GEOTECHNOLOGIEN Status Seminar

"Observation of the System Earth from Space"

GeoForschungsZentrum Potsdam, July 5, 2004

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Abstracts

1. Oral Talks

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2. **The IERS Information and Database System**

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The goal of the new information system for the International Earth rotation and reference Systems service (IERS) is to maintain the data and information flow between the participating institutions and the users of the IERS. Therefore, all relevant data and products of the IERS are archived and information related to the IERS and its products are presented. The consistency and timeliness of the information are being guaranteed by managing the information in a database. Moreover, meta information of all products are stored in a database to allow the users to search for specific data or topics.
The system is running on an Apache Web Server. The relational database management system MySQL is used to model and store general information as well as meta information of the products. The Web interface to access, browse and search these information is realized in PHP, a widely-used general-purpose scripting language that is especially suited for Web development.
The poster gives examples how the meta information about the IERS products are obtained and stored in the database and how the Web interface can be used to browse the information and to perform specific requests on the data.

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3. **The ITRF for Science and Practice in the Future**

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The International Terrestrial Reference Frame (ITRF) is the basis for all coordinates describing positions and movements of points at the Earth surface and in the near space. It is used in all kind of precise positioning in practice, e.g., navigation, engineering, land management, GIS, and in science, e.g., geodynamics, global change, sea level, geo-risk and disaster research. The principal requirements for applications in practice are reliability, stability and continuance of the reference systems. In science we need high accuracy, global validity and consistency of different parameter groups.
The present realizations of the ITRF meet very well these requirements. There are, however,

some shortcomings. The reliability suffers from too many weakly determined positions and velocities. Abrupt jumps in the origin of consecutive realizations damage the continuity of the reference frame. The generally high accuracy is interrupted by outliers with less precision. The global coverage is not homogeneous, and the geometric reference systems are neither consistent among themselves nor with respect to gravity systems.
The future ITRF has to include only reliable and highly accurate point positions. It has to be modelled consistently with all observation methods. Two levels of realization are proposed: A continuous frame with epoch coordinates and (linear and periodic) velocities, and a time series of frames (e.g., weekly) to count for discontinuities, e.g., caused by earthquakes and anthropogenic or environmental interferences (e.g., ground water changes).

4. Consistency and combination issues in VLBI data analysis

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From a conceptual point of view the generation and also the combination of reference frame and EOP parameters from VLBI observations seem to be straight forward. In practice, however, three different levels of consistency issues exist: a) between TRF, polar motion and UT1, b) between CRF, UT1 and celestial pole offset, and c) throughout TRF, EOP and CRF.
The first level a) is generally no problem in the estimation and combination process via SINEX files and will soon be the standard procedure to convey consistent parameters. Because the determination of a CRF is involved, the other two items are less clear at the moment. So far, the best realization of a CRF, the ICRF with its extensions, was generated in a very special solution setup. An attempt is now being made in simultaneously estimating station positions, Earth orientation parameters (EOP) and quasar positions. The solution is computed using a modified least-squares approach of the VLBI software OCCAM and DOGS-CS under development at DGFI. The procedure provides an unbiased solution by choosing an appropriate datum definition, e.g. by including no-net- rotation (NNR) and no-net-translation (NNT) conditions for station positions and velocities w.r.t. ITRF2000, and NNR conditions for source positions w.r.t. ICRF.

5. Towards a rigorous combination of space geodetic data

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A major goal of the IERS Combination Research Centers is to develop methods and software for a rigorous combination of space geodetic data to improve the consistency and accuracy of the IERS products (e.g. ITRF, ICRF, EOPs). Key issues are the treatment of remaining systematic errors (biases) between techniques, and to fully exploit the complementarity of the contributing space geodetic observations within the combination procedure.
This presentation concentrates on two major DGFI and FESG research activities contributing to these subjects:
(1) The time series analysis of station positions and datum parameters derived from

"weekly" VLBI, SLR, GPS and DORIS solutions to identify, understand and remove systematic biases between techniques. We focus on the comparison of the results at co-location sites and on handling non-linear site motion, seasonal variations, seismic effects, etc.;

(2) The CONT02 activities aim at a rigorous combination of VLBI data of eight telescopes for a 15-day period in October 2002 and global GPS (SLR) data of the same time span, taking much care to use identical models and the same parameterization. All common parameters (e.g. station coordinates, EOPs, tropospheric zenith delays and gradients) are studied within this rigorous combination and the results obtained are presented.

6. Integration of Space Geodetic Techniques and Establishment of a User Center in the Framework of the International Earth Rotation and Reference Systems Service (IERS)

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In the last years it became very clear that highly accurate and consistent products of the International Earth rotation and Reference systems Service (IERS) are of vital importance for all types of geomonitoring and Earth's system research (GMES, GEO, …). In particular the new satellite missions (CHAMP, GRACE, GOCE, JASON-1 etc.) require a very accurate global reference frame as a crucial basis to accomplish their scientific goals, be it for precise orbit determination, gravity field estimation, monitoring of sea level change or other geodynamic and geophysical purposes. Also the Galileo system (orbit and clock determination) and the Galileo users will profit from a stable high-accuracy reference frame as a part of the basic infrastructure for all navigation and positioning applications and geo-referencing.
The accuracy achieved today by the individual space geodetic observing techniques – Very Long Baseline Interferometry (VLBI), Global Positioning System (GPS), Satellite and Lunar Laser Ranging (SLR, LLR), and the French Doppler system DORIS – is mainly limited by systematic errors of the individual techniques. Therefore, the thorough integration and combination of the techniques into a consistent Global Geodetic Observing System (GGOS, established in 2003 as the primary future project of the International Association of Geodesy) is mandatory to achieve major improvements in the quality of the IERS products.
With the cooperative effort of the five institutions participating in this project and the financial support of the BMBF Geotechnologien-Programm significant progress was made to reach this goal and Germany now plays a very prominent role in the IERS and GGOS in general and in the integration of the space geodetic techniques in particular.
This contribution will summaries the present status and future steps of the IERS on its way towards GGOS and a rigorously combined set of products and the progress and results we obtained and contributed in the framework of the IERS Geotechnologien-Programm.
Within another 3 years (assuming a continuation of the project), together with an international cooperative effort, a fully operational generation of a new, highly accurate and consistent and combined palette of IERS products (ITRF/EOP/ICRF) together with a powerful IERS database and information system can be realized and handed over to national state institutions (like e.g. BKG or IGN) suitable for routine production. A multitude of

applications crucial for the understanding the changing planet Earth will benefit from these developments.

7. **GOCE-GRAND and its Role in the ESA GOCE Ground Segment**

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Apart from the actual mission operations the, ESA GOCE ground segment is in charge for the instrument calibration and validation and for the processing chain from the raw data (level 0), via calibrated instrument data (level 1b) to final precise orbits and gravity field products (level 2). Each step of this processing chain is covered by a separate project under ESA contract. The tools and methods developed within GOCE-GRAND provided the basis for the selection of several GOCE-GRAND partners into these official ESA projects.
The paper explains the GOCE-GRAND contributions to the various ground segment elements. In particular the activities of the GOCE-GRAND partners within ESA's High Level Processing Facility (HPF), which is generating the final orbit and gravity field products, are addressed. IAPG leads a consortium of 10 European institutes with complementary expertise (including 3 GOCE-GRAND partners), which is developing and in a later stage also operating the HPF under contract of ESA. The expertise collected during the GOCE-GRAND project was a key for being selected for this ground segment element.

8. **GOCE gravity field modelling: A challenge to calculus**

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The optimal assimilation of all the measurements of the GOCE satellite to obtain the best gravity field model is a great challenge for the scientific community. Due to the large amount of data, the special characteristics, and the high resolution of the estimated model, most of the traditional numeric strategies fail or run out of time, memory, and numerical stability. Therefore, many procedures must be re-designed, or well-tailored for this special application. In addition new developments are necessary to overcome the numerical problems. Only the utilization of special data characteristics, such as regularity, allows us to tackle this huge and demanding task. Nevertheless, fast multi-processor systems are still necessary to execute the computations in a reasonable time. Finally sophisticated statistical procedures and hypothesis tests are indispensable to guarantee the quality and reliability of the estimated models.

9. **GOCE-GRAND: Validation Strategies, Temporal Reductions and Use of GRACE**

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The satellite mission GOCE (Gravity Field and Steady-state Ocean Circulation Explorer) is being prepared for launch in 2006 to determine the Earth gravity field from differential accelerometry aboard one satellite.
GOCE is a challenging project, from the instrumental as well as from the conceptual point of view. Therefore, several calibration steps (in orbit and in post-processing) are required to achieve the anticipated accuracy of the gravitational gradients at the Milli-Eötvös (mE) level. The observed gradients have to be reduced by temporal gravity variations, using geophysical models and/or GRACE results, not to contaminate the static gravity field solution. Independent validation procedures are needed to assure the accuracy standard of the resulting gravity field quantities (e.g. gravity gradients, gravity anomalies, geoid heights and geopotential spherical harmonic coefficients). Those validation concepts may be based on terrestrial gravity data, comparisons of the GOCE measurements in cross-overs or other strategies like the use of GPS/levelling or altimetric data.
To achieve a maximum accuracy at the long wavelength part of the gravitational spectrum, the complementary GRACE and GOCE data should directly be combined.
In this paper, several aspects of the validation strategy, of the reduction of the temporal parts as well as of the GRACE/GOCE combination are addressed.

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10. The Role of Satellite Gravity and Altimetry Missions for the Detection of Mass Distributions and Mass Transports in the Earth System

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The gravity field of the Earth reflects the mass distribution of the Earth, despite the fact that a detailed density function cannot be determined uniquely because of basic principles of potential theory. The same holds for temporal changes of the gravity field in form of, e.g., monthly snapshots, as a consequence of mass transports. Nevertheless, it is possible together with additional information, as e.g., the precise measurements of surface deformations of the Earth, to detect the causes and effects of spatial and temporal mass variations. A unique constellation of simultaneously operating satellite gravity and altimetry missions, equipped with very precise and novel sensors, allow to investigate the causes of the observed global and regional sea level changes and their relations to variations in the heat and mass content of the oceans, to changes in the polar ice sheets, variations in the continental hydrosphere and to mass transports in the solid Earth.

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11. SAGS4: The New StrapDown Airborne Gravimetry System Prototype

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The Paper presents the construction of the SAGS4 – StrapDown Airborne Gravimetry System – Prototype #4. The concept has been outlined elsewhere, e.g. in the last years' presentation.
The BEK group at the Bavarian Academy of Sciences and Humanities in München is engaged in both prerequisites for airborne gravimetry: Precise satellite positioning for kinematic acceleration determination and observation techniques for the total (in this case: vector-) acceleration aboard an aircraft, i.e. a gravimeter, which is the topic of this

Fluggravimetrie'.
The strapdown concept of SAGS4 has specific advantages over conventional platform instruments, but also presents specific challenges.
SAGS4 employs four QFlex QA3000/30 accelerometers and three fiberoptical gyros and aims at an optimal environment particularly for the accelerometers.
The vibrations on board a light propeller aircraft with a peak power at about 40 Hz is mechanically filtered to pass the ~10..0 Hz signal, also to reduce accelerometer load for higher performance, maintaining aviation security requirements.
Shielding the sensors signals from electromagnetic interference in the aircraft to preserve 10^{-6} made use of a combination of different materials including μ-metal.
For temperature control with 10 W heat loss from the sensors we realized a solution with e.g. helium, special polymers and Peltier elements with a PID controller for heat drain.
Signal processing employs advanced techniques for analogue filters, ADC, and digital filters. Data logging and storage is cared for by an embedded PC104.
SAGS4 is essentially ready for operation, first test flights were successful. The vertical accelerometer pair has already demonstrated its importance for accuracy improvement and error modelling. A comprehensive modelling is underway.

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12. Optimisation of Processing Techniques for Airborne Vector Gravimetry

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Information about the earth gravity field is used for many applications in geophysics and geodesy dealing with figure and structure of our planet. Caused by the thresholds in possible spatial resolution the use of gravity data measured by satellite based systems are restricted to global and regional investigations. An efficient method to get more detailed information is the airborne gravimetry principle. In order to improve the performance of this method in accuracy, resolution and cost effectiveness other sensor configurations and processing algorithms must be investigated.
Two flight tests periods were carried out with a sensor system consisting of numerous GNSS receivers and a commercial high precision strapdown INS to derive the vectorial gravity information out of kinematic accelerations and specific forces.
After a short overview about the system design and the errors models of GNSS and INS measurements the main topic of the presentation is the description, testing and results of used processing procedures. Concerning the kinematic accelerations e. g. the required GNSS receiver network configuration on the ground and the advantages of a multi-antenna design on the aircraft are discussed. Regarding to the inertial measurements the results of sensor calibration and alignment are mentioned. The error stability during the flight periods is evaluated. In a conclusion statements about the performance level of the tested system design can be pointed out.

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13. High precision kinematic GNSS observations up to 50 S/s for airborne gravimetry

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Within the framework of a strapdown airborne gravimetry project of the BEK[1)] the kinematic acceleration of the gravimeter / aircraft has to be derived from GNSS observations. For a higher spatial resolution of gravity vector it is helpful to increase the GNSS observation rate, because that results in an improved resolution of the aircraft dynamics.
Javad Navigation Systems high precision GNSS board, able to provide raw data 100 times per second, is configured for 50 S/s. *NovAtel*'s newest GPS card, the *OEM4-G2*, usual enables a raw data output rate at 20 S/s for both frequencies, which can increased up to 50 S/s with an experimental software.
Because dynamic performance at sampling rates up to 50 S/s is of particular interest, the trajectories resulting from observations of both receivers has been compared to adequate coordinates determined from independent measurements. For ground truth tracking a lift, made available by the *GeoForschungsZentrum Potsdam (GFZ)*, has been employed. An internal vertical scale permits a resolution of 50 S/s and 0.02 mm. Using this lift it was tried to apply various accelerations in order to simulate the dynamics of a light aircraft. The magnitude of the effective receiver noise, the operation of the receiver control circuits under dynamical conditions and the influence of an external oscillator are studied in those experiments.

1) BEK is part of the Bavarian Academy of Sciences and Humanities. It is one of five partners within the ‘Verbundprojekt Fluggravimetrie’, funded by the ‘BMBF-GeoTechnologien-Programm’

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14. The Geosensor Project – Measuring True Rotations in Seismology

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Ring laser measure rotation absolute. When such a gyroscope is made sensitive enough, one can use it to measure rotations associated even with remote earthquakes. Up to now the efforts of some groups to measure rotational movements from teleseismic events have not been successful, because of insufficient sensitivity of the applied measurement devices. During the course of this BMBF- project, we have built a highly sensitive sensor which also measures rotations from distant earthquakes in one plane. The central component is a highly sensitive Helium-Neon- ring laser. Along with other auxiliary sensors like tiltmeter, seismometer, thermometer and a tight reference to the UTC- timescale it forms a complex measurement device, which allows the quantitative analysis of the measurements. This talk outlines the GEOSENSOR design and discusses its properties.

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15. Consistent Observations of Rotational Motions Induced by Distant Large Earthquakes

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We present broadband observations from several large earthquakes of rotational motions recorded by a ring laser in the frequency range up to 1 Hz and compare them to the observations of a collocated broadband seismic instrument. In theory, assuming a plane wave with transverse polarization propagating in horizontal direction, the transverse acceleration – recorded by the seismometer – should be in phase with the vertical component of the ground rotation rate as recorded by our ring laser. The conversion factor between rotation rate and acceleration is 1/2c, c being the phase velocity. For several large earthquakes (e.g. the M8.3 Hokkaido event, 25 September 2003) we compare the acceleration converted to rotation rate with the rotation rate observed by the ring laser gyro. For all examined earthquakes we find remarkable agreement between the two time series suggesting that the ring laser gyro is capable of measuring broadband rotational motions from earthquakes. As expected the conversion factors vary strongly for the different wave types and arrivals (shear-waves, surface waves). We attempt to model these observations with synthetic seismograms.

16. CHAMP Mission and Data Use

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Since the launch four years ago the geoscientific satellite CHAMP has been delivering regularly and in accordance with the original mission's baseline observations of the Earth gravity and magnetic field, and of the neutral atmosphere and ionosphere. The highly operational ground segment consisting of the Mission Operation System, the Science Data System, and the Information System and Data Centre secures the proper performance of the satellite and payload systems, the data flow from the telemetry and dedicated ground station networks to the processing centres, the product generation and the product dissemination. Novel high-level products are derived from the CHAMP on-board data: new generation global gravity and magnetic field models, and models of the evolution of the atmospheric and ionospheric state in space and time. A huge international community of almost 400 external user groups is registered at GFZ's CHAMP data centre for accessing low- and high-level CHAMP data products, triggering new scientific developments and applications in geodesy, geophysics and oceanography as well as in meteorology, space weather and climatology. According to actual orbit decay predictions CHAMP will extend its designed five years operations life-time by about 2.5 years. The recovery of the geopotential fields will largely benefit from the decreasing orbit altitude over the coming years.

17. Main and Crustal field models from CHAMP magnetic field measurements

S. Maus, M. Rother, S. Choi and H. Lühr

GeoForschungsZentrum Potsdam

The accurate total field and vector measurements of the CHAMP satellite mission provide unprecedented opportunities for unraveling the temporal and spatial variations of the geomagnetic field. Here, we report on the latest improvements in our main and crustal field models. The Potsdam Magnetic Model of the Earth (POMME) was updated with a parametrization of the time varying magnetospheric field using the new Est and Ist indices (http://www.ngdc.noaa.gov/seg/geomag/est_ist.shtml), which separate the Dst index into external and internal induced contributions. We also report on advances in the treatment of attitude bias and discuss the reliability and resolution of the estimated secular variation and acceleration. Our latest crustal field model MF3 is corrected for ocean tidal signals and polar electrojet fields. It extends to spherical harmonic degree 90 and provides a stable representation of the crustal field down to about 50 km above the Earth's surface.

18. Search for Earthquake signatures in the ionosphere by ground and space based GPS measurements

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The ionospheric response to earthquakes has been reported in the literature since many years. Since energetic coupling from the lithosphere via the atmosphere to the thermosphere/ionosphere is realized by acoustic waves, ionospheric radio occultation (IRO) measurements onboard CHAMP were analyzed to search for a correlation. As it will be shown, the IRO measurements detect numerous wavelike or irregular phenomena in the ionosphere. Although wave like phenomena were observed in the spatial and temporal vicinity of earthquakes, no evidence could be found that they were really associated to earthquakes. The results of case and statistical studies are discussed.

In a parallel study, using the dense GPS network in North America, relative TEC data derived from differential phases were analyzed to detect signatures in correlation to selected earthquakes of magnitude > 6. Earthquake related structures were found after the Denali earthquake on 3/11/2002 and during the California earthquake on 22/12/ 2003. It is assumed that these significant structures are associated to acoustic waves excited in the atmosphere by seismic waves. Detection techniques and wave propagation features will be discussed.

19. Development of the German GRACE Science Data System

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GeoForschungsZentrum Potsdam, Dept. 1: Geodesy and Remote Sensing

The GRACE Science Data System (SDS) was developed in a joint effort between the Jet Propulsion Laboratories (JPL), the University of Texas Center for Space Research (UTCSR) and the GeoForschungsZentrum Potsdam. The presentation will focus on the development status of the German part of the SDS. The main tasks are the acquisition of ancillary and GRACE level-0 raw data, the development of a data archiving and dissemination facility (GRACE-ISDC), the routine generation of an atmosphere and ocean de-aliasing product and the upgrade of the GFZ Earth Parameter and Orbit System (EPOS) software for the fast and numerically stable production of monthly and static gravity fields.

20. **CHAMP-DACH/GRACE:**
Global Mean Gravity Fields from CHAMP and GRACE, and the Combination with High Resolution Surface Data

Ch. Reigber [1], P. Schwintzer [1], R. Schmidt [1], F. Flechtner [1], U. Meyer [1], R. König [1], K.-H. Neumayer [1], Ch. Förste [1], F. Barthelmes [1], R. Stubenvoll [1], S.Y. Zhu [1], H. Meixner [2], J.C. Raimondo [2]

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With the CHAMP satellite mission, launched in July 2000, for the first time a dedicated configuration for gravity field recovery from space has been realized: a low and near-polar orbit, an on-board accelerometer, and a continuous precise tracking by the high-flying GPS satellite constellation. These characteristics led to a break-through in the determination of the long wavelength gravitational field from one satellite only and already from a limited amount of mission data. The twin GRACE satellites, based on CHAMP heritage, were launched in March 2002, following each other on the same orbit in a distance of about 200 km. Thanks to ultra-precise K-band ranging between the two satellites, another striking step foreward in improving the quality and resolution of global high- to medium-wavelength gravity field models could be made. The CHAMP and GRACE satellite-only models are of great importance for oceanographic applications, the precise recovery of sea surface topography from altimetry. The combination of the CHAMP and GRACE fields, being limited in spatial resolution due to signal attenuation with altitude, with surface data from altimetry over the oceans and gravimetry over the continents results in a high-resolution global gravity field model. In terms of geoid heights, the accuracy of such a model is if compared to the pre-CHAMP era in the long- to medium-wavelength part of the gravitational spectrum improved from the meter- to mm-level, allowing a more thorough interpretation of the gravity field for geodynamic processes in the Earth's mantle/lithosphere system.

21. **Time-Variable Gravity from GRACE and Hydrology**

R. Schmidt, F. Flechtner, A. Güntner, R. König, Ul. Meyer, K.-H. Neumayer, S. Petrovic, Ch. Reigber, P. Schwintzer, S.-Y. Zhu

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The primary mission goal of the Gravity Recovery And Climate Experiment (GRACE) mission is to map fluctuations in the Earth's gravity field to unprecedented accuracy over a spatial range from 400 km to 40,000 km with monthly resolution during its nominal 5-year lifetime. GRACE will thus be able to constrain mass transports related to geophysical and climatological processes causing the observed gravity changes. This contribution focusses on mass redistribution induced by changes in global continental water storage as one major source for gravity variations, causing geoid variations at the 1-cm level at seasonal time scales. Based on current monthly GRACE gravity fields generated at GFZ Potsdam, the obtained results indicate a sensitivity to hydrological-related mass redistribution in large river basins down to structures of 800 km half-wavelength. For verification of the GRACE temporal gravity recovery results data from different global hydrology models are used for comparisons in the spectral and the space domain.

2. Posters

1. **The Combination Research Center (CRC) at GeoForschungsZentrum Potsdam (GFZ)**

Sheng-Yuan Zhu, Chuang Shi

GeoForschungsZentrum Potsdam

During the last three years the GFZ CRC has concentrated on improving both reference frame and gravity field models. To this end, integrated solutions based on ground and LEO satellite data, mainly from CHAMP and GRACE, were used. This approach has increased the accuracy and reliability of the reference frame and gravity field model solution at the same time. Efforts were focussed on the following three topics:

1. Combination of the various satellite techniques SLR, GPS, DORIS, and PRARE at observation level. Thereby the consistency of solutions can be improved and discrepancies between different techniques can be reduced.
2. Combination of ground GPS data with on-board LEO data. Thus reference frame and gravity solution considerably gain quality.
3. Collocation of on-board LEO data such as SLR and GPS data for CHAMP and GRACE. Using this approach, the reference frame can be improved and center-of-mass corrections as well as antenna phase center errors can be checked.

These topics are discussed and a few numerical examples are given for illustration.

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2. **The IERS Combination Pilot Project**

Markus Rothacher, Robert Dill, Daniela Thaller

Today the various products of the IERS, especially the International Terrestrial Reference Frame (ITRF), the International Celestial Reference Frame (ICRF) and the Earth Orientation Parameter (EOP) series, are still combined independently and in most cases without using the full variance-covariance information. In this way the consistency of the products cannot be guaranteed.

In view of the challenges that the IERS is facing with the new satellite missions (gravity, altimetry, astrometry), with the International Global Geodetic Observing System (IGGOS) project of the International Association of Geodesy (IAG), and with many other applications, we have to strive for reaching a fully rigorous combination of all the parameters common to more than one space geodetic technique.

The IERS Combination Pilot Project (CPP), started on February 29, 2004, should be a major step towards more consistent, routinely generated IERS products based on "weekly" SINEX solutions made available by the various Technique Services, containing site coordinates, EOPs, and, possibly, quasar coordinates. The major goal of the CPP will be to develop optimum strategies for a rigorous combination (including weighting schemes, datum definition, use of local ties, treatment of systematic biases, ...).

The new products resulting from these combination procedures are expected to replace a considerable part of the present IERS products in the future.

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3. **Combination and analysis of subdaily ERPs from GPS and VLBI**

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The latest harmonic analysis of subdaily earth rotation parameter series from GPS and VLBI show a very good agreement with studies of the subdaily tidal excitation in polar motion and variation of length of day. Nevertheless there are still some inconsistencies between the results from GPS and VLBI only. Besides a combination of different space geodetic techniques in the time series analysis procedure we tried a combination of the original subdaily time series in advance of this analysis. We developed a new combined subdaily time series from GPS and VLBI data. This combined time series removes problems with large data gaps and unevenly spaced data and enhances the signal-to-noise ratio. Our combination scheme handles problems arising from the adjustment of different, time variable offsets and different error levels. In addition, we can combine UT1-UTC from VLBI with the first time derivative of UT1-UTC provided by GPS. On the basis of J. Vondraks combined smoothing (J.Vondrak, A.Cepek, 2000: Combined smoothing method and its use in combining Earth orientation parameters measured by space techniques. Astron. Astrophys. Suppl. Ser. 147, 347-357) we designed a three step combination. In a first step we remove low frequency variations from each single time series and adjust a kind of running mean level of both series. In a second step both time series are combined in a weighted least squares estimation with a very week smoothing in order to keep as high frequencies as possible. In the last step we resubstitute a mean low frequency part. Results of this combination attempt will be presented.

4. FESG and DGFI results of the CONT02 campaign

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In October 2002 the International VLBI Service for Geodesy and Astrometry (IVS) organized a two-week campaign, named "CONT02", with eight telescopes observing continuously. Daily unconstrained normal equations were generated from these VLBI data and from the observations of a global GPS network of the same time span, taking much care to use identical models and the same parameterization. Due to a large number of common parameters (station coordinates, Earth orientation parameters (EOP) and tropospheric zenith delays and gradients), it can be expected that both techniques benefit from a combination. This paper reports on studies in view of a rigorous combination of all common parameters. In this context the investigation of the impact of the local tie information on the combination results plays a key role. For some of the eight co-located stations also data from water vapor radiometers (WVRs) are available. These data enable an independent comparison of the wet part of the tropospheric zenith delay estimates. Models of sub-daily polar motion and UT1 variations derived from satellite altimetry represent an additional independent source of information for validation.

5. TRF realization at DGFI

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In its function as ITRS Combination Center, DGFI concentrates on the combination of processed space geodetic data to derive ITRS products. Based on the latest space geodetic solutions provided by individual analysis and technique centers, DGFI has computed a combined multi-year solution for station positions and velocites. The poster presents the input data and the TRF combination strategy at DGFI. The results of the combined TRF solution are discussed and compared with ITRF2000. Finally, we address remaining deficiencies and problems regarding current TRF computations. A major error source are systematic biases between techniques and solutions, which need to be identified and removed. Furthermore non-linear site motions (e.g. seismic effects, seasonal variations) are in conflict with constant station velocities. We performed a first TRF computation based on weekly normal equations. This new approach has clear advantages compared to past TRF computations and most promising results were obtained.

6. Time series analysis of station coordinates and datum parameters

B. Meisel, D. Angermann, M. Krügel, H. Müller, V. Tesmer

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As the accuracy of geodetic space techniques increases, time variable effects of a few millimeter such as seasonal signals or other non-linear behaviour become detectable. To achieve a Terrestrial Reference Frame (TRF) with the same accuracy these effects must be investigated in order to handle them properly in the combination.
In this presentation we use weekly solutions of station positions for the space techniques GPS, SLR, VLBI and DORIS. The data are either computed at DGFI or were obtained from the technique services or individual Analysis Centers. To achieve a consistent datum, the individual solutions are transformed by a seven parameter helmert transformation to ITRF 2000. We analyse the resulting time series of transformation parameters (translation and scale) and station positions w.r.t. jumps, periodic signals and other non-linear motion to detect systematic biases between different techniques. A main focus is on seasonal variations which are compared between the techniques and their spacial behaviour is investigated. Finally the necessity to estimate annual signals in the TRF computation is discussed and the results are compared with geophysical modelling.

7. Statistical analyses for the combination of different geodetic space techniques

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For the combination of different geodetic space technique solutions statistical analyses before, during and after the combination processing are of great importance. Two statistical issues are discussed here: The influence of geodetic datum contribution of each technique on the combined product and the estimation of variance factors for the covariance or normal equation matrices of the individual solutions. The investigations are based on weekly solutions for GPS, SLR, DORIS, and VLBI. To analyse the datum effects, the covariance matrix of a loose constraints solution is seperated into a matrix for the reference frame contribution and a matrix for the inner accuracy of the network. The standard deviations and

For estimating variance factors the rigorous variance component estimation (VCE) is applied within the combination modelling. By definition, VCE is an iterative process. Within this process the influences of datum and local tie on the estimation are investigated.

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8. **Consistent VLBI solution DGFI02R04: Simultaneous estimation of a TRF, CRF and the EOP**

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The VLBI solution DGFI02R04 consists of simultaneously estimated station positions, Earth orientation parameters (EOP) and quasar positions. It is computed using the modified least-squares approach of the VLBI software OCCAM (version 6.0) and DOGS-CS. The procedure provides an unbiased solution by choosing an appropriate datum definition, e.g., by including the no net rotation (NNR) and no net translation (NNT) conditions for 25 station positions and velocities w.r.t. ITRF2000, and NNR conditions for 195 source positions w.r.t. ICRF-Ext1. The poster presents the analysis strategy and results using more than 2500 VLBI sessions between 1984 and 2004. Discrepancies between the solution and the a priori values from ITRF2000, ICRF-Ext1, EOP C04 for terrestrial pole coordinates and DUT and the IAU2000 model for the celestial pole offsets are discussed as well as related parameters such as position time series for stations and sources.

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9. **Considering a priori correlations in the combined EOP series from VLBI**

C. Steinforth, A. Nothnagel, J. Campbell, D. Fischer, M. Vennebusch

Geodätisches Institut der Universität Bonn

Earth orientation parameters (EOP) derived by VLBI observations and computed by individual IVS Analysis Centers are being combined routinely on the basis of EOP time series. The current combination strategy actually implies a violation of the basic rule that the same data cannot be used twice in an adjustment process. This fact is presently neglected by treating the input data of the IVS Analysis Centers as "new" data. However, this deficiency can be mitigated by introducing proper correlation coefficients between the analysis centers. Different approaches for deriving such correlations as well as results are presented in this poster. In addition, the current status of the combined series is outlined.

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10. **Geodetic VLBI - The Only Connection between the Celestial and Terrestrial Reference Frames**

Fischer, D., Vennebusch, M., Campbell, J., Nothnagel, A., Steinforth, C.

Geodätisches Institut der Universität Bonn

Very Long Baseline Interferometry is the only geodetic technique which provides a direct geometrical link between the quasi-inertial reference frame of radio sources and the terrestrial reference frame through consistent Earth orientation parameters. The poster describes the basic principles of VLBI and its results which are of fundamental origin and do not rely on

other techniques. UT1 and nutation, in particular, are unique results of the VLBI technique used by many other space geodetic techniques.

11. The IERS Information and Database System

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The IERS Information System comprises publications, data and information related to Earth rotation, reference frames and geophysical fluids, including general information about the products of the IERS.
Presently, all products (e.g. ITRF, ICRF, EOPs, etc.) are provided to the users differently by the individual product centres. The IERS Central Bureau links to them at the central Web site www.iers.org.
The new IERS Database System, operated by the Central Bureau, provides the central access point to search within the data, to work with the data and to download the data. Therefore, all products are converted into a general format using the eXtensible Markup Language (XML) that can be regarded as the future standard format for data and information exchange over the Web. From the transformed data files extended meta information are extracted and stored in the database for search. Using XML the heterogeneous products of the IERS in their various formats can be easily described. Aside the original standard file output, the data and information can be presented multiformly.
This contribution describes the concept and realization of the Database System as well as the reorganized Information System.

12. GOCE-GRAND: The National “Geotechnology” Project in Support of ESA’s First Earth Explorer Mission GOCE

Rummel, R., Th. Gruber and J. Flury

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In autumn 2006 the GOCE (Gravity field and steady state Ocean Circulation Explorer) mission will be launched. It will be the first core mission of ESA’s newly defined “Living Planet Programme”. Its objective is the determination of a global model with maximum spatial resolution of the quasi-stationary gravity anomaly field and geoid.
As national support for the GOCE mission the GOCE-GRAND project was initiated in 2002. It is funded by the German Ministry for Research and Education within the “Geotechnology Theme 2“ - “Observation of the System Earth from Space”. The project focuses on the development of data analysis techniques for determination of the Earth gravity field from the gradiometer observations. The goal is to set up a complete processing chain from the corrected instrumental data sets to the final gravity field solutions. The project is divided into 6 supplementary work packages, which are worked out by five different institutions. Synergies between the work packages and institutions are optimally used in order to reach the common goal. Major parts of the project are transferred to ESA’s level 2 processing system (High Level Processing Facility – HPF), where three of the GOCE-GRAND partners are involved.
The paper provides an overview of the project, the work packages and its synergies as well as

the involvement of GOCE-GRAND in the HPF. Subsequent posters provide more details on the individual work packages.

13. **Mass Transport and Mass Distribution in the Earth System – Contributions of the New Generation of Satellite Gravity and Altimetry Missions to Geosciences**

J. Flury[1], K.H. Ilk[2], R. Rummel[1]

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A unique constellation of simultaneously operating satellite gravity and altimetry missions, equipped with very precise and novel sensors, permit the study of mass anomalies, mass transports and mass exchange. Mass anomalies are deviations of the actual mass distribution from one described by a model, e.g. a model of hydrostatic equilibrium. The anomalies are associated to a variety of dynamic processes and they reflect - in case of the solid Earth - processes on geological time scales. Mass transport, such as ocean water transport or the hydrological water cycle can either be inferred from the measurement of gravity changes or significantly constrained from precise ocean topography. Most exchange between the system components can be monitored by a strict mass balance of land, ice and oceans from gravity and geometry changes. The joint use of geometry and gravity allows, in addition, the separation of physical causes, such as thermal expansion and mass surplus in the oceans.

14. **GOCE-GRAND: Semi-Analytic Gravity Field Analysis from Kinematic Orbits, Energy Integral and Gravity Gradients**

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GOCE gravity field determination is based on the combination of the long-wavelength part derived from satellite-to-satellite tracking (SST) between the GPS system and GOCE, and the short-wavelength part computed from satellite gravity gradiometry (SGG). From the high-low GPS to GOCE SST data precise kinematic orbits are derived. This is a purely geometric way of orbit determination where use of any a priori gravity model is avoided. The method has been successfully applied to CHAMP GPS data and yields an orbit precision of a few centimetres in three dimensions.
The kinematic orbits are then employed for the determination of the long-wavelength part of the gravity model. Our approach is the use of the energy integral. It allows the direct derivation of the anomalous gravity potential from orbit velocities. The latter are derived from the kinematic orbits by numerical differentiation. The proper formulation of the stochastic model is currently under investigation. Also non-gravitational forces, as given by the common mode accelerations of the gradiometer need to be taken into account, as well as the direct and indirect gravitational effects of sun, moon and planets.
From the anomalous potential at satellite altitude and from the tensor components measured by the gravity gradiometer a gravity model is deduced using a Semi-Analytical Approach (SA). It is gravity field analysis in the frequency domain taking advantage of certain symmetries in the linear system of equations. This method reduces significantly the computational burden with only little loss in terms of precision. It is in particular suited for

processing.

15. **GOCE and Supercomputing**

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Parallel computers have evolved from experimental contraptions in laboratories to become the everyday tools of computational scientists who need the ultimate in computer recources in order to solve their problems. In the same way geodesists reach the limits of present computer capabilities. As a result of the ongoing satellite missions (CHAMP/GRACE/GOCE) huge amounts of data become available. As a consequence serial computing has to be replaced by parallel computing. This poster demonstrates the techniques the modern geodesist uses to take the challenges of global gravity recovery. It is shown how a cluster of parallel personal computers is used to compute high resolution gravity models in parallel. The Message Passing Interface is used to bundle the power of 18 Processors to a high speed supercomputer.

16. **The Use of regional Focussing Techniques for the Determination of the Gravity Field of the Earth**

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Institute of Astronomical and Physical Geodesy, Technical University of Munich

GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) is a dedicated gravity field mission envisaged for the years 2006 to 2007, which has the potential of deriving the static part of the gravity field with unprecedented accuracy in the high resolution spectral part. Especially for this mission regional focussing techniques will gain in importance, particularly in the rough parts of the gravity field. Therefore, a solution strategy tailored to the specific gravity field features is useful. The method presented here is based on a combination of a global spherical harmonics representation and additional regional refinements, represented by space localizing base functions of spline type. Simulation results are presented to demonstrate this approach.

17. **An approach for the GOCE scenario analysis in terms of Earth Gravity Field recovery**

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An approach for the analysis of the GOCE observation scenario is presented. First, CHAMP-like satellite-to-satellite tracking in the high-low mode on acceleration level is performed, namely by second-order numerical differentiation of the kinematic GOCE orbit. Gradiometric information is handled according to both gravity gradients and rotational invariants of the gravitational tensor. Collocation of the two data sets in regard to the inversion of the combined normal equation system is established as well as an efficient implementation on a

parallel processing platform, namely a 16 processor shared memory supercomputer. Further, regularization of the least squares problem is carried out. A brute-force calculation providing the whole variance-covariance information of the solution is presented as well as an iterative approach based on the LSQR method. For the last one preconditioning is realized. State of the art results are pointed out in a simulated closed-loop observation scenario. This work is part of the GOCE-GRAND project supported by the Geotechnologien II program (BMBF grant No. 03F0329B).

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18. **GOCE-GRAND: Gradiometer Data Reduction, Combination and Processing**

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The goal of the GOCE mission is a high-resolution static gravity field. Hence, it is necessary to eliminate both the high-frequency and the seasonal temporal gravity effects in the GOCE observations. The most important sources of these variations are redistributions of masses in the atmosphere, oceans, cryosphere and in the continental water storage. The prediction of time varying gravity based on existing models for the above mentioned mass redistributions has been critically investigated. It follows that, contrary to ocean and atmosphere, the existing global hydrological models are the main source of the uncertainties and presently inadequate for the reduction of GOCE observations. The proposal is to use the series of GRACE monthly gravity field solutions in order to deduce the characteristics of sub-seasonal, seasonal and interannual hydrological variations and the remaining effects which are not contained in the atmospheric and oceanic models and to combine GOCE with a GRACE derived static field to stabilize the long-wavelength part of the gravity model solution. Aliasing, in particular due to ocean tides, is another important problem to be solved.
The mass changes as deduced from the geophysical models are developed into spherical harmonics, from which gravitational gradients are computed along a simulated GOCE orbit. The resulting gradients are compared with the specifications of the GOCE gradiometer performance.
GOCE gravity field recovery simulations are performed and analysed using one month of simulated gradiometer data that are processed by the EPOS software extensions presently being under development.

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19. **GOCE-GRAND: Validation Approaches for Level-1b and Level-2 Data**

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The accuracy planned for GOCE data products requires special independent concepts for validation at each product level. While the raw data calibration and validation is performed within ESA's ground segment, published Level-1b and Level-2 products should be validated independently. The validation of Level-1b products, namely orbit (SST) and gradiometer

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(SGG) data, have to be investigated in different ways, considering that some experiences with SST data already exist from the active low earth orbiter (LEO) satellite missions, whereas the treatment of SGG data has to be developed from scratch. The validation of the Level-2 products (mainly the high precision static gravity field model) might be achieved by techniques already proven from validation approaches for recent geopotential models (GPM). Nevertheless, those methods have to be tested with respect to the requirements of the high accuracy and high resolution class aimed for with GOCE.
This poster presents both, new approaches to obtain validation values especially for the gradiometric measurements, as well as a close look to the established techniques of GPM validation, whether they are suitable for the new requirements or not.
For the computation of validation gradients from terrestrial gravity data, two upward continuation methods (least squares collocation and integral formulas based on the spectral combination technique) are considered and their results are compared. Additional quality information can be drawn from the comparison of SGG measurements at geographical identical positions.
The complete GOCE GPM can further be validated by comparisons with global altimetric data bases or, regionally, with GPS levelling data.

22.

Augmentation of a Two-Gimbal Gravimeter Platform to a Hybrid Inertial Navigation System

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The submission explains the evolution of the airborne gravimeter at the Institute of Flight Guidance and Control of the Technical University of Braunschweig (IFF). The sensor concept is based on a gravimeter from the Russian manufacturer Elektropribor consisting of a high precision two-gimbal inertial platform and the gravimeter sensor Chekan-A. The instruments were purchased and modified for airborne application in cooperation with the Russian manufacturer. The two-gimbal platform has been augmented with an additional ring laser gyro (drift: 0.003 deg/h) in order to gain the heading information by a strapdown calculation and to extend the system to an autarkic inertial navigation system (INS). The system is an extreme precise three axis inertial platform with superposed strapdown and gimbal measurements. The incorporated sensors reside at the upper bound of precision of today's state of the art techniques. The system also encloses a GPS-receiver (performing carrier-phase measurements) and a statoskop (differential barometric height determination). At the IFF the system has been tested both in ground and air vehicles.
In recent years the scientific and economic aim for airborne gravimetry arose to achieve an accuracy in the measurement of vertical acceleration of 10-5 ms-2 with a spatial resolution of 1 km (full wavelength). The paper will present the contributions the IFF can make to achieve this aim.
The IFF participates in the joint research project "Entwicklung der Fluggravimetrie unter Nutzung von GNSS-Satellitenbeobachtungen" ("Development of airborne gravimetry including GNSS satellite observations").

23.

Airborne Gravimetry: Activities and Achievements 2002-2004

Boedecker, G.; Abdelmoula, F.; Cremer, M.; Kreye, Ch.; Loehnert, E.; Stelkens, T.

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The German R&D activities on airborne gravimetry funded by the 'BMBF-Geotechnologien-Programm' are coordinated within the 'Verbundprojekt Fluggravimetrie' of three partners pursuing different hardware approaches for airborne gravimeters and two partners for the transfer to (commercial) application.
The partners are:

- Bavarian Academy of Sciences, München > BEK
- Technical University Braunschweig > IFF
- Aerodata Systems, Braunschweig > Aerodata
- IfEN-GmbH für Satellitennavigation, Neubiberg > IfEN-GmbH
- University FAF München, Neubiberg > EN

One major common activity are test flights on a Do128-6 of IFF which are carried out in the Braunschweig-Magdeburg area, because in this region there are big gravity anomalies over salt domes; also, this area is favourable for GPS-ground reference stations and for logistics. Several test flights within two test campaigns were flown with Gigabytes of high frequency positioning, acceleration and atmospheric etc. etc. data.
The poster provides some overview and examples of the activities and achievements.

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24. **Global gravity field modelling using GRACE observables**

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This presentation summarizes methods and sample results of global gravity field modelling from GRACE data at the Stuttgart University. The so-called space gravity spectroscopy based on balancing relative inter-satellite acceleration with geopotential gradient differences is used for derivation of global geopotential models. They are represented by either a finite set of the Stokes coefficients or surface integral means of geopotential corresponding to geographical cells on the surface of a reference sphere. A newly developed numerical algorithm allows for estimation of approximately 20,000 unknowns with a full variance-covariance matrix on an ordinary personal computer. This corresponds to degree/order 140 of the spherical harmonic expansion. The model is further completed for short-periodic effects (high-frequency temporal de-aliasing) such as solid Earth tides, ocean tides and atmospheric mass variations. Sensitivity of the model to observation noise (commission errors) as well as truncation of the spherical harmonic expansion (omission errors) is also discussed.

20.
