

A long-term cooperation in education and research in the field of geodesy between KIT and UFPR

Claudia Pereira Kruger¹ and Jorge Antônio Silva Centeno²

1 Laboratory of Space Geodesy and Hydrography, Federal University of Paraná,
E-Mail: ckrueger@ufpr.br

2 Department of Geomatics, Federal University of Paraná,
E-Mail: centeno@ufpr.br

Abstract

This article presents the results obtained within the international academic cooperation between Federal University of Paraná, in Brazil, and the University of Karlsruhe, in Germany. The focus was on the development of the two projects: GEOMACK-I (UNIBRAL Program), and SIRGAS Densification in Brazil with High Precision GPS Positioning, error modelling and integration of the vertical component (PROBRAL Program). Also presented is the main research developed within this cooperation.

1 The International Cooperation with UFPR

From 1981 to 1983, an international agreement allowed the cooperation between Brazil and Germany and the strengthening of the Graduate Program in Geodetic Sciences (PPGCG) of the Federal University of Paraná (UFPR) with the support of the German Agency for Technical Cooperation (GTZ) (Bähr 2005). This initiative helped to consolidate the Brazilian Graduate Program and opened the establishment of long-term technical and scientific cooperation between UFPR and German faculties.

Although the contact lost intensity during the 1990s, it was intensified since 2001, expanding academic mobility to a new partner, the University of Karlsruhe (now KIT, Karlsruhe Institute of Technology). Within a GEOMACK-1 project, one of the first projects of the so called UNIBRAL initiative of CAPES/DAAD was established. This project had the financial support of CAPES (Brazilian academic exchange service, Coordenação de Aperfeiçoamento de Pessoal de Nível

Superior) and DAAD (German academic exchange service, Deutscher Akademischer Austausch Dienst) (*UNIBRAL (CAPES/DAAD)* nodate) and was coordinated by Prof. Dr. Hans-Peter Bähr and Prof. Dr. Claudia Krueger.

The GEOMACK-1 project included brief teaching missions of professors from Karlsruhe in Curitiba. Prof. Dr. Bernhard Heck of the Geodetic Institute of KIT was one of the German professors that showed great enthusiasm in the initiative and visited Curitiba within the project. During 2004 and 2005, he developed academic activities with active participation in the UFPR Graduate Program. After the UNIBRAL project ended, he provided the basis for a new joint project within the PROBRAL program (CAPES/DAAD) entitled „SIRGAS Densification in Brazil with High Precision GPS Positioning: error modelling and integration of the vertical component“. In the following, a summary of the results achieved in these projects coordinated by Prof. Dr. Bernhard Heck is presented.



2 GEOMACK-1 (UNIBRAL Program)

GEOMACK-I (GEOMatics in Curitiba and Karlsruhe) was part of the first group of projects approved by CAPES within the UNIBRAL program (*UNIBRAL (CAPES/DAAD)* nodate). Its aim was to strengthen the academic exchange at the undergraduate level and to establish bridges for academic mobility. Therefore, activities were proposed to increase the exchange of undergraduate students, academic staff and researchers, approach the curricular structures, aiming at a future mutual recognition of credits and the implementation of scientific research in close cooperation of the institutions including training practice for students.

The focus was on the undergraduate courses of Cartography and Surveying (UFPR/BRAZIL) and Geodesy and Geoinformatics (KIT/Germany). The project lasted for four years (2002-2005), and was carried out in two phases (each lasting for two years).

The goals for the first phase were:

- Exchange of academic staff to assess the compatibility of subjects between the two institutions and to obtain the necessary information for the recognition of these subjects by the collegiate body of the course;
- establish appropriate rules and student selection criteria, as well as, determine the potential number of participants;
- gain experience through the academic exchange; and
- identify new research lines and topics of interest to propose collaborative research projects.

Based on the analysis of the curricula of the institutions, three groups of subjects have been identified in order to align their curricula and establish the mutual acceptance. These were:

- subjects that can be recognized immediately (for instance: Remote Sensing, Digital Image Processing, Photogrammetry I and II, Measurements and Methods in Geodesy, Supervised Practice and Final Project);
- subjects that can be recognized after including minor modifications; and
- subjects that can be recognized but should be carefully analyzed.

The exchange program also allowed students to participate in subjects that were not offered in Brazil, thus expanding their knowledge. It also established the possibility of including new elective subjects within the undergraduate Cartography and Surveying Program with similar content as the German program; a fact that contributed positively to the modernization of the curriculum.

The GEOMACK-1 project had great success. It woke up the interest of the students to visit a foreign university as well as to learn a foreign language. Figure 2.1 shows student mobility development between the years 2001 and 2005. There was a shift of one year between the start of the projects in Germany and Brazil. The intense participation of the Brazilian students is clearly visible in the graphic, while it is also noticeable that the interest of the German students grew constantly over the years. It should be noted, however, that Brazil began its student mobility in 2002, having a total of five students in its student exchange program in this year. The collegiate body of the undergraduate course in Cartography and Surveying gave the expected support, for example, by approving the fast acceptance of the subjects studied in Germany.

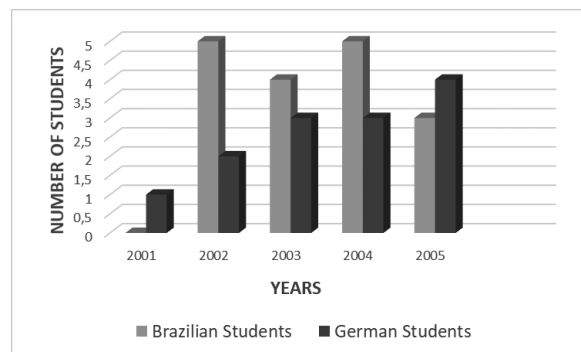


Figure 2.1: Exchange students in GEOMACK-1

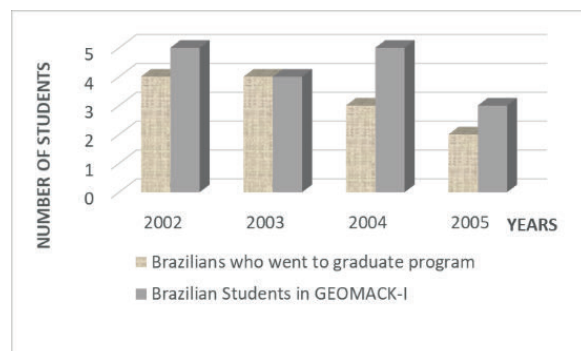


Figure 2.2: Students' behavior with respect to graduate program and GEOMACK-1

A consequence of the exchange project was that the experience gained abroad opened up new horizons for the involved students, awakening interest for research at higher levels. In this regard, Figure 2.2 shows the number of students that participated in the GEOMACK-1 project and later followed some graduate program, including doctor studies in Germany and Brazil.

The project, which has lasted four years, got a positive evaluation and it was well accepted by the students and teachers community, covering the academic interests of both institutions. It is important to note that there was a brisk demand from students of both educational institutions, despite having a small number of students in each course. The improvement in the academic performance of the Brazilian students was evident, since the search for international experience is growing since then.

Besides the students' exchange, lecturers of both institutions held seminars resp. courses at the partner university and were closely cooperating with their colleagues (e.g., collaborative research). A representative example is given by the research in atmospheric refraction and error sources in the precise GPS positioning which was carried out in close cooperation between the chair of Prof. Heck and members of the Geodynamics Laboratory at the University of Karlsruhe.

Within the fruitful partnership a significant number of SCI-journal publications were published. In addition, contributions to various national and international conferences were made. An very important output in scientific terms is given by the large number of undergraduate theses (e.g., Pitz 2003; Franco de Lacerda 2004; Pitz 2004).

As the outcome of the first project was positive in all aspects and the treated topics were of common scientific interest, a follow up project was the natural consequence. In this context, the GEOMACK-1 project established the basis for the proposal of a successor project within the PROBRAL program.

3 PROBRAL Program

In 2004, the Postgraduate Program in Geodetic Sciences (PPGCG) of the Department of Geomatics (DGE-OM) of the Federal University of Paraná (UFPR) and the Geodetic Institute of the University of Karlsruhe (GIK/UniKa) started working on a joint

project called „SIRGAS Densification in Brazil with High Precision GPS Positioning: error modelling and integration of the vertical component“, which was successfully submitted in 2005 to the PROBRAL joint program, funded by the academic exchange services CAPES and DAAD. The coordinators of this project were Prof. Dr. Claudia Krueger and Prof. Dr. Bernhard Heck. An important aspect of PROBRAL projects is to transfer technology between the two cooperating institutes.

The specific goals of this cooperation were related to research and higher education. At the beginning of the PROBRAL project the following aims were set:

- To qualify human resources at the graduate course in Geodetic Sciences and especially in Geodesy;
- to improve the knowledge of teachers in the field of Geodetic Sciences;
- to strengthen the exchange of scientific information;
- to contribute to the definition of SIRGAS vertical datum and its materialization in Brazil;
- to investigate errors in high-precision GNSS positioning;
- to understand and model errors in high-precision positioning using artificial intelligence;
- to increase the scientific production of the post-graduate program in Curitiba;
- to increase the scientific production by scientific and technical papers;
- to establish joint research in priority areas of Geodetic Sciences; and
- to improve the intercultural competences of all participants.

The joint research project was divided into three sub-projects related to:

- I Investigation of important error sources in precise GNSS positioning aiming for a better modeling of these errors.
- II Analysis and improvement of the Brazilian vertical network and integration with SIRGAS project.
- III Application in three-dimensional monitoring of the Earth's surface.

The Brazilian participants carried out several studies and field missions within the four-years project (2006-2009). Within this period, five study missions were carried out. This involved the participation of students of the Brazilian graduate program (Jaime Freiberger Jr.

in 2006; Roberto T. Luz in 2006; Mauricio I. Sejas in 2007; Rodrigo M. Gonçalves in 2008 and Vagner G. Ferreira in 2008) and the German graduate program with three doctorate students (Franziska Wild-Pfeiffer in 2006; Andreas Knöpfler in 2006, 2008 and 2009; and Xiaoguang Luo in 2007, 2008 and 2009). During their stay at the UFPR, the German students were able to obtain cultural experience and gain language skills, as well as expand their teaching abilities.

The project proved to be very successful, including joint mentoring of doctor research projects as well as increased number of joint publications in scientific journals, books and proceedings and oral resp. poster presentations at symposiums. The successful submission of two graduate works, three masters theses and five PhD. theses document the success (Krueger and Heck 2012). The intense productivity was based, on one hand, on the good personal relationship between the project partners in Brazil and Germany, and, on the other hand, on the balanced contributions of the partners.

In sub-project I, the first results were achieved with the research on the calibration of GPS antennas together with the analysis of the effect of the multipath propagation. One of the main aims in this sub-project was to establish a relative receiver antenna calibration field for GNSS instrumentation on the roof of the „Astronomical Laboratory Camil Gemael“ called BCAL/UFPR (<http://www.lageh.ufpr.br/>), located in the Polytechnic Campus of the UFPR in Curitiba (Brazil). Within this project, three stable and long-lasting pillars (1000, 2000, and 3000) were built, based on experiences obtained at the GIK related to the establishment and the monumentation of the geodetic network sites. For further details see

The studies carried out by the group of Geodetic Reference and Satellite Altimetry Laboratory (LARAS) in the sub-project „Integration of the Brazilian vertical network to SIRGAS“ allowed to define procedures to integrate the data from geometric leveling, gravity, tide gauge stations and satellite altimetry.

The sub-project III started with the analysis of spatio-temporal data and the construction of a CGIS (Coastal GIS) based on data composed of historical maps using remote sensing and satellite geodesy to extract the coastline.

With the development of this research project, the following points were also achieved:

- Contribution to the resolution of problems related to the precise GNSS positioning and environmental monitoring in Brazil;
- establishment of the first calibration site for GNSS antennas in Brazil and South America; and
- the contribution to the bi-nationally supervised doctoral and post-doctoral formation that allows an international experience in centers of excellence and consolidated the exchange (personal correspondence) with German institutions.

4 Selected research developed in Geodesy

4.1 Monitoring the Isthmus of „Ilha do Mel“ (Honey Island)

The „Ilha do Mel“ island is located at the entrance of the Paranaguá bay. It is an environmental preservation area and is protected by law. It has intense touristic activities that provide financial income for its inhabitants. The island covers an area of 27 km² and the length of the coastline is close to 36.5 km. It consists of two parts linked by a thin isthmus: The largest at the northwest and the smallest at the southeast. Studies have been carried out regarding the separation of the two parts, which would cause significant changes in the delta of the Paranaguá river and the routes of the ships that sail to the Paranaguá port, and would also affect the tourism in the island. The first scientific study on the deformation of the island and its consequences was made in 1954, when the scientists supposed that one day the „Ilha do Mel“ island would be divided into two parts. The erosion process at the area of the isthmus of the „Ilha do Mel“ has been reported constantly by the local press due to the destruction effects on the surrounding buildings as well as problems with the electrical power supply.

In the 1990s, the first double frequency GPS measurements based on kinematic relative positioning were made to detect the coastline and volumetric changes in this area. The comparison between measurements of the years 1997 and 2003 (figure 4.1) showed changes of the coastline in the southeast and in the northwest part of the isthmus (Pitz 2003). The coastline

in the northwest and in the southeast of the Isthmus is affected by retro gradation and moving towards the South American continent. The results obtained in different volumetric analyzes show that there is no constant pro- or retro gradation effect working in the Isthmus area.

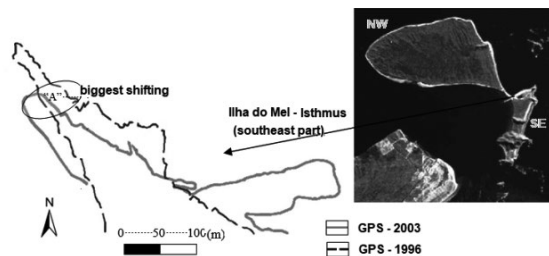


Figure 4.1: The Variation of the coastline in the southeast part of the Isthmus and the comparison between the coastline SE, 1996/2003 (Krueger et al., 2009) .

The erosion at the „Ilha do Mel“ Island is caused by natural processes as well as by human influence. Monitoring the evolution of the region could be improved by creating a geodetic and cartographic base that would provide systematic and up-to-date information on the current state. It would support a permanent study and a better understanding of the current environmental risks and challenge. It would also provide hints to control both: future human activities and natural factors caused by environmental and climate changes.

The studies developed by the PROBRAL team found a significant change in the width and volume of the isthmus. Figure 4.2 shows the planialtimetric map produced by the data that were collected in 2013 in the isthmus. Altimetric differences around 2.7 meters (-0.1 m to 2.6 m) were noticed. These results indicated a progradation but deeper analysis showed that these variations occurred due to human interventions in the study area, for example, dredged material was deposited on the isthmus. New measurements are planned to be done in this area. The data will be processed and results will be available soon.

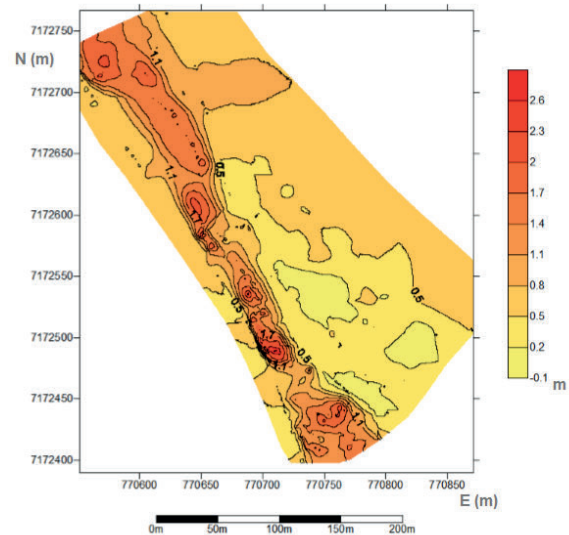


Figure 4.2: The Isthmus planialtimetry in 2013 (UTM coordinates, WGS-84), (Buchmann and Kummer, 2013) .

4.2 Baseline Calibration for GNSS antennas in Brazil

Within the PROBRAL project, a relative, pillar-based GPS/GNSS antenna calibration infrastructure was established in Curitiba. The pillars were built following the specifications of IBGE (Brazilian Institute of Geography and Statistics), responsible for surveying and mapping in Brazil. This calibration field assures important studies which will continue to contribute to solving problems related to GNSS (Global Navigation Satellite Systems) precise positioning in Brazil, especially focusing on the height component. The calibration of GNSS antennas by the proposed method (relative calibration) has advantages in terms of performance and precision considering the basic investments for the installation of equipment, measurements, and maintenance. The operational efforts are reduced since measurements are performed automatically. By this efficient method the phase center offsets (PCO) as well as elevation- and azimuth-dependent antenna phase center variations (PCV) can be determined with high resolution and considerable reduction of multipath effects. The first experiments showed that by relative calibrations of antennas with respect to an individually absolute calibrated antenna, the same level of precision can be achieved as in absolute calibration. The relative antenna calibration field was the first established in Latin America. The experiments carried out in Brazil showed the influence of multipath acting

with similar intensity on the calibration pillars 1000 (West) and 2000 (North) (Schaefer 2007; Freiburger Junior 2007). The results obtained in Germany proved that the influence of the multipath effect is extremely important and should be considered in high precision GNSS measurements. Different experiments were carried out by applying the relative calibration method to determine and compare different calibration parameters for the TRM 22020.00+GP antenna. This antenna was calibrated in three sessions of 24 hours, with a data-sampling rate of 15 seconds. The WaSoft/Kalib software was used to process the GNSS phase observations. PCO- and PCV-values were determined relatively with respect to a 3D choke ring antenna type, which was calibrated absolutely by Geo++ (Garbsen, Germany). In this context, five antennas of the same model (Trimble Zephyr GNSS Geodetic II) were calibrated at BCAL/UFPR. The goal of the case study was to verify the difference between individual parameters determined at BCAL/UFPR and mean parameters published by the NGS (National Geodetic Service, USA). The results generated were promising. The obtained results indicate that the calibration parameters vary with time for a given antenna. Thus, taking calibration values into account is recommended when high precision surveys are to be performed. It was also noticed that the values of the vertical component of PCO suffer greater variations during rainy periods and high relative humidity. In general it was found out that antennas of different models show increased values in the vertical component of the PCO when there is a reduction in the average moisture associated with an increase in the mean temperature. Other results can be found in Huinca (2014) and Huinca et al. (2015).

Future investigations will focus on a more detailed analysis of low-elevation antenna parameters in combination with site-specific effects. In addition, the effects of individual calibration parameters with respect to estimated coordinates will be evaluated.

4.3 Integration of the Brazilian vertical network to SIRGAS

In order to integrate the Brazilian vertical network into SIRGAS, a software, written in Fortran and Octave, was designed. This was necessary in order to take into account the peculiarities of the Brazilian context,

emphasizing the importance of semi-automatic assembly of the vertical network in geopotential numbers. This was done using the program IDNOS. Gravity and leveling data from IBGE were analyzed with respect to problems related to forming up geopotential differences; for this purpose, a subset of recently observed RAAP (Brazilian Fundamental Vertical Network) lines was identified, in which for all benchmarks gravity information was available. Simulating different scenarios concerning the lack of gravity observations, the results indicated an overoptimistic estimation of the quality of the gravity interpolation. A rigorous adjustment of the leveling network showed excessive distortions in the height values, as well as problems arising from heterogeneities in the region of Imbituba (Brazil). A subnetwork of RAAP connecting three tide gauge stations (Imbituba, Macaé, Salvador) was selected as a reference for the study of the sea surface topography at the Brazilian coast. These tide gauge stations have been interconnected by suitable satellite altimetry tracks that are virtually collinear to these stations. The first attempts in height transfer via satellite altimetry proved to be promising, although major inconsistencies at crossover points were detected.

In the doctoral thesis of Ferreira (2011) a novel procedure of GNSS leveling was founded and tested, based on the fixed GBVP. This procedure uses GNSS ellipsoidal heights in combination with gravity disturbances for the determination of geopotential numbers. For a topographical Earth surface the fixed geodetic boundary value problem (GBVP) cannot be solved analytically; therefore a series expansion of Molodensky-Brovar type has been derived. The theory has been applied to two case studies, one in the Federal State of Baden-Württemberg, Germany, and the other in Paraná State, Brazil. The results showed that the achievable precision strongly depends on the resolution of the gravity data coverage; lack of gravity data in Brazil has been identified as the major error source.

4.4 Application in three-dimensional monitoring of Earth's surface

The goal of this study carried out in the framework of the doctoral thesis of Gonçalves (2010) was to compare and assess the three shoreline prediction models: robust parameter estimation, neural network, and lin-

ear regression. A section of the Brazilian coast in the vicinity of Matinhos Beach in the State of Paraná has been selected for a case study using material from analogue photogrammetry (years 1954, 1963, 1980, 1991, and 1997) and recent GPS data (year 2001, 2002, 2005, and 2008) for control. For the case study the best results concerning prediction of the shoreline kinematics have been obtained using the robust estimation model.

5 Final remarks

The long term cooperation between UFPR and KIT in the field of Geodesy is a result of intense work of several years and the dedication of the research staff in both universities. On the German side, the first steps that were introduced by Prof. Dr. Bähr found a high quality follower in the person of Prof. Dr. Bernhard Heck. He pushed the German side towards the exchange and the interaction with the UFPR. It is remarkable what efforts he made during the many hours he spent learning Portuguese and Brazilian culture, along with the technical support he gave to the project members.

The studies presented here are a short compilation of projects, which would have not been possible without the dedication of the German and Brazilian scientists that worked together in a synergic manner, combining competences and summing efforts towards the academic approach of two different countries.

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