REPORT
International Workshop
„Airborne Geodesy and Geophysics with Focus on Polar Applications"
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Workshop

The International Workshop „Airborne Geodesy and Geophysics with Focus on Polar Applications" was held in Dresden, Germany, from 19 to 21 April 2017. It was supported by the German Research Foundation (DFG), the International Association of Geodesy (IAG), the Scientific Committee on Antarctic Research (SCAR) and the German Society for Polar Research (DGP). The support of the DFG is specially acknowledged because the workshop was organized as a thematic workshop in the framework of the DFG Priority Program (SPP 1294) "Atmospheric and Earth System Research with HALO".
The workshop was the third in a series of thematic workshops on airborne techniques in polar geosciences. Following respective workshops in Dresden (Germany) in 2009 and in Potsdam (Germany) in 2012, this time we welcomed about 40 participants from six countries (Germany, United Kingdom, USA, China, Norway, Denmark). During six oral sessions, one poster session – accompanied by a small technology display – and a concluding panel discussion, the participants discussed the present status and future prospects of geoscientific airborne surveying in the polar regions.

Rationale

The polar regions with their continental ice sheets and partly ice-covered oceans play a crucial role in the Earth system. They are critical to understanding and predicting climate evolution and global sea level change. Antarctica, however, confronts us with an especially hostile environment and a vast extent that make huge areas inaccessible to any ground-based research.
On global to continental scales, satellite missions make a variety of observations related to all fields of polar science. However, satellite-based measurements are limited in resolution, sensitivity and accuracy. Higher resolution and more accurate observations are required in order to answer questions related to the gravity field and inner structure of the Earth or to the geometry and properties of the ice sheet.
In this context, airborne platforms offer the most amenable and powerful means of surveying the polar areas. Airborne platforms are adaptable to meet a diversity of scientific demands, bridging the gaps between a wide range of sparse ground-based point observations and satellite measurements. The huge variety of airborne platforms available today also offers the prospect to conduct surveys with a variety of survey resolutions and extents.

Concise overview of the oral sessions

M. Scheinert, host of the workshop and chair of IAG Subcommission 2.4f "Gravity and Geoid in Antarctica", reported on the rationale, on the progress of the Antarctic Geoid Project (AntGG) and on project plans to utilize the new German research aircraft HALO to survey the Antarctic (ANTHALO). In further talks the progress and accomplishments of various airborne survey campaigns were reported, such as in Alaska for the inference of the new geoid in the US (M. Youngman), in Antarctica through AWI's efforts since 2013 (G. Eagles), in East Antarctica utilizing the new Chinese aircraft "Snow Eagle" (X. Cui), and in the Arctic and Antarctic by the DTU Space group (R. Forsberg).

A second group of talks dealt with the analysis of airborne data to quantify specific geodetic and geophysical parameters. F. Barthelmes and B. Lu reported on the processing of airborne gravity, especially from the GEOHALO mission, and on its application for regional gravity field modelling. Using GEOHALO's gravity T. Schaller inferred the bathymetry in the Mediterranean and gave an outlook to the Antarctic case where the subglacial topography is of interest. K. Tinto discussed the inversion of gravity data for the inference of bathymetry below floating ice shelves and how such inversions can be constrained by geological information. M. Semmling reported on the challenging technique of GNSS reflectometry and its application to the inference of sea-ice and ice-sheet properties.

Thus, there was a close linkage to those talks that focused on the geophysical interpretations of polar airborne data. Themes comprised radar sounding for bathymetry and subglacial freshwater discharge in Antarctica (J. Greenbaum) and the subglacial conditions and flow history of the Recovery region, Antarctica (A. Dietz). F. Ferraccioli gave an overview of the interpretation of recently acquired data from the South Pole region, while T. Jordan focused on an interpretation of an extinct rift system in the Weddell Sea region. The recently investigated subglacial lake and canyon system in Princess Elizabeth Land, Antarctica, was discussed by D. Blankenship (talk given by J. Greenbaum). The search for the best "oldest ice" drilling location is currently a focus in Antarctic sciences. Respective studies in Mary Bird Land and little Dome C area were reported by D. Young.

Finally, several talks dealt with the prospects for development of technologies. N. Brady introduced an improved platform levelling system for airborne gravimetry, which improves accuracy and has the ability to carry out draped flights. Although having been investigated by a number of groups, the strapdown assemblage and technique in airborne gravimetry has not lead to resounding success. Recently, with improved calibration and analyses methods, strapdown gravimetry exhibits promising results (D. Becker). This topic was continued by T. Jensen in a talk that combined gravity data from strapdown and stabilized platform systems. D. Steinhage introduced AWI's research aircraft and extensive suite of airborne instrumentation. F. Pätzold discussed the further technological development of airborne gravimetry in a presentation that provided valuable incitements for the concluding panel discussion. The investigation of temperate glaciers using helicopter-based GPR was discussed by N. Blindow. Further developments in radio-echo sounding (RES), especially with the application of ultra-wideband techniques, were reported by P. Gogineni (talk given by D. Steinhage). Last but not least, T. Bucher and J. Brauchle introduced the Modular Airborne Camera System (MACS) that offers a flexible solution to meeting the various imaging needs of the wide range of polar scientific applications, built around a suite of different-sized metric cameras. As an example, they reported on the MACS project to investigate the Himalaya region.

Discussion

Polar science is no exception to the observation that the choices of research methods and equipment should primarily be driven by science questions. The panel discussion made clear that airborne techniques and equipment remain the leading choice to investigating a tremendous range of questions in polar regions.

Science questions

In geodesy, gravity data are needed globally. Recent airborne surveys, especially those over the polar gap area in Antarctica, have led to an improvement in coverage of such data. Nevertheless, more surveys are needed, especially over the Antarctic ocean and the continent-ocean transition zones. There, airborne gravity provides valuable data to infer further quantities, such as bedrock topography and grounding line location. The latter is especially crucial for ice mass balance studies by the input/output method.
Currently, airborne gravimetry has limitations in accuracy (1 mGal level) and is, due to the available sensors (accelerometer on a stabilized platform or in a strapdown mounting), a relative method. Airborne gravimetry has not yet been applied for gravity change studies. This might change with the onset of new technologies (see below), which will allow drift-free and absolute measurements to be repeated over specific areas.
Airborne surveys that enable inferences of ice-sheet elevations (laser altimeter and scanner, RES, GNSS reflectometry, stereo photogrammetry) are especially valuable in studies of those regions where satellite altimetry provides contradictory results. In this respect, the inner East Antarctic plateau is the region with the worst signal-to-noise ratio, and this impedes better insight into the ice-sheet mass balance by both the altimetric and the input/output methods. Airborne surveys can provide repeated measurements to study elevation change directly but also data (potentially in connection with true ground-truth data) for validation and, eventually, calibration of satellite data.

In geophysics, exploration and interpretation can be improved with denser data coverage. A flight profile layout that features sparse line spacing acquired along just one direction might preclude the detection of certain features. Here, the entire suite of available platforms – from long-range aircraft to UAVs enabling high-resolution surveys – should be taken into consideration. It was emphasized that regions with inferior data density or quality (e.g. surveys pre-dating GPS) need to be re-surveyed. Furthermore, there is an urgent need for science that better links the earth interior with the cryosphere (e.g. via studies of geothermal heat flux or mantle rheology). Also, geophysical findings should be better communicated to geology to foster further interpretation and synthesis.

The demands of glaciology are closely linked to those of geophysics, geology and geodesy. Glaciologists need a better knowledge of subglacial properties and boundary conditions (e.g. subglacial water and drainage patterns, geothermal heat flux) that can be fed into ice-sheet modelling to improve our understanding of related processes. The spatial resolution of these data should be increased to scales from which internal ice sheet properties can be inferred. In this respect, airborne methods provide the only tool that is capable of laterally correlating the high-vertical-resolution information between existing and planned deep ice cores. It was also discussed that it might be desirable to overcome the largely artificial distinctions that have led to rather different treatments and understanding of the East Antarctic and West Antarctic ice sheets. With denser and more reliable (yet accurate) data we might be able to investigate properties and processes at a much higher level of heterogeneity. For this, glacial-isostatic adjustment modelling that connects ice mass changes (from the last-glacial maximum up to the present) with Earth's interior (the rheological properties from the crust down to the lower mantle) is a prominent example.

It was also discussed whether it is necessary to know the geology in the entire Antarctic or in specific areas only. In the first instance, existing (and published) recent compilations (like AntGG and ADMAP) should be developed and used more intensively. These compilations are based to a great extent on airborne surveys. Existing models (e.g. of tectonics and past geological processes) will need to be verified because of their implications for further interpretation.

In conclusion, it was stated that it is necessary to strengthen efforts towards integration of the different models being produced and used by the various disciplines. As already outlined, airborne surveys are the method of choice in the polar regions to gather diverse data in a consistent way. Therefore, airborne methods are best suited for validation of data and data products, for reconnaissance in the preparation of challenging projects (e.g. new drilling and the search for oldest ice).

Target areas

Besides the general applicability of airborne surveying to the remote and vast areas of the Arctic and the Antarctic, some regions have been identified that should be a target of intensified investigation in the near future. These are the interior of East Antarctica (see above), the Bellingshausen Sea embayment, the Weddell Sea region and the Astrolabe Basin. In particular, more emphasis should be placed on the offshore/onshore transition zones that are so crucial for mass balance studies and understanding the ice sheet's response to the ocean. There are many further synergies, not least of which those that feed into sea level change studies. For example, tectonic structures and grounding lines are major features that need to be characterized with both greater precision and accuracy. It is imperative that the ocean/continent transition zones (especially in Antarctica) should be taken into consideration when designing surveys. However, Greenland and the Arctic should not be neglected in future work. Although subglacial lakes and drainage systems have been detected beneath the Greenland ice sheet, the dynamics of its ice sheet are still far from being fully understood. In this respect, the north-east Greenland ice stream (NEGIS) and the surging behavior of glaciers in both Greenland and Svalbard should be brought further into focus.
In summary, it has to be stressed that we need to look into both poles for a better understanding of processes linking cryosphere with the solid Earth and the (global) ocean.

Development of technology and methods

Nowadays, a complete suite of sensors is available for geoscientific airborne surveys. Depending on the size of the platform, payloads may consist of anything between a single (main) sensor and an integrated multidisciplinary suite of sensors. Common to all surveys is the need for a precise determination of the flight trajectory by means of GNSS, potentially complemented by an INS.

With regard to radar echo sounding (RES), recent developments lead to multifrequency systems and to systems exploiting further frequencies. In particular, one has to mention new ultra-wideband systems (reaching from 150 to 500 MHz), which are capable of simultaneously inferring both subglacial topography and internal ice layering. The ability to study the sub-surface of ice sheets can be improved by the concept of multistatic L-band radar. This concept is investigated, e.g., using signals of GNSS constellations for reflectometry or using L-band signals for tandem radar satellites. Observations at various incidence angles, as provided by deploying radar receiver and transmitter on different platforms (multistatic radar), perspectively allow tomographic investigations of ice sheets. Also, the development of polarimetric radars has to be mentioned. The penetration and resolution of these techniques depend on instrument power and on firn density distribution with depth, but potentially allow the definition of anisotropy within the ice body. At the same time, the field of applications has been enlarged, stretching from applications on land and close to the poles, but also to any glaciated environments and to snow cover on sea ice.

In terms of laser altimeter and laser scanners, there are numerous applications taking advantage of the diverse ranges and resolutions of available sensor-platform combinations. With respect in particular to ice-surface elevation and roughness (small-scale topography), metric cameras open the door to

a whole field of powerful applications. It has been recommended to integrate metric cameras (instead of the currently used low-quality non-metric cameras) as a standard sensor in airborne surveys.
Special emphasis was given to the question of the future development of airborne gravimetry. Close collaborations between technology developers and scientific users are important to guide and make use of new developments (e.g. atom interferometry). At present, accelerometers based on the spring force principle are the prevailing method in airborne gravimetry. This has started to be complemented by the promising developments in strapdown gravimetry using carefully calibrated and controlled IMUs.
IMUs are also a perfect candidate for integration into platforms smaller than fixed-wing aircraft such as UAVs (unmanned aerial vehicles). IMU payloads might weigh as little as five kilograms or less, and are needed anyway to solve for attitude and to support trajectory solutions.

Regarding UAVs, it was stated that they might provide a link between ground-based and fixed-wing airborne surveys. However, their payload limitations mean that UAV applications need to be focused on very specific science purposes. It was proposed to increase the cooperation in that field such that (time consuming and expensive) developments are not needlessly duplicated. The task of finding a suitable umbrella for such cooperation remains open.
Also, the possibility of intensified cooperation between institutes and countries needs to be discussed with respect to logistic and hardware issues. For instance, this could be done by setting up a pool of UAVs serving a specific survey purpose (see above) but also to open access to new hardware developments like the next-generation Iridium for broadcasting status information and data.