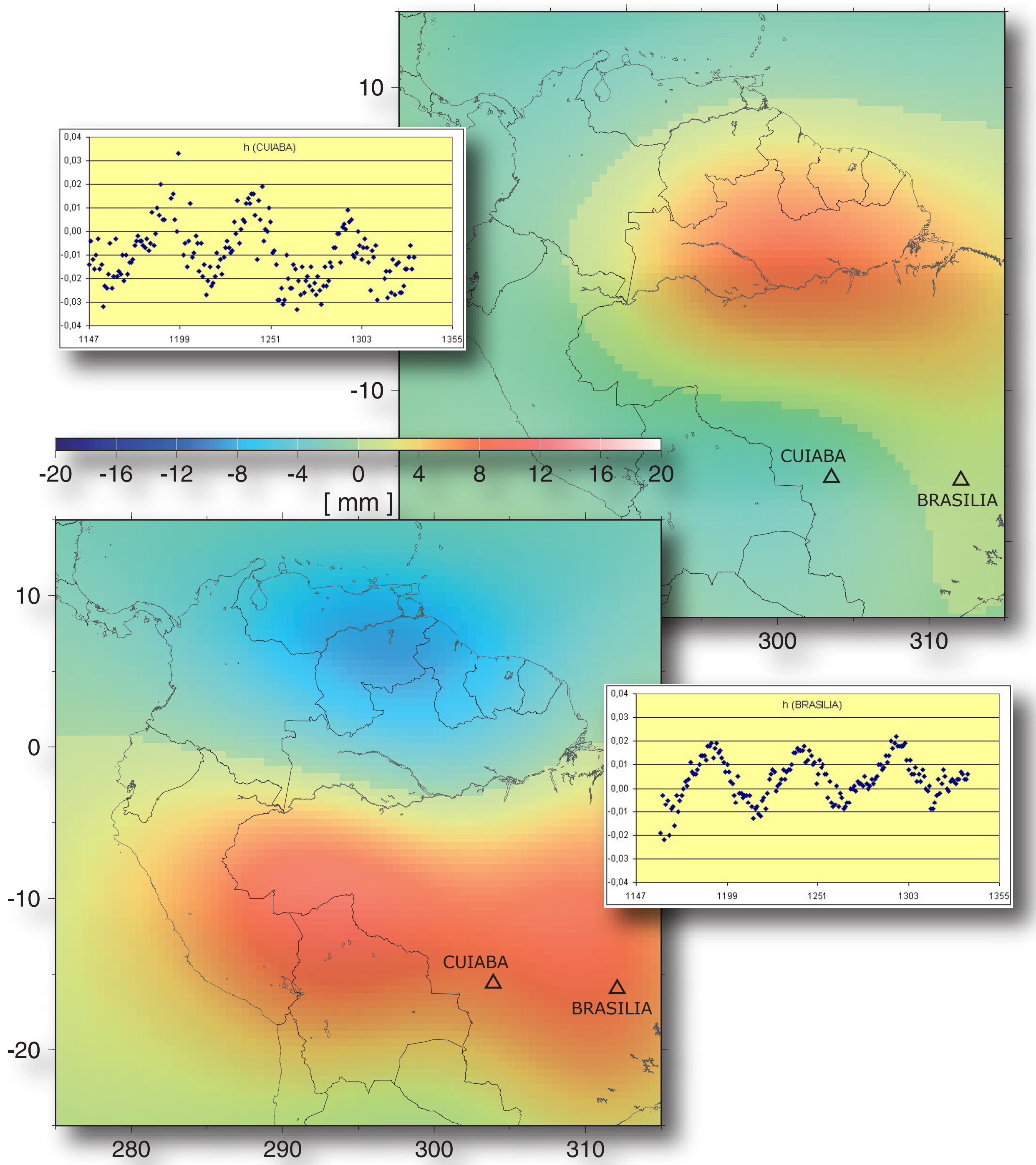
Deutsches Geodätisches Forschungsinstitut (DGFI)

ANNUAL REPORT 2004/2005



Time variation of the gravity field in northern South America: The lower left panel shows geoid height variations between 10-day solutions for March and September 2003 computed from GRACE data by regional modelling. The top right panel shows the corresponding difference shifted about three months. The two other panels display four years time series of height variations observed by GPS in Cuiaba and Brasilia.

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2nd Edition

The Institute

The German Geodetic Research Institute (Deutsches Geodätisches Forschungsinstitut, DGFI) is an autonomous and independent research institution located in Munich. It is supervised by the German Geodetic Commission (Deutsche Geodätische Kommission, DGK) at the Bavarian Academy of Humanities and Sciences (Bayerische Akademie der Wissenschaften, BAdW). The research covers all fields of geodesy and includes the participation in national and international research projects as well as various functions in international bodies.

Research Programme

The general theme of the DGFI working programme was changed in the last year in order to meet the requirements of international activities and the demands of modern society. It is defined as "Geodetic research for observing and analysing the System Earth". This theme reflects the scientific orientation of Geodesy as the discipline of the measurement and mapping of the changing Earth, and responds to the challenges to Geodesy for a better representation of global change and geodynamic phenomena and processes. It comprises geometric and gravimetric observations and includes the fundamentals of geodetic reference systems, the study of geodetic observation techniques and analysis methods, and the modelling of geodetic parameters.

Motivation

The present societal challenges to Geodesy are based on the increasing consciousness of helplessness of mankind against natural hazards. Extreme disasters can only be prevented if the characteristics and processes of earthquakes, tsunamis, floodings, etc. are well understood in order to envisage a prognosis of future events. Geodesy is capable of measuring effects of such processes by observing the variations of the Earth's rotation, the Earth's surface geometry, and the Earth's gravity field. As these variations are very small, all efforts have to be undertaken to exhaust the full information included in the geodetic measurements. This can only be done by a thorough study of the techniques, models and results, and by the development of sophisticated methods for observing and analysing the parameters describing the dynamics of the System Earth.

Practical Applications

The basis of all geodetic measurements and derived parameters (time-variable position coordinates, gravity values, etc.) are unique reference systems. A fundamental research of DGFI is therefore dedicated to this field. The frames realizing the reference systems are also used in many practical applications. The celestial reference frame enables to describe the orientation of Earth in space. It is necessary for space travel, global navigation, astrometry etc. The terrestrial reference frame serves as the basis for all precise positioning in surveying, engineering, navigation, and geo-information systems. It allows the unification of all national and continental reference systems, which is a prerequisite for globalisation of society and economics. The Earth's gravity is represented with respect to physical reference surfaces, e.g., the geoid as an equipotential surface or the mean sea level in a state of equilibrium. It is also the reference for physical heights used in practical applications (levelling, barometric heights). The DGFI research activities support these applications.

University Connections

DGFI is cooperating very closely with the German universities offering geodetic education. This is mainly done under the umbrella of the DGK but also in bilateral arrangements. Members of DGFI give lectures and courses at various universities. Doctoral or Diploma theses are supervised by DGFI members. Interdisciplinary cooperation is installed with university institutes for Geophysics, Meteorology and Oceanography.

Research Group Satellite Geodesy (FGS)

Most intensive cooperation exists with the Technical University of Munich (TUM), in particular within the Research Group on Satellite Geodesy (Forschungsgruppe Satellitengeodäsie, FGS). It is a consortium formed by TUM's Institute of Astronomical and Physical Geodesy (IAPG) and Research Establishment (Forschungseinrichtung) Satellite Geodesy (FESG), the Geodetic Institute of the University Bonn (GIUB), the Federal Agency (Bundesamt) for Cartography and Geodesy (BKG), and the German Geodetic Research Institute (DGFI).

International Integration

The research of DGFI is integrated within several international services, programmes and projects, in particular of the International Association of Geodesy (IAG). DGFI recognizes the outstanding role of the scientific services of IAG for practice and research, and cooperates in several of these services as data, analysis and research centre. Members of DGFI have taken leading positions and supporting functions in IAG's scientific commissions, projects, working groups and study groups. DGFI also participates in the research programmes and bodies of the European Union (EU) and the European Space Agency (ESA). It cooperates in several United Nations' (UN) and inter-governmental institutions and activities.

Structure of the Programme

The present research programme for the years 2005-2006 was set up during an internal workshop on May 17 and 18, 2004. It was evaluated and revised by the Scientific Council (Beirat) of DGK, and approved by the DGK General Assembly on November 18, 2004. It is divided into the four long-term research fields

1. Earth System Observations,
2. Earth System Analysis,
3. International Services and Projects,
4. Information Systems and Scientific Transfer.

System observations include the modelling of observation techniques, methods and approaches of data processing and data combination, definition and realization of reference systems, and provision of consistent results. System analysis deals with the study of the properties and interactions of system elements which are reflected by the corresponding geodetic parameters and their correlation among one another. The participation in international services and projects, and the maintenance of information systems and science transfer are indispensable requirements for a research institute. The research fields are subdivided into specific topics, twenty-two in total. DGFI scientists are working simultaneously in several scientific topics in order to ensure the connection between the different fields and the consistency of methods, models and results.

1 System Observations

This major research field includes fundamental investigations on the modelling and combination of the different space geodetic observation data, such as the Global Navigation Satellite Systems (GNSS), Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), satellite altimetry and gravity sensors (SST, gradiometry). These observations are the basis allowing a highly precise determination of the geometry, the rotation and the gravity field of the Earth and its variations in time.
The research activities are divided into six topics. In topic 1.1 the work concentrates on the modelling of the different observation types to achieve a unification of the models and to improve the consistency between the techniques. Fundamental research concerning the realization of the terrestrial and the celestial reference frame is subject of topics 1.2 and 1.3, respectively. In topic 1.4 the activities concentrate on the development of combination methods for a consistent parameter determination. Subject of topic 1.5 is the modelling for earth gravity field parameters. Topic 1.6 deals with methods for the height determination aiming at the unification of height systems.

1.1 Modelling for space geodetic observations

The minimization of systematic differences between the data and results of geodetic space techniques requires a continuous improvement and standardization of physical and mathematical modelling.

Effect of snow accumulation on the height of GPS sites

GPS observations were studied with regard to the accuracy of the height component. The coordinate time series of some permanent GPS stations frequently exhibit biases in the vertical component which last some days up to several weeks. As this effect occurs only during winter time it can most likely be caused by snow accumulation on the antenna. Therefore, data from permanent stations were analysed, and an experiment was carried out during which the snow accumulation on the antenna was continuously monitored. Each processed baseline comprised one antenna which was permanently kept free of snow. In the experiment a snow pack of about 20 cm on the DGFI antenna resulted in an apparent height variation of -4 to -5 cm as shown in figure 1.1.1. This effect is fully compensated by variations of the troposphere parameters simultaneously estimated in the adjustment. An asymmetric melting of the snow cover also results in a distortion of the horizontal position estimate.

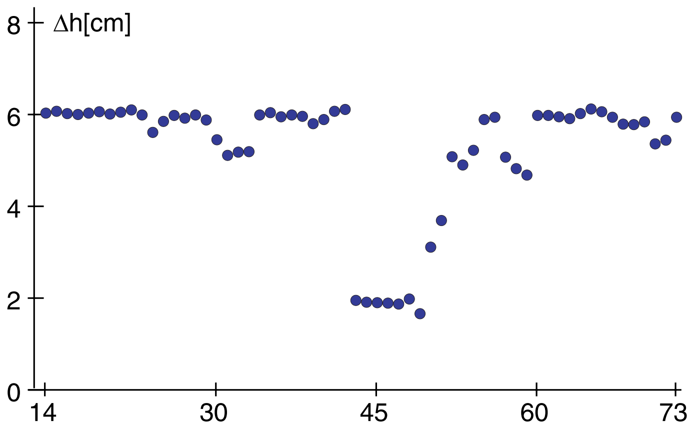


Fig. 1.1.1: Ellipsoidal height difference DGFI - OBET = -54.48 m + Δh during the period 2005, day 014-073.

Consistent modelling of GPS and VLBI observations

The observations from the VLBI campaign CONT02 and of colocated GPS stations of a global network were used to study aspects of a rigorous combination. This was done within a joint project of

Tab. 1.1.1: Time resolution and parameterization of common parameters of GPS and VLBI and relevant a priori models.

Parameter	temporal resolution	parameterization	a priori and functional modelling
station coordinates	daily	constant	solid earth tides: IERS Conventions 2003 pole tides: identical mean pole values ocean loading: Scherneck model based on FES95.2
pole coordinates, UT1-UTC, nutation corrections	2h/1h daily	piece-wise linear piece-wise linear	a priori values: IERS C04 interpolation: linear nutation and precession model: IAU2000
tropospheric zenith delays tropospheric gradients	2h/1h daily	piece-wise linear constant	a priori values: Saastamoinen mapping function: Niell mapping function

DGFI and FESG at TU Munich. As GPS and VLBI are both microwave techniques, they have not only station coordinates and Earth orientation parameters in common, but also tropospheric zenith delays and gradients. To perform a combination as rigorously as possible, the functional models of both techniques were adapted carefully. The same models were used and the parameters were set up identically in the two software packages OCCAM (VLBI) and the Bernese GPS software. In a previous step, the VLBI data, usually managed in sessions starting and ending at 17 h UTC, were concatenated to files from 0 h to 24 h UTC according to GPS, optimizing the compatibility. The GPS computation was done using absolute antenna phase centre corrections. The axis offsets for the VLBI antennas used in the analysis were the official IVS values. Table 1.1.1 gives an overview of the corresponding models and parameters and their temporal resolution used in the GPS and the VLBI software. The homogeneous modelling of both techniques reduced the systematic differences considerably. A very good agreement between the tropospheric zenith delay estimates from GPS and VLBI was achieved. An example is shown in 1.4.

1.2 Foundations of terrestrial reference systems

In its function as one of the ITRS Combination Centres of the IERS (see 3.1), DGFI is strongly involved in the realization of the International Terrestrial Reference Frame. During the period 2004/2005 the research activities are concentrated on the computation of ITRF2004, which is to replace the current ITRF2000. It is based on weekly input data including station positions and the Earth Orientation Parameters (EOP) as common parameters of all techniques. This enables for the first time a consistent adjustment of station positions and EOP. Additionally, the weekly input data allow to consider periodical signals as well as discontinuities in the station positions. The new type of input data requires an advanced processing strategy. New methods are developed, investigated and implemented in the ITRF computation process.

Analysis of input data concerning datum information

Weekly GPS, SLR and DORIS and session-wise VLBI input data are provided by the services in SINEX format. The files are converted into normal equations, and constraints are removed if necessary and possible. Then the normal equations are analysed concerning the included datum information. Therefore, the geometric part and the part of datum information of the network are separated. The results are used to decide how the normal equations should be handled within the combination process, since not all included datum information is suitable to be used for the ITRF solution.

Accumulation of weekly input data

Within the step of intra-technique combination, the weekly input data are accumulated to technique-specific multi-year solutions. Firstly, series of station positions and EOP are generated by applying similarity transformations between weekly solutions and a first multi-year solution. They are analysed to identify outliers in the solutions and to detect periodic signals and discontinuities in station positions (see also 2.7). Then the normal equations are stacked technique-wise again considering the discontinuities provided by the technique centres or identified by analysing the time series. Station velocities are also set up in this step. Additionally Helmert transformation parameters are introduced in the case of GPS and DORIS because the datum information contained in the normal equations should not be used for the TRF datum realization.

New strategies for local tie implementation

Based on the new type of input data strategies are developed for the selection of terrestrial measurements at co-location sites (local ties) to integrate the different space geodetic techniques. As common parameters of all techniques the EOP represent an additional global tie and enable a more consistent rotation datum of the ITRF solution. Furthermore the EOP values provide valuable information for the validation of local ties. Two criteria are defined, which have to be fulfilled from the set of local ties introduced in the combination:

(1) The consistency of the reference frame should be maximized. Combining the station networks but not the EOP of two techniques the mean offsets between the x-pole and y-pole derived from the two techniques are a measure of the achieved consistency.

(2) The deformation of the reference frame shall be minimized. The RMS of a similarity transformation between the combined and single technique solutions is used to quantify the network deformation.

Table 1.2.1 describes the solution types performed and compared:

Tab. 1.2.1: Solution types.

solution type	description
sing	single technique solutions for comparison
dist	vector lengths of 26 co-location sites are used
17d3	local ties in three components are introduced for 17 co-location sites
9d3	local ties in three components are introduced for 9 co-location sites showing differences between terrestrial measurements and space techniques of 1.5 cm or smaller

Figure 1.2.1 shows the comparison of the solution types for the combination of a GPS and a VLBI solution introducing local tie information with standard deviations of 0.1, 0.3, 1.0 and 3.0 mm. The most consistent and least deformed solution can be achieved using only a few good and well distributed sites (solution type 9d3).

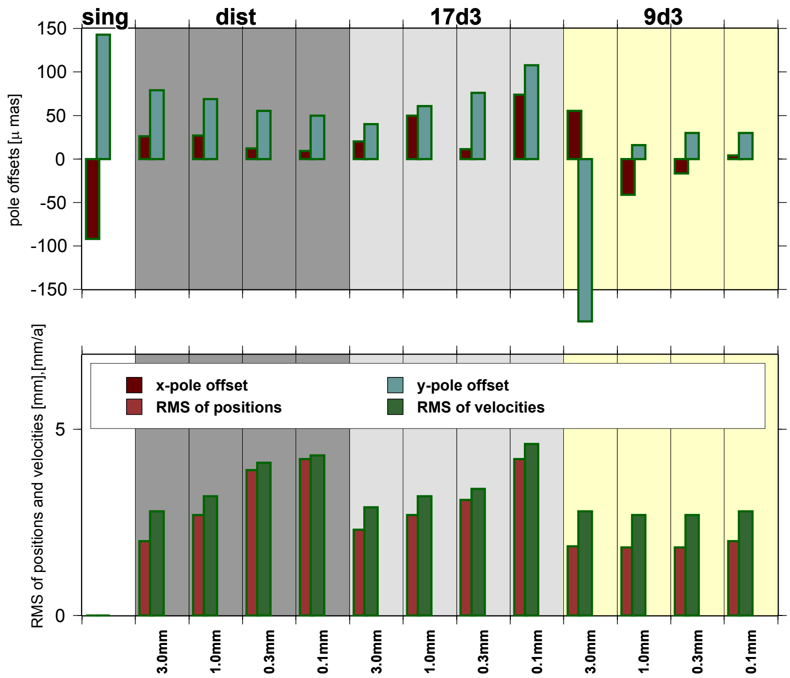


Fig. 1.2.1: Accuracy of different solution types for the combination of GPS and VLBI.

It can be recognized that there are large variations in the pole offsets between GPS and VLBI between the different solution types. This shows the high dependency of the results from the type of datum realization. If only a subset of nine local ties is used, the offsets get close to zero, as shown in figure 1.2.2 for the x-pole.

The combination which is based only on vector lengths (dist) gives suitable results although this solution is not as stable as

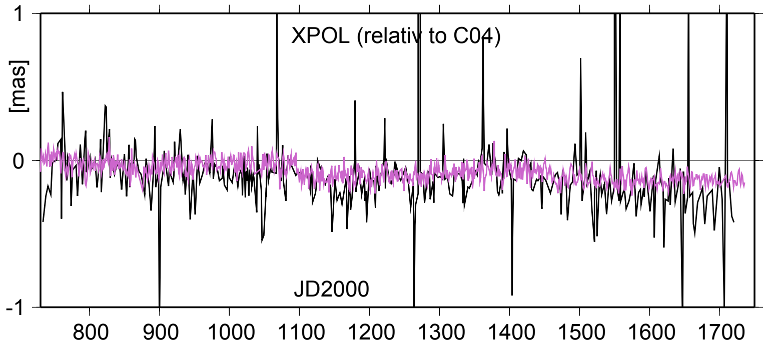


Fig. 1.2.2: GPS and VLBI x-pole time series for solution type 9d3 (offset: 0.004mas, RMS(GPS): 0.06mas, RMS(VLBI): 0.18mas)..

those based on tie information in three vector components. However, this solution type has the following two advantages: (1) Orientation errors in the local network are eliminated and (2) discrepancies in the height component of the tie have a smaller influence on the combination, since the horizontal dimension of the local networks is in the most cases much larger than the vertical. Simulation studies are performed to investigate whether this solution type can be used as an alternative to the present method if all VLBI stations are colocated with GPS. For the current global VLBI network it could be shown that a combination based on vector lengths at 56 (simulated) co-location sites is more stable than a combination using ties in three components for 17 sites, which are used in the present realizations.

1.3 Realization of a celestial reference system

The focus of this research topic is a realization of the celestial reference system (CRS), namely a set of coordinates of several hundred radio sources which are uniquely observed by the space geodetic technique Very Long Baseline Interferometry (VLBI).

Time dependence of estimated source positions

Figures 1.3.1 and 1.3.2 show time series of session-wise estimated positions of some sources with a quite distinct time dependence (moving medians of 30 values each are presented in red).

Fig. 1.3.1: Time series of right ascension estimates of the source 4C39.25.

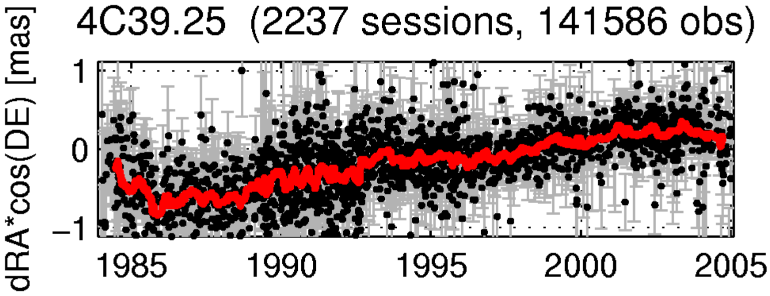
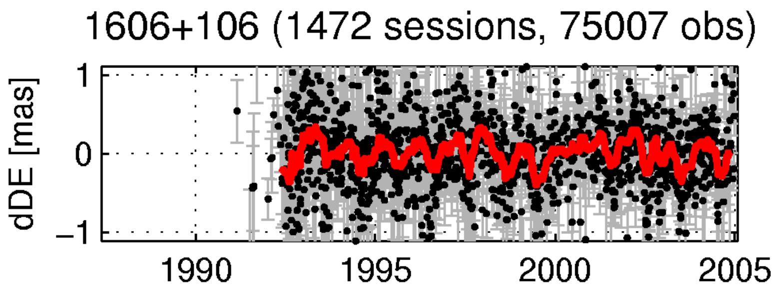


Fig. 1.3.2: Time series of declination estimates of the source 1606+106.



Although source position time series should not directly be interpreted as “real” spatial movements of the radio sources, they provide the basis for an advanced analysis of shortcomings in the modelling: the cause of the phenomenon illustrated in figure 1.3.1 is assumed to be a spatial relocation of the energy maxima of the sources, e.g. by ejecting material, so-called “jets”. But, it must be mentioned that the physics of radio sources is not yet completely understood. The cause of the annual signals in figures 1.3.2 is even more unclear - possible reasons might be a shortcoming in the correction for the annual aberration or erroneously modelled annual effects like tropospheric influences.

These results strongly suggest to investigate the time dependent behaviour of the source positions in more detail. Today, as in ICRF, it is still common use to model the source positions as constant in time. A first approach implemented by DGFI was to extend the VLBI solution by the option to estimate also the first time derivatives of the source positions. This comprised the computation of the corresponding partial derivatives in the VLBI software OCCAM, as well as the realization of an appropriate non deforming datum for such parameters with the DGFI software DOGS-CS. First results generally confirm values that were determined with the time series approach described before. It is expected that a broader knowledge in this field will be a fundamental input for the generation of a new realization of the International Celestial Reference Frame, ICRF (see also 3.5).

Consistent reference frames

The parameters of a celestial (inertial) reference frame are in VLBI solutions, up to a certain extent, always dependent on other parameters such as station positions and velocities (TRF) and the Earth orientation parameters (EOP). This is why much effort was spent on computing a solution, in which VLBI observations are analysed with all the unknown parameters estimated simultaneously. As a consequence, the TRF, CRF as well as the EOP determined in such a way will be fully consistent with each other on the one hand and completely unbiased on the other. This is of particular importance because VLBI observations of high quality today cover more than 20 years. Both, the homogeneity between the frames and the EOP and the homogeneity of all parameters in time are not ensured by todays products of the IERS.

The actual DGFI VLBI solution 05R02 comprises 2699 sessions between 1984 and 2005, each about 24 h long, including a total of 49 telescopes (of which 46 are part of ITRF2000) observing 1954 sources (of which 562 are part of ICRF-Ext1). Session-wise datum free normal equations were set up with the VLBI software OCCAM 6.0 (modified for estimating source positions) and accumulated to one common equation system with the DGFI software DOGS-CS. This equation system can be solved either by fixing station positions and velocities as well as source positions to the values given in ITRF2000 and ICRF-Ext1 (with the EOP estimated), or applying a non-biasing datum, namely NNR and NNT, e.g. for 25 stable stations w.r.t. ITRF2000 and NNR, e.g. for 199 stable sources w.r.t. ICRF-Ext1. Comparisons between the results of such different approaches confirm the necessity of a solution where TRF, CRF and the EOP are estimated simultaneously:

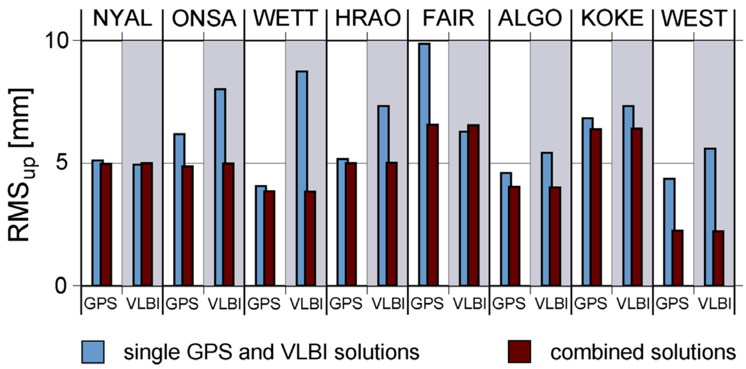
- IERS EOP C04 is not consistent to ICRF-Ext1 and the VLBI-part of ITRF2000 (see e.g. topic 3.1),
- ITRF2000 and ICRF-Ext1. were not computed using the same modelling, which can influence the parameters of the respectively other frame systematically,
- station and source positions can in VLBI solutions depend significantly on each other, especially in case of weakly determined objects.

VLBI contributions to a combination of space geodetic techniques

GPS derived rates of daily terrestrial pole, dUT1 and nutation angles are highly precise. However, the long-term information in dUT1 and nutation series determined with satellite techniques is strongly depending on the estimation strategy and/or the mathematical formulation of the orbits. Because of its direct link to the CRF, VLBI can determine low frequencies in dUT1 and nutation uniquely stable, whereas the higher frequencies of VLBI-derived EOP (especially of the terrestrial pole) are of lower precision due to two more or less technical reasons: firstly, VLBI observes in terrestrial networks that usually do not cover the whole globe; secondly, VLBI telescopes observe each source only for a few minutes. That limits the separability of topocentric parameters in high temporal resolution such as the ones to model the influences of the troposphere and the station clocks. Therefore, adequately combined GPS and VLBI observations will give the best EOP results in the whole frequency domain and provide optimal precision, stability and interpretability for the whole set of parameters of the techniques involved.

The fundamental benefit of such an approach was demonstrated by a rigorous combination of VLBI data from 15 days of continuous VLBI observations in October 2002 (‘CONT02’) and the corresponding GPS data, carried out in close cooperation with the Research Establishment Satellite Geodesy (FESG) at the Technical University of Munich (for details see 1.1, 1.4 and 3.1). Examples of combined and uncombined station repeatabilities are presented in figure 1.3.3. Another attempt to promote combination efforts was the participation in the IERS Combination Pilot Project, which is described in 3.1. As the VLBI contributions to this pilot project were coordinated by the IVS, a detailed description is also given in 3.5.

Fig. 1.3.3: Comparison of the repeatabilities of daily GPS and VLBI height estimates using the data of the CONT02 campaign, estimated in single solutions (blue) as well as in a combined solution (red).



1.4 Combination of space geodetic observations

To optimize the combination of geodetic space observations investigations were done focussing on estimation methods and processing procedures. The rigorous variance component estimation (VCE) was introduced and intensively analysed. VCE is now routinely applied by the ILRSB combination centre (see section 3.4). First experiences of a regular intra-technique combination led to the development and application of quality and reliability criteria within the estimation process. Further steps towards a rigorous combination were developed. As to processing procedures, the development of an automatic combination flow was continued. Additionally, a report on the combination software updates is given.

Variance component estimation

VCE is an absolute estimation method for weighting the covariance or normal matrices of the input solutions. Its main characteristic is that it uses the full covariance matrices of the input solutions (which is not the case for relative weighting methods). After having applied VCE on a weekly routine basis for several months in the SLR intra-technique combination, some promising features are presented in the following examples.

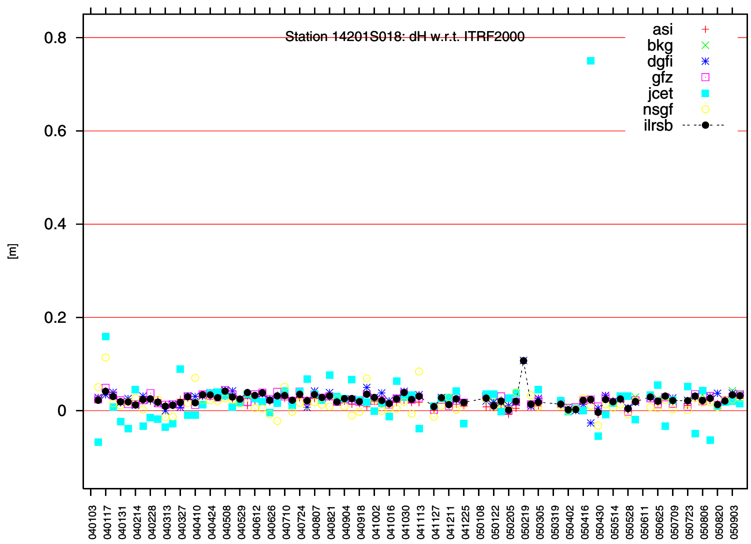


Fig. 1.4.1: Time series of height estimates at Wettzell.

In figure 1.4.1, a time series of height estimates w.r.t. ITRF2000 is presented starting at week 040103 (seven days before day 2004-01-03) and ending at week 050910. They are derived from minimal constraint solutions of the analysis centres ASI, BKG, DGFI, GFZ, JCET, NSGF and of the ILRS Combination Centre ILRSB (see section 3.4). The combined solutions "ilrsb" represent (as expected) a mean time series. In the beginning the input solutions "jcet" and "nsgf" scatter a lot. Table 1.4.1 contains the estimated variance components (VC) with their variances for the first five weeks. For week 040117 (largest scattering of "jcet" and "nsgf") the variance components of both solutions are also large, as expected. The only deviation of the combined solution from the mean time series is to be seen in week 050219. The variance components in table 1.4.1 do not show peculiarities.

Tab. 1.4.1: Variance components (VC) in the beginning of the time series at Wettzell.

week	AC	VC	variance of VC
040110	asi	6.3	0.3
	dgfi	30.6	1.1
	gfz	0.8	0.1
	jcet	9.9	0.5
	nsgf	11.6	0.5
040117	asi	9.7	0.4
	dgfi	8.7	0.4
	gfz	2.1	0.1
	jcet	18.3	0.8
	nsgf	11.9	0.5
040124	asi	5.8	0.3
	dgfi	18.2	0.6
	gfz	0.1	0.0
	jcet	2.3	0.1
	nsgf	0.1	0.0
040131	asi	4.8	0.3
	dgfi	3.9	0.2
	gfz	2.6	0.1
	jcet	17.4	0,7
050219	asi	4.3	0.3
	dgfi	3.1	0.1
	gfz	1.1	0.1
	jcet	2.4	0.2
	nsgf	18.4	0.7

In week 050423 a large jump of "jcet" can be seen. Table 1.4.2 contains the variance components of the analysis centres involved and the estimated coordinate increments dp with standard deviations (st. dev.) in X-, Y-, and Z directions. Although the standard deviations are relatively small, the „jcet" solution does not significantly disturb the combined solution - another positive effect of the VCE.

Tab. 1.4.2: Variance components (VC) and coordinate estimates for week 050423.

week	AC	VC	variance of VC
050423	asi	3.9	0.3
	dgfi	22.3	0.6
	gfz	0.2	0.0
	jcet	17.0	0.5
	nsgf	10.3	0.7

14201S018 Wettzell		
coordinate	dp [m]	st.dev. [m]
X	0.457	0.021
Y	0.133	0.006
Z	0.582	0.025

Another interesting feature of the VCE is revealed in figure 1.4.2. Offset in the range bias between the "asi", "bkg", "dgfi", "gfz" solutions and the "ilrsb" combined solution on the one side and the "jcet" and the "ngsf" solutions on the other side obviously exists for the station Riyad.

For example in the weeks 040626 to 040724 (table 1.4.3), the variance components of "asi", "dgfi", and "gfz" are on a similar level as those of "jcet" and "nsgf". The standard deviations of the individual solutions are in the same range. The combined solution is not a mean of all individual solutions (as may be expected), but rather a mean of the "asi", "dgfi" and "gfz" solutions

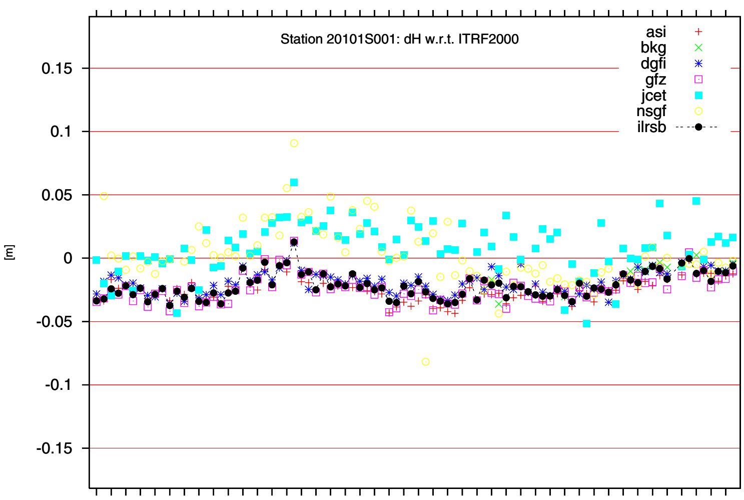


Fig. 1.4.2: Time series of height estimates at Riyad.

Tab. 1.4.3: Variance components and height estimates at station Riyad from week 040626 to 040724.

Estimated variance components						
Week	ASI	DGFI	GFZ	JCET	NSGF	
040626	3.9	1.2	0.6	2.2	16.8	
040703	8.9	3.0	0.4	1.5	14.9	
040710	8.4	0.1	0.1	4.3	9.4	
040717	none	17.9	0.1	0.7	0.1	
040724	8.6	7.4	3.4	12.8	17.4	
Estimated height increments [m] and st. dev. [m] for 20101S001 Riyad						
Week	ASI	DGFI	GFZ	JCET	NSGF	ILRSB
040626	-20 ± 3	-17 ± 3	-23 ± 2	28 ± 8	32 ± 8	-21 ± 12
040703	-5 ± 4	-8 ± 8	-1 ± 2	32 ± 12	18 ± 8	-6 ± 14
040710	-11 ± 4	-2 ± 7	-6 ± 7	32 ± 8	55 ± 7	-4 ± 10
040717	none	12 ± 12	14 ± 18	60 ± 9	91 ± 16	13 ± 23
040724	-18 ± 3	-10 ± 4	-13 ± 5	28 ± 6	33 ± 6	-13 ± 9

only. That may have following reason: Only the “jcet” and “ngsf” solutions also solve for range biases, the others do not. Because solutions with estimated range biases are less stable than the ones without range biases, the correlations between the estimated parameters are generally higher.

Quality and reliability measures

During the combination process, several reliability and quality measures are calculated and analysed in order to obtain optimal combination results. Among these measures (which were introduced in the previous Annual Report 2003/04, section A4) are the eigenvalue criterion and the ‘z-measure’. It turns out that the z-measure is superior to the eigenvalue analysis. For the SLR unconstrained normal equation matrix, the z-measure values should be very large for the translation parameters tx, ty, tz and for the scale sc, but very small (in theory zero) for the rotations rx, ry, and rz (see table 1.4.4). For the week 969810, the three smallest eigenvalues and the z values for the rotations of “gfz” are close to zero, in contrast to the other values as it should be. In week 960817, the eigenvalues are also correct, but the z-measures for the rotations of “gfz” are too big.

Tab. 1.4.4: Rank type criterion.

week960810							
AC	tx	ty	tz	rx	ry	rz	sc
asi	2.22e+06	1.98e+06	2.67e+05	6.96	6.96	0.00245	3.03e+06
dgfi	8.94e+05	9.02e+05	1.04e+05	19	24	-1.62	1.36e+06
gfz	3.08e+06	2.44e+06	3.33e+05	76.1	77.3	0.00576	4.14e+06
jcet	3.59e+06	3.38e+06	4.29e+05	13.3	12.5	1.18	5.28e+06
nsgf	6.95e+05	7.22e+05	1.11e+05	43.7	43.5	21.3	1.09e+06
week960817							
AC	tx	ty	tz	rx	ry	rz	sc
asi	8.95e+05	1.1e+06	1.47e+05	3.39	3.97	0.00193	1.48e+06
dgfi	7.53e+05	8.65e+05	7.93e+04	29.4	27.9	3.55	1.24e+06
gfz	1.55e+06	1.65e+06	3.39e+05	7.48e+04	2.89e+04	4.22e+04	2.57e+06
jcet	2.62e+06	2.87e+06	3.92e+05	13.6	13	2.1	5.11e+06
nsgf	2.12e+05	2.76e+05	4.06e+04	21	20.9	10.6	3.31e+05

Relative weighting of different space geodetic observation techniques

The weighting of the heterogeneous input data from different space geodetic techniques may be performed by a variance component estimation (VCE). Problematic issues are a proper implementation of the local tie information and the handling of possible remaining biases. Time series of station coordinates contain valuable information to derive relative weighting factors between different techniques as well and may help to validate the results of a VCE. We used the mean RMS values (given in table 1.4.5) of the time series of a subset of good reference stations for each technique to estimate weighting factors.

Tab. 1.4.5: Mean RMS values of station position time series.

Techn.	TC / AC	North [mm]	East [mm]	Up [mm]
GPS	IGS	0.22	0.26	0.64
VLBI	DGFI	0.53	0.52	1.5
SLR	DGFI	3.1	3.6	2.7
DORIS	IGN / JPL	2.7	3.7	2.5

Steps towards a rigorous combination

The joint combination studies of DGFI and FESG based on the continuous VLBI campaign CONT02 were continued. Important changes were done in the processing of the single techniques. The VLBI data were now processed using the new antenna axis offsets provided by the IVS. New GPS input data were generated with a refined version of the Bernese GPS Software (a bug in the computation of solid Earth tides was corrected).

These reprocessed VLBI and GPS data improved many of the results derived from a combination: The repeatabilities of the combined station position parameters are clearly better than for single VLBI and GPS solutions (see section 1.3, figure 1.3.3). The discrepancies between the coordinate differences derived from the space techniques and the terrestrial measurements (local ties) become significantly smaller for most of the co-location sites due to these changes. The discrepancies between the estimated tropospheric zenith delay differences derived by GPS and VLBI and the theoretical differences resulting from the height difference between the two monuments decrease as well (see table 1.4.6; the theoretical

Tab. 1.4.6: Comparison of tropospheric zenith delay differences [mm] from the Saastamoinen model and the space geodetic techniques for CONT02 and long-time series.

Site	CONT02				Long-Time-Series	
	Model	ΔZD	ΔZD-Model	Radome	ΔZD-Model	Radome
		GPS-VLBI	GPS-VLBI		GPS-VLBI	
Ny-Alesund	0.96	-0.50	-1.46	SNOW	-1.41	NONE / SNOW
Onsala	4.53	1.17	-3.36	OSOD	-3.55	DUTD / OSOD
Wettzell	0.98	1.26	0.28	NONE	-1.09	NONE
Hartebeesthoek	0.46	-0.40	-0.86	NONE	-0.89	NONE
AlgonquinPark	7.33	7.28	-0.05	NONE	-0.55	NONE
Fairbanks	3.90	0.74	-3.16	JPLA	-4.53	NONE / JPLA
KokeePark	3.04	8.40	5.36	NONE	5.14	JPLA / NONE
Westford	0.57	4.38	3.81	NONE	4.21	NONE

values are computed using the Saastamoinen model and a standard atmosphere). Since the CONT02 campaign contains only 14 days of data, the results for the tropospheric zenith delays are compared to values derived from reprocessed VLBI and GPS long-time series spanning up to 10 years. The VLBI data were processed at DGFI, the GPS solutions were computed by FESG in cooperation with the Technical University of Dresden.

Towards automatic processing

The automatic processing of the ILRSB Combination Centre was refined by several new methods. After introducing the rigorous VCE, negative variance components occurred. In each case, deficiencies in the minimal constraint solutions of the input data could be found, e.g. unrealistic EOP estimates or negative diagonals of the covariance matrix for the coordinate estimates. After eliminating the stations with negative diagonals in the input solution or deleting the input solution in case of unrealistic EOP, only positive variance components were obtained. Appropriate methods for the elimination of these stations or for the deletion of total input solutions were developed in order to guarantee an automatic process flow.

Updates of the combination software

Updates of DOGS-AS (Analysis Software):

- refinements of the VCE method,
- new methods for the validation of input and combined solutions (quality and reliability criteria),
- new methods for pass/fail criteria within the automatic processing.

Updates of DOGS-CS (Combination and Solution):

- All the routines were adapted to run also on 64-bit processors with either 32-bit or 64-bit default integer length.
- The routines were tested with two more compilers, the GNU g95 compiler and the Intel ifort 9.0 compiler. The Intel compiler is able to generate multithreaded code to run on Itanium based Linux clusters. This enables to solve normal equations with 30000 unknowns to be solved, as needed for the current TRF determination.
- CS_COND can now set up pseudo observation equations for the distance or the distance change of two sites, which helps to use local ties with uncertain orientation, and the equations for the three types of no-net-scale conditions.
- The eigenvalue tool CS_EIWE was expanded by the option to plot the eigen values of a normal equation matrix as a function of the weight given to (pseudo-) observation equations. This helps to control the weight of the datum conditions for (free) systems of equations.
- CS_INPAR, the routine for the introduction of additional parameters to a given system of equations, was extended to include Earth orientation parameters into common rotations of station positions and velocities.

1.5 Modelling for parameters of the Earth gravity field

This new topic aims to estimate gravity field models from data of CHAMP, GRACE and (later on) GOCE. The rationale to do this in parallel to other groups is to get full control about the error budget (in terms of the variance-covariance matrix), to investigate alternative parametrisation for gravity field variations (which is innovative), and to create a basis for the high resolving gravity field modelling, focused on in topic 2.2 below.

It is known, that the estimation of Stokes coefficients from CHAMP and GRACE data is difficult due to changing ground track pattern (caused by the decaying orbits) and alias effects caused by sampling high frequency gravity variations of atmospheric and oceanic processes. Thus, it was decided to focus first on

- a numerically stable algorithm for the least squares estimate of Stokes coefficients
- the preparation of the best known ocean tide models.

Q-R factorization by fast Givens

Orthogonal transformations are known to provide higher numerical stability than the normal equation approach. Already small size least squares problems may have normal equations where the inversion fails while Q-R factorization gives exact results.

$$\|\mathbf{Ax}-\mathbf{b}\|_2^2 \rightarrow \min$$

is equivalent to

$$\|(\mathbf{Q}'\mathbf{A})\mathbf{x}-\mathbf{Q}'\mathbf{b}\|_2^2 \rightarrow \min$$

where

$$\mathbf{Q}'\mathbf{A}=\mathbf{R}=\begin{bmatrix}\mathbf{R}_1\\ \mathbf{0}\end{bmatrix} \quad \text{and} \quad \mathbf{Q}'\mathbf{b}=\begin{bmatrix}\mathbf{c}\\ \mathbf{d}\end{bmatrix}$$

such that

$$\|\mathbf{Ax}-\mathbf{b}\|_2^2=\|\mathbf{R}_1\mathbf{x}-\mathbf{c}\|_2^2+\|\mathbf{d}\|_2^2 \rightarrow \min$$

Let $\mathbf{Ax} = \mathbf{b}$ be a system of observation equations with $\mathbf{A}$ an $m \times n$ coefficient matrix and $m \geq n$. The least squares solution $\mathbf{x}$ minimizes the norm of residuals (as shown left, first equation). With an orthogonal matrix $\mathbf{Q}$ (which has the property $\mathbf{Q}'\mathbf{Q} = \mathbf{I}$) the matrix $\mathbf{A}$ can be transformed to upper triangular form $\mathbf{R}$ such that $\mathbf{A} = \mathbf{QR}$ or $\mathbf{Q}'\mathbf{A} = \mathbf{R}$. For the least squares solution it is then equivalent to minimize the transformed systems (see left). As seen from the last equation, left hand, the minimum is achieved for $\mathbf{x} = \mathbf{R}_1^{-1}\mathbf{c}$ and the square sum of residuals is then given by $\|\mathbf{d}\|_2^2$. The variance covariance matrix can be derived from $\mathbf{R}_1$ by

$$(\mathbf{A}'\mathbf{A})^{-1} = (\mathbf{R}'\mathbf{Q}'\mathbf{Q}\ \mathbf{R})^{-1} = (\mathbf{R}_1'\mathbf{R}_1)^{-1} = \mathbf{R}_1^{-1}\ (\mathbf{R}_1')^{-1}$$

A sequence of Givens transformation is one possibility to set up an orthogonal transformation $\mathbf{Q}$. In its fast form (also known as square-root-free) it is comparable in speed to Housholder transformation. Moreover, Givens transformation of the matrix $\mathbf{A}$ can be applied row by row which allows to process sequentially the matrix of observations. In this way very large systems without any limitation to the number m of observations can be handled. The memory requirements are basically limited to the upper triangular system $\mathbf{R}_1$ of unknowns.

In the present application the fast Givens Q-R factorization is performed by an existing FORTRAN module realizing the algorithm as described by Lawson and Hanson (1974, p.60-62). The price for the fast form of the Givens transformation are additional elements (as much as unknowns) that control the scaling of the system and require from time to time a re-scaling to avoid numerical overflow. The only limitations of the sequential procedure is that there is no possibility to handle correlated observations.

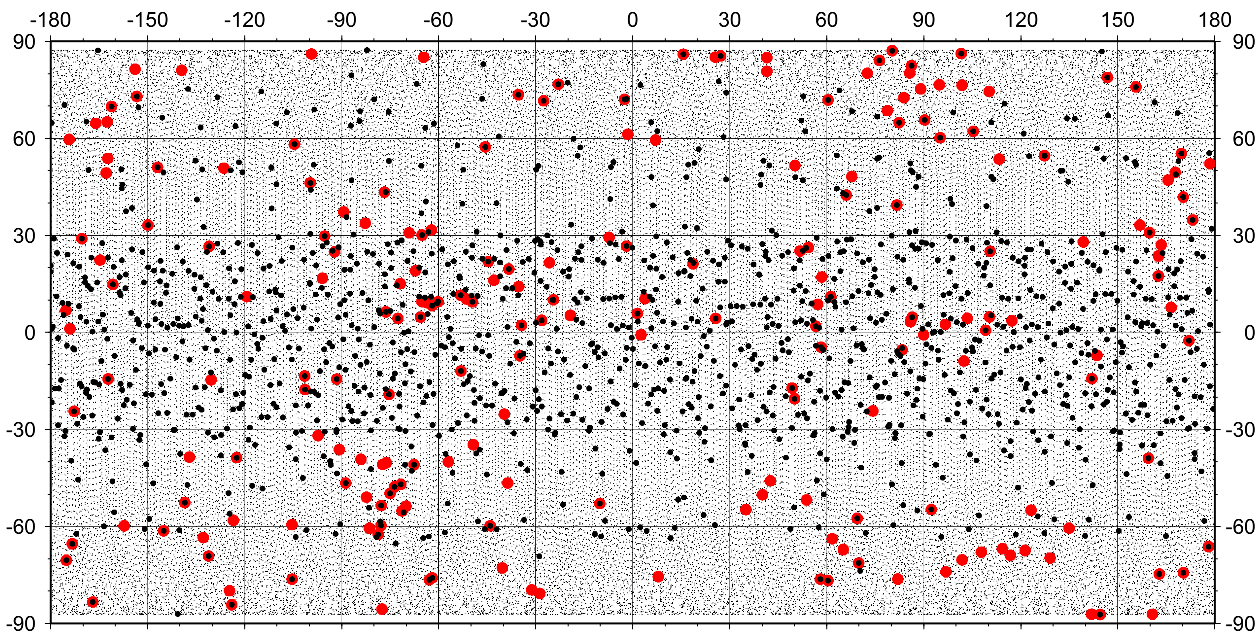
Treatment of integration constants

Using the energy balance approach the values of the disturbing potential are computed along the trajectory from the velocity of the satellite, the normal potential, the centrifugal potential, the tidal potential and the integration of non-gravitational accelerations. These potential values are known up to an integration constant which remains fixed as long as an unbroken sequence of observations is treated. These constants are to be re-initiated whenever the sequence of observations is broken – either by gaps or outliers in the ephemeries, by data gaps of the star-trackers or by gaps or re-settings of the accelerometer. Thus, beside the Stokes coefficients the integration constants are additional unknowns which would dramatically increase the size of the system. To limit the size of the system, these unknowns are eliminated 'in advance' that is during the transformation of the observation equations. This is accomplished by summing up all N_c observation equations with the same constants and then subtracting this summation equation with the weight $1/N_c$ (which is realized in the Q-R transformation by *adding* the summation equation with the weight $-1/N_c$).

Simulation with EIGEN-GRACE1S

The solution algorithms and the treatment of (unknown) integration constants have been validated with simulated data. The kinematic GPS orbit of CHAMP, as provided by Rothacher and Svehla (2003) with a 30 second sampling was complemented by the values of the disturbing potential of the EIGEN-GRACE1S gravity field model. Data gaps were flagged to indicate any change in the integration constants. With the Q-R transformation and the treatment of integration constants as described above, it was possible to recover the Stokes coefficients of the EIGEN-GRACE1S gravity field model from a one month subset of the simulated data. This proves that the solution strategy is correct but also demonstrates that the data *distribution* shown in figure 1.5.1 is – in general – sufficient for a stable estimation of Stokes coefficients.

Fig. 1.5.1: Geographical distribution of the CHAMP trajectory (with 30 second sampling) for a 30 day period. Red dots indicate re-settings due to gaps of the kinematic orbit. Black dots show the distribution of re-settings due to discontinuities of the accelerometer data. These re-settings increase significantly within the latitude band ±30° and cause stability problems.



Tidal potential of Moon and Sun

The reduction of the direct gravitational effect of Sun and Moon is straightforward. For the energy balance approach it can be most easily computed in terms of the tidal potential $V_{M\backslash S}$ by

$$V_{M\backslash S} = \frac{GM_{M\backslash S}}{d_{M\backslash S}} \left(\frac{r}{d_{M\backslash S}} \right)^2 \left[\frac{3}{2} \cos^2 \psi - \frac{1}{2} \right]$$

where the index 'M\S' stands either for the Moon or the Sun, $GM_{M\backslash S}$ is the product of the gravitational constant and the mass of the attracting body (Moon or Sun), $d_{M\backslash S}$ is the distance from the geocentre to the attracting body and r and ψ are the geocentric radius to the point of computation and the spherical distance between the direction to this point and the attracting body respectively. The ephemeries of Moon and Sun are derived from the JPL ephemeries file DE405.

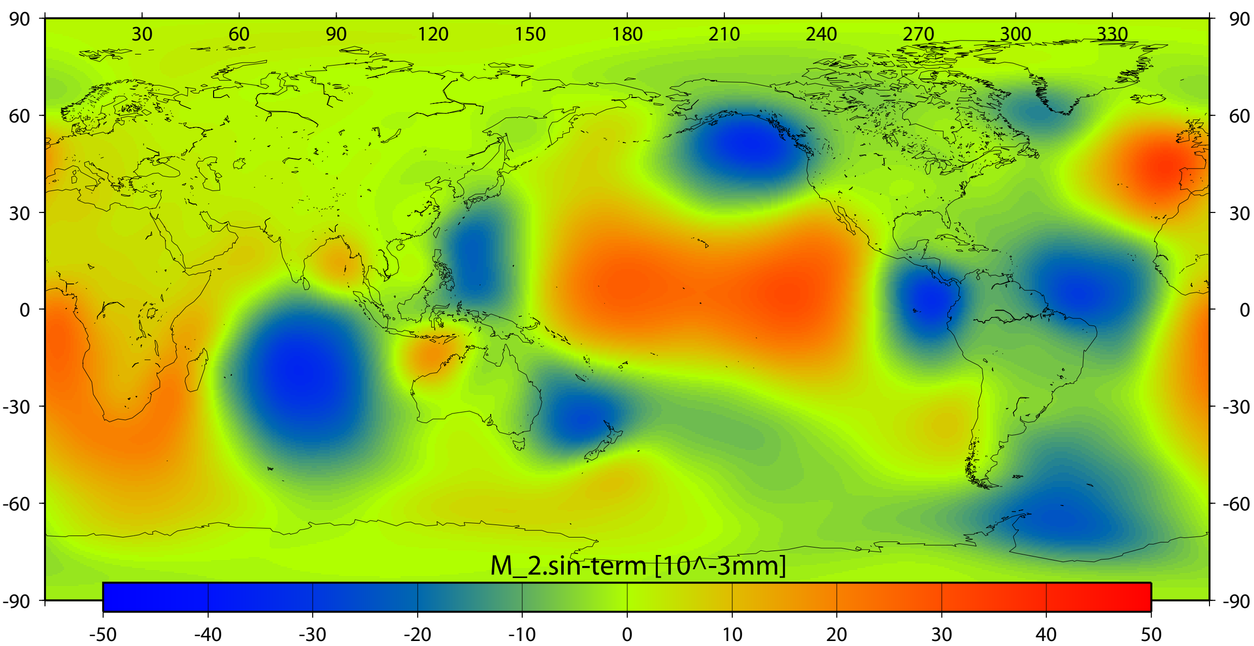
Potential of ocean tides

The effect of ocean tides requires somewhat more attention, because the errors of some of the latest ocean tide models (e.g. GOT00.2) have still significant influence on the gravity field modelling. One of the most recent models, FES2004, is available and shall be applied to the CHAMP and GRACE data processing. FES2004 gives amplitudes and phases for the dominant partial tides, tabulated on a 7.5´-grid. The transformation to a spherical harmonic representation suitable to compute the tidal potential at any point in space is accomplished by the following steps:

- amplitudes and phases are expressed as cosine and sine-terms;
- the product of mean water density and the tidal elevation define simple layer densities (for both, cosine and sine-terms) which are developed into a series of spherical harmonics;
- the spherical harmonic coefficients are finally re-scaled to Stokes coefficients, taking into account the indirect effect caused by the elastic deformation of the Earth;

These steps have to be performed for all major partial tides. Figure 1.5.2 shows geoid heights due to the sine-term of the M_2 tide.

Fig. 1.5.2: Amplitude of geoid height variations [10^{-3}mm] as caused by the sin-term of the direct and indirect effect of the M_2 ocean tide.



1.6 Unification of height systems

At present, the existing physical (normal H^N or orthometric H^O) heights and the local (quasi)geoid (ζ, N) models refer to the individual equipotential surfaces passing through the tide gauges defining the classical height datums. These tide gauges are not on the same equipotential surface, since the mean sea level used as a reference is affected by different local phenomena, such as the sea surface topography, ocean surface rise, vertical crustal movements, etc. Under these circumstances, the existing height datums confine the appropriate combination of the geometrical terrestrial reference system (frame) with the physical one, i.e. the relation $h = H^O + N = H^N + \zeta$ (h = heights above a global ellipsoid) is not satisfied. It is only possible if the geopotential numbers to derive H^O or H^N refer to a globally defined reference level W_0. This faces up two immediate problems: the determination of a global W_0 value and the establishment of the relationship between the local height datums and the global one.

Empirical determination of W_0

The empirical determination of W_0 becomes a feasible issue since accurate derived satellite altimetry Mean Sea Surface (MSS) models and precise Global Gravity Models (GGM) are available. The traditional solution of supposing W_0 identical to a predetermined normal potential U_0 is no longer required. It can be estimated using:

$$\int_{S_0} (W - W_0)\, dS_0 = \min$$

where S_0 is the global ocean surface, and

$$W = \frac{GM}{r}\left[1 + \sum_{n=1}^{\infty}\sum_{m=0}^{n}\left[C_{nm}\cos m\lambda + S_{nm}\sin m\lambda\right]P_{nm}(\cos\theta)\right] + \frac{1}{2}\omega^2 r^2 \sin^2(\theta)$$

The W_0-value corresponds to the weighted mean geopotential value over the total ocean surface (Listing definition). In order to establish the reliability of this formulation, W_0 was empirically estimated by combining different GGMs (EGM96, TEG4, GGM02S, EIGEN-CG03C) and several MSS models (CLS01, KMS04, GFSC00.1, and a series of annual models from 1993 to 2001 derived at DGFI from T/P). The results show the dependence of W_0 on the GGM's degree n, on the latitudinal extension and spatial resolution of the MSS models, and on time.

The GGMs are reduced to epoch 2000.0 and, as far as given in the tide-free system, transformed into the zero-tide system to make them consistent with the MSS models. Although W_0 does not change from one to another tide system, its determination must be based on a MSS-model and a GGM in the same tide system; if they are not consistent, the estimated W_0 value is biased.

After our results (figures 1.6.1 to 1.6.4 and table 1.6.1), W_0 is nearly independent of the GGM, slightly dependent on the MSS model and strongly dependent on the latitudinal extension. Its variation with time is (until now) almost negligible, but the sea surface is constantly changing, and after some years this dependence could reach significant values. In this way, it is necessary to define a reference epoch of W_0 as a convention. This convention should also include, among other adoptions, the W_0 variation with time, the latitudinal extension of the computation area and the spatial resolution of the MSS-model to be used.

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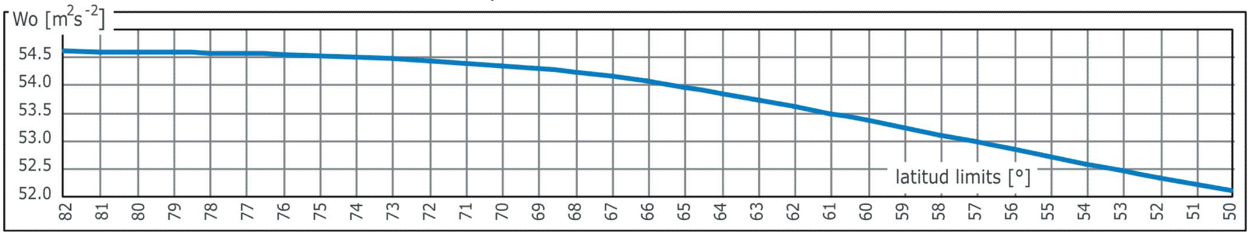


Fig. 1.6.1: Dependence of W_0 on latitudinal extension (the value 62 636 800 m^2s^{-2} has to be added). W_0 decreases if the computation zone is reduced. The apparent stability of W_0 at high latitudes is due to the little sea surface change in the polar regions. At the middle latitudes the W_0 mean rate is -0,13 m^2s^{-2}. It means, if the computation zone is reduced by 1° in latitude, the W_0 surface will be 1 cm higher.

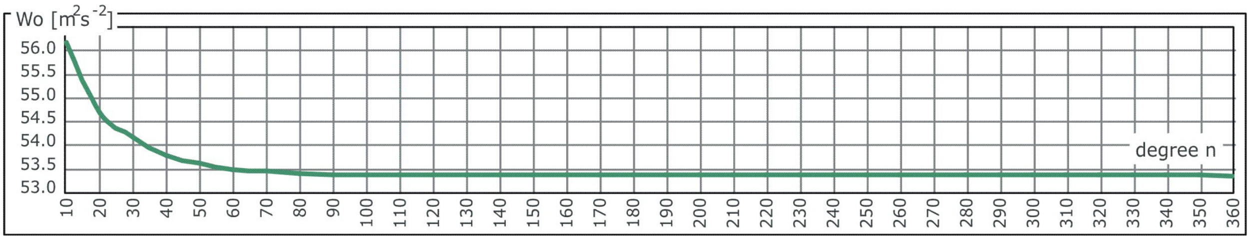


Fig. 1.6.2: Dependence of W_0 on the GGM's harmonic degree n (the value 62 636 800 m^2s^{-2} has to be added). In general, when the retained harmonic degree n grows, the difference between the corresponding W_0-values decreases. Nevertheless, above n =120 the variation of W_0 is smaller than 0,001 m^2s^{-2}. That means, the dependence of W_0 on the harmonics n>120 is negligible.

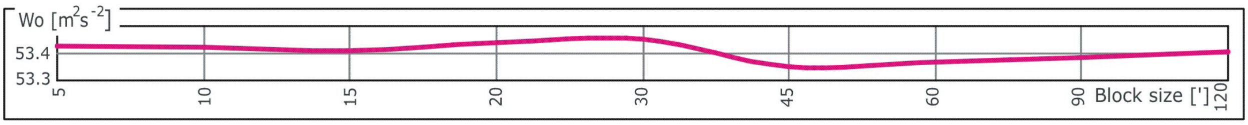


Fig. 1.6.3: Dependence of W_0 on the MSS's spatial resolution (the value 62 636 800 m^2s^{-2} has to be added). The largest deviation occurs between 30' and 45' blocks, while W_0 is very similar in the case of other cell sizes. In this way, one can say that 1° x 1° is a well-representative cell size.

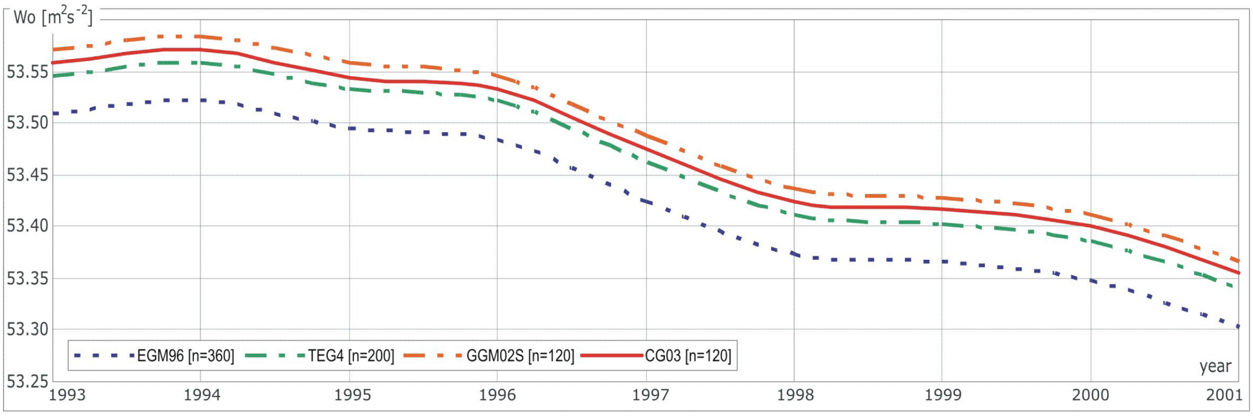


Fig. 1.6.4: Annual W_0 values derived from different GGMs and yearly MSS-models from T/P 1-365 cycles (1° x 1°, φ= 60°N/S, the value 62 636 800 m^2s^{-2} should be added). The yearly W_0 values are obtained combining each annual MSS-model with the GGMs reduced to the same epoch. The variation of W_0 is highly correlated with the variation of MSS. The largest annual changes happened in 1996/1997 (-0,06 m^2s^{-2}), 1997/1998 (-0,05 m^2s^{-2}) and 2000/2001 (-0,05 m^2s^{-2}). The total variation of W_0 between 1993 and 2001 is -0,20 m^2s^{-2}. The absolute level differences between the used GGMs are assumed insignificant, since they are lower than 5 mm.

Tab. 1.6.1: W_0 values derived from different GGMs and MSS-models [in m^2s^{-2}]. The dependence of W_0 on the GGM's degrees n > 120 is negligible. The largest variations are due to the extension of the computation area (φ= 60° N/S or φ= 80° N/S). However, at the same latitudinal range the W_0 values are consistent. The variation from one GGM to another (at the same degree and latitude coverage) is less than 0,02 m^2s^{-2}. The discrepancies between the W_0-values derived from different MSS-models are greater by including high latitudes than by middle latitudes. These differences can be assumed as a consequence of the different models applied to analyse the altimetric data in each MSS-model, and also the inter-annual ocean variability averaged over distinct periods of time.

MSS	n	EIGEN-CG03C	EGM96	TEG4	GGM02S	φ [N/S]
CLS01	120	62 636 853,35	62 636 853,37	62 636 853,38	62 6368 53,36	60/60
	200	53,35	53,37	53,37		60/60
	360	53,35	53,36			60/60
KMS04	360	53,24	53,26			60/60
GSFC00.1	360	53,58	53,59			60/60
CLS01	120	62 636 854,61	62 636 854,62	62 636 854,65	62 636 854,61	82/80
	200	54,61	54,62	54,64		82/80
	360	54,61	54,61			82/80
KMS04	360	54,46	54,45			82/82
GSFC00.1	360	54,93	54,93			80/80

2 System Analysis

The processes of the system Earth are in general described by mathematical and physical models. Today, an increasing number of parameters used to characterize state and temporal evolution of these processes become measurable through observations of precise geodetic space techniques. The present research field "system analysis" shall investigate the interrelationship between geodetic observations and model parameters. The thorough analysis of parameters – most rigorously estimated by combining different geodetic space techniques – promises to overcome the weakness of individual observation approaches as, for example, low sensitivity or insufficient sampling rates. Moreover, system analysis can help to improve the signal-to-noise ratio, to identify model deficiencies, and to introduce novel or extended parameterization with the final goal to obtain a more precise description of processes of the system Earth.
The seven research topics pick up urgent problem areas for this type of analysis. The new parameterization of Earth orientation by means of the celestial ephemeris origin requires the development of new parameter series and software adoption (Topic 2.1). Wavelets are appropriate base functions for a local high resolution description of the gravity field, and the combination of satellite models and surface gravity data is to be elaborated (Topic 2.2). The geographically different evolution of the mean sea level shall be described kinematically (Topic 2.3). New gravity field missions provide integrated observations of water mass redistribution in the system Earth. Forward modelling and global mass balance can help to improve the weakest components of the global water cycle, the solid Earth hydrology (Topic 2.4). Single layer models of the ionosphere are an insufficient description of the highly variable electron content which can be derived from two-frequency GPS observations (Topic 2.5). Actual plate kinematic models shall be extended to the vertical tectonic motions based on a new model for the deformations of the solid Earth (Topic 2.6). Finally, Topic 2.7 focuses on the analysis of time series for geodetic parameters to improve the identification and decomposition of physical signal, systematic and random errors.

2.1 Relation between CRS and TRS

The transition from the vernal equinox to the celestial ephemeris pole as the equatorial reference axis of the celestial intermediate system gave rise to a new definition of universal time (UT). Thorough investigations have been performed to clarify this subject.

Equatorial reference directions of mean solar time and universal time

The fictitious mean sun

As reference direction of mean solar time, the "fictitious mean sun" was introduced by Newcomb (1895). It moves on the mean equator with a constant sidereal velocity, i.e. with a constant angular velocity relative to an equatorial reference direction which has no motion component along the equator. The fictious mean sun was defined so that its right ascension with respect to the mean vernal equinox was at the epoch J 1900.0 equal to the mean ecliptical longitude of the sun and that its angular velocity on the mean equator relative to the mean vernal equinox was at the epoch J 1900.0 equal to the mean angular velocity of the sun on the ecliptic relative to the mean vernal equinox. That leads to Newcomb's formula for the right ascension of the fictitious mean sun:

$$\alpha_m = 18^h 38^m 45.^s836 + 8\,640\,184.^s542\, T + 0.^s0929\, T^2 \ ,$$

where T is the number of julian centuries of 36525 days (of terrestrial time, TT) since the epoch J 1900.0.

The quadratic term, as well as a part of the deviation of the linear term from $100 \cdot 360° T = 8\,640\,000^s\, T$, takes the accelerated precessional motion of the mean vernal equinox along the mean equator (precession in right ascension) into account. The revolution period of the fictitious mean sun relative to the mean vernal equinox is a Besselian year. Its duration of $365.^{d}242\,198\,79 - 0.^{d}000\,007\,85\,T$ decreases slightly faster than the duration of a tropical year (which is defined by the mean motion of the sun on the ecliptic relative to the mean vernal equinox) of $365.^{d}242\,198\,79 - 0.^{d}000\,006\,14\,T$.

If the directon of the fictitious mean sun is not referred to the mean vernal equinox, but to a reference direction which has no sidereal motion along the mean equator and conincides at the epoch J 1900.0 with the mean vernal equinox, its right ascension β_m is given by a linear function of time:

$$\beta_m = 18^h38^m45.^s836 + 8\,639\,877.^s302\,T\ .$$

The transitions from Newcomb's precession model to the IAU precession model of 1976, from the FK4 system to the FK5 system (the former has a slow rotation relative to the latter) and from the epoch J 1900.0 to the epoch J 2000.0 resulted in the new formula for the right ascension α_m of the fictitious mean sun:

$$\alpha_m = 18^h41^m50.^s548\,41 + 8\,640\,184.^s812\,866\,t\ + \\ + 0.^s093\,104\,t^2 - 0.^s000\,006\,2\,t^3\ ,$$

where t is the number of julian centuries of 36525 days (of terrestrial time, TT) since the new epoch J 2000.0 = 2000, Jan 1, 12^h TT.

The reference direction of universal time

The reference direction of universal time is different from the fictitious mean sun. It was until 2002 defined as a direction revolving on the mean equator with the right ascension α_u with respect to the mean vernal equinox:

$$\alpha_u = 6^h41^m50.^s548\,41 + 8\,640\,184.^s812\,866\,t_u + \\ + 0.^s093\,104\,t_u^2\ -\ 0.^s000\,006\,2\,t_u^3\ ,$$

where t_u is the number of julian centuries of 36525 days of universal time (UT) since the epoch 2000, Jan 1, 12^h UT.

The reference direction of universal time moves relative to the mean vernal equinox with respect to universal time exactly as the fictitious mean sun moves relative to the mean vernal equinox with respect to terrestrial time. (Thus the reference direction of universal time is affected by the irregularities of universal time.) Hence, universal time, being defined as the Greenwich hour angle of its reference direction, directly depends solely on the rotation of the earth and only indirectly on time. Therefore, the earth orientation parameters Greenwich mean sidereal time (GMST) and universal time (UT) can be transformed into one another without any information on time. In contrast, mean solar time, being defined as the hour angle of the fictitious mean sun $\pm 12^h$, directly depends both on the orientation of the earth and on time.

The right ascension α_m of the fictitious mean sun expresses the difference of two sidereal motions on the mean equator: the uniform annual motion of the fictitious mean sun, which is described by the major part of the linear term, minus the accelerated motion of the vernal equinox, which is described by the minor part of the linear term and by the quadratic and cubic terms. Both motions are functions of terrestrial time.

The definition of universal time as a pure orientation parameter of the earth requires, however, that its reference direction has a uniform sidereal motion with respect to universal time. Therefore, the part of the right ascension α_u which describes the annual sidereal motion of the reference direction must be a linear function of universal time. The other part of α_u, which takes the accelerated sidereal motion of the mean vernal equinox into account, should, however, be a function of terrestrial time because the precession of the mean vernal equinox is given as a function of terrestrial time. But actually, the whole right ascension α_u is represented as a function of universal time. Thus the accelerated sidereal motion of the mean vernal equinox is compensated defectively.

The celestial ephemeris origin as a new reference direction of right ascensions

This fault was only recently removed by substituting the celestial ephemeris origin, which has no sidereal motion along the equator, for the vernal equinox as reference direction of right ascensions. Besides, the former inconsistency arising from the fact that the equatorial reference directions were defined partly on the mean equator and partly on the true equator was removed. Now everything is on the true equator.

The fictitious mean sun now moves on the true equator, its right ascension β_m with respect to the celestial ephemeris origin being

$$\beta_m = 18^h 41^m 50\overset{s}{.}548\,41 + 8\,639\,877\overset{s}{.}317\,119\, t \,.$$

Similarly, the reference direction of universal time now moves on the true equator, its right ascension β_u with respect to the celestial ephemeris origin being

$$\beta_u = 18^h 41^m 50\overset{s}{.}548\,41 + 8\,639\,877\overset{s}{.}317\,119\, t_u \,.$$

Its sidereal motion is not quite uniform because of its coupling with universal time. So it is affected by all irregularities of earth rotation, scaled down by the factor 0.00273.

2.2 High resolution gravity field models

The basic idea of a multi-resolution representation (MRR) is to decompose a given input signal into a number of detail signals. In order to establish a high-resolution gravity model satellite data have to be combined with surface data since different measurement types generally cover different parts of the frequency spectrum as can be seen in figure 2.2.1. To be more specific, satellite data provide low- and medium-frequency information of the geopotential, whereas local or regional surface data cover the medium- and the high-frequency parts.

In the last year's annual report we presented in project B2 the high-resolution gravity model WMG-S/T of Colombia computed by means of FFT-based numerical integration techniques. This model means the sum of a CHAMP-only solution for the low-level, i.e. the long-wavelength part, and a "surface-only" solution for the medium- and high-level, i.e. the medium- and short-wavelength parts. This year we present an improved wavelet gravity model, denoted as DGFI-WM-CHAMP01C, of Colombia computed following the steps shown in Figure 2.2.1. Thus, the detail signals of the low levels were calculated from CHAMP data by parameter estimation and the detail signals of the high levels from surface data using FFT-based numerical integration techniques. However, the detail signals of the medium levels require a special handling, because they are present in both the satellite and the surface data, i.e. there exists an overlapping part.

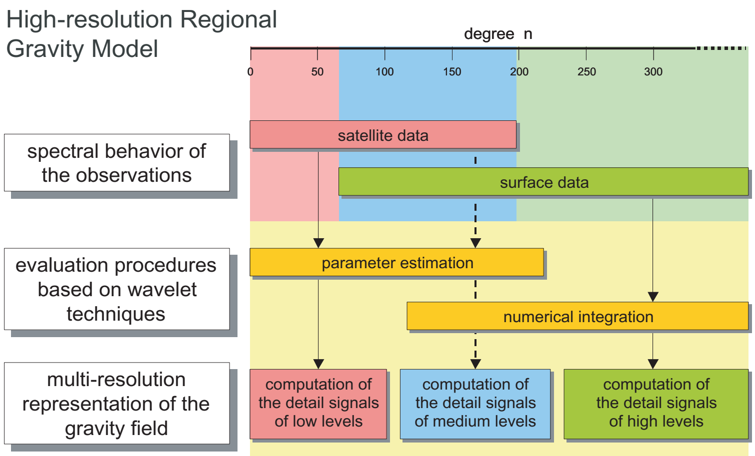


Fig. 2.2.1: The upper part shows the spectral sensitivity of satellite and surface gravity data. The bottom part outlines the computation scheme of DGFI-WM-CHAMP01C for the different detail signals

Generalized Blackman scaling function

Before we briefly outline the chosen parameter estimation method and the data combination procedure for the overlapping part, we introduce a generalized version of the Blackman scaling function defined in order to make the MRR more flexible. As can be seen from Figure B2.1 of the last year's annual report the Blackman wavelet functions, computed from the Blackman scaling function, are compactly supported, i.e. strictly band-limited in the frequency domain. Now, the new generalized Blackman scaling function is characterized by the possibility to vary the width of the pass-band of the Blackman wavelet functions as can be seen from Figure 2.2.2. As an example the wavelet function with parameter $b = 1.55$ of level 11 covers the frequency range between degree 80 and degree 192. Note, that for $b = 2$ the gen-

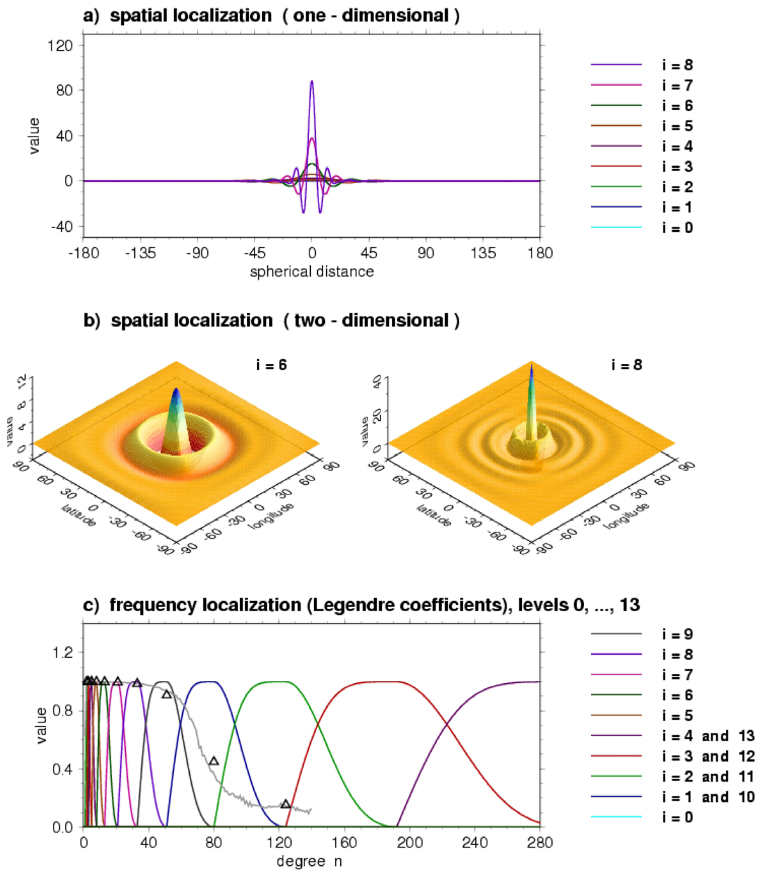


Fig. 2.2.2: Generalized Blackman wavelets for different levels i. Whereas the panels a) and b) display the spatial localization, panel c) shows the frequency (degree) behavior; compare with Fig. B2.1 of DGFI Annual Report 2003/2004. The grey colored curve is the Wiener filter line of GFZ's gravity model EIGEN-CHAMP03S based on signal and error degree variances. The triangles mean weights of the level combination procedure; see Fig. 2.2.4.

eralized Blackman scaling function equals the Blackman scaling function used last year for the model WMG-S/T.

Parameter estimation and regularization

A flowchart of the estimation procedure applied to the satellite input data is shown in Figure 2.2.3. Since the normal equation is ill-conditioned due to the downward continuation and probably singular due to the distribution of the scaling functions, a regularization method has to be applied. For that purpose we introduce prior information for the unknown scaling coefficients and formulate a linear model with unknown variance components for the satellite input data and the prior information. Note that the quotient of the variance components can be interpreted as reg-

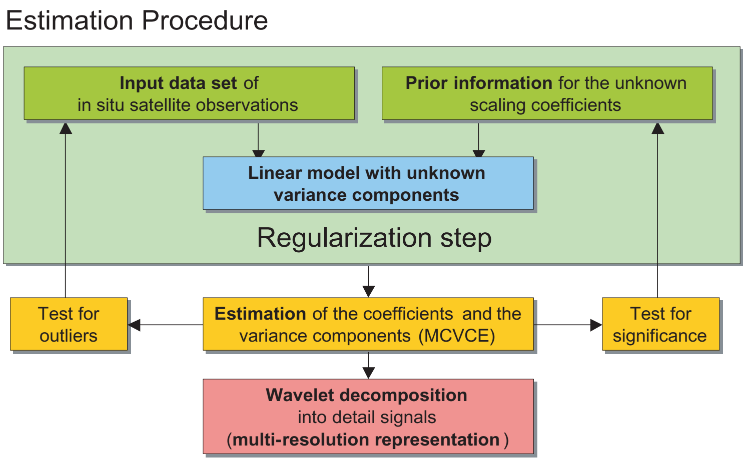


Fig. 2.2.3: Flowchart of the parameter estimation procedure used in DGFI-WM-CHAMP01C. The estimated results can also be used to check the input data for outliers and to test the significance of the estimated coefficients.

ularization parameter. Here we use a fast Monte-Carlo implementation of the iterative maximum-likelihood variance component estimation (MCVCE) for solving the linear model. The estimated results are the input of the wavelet decomposition, i.e. the computation of the satellite detail signals. For DGFI-WM-CHAMP01C we computed satellite detail signals h_i^{sat} up to level 11, i.e. degree 192. The preparation of the CHAMP input data set was already described in the last year's annual report. Naturally, parameter estimation does not require a reduction of the data to a mean orbital sphere. As reference model we used again EGM 96 up to degree 120.

In the same way as last year, the 2´ x 2´ residual Faye anomalies on the Earth's surface (following Molodenski's theory) of Colombia were decomposed into detail signals using numerical integration techniques. But this time we used the generalized Blackman scaling function with b = 1.55 and obtained surface detail signals h_i^{sur} between level 9 and level 18, i.e. we solved for signals parts up to degree 4133.

Combination strategy

As mentioned before a combination strategy has to be applied to the results from the satellite and surface data in order to derive a high-resolution gravity model

$$\zeta(\mathbf{x}) = \bar{\zeta}(\mathbf{x}) + \sum_{i=i'}^{I} w_i^{sat} h_i^{sat}(\mathbf{x}) + \sum_{i=i'}^{I} w_i^{sur} h_i^{sur}(\mathbf{x}) \qquad (1)$$

for the height anomaly $\zeta(\mathbf{x})$, wherein $\bar{\zeta}(\mathbf{x})$ means the height anomaly computed from EGM 96 up to degree 120; $\mathbf{x}$ is the position vector. The level weights w_i^{sat} and w_i^{sur} of the detail signals calculated from satellite and surface data are restricted to $0 \le w_i^{sat} \le 1$, $0 \le w_i^{sur} \le 1$ and

$$w_i^{sat} + w_i^{sur} = 1 \quad \text{for} \quad i = i',...,I \quad .$$

We determined the satellite level weights w_i^{sat} for i = 9, 10, 11 from the Wiener filter curve of GFZ's CHAMP-only model EIGEN-CHAMP03S shown in panel c) of Figure 2.2.2. Figure 2.2.4 displays the numerical values of the level weights introduced in Eq. (1). Finally, Figure 2.2.5 shows the height anomalies (1) of the high-resolution gravity model DGFI-WM-CHAMP01C of Colombia up to the indicated level.

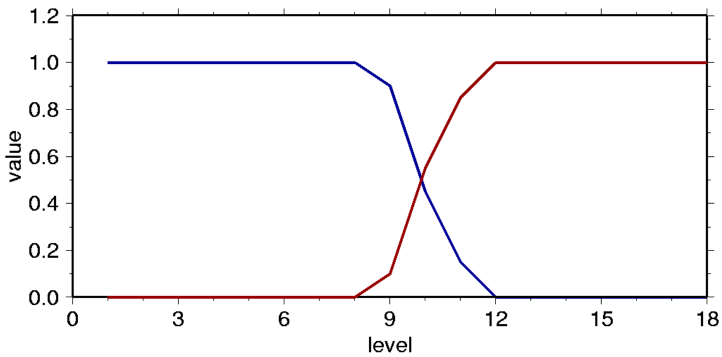


Fig. 2.2.4: Level weights w_i^{sat} (blue) and w_i^{sur} (red) of the detail signals in Eq. (1) with I = 18. The weights were computed from the Wiener filter curve shown in Fig. 2.2.2c.

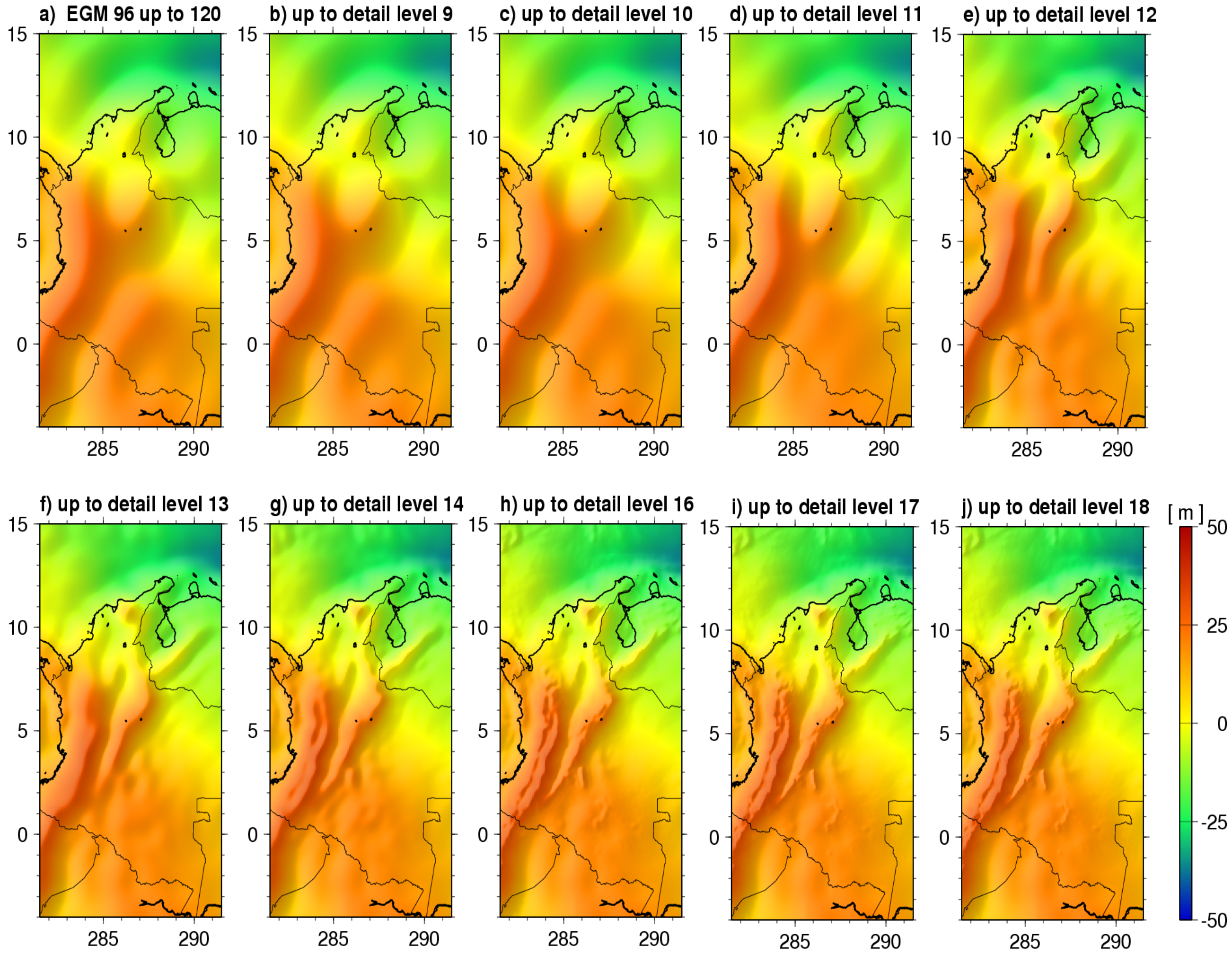


Fig. 2.2.5: Construction of DGFI-WM-CHAMP01C (height anomalies): panel a) shows the height anomalies computed with EGM 96 up to degree 120; the panels b) to j) mean the height anomalies up to the indicated detail level.

Spatio-temporal gravity fields

Besides DGFI-WM-CHAMP01C we also applied the parameter estimation procedure (Figure 2.2.3) to real GRACE data in order to derive spatio-temporal gravity fields DGFI-WM-GRACE01S. We used residual GRACE geopotential difference observations kindly provided by Shin-Chan Han from the Ohio State University. These data result from the energy balance approach applied to GRACE L1B data, i.e. KBR data, accelerometer data and precise orbits. Here we introduced the gravity model GGM01C of CSR as static reference model.

As mass variations due to atmosphere, tidal and non-tidal ocean variability were considered during the pre-processing steps, the residual GRACE geopotential difference observations should mainly reflect the variations in continental water storage. For the computation of time-dependent geoid undulations $N(\mathbf{x},t)$ we introduce the spatio-temporal MRR

$$N(\mathbf{x},t) = \bar{N}(\mathbf{x}) + \sum_{i=i'}^{I} n_i(\mathbf{x},t) \qquad (2)$$

wherein $\bar{N}(\mathbf{x})$ are the geoid undulations of GGM01C.

Comparison with hydrology

Our study is again related to the northern part of South America including the Amazon basin. The data cover the time span from February until December 2003 except June 2003. For the numerical evaluation we chose the generalized Blackman scaling function with parameter $b = 2.3$ and highest resolution level $I = 4$, i.e. we solved for signal parts until degree 64. In contrast to the procedure we used for the satellite part of DGFI-WM-CHAMP01C we estimated the detail signals n_i for levels $i = 2,3,4$ from different data sets. The idea behind is the fact that the determination of finer structures of the gravity field needs a denser distribution of satellite tracks than the computation of coarser structures. Hence, the estimation of the level-4 detail signal should be based on a longer observation period than the level-3 detail signal. Table 2.2.1 shows the selected information to create the different data sets for establishing the desired spatio-temporal MRR (2).

For each data set the parameter estimation was performed according to figure 2.2.3. As an example, figure 2.2.6 shows the estimated level-3 detail signals of DGFI-WM-GRACE01S computed from ten data sets each covering an observation period of one month according to table 2.2.1. Similar results were obtained for the remaining levels $i = 2$ and $i = 4$ (not shown here).

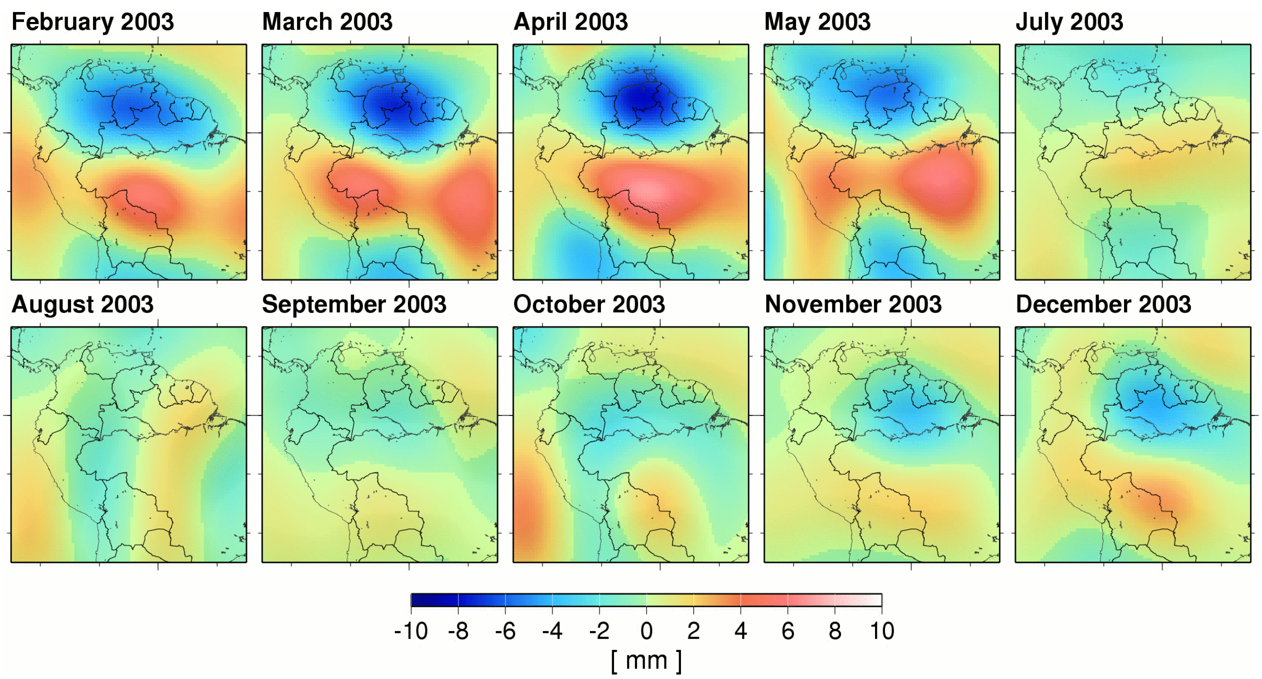


Fig. 2.2.6: Monthly solutions for the level-3 detail signal of the geoid undulations according to Eq. (2). The results contain signal parts up to degree 27.

Seasonal variations of the estimated geoid undulations with respect to the reference model GGM01C are clearly detectable. Following Farrell's theory the estimated variations of the gravity field can be transformed in so-called equivalent water heights (EWH) which can be compared with hydrological models. Figure 2.2.7 shows exemplarily the results for EWH up to level 3 for six months in comparison with the corresponding representation of the Land Dynamics (LaD) model from Milly and Shmakin.

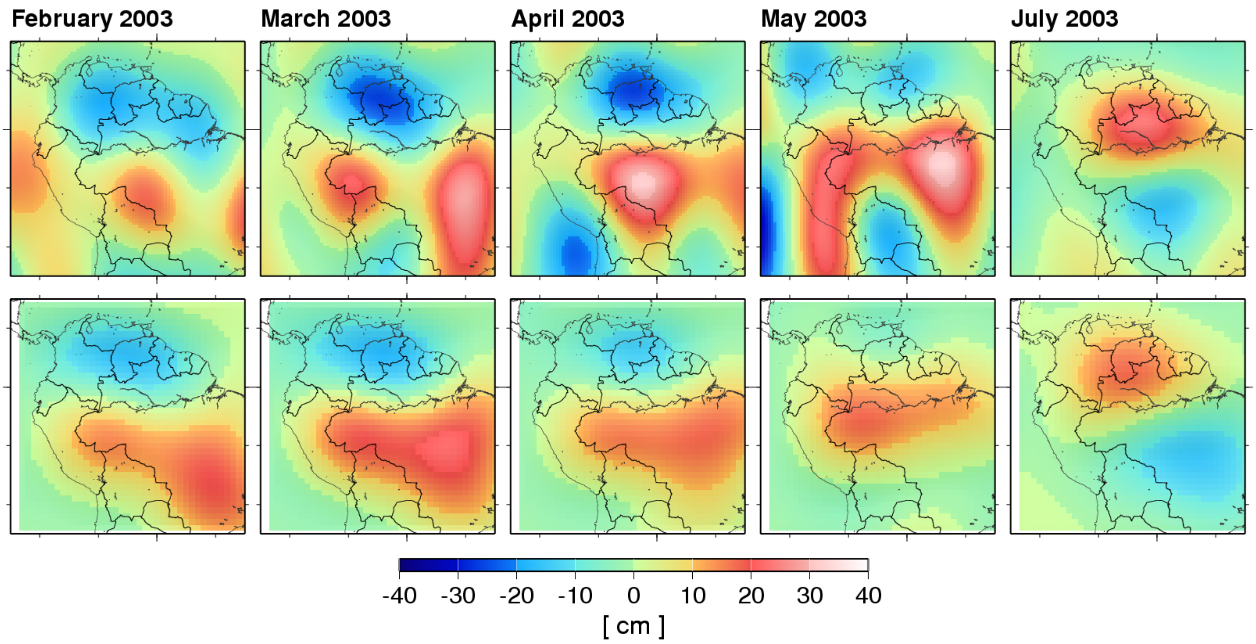


Fig. 2.2.7: Monthly solutions of equivalent water heights from DGFI-WM-GRACE01S (upper panels) and from the LaD model (lower panels) up to level i = 3.

The GRACE solutions show obviously more variations. One conclusion is that, apart from remaining errors within the GRACE observations, the LaD model underestimates the water storage change within the Amazon region.

Tab. 2.2.1: Level-dependent observation period, total number of observations within the corresponding time span and highest degree value related to the level-i generalized Blackman scaling function with b = 2.3.

level i	observation period	number of observations	highest degree
2	10 days	4000-5000	12
3	1 month	13000-15000	27
4	3 months	20000-25000	64

2.3 Kinematic of the mean sea level

Previous analyses of altimeter data showed that there are significant, but rather different regional evolutions of the mean sea level – with mean drifts up to ±25 mm/year. Therefore, a simple averaging of sea surface heights is no longer adequate and shall be replaced by a *kinematic* description of the mean sea level. An essential step towards this description is the cross-calibration of all altimeter missions in order to fully utilize the combined space-time sampling of altimeter systems with different orbit characteristics.

Multi-mission cross-calibration

For the first time, an innovative, utmost rigorous cross-calibration of up to four altimeter satellites operating simultaneously was performed. Data from TOPEX/Poseidon, ERS-2, GFO, and Jason1 were used to compute – in all combinations – nearly simultaneous single and dual satellite crossover differences. Only crossover events with a time difference of less than 3 days were taken, to ensure that the crossover differences are as little as possible affected by sea level variability. The total set of crossovers provides a rather dense sampling of the orbits of all satellites and realizes a rigid network with high redundancy to obtain a reliable estimate of the radial error components of all altimeter systems considered.

Discrete crossover analysis (DCA)

The multi-mission cross-calibration was performed by means of the 'discrete crossover analysis' (DCA), already described in the previous annual report. In contrast to the limited computations (for a 14-day period only) performed so far, the present analysis was applied to a sequence of 362 ten-day periods, spanning nearly a full decade, namely June 1995 up to February 2005 (corresponding to TOPEX cycles 096-457).

The rank defect of DCA, known to be exactly 1, is removed by a single constraint, forcing the *sum* of TOPEX error components to zero. Thus the geocentric realization of the TOPEX orbit is – on average – accepted. (There is anyway no possibility to validate or improve the *absolute* geocentric realization by cross-calibration.) However, the single constraint preserves the capability to obtain individual radial error estimates for TOPEX – just as for all other missions. This is the innovative aspect of the present multi-mission DCA: up to now TOPEX orbits were not changed and were not subject to error estimates. The systematic errors shown in figure 2.3.1 demonstrate, however, that there is no justification for such a prominent role of TOPEX.

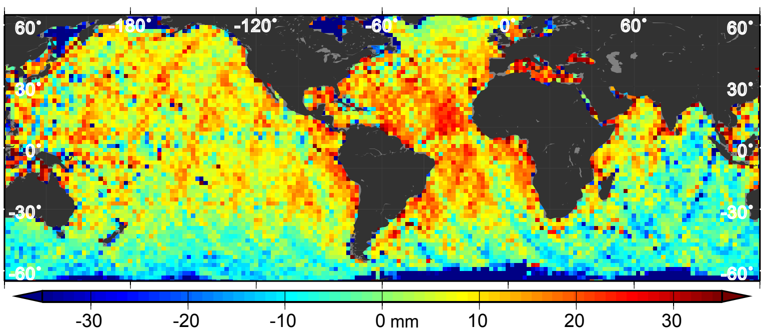


Fig. 2.3.1: Mean sea surface height differences between TOPEX and Jason1 during their tandem phase (TOPEX cycle 344 - 365) where both satellites measured along the same ground track - with only 70 seconds delay. The differences [mm] reveal significant pattern with systematic, geographically correlated errors of the radial component of one or both satellites.

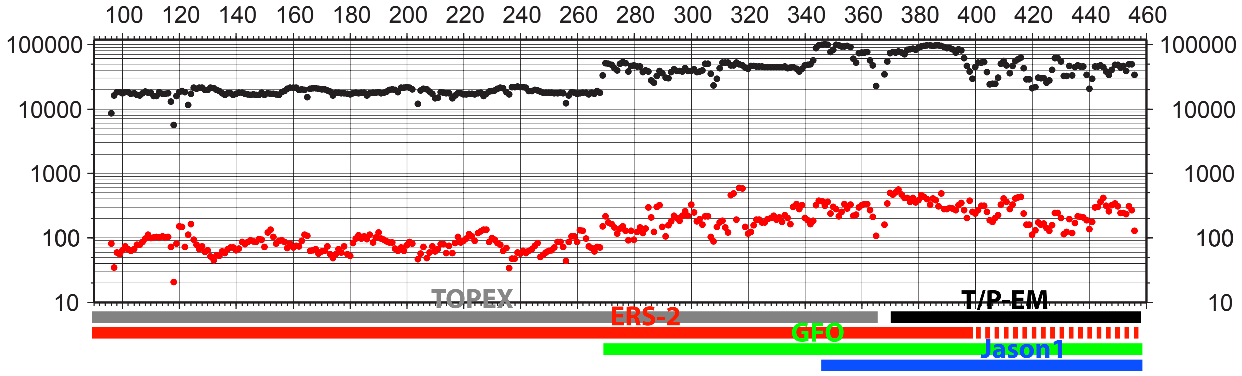


Fig. 2.3.2: The total number of single and dual satellite crossovers used for each ten-day cycle (black dots) increases significantly with the number of contemporary missions. As long as there are only TOPEX and ERS-2, the number is about 20000. The number reaches a maximum of about 100000 with the launch of Jason1 – and goes down again after the failure of the ERS-2 tape recorder (at TOPEX cycle 396). The analysis was iterated twice with the previous solution taken as an approximation for the next iteration. The red dots indicate the number of crossovers skipped because their residuals exceed $3 \times \sigma_0$.

Analysis Results

Every ten-day period was extended by a three-day overlap to neighbouring periods to minimize boundary effects. As shown in figure 2.3.2, the total number of crossovers treated within a single analysis increases with the number of contemporary missions and reaches a maximum of about 100000 (for 4 missions). Concatenating all error estimates of the central ten-day periods, time series of discrete error components are created for all altimeters. Using these time series, empirical auto-covariance functions were estimated for each mission (see figure 2.3.3). The variances clearly indicate the relative accuracies of the missions analysed. The auto-covariance functions for all missions have a clear increase for a time delay of one orbital revolution – an indication of the presence of geographically correlated errors.

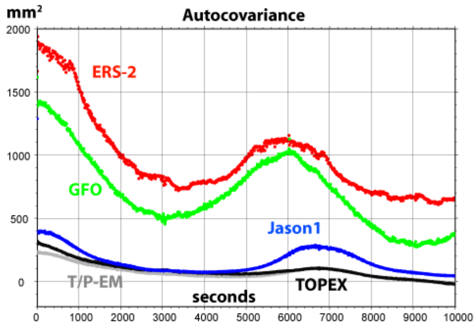


Fig. 2.3.3: Empirical autocovariance function for the radial error components of all missions.

The overall crossover statistic, illustrated in figure 2.3.4, shows the gain obtained by the DCA. It is given by the ratio of rms-values of the crossover differences before and after the analysis. Up to cycle 266 (with 2 missions only), rms values of about 9 cm are reduced by 1 - 2 cm only. When Jason1 enters the DCA (at TOPEX cycle 344), the gain becomes significant: rms values of about 11 cm are reduced to about 7 cm! The few rather high rms values are due to known orbit anomalies of GFO.

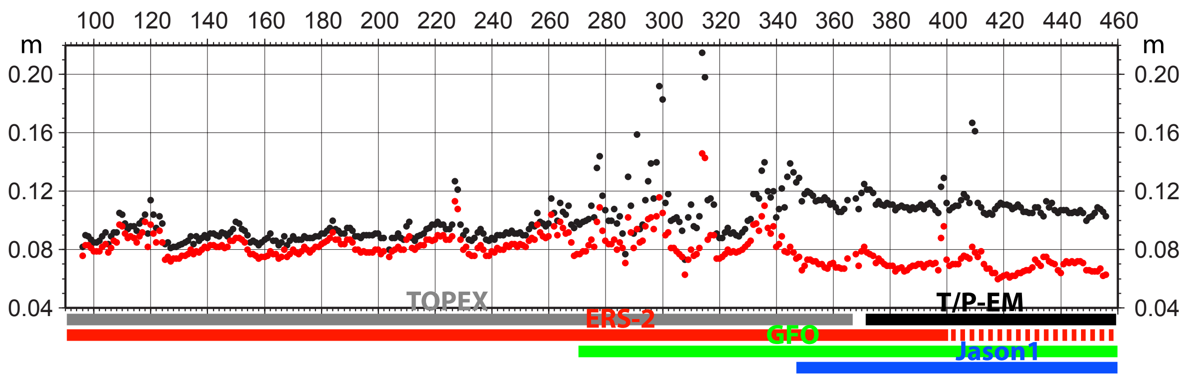


Fig.2.3.4: Crossover rms values before (black dots) and after (red dots) analysis. Up to cycle 266 (with TOPEX and ERS-2 only) the analysis gain is moderate: the rms values (on average about 9cm) is reduced by 1-2cm. From cycle 344 on (all four missions), the analysis gain is significant: the rms values of about 11cm is reduced to about 7cm. Large rms values are due to significant orbit errors. E.g., GFO had a momentum wheel anomaly at cycle 118 (corresponding to TOPEX cycle 409/410).

Relative range biases and centre-of-origin shifts

The DCA automatically captures any differences of the range biases between the altimeter systems analysed. A range bias is a constant error of the altimeter observations, visible by the mean value of the estimated error components. As the sum of TOPEX errors was always forced to zero, the mean range error of TOPEX will be zero too, and for the other altimeter systems the mean error gives an estimate of the *relative* range bias, relative to the (unknown) TOPEX range bias.

It is also of particular interest to investigate how the estimated errors are geographically distributed. The systematic error pattern may be explained by inconsistencies in the centre of origin implied by the satellite orbit. To estimate both range biases Δr and centre-of-origin shifts Δx, Δy, Δz the model

$$x_i + v_{x_i} = \Delta r + \Delta x \cos\phi \sin\lambda + \Delta y \cos\phi \cos\lambda + \Delta z \sin\phi$$

was fitted by least squares to the error components of every cycle and for every mission. Figure 2.3.5 shows the result for the relative range biases.

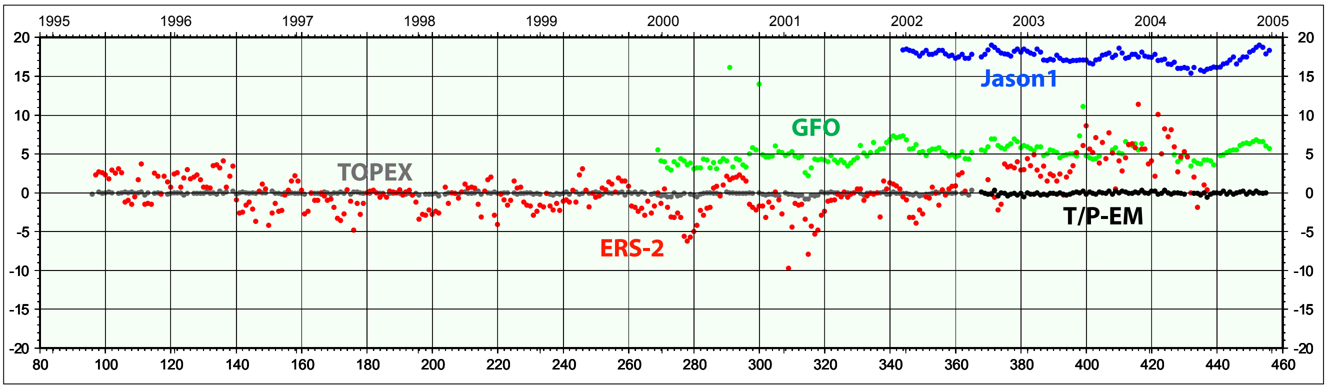


Fig. 2.3.5: Range biases , estimated simultaneously for up to four contemporary altimeter missions. The range biases are relative to TOPEX (TOPEX-EM) as the sum of TOPEX errors was forced to be zero.

Geographically Correlated Errors

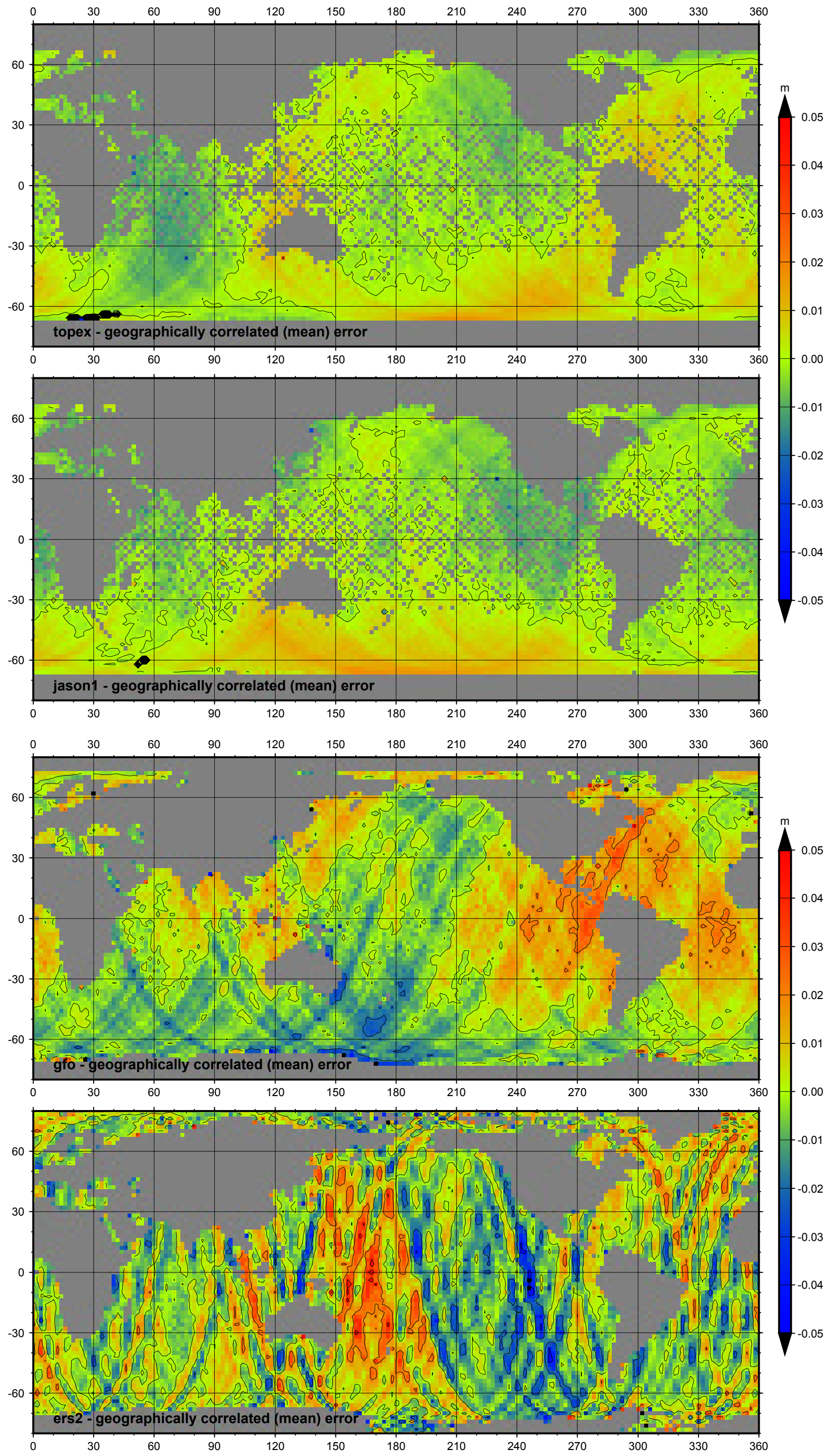
From Kaula's theory it is known that the radial orbit errors of ascending (Δr^{asc}) and descending passes (Δr^{desc})

$$\Delta r^{asc} = \Delta\gamma + \Delta\delta \quad \text{and} \quad \Delta r^{desc} = \Delta\gamma - \Delta\delta$$

are composed of a "mean" ($\Delta\gamma$) and a "variable" part ($\Delta\delta$). The DCA included a book-keeping about which error components belong to ascending or descending ground tracks. For each mission, the error components of ascending and descending tracks were averaged independent from each other on a 2°×2° grid. These means were taken as an estimate for Δr^{asc} and Δr^{desc} and then used to compute $\Delta\gamma$ and $\Delta\delta$ by

$$\Delta\gamma = (\Delta r^{asc} + \Delta r^{desc})/2$$
$$\Delta\delta = (\Delta r^{asc} - \Delta r^{desc})/2$$

Fig. 2.3.6: Geographical distribution of mean radial errors [meter] for TOPEX, Jason1, GFO and ERS-2 (from top to bottom). Although TOPEX and Jason1 have identical orbits and the ephemeris for both satellites were based on the JGM3 gravity field, the error patterns differ significantly. TOPEX shows up to ±2 cm errors in the South East Pacific and Atlantic while Jason1 has its maximum error in the South Pacific and Tasman Sea. The mean orbit error for GFO and ERS-2 are considerably higher (up to ±5 cm) and have an even more pronounced geographical pattern. The most outstanding feature for ERS-2 is the strong correlation of the mean error with the ground tracks.



The mean orbit error $\Delta\gamma$ is dangerous because it is not visible in single satellite crossover differences, but maps directly into the sea surface heights. Figure 2.3.6 shows the geographical distribution of the mean errors with significant geographical patterns for all missions. The mean error for TOPEX and Jason1 is less than ±2 cm . For GFO and ERS-2, the error is up to ±5 cm.

2.4 Effect of mass displacements

Variations of the Earth's gravity field reflect the integral effect of mass redistributions within and between the various components of the Earth system. The largest effects are caused by the atmosphere and by the oceans. While the atmospheric contribution can be assessed quite well from globally distributed atmospheric pressure observations and reanalysis data, the knowledge of the ocean induced gravity field variations is limited. Direct observations of ocean bottom pressure variations which are linked to oceanic mass variations are scarcely available.

Ocean induced gravity field variations

For more than a decade, satellite altimetry has enabled the monitoring of the sea surface and its temporal variations with an accuracy of a few centimetres. However, to a large extent observed sea level anomalies are caused by the steric effect, i.e. the volume change due to variations of temperature and salinity. Therefore the altimetry observations cannot directly be related to oceanic mass variations. Prior to the estimation of the ocean induced gravity field changes, the effect of thermohaline expansion must be removed from the time series.

Separation of steric and non-steric sea level changes

Steric and non-steric sea level changes are separated by relating the sea level anomalies of the TOPEX/Poseidon mission between 1993 and 2004 to simulations which are performed with the global Ocean Model for Circulation and Tides (OMCT). As the altimetry observations have already been corrected for ocean tides using the FES2004 model, an OMCT version which solely regards oceanic circulation is applied. The model is driven by ERA-40 reanalyses (1957–2001) and operational ECMWF analysis data (2001–2004) considering heat and freshwater fluxes, wind stresses, atmospheric pressure variations as well as effects arising from loading and self-attraction. OMCT allows for an independent assessment of the thermohaline expansion. Since the ocean model takes atmospheric pressure forcing into account, no inverse barometric correction is applied to the altimetry observations.

The steric sea level variations from OMCT are provided with a horizontal spatial resolution of 1.875 degrees and a time step of 30 minutes. The respective fields are averaged for 10-day intervals in order to match the temporal resolution of the TOPEX cycles. The altimetry observations are adapted to the spatial grid of OMCT by means of nearest neighbourhood interpolation.

In order to compare observed and steric sea level anomalies, principal component analyses (PCA) are performed. The dominant annual oscillation, which explains about 22% of the entire observed variability, has been removed from all time series. Figure 2.4.1a shows the first two modes of the PCA of the observed sea level anomalies. Mode 1, which accounts for 13% of the variability clearly features the strong El Niño signal in 1997/1998. The second mode, which is much smaller, shows sea level variations in mid and high latitudes which are due to atmospheric pressure anomalies.

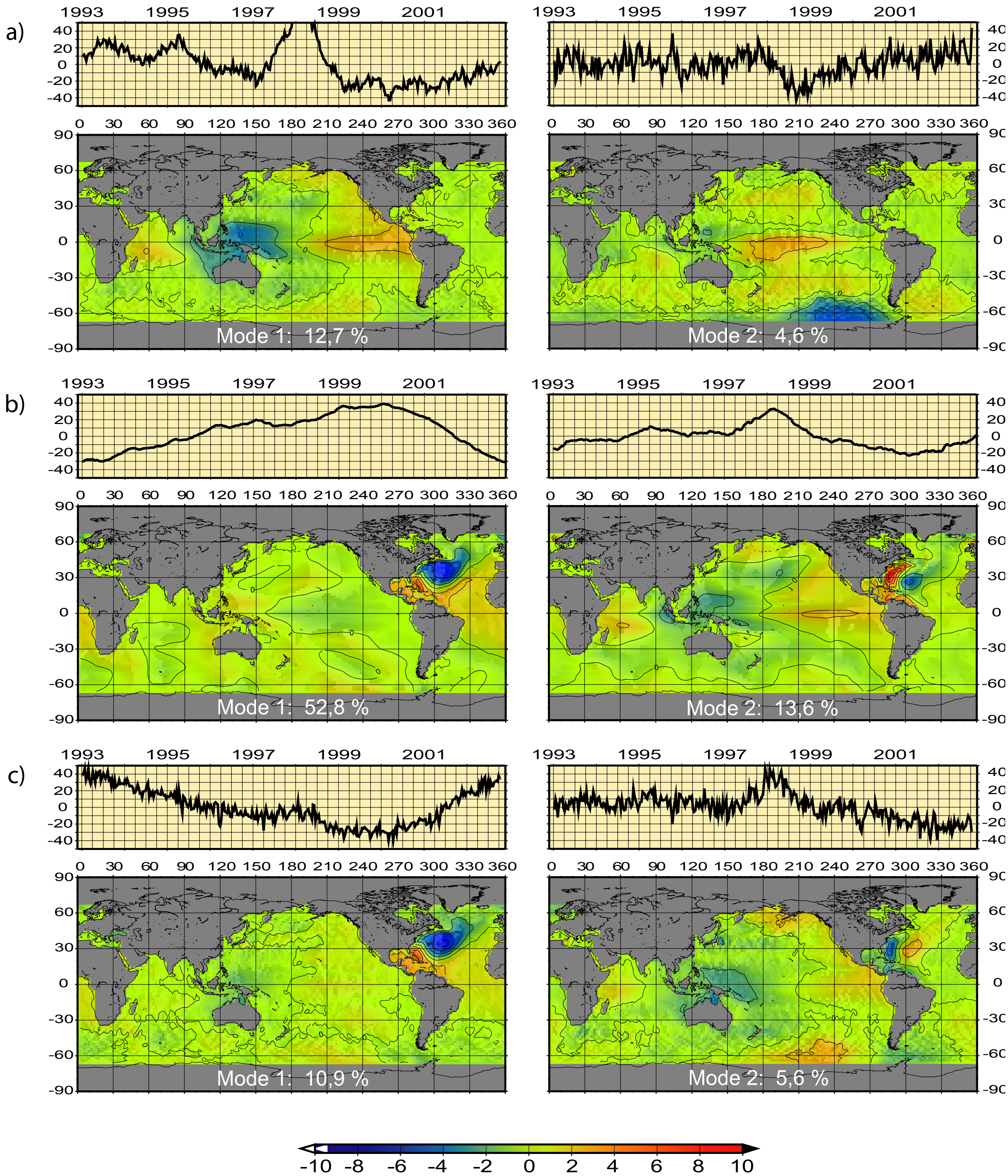
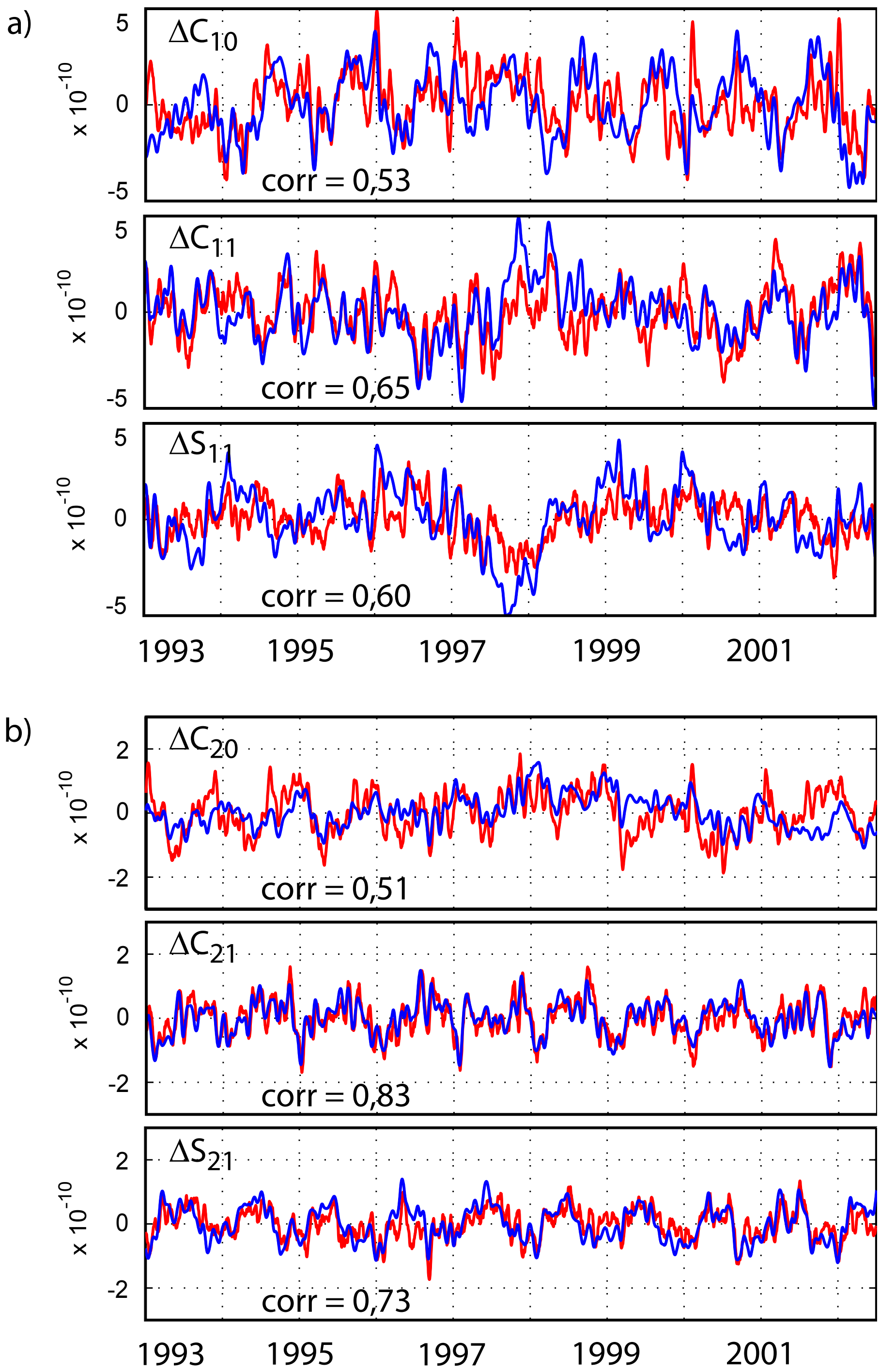


Fig. 2.4.1: Modes 1 and 2 of the principal component analyses of (a) observed sea level anomalies, (b) steric sea level anomalies from OMCT, and (c) reduced sea level anomalies.

The first two modes of the steric sea level anomalies from OMCT are displayed in Figure 2.4.1b. As above, the annual signal has been removed. Mode 1 is characterised by a strong feature in the North Atlantic which covers 53% of the total variability. The rest of the ocean does not show any major structures in this mode. The signal increases until 2001 and decreases afterwards. This effect might be caused by the change of the atmospheric forcing conditions of OMCT and is therefore not physically explainable. In mode 2 which is also rather strong, a clear El Nino signal is obvious. The further modes which are much weaker (not shown) feature some variability in the central regions of the ocean, but not in higher latitudes.

The artificial structure in the steric sea level anomalies in the North Atlantic is carried over into the reduced sea level anomalies (i.e., the observed sea level anomalies reduced by the steric effect). Mode 1 of the respective PCA (Figure 2.4.1c) is clearly influenced by this effect. Mode 2 accounts for only 5% of the variability and features some variations due to the atmospheric pressure anomalies in higher latitudes, which are not influenced by the steric correction. Besides, the El Nino structure is visible.

Fig. 2.4.2: Stokes coefficients of degree 1 and 2 from reduced sea level anomalies (blue) in comparison with the respective time series from OMCT bottom pressure variations (red).



But its signal strength is much weaker than in the observed SLA (cf. figure 2.4.1a). Hence, an essential part of the observed El Nino signal can be explained by thermohaline expansion.

Low degree Stokes coefficients from reduced sea level anomalies

The reduced seal level anomalies are converted into low degree Stokes coefficients. Figure 2.4.2a shows the degree 1 coefficients from altimetry (blue) in comparison with the respective coefficients from modelled OMCT bottom pressure variations (red). All curves are characterized by a distinct annual variability. Correlations between the time series are quite good especially in the equatorial components ΔC_{11} and ΔS_{11} which are clearly influenced by the 1997/1998 El Nino. This effect is stronger in the observations than in the ocean model.

For the second degree coefficients (figure 2.4.2b), the agreement with OMCT is much better in ΔC_{21} and ΔS_{21} than it is in ΔC_{20}. Here the ocean model shows a clear annual oscillation which is not so obvious in the coefficients computed from the reduced sea level anomalies. The agreement of the other two coefficients is evident.

Comparison of the results with independent data

In order to compare the results of this study with independent data, the combined effect of ocean and atmosphere is computed. The mass variations from altimetry are combined with the atmospheric ERA-40 and ECMWF surface pressure fields, which correspond to the forcing conditions of OMCT. The time series of the second degree Stokes coefficients of the combined atmospheric and oceanic effect are displayed in figure 2.4.3 (green). While ΔC_{20} and ΔS_{21} are dominated by annual signals, both subsystems tend to compensate each other in the case of ΔC_{21}.

For ΔC_{20} the agreement between the combined result and a time series of Cox and Chao, which is based on SLR-analyses, is very

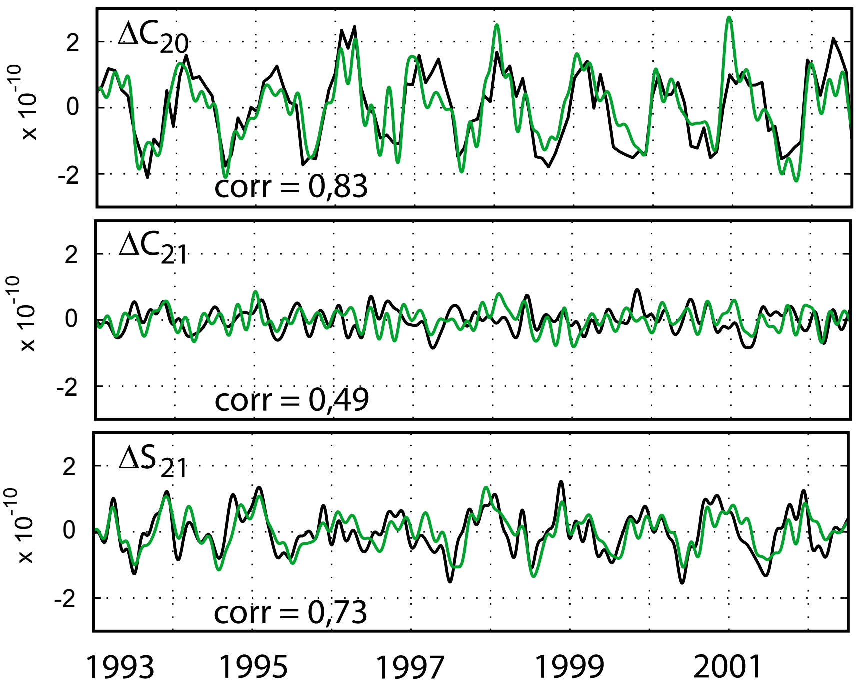


Fig. 2.4.3: Atmospheric and oceanic induced variations of the degree 2 Stokes coefficients (ECMWF/ERA40 + reduced sea level anomalies, green) in comparison with independent time series (black). The latter are based on SLR-Analyses (ΔC_{20}) and the C04 series for polar motion (ΔC_{21},ΔS_{21}).

good. External time series for ΔC_{21} and ΔS_{21} are computed from Earth rotation parameters which are taken from the C04 series of the IERS. Although their characteristics are explained quite reasonably by the atmospheric and oceanic mass variations, the correlation coefficient is not so high in the case of ΔC_{21}. Here the best agreement is reached at the beginning and towards the end of the time series, but in between there are some clear discrepancies.

In order to improve the agreement between the model results and geodetic time series, the analysis will be extended to other geophysical fluids like continental hydrology, snow or ice coverages. In a further step, higher degree Stokes coefficients are to be compared with gravity field variations as seen by CHAMP and GRACE.

2.5 Modelling of the ionosphere

The knowledge of the electron density is the keypoint in correcting electromagnetic measurements for ionospheric disturbances. Generally, the ionosphere is defined as a thick shell of electrons and ions, which envelopes the Earth from about 60 to 1000 km height. In the last year's annual report we presented a regional space-time model of the electron density distribution mathematically based on wavelet strategies and physically controlled by the NeQuick model. To be more specific, in this approach we described selected NeQuick model parameters by means of two-dimensional (2D) wavelet expansions.

This year we present a three-dimensional (3D) model of the electron density. As already described in topic 2.2, the multi-resolution representation (MRR) enables a signal to be observed at different resolutions levels. Consequently, our procedure is based on the determination of the space- and time-dependent electron density $N(\mathbf{x},t)$ as a 3D MRR from so-called geometry-free GPS measurements ($\mathbf{x}$ = position vector, t = time). The basic observation equation was presented in the DGFI annual report 2002/2003 on page 42. Thus the GPS observations provide information about the slant total electron content (STEC), defined as the integral of the electron density along the signal-path between a satellite and a receiver.

The determination of the electron density from GPS measurements is mathematically known as an inverse problem. To solve this problem we split the electron density $N(\mathbf{x},t)$ into a given physical or empirical reference model $N_0(\mathbf{x},t)$, such as NeQuick or IRI, and an unknown mathematical correction term $\Delta N(\mathbf{x},t)$. For modelling the correction term we choose the series expansion

$$\Delta N(\mathbf{x},t) = \sum_{k_1=0}^{K_1-1}\sum_{k_2=0}^{K_2-1}\sum_{k_3=0}^{K_3-1} d_{I;k_1k_2k_3}(t)\,\Phi_{I,k_1}(\lambda)\,\Phi_{I,k_2}(\varphi)\,\Phi_{I,k_3}(h) \qquad (1)$$

in terms of 3D tensor-product B-splines, i.e. products of three so-called endpoint-interpolating 1D quadratic B-splines $\Phi_{I,k}$ of resolution level I depending on longitude λ, latitude φ and height h, respectively. Figure 2.5.1 shows both 2D B-splines, i.e. products of two 1D B-spline functions depending on longitude and latitude, and 1D height-dependent B-splines. Generally, a 1D B-spline is

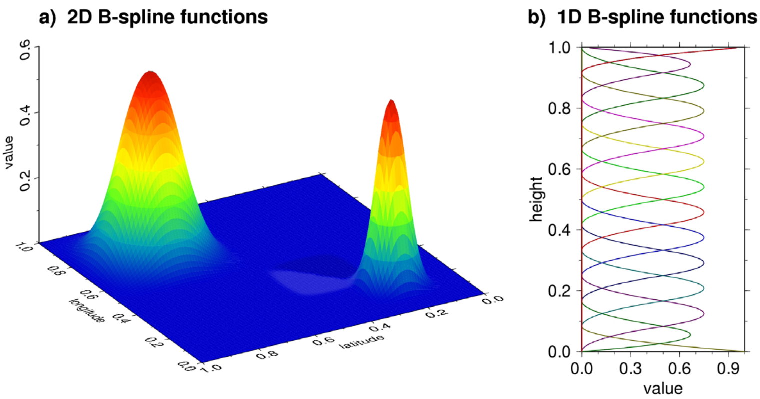


Fig. 2.5.1: a) 2D B-spline functions for resolution levels I = 1 with $k_1 = k_2$ = 5 (left peak) and I = 2 with $k_1 = k_2$ = 3 (right peak). The shift values k_1 and k_2 define the position of the peak within the unit square. For I = 2 the upper limits of the sums in Eq. (1) are given as $K_1 = K_2$ = 14. b) 1D B-spline functions for resolution level I = 2 and shift values k = 0,..., 13.

compactly supported within the unit interval and centered at position (shift) k. The higher the resolution level (scale) I is chosen, the sharper becomes the peak. The observation equation for a geometry-free GPS measurement is obtained by inserting Eq. (1). Herein the B-spline coefficients $d_{I;k_1k_2k_3}$ are unknowns.

In order to simplify the explanations we reduce in figure 2.5.2 the 3D problem to a 2D problem neglecting the latitude-dependency. Thus, the white and black dots indicate the centers (k_1, k_3) of the B-spline functions in the longitude-height plane. Due to their compact support, only B-splines related to the white dots, i.e. within the indicated band, have non-zero entries in the observation equations. Obviously a B-spline coefficient $d_{I;k_1k_2k_3}$ is computable only if sufficient data are given close to the peak of the corresponding B-spline function. Hence, in case of large data gaps, many addends can be excluded from the expansion (1).

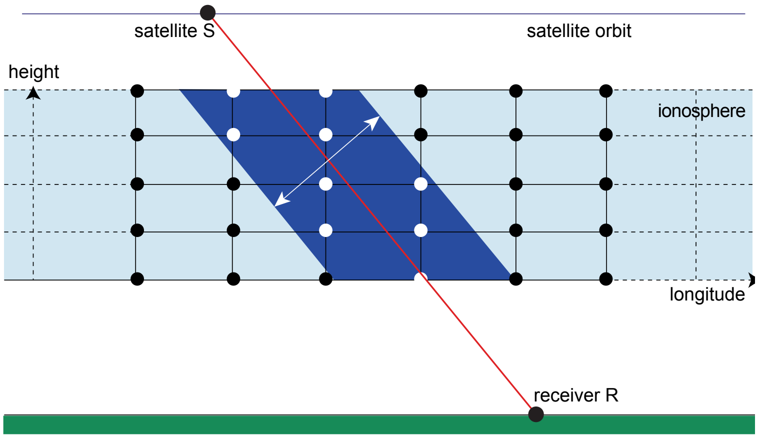


Fig. 2.5.2: Relation between a GPS measurement and the distribution of the B-spline functions. The dots indicate the grid of the centres of these base functions. The width of the band along the ray-path depends on the value for the resolution level I. The higher the level value is chosen, the narrower is the band.

The flowchart shown in figure 2.2.3 of topic 2.2 can be adapted to the estimation of the unknown B-spline coefficients of the expansion (1). Prior information is introduced for regularization, i.e. for stabilizing the normal equation system. The regularization parameter is calculated by estimating the variance components of the observations and the prior information. The MRR

$$\Delta N(\mathbf{x},t) = \Delta N_{i'}(\mathbf{x},t) + \sum_{i=i'}^{I-1} n_i(\mathbf{x},t) \qquad (2)$$

provides the detail signals $n_i(\mathbf{x},t)$ using 3D B-spline wavelets. The corresponding 3D B-spline wavelet coefficients are computable from filter bank schemes using fast numerical algorithms.

In order to demonstrate the procedure, we modelled a one-hour 2D data set of vertical total electron content (VTEC) measurements over South America. As VTEC reference model we used a global spherical harmonics expansion up to degree and order 15. The estimation of the 2D B-spline coefficients of the VTEC correction term ΔVTEC was performed following the steps of figure 2.2.3. In figure 2.5.3 we show exemplarily a 2D tensor B-spline wavelet for resolution level i = 2.

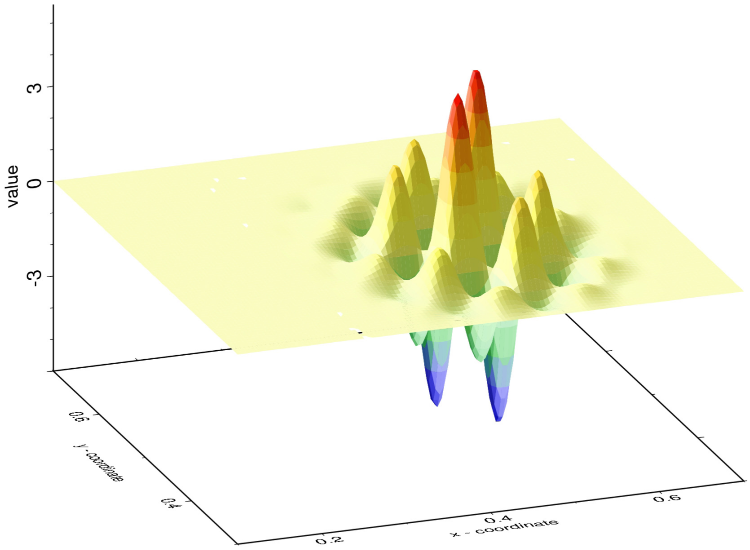


Fig. 2.5.3: 2D tensor B-spline wavelet for resolution level i = 2. This function is sensitive to diagonal structures. In addition, other 2D tensor B-spline wavelets exist which are sensitive to structures parallel to the longitude and the latitude axis.

Figure 2.5.4 displays the estimated MRR of the VTEC correction term. The bottom panels display estimations of ΔVTEC at different resolution levels. These signals mean low-pass filtered, i.e. smoothed versions of the input data. The signals in the upper panels are the detail signals, i.e. the differences between the two related smoothed signals. The detail signals mean band-pass filtered versions of the input data. Since the B-spline wavelets are semi-orthogonal the detail signals of different levels are even independent of each other. (The expression “semi-orthogonal” means, that the wavelets of different levels are orthogonal to each other, but not necessarily the wavelets of the same level.) The core of the applied filter-bank procedure is a down-sampling algorithm, i.e. the lower the level the smaller is the number of B-spline and wavelet coefficients. In table 2.5.1 these numbers are listed.

Tab. 2.5.1: Numbers of B-spline and wavelet coefficients of the levels i = 1,...,4. The sum of both is equal to the number of B-spline coefficients of the next higher level.

level j	number of B-spline coefficients	number of wavelet coefficients
4	2500	0
3	676	1824
2	196	480
1	64	132

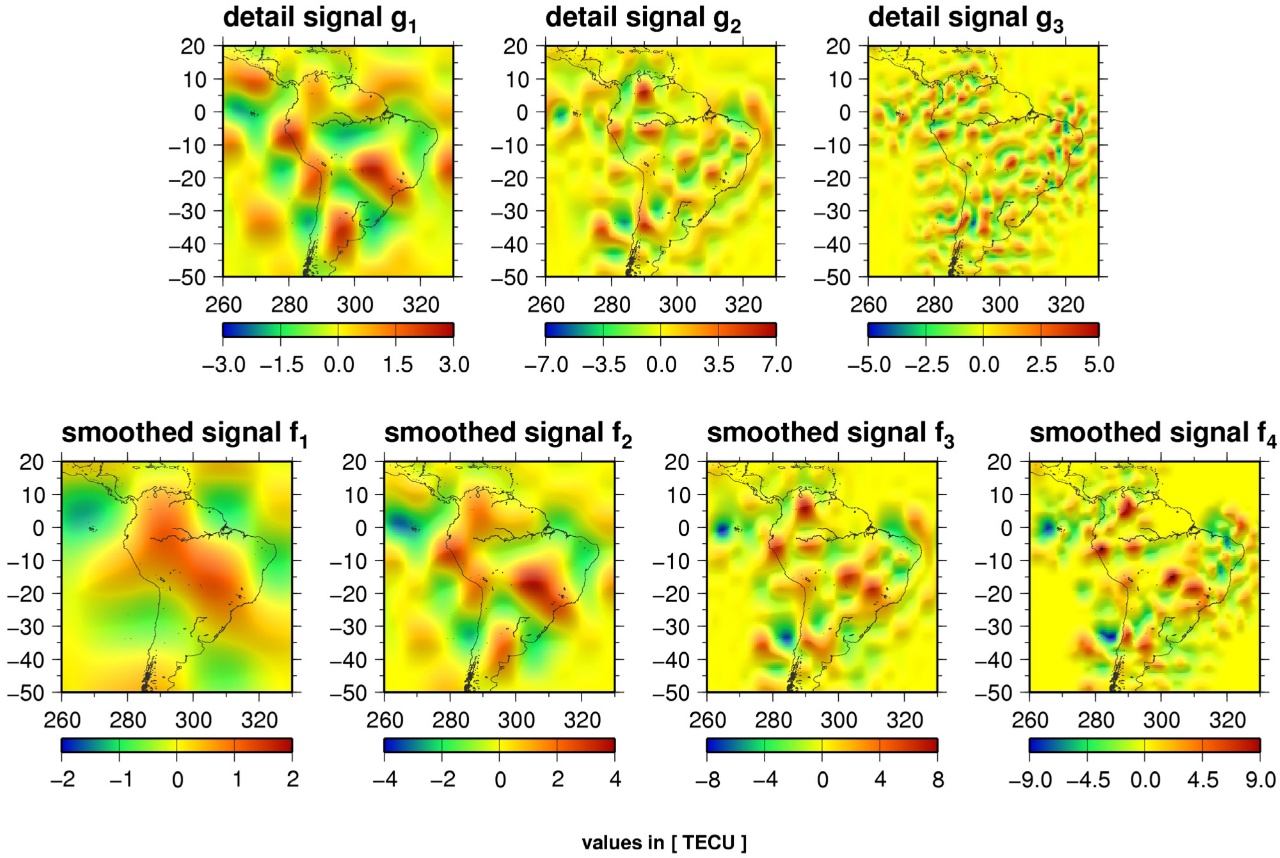


Fig. 2.5.4: Estimated MRR of a one-hour VTEC correction term ΔVTEC. The bottom panels show from the right to the left the successive low-pass filtering process. Each of the detail signals, shown in the upper panels, is related to a specific frequency band.

2.6 Models of crustal deformation

DGFI computes regularly **A**ctual **P**late **KI**nematic and crustal deformation **M**odels (APKIM) based on station velocities derived from space geodetic observations (GPS, SLR, VLBI, DORIS). These models serve for geophysical interpretations and as a reference for the kinematic component of the International Terrestrial Reference Frame, i.e., for realizing the constraint of global no net rotation (NNR) by summing up a grid of modelled velocity vectors over the entire globe and constraining them by estimating a common rotation vector so that their square sum becomes minimal. The rigid plates' motions of this model are represented by geocentric plate rotation vectors. The deformation zones between and inside the plates (inter-plate and intra-plate deformations) are modelled by physical (e.g., viscous-elastic-plastic finite elements) or mathematical methods.

APKIM2004P

The latest model APKIM2004P was computed in 2005 as a basis for the ITRF2004. The geometric plate model, i.e. the boundaries of the rigid plates and deformation zones were taken from the geologic-geophysical plate model PB2002 (Bird 2003). A total of 18 plate rotation vectors of this model could be estimated from the geodetic observation data, which were linear station velocities derived from time series of station coordinates provided by the services or individual analysis centres (table 2.6.1). At a first glance, there is a good agreement between the geodetically determined plate rotation vectors and the geologic model. A strict statistical analysis, however, shows significant discrepancies in more than half of the vectors.

Tab. 2.6.1: Input data for the estimation of 18 plate rotation vectors in APKIM2004P.

Technique	Time Span	Stations	Characteristics
GPS	1996 – 2004	227	Combined weekly solutions from IGS (official input for ITRF2004)
SLR	1985 – 2004	38	Weekly normal equations from DGFI (input to ILRS for ITRF2004)
VLBI	1984 – 2004	39	Sessions' normal equations from DGFI (input to IVS for ITRF2004)
DORIS	1993 – 2003	74	Weekly solutions from IGN (input to IDS for ITRF2004)
total		378	Station occupations on rigid plates

Three deformation zones (called orogenes in PB2002) were modelled by a least squares collocation approach: the Alpine orogene, the Persia-Tibet-Burma (PTB) orogene, and the Gorda-California-Nevada orogene. The deformations of the Alpine and the PTB are exemplarily shown in figures 2.6.1 and 2.6.2. The images are quite similar to the detailed representations of the Geodyssea Project (Simon et al., 1999) and the Mediterranean Project (Heidbach 2000).

The APKIM2004P is still a preliminary solution because the final input data for ITRF2004, to be provided by the services as combinations of all solutions from the individual techniques' analysis centres, was not yet available (September 2005).

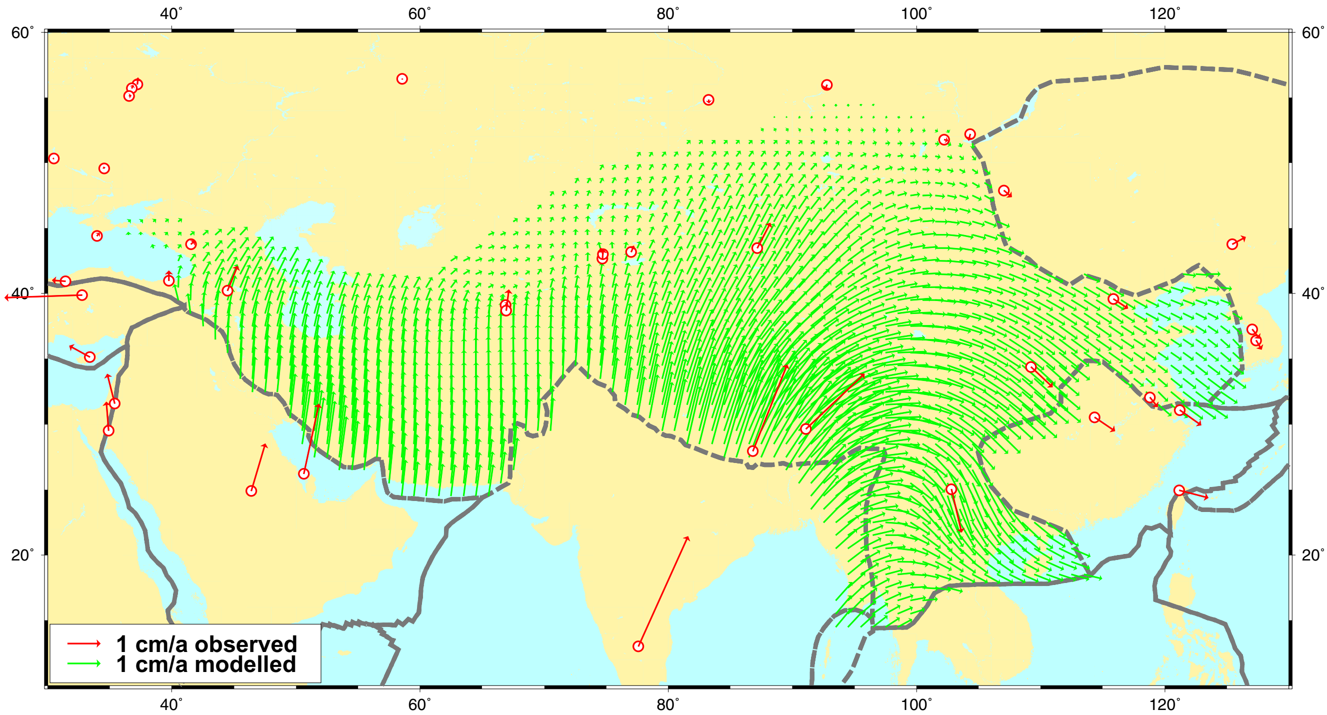


Fig. 2.6.1: Deformation of the Persia-Tibet-Burma orogene by least squares collocation using station velocities observed by space geodetic techniques.

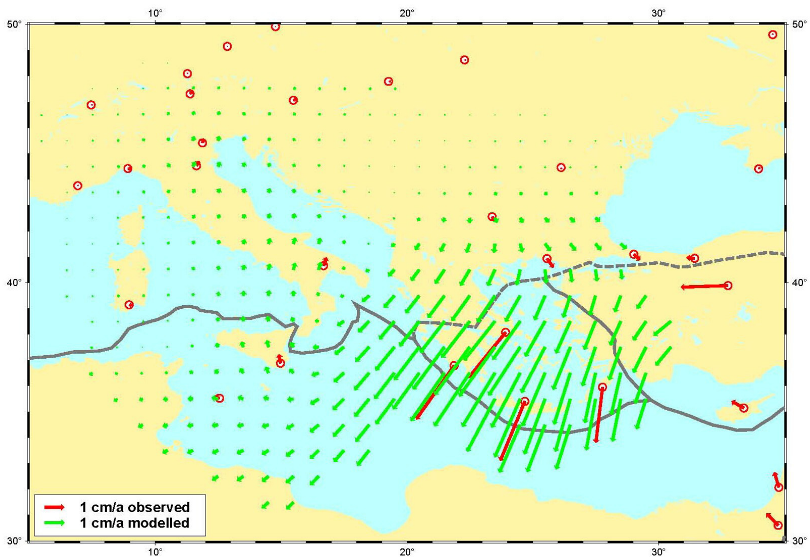


Fig. 2.6.2: Deformation of the Alpine orogene by least squares collocation using station velocities observed by space geodetic techniques.

2.7 Analysis of time series of geodetic parameters

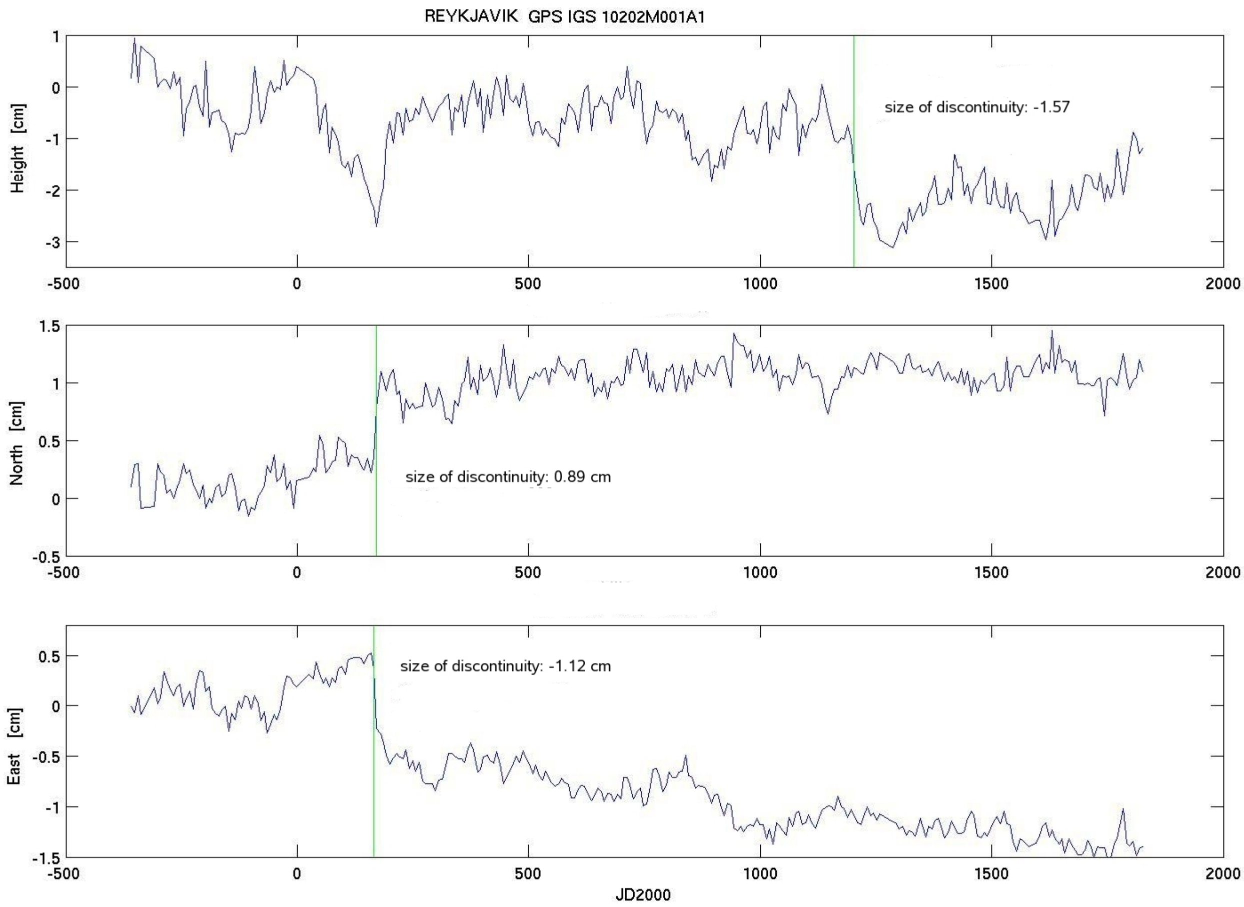
Time series of station positions

In the context of ITRF2004 we compute time series of station positions of the input data. To realize comparable time series, it is essential to achieve a consistent datum of all the data. Therefore we used the accumulated multi-year solutions (see topic 3.1) as reference, reduced outliers from the epoch normal equations, introduced the positions of the multi-year solutions as approximate values and applied a minimum constraint datum over a set of reference stations before inverting the epoch normal equation.

Detection of discontinuities

We started to develop methods to automatically detect discontinuities in station position time series, e.g. of GPS. This is an important task related to the computation of an International Terrestrial Reference Frame (see topic 1.2) from epoch data sets. Whenever discontinuities were detected, new position and velocity have to be estimated. Figure 2.7.1 shows some preliminary results at the station Reykjavik. It shows that the earthquake in the year 2000 is well detected but problems still arise e.g. if strong periodic variations are present in the timeseries.

Fig. 2.7.1: Example of detected discontinuities at GPS station Reykjavik, Iceland.



Analysis of station positions in South America

In the context of the IGS Regional Network Associate Analysis Centre SIRGAS (RNAAC), a new solution was processed using the Bernese 5.0 software (see topic 3.2). The time series of weekly estimated station positions were analysed, e.g. to investigate post-seismic behaviour in connection with three major earthquakes (El Salvador, Arequipa, Manzanillo).

3 International Services and Projects

The participation in international services and projects is a major constituent of the DGFI research. DGFI has taken the responsibility for data centres, analysis centres and other functions in several scientific services of the International Association of Geodesy, and provides therewith the results emerging from the basic research fields (sections 1 and 2) directly for application in routine product generation. In the International Earth Rotation and Reference Systems Service (IERS) DGFI is one of the three official Combination Centres for the International Terrestrial Reference Frame (ITRF) and a Combination Research Centre (CRC). In the International GNSS Service (IGS), DGFI operates the Regional Network Associate Analysis Centre for Latin America from Mexico to Tierra del Fuego (RNAAC-SIR). For the International Laser Ranging Service (ILRS), DGFI acts as one of the two Global Data Centres (EUROLAS Data Centre, EDC), as an Analysis Centre (AC) and as a Combination Centre (CC). In the International VLBI Service for Geodesy and Astrometry (IVS), DGFI is also an Analysis Centre (AC). In the planned International Altimetry Service (IAS) DGFI has got the leading role for its installation. In IAG's Global Geodetic Observing System (GGOS), DGFI participated in the initial implementation phase. Furthermore, DGFI participates in some international projects, in particular by operating permanent GPS stations and analysing the data for the IGS Tide Gauge benchmark monitoring project (TIGA) and the EC Project for the detection and control of crustal deformations in the Alpine region (ALPS-GPS QUAKENET).

3.1 ITRS Combination Centre / IERS Combination Research Centre

This section summarizes the DGFI activities during the period 2004/2005 in its function as an ITRS Combination Centre and as an IERS Combination Research Centre (CRC) within the International Earth rotation and Reference systems Service (IERS). Within the Research Group on Satellite Geodesy (Forschungsgruppe Satellitengeodäsie, FGS), DGFI, FESG (Forschungseinrichtung Satellitengeodäsie, TU München) and GIUB (Geodätisches Institut, Universität Bonn) established a joint CRC. Until December 2004, a significant part of the work was funded by the programme GEOTECHNOLOGIEN of BMBF and DFG, Grant 03F0336C.

ITRS Combination Centre

Based on the experiences gained from previous TRF computations at DGFI, advanced combination methods for an improved realization of the terrestrial reference frame were developed. The refined approach is based on the combination of epoch normal equations (weekly / daily data sets) containing station positions and Earth orientation parameters (EOP), which allows to account for all non linear effects (e.g., periodic signals, discontinuities) in station positions and to ensure consistency between the TRF and the EOP. The work within the ITRS Combination Centre is closely related to the research topics 1.2, 1.4 and 2.7.

ITRF2004 input data

Table 3.1.1 summarizes the characteristics of the ITRF2004 input data (status: Sept. 2005), which were submitted according to the IERS Call for long time series of epoch SINEX files for ITRF2004 and as a supplementation for the IERS Combination Pilot Project.

In the case of GPS, SLR and VLBI official single-technique combined solutions were submitted by the Techniques' Combination Centres, namely the National Resources Canada (NRCan/IGS), the Geodetic Institute of the University Bonn (GIUB/IVS), and the Agenzia Spaziale Italiana (ASI/ILRS). Until now, no combined DORIS solution is available from the IDS. Three solutions of individual DORIS Analysis Centres (IGN, INA, LCA) are included in ITRF2004. In addition to the SINEX solutions the Technique Centres also provided a list with information about discontinuities (e.g., equipment changes, earthquakes) in station positions, which are used as input by the ITRS Combination Centres.

Tab. 3.1.1: Summary of ITRF2004 submissions.

Techn.	Service AC	Data	Time period	Parameters	Constraints
GPS	IGS NRCan	467 weekly solutions	1996 - 2004 from June 1999 from March 1999	Station positions EOP (pole rates, LOD) geocenter	NNT: 0.1 mm NNR: 0.3 mm NNS: 0.02 ppb
VLBI	IVS GIUB	2017 daily sess. free NEQs	1984 - 2004	Station positions EOP (pole, UT1 + rates)	none none
SLR	ILRS ASI	608 weekly solutions	1993 - 2004	Station positions EOP (pole + LOD)	1 m 1 m
DORIS	IGN	625 weekly solutions	1993 - 2004	Station positons EOP (pole, UT1 + rates)	loose
	INA	603 weekly solutons	10 / 92 - 06 / 2004	Station positions EOP (pole, UT1 + rates)	loose
	LCA	632 weekly solutons	1993 - 2004	Station positions EOP (pole)	loose

Combination methodology

The combination methodology for the ITRF2004 computation applied at DGFI comprises the following major steps:
- analysis of ITRF2004 submissions as input data and generation of normal equations,
- analysis of time series and combination for each technique (intra-technique combination),
- comparison and combination of different techniques (inter-technique combination),
- generation of the final combined solution by applying minimum datum conditions.

Status of ITRF2004 computations at DGFI

The ITRF2004 submissions are not yet completed; in particular in the case of SLR and VLBI, re-processed input data will be provided by the ILRS and IVS. Thus, no final ITRF2004 computations could be performed so far. The major focus of the TRF computations on the basis of the weekly input data was (1) to identify remaining deficiencies; (2) to provide feedback to the Technique Centres and to the contributing Analysis Centres; (3) to validate and enhance the combination procedure; (4) to perform first comparisons among the ITRS Combination Centres.

GPS intra-technique combination

The GPS intra-technique combination results can be considered as almost final. The GPS position time series were analysed to identify non linear station motions, which were then considered within the accumulation of the weekly SINEX files. The final result is a multi-year solution with station positions, velocities and EOPs. Figure 3.1.1 shows the time series of weekly station positions along with the position and velocity estimates of the accumulated multi-year solution for the GPS station HOFN, Iceland. A discontinuity in the station height of about 5 cm was mainly

Tab. 3.1.2: Station velocity estimates of different solutions for GPS station HOFN, Iceland.

Solution	Time period JD2000	Estimates [mm/yr]
1	-786.5 - 619.7	4.5 ± 1.4
2	627.5 - 1825.5	8.7 ± 1.1
Difference		4.2 ± 1.8

caused by removing the radome, which led to two different solutions for this station. The velocity estimates of these two solutions before and after the event differ by 4.2 mm (see table. 3.1.2). An important issue (also for many other GPS stations) is the question, whether the velocities of a station estimated in different solutions should be set equal or not. For the application of statistical tests, it is important that the standard deviations are realistic, which requires sophisticated weighting methods.

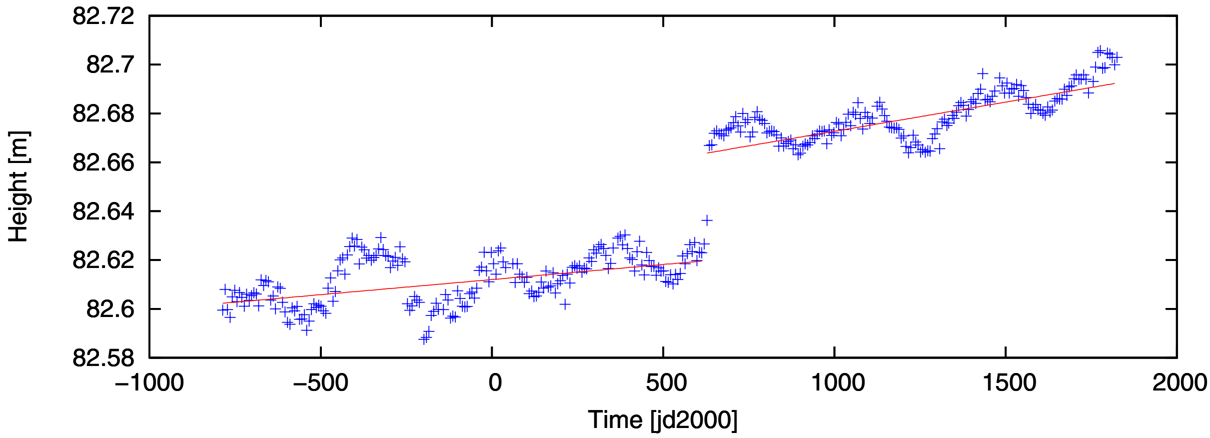


Fig. 3.1.1: Height time series and velocity estimates of GPS station HOFN, Iceland.

Inter-technique combination

Co-location sites are key elements for the combination of different space techniques and for the datum realization of the combined solution (see section 1.2). New strategies for the selection and implementation of local tie information were developed using the ITRF2004 submissions and other time series solutions as input data. Criteria for the selection are a maximal consistency and a minimal deformation of the combined solution. As common parameters of the different techniques, the EOPs are well-suited to “measure” this consistency, and furthermore they serve as “global ties” to stabilize the rotation datum.

IERS Combination Research Centre

The DGFI activities as IERS Combination Research Centre can be divided into the following major topics:

- refinements of the SLR intra-technique combination,
- simultaneous estimation of a TRF, the EOP, and a CRF with VLBI data,
- steps towards a rigorous combination of VLBI, GPS and SLR data using CONT02 data,
- IERS Combination Pilot Project.

Refinements of the SLR intra-technique combination

Since June 2004, DGFI has served as an official ILRS Backup Combination Centre (see section 3.4). It is obliged to compute weekly a combined SLR solution as an official product (SINEX files with station positions and EOPs) for the ILRS and as input for the weekly combination of SLR data with other techniques within the IERS Combination Pilot Project. During this period, DGFI refined the intra-technique combination methodology and software for an automated processing to guarantee an operational combination of the individual SLR solutions on a weekly basis.

Simultaneous estimation of a TRF, the EOP, and a CRF with VLBI data

DGFI computed a VLBI solution with simultaneous estimation of station positions and velocities (TRF), radio source positions (CRF) and the full set of Earth orientation parameters (EOP). The results of this completely undistorted VLBI solution were compared with the official IERS products, namely the IERS C04 series of the EOP, ITRF2000, and ICRF-Ext1 (see sections 1.3 and 3.5). A graphical representation of a comparison of the EOP from the VLBI solution and IERS C04 is provided in figure 3.1.2. Assuming that the VLBI solution is free of (systematic) errors, the results indicate inconsistencies between the IERS C04, ICRF-Ext1, and the VLBI part of ITRF2000. The observed discrepancies demonstrate the need for the development of rigorous combination methods for the generation of consistent IERS products, as for example envisaged within the IERS Combination Pilot Project (see below).

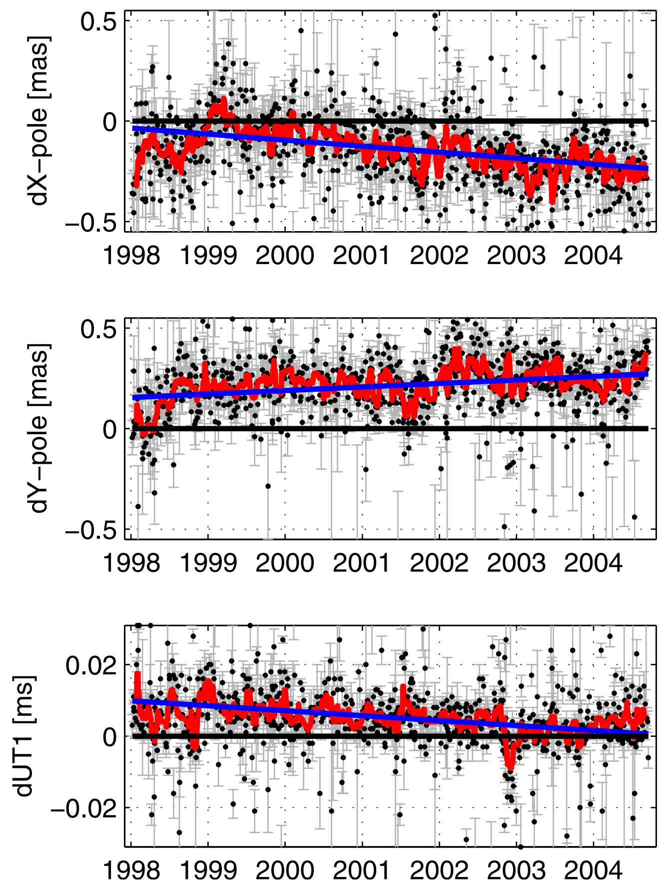


Fig. 3.1.2: Differences between the EOP of the VLBI solution and IERS C04 from 1998 until 2004 (solid lines show the median of 10 values and a best-fitting linear function).

CONT02 Combination

The combination studies performed by Forschungseinrichtung Satellitengeodäsie TU München (FESG) and DGFI using data of the continuous IVS campaign CONT02 were continued. The close cooperation between these two institutions established the basis for a detailed adaption of the GPS software and the VLBI software concerning models and parameterization to avoid systematic differences between the technique contributions (see section 1.1). The achieved results demonstrate the potential of such a rigorous combination of GPS and VLBI data (see sections 1.3 and 1.4).

IERS Combination Pilot Project

The IERS Combination Pilot Project (CPP) aims at more consistent, routinely generated IERS products. “Weekly” SINEX solutions, which are available from the different technique services, contain station positions, EOPs, and, possibly, quasar coordinates. These solutions shall be rigorously and routinely combined into consistent IERS products. In the frame of the CPP, DGFI provides individual SLR and VLBI solutions and combined SLR solutions for the intra-technique combination. It was nominated by the IERS as a combination centre for the inter-technique combination. The presently available SINEX files were analysed regarding the suitability for a rigorous combination. The methodology for the weekly inter-technique combination of station positions and EOPs, including input data check and validation of the results, was developed and implemented in the DGFI software DOGS-CS.

During the CPP and within the IERS Working Group on Combination it was recognized that the weekly SINEX solutions now routinely generated by the Technique Centres are not sufficient to generate combined inter-technique solutions over longer time periods. It was found that a refined TRF realization is an essential prerequisite for the weekly inter-technique combination of the space geodetic observations. The computation of a new ITRF2004 solution is currently in progress by the ITRS Combination Centres, namely IGN, NRCan and DGFI (see above).

3.2 IGS Regional Network Associate Analysis Centre for SIRGAS

Since the start of the regional densification of the IERS Terrestrial Reference Frame (ITRF) initiated by the International GPS Service (IGS) in June 1996, the DGFI has been acting as an IGS Regional Network Associate Analysis Centre. Weekly coordinate solutions based on all available observations are generated and submitted to the IGS Global Data Centres.

RNAAC SIR network status

By the end of September 2005, the RNAAC network consists of 99 GPS stations, 46 of them are regional stations (see figure 3.2.1).

Fourteen new stations in Mexico were included in the IGS RNAAC SIR processing, and the data of the IGS station Aguascalientes (INEG) are available again. Additionally the new regional station Heredia (ETCG) in Costa Rica substitutes the old station Limon (MOIN). Considerable efforts are done by several South American countries to increase the number of their permanet GPS stations. Colombia installed 26 new stations; the data will be provided soon. In Argentina the station Puerto Deseado is now operational, the processing of its observations will start in some weeks. Three new prospective stations are in discussion: Corrientes (CORR), Mendoza (MZAC), Rosario (UNRO). Negotiations with the Dominicanian Republic are on the way for including four stations (see figure 3.2.1).

Processing strategy changes

The data processing at DGFI is done with the Bernese Processing Engine (BPE). Since the beginning of 2005 (GPS week 1304) the new version 5.0 has been used. At the same time the elevation cutoff angle was changed from 10 to 5 degrees, and the Niell mapping function is used for estimating the tropospheric delay. In parallel the processing with the BPE version 4.2 is continued for analysing the differences between both versions. At some stations a height discontinuity in the time series was detected, probably mainly due to the lower elevation cutoff angle.

Weekly position solutions

DGFI is providing weekly position solutions as a support to all South and Central American countries. For this purpose the BPE version 5.0 is also used, but the processing strategy was slightly changed. Prior to 2005 the solutions were referred to IGb00 by constraining the positions and velocities of nine stations. Now the no-net-rotation and no-net-translation conditions are applied to these nine stations so that they are no longer fixed.

Monitoring of episodic events

Proper modelling of episodic events like earthquakes have to be considered in station coordinates and velocity estimations. This time, the IGS RNAAC station Iquique (IQQE) was affected by the strong earthquake near Tarapaca (see figure 3.2.1). The magnitude was M=7.8 at a distance of 115 km and a depth of 117 km. Our estimation of the impact on station IQQE leads to a displacement of 1.0 cm in the south, 3.9 cm in the west, and 2.6 cm in the height component.

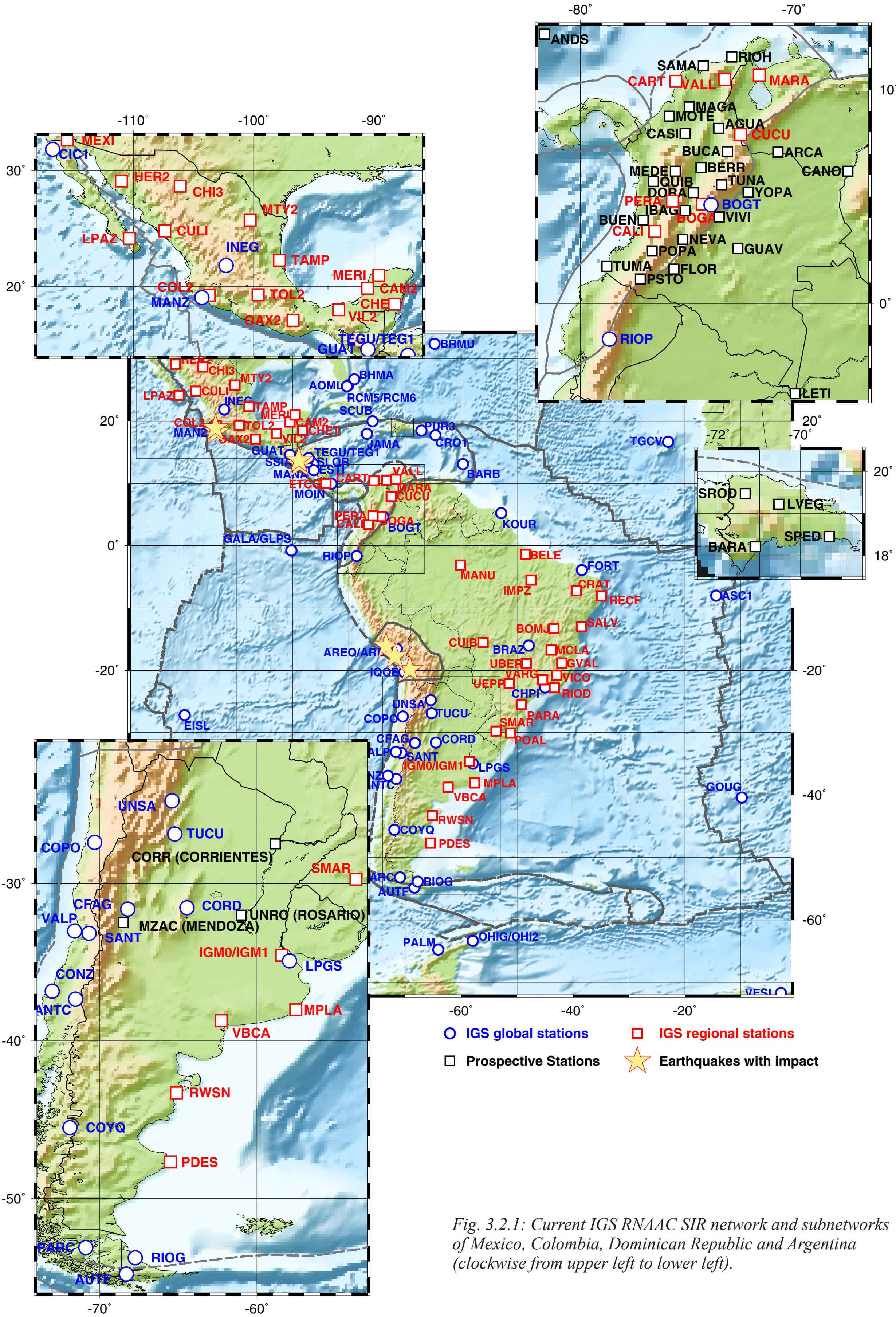


Fig. 3.2.1: Current IGS RNAAC SIR network and subnetworks of Mexico, Colombia, Dominican Republic and Argentina (clockwise from upper left to lower left).

3.3 Continuously operating GPS stations

Since 1998 DGFI has installed permanent GPS stations in cooperation with several national organizations in South America and Europe (table 3.3.1). They are managed in a remote way, i.e. the data tracking and data transfer are automated and centralized at DGFI. All the stations are integrated in specific projects, such as the IGS TIde GAuge benchmark monitoring project (TIGA), EC INTERREG IIIB Alpine Space crustal deformation project (ALPS-GPS QUAKENET), densification of the International Terrestrial Reference Frame (RNAAC SIR, see section 3.2), and definition and realization of vertical reference systems (SIRGAS-WGIII, see section 1.6).

Tab. 3.3.1: Continuously operating GPS stations installed and operated by DGFI.

Station	Place	Receiver/Antenna	Date of installation
BOGA	Bogotá (Colombia)	Leica CRS1000 / LEIAT504	Feb. 2000
BREI	Breitenberg (Germany)	Leica GRX1200 Pro / LEIAT504	July 2005
CART	Cartagena (Colombia)	Leica CRS1000 / LEIAT504	Feb. 2000
FAHR	Fahrenberg (Germany)	Leica GRX1200 Pro / LEIAT504	July 2005
HGRA	Hochgrat (Germany)	Leica SR520 / LEIAT504	July 2005
HRIE	Hochries (Germany)	Leica SR520 / LEIAT504	July 2005
MARA	Maracaibo (Venezuela)	Leica SR9500 / LEIAT303	Feb. 1998
MPLA	Mar del Plata (Argentina)	Leica MC1000 / LEIAT504	Oct. 2002
PDES	Puerto Deseado (Argentina)	Leica RS500 / LEIAT504 LEIS	May 2005
RWSN	Rawson (Argentina)	Ashtech UZ-12 / ASH700936M_D	Nov. 1999
TORS	Torshavn (Faroe Islands)	Leica CRS1000 / LEIAT504	Feb. 2001
VBCA	Bahía Blanca (Argentina)	Leica SR9500 / LEIAT303	Dec. 1998
WART	Wartsteinkopf (Germany)	Leica SR520 / LEIAT504	July 2005

TIde GAuge benchmark monitoring project (TIGA)

DGFI contributes to the TIGA project of the International GNSS Service (IGS) by operating some permanent GPS stations at (or close to) tide gauges and by processing a GPS network of 54 stations (22 of them at tide gauges) covering the entire North and South Atlantic ocean (figure 3.3.1). This network is processed weekly following the general IGS strategy. The SINEX files of the free network adjustment are provided to the TIGA Associate Analysis Centres (TAAC) and other users through the web site http://adsc.gfz-potsdam.de/tiga/index_TIGA.html, options: download/SINEX file holding. At present, there are 130 weekly solutions available, including one week per month from June 2000 until December 2003 and every week since January 2004.

A first combined solution DGFI05P01 (TIGA) was computed using 400 daily solutions, which were regularly distributed over the almost five years of data analysis. Stations with short time series were excluded. In addition, the possible discontinuities or systematic effects to be modelled in the combination are pre-analysed by generating time series of station coordinates. They are generated as a cumulative solution by a transformation of the individual daily solutions.

Tab. 3.3.2: Differences between the velocities obtained from DGFI05P01 (TIGA) and IGb00.

Station	North [mm/a]	East [mm/a]	Up [mm/a]
CHUR	0,3	0,5	0,3
CRO1	1,9	-4,3	-1,2
FORT	-1,3	0,4	-2,3
GOUG	-6,1	5,3	6,3
NKLG	0,9	-2,8	-2,8
OHI2	1,2	-0,6	0,4

The positions and velocities of all stations are estimated defining the geodetic datum by constraining ten IGS stations to their IGb00 values (figure 3.3.1). Table 3.3.2 shows the differences between the estimated velocities of DGFI05P01 (TIGA) and IGb00 for common stations, none of which included as fiducials for the datum definition.

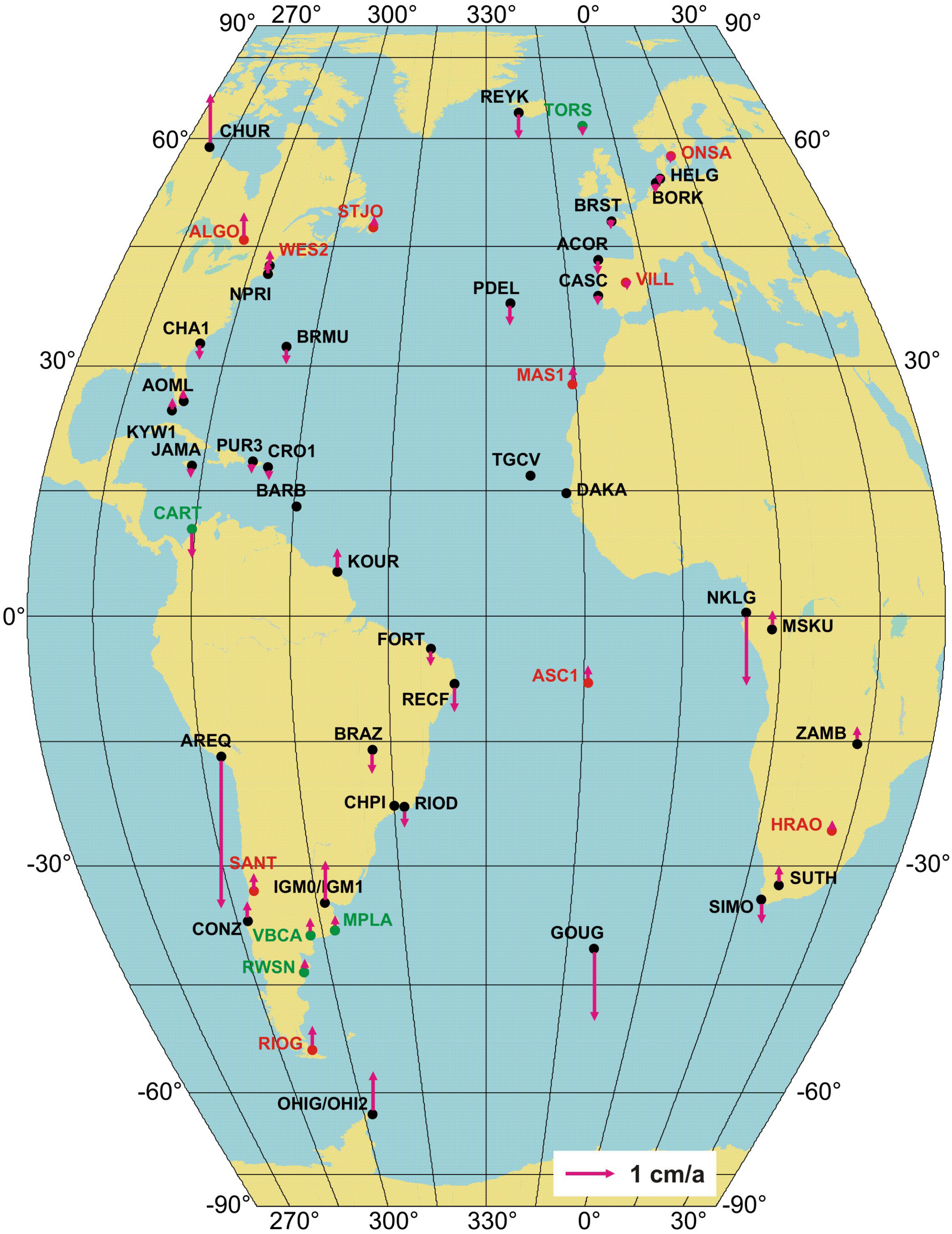


Fig. 3.3.1: GPS network processed at DGFI within the TIGA project and vertical velocities of the solution DGFI05P01 (TIGA) (green: DGFI permanent stations, red: fiducial stations).

CIP INTERREG IIIB: Alpine Space Programme, Project ALPS-GPS Quakenet

In the frame of the European Community Initiative Programme (CIP) INTERREG IIIB, Alpine Space Programme, Project ALPS-GPS QUAKENET, a partnership of ten institutions from Italy, Germany, France and Slovenia establishes a network of about 30 GPS stations to study crustal deformations in near real-time in order to improve natural disaster prevention in this region. The team is in close cooperation with other groups in Austria and Switzerland.

DGFI installed in 2005 five GPS stations along the northern boundary of the alps (figures 3.3.2 and 3.3.3). They are all located on stable bedrock in altitudes of between 1600 m and 2000 m to represent the motion of the surrounding region. The observation data are directly transferred to the operations data centre at DGFI and then forwarded to the GPS QUAKENET project data base in Trieste, Italy. Three data processing centres will process and analyse the data. The results will be used to formulate a master model of continental deformation in the Alps for earthquake hazard reduction, landslides monitoring and meteorological effects.

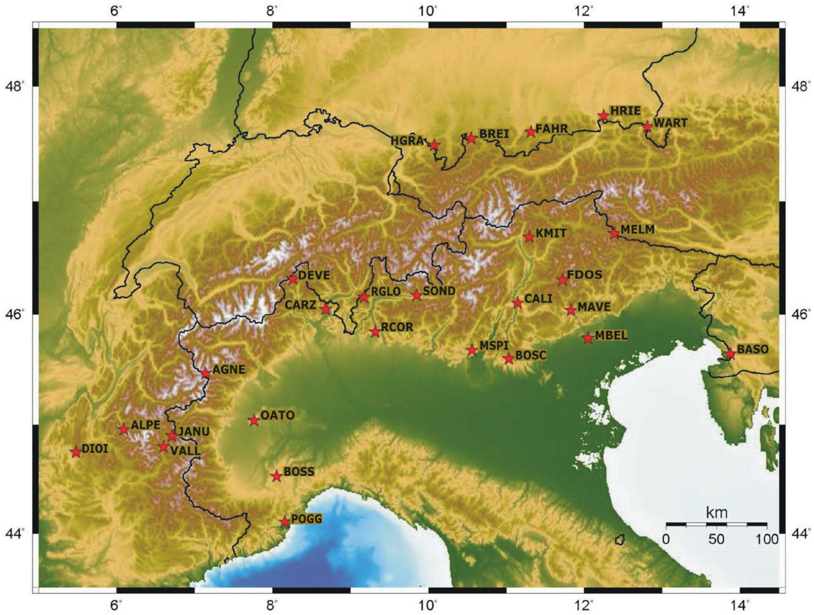


Fig. 3.3.2: ALPS-GPS QUAKENET.

Fig. 3.3.3: ALPS-GPS station Fahrenberg (FAHR).

3.4 ILRS - International Laser Ranging Service

DGFI contributes to the ILRS in the maintenance of the global SLR (Satellite Laser Ranging) network as

- Data centre,
- Analysis centre,
- Backup combination centre.

All these contributions are part of international agreements and are controlled by the ILRS governing board and the ILRS Analysis Working Group (AWG), respectively.

ILRS Global Data Centre EDC

The DGFI runs, besides the EUROLAS Data Centre (EDC), the ILRS Global Data Centre. The second ILRS Global Data Centre is at CDDIS/NASA.

Since November 1995 the SLRmail and SLReport exploders at EDC distributed 1384 SLRmails (an increase of 125 compared to last year) and 6055 SLReports (an increase of 1676) to the permanently updated distribution lists. The other exploder URGENT Mail circulated 55 e-mails (increase of 25) since August 15, 2003.

Corresponding to an agreement of the ILRS Data Format and Procedures Working Group, the access to the data is now identical at both ILRS Global Data Centres. The structure of the ftp servers is shown in figure 3.4.1. The old ftp structure of EDC is still accessible.

The JASON-1 / TOPEX Tandem, ETALON-1/2, ENVISAT, LARETS and Gravity Probe-B campaigns are continued, no new campaign was appointed.

In the time period from October 2004 to August 2005, 37 SLR stations observed 32 satellites (including the four moon reflectors). Table 3.4.1 shows the EDC data base content on August 31, 2005. This content is compared with the content of the CDDIS data base and has to be updated at EDC and/or CDDIS in case of missing data.

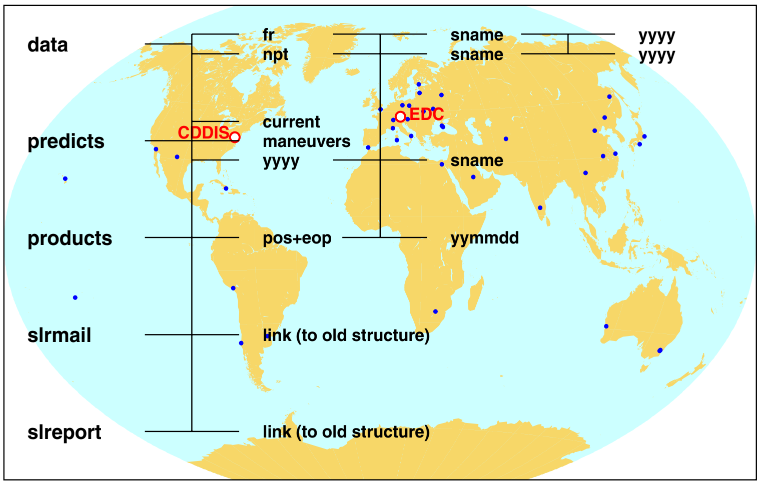


Fig. 3.4.1: Structure of the ftp servers at EDC and CDDIS/NASA.

Tab. 3.4.1: Content of ILRS/EDC data base on August 31, 2005 for the product normal points (including Lunar Laser Ranging (LLR) observations to four moon reflectors).

Satellite	Number of Passes		Satellite	Number of Passes		Satellite	Number of Passes	
	Increase 05	2005		Increase 05	2005		Increase 05	2005
ADEOS		671	GLONASS-70		1430	ICESAT	575	575
AJISAI	9880	92313	GLONASS-71		2617	JASON-1	7512	26585
BEACON-C	5328	37540	GLONASS-72		3260	LAGEOS-1	7468	68894
CHAMP	1334	7910	GLONASS-74		39	LAGEOS-2	6450	60381
DIADEME-1C		1393	GLONASS-75		300	LARETS	3764	7036
DIADEME-1D		1585	GLONASS-76		301	LRE/H2A		75
ENVISAT	5116	18003	GLONASS-77		343	METEOR-3		409
ERS-1		10524	GLONASS-78		2712	METEOR-3M	292	1576
ERS-2	5160	48337	GLONASS-79		3237	MOON-1	64	384
ETALON-1	1315	10785	GLONASS-80		4466	MOON-2	84	298
ETALON-2	1230	10906	GLONASS-81		275	MOON-3	404	2387
FIZEAU		4243	GLONASS-82		244	MOON-4	12	594
GEOS-3		2237	GLONASS-84	1170	6442	REFLECTOR		3728
GFO-1	4338	27193	GLONASS-86	28	1232	RESURS-01-3		2011
GFZ-1		5606	GLONASS-87	1347	4646	STARLETTE	7855	69403
GLONASS-62		963	GLONASS-88	100	114	STARSHINE-3		48
GLONASS-63		1952	GLONASS-89	1214	3848	STELLA	3987	43745
GLONASS-64		81	GLONASS-95	6	6	SUNSAT		1864
GLONASS-65		397	GPS-35	590	5737	TIPS		1849
GLONASS-66		1544	GPS-36	600	5147	TOPEX/POS.	9597	84988
GLONASS-67		4299	GRACE-A	1823	6246	WESTPAC-1		5620
GLONASS-68		875	GRACE-B	1685	5540	ZEIA		146
GLONASS-69		945	GRAVITY PROBE-B	1522	1703	Sum of all	91850	732783

ILRS Analysis Centre

The processing of weekly SINEX files from tracking data to the geodetic satellites Lageos-1/2 and Etalon-1/2 is an ongoing process which is fully automated. These solutions contain station coordinates and Earth orientation parameters as a loosely constrained solution. All results from the processing are filed to the databases at CDDIS and EDC.

The number of stations included in the individual solutions differ between the analysis centres, but they all deliver daily earth orientation parameters. The treatment of biases and the models used in the processing are also not identical. But the combined solutions of both combination centres show good agreement with each other. Figure 3.4.2 shows the number of stations contributing to the weekly SINEX files from the individual analysis centres.

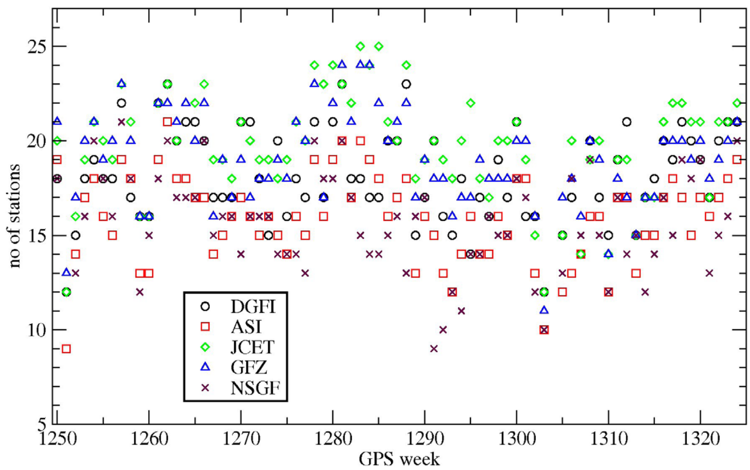


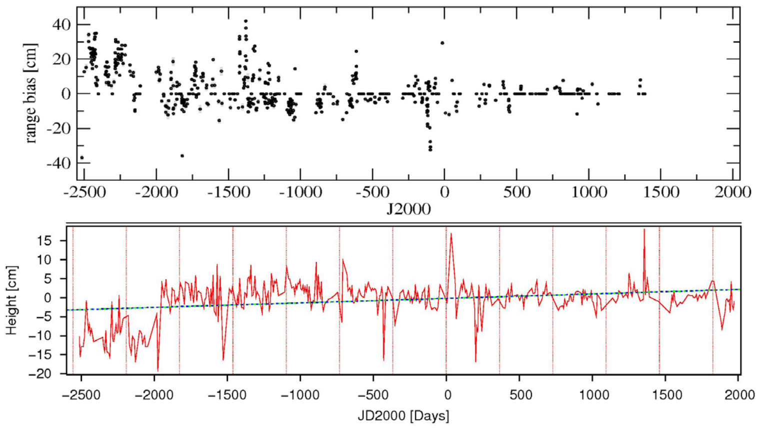
Fig. 3.4.2: Number of stations included in weekly individual solutions.

Another project in 2005 was the reprocessing of SLR data back to 1993 to produce an ILRS combined solution which can contribute to the new ITRF2004 reference frame. For this purpose all ILRS analysis centres have agreed to reprocess tracking data to both Lageos satellites back to 1993 in a homogeneous way, using the same models and editing criteria (at least 10 observations per station during one week).

The results of the six analysis centres did not agree well in the beginning so that several iterations were necessary, including corrections to the SINEX files produced by the centres.

During the combination process, the handling of station biases in solutions turned out be a critical point: The estimated height component of some stations, especially Graz and Riga, were quite sensitive to range biases that are not accounted for. Figure 3.4.3 shows the range biases determined for Riga and the resulting station height. One could see that in 1994 (corresponding approximately to day number -2000 in the figure) there is a jump in the height component. Starting from that point, the range biases changed from pure positive values to a scatter around zero. The effect of the biases seems to be evident.

Fig. 3.4.3: Riga range biases and station height variations (from combination of the ILRS Primary Combination Centre , ILRSA).

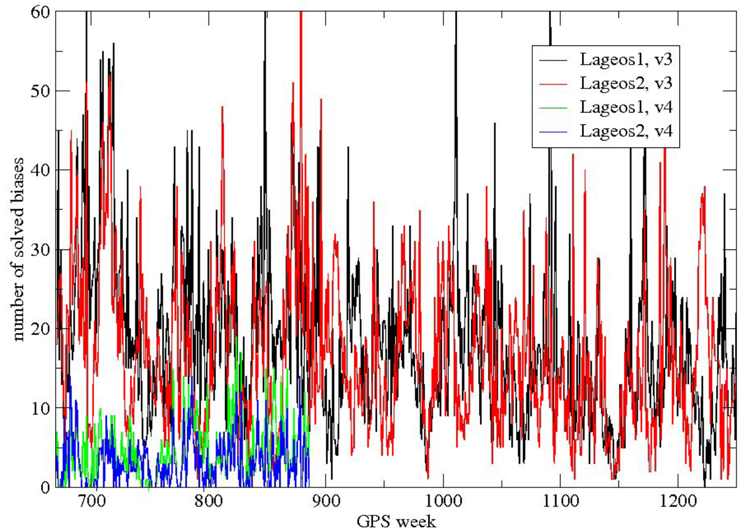


For Graz on the other hand, a core station, for which no biases are to be estimated there is a jump in 1996, which could possibly be explained by range biases prior that period. Version 4 of the solution contains biases for Graz before 1996 and no biases for Riga in 1993 and early 1994. Additionally version 4 contains less biases for all other stations. The overall biases per week for the backward processing period from 1993 to 2003 is given in figure 3.4.4. One could see that the reprocessed version 4 contains significantly less bias values.

ILRS Combination Centre (ILRSB)

At the ILRS/AWG meeting in June 2004 in San Fernando (Spain) DGFI was elected as the backup combination centre. Since then the weekly combination of the contributions from the individual analysis centres (see previous paragraph) runs routinely on every Wednesday. The combined products are delivered to CDDIS and EDC.

Fig. 3.4.4: Number of biases determined in one weekly satellite solution.

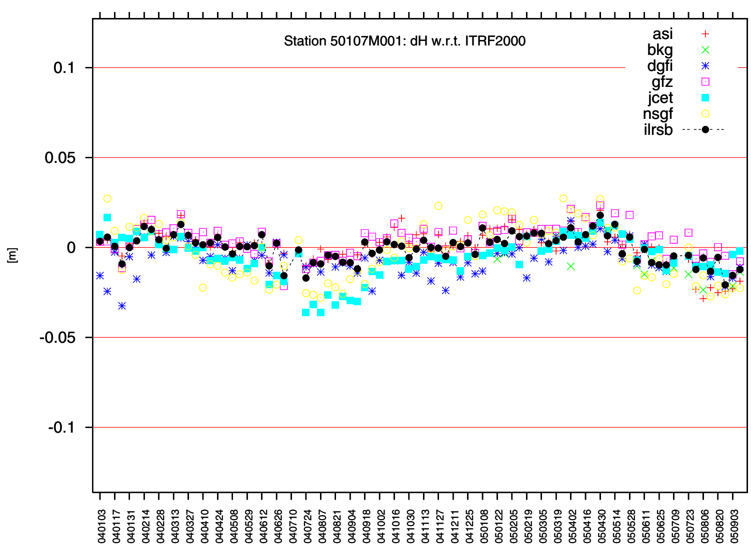


In the processing the individual SINEX files were combined on the basis of normal equations, which were solved with minimum constraints. Figure 3.4.5 shows the height variations for Yarragadee during the period January 2004 to September 2005. The individual solutions agree to below 3 cm, but a periodical signal remains. In the combined solution (from ILRSB), this signal is also visible.

Another project was the reprocessing of the weekly SINEX files back to 1993 for the combined SLR solution, which will contribute to ITRF2004. DGFI produced three solutions based on the releases of the anlaysis centres. In September a version 4 for the period 1993 to 1996 was produced for discussion at the ILRS/AWG meeting in Eastbourne (Great Britain) in October 2005.

Since July 2005, solutions have been based on a full variance component estimation. This leads to better results and reduces the difference to the solution of the primary analysis centre at ASI (Agentia Spatiale Italiano), which is based on the combination of individual solutions. The new strategy will also be used for the reprocessing of the weekly SINEX files for ITRF2004.

Fig. 3.4.5: Height variations of Yarragadee (Australia) from January 2004 to September 2005.



3.5 IVS Analysis Centre

IVS OCCAM working group

As all work at DGFI related to VLBI (see also 1.3) is done with the VLBI software OCCAM, the collaboration in the IVS OCCAM Working Group is of particular importance for the DGFI IVS analysis centre. The general task of the OCCAM working group is to regularly improve the OCCAM software. It is chaired by Oleg Titov from Geoscience Australia (Canberra, Australia), leading members are scientists from the Vienna University of Technology (Vienna, Austria), the St. Petersburg University, the Institute of Applied Astronomy (both St. Petersburg, Russia) and DGFI. The actual version 6.0 of the software was officially released in February 2004 during the IVS General Meeting in Ottawa, Canada. Since then, the software was upgraded in many parts, especially the code that solves the equation systems with the least squares approach, which now allows also to estimate source positions. This was done in very close cooperation with the Vienna University of Technology, during several small working meetings, the last ones in February and September 2005.

IVS VLBI contribution to the IERS Combination Project

The IERS Combination Pilot Project, which was started in the beginning of 2004, is a major step towards more consistent, routinely generated IERS products (for details see 3.1). The DGFI VLBI contribution were SINEX files for 2666 daily sessions between 1984 and 2005, submitted to the IVS on a quasi operational basis. These files contain the Earth orientation parameters and station positions for each 24-hour session as decomposed normal equations in the SINEX format. The IVS-combined normal equations for each single VLBI session, compiled from results of up to seven IVS analysis centres each, is the VLBI contribution to the IERS Combination Project, and to the up coming realization of the International Terrestrial Reference Frame ITRF2004.

Towards a new realization of the International Celestial Reference Frame (ICRF)

The International Celestial Reference System (ICRS) is realized by the coordinates of several hundred radio sources observed by VLBI (for the last realization “ICRF-Ext1”, data until 1998 were used). The IERS as well as the IVS aims for a new realization of the ICRS in the next years, which shall, if feasible, be generated by combining several VLBI solutions. The first comparisons of radio source catalog test solutions of several IVS analysis centres were presented during the 6th IVS Analysis Workshop, held in Noto, Italy in April 2005. DGFI contributions to these efforts were a CRF solution computed with OCCAM as well as investigations concerning the homogeneity of catalogues computed with different solution setups.

Interim VLBI terrestrial reference frame VTRF2005

Since the ITRF2000 was based only on observation data until the end of 2000, the quality of this TRF deteriorated for the time since then. In order to provide a terrestrial reference frame for operational VLBI determinations of EOP and atmospheric water vapour content, recent TRF realizations from five analysis centres were combined by the IVS analysis coordinator to the terrestrial VLBI reference frame VTRF2005. These five solutions were computed with the VLBI software packages OCCAM (by DGFI and Geoscience Australia, Belconnen, Australia), Steel-Breeze and Calc/Solve.

3.6 Planning and realization of an International Altimeter Service

Endorsements/Resolutions by GLOSS, IAG (and IAPSO?)

The Planning Group for the International Altimeter Service (IAS-PG), initiated by C.K. Shum, Phil Woodworth, G. Mitchum and Wolfgang Bosch (chair), continued its work. Besides the formal endorsement by the GLOSS programme of the International Oceanographic Commission (IOC), the Planning Group was further encouraged by an official resolution of the IAG Executive Committee, issued at the 2005 assembly in Cairns, Australia. The same resolution is also expected to be issued by the Executive Committee of IAPSO, the International Association of the Physical Science of the Oceans.

Terms of References of IAS-PG

The IAS Planning Group (IAS-PG) studies the rationale, feasibility and scope of an International Altimeter Service (IAS) and develops an implementation plan for it. IAS shall serve the altimeter user community with the longest possible time series of harmonized multi-mission altimeter observations with up-to-date geophysical corrections and consolidated geocentric reference and with related sea level products. The activities comprise:

- to collaborate with space agencies, processing centres, data and product archives, other existing or emerging observing systems and with scientific organisations and expert groups,
- to identify categories of altimeter users and compile their requirements, considering already available key documents from previous studies and projects,
- to elaborate the basic functionality to be provided by an IAS and compile a list of data and products to be considered by an IAS,
- to identify and describe the components, necessary or recommended to fulfil the IAS objectives and functionality,
- to propose an organisational structure for the IAS taking into account the responsibilities of space agencies and other entities, which are able to host or support the envisaged service,
- to report to IAG, GLOSS, IAPSO and other bodies related to satellite altimetry on the state of planning and implementation of an IAS.

Mailing list

As the IAS-PG is not funded, discussions have to be organized by business meetings, which are attached to scientific conferences or general assemblies, or by electronic mail. To facilitate the e-mail exchange a mailing list has been created. Any e-mail, sent to ias-pg@dgfi.badw.de is sent to registered members of the list. In addition, all e-mails distributed this way are archived (see http://www.dgfi.badw.de/lists/ias-pg) and may be viewed in different ways – sorted according to threads, date, and author. All members of the IAS-PG were initially registered to receive the messages posted to the mailing list. The list is open and unmoderated. Anyone may subscribe to the mailing list and receive then all messages posted to the list. In addition, anyone may contribute to the discussion by posting his own e-mails. Several e-mails with requests for comments (RFC) were used by the chair of the IAS-PG to push forward discussions on particular topics.

Collaborative WIKI Website

It was soon recognized that the e-mail list is a necessary tool, but not well suited to synthesize different contributions of the

IAS-PG members. It was therefore decided to install in addition a so called 'WIKI', a collaborative web site, see http://www.dgfi.badw.de/wiki . This WIKI allows everybody to edit existing pages or to create new pages within the web site dedicated to the objectives of the IAS-PG. A very simple syntax is used to do this and to create headings, lists and internal as well as external links. After its creation, most of the contributions of the mailing list were compiled and synthesized to the IAS-PG WIKI. The main page of the WIKI web site is shown in figure 3.6.1.

Conclusions

The following conclusions summarize the most important results of the work performed so far within the IAS Planning Group:

- There is a general agreement that an International Altimeter Service (IAS) is necessary and should be created as soon as possible.
- The IAS shall integrate the envisaged altimetry services into the Global Earth Observing System of Systems (GEOSS) and let altimetry become an essential element of Global Ocean and Geodetic Observing Systems (GOOS, GGOS).
- IAS shall provide a unique point-of-contact for altimeter users and support all applications of satellite altimetry, including, for example, applications for oceanography, coastal zones, hydrology, geodesy, cryosphere.
- IAS shall support calibration and validation activities, assess data and product quality, and recommend improvements for generation and delivery of data and products.
- IAS will not replace but be based on the voluntary contribution of the many existing data, analysis, and product centres already providing service functions. Thus, IAS will have to

Fig.3.6.1: Screenshot of IAS-PG WIKI, a collaborative web site, that serves as a forum for discussion on the envisaged International Altimeter Service and is used to compile and synthesize contributions from the members of the IAS-Planning Group.

coordinate a network of centres. User request are to be re-directed to and resolved by these centres, which keep the desired data.
- IAS must ensure that intellectual property rights remain with and proper referencing is made to the generating node, whenever data, products or algorithms are provided or used in publications.
- A unification of data formats is neither feasible nor desirable. Instead, IAS shall provide generic tools, which keep the necessary metadata to inform about data content and allow extracting data with content and format upon user request.
- IAS shall integrate and share distributed resources (data bases) from multiple institutions, each with their own policy and mechanism on the bases of standard, open, and general-purpose protocols and interfaces.

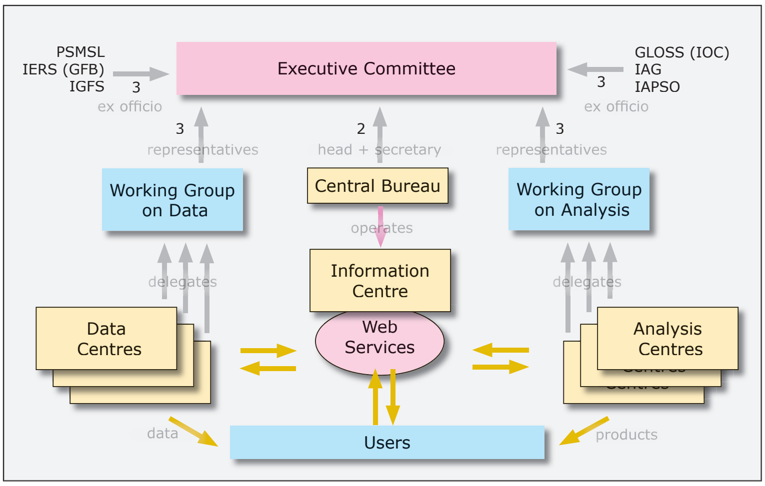
Drafting the Terms of Reference for the envisaged IAS

At present the IAS-PG focuses on drafting the terms of reference for the envisaged IAS. The organisation and structural elements of the other services were carefully studied. Not everything can be transferred. Like most of the other services, IAS can be realized only as voluntary collaboration of existing national and international organisations or legal entities.

A draft organigram is shown in figure 3.6.2. The organisational elements of IAS will at least comprise
- Executive Committee (decisions, policies, control and coordination, representation to external organisations),
- Central Bureau (day-to-day operation, operating the Information Centre, publishing documents, organizing meetings),
- Working Groups on Data and on Analysis. Other working groups (ad-hoc or standing) are created on demand.

Permanent components of the IAS could be
- Data Centres, (data and product generation, archiving and dissemination, compiling and provision of metadata),
- Analysis Centres (analysis of altimeter data and products, calibration and validation activities, model and algorithm development), and an
- Information Centre (user point-of-contact, summary information about data and products).

Fig. 3.6.2: Draft organigram showing the permanent components and organisational elements which could be part of the envisaged International Altimeter Service IAS.



3.7 Contributions to the Global Geodetic Observing System (GGOS)

The Global Geodetic Observing System (GGOS), the “flagship” of the International Association of Geodesy (IAG), underwent its initial definition phase from September 2003 to August 2005. The principal goals of this period were the definition of the final GGOS structure and the development of the GGOS science plan. Besides these goals, GGOS should be introduced to the scientific community and to international political and societal bodies. DGFI participated intensively in these activities, e.g. as the GGOS secretary.

A draft of the GGOS implementation plan including a proposal of the final structure was prepared by a sub-group of the GGOS Project Board and presented to the IAG Executive Committee at the IAG, IAPSO, IABO Conference “Dynamic Planet 2005”, Cairns, Australia, August 2005. It was accepted as the basis for the future development of GGOS. A principal component of GGOS is the activities in the frame of IAG’s membership in the “Group on Earth Observation” (GEO), where GGOS is part of the “Global Earth Observation Systems of Systems” (GEOSS). The Director of DGFI was appointed as IAG’s representative in the GEO Subgroup 2 “Capacity Building”, later GEO Committee “Capacity Building and Outreach”. DGFI members participated in the following activities for GGOS (see table 3.7.1).

Tab. 3.7.1: DGFI acivities for GGOS

Jan. 2004:	EPIGGOS group constitutional meeting and ToR establishment
Feb. 2004:	Submission of GAGOS SSA proposal to EC by GFZ/NMA/DGFI for EPIGGOS
Feb. 2004:	GGOS presentation at IVS 2004 General Meeting in Ottawa (Drewes)
June 2004:	GGOS presentation at ILRS Workshop in San Fernando (Drewes)
July 2004:	GGOS presentation at 35th COSPAR meeting in Paris (Drewes)
July 2004:	1st Submission of the geodetic input to the draft GEOSS 10Yr Implementation Plan and Reference Document
Aug. 2004:	GGOS presentation in Geodesy Dept., University of Bogota (Drewes)
Sep. 2004:	2nd Submission of the geodetic input to the draft GEOSS 10Yr Implementation Plan and Reference Document
Oct. 2004:	GGOS presentation at Congress on Earth Sciences in Santiago, Chile (Drewes)
Nov. 2004:	GGOS Poster for GEO 5 meeting in Ottawa (Bosch)
Mar. 2005:	First GGOS Workshop in Potsdam
Mar. 2005:	GGOS Homepage structure using Typo3 content management system (Bosch)
Apr. 2005:	GGOS presentation at FIG Working Week 2005 / GSDI-8 and at Joint Board of Geospatial Information Societies meeting, Cairo (Drewes)
June 2005:	GGOS presentation at 8th United Nations Regional Cartographic Conference for the Americas, New York (Drewes)
Aug. 2005:	GGOS Poster for IAG, IAPSO, IABO Conference, Cairns (Bosch)
Aug. 2005:	Presentation of the GGOS Science Rationale at IAG Conference, Cairns (Drewes)

Besides the organizational matters, DGFI started to work in the principal GGOS scientific objective, which is the integration of the different geometric and gravimetric observation techniques, models and approaches with the goal to ensure the consistency of geodetic products. The first step is the combination of different geometric methods for a common adjustment of the terrestrial reference frame (station positions and velocities), the Earth orientation parameters (nutation, pole positions, UT1), and the

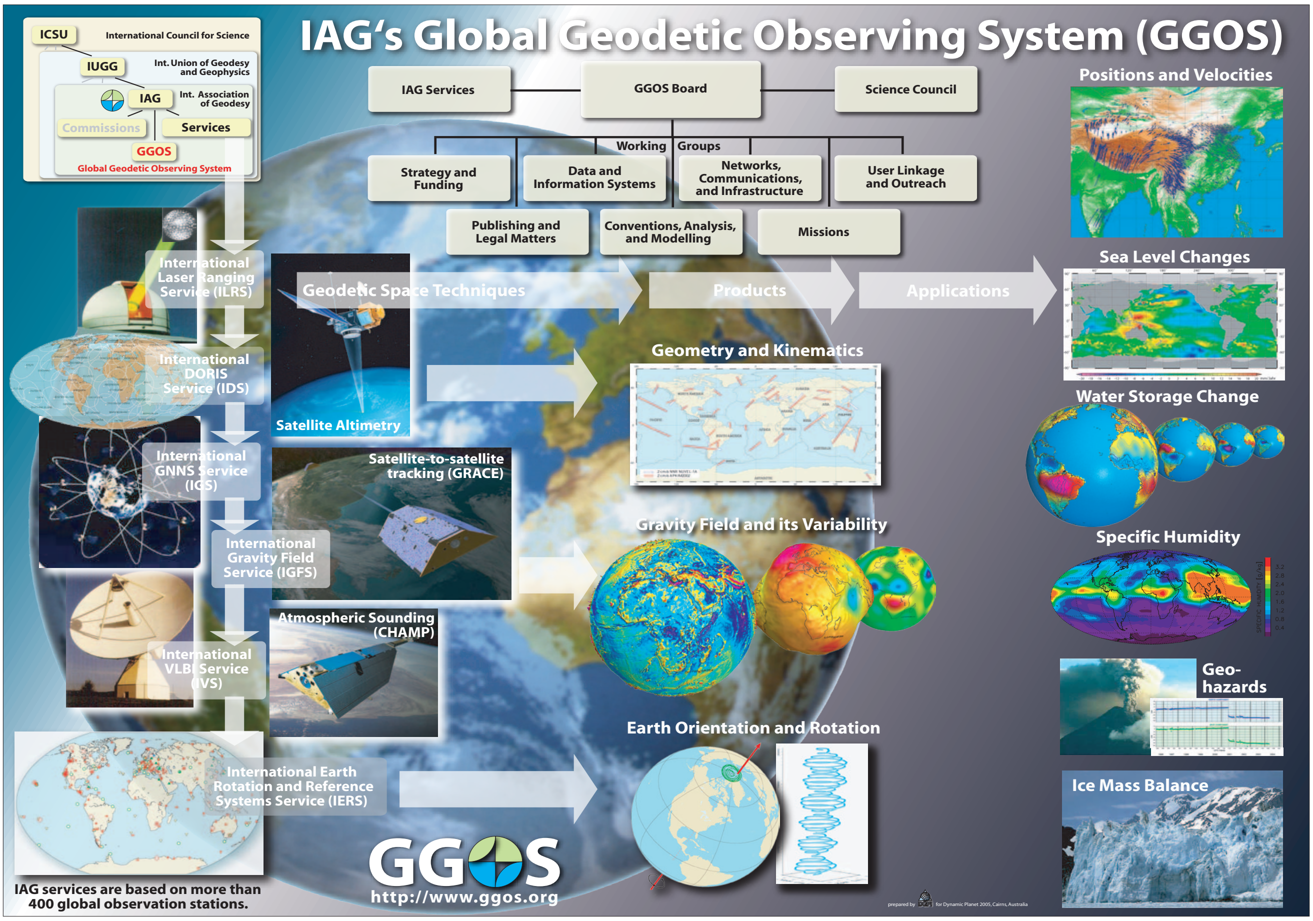


Fig. 3.7.1: Interrelationships between geodetic space techniques, products and applications relevant for the Global Geodetic Observing System (GGOS).

celestial reference frame (quasars positions). In parallel we combine the different gravimetric methods for gravity field determination (geoid, anomalies) in terms of the observations of satellite missions (satellite-to-satellite tracking, kinematic orbits, satellite altimetry). For details on these research topics see sections 1.4, 1.5, 2.1, 2.2, and 2.4.

4 Information Services and Scientific Transfer

Scientific research substantially relies on an intensive information exchange. On the one hand this implies that data and informations are to be accessed from numerous external sources. On the other hand the results of the research performed at DGFI must be made available to the public in general and – more specific – the geo-scientific community. Today, data and information exchange is more and more facilitated by Internet. Therefore, considerable effort is directed to the set up and maintenance of the hard- and software for file transfer server, administration of mailing lists, and the operation of Internet servers. The DGFI maintains a home page (http://www.dgfi.badw.de/) which presents all research activities of the institute in detail. Additional independent Internet sites are maintained for the intensive engagement within Commission 1 of the International Association of Geodesy (IAG), a geodesy information system GeodIS, and the "Deutsche Geodätische Kommission" (DGK).
Besides the Internet, print media are still very important for the documentation of scientific work. DGFI scientists publish in books, monographs, reviewed journals, conference proceedings, technical reports and the publication series of the DGK. The most recent volumes of the DGK publications are provided online as electronic documents. DGFI itself issues scientific reports and the Bulletin of the IAG, Commission 1 (formerly the CSTG Bulletin). Moreover, the work of DGFI scientists is documented by numerous contributions to scientific workshops, symposia, and conferences either in terms of posters or as oral presentations. Finally, information exchange takes place through the participation in workshops, symposia, and conferences, the membership in scientific organisations, and is also promoted by the mutual exchange of scientists, mostly organized in the context of international cooperation.

4.1 Internet representation

Internet is widely used as a medium to exchange data and scientific information. Several independent Internet sites are set up and maintained by DGFI, to inform about

- the institute and its research programme (DGFI home page),
- its involvement in the Commission 1 of the International Association of Geodesy (IAG),
- the "Deutsche Geodätische Kommission (DGK)", and
- a Geodesy Information System GeodIS.

Moreover, Internet is used to maintain

- several file transfer servers for extensive data exchange, required for DGFI acting as data and analysis centres,
- mailing lists for services and international projects,
- collaborative Internet site for specific projects, and an
- Intranet site to support compilation and distribution of internal information (blackboard, calendar, library).

Typo3 Content Managament System

The growing demands for multiple Internet representations were solved by installation and use of the Typo3 Content Management System (CMS). A CMS administrates the pages of an Internet site by a data base system, ensures a common layout by pre-defined templates and provides simple interfaces to the editors - which are in the present case scientists, responsible for the page content. With Typo3, any computer connected to the Internet can be used, to create, modify or delete pages by means of a browser interface – without experiences in Internet specific "mark up" languages like HTML or CSS. Typo3 is an 'Open Source' project and as such available free of charge. It is one of the most actively developed content management systems, applied by many commercial sites. Typo3 provides comfortable functions to handle graphics - a necessary feature for the presentation of scientific results.

DGFI home page

The DGFI home page is maintained to inform about the research programme and the scientific results. The home page is available under the location

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http:/www.dgfi.badw.de
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It represents structure and content of the actual research programme, gives short information about the ongoing research topics and the national and international projects, DGFI is involved in. The multiple contributions of DGFI to international services is represented. The home page also provides a complete list of papers and reports published since 1994 by the employees and a compilation of all posters and presentations. Most recent publications and posters are – as far as possible – available in electronic form (mostly with the portable document format, pdf). Figure 4.2.1 shows the present layout, based on the Typo3 content management system.

Fig. 4.2.1: Screen shot of the DGFI home page

Internet site for IAG, Commission 1

DGFI scientists contribute significantly to scientific organisations, in particular the Commission 1 "Reference Frames" of the IAG which is identical to the COSPAR Subcommission B2, "Coordination of Space Techniques". The leading role, given by presidency, chair of an Intercommission Project, and chair of a Study Groups, requested a self standing internet presentation which is available under

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http://iag.dgfi.badw.de
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The site provides general informations about structure, organisation and general objectives of the Commission 1 and compiles an overview to all sub-commissions, inter-commission projects and study groups with numerous subpages, giving the terms-of-references and the objectives of all entities. The start page of the IAG, Commission 1 home page is shown in figure 4.1.2

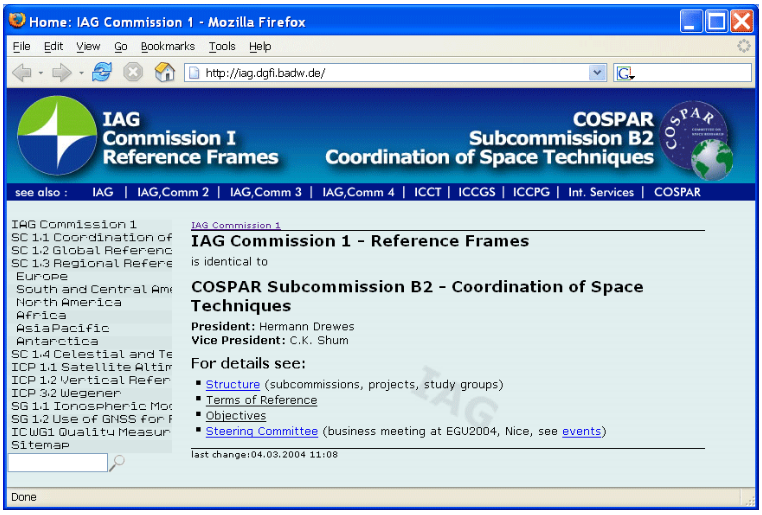

Fig. 4.1.2: The IAG, Commission 1 home page

Geodesy Information System GeodIS

The geodesy information system GeodIS, located at

`http:/www.dgfi.badw.de/~geodis`

is further maintained by DGFI with the objective to compile informations about the most important areas of physical geodesy. The intention of GeodIS is to help people in finding information on and data relevant to geodesy. As an example; GeodIS provides a summary about the relevant scientific organizations and the international services with direct links to the corresponding home pages.

Internet site for Deutsche Geodätische Kommission (DGK)

Another Internet site is maintained for the “Deutsche Geodätische Kommission” (DGK). The site is available at location

`http://dgk.badw.de`

and informs about the structure of the DGK, the membership, working groups, geodetic research institutes in Germany, and – above all – the numerous publications of DGK.

The list of DGK publication is administrated by means of a MySQL data base system. On top of this system there is a comfortable search function for the DGK publications allowing to look for author(s), year or period of years, keywords and substrings within the title of publication (see figure 4.1.3). The search result, showing all publications fulfilling the criteria can be further edited, in order to get exactly the list of those publications that are of interest. The final list can be used to order the publication by submitting an e-mail to the DGK office.

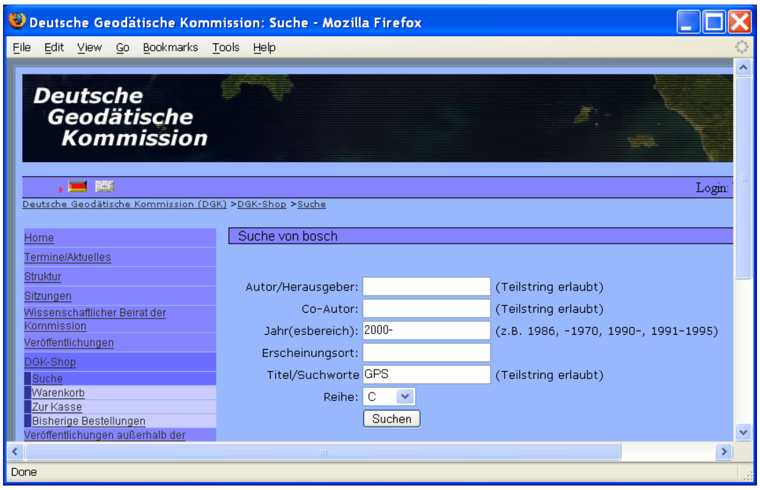

Fig.4.1.3: The input mask to perform a search within the DGK list of publications

Online catalogue of DGK publications

In addition to this search function, the catalogue of all DGK publications is created from the data base entries and dynamically updated as soon as new publications are added. The complete catalogue is also generated in electronic form (as pdf file) and provided for a download free of charge.

Mailing lists

Several mailing lists are maintained by DGFI to fulfil the requirements for information exchange within the ILRS Global Data Centre (see topic 3.4) or to support discussions within the Planning Group of the International Altimeter Service (see topic 3.6). The mailing lists are partly realized by a set of 'bash'-scripts, which are automatically executed according to pre-defined schedules or 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

Finally it should be mentioned that another server behind a firewall is used to provide Intranet functionality – again on the basis of the Typo3 content management system. The internal information exchange is supported by a black board, a meeting calendar, the access to the library data base, 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.

4.2 Publications

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4.3 Posters and oral presentations

ANGERMANN, D.: Geometrische Referenzsysteme. INTERGEO2004, Stuttgart, 13.10.2004.

ANGERMANN, D.: Realisierung des terrestrischen Referenzsystems. FGS Workshop, Höllenstein, 7.10.2004.

ANGERMANN, D.: Analysis of local tie information and biases. IERS Combination Workshop. San Francisco/Napa Valley, USA, 11.12.2004.

ANGERMANN, D.: Analysis and combination of weekly input data. IERS Combination Workshop, San Francisco/Napa Valley, USA, 11.12.2004.

ANGERMANN, D.: Results of CONT02 combination studies. IERS Combination Workshop, San Francisco/Napa Valley, USA, 11.12.2004.

ANGERMANN, D.: First experiences with the official ILRS combination solutions. ILRS AWG Meeting, San Francisco, USA, 13.12.2004.

ANGERMANN, D.: Towards a refined realization of the terrestrial reference system. AGU Fall Meeting 2004, San Francisco, USA, 14.12.2004.

BOSCH, W.: Die Meeresoberfläche - Narbengesicht einer sich wandelnden Erde. Geodätische Woche, Stuttgart, 13.10.2004.

BOSCH, W.: Untersuchungen mit GRACE-only Schwerefeldmodellen. FGS Workshop, Höllenstein, 28.10.2004.

BOSCH, W.: Multimission crossover analysis. OST Science Team Meeting, St. Petersburg, Florida, USA, 04.-06.11.2004 (Poster).

BOSCH, W.: Der globale Wasserkreislauf aus der Sicht der Geodäsie. Bayer. Akademie der Wissenschaften, 17.01.2005.

BOSCH, W.: Wissenschaftliche Dienste der FAGS (IUGG/IAG) - Grundlagen für GGOS. DFG Hearing "Geoportale", Univ. Hannover, 21.02.2005.

BOSCH, W.: Combining CryoSat with classical altimeter systems. CryoSat Workshop, ESRIN, Frascati, Italy, 08.-10.03.2005 (Poster).

BOSCH, W.: Die Meeresoberfläche - Narbengesicht einer sich wandelnden Erde. Wettzell, Bayer. Wald, 17.03.2005.

BOSCH, W.: Impact of reference frame instabilities on satellite altimetry. EGU General Assembly, Vienna, Austria, 29.04.2005.

BOSCH, W.: Lectures on satellite altimetry. Universidade Federal do Paraná (UFPR), Curitiba, Brasil, 16.-17.05.2005.

BOSCH, W.: About new gravity field models. IV Colóquio Brasileiro de Ciências Geodêsicas, Universidade Federal de Paraná (UFPR), Curitiba, Brasil, 18.05.2005.

BOSCH, W.: Satellite altimetry - status and perspectives. IV Colóquio Brasileiro de Ciências Geodêsicas, Universidade Federal de Paraná (UFPR), Curitiba, Brasil, 18.05.2005.

BOSCH, W.: Satellite altimetry: multi-mission cross calibration. IAG, IAPSO, IABO Joint Conference "Dynamic Planet 2005", Cairns, Australia, 24.08.2005.

BOSCH, W.: Discrete crossover analysis. IAG, IAPSO, IABO Joint Conference "Dynamic Planet 2005", Cairns, Australia, 25.08.2005.

BOSCH, W., L. FENOGLIO-MARC, G. WÖPPELMANN, G. LIEBSCH: Coastal sea surface topography from altimetry, gravity, and tide gauge data (COSSTAGT). OST Science Team Meeting, St. Petersburg, Florida, USA, 04.-06.11.2004 (Poster).

DALAZOANA, R., W. BOSCH, R. SAVCENKO: Comparing sea level time series from altimetry and Brazilian tide gauges. FGS Workshop, Höllenstein, 27.-29.10.2004 (Poster).

Drewes, H.: Curso ‘Sistemas de Referencia en Geodesia’. Instituto Geográfico Militar, Santiago, Chile, 18.-21.10.2004.

Drewes, H.: Deformación de la corteza terrestre en América del Sur. Academia Politécnica Militar, Santiago, Chile, 19.10.2004.

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Drewes, H.: Forschungsprogramm 2005/2006 des DGFI. Beirat der DGK, München, 05.11.2004.

Drewes, H.: Die Arbeiten des DGFI in den Jahren 2003/2004. DGK Vollsitzung, München, 18.11.2004.

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Drewes, H.: INTERREG III B Alpine Space Integrated GPS Network - DGFI Part. ALPS GPS-Quakenet Meeting, Grenoble, France, 10.02.2005.

Drewes, H.: GGOS Overview. First GGOS Workshop, Potsdam, 01.03.2005.

Drewes, H.: The Global Geodetic Observing System (GGOS) of the International Association of Geodesy (IAG). FIG Working Week 2005 and GSDI - 8, Cairo, Egypt, 18.04.2005.

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Drewes, H.: ITRF 2004 approach of the ITRS Combination Centre at DGFI. IERS Directing Board Meeting, Vienna, Austria, 28.04.2005.

Drewes, H.: Global Reference Systems. INTERREG III B Alpine Space GPS-Quakenet Workshop, Milano, Italy, 23.05.2005.

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Drewes, H.: The Global Geodetic Observing System (GGOS) of the International Association of Geodesy (IAG). 8th United Nations Regional Cartographic Conference for the Americas, New York, USA, 28.06.2005.

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Drewes, H.: GGOS science rationale. IAG, IAPSO, IABO Joint Conference “Dynamic Planet 2005”, Cairns, Australia, 24.08.2005.

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Hornik H., C. Lüdecke: Wilhelm Filchner and Antarctica. 1st SCAR Workshop on History of Antarctic Research, Munich, 02.-03.06.2005 (Poster).

Kelm, R.: Konzepte und Resultate der offiziellen ILRS Kombinationszentren ASI und DGFI. FGS Workshop, Höllenstein, 28.10.2004.

Krügel, M.: Bedeutung von Kolokationsstationen bei der Realisierung terrestrischer Referenzsysteme. Geodätische Woche, Stuttgart, 14.10.2004.

Krügel, M.: Rigorose Kombination von hochaufgelösten Erdrotations- und Troposphärenparametern aus GPS und VLBI. FGS Workshop, Höllenstein, 28.10.2004.

Krügel, M.: Frontiers in the combination of space geodetic techniques. IAG, IAPSO, IABO Joint Conference “Dynamic Planet 2005”, Cairns, Australia, 25.08.2005.

Krügel, M.: Advances in terrestrial reference frame computations. IAG, IAPSO, IABO Joint Conference “Dynamic Planet 2005”, Cairns, Australia, 22.08.2005.

Krügel, M., D. Angermann: Strategies for the analysis and implementation of local tie information within the inter-technique combination. EGU General Assembly, Vienna, Austria, 24.-29.04.2005 (Poster).

MARCOS, M., G.WÖPPELMANN, M. KARPYTCHEV, W. BOSCH, L. FENOGLIO-MARC, G. LIEBSCH: Sea level variability in the Gulf of Biscay from tide gauges and altimetry. IAG, IAPSO, IABO Joint Conference “Dynamic Planet 2005”, Cairns, Australia, 23.08.2005 (Poster).

MEISEL, B.: Zeitreihenanalysen von Stationspositionen und verfeinerte TRF Berechnung aus ‘wöchentlichen’ Daten. FGS Workshop, Höllenstein, 27.10.2004.

MEISEL, B., D. ANGERMANN, H. DREWES, M. KRÜGEL, H. MÜLLER, V. TESMER: The influence of time variable effects on the terrestrial reference frame. EGU General Assembly, Vienna, Austria, 24.-29.04.2005 (Poster).

POTTS, L., C.K. SHUM, S. GE, D.K. BILITZA, M. SCHMIDT, TH. HOBIGER, H. SCHUH: MURIM (MUlti-Resolution Ionosphere Model): preliminary results. EGU General Assembly, Vienna, Austria, 24.-29.4.2005 (Poster).

SÁNCHEZ, L.: SIRGAS GT III "Vertical Datum": Estado actual y tareas urgentes. SIRGAS Workshop Aguascalientes, Mexico, 10.12.2004.

SÁNCHEZ, L.: Proposed realization of the South American Vertical Reference System. SIRGAS Workshop, Aguascalientes, Mexico, 09.-10.12.2004 (Poster).

SÁNCHEZ, L.: Definition and realization of the SIRGAS vertical reference system within a globally unified height system. IAG, IAPSO, IABO Joint Conference “Dynamic Planet 2005”, Cairns, Australia, 22.08.2005.

SAVCENKO, R.: Zeitreihenanalyse von Altimeterdaten. INTERGEO2004/Geodätische Woche, Stuttgart, 13.10.2004.

SAVCENKO, R.: Kinematik des Meeresspiegels - ein neues Produkt? FGS Workshop, Höllenstein, 28.10.2004.

SCHMIDT, M.: Multi-Resolutionsdarstellung des Gravitationsfeldes aus regionalen Datensätzen. FGS Workshop, Höllenstein, 28.10.2004.

SCHMIDT, M.: Regional gravity modelling based on multi-resolution representation. Institute of Geodesy and Geophysics, University of Technology, Vienna, Austria, 09.11.2004.

SCHMIDT, M.: Hochauflösende regionale Schwerefelder. IAPG Seminar, Techn. Univ. Munich, 14.06.2005.

SCHMIDT, M.: Wavelet modelling in support of IRI. IRI 2005 Workshop, Tortosa, Spain, 30.06.2005.

SCHMIDT, M.: Regional multi-resolution model of the gravity field from satellite and surface data. Regional Modelling Workshop, Potsdam, 11.07.2005.

SCHMIDT, M.: Regional high-resolution spatio-temporal gravity modelling from GRACE data using spherical wavelets. IAG, IAPSO, IABO Joint Conference “Dynamic Planet 2005”, Cairns, Australia, 23.08.2005.

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SCHMIDT, M., V. TESMER, H. SCHUH: Wavelet analysis of the VLBI nutation series with respect to FCN. EGU General Assembly, Vienna, Austria, 24.-29.04.2005 (Poster).

SCHMIDT, M., C. BRUNINI, A. MEZA: Towards a regional modelling of the electron density of the ionosphere using GPS observations. EGU General Assembly, Vienna, Austria, 24.-29.04.2005 (Poster).

SCHMIDT, M., J. KUSCHE, L. SÁNCHEZ, C.K. SHUM, J. VAN LOON, S.-C. HAN: High-resolution regional gravity model from satellite and terrestrial data using spherical wavelet theory. EGU General Assembly, Vienna, Austria, 24.-29.04.2005 (Poster).

SCHMIDT, M., C. ZEILHOFER: Ionospheric electron density determination based on GPS observations and B-spline representation. IAG, IAPSO, IABO Joint Conference “Dynamic Planet 2005”, Cairns, Australia, 25.08.2005 (Poster)

SEEMÜLLER, W.: IGS Regional Network Associate Analysis Centre for SIRGAS (RNAAC SIR). SIRGAS Workshop, Aguascalientes, Mexico, 09.12.2004.

SEEMÜLLER, W.: Station positions and velocities of the IGS Regional Network for SIRGAS. SIRGAS Workshop, Aguascalientes, Mexico, 09.-10.12.2004 (Poster).

SEITZ, F.: Atmosphärische und ozeanische Antriebe der Chandler-Schwingung. Meeting of the working group ‚Dynamisches Erdsystemmodell' of the DFG-Project ‚Rotation der Erde', München, 04.10.2004.

SEITZ, F.: Zur Anregung der Chandler-Schwingung. Geodätische Woche, Stuttgart, 14.10.2004.

SEITZ, F.: Atmosphärische und ozeanische Beiträge zur Anregung der Chandler-Schwingung. FGS Workshop, Höllenstein, 27.10.2004.

SEITZ, F.: Atmosphärische und ozeanische Einflüsse auf die Rotation der Erde - Ergebnisse eines dynamischen Erdsystemmodells. Seminar des Instituts für Meereskunde, Universität Hamburg, Hamburg, 26.11.2004.

SEITZ, F.: Der Einfluss von Massenverlagerungen auf Rotation, Schwerefeld und Oberflächengestalt der Erde. Meeting of the working group 'Dynamisches Erdsystemmodell' of the DFG-Project 'Rotation der Erde', Bonn, 02.05.2005.

SEITZ, F.: Ocean induced gravity field variations from satellite altimetry and ocean modelling. IAG, IAPSO, IABO Joint Conference "Dynamic Planet 2005", Cairns, Australia, 23.08.2005.

SEITZ, F.: Random process excitation of the free polar motion of a dynamic Earth system model. IAG, IAPSO, IABO Joint Conference "Dynamic Planet 2005", Cairns, Australia, 25.08.2005 (Poster).

SEITZ, F.: Dynamisches Modell des Systems Erde. Evaluation of the research and development programme 2006-2010 of the 'Forschungsgruppe Satellitengeodäsie' FGS, Kötzting, 30.09.2005.

SEITZ, F., M. SCHMIDT: Atmospheric and oceanic contributions to Chandler wobble excitation determined by wavelet filtering. EGU General Assembly, Vienna, Austria, 24.-29.04.2005 (Poster).

TESMER, V.: Homogeneously reprocessed GPS and VLBI long time series: first comparisons and future options. 5th IVS Analysis Workshop, Noto, Italy, 21.04.2005.

TESMER, V.: Influence of the solution setup on DGFI estimated CRF solutions. 5th IVS Analysis Workshop, Noto, Italy, 21.04.2005.

TESMER, V.: CONT02: Studying rigorously combined GPS and VLBI data. 17th European VLBI Meeting for Geodesy and Astrometry, Noto, Italy, 22.04.2005.

THALLER, D., M. KRÜGEL, M. ROTHACHER, D. ANGERMANN, R. SCHMID, V. TESMER: Tropospheric parameters and subdaily EOP from combination of independent space geodetic data. AGU Fall Meeting 2004, San Franisco, USA, 13.-17.12.2004 (Poster).

4.4 Membership in scientific bodies

International Council for Science (ICSU)

- International Lithosphere Programme (ILP) (Bureau member: H. Drewes)
- Committee on Space Research (COSPAR): Subcommission B2: International Coordination of Space Techniques for Geodesy and Geodynamics (President: H. Drewes)

International Union of Geodesy and Geophysics (IUGG)

- IUGG Representative to Panamerican Institute for Geography and History, PAIGH (H. Drewes)
- IUGG Representative to United Nations Cartographic Office (H. Drewes)
- IUGG Inter-Association Commission on Geophysical Risk and Sustainability (H. Drewes)

International Association of Geodesy (IAG)

- IAG Commission 1: Reference Frames (President: H. Drewes)
- IAG-Representative to Sistema de Referencia Geocéntrico para las Américas, SIRGAS (H. Drewes)
- Inter-Commission Project 1.1: Satellite Altimetry (Chairman: W. Bosch)
- Inter-Commission Project 1.2: Vertical Reference Frames (L. Sánchez)
- Inter-Commission Committee on Theory (ICCT) Working Group “Inverse Theory and Global Optimization” (M. Schmidt)
- Subcommission 1.3a: IAG Reference Frame for Europe (Secretary: H. Hornik)
- Subcommission 1.3a: IAG Reference Frame for Europe, Technical Working Group (H. Hornik)
- Subcommission 1.3b: SIRGAS, Working Group I “Reference Frame” (W. Seemüller)
- Subcommission 1.3b: SIRGAS, Working Group III “Vertical Datum” (President: L. Sánchez)
- Working Group 1.2.3 and Inter-Commission Committee on Theory (ICCT) Working Group 3: Integrated theory for crustal deformation (B. Meisel)
- Working Group 2 “Interactions and consistency between terrestrial reference frame, Earth rotation and gravity field”, Subcommission 1.1 “Coordination of Space Techniques” (Chairman: D. Angermann)
- Study Group 1.1: Ionosphere Modelling and Analysis (Chair: M. Schmidt)
- Study Group 1.3 and Inter-Commission Committee on Theory (ICCT) Working Group: Quality measures, quality control, and quality improvement (M. Krügel)
- Study Group 2.3: Satellite Altimetry: data quality improvement and coastal applications (W. Bosch)
- Project Integrated Global Geodetic Observing System, IGGOS (Secretary: H. Drewes)
- International Earth Rotation and Reference Systems Service (IERS): IERS Working Group on Combination (D. Angermann)
- International Earth Rotation and Reference Systems Service (IERS): ITRS Combination Centre (Chair: H. Drewes)
- International Earth Rotation and Reference Systems Service (IERS): Working Group Site Survey and Co-location (D. Angermann)
- International Laser Ranging Service (ILRS): Governing Board (H. Drewes, W. Seemüller)
- International Laser Ranging Service (ILRS): Analysis Working Group (D. Angermann, R. Kelm, H. Müller)
- International Laser Ranging Service (ILRS): Data Formats and Procedures Working Group (Chairman: W. Seemüller)
- International VLBI Service for Geodesy and Astrometry (IVS): Analysis Centre (H. Drewes, M. Krügel, V. Tesmer)

Group on Earth Observation (GEO)

- Committee on Capacity Building and Outreach (IAG Delegate: H. Drewes)

Centre National d'Etudes spatiales (CNES) / National Aeronautics and Space Administration (NASA)
- Ocean Surface Topography Science Team for Jason (Joint Altimetry Satellite Oceanography Network) (W. Bosch)

Consortium of European Laser Stations EUROLAS
- Member in the EUROLAS Board of Representatives (W. Seemüller)
- EUROLAS Secretary (W. Seemüller)

Deutsche Geodätische Kommission (DGK)
- "Ständiger Gast" (H. Drewes)
- Working Groups "Rezente Krustenbewegungen", "Theoretische Geodäsie" (several collaborators)

Deutsche Forschungsgemeinschaft (DFG)
- Deutscher Landesausschuß für das Internationale Lithosphärenprogramm (H. Drewes)

Deutscher Verein für Vermessungswesen (DVW), Gesellschaft für Geodäsie, Geoinformation und Landmanagement
- Working Group 7 "Experimentelle, angewandte und theoretische Geodäsie" (H. Drewes)

4.5 Participation in meetings, symposia, conferences

Meeting of the working group 'Dynamisches Erdsystemmodell' of the DFG-Project 'Rotation der Erde', München, 04.-05.10.2004 (Bosch, Drewes, Seitz, Tesmer)

INTERGEO2004/Geodätische Woche, Stuttgart, 12.-15.10.2004 (Angermann, Bosch, Drewes, Krügel, Savcenko, Seitz)

Congreso Ciencias de la Tierra, Santiago, Chile, 18.-21.10.2004 (Drewes)

FGS Workshop, Höllenstein, 27.-29.10.2004 (Angermann, Bosch, Drewes, Kelm, Krügel, Meisel, Savcenko, Schmidt, Seitz, Tesmer)

FGS Directing Board Meeting, Höllenstein, 27.- 29.10.2004 (Bosch, Drewes)

Coordinator Meeting DFG Priority Research Programme 'Massentransporte und Massenverteilung im System Erde', Inst. für Astronomische und Physikalische Geodäsie, Techn. Univ. München, 01.- 02.11.2004 (Bosch)

OST Science Team Meeting, St. Petersburg, Florida/USA, 04.-06.11.2004 (Bosch)

DGK Scientific Council, München, 05.11.2004 (Angermann, Drewes, Hornik)

Research stay at the 'Observatoire de Paris', Paris, France, 07.11.-04.12.2004 (Tesmer)

EUREF Technical Working Group Meeting, 08.-09.11.2004, Prague, Czech. Rep. (Hornik)

DGK Annual Meeting, München, 17.-19.11.2004 (Drewes, Hornik)

SIRGAS Workshop, Aguascalientes, Mexico, 09.-10.12.2004 (Drewes, Sanchez, Seemüller)

IERS Combination Workshop 2004, San Francisco/Napa Valley, USA, 11.12.2004 (Angermann)

ILRS Analysis Working Group Meeting, San Francisco, USA, 13.12.2004 (Angermann)

AGU Fall Meeting 2004, San Francisco, USA, 13.-17.12.2004 (Angermann)

DFG Hearing 'Nutzung von Satellitendaten zum Studium des Ozeans', Inst. f. Meereskunde, ZMK, Hamburg, 16.-17.12.2004 (Bosch)

COSSTAGT Project Meeting, BKG, Frankfurt am Main, 26.-27.01.2005 (Bosch, Savcenko)

Research stay at the Techn.Univ. Delft, 07.02.-11.02.2005 (Schmidt)

INTERREG III B Alpine Space Integrated GPS Network (ALPS GPS-Quakenet) Meeting, Grenoble, France, 10.-11.02.2005 (Drewes)

DFG Hearing "Geoportale", Univ. Hannover, 21.-22.02.2005 (Bosch)

OCCAM Working Meeting, Techn. Univ. Wien, Vienna, Austria, 24.02.-25.02.2005 (Tesmer)

First GGOS Workshop, Potsdam, 01.-02.03.2005 (Drewes)

Research stay at the Universidad Nacional de La Plata, Argentina, 01.03.-30.03.2005 (Schmidt)

Cryosat Workshop, ESRIN, Frascati, Italy 08.-10.03.2005 (Bosch)

FGS Executive Board Meeting, Frankfurt am Main, 11.03.2005 (Bosch, Drewes)

EUREF Technical Working Group Meeting, Brussels, Belgium, 14.-15.03.2005 (Hornik)

DKG Arbeitskreis "Rezente Krustenbewegungen", Darmstadt, 18.03.2005 (Angermann)

FIG Working Week 2005 and GSDI-8, Cairo, Egypt, 16.-21.04.2005 (Drewes, Sánchez)

AFREF Meeting, Cairo, Egypt, 18.04.2005 (Drewes, Sánchez)

5th IVS Analysis Workshop, Noto, Italy, 21.-22.04.2005 (Tesmer)

17th European VLBI Meeting for Geodesy and Astrometry, Noto, Italy, 22.-23.04.2005 (Tesmer)

INTERREG III B Alpine Space GPS-Quakenet Workshop, Milano, Italy, 23.-25.04.2005 (Drewes)

ILRS Analysis Working Group, Vienna, Austria, 25.04.2005 (Kelm, Müller)

EGU General Assembly, Vienna, Austria, 25.-29.04.2005 (Bosch, Kelm, Meisel, Müller, Schmidt, Seemüller)

SCL/ILP Bureau Meeting, Vienna, Austria, 27.04.2005 (Drewes)

IERS Directing Board Meeting, Vienna, Austria, 28.04.2005 (Drewes)

Meeting of the working group ‘Dynamisches Erdsystemmodell’ of the DFG-Project ‘Rotation der Erde’, Bonn, 02.-03.05.2005 (Bosch, Seitz)

DGK Task Force Public Relations, Hannover, 03.05.2005 (Hornik)

IV Colóquio Brasileiro de Ciências Geodêsicas, Universidade Federal de Paraná (UFPR), Curitiba, Brasil, 18.-20.05.2005 (Bosch)

EuroGeographics Expert Group on Geodesy, Vienna, Austria, 30.05.2005 (Hornik)

EUREF Technical Working Group meeting, Vienna, Austria, 01.06.2005 (Hornik)

EUREF, Symposium, Vienna, Austria, 02.-05.06.2005 (Hornik)

IRI 2005 Workshop, Tortosa, Spain, 26.06.-01.07.2005 (Schmidt)

8th United Nations Regional Cartographic Conference for the Americas, New York, USA, 27.-30.06.2005 (Drewes)

DGK Task Force Public Relations, Hannover, 29.06.2005 (Hornik)

Regional Modelling Workshop, Universität Potsdam, 11.-12.07.2005 (Schmidt)

Coordinators Meeting DFG Priority Research Programme ‘Massentransporte und Massenverteilungen im System Erde’, DGFI, München, 15.07.2005 (Bosch, Drewes)

IAS-PG Business Meeting, Cairns, Australia, 22.08.2005 (Bosch)

GGOS Project Board Meeting, Cairns, Australia, 22.08.2005 (Drewes)

IAG, IAPSO, IABO Joint Conference “Dynamic Planet 2005”, Cairns, Australia, 22.-26.08.2005 (Bosch, Drewes, Krügel, Sánchez, Schmidt, Seitz)

IAG Commission 1 Meeting, Cairns, Australia, 23.08.2005 (Bosch, Drewes, Schmidt)

IAG Executive Committee Meeting, Cairns, Australia, 24.08.2005 (Drewes)

OCCAM Working Meeting, Techn. Univ. Wien, Wien, Austria, 31.08-02.09.2005 (Tesmer)

Coordinators Meeting DFG Priority Research Programme ‘Massentransporte und Massenverteilungen im System Erde’, IMG, Frankfurt, 22.09.2005 (Bosch)

Evaluation of the research and development programme 2006-2010 of the ‘Forschungsgruppe Satellitengeodäsie‘ FGS, Kötzting, 29.-30.09.2005 (Angermann, Bosch, Drewes, Krügel, Richter, Sánchez, Seitz, Tesmer)

4.6 Guests

10.05.-09.11.2004:	R. Dalazoana, Universidade Federal do Paraná (UFPR), Curitiba, Brasil.
06.-12.10.2004:	Prof. Ming-Jun Lai, Dept. of Mathematics, University of Georgia, Athens/ Georgia, USA.
02.12.2004:	Prof. M. Becker, Inst. f. Physikalische Geodäsie, Technische Universität Darmstadt.
18.01.2005:	Dr. M. Kuhn, Curtin University of Technology, Perth, Australia.
15.02.2005:	Dr. H. Wilmes, Bundesamt für Kartographie und Geodäsie, Frankfurt am Main.
18.02.2005:	Prof. G. Beutler, Univ. Bern, Swiss.
07.03.2005:	Prof. C. Rizos, Univ. of New South Wales, Sidney, Australia.
07.04.2005:	Dr. B. Richter, Bundesamt für Kartographie und Geodäsie, Frankfurt am Main.
16.06.2005:	Dr. D. Bilitza, GSFC NASA, USA.
11.-13.07.2005:	Dipl.-Ing. M. Vennebusch, Geodätisches Institut, University Bonn.
18.-20.07.05:	Dipl.-Ing. R. Heinkelmann, Institut für Geodäsie und Geophysik, Techn. Univ. Wien, Austria.

Prof MSc Gustavo Acuna, Universidad del Zulia, Maracaibo, worked at DGFI in the frame of his PhD study at the “Technische Universität München”.

5 Personnel

5.1 Number of personnel

Total staff of DGFI during the 2004/2005 period (incl. DGK Office):

Regular budget

12 scientists
10 technical and administrative employees
1 worker
5 student helpers with an average of 276 hours/year
4 students in practical courses
3 minor time employees

Project funds

3 junior scientists

5.2 Lectures at universities

University courses given by DGFI scientists:

Hon.-Prof. Dr. H. Drewes: 'Geodätische Geodynamik', Technische Universität München, WS 2004/2005

Dr. B. Richter: "Geodätische Bezugssysteme", Univ. Stuttgart, WS 2004/2005

5.3 Graduations and honours

Doctoral graduation:

25.10.2004: Dipl.-Ing. Florian Seitz: Atmosphärische und ozeanische Einflüsse auf die Rotation der Erde - Numerische Untersuchungen mit einem dynamischen Erdsystemmodell. Techische Universität München.

Honour:

06.05.2005: Hon.-Prof. Dr. H. Drewes was honoured with the "Cavaleiro do Ordem do Mérito Cartográfico" of the Sociedade Brasileira de Cartografia, Geodésia, Fotogrametria e Sensoriamento Remoto (SBC).