International Workshop

„Airborne Geodesy and Geophysics with Focus on Polar Applications“

Dresden, 19 – 21 April 2017

TECHNISCHE UNIVERSITÄT DRESDEN

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Wednesday, 19 April 2017

Session 1	**13:00**	**14:50**	***Session chair: Mirko Scheinert***	
	13:00		*Welcome and Introduction*	
	13:30		Scheinert, Mirko	The Antarctic Geoid Project (AntGG), ANTHALO and beyond
	13:50		Youngman, Monica	GRAV-D Research in Alaska and Development with UAVs
	14:10		Eagles, Graeme	AWI's Aerogeophysical Surveys in Antarctica since 2013
	14:30		Cui, Xiangbin	A new airborne geophysical platform and its application in the Princess Elizabeth Land during CHINARE 32 and 33 in East Antarctica
Coffee Break	**14:50**	**15:30**		
Session 2	**15:30**	**17:10**	***Session chair: Kirsty Tinto***	
	15:30		Barthelmes, Franz	On processing of airborne gravity
	15:50		Lu, Biao	Regional gravity field modeling based on GEOHALO mission
	16:10		Schaller, Theresa	GEOHALO bathymetry
	16:30		Forsberg, René	Polar airborne and marine gravimetry in the Arctic and Antarctica
	16:50		Greenbaum, Jamin	The East Antarctic Grounding Line Experiment and Land-Ice/Ocean Network Exploration with Semi-autonomous Systems projects: Fixed-wing and helicopter gravity and radar sounding for bathymetry and subglacial freshwater discharge in East and West Antarctica
Icebreaker	**19:00**		**Restaurant "Altmarktkeller"**	

Thursday, 20 April 2017

Session 3	**09:00**	**10:20**	***Session chair: Graeme Eagles***	
	09:00		Brady, Nigel	An Improved Platform Levelling System for an Airborne Gravity System Used in an Antarctic Survey Project
	09:20		Becker, David	Experiences and prospects for strapdown airborne gravimetry in polar regions
	09:40		Jensen, Tim	Combining Airborne Gravity Estimates from Stabilised-Platform and Strapdown Systems
	10:00		Pätzold, Falk	Further technological development of airborne gravimetry
Coffee Break	**10:20**	**11:00**		
Session 4	**11:00**	**12:20**	***Session chair: Jamin Greenbaum***	
	11:00		Bucher, Tilman	MACS – Modular Airborne Camera Systems Customized to specific carriers, environments and applications
	11:20		Brauchle, Jörg	MACS-Himalaya: A Photogrammetric Aerial Camera System Designed for Extreme Environments

	11:40		Semmling, Max	Assessment of GNSS reflectometry for sea-ice and ice-sheet altimetry
	12:00		Steinhage, Daniel	Instruments for Geodesy and Geophysics on board of AWI's research aircraft
Lunch Break	**12:20**	**13:40**		
Session 5	**13:40**	**15:00**	***Session chair: David Becker***	
	13:40		Gogineni, Prasad	Radar Instrumentation of long-range and high-altitude aircraft for scientific research and operational applications on Antarctica
	14:00		Blindow, Norbert	Helicopter-based Ground Penetrating Radar (25 and 50 MHz) for Glaciological Investigations
	14:20		Dietz, Anja	Revealing subglacial conditions and past flow history of the Recovery Region, Antarctica using airborne radar data
	14:40		Ferraccioli, Fausto	New aerogeophysical views of the South Pole Frontier
Poster Session	**15:00**	**17:00**	**with Technology Display and Coffee**	
Social Event	**18:45**		**Steamer Boat tour on river Elbe including dinner buffet**	

Friday, 21 April 2017

Session 6	**09:00**	**10:20**	***Session chair: Maximilian Semmling***	
	09:00		Blankenship, Donald	ICECAP/PEL aerogeophysical data confirm an extensive subglacial lake and canyon system in Princess Elizabeth Land, East Antarctica
	09:20		Tinto, Kirsty	Geologically informed bathymetry across Antarctic grounding lines from Operation IceBridge and ROSETTA-Ice aerogravity
	09:40		Young, Duncan	Surveying subglacial massifs in Antarctica for geodynamics and old ice: Case studies from Marie Byrd Land and little Dome C
	10:00		Jordan, Tom	A geophysical view of the Weddell Sea Rift System: Past, present and future investigations
Coffee Break	**10:20**	**11:00**		
Session 7	**11:00**	**12:30**	***Moderation: Mirko Scheinert***	
	11:00	12:15	Podium Discussion	Geoscientific airborne surveying of polar regions: Present status and future prospects
	12:15		Closing	
Lunch Break	**12:30**			
	13:30		*Workshop venue closes*	

The Antarctic Geoid Project (AntGG), ANTHALO and beyond

Mirko Scheinert
TU Dresden

Antarctica with its hostile environment and vast extension still remains the largest gap in gravity and other geoscientific data. In global gravity field modelling one has to deal especially with the polar data gap originating from the orbit characteristics of the dedicated satellite gravity missions.
To improve the availability of terrestial gravity data and to foster new ground-based and airborne surveys an appropriate group within the International Association of Geodesy (IAG) was initiated. The activities of this IAG Subcommission 2.4f "Gravity and Geoid in Antarctica" (AntGG) are closely linked with those of the SCAR Expert Group "Geodetic Infrastructure in Antarctica" (GIANT).
This presentation will review recent activities. A first Antarctic-wide dataset of terrestrial gravity anomalies could be published in 2016. With data of recent and upcoming surveys becoming available it is planned to update this dataset in the near future.
In this respect also the planned airborne mission ANTHALO will be treated. This mission will comprise, besides aerogravimetry, a variety of geophysical-geodetic and atmospheric measurements.
Finally, an outlook on synergetic effects will be given when linking airborne measurements with ground-based and satellite observations.

GRAV-D Research in Alaska and Development with UAVs

Monica Youngman[1], Dr. Simon Holmes, Dr. Theresa Damiani
[1] U.S. National Geodetic Survey

The U.S. National Geodetic Survey's (NGS) Gravity for the Redefintion of the American Vertical Datum (GRAV-D) project is collecting airborne gravity data to support a 1 cm geoid. Started in 2008, this project will collect airborne gravity data over the entire U.S. and territories by 2022. As of March 1, 2017, the project was 58% complete. This presentation will focus on two research and development topics: 1) geoid improvements in Alaska resulting from GRAV-D data collection and 2) development of an optionally piloted aircraft (OPA) platform for gravity measurements.
Prior to GRAV-D, Alaska gravity measurements had significant data gaps that of caused errors in the gravimetric and hybrid geoid models. By adding the airborne gravity data collected in Alaska from GRAV-D into the geoid models, significantly improvements are apparent. We present comparisons of: the most recent NGS official gravimetric and hybrid geoids; the most recent experimental geoid that incorporates the airborne gravity data; the National Geospatial-Intelligence Agency's Earth Gravitational Model 2008 (EGM2008)' and satellite gravity data.
The GRAV-D project has also been researching unmanned platforms as a potential way to improve airborne gravity surveying in the Arctic. In April 2016, we completed the first test flights on a Centaur OPA that combines a stable, unmanned autopilot system with a safety pilot to avoid airspace restriction. The first operational survey started March 13th, 2017 and preliminary results will be shown for the first time.

AWI's Aerogeophysical Surveys in Antarctica since 2013

Eagles, Graeme[1]., Steinhage, D[1]., Läufer, A[2]., Ruppel, A[2]., and Jacobs, J[3].
1 Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research
2 Federal Institute for Geosciences and Natural Resources (BGR)
3 University of Bergen, Norwegian Polar Institute

Polar 5 and 6, the two multi-purpose polar research aircraft of the Alfred Wegener Institute, were configured for geophysical survey work in and around Dronning Maud Land, Antarctica, during the 2013/14, 2014/15, 2015/16, and 2016/17 seasons. In late 2013, a survey was started over the oceanic crust north of Prydz Bay, concentrating on the collection of magnetic anomaly data with a Scintrex Cs-3 caesium vapour magnetometer mounted outboard in a tail boom, compensated for aircraft effects using 3-component measurements collected with an onboard Billingsley fluxgate magnetometer. The data confirm the presence of seafloor spreading anomalies of Cretaceous age there, and the survey is planned for completion in the coming seasons. Later in the same season and during the following season, a large programme of nearly 30 survey flights concentrated on the Sør Rondane and neighbouring region as part of a long-standing collaboration between AWI and the Federal Institute for Geosciences and Natural Resources (BGR). Magnetic anomaly data from this survey have been interpreted in terms of the amalgamation of the supercontinent Gondwana by the collision of multiple volcanic island arcs between the cores of more ancient continents that today make up parts of the interiors of Antarctica, Africa and Arabia. Gravity data collected with a LaCoste and Romberg AirSea gravimeter and AWI's new Gravimetric Technologies GT2A gravimeter reveal topographic and deeper crustal information from below the region's thick ice cover. A broad subglacial channel between Sør Rondane and the Yamato mountains seems to date from pre-glacial times, when it would have hosted a major river system that transported a great thickness of sediments, eroded from the interior of Antarctica, to the neighbouring ocean. In comparison with coincident ice-radar data, upcoming work will examine whether or not the longevity of this feature can be explained in terms of its tectonic inheritance. In 2015/16 and 2016/17, Polar 5 operated out of Neumayer and Kohnen stations to focus on the densification of existing survey profiles over the Forster Magnetic Anomaly from 10 km to 5 km spacing. Interpretation of these data will help sharpen our understanding of the final amalgamation of Gondwana, complementing the advances that have been possible in the region around Sør Rondane. In 2015/16, a further two high-resolution survey flights have collected magnetic and gravity data over the Ekström ice shelf, much increasing our knowledge of the geophysical setting occupied by the Neumayer III station at which AWI carries out year-round observational science. The gravity data in particular will be used to model the depth to the seafloor underneath the floating ice shelf, a target for upcoming geological drilling. Using 'piggy back' installations accompanying glaciological surveys late in the 2013/14 and 2016/17 seasons, AWI has also collected gravity and magnetic data over the largely-unknown Recovery Lakes and Dome F regions.

A new airborne geophysical platform and its application in the Princess Elizabeth Land during CHINARE 32 and 33 in East Antarctica

Cui Xiangbin, Sun Bo, Guo Jingxue, Tang Xueyuan
Polar Research Institute of China, Shanghai, China
Jamin S Greenbaum, Laura Lindzey, Feras Habbal, Duncan Young
University of Texas, Institute for Geophysics, USA

The ice thickness, subglacial topography and bedrock conditions of Princess Elizabeth Land (PEL) in central East Antarctic Ice Sheet (EAIS) are still unknown due to lack of direct geophysical measurements. This prevents our understanding of the ice sheet dynamics, subglacial morphology and climate evolution in the region. According to recent results from remote sensing results, it's very likely that there's a large, previously undiscovered subglacial lake and subglacial drainage networks existing beneath the ice sheet in PEL with possible subglacial canyons extend over a distance of ~1100 km from inland to coast. But there's no direct measurements to identify them yet. China deployed its first fixed-wing airplane named Snow Eagle 601 and implemented airborne geophysical investigation in PEL during the 32nd and 33rd Chinese National Antarctic Research Expeditions (CHINARE 32 and 33, 2015/16 and 2016/17). The HiCARS deep ice-penetrating radar system and other instruments including GT-2A gravimeter, CS-3 magnetometer, laser altimeter, GPS and camera, were installed in the airplane to measure the ice sheet and subglacial conditions, as well as bedrock geology and tectonic. The field campaign was built beside Russian airfield (ZGN) near Zhongshan Station. During CHINARE 32, the airborne surveying grid was designed as radial lines from ZGN so as to investigate the region as large as possible, and total flight lines are ~32 000 km. During the CHINARE 33, airborne survey will pay attention to the subglacial lake and subglacal canyons. Here, we introduce the Snow Eagle airborne geophysical platform firstly. Then, we present some preliminary results from CHINARE 32 and CHINARE 33.

On processing of airborne gravity data

Franz Barthelmes[1], Biao Lu, Svetozar Petrovic, Christoph Förste, Hartmut Pflug, Frank Flechtner, Zhicai Luo, Kaifei He, Min Li, Mirko Scheinert
1 GFZ German Research Centre for Geosciences

Nowadays, airborne gravimetry is very important method to improve our knowledge about the Earth gravity field. The gravimeter Chekan-AM onboard the German High Altitude and Long Range (HALO) aircraft makes gravimetry in hardly accessible places possible, like in the polar regions of the Earth. A preparatory campaign on HALO has been carried out over Italy in 2012 to test the performance of the air-sea gravimeter Chekan-AM aboard such a jet aircraft. Specifically, the processing strategy of data measured with this gravimeter is studied. To subtract the vertical kinematic accelerations from the values measured by the gravimeter, four different versions of kinematic accelerations derived from measurements of Global Navigation Satellite Systems (GNSS) have been computed: based on raw Doppler observations and Doppler observations derived from carrier phase measurements, both at 1 Hz and 10 Hz. They are investigated to find the best results based on two criteria: comparing the airborne gravimetry results with the combined global Earth gravity field model EIGEN-6C4, and checking the crossover points of the airborne gravimetry tracks. To remove the high-frequency noise, a low-pass filter with a cutoff wavelength of 200 s, realized by Fast Fourier Transform technique, is applied to both, Chekan-AM measurements and GNSS-derived kinematic accelerations. To investigate how future airborne gravity campaigns could be designed over regions like Antarctica, a dedicated flight track during the GEOHALO experiment has been flown two times at different heights and speeds of the aircraft. The gravimetric measurements along these two flight paths are investigated and the results show that the equipment worked well also at higher altitude and speed. This result is important for finding the best compromise between accuracy, spatial resolution and costs of future missions, particularly over Antarctica. From the final best results follows an RMS of gravity differences at crossover points of 1.4 mGal. Conclusively, GEOHALO mission was a successful airborne gravimetry experiment.

Regional gravity field modeling based on GEOHALO mission

Biao Lu[1], Franz Barthelmes, Svetozar Petrovic, Christoph Förste, Frank Flechtner, Zhicai Luo, Kaifei He, Min Li, Mirko Scheinert
1 GFZ German Research Centre for Geosciences

Airborne gravimetry mission of GEOHALO campaign in 2012 was successful with an accuracy of 1 mGal according to the gravity differences at crossover points. After processing these gravimetric measurements, regional gravity field modeling was done to demonstrate the benefits of this experiment. Although the combined global models like EIGEN-6C4 and EGM2008 are very good and have a spatial resolution of about 10 km over the region of this mission, we wanted to investigate the situation for a region where the best gravity field model is based on satellite measurements only. Hence, we wanted to check how much a satellite-only model can be improved regionally by using only the airborne measurements and available topography information, and, in particular, how good a derived regional quasigeoid can be. For this purpose, a harmonic function based on point mass potentials has been fitted to the measured gravity values. As expected from the distance between the measured tracks (40 km) the resolution of such a model corresponds to a spherical harmonic model of degree and order of approximately 500. To compute also an improved regional geoid model, the point mass modeling (PMM) and the remove-compute-restore (RCR) technique, using a recent satellite-only model and residual terrain modeling (RTM), were applied. Finally, GNSS/leveling points and the combined gravity field model EIGEN-6C4 (which is very good over Italy) have been used to check the quality of the derived regional point mass model.

Parker-Oldenburg Inversion of airborne gravity data to infer bathymetry and subglacial topography

Theresa Schaller, M. Scheinert
TU Dresden

The inversion of gravity data is a widely used tool in geodesy and geophysics. It can be utilised to obtain unknown interfaces, e.g. bathymetry, subglacial topography or the depth to the Mohorovičić (Moho) discontinuity, in areas where these were not observed directly or are only known with poor resolution. On the other hand, if the interface is known, this method can also be applied to derive an average density for the study area. We analysed gravity data from the GEOHALO mission carried out in June 2012 using the 'High Altitude and LOng research aircraft' (HALO). This mission was conducted in Italy and parts of the Adriatic, Ionian and Tyrrhenian seas. In addition to other geoscientific measurements gravity data was measured with two gravimeters, CHEKAN-AM and KSS32-M.

The offshore parts of the gravity data, measured with the former instrument, were used to infer bathymetry via a Parker-Oldenburg inversion scheme. The resulting depths were validated against a-priori information, yielding an average depth for the respective profile. Best results were achieved in the Tyrrhenian Sea. Here, the correlation between gravity and bathymetry is high and the density in the upper most parts of the crust is not changing significantly. Th profiles in the Adriatic and Ionian seas crossed the boundary between the Eurasian and African plates, thus covering areas with heterogeneous composition. In these areas the correlation between gravity and bathymetry is therefore low and the procedure did not lead to satisfactory results. However, the results show that the method is suitable to derive bathymetric depths with sufficient accuracy in areas, where the geology and tectonic conditions do not change significantly. Further on an outlook is shown on the application of this procedure for the Antarctic continent. For this, the inversion scheme will be modified in order to derive subglacial topography and Moho-depths from gridded (areal) gravity data.

Polar airborne and marine gravimetry in the Arctic and Antarctica

Rene Forsberg, Arne V Olesen
DTU Space

The last decade has seen major advances in completing and improving the gravity field of the polar regions. Large scale aerogravity surveys have filled major voids in Antarctica, such as the DTU-Space/BAS/IAA/UTIG 2009-13 airborne gravity surveys of the Antarctic Peninsula and interior Dronning Maud Land, and the 2015-16 Polar Gap airborne survey of the GOCE southern polar gap. In the Arctic Ocean, numerous new marine surveys have been carried out by a host of different nations as part of UNCLOS activities, including long-range Danish-Canadian aerogravity surveys beyond the North Pole; these data are currently being compiled in a new NGA Arctic Gravity compilation.
In the paper we use the new marine and airborne data for cross-validation, including NASA IceBridge gravity data, and also use the new long-range airborne data to validate satellite gravity data from GOCE and satellite altimetry. We demonstrate that aerogravity accuracies at 1-2 mGal r.m.s. accuracy are obtained in good cases, and also highlight the need for affordable novel IMU-based gravity sensors to augment classical airborne gravimeters. Such IMU sensors open the opportunity for future detailed drone-based gravity surveys, and early tests with similar (lidar) payloads in Greenland are currently underway.

The East Antarctic Grounding Line Experiment and Land-Ice/Ocean Network Exploration with Semi-autonomous Systems projects: Fixed-wing and helicopter gravity and radar sounding for bathymetry and subglacial freshwater discharge in East and West Antarctica

Jamin Greenbaum[1], D. Blankenship, D. Young, T. van Ommen, J. Roberts, S. Bo, G. Jingxue, E. Lemeur, G. Durand, S.H. Lee, J. Lee, W.S. Lee, A. Wåhlin, K. Assmann, L.H. Beem, F.G., L. Jong, W. Wei, L. Lindzey, E. Quartini, T.G. Richter, C.Grima, and P. Heimbach

1 University of Texas Institute for Geophysics

The East Antarctic Grounding Line Experiment (EAGLE) and the Land-Ice/Ocean Network Exploration with Semi-autonomous Systems (LIONESS) projects are large international, collaborative programs focused on understanding the impact of coastal ocean circulation and subglacial freshwater discharge on ice shelf cavities and the inner continental shelves of major glacier outlets in East and West Antarctica. Both projects utilize airborne geophysical platforms: EAGLE manages two Turbo DC-3 aircraft operated by the Australian Antarctic Division (AAD) and the Polar Research Institute of China for coordinated flights along the Indo-Pacific Coast between ~80 E and 160 E; the two EAGLE aircraft are equipped with nearly identical equipment suites that include ice sounding radar systems developed by the University of Texas Institute for Geophysics, three-axis stabilized gravimeters, magnetometers, and laser altimeters. LIONESS manages two helicopter platforms, one hosting a three-axis stabilized gravimeter and another with a four channel ice sounding radar, laser altimeter, and a camera. The LIONESS study areas are Terra Nova Bay and the greater Amundsen Sea region, both in West Antarctica; LIONESS helicopters are deployed by icebreaker for the Amundsen Sea work. Gravity data acquired by both programs are used to improve coastal bathymetry beneath ice shelves and in areas where fast ice and icebergs have limited icebreaker exploration and where satellite-derived bathymetry estimates are poorly-resolved. Ice sounding radar data are used to identify subglacial freshwater discharge locations into ice shelf cavities, determine the morphology of the ice shelves, and directly estimate annual-averaged basal melt rates. The AAD platform additionally deploys Airborne eXpendable Bathy-Thermograph (AXBT) sensors into sea ice leads for independent seafloor depth constraints on the gravity bathymetry inversions. We have found that AXBTs are also useful for detecting the depth of deep, warm water layers and to locate supercooled glacier meltwater outflows. We will show preliminary results from both programs and discuss planned deployments.

An Improved Platform Levelling System for an Airborne Gravity System Used in an Antarctic Survey Project

Nigel Brady
Dynamic Gravity Systems, Broomfield, Colorado

Recent advances in sensor technology have enabled Lacoste and Romberg, zero length spring type, relative gravity meters to improve in accuracy to the point where other non-sensor related sources of error serve to limit the overall accuracy of the system. The horizontal beam balanced with a zero-length spring is renowned for being very sensitive to small changes in gravity which unfortunately also make it more sensitive to sources of noise or errors in the gravity signal. If these sources of error can be reduced or eliminated, then the zero-length spring technology could reach its full potential as a highly accurate survey instrument.

One of these sources of error is derived from the inability of the gimbal platform which the sensor is mounted in, to keep the sensor perfectly level during survey flight. Off level errors occur when the aircraft is unable to maintain straight and level flight along a survey line. The levelling platform of a typical Lacoste and Romberg type dynamic gravity meter utilizes a complex feedback loop involving both accelerometers and gyroscopes with an output connected to torque motors mounted to the platform to sense an off level situation and correct for it. The current system is limited by an inability of the platform to distinguish between an acceleration of the platform due to a change in heading, altitude or speed of the aircraft and a true change in the local gravity vertical. Both situations cause the platform to tilt in response to the new acceleration however the aircraft acceleration creates an error in the gravity measurement. These off-level errors can be corrected for, to a limited degree, depending on the algorithm used and the size and duration of the causal acceleration.

High precision GPS now provides accurate real time position information which can be used to determine if an acceleration is a real gravitational change or due to an anomalous acceleration. The correct implementation of the GPS position using an Inertial Measurement Unit (IMU) can significantly improve the accuracy of the platform levelling including keeping the platform level during course reversals, autopilot wandering or even drape flying during a survey. The use of an integrated IMU typically improves the quality of the gravity data before any processing corrections. The enhanced platform also reduces or even eliminates the time taken to stabilize the platform at the beginning of a survey line therefore improving the efficiency of the data collection. This paper discusses the method and results of tests of the new GPS aided platform system developed by Dynamic Gravity Systems for their Advanced Technology full feedback dynamic gravity system.

Experiences and prospects for strapdown airborne gravimetry in polar regions

David Becker, M. Becker
Physical and Satellite Geodesy, Technische Universitaet Darmstadt

Since 2013, the chair of Physical and Satellite Geodesy (TU Darmstadt) has been involved in several strapdown airborne gravity campaigns, with two of them taking place in Antarctica: The PolarGap campaign (2015/2016) and the FISS campaign (British Antarctic Survey, 2016/2017). Experiences from these campaigns will be presented, focussing on the particular challenges of implementing airborne gravimetry in polar regions. Among these challenges are the large temperature variations, the unavailability of gyro-compassing for initializing the heading angle for the strapdown navigation, and the significantly lower GNSS satellite elevation angles, leading to large instabilities in the vertical channel of GNSS-derived positions and velocities. For a strapdown gravity system, consisting of a thermally stabilized or calibrated navigation-grade strapdown IMU and a two-frequency GNSS receiver, it will be shown that GNSS can be in fact the bottleneck for airborne gravimetry in polar regions. In this context, the opportunities arising from three-frequency GPS and Galileo signals are briefly discussed. Until the implementation of the ANTHALO campaign, being a long-range geophysical airborne survey scheduled for 2020/21 in Antarctica, it is expected that the full Galileo satellite constellation will become available. In addition, first results of strapdown airborne gravimetry performed in drape-flying mode will be presented from the FISS campaign, maintaining a constant altitude over ground. This is a completely new mode of operation for airborne gravimetry, as the classical sensors (mechanical spring gravimeters) typically can not operate during such significant changes of flight altitude above sea level. Among other advantages of using strapdown sensors, this emphasizes the enormous potential emerging from strapdown airborne gravimetry.

Combining Airborne Gravity Estimates from Stabilised-Platform and Strapdown Systems

Tim E. Jensen, J. Emil Nielsen, Arne V. Olesen and Rene Forsberg
DTU Space

For more than two decades, stabilised-platform spring-type gravimeters have been the predominant instrumentation for airborne gravimetry. The use of strapdown Inertial Measurement Units (IMUs) for airborne gravimetry started already in the early nineties, with motivating factors such as smaller size, ease of operation, lower energy consumption and lower price. Moreover, since the IMU contains three accelerometers, it has the potential to do vector gravimetry and estimate the deflection of the vertical. The biggest challenge with strapdown systems has been long term drift in the sensors, leaking into the long-wavelength components of the gravity estimates. The Danish National Space Institute has been carrying out large airborne surveys since the early nineties, using a LaCoste&Romberg (LCR) spring-type gravimeter, mounted on a stabilised platform. In collaboration with the Technical University of Darmstadt, we have been flying an additional strapdown IMU system on campaigns in South America, South China Sea, Africa and Antarctica, since 2013. The strapdown system has proven itself to give stable results during dynamic flight conditions, which often challenges the LCR system, and to resolve more details of the gravity signal. On the other hand, the LCR system has proven itself very reliable in determining the long-wavelength components of the signal, which is essential for geodetic applications.
Results from the two systems and a comparison, highlighting these properties, will be presented. These properties are complimentary, indicating that a merging of the two systems could give superior gravity estimates. A method for combining the estimates will be outlined and results showing an improvement in terms of cross-over differences are shown.

Further technological development of airborne gravimetry

Falk Pätzold, Thomas Rausch
Institute of Flight Guidance, Technische Universität Braunschweig (Germany)

The presentation addresses aspects and questions on the topic of possible future steps in the technological development of airborne gravimetry.
Starting with a short presentation of the history and recent activities in airborne gravimetry research at Technische Universität Braunschweig, the different roles and perspectives of sensor and system developers, airborne campaign operators, (scientific) airborne data users and funding institutions are discussed. Based on our perspective as system developers several aspects for further development steps such as intensifying the interconnections between the stakeholders, establishing standards for systems and procedure characterisation and validation, enhancement of systems integrity, reduction of campaign cost or technology changes are given. We ask the audience to discuss future needs of airborne gravimetry.

MACS – Modular Airborne Camera Systems Customized to specific carriers, environments and applications

Ralf Berger, Jörg Brauchle, Daniel Hein, Frank Lehmann, Karsten Stebner, Sebastian Pless, **Tilman Bucher**
Institute of Optical Sensor Systems, German Aerospace Center (DLR), Berlin

To enable research in a wide range of environments, scales and applications from variable airborne carriers an experimental Modular Airborne Camera System (MACS) has been developed at the DLR Institute of Optical Sensor Systems in Berlin. MACS stands for the concept of a highly flexible photogrammetric sensor system. It consists of a set of calibrated camera heads, a commanding unit and auxiliary measuring devices e.g. for position and orientation. The processing unit simultaneously operates up to 6 camera heads and handles the data processing, storage and output to an optional real-time data-downlink. The geometric flexibility is expressed by the possibility to rapidly change the geometric configuration for oblique or wide-swath imaging. Also the spectral range can be adapted, cameras recording in visual, near infrared and thermal infrared range as well as hyperspectral sensors can be operated simultaneously.

To be able to use a wide range of carriers a further design concept is low weight and small size. Systems have been integrated in (wing)pods (e.g. Stemme S10, Tornado), standard aircraft, helicopters and fixed-wing, multi-rotor and VTOL UAVs. A high level of autonomy is reached by using a GPS-based fully automatic image acquisition.

A rigid and determinable alignment of sensors, optics, position and orientation measurement systems as well as an extensive geometric and radiometric calibration is essential for the photogrammetric 3D capability of the system. It has been developed and verified in several instances over the last years. Industrial grade sensors delivering high frame rates allow 1) very high overlaps of all sensors even at high flight velocities, what qualifies MACS especially for full 3D-reconstruction of nadir and oblique image flights and 2) a High Dynamic Range (HDR) mode, which typically takes a sequence of 3 images with graded integration times, each covering 12 bit radiometric depth, resulting in a total dynamic range of 15-16 bit for any scene to cope with extreme radiometric conditions. Using space engineering know-how and facilities enables DLR-OS to build cameras qualified for extreme environments.

The same in-house developed operating software is used in all MACS sensor systems. It provides images with exact timestamp, position and orientation information to ensure a consistent photogrammetric workflow. Main fields of application so far have been real-time monitoring and information extraction for security applications, full 3D data acquisition for simulation environments especially in urban scenarios and 2,5D mapping in the Himalayas.

An overview over the MACS types with special emphasis on the needs of an extreme polar environment will be given.

MACS-Himalaya: A Photogrammetric Aerial Camera System Designed for Extreme Environments

Jörg Brauchle, Daniel Hein, Ralf Berger, Tilman Bucher
DLR - Institute of Optical Sensor Systems

The DLR Institute of Optical Sensor Systems has developed the MACS-Himalaya, a custom built Modular Aerial Camera System specifically designed for extreme environmental conditions. In 2014 a photogrammetric survey was performed on the Nepalese side of the Himalayas. The remote sensing system was carried in a wingpod by a Stemme S10 motor glider. Amongst other targets the Mt. Everest/Khumbu Region was covered at altitudes up to 9,200 m under temperatures down to -35°C.
The design of the system is adapted to the extreme geometric (steep slopes) and radiometric (high contrast) conditions of high mountain areas. It has a broad overall field of view of 116° across-track (RGB) consisting of a nadir and two oblique looking camera heads and a fourth nadir looking near-infrared camera. This design provides the capability to fly along narrow valleys and simultaneously cover both valley floor and steep flanks with similar ground resolution.
To compensate for extreme contrasts between fresh snow and dark shadows in extremely clear atmospheres a High Dynamic Range (HDR) mode was implemented, which typically takes a sequence of 3 images with graded integration times, each covering 12 bit radiometric depth, resulting in a total dynamic range of 15-16 bit for any scene. This enables dense image matching and interpretation for sunlit snow and glaciers as well as for dark shaded rock faces in the same scene.
Small and lightweight industrial grade camera heads are used and operated at a rate of 3.3 frames per second with 3-step HDR, which is sufficient to achieve a longitudinal overlap of approximately 90% per exposure time at 1,000 m above ground at a velocity of 180 km/h. Direct georeferencing and multitemporal monitoring without the need of ground control points is possible due to the use of a high end GPS/INS system. The operation of the system is fully automatic, a remote real-time mission control and access to the camera is given to the operator if needed.
Products such as dense point clouds, DSMs and true orthomosaics with a ground pixel resolution of up to 15 cm were produced in areas which are usually only covered by satellite imagery. These data are used in the fields of natural hazards, geomorphology and glaciology. A net of ground control points for the absolute geometric verification of the data was installed in a ground campaign.
In the presentation the camera system is introduced and examples and applications from the Nepal campaign are given.

Assessment of GNSS reflectometry for sea-ice and ice-sheet altimetry

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Signals of Global Navigation Satellite Systems (GNSS), e.g., GPS, GLONASS,Galileo or BeiDou, have additional benefit for remote sensing. Signal's refraction is examined already operationally to study the Earth's atmosphere and ionosphere. A growing field of research focuses also on reflected signals to study, e.g., the ocean and the cryosphere. GNSS reflectometry is an innovative Radar technique that uses the precise delay information of the GNSS L-band signals. The diffuse surface scattering can be used to monitor sea-ice formation and wind wave occurrence. The specular part of the signal reflection provides altimetric information of the surface. The retrieval of sea-ice thickness using reflectometry is an important altimetric objective in current methodologic research. Altimetric challenges also arise from specular land reflections.
Airborne and spaceborne missions have been proposed comprising GNSS reflectometry receivers for altimetry in the polar regions. The GNSS-Transpolar Earth Reflectometry exploriNg System (G-TERNS) is a satellite approach in the proposal phase for an ESA Earth Explorer mission. It shall particularly provide dense altimetric observations over sea-ice and the ice-sheet in polar regions. The ANTHALO mission is an approach to use the high-altitude and long-range (HALO) research aircraft to densify particularly gravimetric observations over Antarctica. It also gives the opportunity for altimetric observations. A precursor flight of the ANTHALO mission will start in December 2017 from Cape Town, South Africa, to the Troll research station, Queen Maud Land, Antarctica. The flight track will cover parts of the Southern Ocean, of the iceberg and drift ice belt and of the Antarctic ice shelf.
Observations from an Arcitc reflectometry station are used for a preparatory assessment. The instruments (HALO approved) were set up at the outpost of the Norwegian Polar Institute on top of Zeppelin mountain, Svalbard. A data set has been accumulated almost continously since Summer 2013. The study of an example event during 2014 revealed persistent reflection signatures from the coastal permafrost zone, the fjord and ice-sheet areas. The respective signal-to-noise ratios are 45 dB, 55 dB and 35 dB for one minute signal integration time. Corresponding reflection facets occur with an increasing distance from the receiver at 4 km, 6 km and 25 km. Particularly distant reflections over land topography can have diffuse characteristics that require an adapted altimetric retrieval. The preliminary results, in general, indicate that the HALO setup can resolve permafrost and ice-sheet signal reflections.

Instruments for Geodesy and Geophysics on board of AWI's research aircraft

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Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung

The Alfred-Wegener-Institut operates two ski-equipped aircraft for more than 25 years in polar regions for various scientific applications. The manifold instrumentation of the aircraft comprises measurement devices for atmospheric research, remote sensing as well as geophysical investigations. Driven by the scientific users the available instruments are constantly up-dated and new instruments are introduced to the aircraft, including instruments owned by other institutes.
The suite of available instruments for geodetic and geophysical surveys ranges from especially developed radar systems, adapted gravity meters to of the shelf available instruments such as magnetometer, laser altimeter/scanner, camera systems, and GPS receivers. The configuration of the aircraft can – with some technical restrictions - easily be adapted to the targeted scientific question. Most applications in geodesy, geophysics, and glaciology on polar region require the knowledge of the ice thickness. Thus ice penetrating radar systems are often part of the deployed instruments.
Two recently introduced multi-channel radar systems allow to map the ice thickness as well as internal structure at very high resolution (sub-meter range) and surface morphology on a single flight track. We will present examples to highlight the capability of the new multichannel ice penetrating radar.

Radar Instrumentation of long-range and high-altitude aircraft for scientific research and operational applications on Antarctica

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We are proposing radar instrumentation spanning the frequency range from about 150 MHz to 18 GHz for operation on long-range and high altitude Gulfstream V aircraft. Our proposed instrumentation will consist of an ultra-wideband radar in the Very and Ultra high frequency (VHF-UHF) range to sound and image ice in Antarctica, and map deep internal layers with fine resolution; an L-band radar to measure bottom melt rates of ice shelves and image ice-bed interface; and an ultra-wideband microwave radar operating over the frequency range of 2-18 GHz to determine snow accumulation over ice sheets, measure thickness of snow over sea ice and land as well as to support other applications. We have completed preliminary design and simulations for developing a large cross-track antenna-array of 16 elements for operating the VHF radar sounder/imager over the frequency range of 150-400 MHz. We also completed the preliminary design of the 2 m x 3 m antenna fairing to accommodate a large 2 m × 2 m planar array for the L-band radar (1.2-1.4 GHz) and a 1 m × 0.6 m array for the 2-18 GHz radar. We investigated impacts of antenna arrays and fairing on the aircraft range and performance to ensure its range is not reduced by more than 15%. We estimate that the VHF radar can be used to collect data over a horizontal swath of about 12-20 km per pass based on the ice-bed backscatter response for a nominal G-V survey altitude of about 10 km above the surface. This will significantly reduce the number of flights required to obtain a complete bed topography map for Antarctica. The L-band radar for wide-swath imaging and sounding of low loss ice will be extremely useful for characterizing basal conditions unambiguously to select the best possible site for oldest ice in addition to the determination of bottom melt rates of ice shelves. The ultrawideband microwave radar will map internal layers in polar fin and ice with about 3 cm resolution for estimating snow accumulation on annual, decadal and century scales.

In this presentation we will discuss the scientific and technical requirements for radar instrumentation. We will present our design and simulations, and expected performance of proposed radars. We will show previous results from similar radars on other aircraft in sounding of ice from low- and high-altitude flights on Antarctic and Greenland ice sheets. We will present results from earlier ultra-wideband microwave radar on snow-covered sea ice and land, as well as results of mapping internal layers in polar firn with fine resolution. Finally, we will discuss the use of ultra-wideband microwave radars in other applications such as soil moisture and agriculture.

Helicopter-based Ground Penetrating Radar (25 and 50 MHz) for Glaciological Investigations

Norbert Blindow
Consultant, AirborneGPR

Airborne ground penetrating radar (GPR) measurements of mountain glaciers, polythermal, and temperate ice are a challenge because of surface roughness, internal scattering, and absorption.
From ground based work on temperate ice I learned that center frequencies of 30 MHz or below are a good compromise to measure ice thickness and at the same time depict internal structures like the water table, firn layering and water inclusions.
Stimulated by investigations on the polythermal ice cap of King George Island I designed a 25 MHz impulse GPR to map the crevassed areas of the ice cap by helicopter. Because of the versatility of such systems in airborne geophysics the radar is constructed as an external sling load with a few components inside the helicopter cabin. This also accounts for the large size of directional antennas at > 10 m wavelength in air. Spacially dense sampling is necessary to meet the requirements of data processing. Helicopter speed for the measurements is presently limited to about 40 knots.
Deployments in the European Alps, Patagonian ice fields, and the profiling on King George Island were very successful. The prototype of the UMAIR (University of Münster Airborne Ice Radar) system was later acquired by BGR (Hannover, Germany) and is now one of five operating pulse systems using a similar technology. Three more advanced clones are run in Chile. The most recent system is owned by the University of Erlangen, Germany, and has just had its maiden flight on James Ross Island, Antarctica. For projects assessing e.g. the volume of high Andes glaciers (up to 6000 m a.s.l.) there is also a lightweight 50 MHz version.
A brief description of the system components is given, followed by examples of various applications from deep temperate ice to cold mountain glaciers.

Revealing subglacial conditions and past flow history of the Recovery Region, Antarctica using airborne radar data

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The Recovery Region in East Antarctica consists of Recovery, Bailey and Slessor Glaciers. These glaciers discharge 5 % of the total fresh water outflow of Antarctica into the Filchner Ice Shelf, which is subject to extensive sub-shelf melting under ongoing climate change. Several active subglacial lakes have been identified in the Recovery Region from satellite data, indicating the existence of a dynamic subglacial hydrologic system.
Nevertheless, no direct ice thickness data were available within 200 km. Therefore, BEDMAP2 identified this region as one of two 'poles of ignorance'. To fill this data gap we collected airborne data in the Recovery Region in 2013 and 2015 using the twin otter of the British Antarctic Survey. Here, we present a new bed topography map of the Recovery Region and discuss glacier dynamics using these new radar datasets. The deep trough of the Recovery Glacier reaches up to 2200 m below sea level, and extends 800 km inland from the current grounding line all the way to the large Recovery Lakes. Slessor Glacier shows a rough bed. The fast flow of Slessor Glacier is topographically controlled on one side; however, no topographic boundary can be identified on the other side, towards the Bailey catchment area. From radar return power, we derive that this shear margin of Slessor Glacier is controlled by the existence of subglacial water. Further, we find a connection, a narrow gate, between the Slessor catchment area and Recovery Glacier. No fast ice flow can be observed here nowadays, however there must have been fast ice flow carving and smoothing this gate in the past. We use data from 2015 with higher spatial resolution than the 2013 data to investigate the subglacial Recovery Lakes in detail. This high-resolution data set reveals topographic boundaries within the subglacial lakes and steep mountains at the boundary of the Recovery Lakes. Hence, we show that the Recovery Lakes are not giant lakes, but smaller lakes with swampy areas in between.

New aerogeophysical views of the South Pole Frontier

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Our knowledge of East Antarctica has increased significantly in recent years, aided by extensive international aerogeophysical exploration efforts in particular since IPY. Aerogeophysical and satellite imaging is now helping unveil cryptic crustal provinces and this is enabling new studies of the major tectonic process that shaped East Antarctica (e.g. Ferraccioli et al., 2011, Nature; Aitken et al., 2014, GRL).
However, the South Pole region has remained one of the largest "poles of ignorance", as very little data have been acquired here since pioneering aerogeophysical surveys performed in the 1970's and a single more detailed US corridor flown in the late 1990's from the Transantarctic Mountains to South Pole (Studinger et al., 2006, EPSL).
During the 2015-2016 Antarctic campaign we flew a major aerogeophysical survey over the South Pole, collecting ca 30,000 line km of new radio echo sounding, laser altimetry, airborne gravity and aeromagnetic data. The main aim of the PolarGAP project, supported by the European Space Agency was to fill in the data void in GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) satellite gravity south of 83.3S.
Here we present the new ice thickness, bedrock topography, and gravity and magnetic anomaly images derived from the survey and interpret them to investigate the crustal architecture and tectonic evolution of the South Pole region. The Free-air gravity and radar data reveal the form and extent of the Pensacola-Pole Subglacial Basin that stretches from the Weddell Sea to South Pole. Linear free-air gravity lows within the basin are interpreted as glacially overdeepened grabens flanked by uplifted horst blocks, including the Pensacola Mountains, Patuxent Range and the Argentine Range. The grabens are proposed to be linked to the Jurassic Transantarctic rift system, which at regional to continental-scale, is associated with voluminous magmatism of the Ferrar Large Igneous province. Based on recent geological and airborne geophysical research in the neighbouring Shackleton Range region (Paxman et al., 2017 JGR), as well as the East Antarctic Rift System (Ferraccioli et al., 2011, Nature) and Transantarctic Mountains/Wilkes Subglacial Basin (Ferraccioli et al., 2009, Tectonophysics) we hypothesise that Cretaceous reactivation of these grabens is also plausible.
By combining the new PolarGAP aeromagnetic data with recent aeromagnetic data acquired over the Recovery Glacier region (ICEGRAV project) and satellite magnetic (MF7) data we further investigate the potential influence of basement provinces and their tectonic boundaries on the Pensacola-Pole basin. We show that eastern flank of the basin is controlled by a major inherited crustal boundary, interpreted here as the southern edge of a composite Precambrian microplate, extending from the Shackleton Range to the Pensacola-Pole basin.

ICECAP/PEL Aerogeophysical data confirm an extensive subglacial lake and canyon system in Princess Elizabeth Land, East Antarctica

Sun Bo, Jamin S. Greenbaum, Guo Jingxue, **Donald D. Blankenship**[1], Martin J. Siegert, Naresh Pant, Stewart Jamieson, Tas D. van Ommen, Jason L. Roberts, Neil Ross, and Duncan A. Young
1 UT Austin Institute for Geophysics

Until recently, the subglacial landscape of Princess Elizabeth Land (PEL) in East Antarctica was poorly known due to a paucity of ice thickness measurements. This is problematic given its importance for understanding ice sheet dynamics and landscape and climate evolution. To address this issue, the topography beneath the ice sheet was described by assuming that ice surface expressions in satellite imagery relate to large-scale subglacial features. Doing so revealed a large, previously undiscovered subglacial drainage network hidden beneath the ice sheet in PEL. We interpreted a discrete feature 140 × 20 km in plan form, and multiple narrow sinuous features extending over a distance of □1100 km. We hypothesized that these are tectonically controlled and relate to a large subglacial basin containing a deep-water lake in the interior of PEL linked to a series of long, deep canyons. The presence of deep canyons is confirmed by radio-echo sounding data; drainage analysis suggests that these canyons will direct subglacial meltwater to the coast between the Vestfold Hills and the West Ice Shelf. This hypothesis is tested fully with geophysical data collected by the International Collaborative Exploration of the Cryosphere through Airborne Profiling of PEL (ICECAP/PEL) consortium, operated by the CHINARE 32 and 33 programmes in 2015-16 and 2016-17, respectively. The data reveal the nature of the subglacial topography in PEL, the presence, location, and size of subglacial lakes and their association with surface features; a preliminary gravity inversion over the largest lake indicates that it hosts at least 150 of water beneath the ice-water interface.

Geologically informed bathymetry across Antarctic grounding lines from Operation IceBridge and ROSETTA-Ice aerogravity

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Aerogravity surveys are a vital tool in mapping the otherwise inaccessible region of the sea floor in front of the grounding line of Earth's ice sheets. The stability of the ice sheets is strongly influenced by ocean-ice interactions near the grounding line and knowledge of the bathymetry offshore is an essential boundary condition for coupled ocean-ice models. These models are critical for accurate projection of future sea level globally. The inversion of gravity anomalies is a powerful tool for modelling grounding zone bathymetry, especially when the model incorporates an understanding of the geological structure of the region. This approach produces a robust geologically informed bathymetric model of the seafloor bathymetry.

Geological understanding can be developed using both regional outcrops and other geophysical observations. When combined with other geophysical methods, aerogravity surveys provide insight into the geological structure under grounded ice. Understanding the geological structure of the grounding zone improves the accuracy of bathymetry models from gravity inversions. Models of the behaviour of the ice sheets in the past and future are sensitive to both offshore bathymetry and onshore geological control.

Major surveys of the Antarctic grounding lines have been conducted with NSF and NASA support. NASA's Operation IceBridge has conducted aerogravity surveys in Antarctica since 2009, using the SGL AIRGrav gravimeter on board the NASA DC-8 aircraft. These surveys have been focussed on West Antarctica and the Filchner-Ronne Ice Shelf. The NSF ROSETTA-Ice surveys have completed two seasons of a high-resolution grid over the Ross Ice Shelf. The ROSETTA-Ice surveys combined three different gravity systems from ZLS, DgS and iMAR, mounted inside an LC-130. The IcePod is mounted outside the aircraft to provide additional instrumentation. Together, the IceBridge and ROSETTA surveys provide a new view of the geology and bathymetry around past and present West Antarctic grounding lines. We have developed a rigourous approach to developing geologically informed bathymetry from these data.

Extending these efforts to encompass the entire grounding line of Antarctica will require international collaboration, and will benefit from innovations in technology and new airborne platforms. The three-pronged goal of an international airborne campaign will be to measure the bathymetry close to the grounding line, install instrumentation to measure the water temperature of the ocean, and to constrain the ice thickness inland of the grounding line.

Surveying subglacial massifs in Antarctica for geodynamics and old ice: Case studies from Marie Byrd Land and little Dome C

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We present case studies from two recent aerogeophysical surveys using modified DC-3T ski-equipped Baslers of the interior of the Antarctica ice sheet. The UTIG aerogeophysical suite comprises the HiCARS airborne ice penetrating radar, a tail mounted Geometrics G-823 magnetometer, a Riegl LD90 laser altimeter and a CMG GT-2A polar-aided gravimeter. Positioning is provided by an iMAR FSAS IMU, coupled to an array of GPS receivers. The first case study is focused on the coastal Marie Byrd Land massif in West Antarctica, which may play a key role in the initiation and evolution of the West Antarctic Ice Sheet, as well as representing a key element of the West Antarctic Rift System. The 2013-2014 GIMBLE project surveyed this region at 5 km line spacing. We discuss the evaluation of basal properties for this region and linkages to potential fields analysis of the underlying geology. The second case study is a high resolution survey for old ice near Dome C, East Antarctica, which was surveyed by the ICECAP project in 2016. We discuss implications of this study for the resolution requirements for deep ice sheet access.

A geophysical view of the Weddell Sea Rift System: Past, present and future investigations

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1 British Antarctic Survey

The tectonic evolution of the Weddell Sea region of Antarctica was long lived and complex. The oldest rocks in this region are over a billion years old. Subsequent collisional orogens (~500, and ~250 Ma) and extensive Jurassic rifting, magmatism and microcontinental translation ~180 Ma have scarred this region. Using regional geophysical compilations we recently proposed that the Jurassic movement of the Haag Ellsworth microcontinental block was limited to ~300 km, and that little block rotation occurred (Jordan et al., 2017. Gondwana Research). This model assumes that the observed magnetic structures within the Weddell Sea Rift System are dominantly magmatic, and were associated with two distinct phases of extension. Adjacent to the rift system new high resolution aeromagnetic data over the Foundation Ice Stream reveal the detailed structure of the ~500 Ma orogen. Processing of opportunistic strapdown gravity data collected using a tactical grade INS is able to reveal the continuing impact these structures have on the sub-ice topography. These new aerogeophysical datasets demonstrate the important future role for high resolution data in unravelling the tectonic evolution of this region, and we identify key tectonic structures which should be targeted. The future requirement for extensive high resolution data suggests that new low-cost platforms such as UAV's must be considered for future Antarctic aerogeophysical research.

Posters

Airborne geophysics images a Pan-African transpressional orogen super-imposed on a Grenvillian accretionary belt in central East Antarctica

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The Gamburtsev Subglacial Mountains in interior East Antarctica are underlain by 50-60 km thick crust imaged by seismic and gravity models. In contrast, the Archean to Mesoproterozoic Mawson craton that occupies the Wilkes and Terre Adelie sector of East Antarctica typically features only 40-45 km thick crust. Over 200 km thick and seismically fast lithosphere underlies the Gamburtsev Province, as typically observed over Precambrian lithosphere that has not been substantially reworked during Phanerozoic subduction or collision.

Ferraccioli et al., (2011) proposed that a segment of a stalled orogen, i.e. an orogen where widespread orogenic collapse and root delamination has not occurred, is preserved in the Gamburtsev Province and further hypothesised that its origin relates to widespread accretionary and subsequent collisional events at ca 1 Ga, linked to the assembly of the Rodinia supercontinent. However, recent passive seismic interpretations (An et al., 2015) indicate that crustal thickening relates instead to Pan-African age assembly of Greater India, East Antarctica and Australia within Gondwana (at ca 550 Ma).

Here we interpret a set of enhanced aeromagnetic and airborne gravity images, depth to magnetic and gravity sources and preliminary 2D and 3D forward and inverse models to characterise the crustal architecture of the Gamburtsev Province.

Enhanced aeromagnetic images reveal a system of subglacial faults that segment the Gamburtsev Province into three distinct geophysical domains. Offsets in high-frequency magnetic anomalies are interpreted as revealing a right-lateral predominantly transpressional fault system parallel to the previously proposed Gamburtsev Suture. Magnetic modelling provides support for the existence of positive flower structures and basement push ups. Large-scale Pan-African age transpression in interior East Antarctica is linked here with collision of Greater India and a mosaic of distinct lithospheric provinces in East Antarctica. Pan-African transpression likely reactivated pre-existing fault systems that may have formed during Grenvillian-age accretion of arc terranes, as hypothesised in the interior of Eastern Dronning Maud Land (Jacobs et al., 2015). By compiling aeromagnetic, airborne gravity, and satellite magnetic and satellite gravity data over the Gamburtserv Province and Eastern Dronning Maud Land we assess whether these two areas may be linked together during the inferred Grenvillian accretionary and Pan-African collisional tectonic stages.

Aerogeophysical data as a tool to quantify isostatic responses to erosion- case studies from the Gamburtsev Subglacial Mountains and the Recovery Glacier in East Antarctica

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1 NERC/British Antarctic Survey

The relative roles of climate and tectonics in mountain building and basin evolution have been widely debated. Here we demonstrate the utility of airborne geophysics as a tool to help constrain erosion-driven uplift in two sectors of East Antarctica that differ in terms of their subglacial landscape and geological and glaciological settings: the Gamburtsev Subglacial Mountains and the Recovery Glacier region.
Interpretation of airborne radar data reveals that the pre-glacial fluvial landscape of the Gamburtsevs was overprinted by Alpine-style glacial erosion (Rose et al., 2013 EPSL). In contrast, the bed topography beneath the Recovery catchment is bimodal with the Shackleton Range and Theron Mountains separated by fault-controlled subglacial troughs, occupied by fast-flowing ice streams (Paxman et al., 2017 JGR).
By combining radar and airborne gravity observations, we constrain the subglacial topography, the location of major fault systems and the effective elastic thickness of the lithosphere in the Gamburtsev and Recovery provinces respectively. These constraints enable us in turn to develop new flexural models of intraplate mountain uplift. Inverse spectral and forward modelling methods indicate that the effective elastic thickness of the lithosphere is surprisingly low, considering the cratonic setting of East Antarctica (5–20 km in the Gamburtsev region and 20–25 km in Recovery). 3D flexural models indicate that valley incision has contributed only 17–25% of Gamburtsev peak uplift (Paxman et al., 2016 EPSL). These values are typical of temperate mountain ranges, suggesting that most of the valley incision in the Gamburtsevs occurred prior to East Antarctic Ice Sheet development ca. 34 Ma ago. In the Recovery catchment, flexure accounts for up to 40–50% of peak uplift (Paxman et al., 2017 JGR), suggesting that it is instead linked with more recent selective Oligocene to Neogene age erosion within the Recovery and Slessor ice streams.

Airborne Ground Penetrating Radar Measurements on James Ross Island (Antarctica): First Results

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In this poster we present first results of a field study on Gourdon Glacier (James Ross Island, Antarctica) with a 25MHz ground penetrating radar flown as a sling load by a Bell 212 helicopter.
James Ross Island is located east from the northern Antarctic Peninsula in a region which has undergone considerable changes in the last decades with the retreat or disintegration of several ice shelves (e.g. Prince Gustav Channel, Larsen-A/B). The glaciers of James Ross Island have shown predominantly retreat over the last decades while some glaciers showed also advance. In this context, we investigate the glacier dynamics and mass changes on James Ross Island using different approaches: geodetic glacier mass balances and the flux-gate approach (input-output method). A comprehensive set of field observation (surface mass balance, time lapse camera, automatic weather stations, permanent GPS recorders) is run over several years. Additionally, a detailed remote sensing data analysis is carried out and will be continued in the coming years.
Like most of the glaciers on James Ross Island, Gourdon Glacier is an elongated outlet glacier reaching from ~ 300m a.s.l. to sea level. It is separated by a ~300 to 500 m high steep wall from its receiving catchment area on the plateau of the island. In order to improve the ice flux estimates and to provide basic information on the bedrock topography we started a comprehensive airborne ground penetrating radar (GPR) campaign on Gourdon Glacier in February 2017.
We deployed a 25 MHz GPR system with DGPS, laser altimeter, and IMU for precise geolocation from an Argentine Airforce Bell 212 helicopter. Ice thickness and elevation data were collected on more than 50 km of profiles along with a camera system mounted on the antenna. Our poster presents first results of the GPR measurements of 2017. Preliminary analysis retrieved ice thicknesses of up to 350m. Further measurements are planned for February 2018 and will include repetitions of profiles flown by previous ice thickness surveys from the 1980's and mid 1990's in order to evaluate potential changes in the accumulation area.

Simulation of GNSS reflection amplitudes considering sea ice permittivity and roughness

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Global Navigation Satellite System (GNSS) signals can be exploited to remotely sense sea ice conditions. New opportunities for sea ice and ocean remote sensing are currently under exploration in the field of GNSS Reflectometry. This study focuses on the simulation of GNSS reflection amplitudes based on sea ice permittivity and roughness, which are important parameters for sea ice classification and characterization. The polarimetric ratio between cross- and co-polar signals shall be predicted. For this purpose, the Fresnel reflection coefficients for representative examples of sea ice, sea water and snow with circular polarizations at L-band are presented firstly. The simulated polarimetric ratio for satellites observed at low elevation angle (3°-30°) is then calculated considering sea ice permittivity and roughness. In order to estimate the potential use of reflected GNSS signals for sea ice detection, the simulated observables are evaluated against in-situ measurements. These measurements were obtained during the Fram Strait 2016 cruise of the Norwegian research vessel (R/V) Lanc between 25 August and 13 September 2016. The Fram Strait is the major link between the Arctic and the Atlantic Ocean with regular occurrence of drift ice. The ship's track on its main section went from Svalbard at 10°E roughly along 79°N to the Eastern Greenland coast at 13°W and back. Different ice conditions were encountered: open water with a rough sea surface close to Svalbard, a dense coverage of multiyear drift ice in the center of Fram Strait and multiyear fast ice at the Greenland coast.