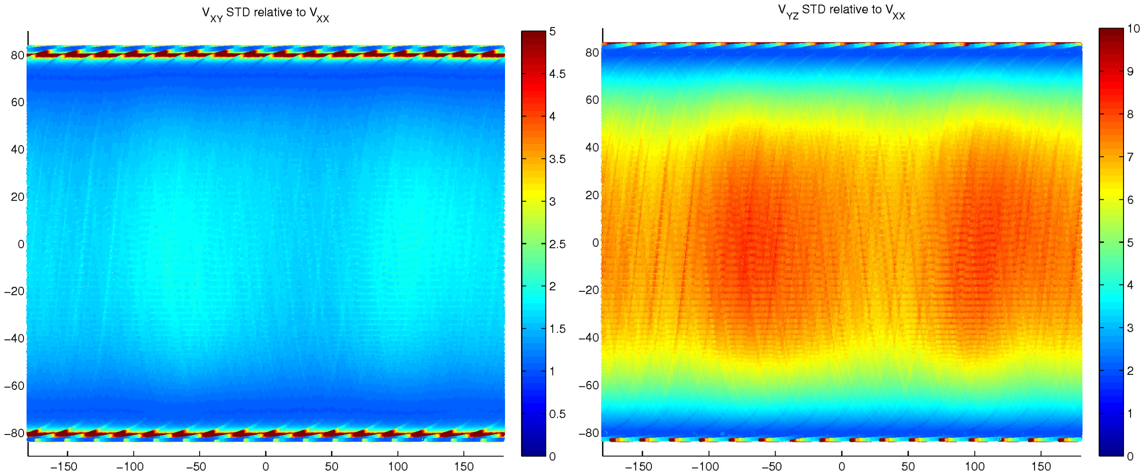

Fig. 4.1: *Standard deviation of V_{XY} (left) and V_{YZ} (right) relative to V_{XX} in crossovers.*

ascending and descending tracks approaches 180 degrees. The standard deviation of V_{XY} is smaller than that of V_{YZ} because the latter is mainly a function of V_{XZ}, whereas the former is a function of V_{XX} and V_{YY} which are more accurate than V_{XZ}.

The differences of the estimated V_{XY} and V_{YZ} gradients with respect to a GOCE global gravity field model are shown in Fig. 4.2. The colour scales have been set to ± 10 mE and ± 25 mE for V_{XY} and V_{YZ}, respectively. As expected from the error propagation in Fig. 4.1 the V_{XY} errors are smaller than the V_{YZ} errors, and the singularities for high latitudes are clearly visible. This is also reflected in the global standard deviation of the V_{XY} errors, which is greater than the error standard deviation of the original data (see Table 4.1). If we limit the area for which the standard deviation is computed to latitudes $|\phi| \leq 75°$ the standard deviation of the V_{XY} errors significantly reduces. For V_{YZ} the singularity close to the poles does not seem to play a major role. In summary, one can state that the accuracy of V_{XY}, in crossovers is at the level of V_{ZZ} (ignoring the singularities), whereas the accuracy of V_{YZ} is a factor of 3 to 4 worse.

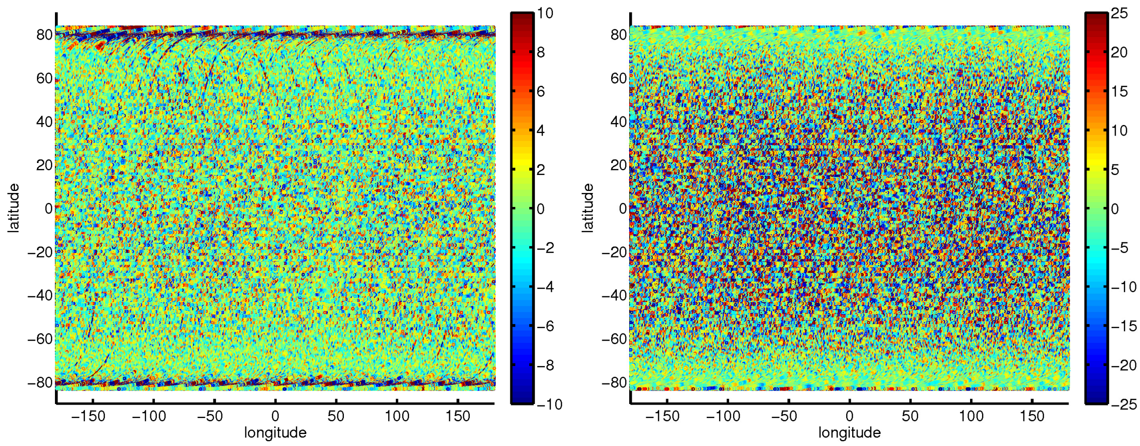

Fig. 4.2: *Errors of V_{XY} (left) and V_{YZ} (right) w.r.t. crossovers in mE $(10^{-12}/s^2)$.*

Table 4.1: *Standard deviation of gravity gradient errors in the MBW [mE].*

	V_{XY}	V_{YZ}	V_{XX}	V_{YY}	V_{ZZ}	V_{XZ}
Original GOCE data	200	160	2	2	3	4
Crossovers, global	383	10	-	-	-	-
Crossovers, $|\phi| \leq 75°$	3	12	-	-	-	-

4.2 Standards and Conventions

In 2009, the Bureau for Standards and Conventions (BSC) was established as a GGOS component (see Fig. 4.3). The BSC is hosted and supported by DGFI and the Institut für Astronomische und Physikalische Geodäsie (IAPG) of the Technische Universität München, under the umbrella of the Forschungsgruppe Satellitengeodäsie (FGS).

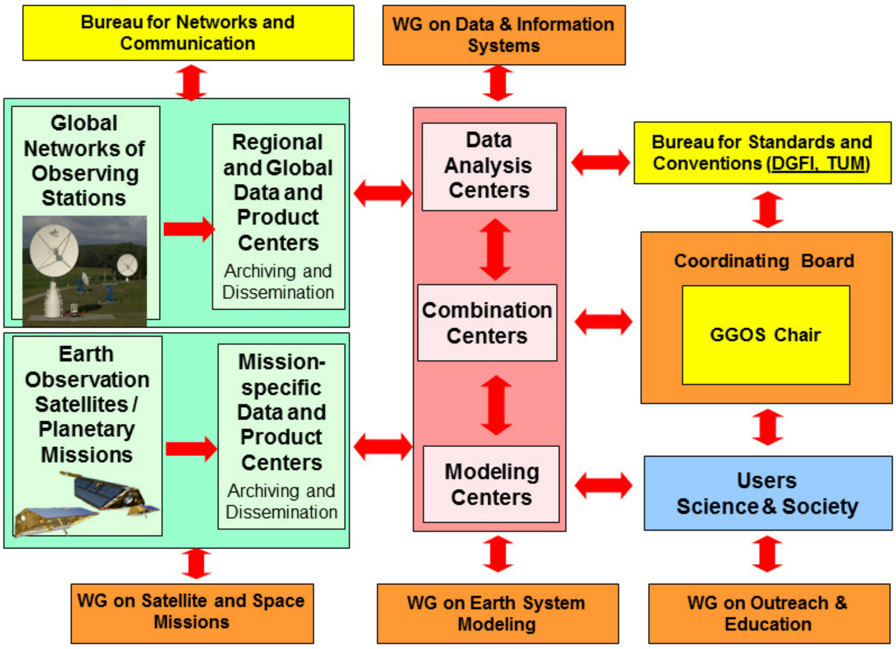

Fig. 4.3: *Organizational structure of GGOS according to M. Rothacher (ETH Zurich, 2011).*

Mission and objectives

The implementation of common standards and conventions for the generation of geometric and gravimetric products is of crucial importance for GGOS. The BSC supports GGOS in its goal to obtain products of highest accuracy, consistency, temporal and spatial resolution, and referring to a unique reference frame stable over decades.

According to the Terms of Reference the objectives of the BSC are:

- To keep track of the strict consideration of adopted geodetic standards, standardized units, fundamental physical constants, resolutions and conventions in the generation of IAG/GGOS products.
- To review, examine and evaluate all standards, constants, resolutions and conventions adopted by IAG or its components and recommend their use or propose the necessary updates.
- To identify gaps, inconsistencies and deficiencies in standards and conventions and to initiate steps to remove them.
- To propose the adoption of new standards where necessary.
- To propagate standards and conventions to the wider scientific community and promote their use.

Present status and activities in 2012

At present, different standards and conventions are in use for the generation of geometric and gravimetric products. Most established and common are the IERS Conventions which are regularly updated (the latest version are the IERS Conventions 2010) and which serve as the basis for the analysis of geometric observations as well as for the definition and realization of geodetic reference systems and for the generation of IERS products. For the analysis of gravimetric observations different standards and conventions are currently in use (e.g., EIGEN, GOCE, EGM2008). Relevant are also the resolutions of IUGG, IAG and IAU as well as standards and fundamental physical constants adopted by external bodies (e.g., ISO, BIPM, CODATA). The key objective of the BSC is to ensure that common standards and conventions are adopted and implemented by all IAG components as a fundamental basis for the generation of consistent IAG/GGOS products. This task requires a close interaction between the BSC and the IAG components, which is (or shall be) accomplished by nominating representatives of the IAG services as Associate Members of the BSC. A major activity of the BSC is presently the compilation of numerical and processing standards based on a review of existing resolutions and all standards and conventions relevant for the generation of the IAG/GGOS products. In this product-based inventory, the BSC presents the current status, identifies gaps and inconsistencies as well as interactions between different products. A publication of the outcome of this evaluation is in progress.

At present, numerical standards relevant for geodesy are defined in various sources such as the Geodetic Reference System 1980 (Moritz 2000), fundamental parameters and current (2004!) best estimates of the parameters of common relevance to astronomy, geodesy, and geodynamics (Groten 2004), the IERS Conventions 2010 (Petit and Luzum 2010), and the GOCE standards (European GOCE Gravity Consortium EGG-C 2010). The values obtained from the different sources are summarized in Table 4.2. The different definitions for some of the quantities are a source for errors and inconsistencies in the analysis and combination of space geodetic observations and product generation.

Table 4.2: *Comparison of numerical standards.*

Quantity	**GRS80 (Moritz 2000)**	**Fundamental Parameters (Groten 2004)**	**IERS2010 (Petit and Luzum, 2010)**	**Unit**
Gravit. constant (GM)	398.6005	398.6004118	398.6004118	$[10^{12}\mathrm{m}^3\mathrm{s}^{-2}]$
Equatorial radius (a)				
– zero-tide value	6378137.0	6378136.62	6378136.6	
– mean-tide value		6378136.72		[m]
– tide-free value		6378136.59		
Flattening factor ($1/f$)				
– zero-tide value	298.25722	298.25642	298.25642	
– mean-tide value		298.25231		[ ]
– tide-free value		298.25765		
Dyn. form factor (J_2)	1082.63	1082.6359	1082.6359	$[10^{-6}]$
Ang. Rot. velocity (ω)	7.292115	7.292115	7.292115	$[\mathrm{rad\ s}^{-1}]$
Potential geoid (W_0)	62636860.85	62636856.4	62636856.0	$[\mathrm{m}^2\mathrm{s}^{-2}]$

4.3 Special functions and series expansion

Derivatives of Legendre polynomials

Spherical base functions defined by a series of Legendre polynomials $P_n(x)$ with $n = 0, 1, 2, \ldots$ are applied, for example, to parameterize the gravitational potential in a regional area of interest; see Section 2.1. Setting up the observation equations for gradiometer observations of GOCE requires then to evaluate the second derivatives of the Legendre polynomials. For this purpose a stable algorithm has been coded, based on the recurrence relation

$$P'_{n+1}(x) = P'_{n-1}(x) + (2n+1) \cdot P_n(x)$$

for $-1 \leq x \leq 1$ with $P'_n(x) = {}^{dP_n(x)}/_{dx}$. The advantage over other recurrence relations is, that it can be applied repeatedly to obtain the first derivative by an initial call (with the Legendre polynomials as input) and the second derivatives by a subsequent call (with the first derivative as input). We verified this procedure for a series up to degree $n = 5000$ and found that for any n and x the Legendre differential equation is fulfilled for some 13 digits when using double precision.

4.4 Development of DGFI's DOGS software

The acronym DOGS, standing for **D**GFI **O**rbit and **G**eodetic parameter estimation **S**oftware, now also applies to software that is not related to satellite orbits. The four main program packages with that name are

DOGS-OC Satellite orbit computation and parameter estimation from observations between satellites and stations

DOGS-RI Parameter estimation from interferometric observations of astronomic radio sources at terrestrial stations

DOGS-CS Combination and solution of large linear equations

DOGS-OV Orbit and parameter visualisation

That software is used in two versions, a stable version for services to which the DGFI is committed, and an experimental version used for research and to participate in pilot projects where future standard models are examined. This year we implemented several models for atmospheric and oceanic loading effects in satellite laser ranging.

Wherever applicable we have to implement two versions of a new model, one of which calculates the disturbing force on the satellite and the other models the effect on a terrestrial station position. In case of atmospheric and oceanic loading, those are the gravitational effect of the loading masses on satellite orbits and the displacement of station positions due to ground pressure.

Atmospheric pressure loading

The diurnal heating of the atmosphere excites oscillations in surface pressure. The gravitational effect of which was already included in form of additional coefficients to the ocean tide model. Now the station displacement was added using the diurnal (S1) and semi-diurnal (S2) loading model of Ray and Ponte described in the IERS Conventions 2010. Those oscillations are commonly referred to as “tidal”.

The non-tidal atmospheric pressure loading is caused by the weather. Data for both methods, station wise surface displacement and Stokes coefficients of the disturbing potential have been generated from NCEP surface pressure by T. van Dam (Global Geophysical Fluid Center).

Ocean loading

The station displacement due to ocean loading has been enhanced to use 342 partial tides whose amplitudes and phases are found by interpolation of the tidal admittances of the 11 main tides generated by the Bos-Scherneck web service.

Ocean pole tide loading

The ocean pole tide is an ocean tide excited by the centrifugal effect of polar motion. It is described by an equilibrium model of Desai. The loading effects on both gravity field and station position are provided in the IERS Conventions 2010. The station part has been implemented in the experimental versions of the DOGS programs.

Related Publications

Angermann D.: *Standards and Conventions for Geodesy*. In: Drewes H., Hornik H., Adam J., Rozsa S. (Eds.), The Geodesist's Handbook 2012. Journal of Geodesy, Vol. 86, 961–964, Springer, DOI: 10.1007/s00190-012-0584-1, 2012

Hugentobler U., Gruber T., Steigenberger P., Angermann D., Bouman J., Gerstl M., Richter B.: *GGOS Bureau for Standards and Conventions: Integrated Standards and Conventions for Geodesy*. In: Kenyon, S. C.; Pacino, M. C.; Marti, U. J. (eds.) Geodesy for Planet Earth, IAG Symposia, Vol. 136, pp 995–998, Springer, DOI: 10.1007/978-3-642-20338-1_124, 2012

5 Information Services and Scientific Transfer

It is of particular importance for fundamental research on geodesy (a rather unacquainted field in geosciences) to provide information on research projects, scientific results, value-added data and products to both the scientific community and the public. Exchange of knowledge and scientific results is a basic requirement for any research that is more and more based on international cooperation. Publications in peer-reviewed scientific journals are still the most acknowledged way of scientific transfer. Section 5.2 provides a list of the papers printed or published online in 2012. It is followed by a list of posters and oral presentations that wered presented by DGFI staff at numerous workshops, symposia and conferences.

Besides, the Internet is intensively used as a platform for information exchange. DGFI maintains a homepage on which all research activities, projects and cooperations of the institute are described in detail. Under the heading of "hot stories" we call attention to the most recent results. Quite a number of additional web sites are maintained by DGFI, particularly those of the Office of the International Association of Geodesy (IAG) and of the German Geodetic Commission (Deutsche Geodätische Kommission, DGK) including an online catalogue with about 1000 publications (predominantly dissertations) published by the DGK. Further internet sites are set up and maintained for large projects, services and national research programmes.

5.1 Internet representation

The Internet has become an indispensable medium for the exchange of data and scientific information. The DGFI maintains several independent internet sites and wikis to meet growing demands for information about different scientific aspects.

Typo3 content management system

The multiple internet sites are realized and maintained by means of the Typo3 content management system (CMS). The content of pages is administered by a database system. Typo3 ensures a common layout by predefined templates and provides simple interfaces to the editors. With Typo3, the internet sites can be remotely administered by means of a browser interface without any need of specific programming knowledge. Typo3 is open source and therefore available free of charge. It is one of the most actively developed CMS, applied by many commercial sites. Typo3 provides comfortable functions to handle graphics – a necessary feature for the presentation of scientific results.

Internet sites set up and maintained by DGFI

Internet sites maintained by the DGFI:

- Deutsches Geodätisches Forschungsinstitut (DGFI)
- Deutsche Geodätische Kommission (DGK)
- Office of the International Association of Geodesy (IAG)
- DFG priority programme "Mass transport and mass distribution in the Earth system" (SPP1257)
- Geocentric Reference System for the Americas (SIRGAS)
- EUROLAS Data Center (EDC)
- Open Altimeter Database (OpenADB)
- Geodesy Information System (GeodIS)

- International Altimetry Service (IAS)
- ESA projects
- IAG Working Groups
- IAG Joint Study Groups

DGFI

The DGFI home page, available at

http://dgfi.badw.de,

informs about the structure and results of the current research programme, ongoing research topics, the national and international projects DGFI is involved in and the multiple contributions of DGFI to international services. The web site (see Fig. 5.1) also provides a complete list of papers and reports published since 1994 by the employees as well as a compilation of all posters and oral presentations. Annual reports and DGFI reports are available in electronic form.

DGK

Another web site is maintained for the “Deutsche Geodätische Kommission” (DGK). It is available at

http://dgk.badw.de

and informs about the structure of the DGK, the membership, sections, geodetic research institutes in Germany, and the numerous publications of DGK. The complete catalogue of DGK publications can be downloaded as a pdf file or browsed by means of a user-friendly search function (see Fig. 5.1).

IAG Office

At the General Assembly of IUGG in Perugia, Italy, the IAG was reorganized. The position of the IAG Secretary General was handed over to the retired director of DGFI, and the IAG Office was established at DGFI. The web site

http://iag.dgfi.badw.de

was installed to support the work of the Office.

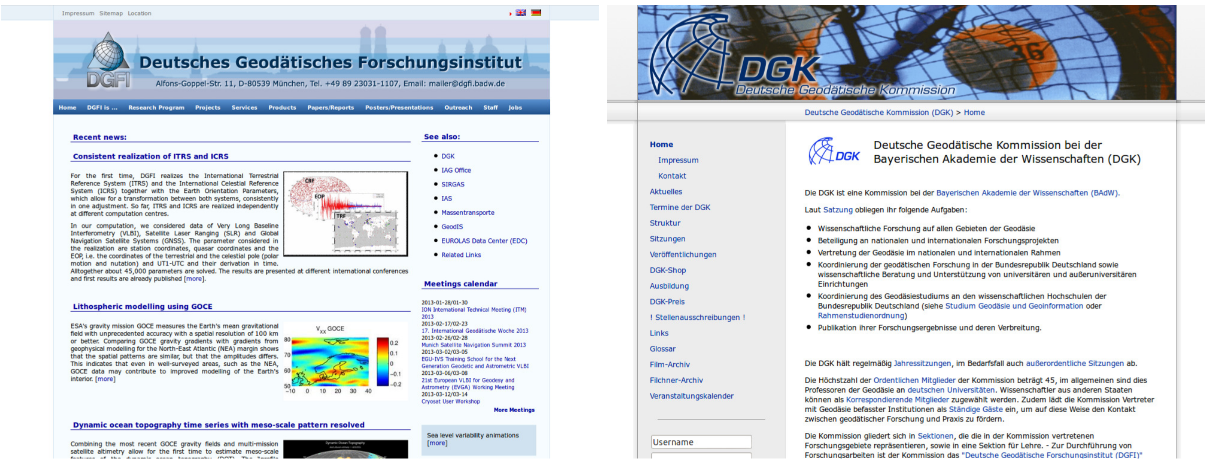

Fig. 5.1: *Screenshots of the home pages of DGFI (left) and DGK (right)*

DGFI priority programme “Mass transport and mass distribution in the Earth system”

Another internet site for the DFG priority programme “Mass transport and mass distribution in the Earth system”, SPP1257, was realized with the Typo3 CMS. It resides on a DGFI server, but has its own domain name

http://massentransporte.de.

The site (see Fig. 5.2) makes the SPP programme known to the public and other scientists (outreach), supports the organization of international symposia, and provides a basis for internal information exchange with links to data and products that are relevant for the priority programme.

SIRGAS

SIRGAS is the Geocentric Reference System for the Americas. The web site is operated by the SIRGAS Vice-President at DGFI and located at

http://sirgas.org.

The SIRGAS web site comprises (see Fig. 5.2)

- a scientific description presenting definition, realization, and kinematics of the SIRGAS reference frame,
- an organizational summary showing the operational structure and functions of the different components of SIRGAS,
- a bibliographic compilation with reports, articles, presentations, and posters related to the SIRGAS activities.

EUROLAS Data Center (EDC)

The EUROLAS Data Center (EDC) provides access to the database of SLR observations and derived products (see Fig. 5.3). This web site informs about the data flow within the Operation Centre (OC) and the data holding of the Data Centre (DC). This site is available at

http://edc.dgfi.badw.de.

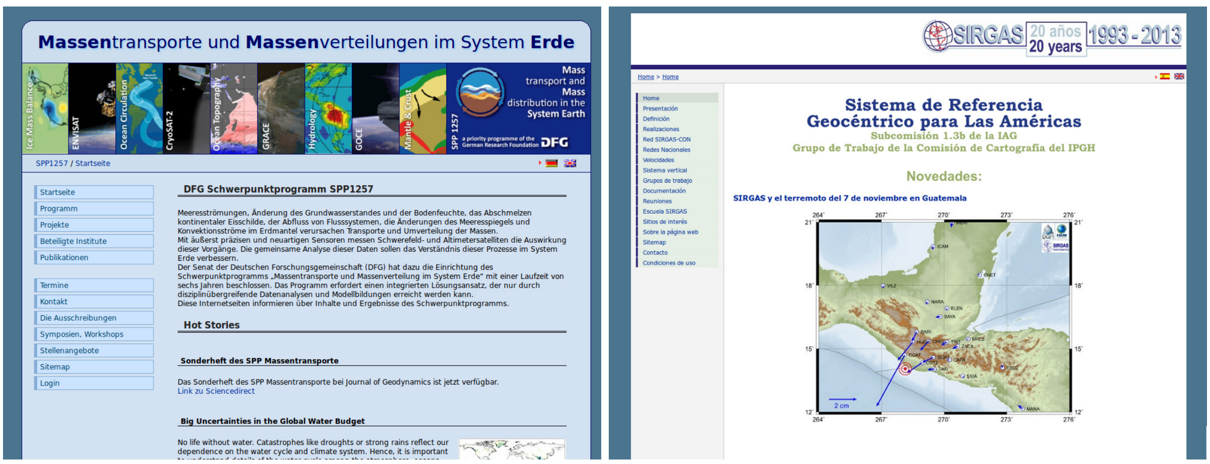

Fig. 5.2: *Screenshots of the web sites of the DFG priority programme "Mass transport and mass distribution in the Earth system" (left) and SIRGAS (right)*

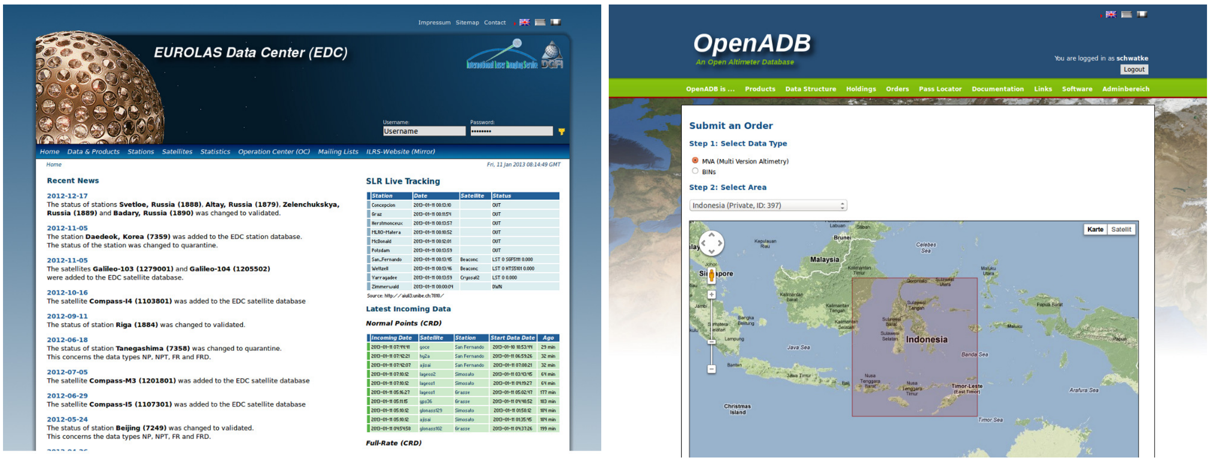

***Fig. 5.3:** Screenshots of the web sites of the EUROLAS Data Center (left) and the Open Altimeter Database (right)*

Open Altimeter Database (OpenADB)

OpenADB is a database for multi-mission altimeter data and derived high-level products. It is designed for users with little experience in satellite altimetry and scientific users evaluating data and generating new products, models and algorithms. OpenADB allows fast parameter updates and enables database extracts with user-defined formats and parameters. The usage of OpenADB is open after registration to anyone (see Fig. 5.3). This site is available at

http://openadb.dgfi.badw.de.

GeodIS

The geodesy information system GeodIS, located at

http://geodis.dgfi.badw.de,

is maintained by DGFI with the objective to compile information about the most important areas of geodesy. The intention of GeodIS is to give support in finding information on and data relevant to geodesy. GeodIS provides also links to the home pages of international scientific organizations.

International Altimetry Service (IAS)

The home page of the International Altimetry Service

- provides a point of contact for general information on satellite altimetry and its applications;
- communicates and interfaces with altimeter mission data providers and with centres which process, archive and analyze altimeter data and other related services and organizations;
- promotes satellite altimetry as a core element of Global Earth Observing Systems;
- helps users to compile and analyze data and to respond to altimeter user requirements.

This site is available at

http://ias.dgfi.badw.de,

but is still under development.

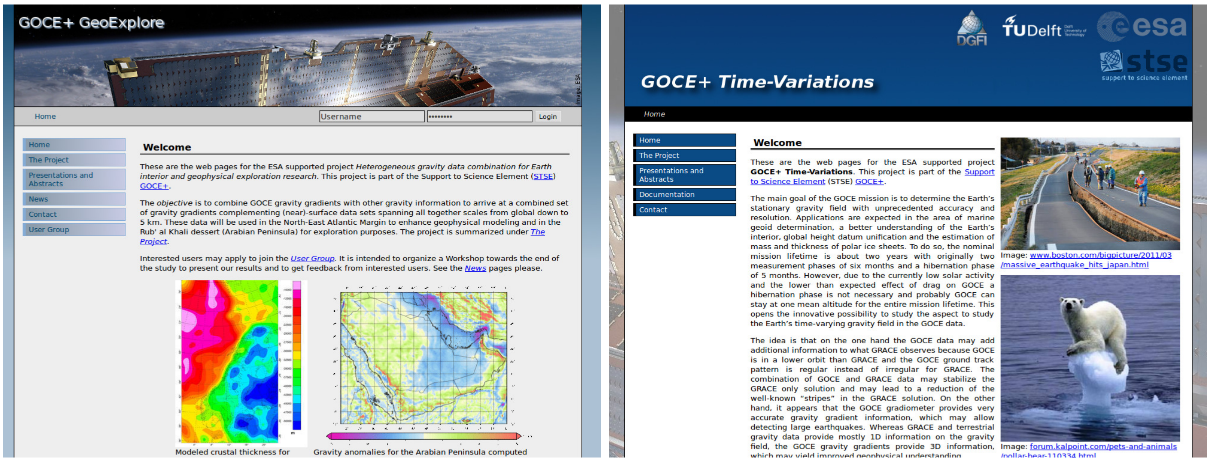

Fig. 5.4: *Screenshots of the ESA project home pages of "GOCE+ GeoExplore" (left) and "GOCE+ Time-Variations" (right)*

ESA projects

The web sites of the GOCE+ GeoExplore and the GOCE+ Time-Variations (see Fig. 5.4) are available at

http://goce4interior.dgfi.badw.de

and

http://gocedt.dgfi.badw.de.

Both web sites provide information about the progress of the projects. Presentations related to the projects are also available.

IAG Working and Joint Study Groups

The DGFI maintains web sites of three IAG Working (IAG-WG) and Joint Study Groups (IAG-JSG).

- IAG Joint Working Group 0.0.1 – “Unified Global Height System” (*http://whs.dgfi.badw.de/*)
- IAG Joint Working Group 1.3 – “Strategies for Epoch Reference Frames” (*http://erf.dgfi.badw.de/*)
- IAG Joint Study Group 0.3 – “Methodologies of Regional Gravity Field Modelling” (*http://jsg03.dgfi.badw.de/*)

Wikis mainted by DGFI

In addition to the different web sites, the DGFI currently maintains seven wikis which are used for information exchange within projects or working groups.

Mailing lists

Mailing lists are maintained by DGFI to fulfill the requirements for information exchange within the ILRS Global Data Centre, the Reference System SIRGAS and CGE. The mailing lists are realized by the ’mailman’ program which transforms submitted e-mails to a specific format which can then be viewed by any internet browser sorted according to date, thread or author.

Intranet

Another server behind a firewall is used to provide Intranet functionality, on the basis of the Typo3 CMS. The internal information exchange is supported by a black board, a meeting calendar, the access to the library database, and numerous pages which can be created, modified or deleted by any of the employees. The pages compile internal information for the work of particular research topics, links to data sets, formats, internal documentation and the necessary meta data.

5.2 Publications

Albertella A., Savcenko R., Janjic T., Rummel R., Bosch W., Schröter J.: *High resolution dynamic ocean topography in the Southern Ocean from GOCE*. Geophysical Journal International, Volume 190, Issue 2, Pages: 922-930, DOI: 10.1111/j.1365-246X.2012.05531.x, 2012

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Angermann D. *Realizations of the terrestrial reference system: Status and new developments*. Geodätisches Kolloquium, Berlin, Germany, 2012-05-10

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Angermann D. *DGFI part of Project PN5*. Kiff-Off Meeting, DFG Forschergruppe "Referenzsysteme", Bonn, Germany, 2012-02-05

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Sánchez L. *Lecture on Precise GNSS Processing and training curse on the Bernese GPS Software*. Heredia, Costa Rica, 2012-12-03/12

Schmidt M., Dettmering D., Liang W. *Multi-Resolution Representation of VTEC in Near Real-Time*. IRI-RT Workshop, Prague, Czech Republic, 2012-03-15

Schmidt M., Hugentobler U., Jakowski N., Dettmering D., Liang W., Limberger M., Wilken V., Gerzen T., Hoque M., Berdermann J. *Multi-scale model of the ionosphere from the combination of modern space-geodetic satellite techniques - project status and first results*. EGU General Assembly 2012, Vienna, Austria, 2012-04-24 (Poster)

Schmidt M. *Introduction to regional modelling*. Workshop on Regional Gravity and Geomagnetic Field Modelling, Bavarian Academy of Sciences and Humanities, Munich, 2012-02-23

Schmidt M., Liang W. *Separation of mass signals within GRACE monthly gravity models*. SPP1257 Workshop on GRACE-Hydrology, 2012-02-13

Schmidt M. *Mathematische Modellbildung in der geodätischen Erdsystemforschung - ausgewählte Beispiele*. Technische Universität München, Munich, Germany, 2012-06-20

Schröter J., Janjic T., Albertella A., Savcenko R., Rummel R., Bosch W., Schwabe J., Scheinert M. *Sea Surface Topography and Mass Transport of the Antarctic Circumpolar Current (GEOTOP)*. GSTM2012, Potsdam, Germany, 2012-09-18

Schwatke C. *Monitoring lake and river level using satellite altimetry*. CGE Seminar FB3, Munich, Germany, 2012-01-27

Schwatke C., Koch T., Bosch W. *Monitoring lake levels by retracking Envisat altimeter data: A case study on Lake Constance*. European General Assembly 2012, Vienna, Austria, 2012-04-22 (Poster)

Schwatke C. *EUROLAS Data Center (EDC) - A new website for tracking the SLR data flow*. European General Assembly 2012, Vienna, Austria, 2012-04-24 (Poster)

Schwatke C., Bosch W., Koch T. *Satellite Altimetry over Inland Water: A New Tool to Detect Geoid Errors!*. European General Assembly 2012, Vienna, Austria, 2012-04-24

Schwatke C., Koch T., Bosch W. *Classifying Radar-Echos of Envisat Altimeter Data for an Optimized Retracking*. 6th Coastal Altimetry Workshop, Riva del Garda, Italy, 2012-09-20/21 (Poster)

Schwatke C., Bosch W. *Kalman filter Approach for geophysical lake level Time Series using multi-mission Altimetry*. 20 Years of Progress in Radar Altimetry, Venice, Italy, 2012-09-24/29 (Poster)

Schwatke C., Bosch W. *Eddy detection by means of a Kalman filter approach applied to multi-mission altimetry*. 4th Argo Science Workshop, Venice, Italy, 2012-09-24/29 (Poster)

Schwatke C., Bosch W. *Lake and river level from satellite altimetry*. GRACE Hydrology Workshop IGG Bonn, 2012-02-13/14

Seitz F., Kirschner S. *Polar motion as boundary condition in an adaptive Kalman filter approach for the determination of period and damping of the Chandler oscillation (invited).*. AGU Fall Meeting, San Francisco, USA, 2012-12-07

Seitz F. *Deutsches Geodätisches Forschungsinstitut: Neuigkeiten und Aktivitäten im Jahr 2012.*. Gemeinsame Sitzung der DGK, SGK, ÖGK, Diessenhofen, 2012-11-07

Seitz F., Kutterer H., Hugentobler U., Pail R., Schmidt M. *GGOS - Konsistente geodätische Erdbeobachtungsdaten als Fundament für das Monitoring und das Verständnis des globalen Wandels; Vorschlag für ein DFG-Rundgespräch.*. 4. Sitzung der DFG-Senatskommission für Zukunftsaufgaben der Geowissenschaften, Hitzacker, 2012-10-22

Seitz F., Hedman K., Spiridonova S. *Intersection of SAR imagery with medium resolution DEM for the estimation of regional water storage changes.*. Geodätische Woche, Hannover, 2012-10-10

Seitz F., Kirschner S. *Application of Earth rotation parameters in Earth system science*. IAU XXVIII General Assembly, Beijing, China, 2012-08-30

Seitz F. *Results of the elections for the new triennium (2012-2015) and new members of Commission 19*. IAU XXVIII General Assembly, Beijing, China, 2012-08-29

Seitz F. *Understanding Earth Rotation: Physical Foundations and Interpretation*. International Summer School on Space Geodesy and Earth System , Shanghai, China, 2012-08-23

Seitz F., Hedman K. *Towards the Separation of Integral GRACE Signals of Continental Water Storage Using Multi-Sensor Space and In-situ Observations.*. AGU Fall Meeting, San Francisco, USA, 2012-12-06 (Poster)

Seitz M., Steigenberger P., Artz T. *Consistent computation of ITRF and ICRF from homogeneously processed observation data*. IVS General Meeting, Madrid, Spain, 2012-03-07

Seitz M., Steigenberger P., Artz T., Nothnagel A. *Consistent realization of ITRS and ICRS*. EGU 2012, Vienna, Austria, 2012-04-26

Seitz M., Steigenberger P., Artz T., Blossfeld M., Angermann D., Heinkelmann R. *Impact of a consistent realization of the ITRS and ICRS on source positions*. AGU, San Francisco, 2012-12-07 (Poster)

Seitz M., Steigenberger P., Artz T., Bloßfeld M., Heinkelmann R., Müller H., Gerstl M. *Simultane Realisierung des terrestrischen Referenzsystems (ITRS) und zälestischen Referenzsystems (ICRS)*. Geodätische Woche, Hannover, 2012-10-10

Seitz M. *Report of the COL Combination Centre at DGFI*. Munich, Germany, 2012-05-29

Singh A., Seitz F., Schwatke C., Güntner A. *Geometrical and gravimetrical observations of the Aral Sea and its tributaries along with hydrological models*. European General Assembly 2012, Vienna, Austria, 2012-04-23 (Poster)

Singh A., Seitz F., Schwatke C. *Observations of water storage variations in the Aral Sea from multi-sensor satellite data*. 2nd IAHR Europe Congress, Munich, 2012-06-28

Singh A., Seitz F., Schwatke C., Bosch W. *Application of the Satellite Altimetry over Terrestrial Water Body: A Case Study on Aral Sea*. 20 Years of Progress in Radar Altimetry, Venice, Italy, 2012-09-25 (Poster)

Wattenbach M., Franz D., Liang W., Schmidt M., Seitz F., Güntner A. *Integration of MODIS LAI products into the hydrological model WGHM indicate the sensitivity of total water storage simulations to vegetation cover dynamics*. EGU General Assembly 2012, Vienna, Austria, 2012-04-27

Wattenbach M., Güntner A., Liang W., Schmidt M., Seitz F., Schmied H.M., Eisner S. *Integration of MODIS LAI products into the hydrological model WGHM indicate the sensitivity of total water storage simulations to vegetation cover dynamics*. GRACE Science Team Meeting (GSTM) and SPP1257 Final Colloquium, Potsdam, Germany, 2012-09-19

Wattenbach M., Güntner A., Liang W., Schmidt M., Seitz F., Müller Schmied, Eisner S. *Integration of MODIS LAI products into the hydrological model WGHM indicate the sensitivity of total water storage simulations to vegetation cover dynamics*. GRACE Science Team Meeting (GSTM) and Final Colloquium of the DFG Special Priority Program (SPP1257) "Mass Transport and Mass Distribution in the System Earth", Potsdam, 2012-09-19

Wattenbach M., Güntner A., Liang W., Schmidt M., Seitz F. *Integration of MODIS LAI products into the hydrological model WGHM indicate the sensitivity of total water storage simulations to vegetation cover dynamics.*. AGU Fall Meeting, San Francisco, USA, 2012-12-05 (Poster)

Wünsch J., Savcenko R., Rieser D., Mayer-Gürr T., Bosch W., Flechtner F., Dahle Ch. *Overview of the COTAGA project*. GSTM2012, Potsdam, Germany, 2017-09-17/19 (Poster)

5.4 Membership in scientific bodies

American Geophysical Union (AGU)

- Journal of Geophysical Research - Solid Earth,
  Associate Editor: Bouman J.

Centre National d'Etudes Spatiales (CNES)/National Aeronautics and Space Administration (NASA)

- Ocean Surface Topography Science Team for Jason-2,
  Member: Bosch W., Dettmering D.
- SARAL/Altika Calibration/Validation Team,
  Member: Bosch W.

Deutsche Geodätische Kommission (DGK)

- *Member: Seitz F.*

Deutsche Gesellschaft für Geodäsie, Geoinformation und Landmanagement (DVW)

- Working Group 7: Experimentelle, Angewandte und Theoretische Geodäsie,
  Member: Seitz F.

European Geosciences Union (EGU)

- Geodesy Division,
  Vice presidents: Bouman J., Schmidt M.

European Space Agency (ESA)

- Cryosat Calibration and Validation Team,
  Member: Bosch W.

International Altimetry Service (IAS)

- Steering Committee,
  Chair: Bosch W.

International Association of Geodesy (IAG)

- IAG Office,
  Secretary General: Drewes H., Assistant Secretary: Hornik H., Treasurer: Küffner W.
- Symposia Series,
  Associate Editor: Sánchez L.
- GGOS Bureau for Standards and Conventions,
  Director: Angermann D.
- GGOS Coordinating Board,
  Member: Angermann D.
- GGOS Executive Committee,
  Member: Angermann D.
- Commission 1 Sub-Commission 1.3b: Regional Reference Frame for South and Central America,
  Vice-Chair: Sánchez L.

- Commission 4 Study Group 4.2: Ionosphere modelling and analysis,
  Chair: Schmidt M., Member: Dettmering D., Liang W.
- ICCT Joint Study Group 0.1: Application of time series analysis in geodesy,
  Member: Schmidt M.
- ICCT Joint Study Group 0.3: Methodology of regional gravity field modelling,
  Chair: Schmidt M., Member: Haberkorn C., Lieb V.
- ICCT Joint Study Group 0.5: "Multi-Sensor Combination for the Separation of Integral Geodetic Signals",
  Chair: Seitz F., Member: Schmidt M., Seitz M.
- ICCT Joint Study Group 0.6: Applicability of current GRACE solution strategies to the next generation of inter-satellite range observations,
  Member: Bouman J., Haberkorn C., Schmidt M.
- Joint Working Group 0.1.1. on Vertical Datum Standardization,
  Chair: Sánchez L.
- Joint Working Group 1.1 "Tie vectors and local ties to support integration of techniques",
  Member: Seitz M.
- Joint Working Group 1.3 "Strategies for epoch reference frames",
  Chair: Seitz M., Member: Bloßfeld M., Sánchez L.
- Joint Working Group JWG2.8 "Modeling and Inversion of Gravity-Solid Earth Coupling",
  Member: Bouman J.
- Working Group 1.3.1 on Integration of Dense Velocity into the ITRF,
  SIRGAS representative: Sánchez L.
- Working Group 1.3.2 on Deformation Models for Reference Frames,
  Member: Sánchez L.

International Astronomical Union (IAU)

- Commission 19, Rotation of the Earth,
  Secretary: Seitz F.
- Working Group on the ICRF-3,
  Member: Seitz M.

International Earth Rotation and Reference Systems Service (IERS)

- ITRS Combination Centre,
  Chair: Seitz M.
- Working Group "Combination on the Observation Level",
  Co-Chair: Seitz M., Member: Angermann D., Bloßfeld M.
- Working Group "Site survey and co-location",
  Member: Angermann D., Schmid R., Seitz M.
- IERS Working Group on Site Coordinate Time Series Format,
  Member: Seitz M.
- Working Group on SINEX format,
  Member: Seitz M.

International GNSS Service (IGS)

- Governing Board,
  Member: Schmid R.
- Antenna Working Group,
  Chair: Schmid R.
- GPS Tide Gauge Benchmark Monitoring - Working Group,
  Member: Sánchez L.

International Laser Ranging Service (ILRS)

- Governing Board,
  Member: Müller H.
- Operations Centre (EDC),
  Chair: Schwatke C.
- Data Centre (EDC),
  Chair: Schwatke C., Member: Müller H.
- Analysis Working Group,
  Member: Müller H., Member: Bloßfeld M.
- Working Group "Data Formats and Procedures",
  Chair: Müller H., Member: Schwatke C.

International VLBI Service for Geodesy and Astrometry (IVS)

- Operational Analysis Centre,
  Member: Seitz M.

Modelado de movimientos no lineales en el establecimiento de marcos de referencia

- *Member: Sánchez L.*

Sistema de Referencia Geocéntrico para las Américas (SIRGAS)

- *Vice president: Sánchez L.*
- Working Group 1: Reference frame,
  Member: Sánchez L.

5.5 Participation in meetings, symposia, conferences

2012-01-09/10 :
GOCE+ GeoExplore Progress Meeting 2, Munich, Germany
Bosch W., Bouman J., Fuchs M., Haberkorn C., Lieb V., Schmidt M., Schwatke C.

2012-02-13/14 :
SPP1257 Workshop on GRACE-Hydrology, Bonn, Germany
Bosch W., Liang W., Schmidt M.

2012-02-16 :
GOCE HPF Product Acceptance Review, Noordwijk, The Netherlands
Bouman J., Fuchs M.

2012-02-17 :
GOCE HPF Progress Meeting 24, Noordwijk, The Netherlands
Bouman J., Fuchs M.

2012-02-21/22 :
Statusseminar der Forschergruppe Erdrotation (FOR584), Frankfurt/Main, Germany
Angermann D., Bloßfeld M., Göttl F., Panafidina N., Seitz M.

2012-02-23/24 :
Workshop on Regional Gravity and Geomagnetic Field Modelling, Bavarian Academy of Sciences and Humanities, Munich, Germany
Bosch W., Bouman J., Dettmering D., Fuchs M., Haberkorn C., Lieb V., Schmidt M., Schwatke C.

2012-03-05/08 :
7th IVS General Meeting, Madrid, Spain
Bloßfeld M., Seitz M.

2012-03-12/13 :
PPP-RTK & Open Standards Symposium, Frankfurt/Main, Germany
Dettmering D.

2012-03-14/28 :
Cooperation with the Universidad de Concepción, Visit, Concepción, Chile
Müller H., Stefka V., Mora J.

2012-03-15 :
IRI Real-time Workshop, Prague, Czech Republic
Liang W.

2012-03-15 :
RealGOCE Project Meeting, Bonn, Germany
Bosch W., Fuchs M, Lieb V.

2012-04-21 :
ILRS Analysis Working Group Meeting, Vienna, Austria
Müller H., Schwatke C.

2012-04-23 :
ILRS Data Formats and Procedures Working Group Meeting, Vienna, Austria
Müller H., Schwatke C.

2012-04-23/27 :

European Geosciences Union (EGU) General Assembly 2012, Vienna, Austria
Bosch W., Bouman J., Dettmering D., Fuchs M., Liang W., Lieb V., Schmidt M., Schwatke C.

2012-04-27 :

GGOS Coordinating Board Meeting, Vienna, Austria
Angermann D.

2012-05-02/03 :

Kick-Off Meeting, DFG-Forschergruppe "Referenzsysteme", Bonn, Germany
Angermann D., Bloßfeld M., Panafidina N., Schmid R.

2012-05-08/09 :

GOCE+ GeoExplore Mid-Term Review, Trondheim, Norway
Bouman J., Fuchs M., Schmidt M.

2012-05-10 :

Evaluierung der Deutschen Geodätischen Kommission, Bayerische Akademie der Wissenschaften, München, Germany
Hornik H.

2012-05-24 :

Statusseminar Weltraum Phase III, Projekt RealGOCE, Potsdam, Germany
Bouman J., Lieb V.

2012-05-29 :

COL-WG Meeting, Munich, Germany
Bloßfeld M. Müller H., Seitz M.

2012-06-26/28 :

GGOS Retreat, Frankfurt/Main, Germany
Angermann D.

2012-07-03/05 :

RegGrav Project: Final meeting, Munich, Germany
Bosch W., Bouman J., Dettmering D., Haberkorn C., Lieb V., Schmidt M., Schwatke C.

2012-07-05/06 :

GOCE HPF Progress Meeting 25, Frascati, Italy
Bouman J.

2012-07-22 :

40th IGS Governing Board Meeting, Olsztyn, Poland
Schmid R.

2012-07-23 :

Sitzung des Wissenschaftlichen Ausschusses der Deutschen Geodätischen Kommission, Bundesamt für Kartographie und Geodäsie, Frankfurt/Main, Germany
Hornik H.

2012-07-23/27 :

IGS Workshop 2012, Olsztyn, Poland
Sánchez L., Schmid R.

2012-08-13/17 :
AOGS - AGU (WPGM) Joint Assembly, Singapore, Singapore
Hornik H., Drewes H., Sánchez L.

2012-08-15 :
Third meeting of the IAG EC 2011-2015, Singapore, Singapore
Hornik H., Drewes H.

2012-08-18/20 :
International Symposium on Space Geodesy and Earth System, Shanghai, China
Seitz, F.

2012-08-21/25 :
International Summer School on Space Geodesy and Earth System, Shanghai, China
Seitz, F.

2012-08-26/31 :
IAU XXVIII General Assembly, Beijing, China
Seitz, F.

2012-09-17/19 :
GRACE Science Team Meeting 2012, DFG SPP 1257 Abschlusskolloquium, Potsdam, Germany
Bosch W., Liang W., Savcenko R., Schmidt M.

2012-09-17/29 :
Cooperation with the Universidad de Concepción, Visit, Concepción, Chile
Müller H.

2012-09-20 :
Meeresspiegel-Workshop, Potsdam, Germany
Bosch W., Savcenko R.

2012-09-20/21 :
6th Coastal Altimetry Workshop, Riva del Garda, Italy
Schwatke C.

2012-09-21 :
GOCE L1B Reprocessing Conclusive Meeting, Munich, Germany
Bouman J., Fuchs M.

2012-09-24/26 :
20 Years Progress in Radar Altimetry Symposium, Venice, Italy
Bosch W., Dettmering D., Schwatke C.

2012-09-25/26 :
International DORIS Service (IDS) Workshop, Venice, Italy
Dettmering D.

2012-09-27/28 :
Ocean Surface Topography Science Team Meeting (OSTST), Venice, Italy
Bosch W., Dettmering D., Schwatke C.

2012-09-27/29 :
ARGO Workshop, Venice, Italy
Schwatke C.

2012-10-09/11 :

Geodätische Woche 2012, Hannover, Germany
Angermann D., Dettmering D., Haberkorn C., Seitz F., Seitz M.

2012-10-09/12 :

International Symposium on Gravity, Geoid and Height Systems GGHS 2012, Venice, Italy
Bouman J., Lieb V., Sánchez L.

2012-10-15 :

GOCE+ GeoExplore Progress Meeting 3, Enschede, The Netherlands
Bouman J., Fuchs M., Schmidt M.

2012-10-16/17 :

GOCE Solid Earth Workshop, Enschede, The Netherlands
Bouman J., Fuchs M., Schmidt M.

2012-10-18 :

GOCE+ Theme 2 Joint Science Meeting, Enschede, The Netherlands
Bouman J., Fuchs M., Schmidt M.

2012-10-22/23 :

4. Sitzung der DFG-Senatskommission für Zukunftsaufgaben der Geowissenschaften, Hitzacker, Germany
Seitz, F.

2012-10-22/26 :

Establishment of a SIRGAS Processing Centre in Chile, Concepción, Chile
Drewes H., Sánchez L.

2012-10-29/31 :

SIRGAS General Meeting 2013, Concepción, Chile
Drewes H., Sánchez L.

2012-11-03 :

ILRS Analysis Working Group Meeting, Frascati, Italy
Müller H.

2012-11-07/09 :

Gemeinsame Sitzung der Deutschen Geodätischen Kommission (DGK), der Österreichischen Geodätischen Kommission (ÖGK) und der Schweizerischen Geodätischen Kommission (SGK) / Jahressitzung der Deutschen Geodätischen Kommission, Diessenhofen bei Schaffhausen, Switzerland
Hornik H., Seitz F.

2012-11-15/16 :

DFG round table discussion: Understanding the global freshwater system by combining geodetic and remote sensing information with modelling, Franfurt/Main, Germany
Seitz F., Schmidt M., Bosch W.

2012-11-19 :

Besprechung von IAG-Angelegenheiten, Technical University, Budapest, Hungary
Hornik H., Drewes H.

2012-11-22 :

GOCE+ Time-Variations Final Review, Noordwijk, The Netherlands
Bouman J., Fuchs M., Lieb V.

2012-11-22 :
GOCE+ Theme4 Final Review, Noordwijk, The Netherlands
Bouman J., Fuchs M., Lieb V.

2012-12-01 :
GGOS Consortium Meeting, San Francisco, USA
Angermann D.

2012-12-01 :
GGOS Coordinating Board Meeting, San Francisco, USA
Angermann D.

2012-12-02 :
IERS Directing Board Meeting, San Francisco, USA
Angermann D.

2012-12-03/07 :
American Geophysical Union (AGU) Fall Meeting 2012, San Francisco, USA
Angermann D., Bouman J., Seitz F.

2012-12-04 :
GGOS Bureau on Networks and Communications, San Francisco, USA
Angermann D.

2012-12-05 :
IERS Working Group on Time Series, San Francisco, USA
Angermann D.

5.6 Guests

2012-02-23/03-02 :	M. Naeimi, Institute of Geodesy, University of Hannover, Germany
2012-03-20/21 :	A. Heiker, Geodetic Institute, University of Hannover, Germany
2012-06-01/11-29 :	X. Wang, Shanghai Astronomical Observatory, Chinese Academy of Sciences
2012-06-08/18 :	Dr. A. O. Alothman, National Center for Electronics, Communications & Photonics, King Abdulaziz City for Science and Technology (KACST), Riyadh, Saudi Arabia
2012-06-12 :	15 students, Jade University, Oldenburg, Germany
2012-06-15 :	Delegation of 20 professors, Chinese Academy of Sciences (CAS)
2012-07-02/05 :	PD Dr. K. Börger, Amt für Geoinformationswesen der Bundeswehr, Euskirchen, Germany
2012-07-03/05 :	OL H. List, Amt für Geoinformationswesen der Bundeswehr, Euskirchen, Germany
2012-07-16/24 :	Prof. Dr. J. C. Báez, Universidad de Concepción, Concepción, Chile
2012-07-25 :	Mrs Wehrwig with eight secondary school teachers, High School, Ottobrunn (München)
2012-07-27 :	Prof. S. Jin, Shanghai Astronomical Observatory, Chinese Academy of Sciences
2012-08-08/10 :	P. Brieden, Institut für Erdmessung, Leibniz Universität Hannover, Hannover, Germany
2012-10-24 :	Dr. A. Güntner, Dr. M. Wattenbach, GFZ Potsdam, Germany
2012-11-05 :	Dr. V. Mohrholz, S. Quandt, Institut für Ostseeforschung (IOW), Warnemünde, Germany
2012-12-13 :	M. Schindelegger, TU Wien, Austria
2012-12-14 :	Prof. Dr. V. Michel, Universität Siegen, Siegen, Germany

6 Personnel

6.1 Number of personnel

Total staff of DGFI during the 2012 period (including DGK Office):

Regular budget

13 (14 till 2012-10-31)	scientists
6	technical and administrative employees
1	worker
6	student helpers with an average of 230 hours/year
1	part-time employee

Project funds

4 (5 till 2012-10-31)	junior scientists
2 (3 till 2012-10-31)	postdoc scientists

Funding of the following projects is gratefully acknowledged:

COTAGA Combined ocean tide analysis by GRACE and altimetry data (DFG)

GEO-TOP Sea surface topography and mass transport of the Antarctic Circumpolar Current (DFG)

PROMAN Project management and scientific networking (DFG)

CEMIG Consistent estimation of water mass variations in different continental storage compartments by combined inversion of a global hydrological model with time-variable gravity and complementary observation data (DFG)

MuSIK Multi-scale model of the ionosphere from the combination of modern space geodetic satellite techniques (DFG)

FOR 584, P6 Integration of Earth rotation, gravity field and geometry using space geodetic observations (DFG)

FOR 584, P9 Combined analysis and validation of Earth rotation models and observations (DFG, till 2012-05-15)

REAL-GOCE Real data analysis GOCE, GEOTECHNOLOGIEN programme (BMBF, till 2012-05-31)

GOCE HPF Validation and frame transformation of GOCE gravity gradients (ESA/TUM)

GOCE+ GeoExplore Heterogeneous gravity data combination for Earth interior and geophysical exploration research (ESA)

GOCE+ Time Variations Feasibility study to the potential of GOCE data to detect temporal gravity field variations (ESA)

Analysis System Chile Geodetic observation and analysis system in seismically active regions in Chile (BMBF, till 2012-10-31)

FOR 1503, PN5 Consistent celestial and terrestrial reference frames by improved modeling and combination (DFG)

FOR 1503, PN6 Consistent dynamic satellite reference frames and terrestrial geodetic datum parameters (DFG)

6.2 Lectures at universities

Bosch W. University lectures ”Oceanography and Satellite Altimetry”, TU München, WS 2011/12 and WS 2012/13

Bouman J. University lectures ”Gravity and Magnetic Field from Space”, TU München, WS 2011/12 and WS 2012/13

Schmidt M. University lectures ”Numerical Modelling”, TU München, WS 2011/12 and WS 2012/13

Schmidt M. University lectures ”Mathematische Methoden der Satellitengeodäsie”, TU München, SS 2012

Seitz F. University lectures ”Earth System Dynamics”, TU München, WS 2012/13

6.3 Lectures at seminars and schools

Seitz F. Summer school lecture "Earth Rotation", International Summer School on Space Geodesy and Earth System, Shanghai, China, 2012-08-23

6.4 Miscellaneous

Bouman J. Reaccreditation of the Faculty of Geotechnical Engineering (chair), University of Zagreb, Croatia, 2012-03-25/27

Bouman J. Reaccreditation of the Faculty of Geodesy (member), University of Zagreb, Croatia, 2012-03-27/29

Schmidt M. Organisation of the ”Workshop on Regional Gravity and Geomagnetic Field Modelling” in cooperation with Gerlach, C. (KEG, BAdW, Munich) and Kusche, J. (IGG, University of Bonn), BAdW, 2012-02-23/24

Seitz F. Speaker of the Focus Area ”Water” within the International Graduate School of Science and Engineering (IGSSE) at the TU München