

## FIELD OPERATIONS AND PROGRESS OF CHINESE AIRBORNE SURVEY IN EAST ANTARCTICA THROUGH THE “SNOW EAGLE 601”

X. Cui<sup>1,\*</sup>, J. Guo<sup>1</sup>, L. Li<sup>1</sup>, X. Tang<sup>1</sup>, B. Sun<sup>1</sup>

<sup>1</sup> Polar Research Institute of China, Jinqiao Road 451, Pudong New District, Shanghai, China - (cuixiangbin, guojingxue, lilin, tangxueyuan, sunbo) @pric.org.cn

Commission III, WG III/9

**KEY WORDS:** Airborne Survey, “Snow Eagle 601”, Princess Elizabeth Land, Radio Echo Sounding, East Antarctica

### ABSTRACT:

The Antarctic plays a vital role in the Earth system. However, our poor knowledge of the Antarctic limits predicting and projecting future climate changes and sea level rising due to rapid changing of the Antarctic. Airborne platforms can access most places of this hostile and remote continent and measure subice properties with high resolution and accuracy. China deployed the first fixed-wing airplane of “Snow Eagle 601” for Antarctic expeditions in 2015. Airborne scientific instruments, including radio-echo sounder, gravimeter, magnetometer, laser altimeter etc., were configured and integrated on the airplane. In the past four years, the airborne platform has been applied to survey the Princess Elizabeth Land, the largest data gap in Antarctica, Amery Ice Shelf and other critical areas in East Antarctica, and overall ~ 150,000 km flight lines have been completed. Here, we introduced the “Snow Eagle 601” airborne platform and base stations, as well as field operations of airborne survey, including aviation supports, daily cycle of the scientific flight, data processing and quality control, and finally summarized progress of airborne survey in the past four years.

### 1. INTRODUCTION

The Antarctic, including the Antarctic Ice Sheet (AIS), the continent, the surrounding Southern Ocean and annually changed sea ice, comprises a critical part of the Earth System. The most uncertainties in evaluating and estimating future global sea level rising and climate change are changes of the Antarctic with a warming climate (IPCC, 2019; Edward et al., 2019). Our knowledge of the Antarctic is still very poor due to significant lacking of measurements. The large extent, remote location, icy properties and hostile conditions make it very hard to observe from ground. In the past decades, space-borne observations have helped to characterize the Antarctic and monitor its changes with high efficiency of mapping the Antarctic repeatedly and in continental scale (Dirschel et al., 2020). However, it is difficult for satellite remote sensing to survey subice properties of the AIS and geology of the continent. Satellite observations are also limited by data spatial resolution and accuracy.

Airborne survey has been developed and extensively used in the Antarctic since the 3rd International Polar Year (IPY 3, 1957-58). Airborne measurements contributes our most knowledge of geometry, internal structure and subglacial topography of the AIS, and magnetic and gravity anomaly of the continent. For example, the most important direct ice thickness measurements in Bedmap 2, the recently released compilation of ice thickness and bedrock elevation of the AIS, are largely contributed by airborne radar observation (Fretwell et al., 2013). Airborne platforms can install multidisciplinary instruments, and offer the most flexible and powerful means of surveying the Antarctic. Although techniques and equipment of satellite and ground-based observation are improved significantly, airborne survey remains the leading choice for addressing the tremendous range of questions in the Antarctic (Bell et al., 2011; Jeofry et al., 2018; Jordan et al., 2018; Karlsson et al., 2018; Scheinert et al., 2017; Schroeder et al., 2019; <https://www.cresis.ku.edu>).

In 2015, China deployed the first fixed-wing airplane——“Snow Eagle 601”, a BT-67 aircraft, for Chinese National Antarctic Research Expedition (CHINARE, Cui et al., 2018). The airplane was modified to be adaptable to operation and scientific

observation in polar regions. Scientific instruments configured and integrated in the airplane include airborne radio echo sounder (RES), gravimeter, magnetometer, laser altimeter, camera and Global Navigation Satellite System (GNSS). During the 32nd Chinese National Antarctic Research Expedition (2015/16), the airborne platform was firstly applied to investigate Princess Elizabeth Land (PEL), the largest data gap in Antarctica (Cui et al., 2017). Meanwhile, the International Collaborative Exploration of Cryosphere by Airborne Profiling in PEL (ICECAP/PEL) for scientific operations of “Snow Eagle 601” was initiated by China, USA and UK.

In this work, the “Snow Eagle 601” airborne platform and scientific base stations were introduced firstly; then, field operations of Chinese airborne survey, including aviation supports, daily cycle of the scientific flight, and data processing and quality control (QC) were introduced in detail; finally, progress of airborne survey in the past four years was summarized.

### 2. “SNOW EAGLE 601” AIRBORNE PLATFORM AND BASE STATIONS

The “Snow Eagle 601” is a BT-67 aircraft modified from the old DC-3 aircraft with standard improvements and modifications for polar operations, such as new turbine engine, modern electrical system, structural reinforcement, ski/wheel gear, oxygen system, air conditioner, large cargo door etc. (Figure 1). There are about seven BT-67 airplanes operated in Antarctica every year to provide logistical supports and scientific services. Extensive applications in Antarctica prove its adaptability and capability for polar operations.

The “Snow Eagle 601” is deployed by China for three objectives including scientific observation, logistical transportation and emergency rescue. The airborne scientific instruments are configured mainly focusing on aerogeophysical investigation, including an improved High Capability Airborne Radar System (HiCARS), a GT-2A gravimeter and a CS-3 magnetometer, as well as laser altimeter, camera and GPS to provide referencing surface and position information. The HiCARS has deep

penetrating capability and relatively high vertical resolution, and can be used to measure ice thickness, subglacial conditions and internal structure of ice sheets. The GT-2A gravimeter and CS-3 magnetometer have good performance in Antarctica, and can help to infer deep geologic and tectonic structures of the continent. All airborne instruments except for the GT-2A gravimeter are integrated by the Environment for Linked Streams Acquisition (ELSA) system which is developed by University of Texas, Institute for Geophysics (UTIG). ELAS allows operators to manage and monitor data acquisition and check data quality in real time in the airplane. More introductions about the “Snow Eagle 601” airplane and airborne scientific system can be found in Cui et al. (2018).



Figure 1. The “Snow Eagle 601” airplane flying over icebergs in coastal areas of Larsemann Hills, East Antarctica. Two flat plate antennas are installed under two wings respectively; the CS-3 magnetometer is installed in the tail boom; the GT-2A gravimeter is installed in the airplane.

In the past four years, aviation operations of “Snow Eagle 601” are primarily based on the Russian Progress Station skiway, about 10 km away from Chinese Zhongshan Station in Larsemann Hills. A seasonal camp is constructed beside the skiway, consisting of specially designed cabins and containers for field accommodation, power supply, working and storage (Figure 2). Two GPS base stations are installed on the top of two cabins for potential post differential processing of airborne GPS data. A magnetic base station is installed a little far away from the camp to collect data for daily variety correction of airborne magnetic measurements. Gravity tie measurements between landing point of the aircraft and gravity base at Zhongshan Station are conducted every season for post gravity anomaly calculations.



Figure 2. The temporary camp beside the Russian Progress Station skiway. Two GPS base stations are located on the top of two cabins, the magnetometer base station and scientific base stations

### 3. FIELD OPERATIONS

#### 3.1 Aviation Operations

The “Snow Eagle 601” belongs to Polar Research Institute of China (PRIC), but now is registered in Canada. Kenn Borek Air (KBA), a professional company operating most BT-67 and Twin Otter airplanes in polar regions, provides services of aviation operations of the airplane. At the beginning of a season, the “Snow Eagle 601” need fly to Antarctica from Calgary in Canada, passing by McAllen in USA, Liberia in Costa Rica, Guayaquil in Ecuador, and Arica, Talcahuano, Punta Arenas in Chile. The first stop in Antarctica is UK’s Rothera Station. Then, the “Snow Eagle 601” flies to Zhongshan Station via USA’s South Pole Station.

A field team with about 6 members organized by PRIC will provide logistical supports for aviation operations, for example refueling, transportation, camp and vehicle maintenance, and communication. Another field team with about 6 members will take in charge of airborne survey, including flight operations (FOP) and base operations (BOP). The main duty of FOP is to install and maintain all airborne instruments, design flight plans, and collect data in the airplane. BOP focuses on data processing and QC, and operations of base stations.

#### 3.2 Daily Cycle of Scientific Flight

Before a science flight, at least two flight plans should be prepared for the crew to determine where to go according to weather conditions in target areas and flight limitations (e.g., flight range, flight altitude etc.). A flight plan should be designed under full considerations of scientific significance and objectives, existed survey lines and measurements in target areas, and flight limitations. Waypoints along the flight route with longitude and latitude should be provided for the flight navigation, and surface elevations, flight height over the surface and flight altitude should be noted in the flight plan. We also introduce the PST (Project/Set/Transect, e.g., PEL/GCX0g/X148a) concept, a system of data organization, to manage flight profiles and data processing. The “Project” is a systematically organized survey plan, and can be names of target areas or scientific campaigns (e.g., PEL is Princess Elizabeth Land). The “Set” is either a particular survey platform or a particular subset of the “Project” (e.g., GCX0g is the seventh version of the first acquisition system on C-FGCX, “Snow Eagle 601”’s registered code in Canada). The “Transect” is a particular survey line within a “Project”. PSTs are imported into data acquisition system by FOP during the flight. Each PST is a unique transects of data collected at a discrete location and at a particular time, and it is very useful for future data processing, classification and interpretation.

In a daily mission cycle, at least half an hour before the flight, FOP and BOP should start pre-flight airborne gravimeter and GPS data collection and operations of base stations respectively; during the flight, FOP focuses on data collection in the airplane, and BOP operates base stations on ground; after the airplane landing, FOP and BOP need at least half an hour to complete post-flight airborne gravimeter and GPS data collection and operations of base stations respectively. Finally, data from airborne instruments and base stations, and all documents, including the flight plan, flight notes, airborne instrument checklists, produced during the flight should be moved to BOP for data processing, QC and archiving. Data QC results should be checked and discussed by both FOP and BOP before the next flight to confirm that all instruments operate well and data are reasonable in target regions.

### 3.3 Data Processing and QC

Data are preliminarily processed in field to produce analyzable data files of different instruments with corresponding PSTs. All measurements will be linked to GPS positions according to an accurate recording time generated by ELSA. Field data processing is implemented by BOP in the camp or Zhongshan Station. Raw data in different medias are firstly downloaded to a QNAP RAID (Redundant Array of Independent Disks), and then are “breakout” into readable binary and ASCII files, which are separated into different instrument streams and different PSTs. Moreover, each data stream from one airborne instrument will be processed through specially designed “code package” to improve data quality for further data plotting and QC during the “breakout”. For example, airborne RES data are processed through down conversion, removal of direct current (DC) offsets, pulse compression, coherent stacking and incoherent stacking (area with blue background in Figure 3).

Data QC in field is used to evaluate performance of all instruments and confirm that data collected in target regions are acceptable and reasonable. We also can identify that do we get the data required to answer our science questions. Data after processing are plotted and analyzed for every single instrument based on a uniform standard which classifies data quality into four levels of good, moderate, not good and bad. Meanwhile, consistencies of data from different instruments are analyzed to access flight status, ice and geology mapping results. For example, ice mapping results are accessed by analyzing consistencies of data from high gain channel of RES, the airborne Global Positioning System (GPS) antenna at center of airplane gravity (CG), Inertial Measurement Unit (IMU), and laser altimeter (Figure 4a). Results of data QC are finally labeled and filled in the QC review sheet with blue, yellow, orange and pink colors corresponding to levels of good, moderate, not good and bad respectively (Figure 4b).

Raw data, processed data, flight notes, airborne instrument checklists, base station checklists, and documents produced during data processing and QC, will be archived in different tapes with tape driver for every flight after data processing and QC.

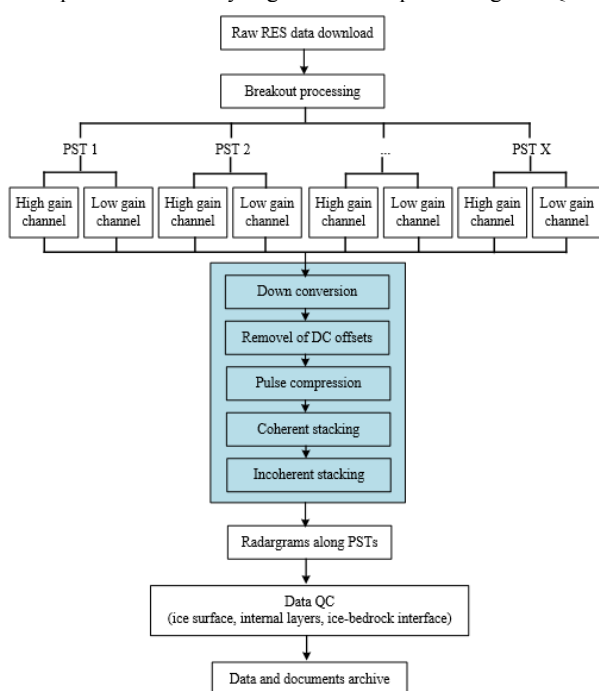


Figure 3. Airborne RES data processing and quality control in field

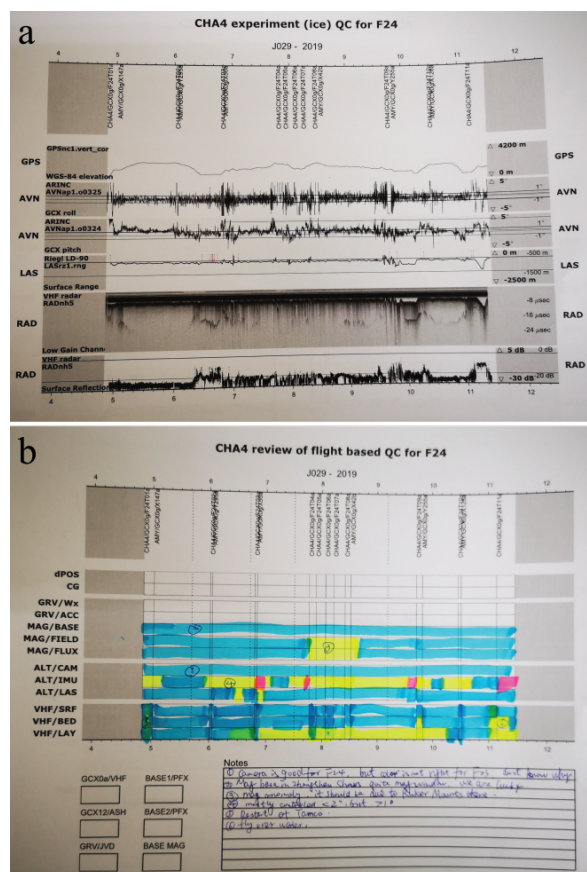


Figure 4. Ice QC (a) and review (b) sheets for data quality control. VHF/SRF, VHF/BED and VHF/LAY are QC reviewing results of ice surface, ice-bedrock interface and internal layers of radar data; CHA4 is the 35<sup>th</sup> CHINARE (2018/19)

## 4. PROGRESS

Airborne survey in Antarctica is one of the most important applications of “Snow Eagle 601”. Flight hours of scientific observation is kept at about 120 hours every year, while the total flight hours are about 190 hours. In the past four years, data along ~150,000 km surveying lines have been successfully acquired by “Snow Eagle 601”. Flight lines cover several critical areas in East Antarctica, such as PEL, Amery Ice Shelf, West Ice Shelf, Ridge B, Gorge V Coast, David Glacier Catchment, etc., as shown in Figure 5.

The airborne survey in PEL has the highest priority in the past four years. The motivations are to fill this largest data gap in Antarctica (Fretwell et al., 2013; Golynsky et al., 2018; Scheinert et al., 2016), including mapping ice sheet geometry, bedrock topography and subglacial conditions, measuring gravity and magnetic anomaly to infer geological properties and structures of PEL. Moreover, satellite remote sensing results show a large subglacial lake potentially developed in PEL, and extensive canyon system beneath ice may link the lake with coastal ice sheet and grounding zone of West Ice Shelf (Jamieson et al., 2016). Airborne data collected in PEL will help to identify and characterize the subglacial lake and canyon system in detail, and provide critical boundary conditions and parameters for models to study their impacts to dynamics and instability of ice sheet in the sector. Further airborne surveys over Amery Ice Shelf and West Ice Shelf, two large ice shelves in East Antarctica, will contribute to studies of dynamic changes of ice shelves and their vulnerability to warming ocean. Two flights over Ridge B, the most interior of East Antarctic Ice Sheet, have great significance to searching for the oldest ice in the region. Airborne surveys



over Titan Dome have the similar motivations with surveys over Ridge B. Airborne surveys over West Ice Shelf, northern part of Amery Ice Shelf, Gorge V Coast and David Glacier Catchment are all initiated by both ICECAP/EAGLE (East Antarctic Grounding Lines Experiments) and ICECAP/PEL campaigns through international QPQ collaborations with Australia and USA (black boxes in Figure 5). To characterize and evaluate fast changes of ice shelves and ice sheets in coastal areas are the main motivations of ICECAP/EAGLE.

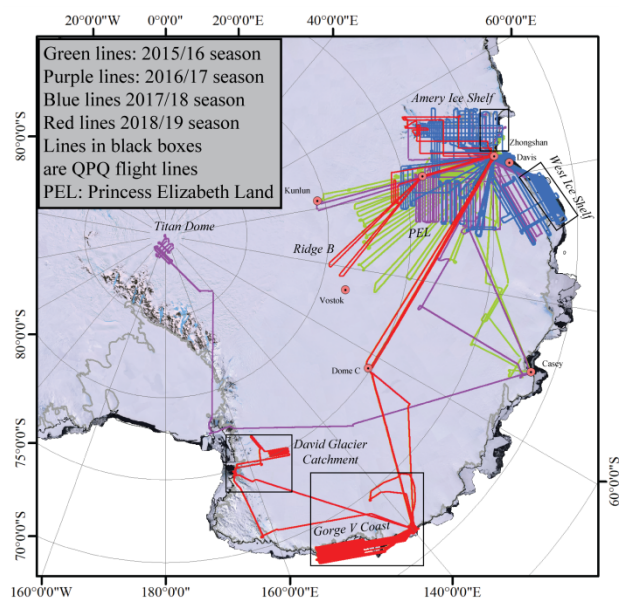


Figure 5. Flight lines coverage. Background is the LIMA (Landsat Image Mosaic of Antarctica) mosaic

## 5. CONCLUSIONS

Our knowledge of the AIS and geology of the continent has been significantly improved through international airborne survey since the 3rd IPY in 1960s when airborne platforms were firstly applied in Antarctica. In 2015, China deployed the “Snow Eagle 601” airplane for Antarctic expeditions. Airborne RES, gravimeter, magnetometer, laser altimeter and camera were configured and integrated on the airplane for scientific surveys. In the past four years, the airborne platform has been applied to survey PEL, the largest data gap in Antarctica, through international campaign of ICECAP/PEL. Furthermore, the airborne survey was extended to Amery Ice Shelf, West Ice Shelf, Ridge B, Gorge V Coast, David Glacier Catchment, etc.. Overall ~150,000 flight lines have been completed in East Antarctica. Field operations of the “Snow Eagle 601”, including logistical supports, flight plan design, airborne data collection, operations of base stations, data processing and QC, have been systematically implemented to serve further scientific researches. Meanwhile, reliability and capability of the airborne platform was verified and proved. Data collected over these critical areas in Antarctica will be great contributions to international efforts on Bedmap, ADMAP and AntGG compilation, as well as AntArchitecture studies in continental scale in future (Fretwell et al., 2013; Golynsky et al., 2018; Scheinert et al., 2016; Winter et al., 2019). Also, the “Snow Eagle 601” airborne platform will keep playing active roles in investigate the Antarctic.

## ACKNOWLEDGEMENTS

This work was supported by the National Key Research and Development Program of China (2019YFC1509102), the

National Natural Science Foundation of China (41941006, 41730102, 41776186). We thank the CHINAREs, scientists from UTIG and crew from Kenn Borek Air Ltd. for their support of airborne survey operations.

## REFERENCES

- Bell, R. E., Ferraccioli, F., Creyts, T. T., Braaten, D., Corr, H., Das, I., . . . Rose, K. 2011. Widespread persistent thickening of the East Antarctic Ice Sheet by freezing from the base. *Science*, 331(6024), 1592-1595.
- Cui, X., Greenbaum, J. S., Beem, L. H., Guo, J., Ng, G., Li, L., . . . Sun, B. 2018. The first fixed-wing aircraft for Chinese Antarctic Expeditions: Airframe, modifications, scientific instrumentation and applications. *Journal of Environmental and Engineering Geophysics*, 23(1), 1-13.
- Cui, X., Wang, T., Sun, B., Tang, X., & Guo, J. 2017. Chinese radioglaciological studies on the Antarctic ice sheet: Progress and prospects. *Adv. Polar Sci*, 28, 161-170.
- Dirscherl, M., Dietz, A. J., Dech, S., & Kuenzer, C. 2020. Remote sensing of ice motion in Antarctica—A review. *Remote Sensing of Environment*, 237, 111595.
- Edward, H., Pattyn, F., Navarro, F., Favier, V., Goelzer, H., van den Broeke, M., . . . Bulthuis, K. 2019. Mass balance of the ice sheets and glaciers—progress since AR5 and challenges. *Earth-science reviews*.
- Fretwell, P., Pritchard, H. D., Vaughan, D. G., Bamber, J. L., Barrand, N. E., Bell, R., . . . Casassa, G. 2013. Bedmap2: improved ice bed, surface and thickness datasets for Antarctica. *The Cryosphere*, 7(1), 375-393.
- Golynsky, A., Ferraccioli, F., Hong, J., Golynsky, D., von Frese, R., Young, D., . . . Kiselev, A. 2018. New magnetic anomaly map of the Antarctic. *Geophysical Research Letters*, 45(13), 6437-6449.
- IPCC, 2019: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegria, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.
- Jamieson, S. S., Ross, N., Greenbaum, J. S., Young, D. A., Aitken, A. R., Roberts, J. L., . . . Siegert, M. J. 2016. An extensive subglacial lake and canyon system in Princess Elizabeth Land, East Antarctica. *Geology*, 44(2), 87-90.
- Jeofry, H., Ross, N., Corr, H. F., Li, J., Gogineni, P., & Siegert, M. J. 2018. A new bed elevation model for the Weddell Sea sector of the West Antarctic Ice Sheet. *Earth System Science Data*, 10(2), 711-725.
- Jordan, T., Martin, C., Ferraccioli, F., Matsuoka, K., Corr, H., Forsberg, R., . . . Siegert, M. 2018. Anomalously high geothermal flux near the South Pole. *Scientific reports*, 8(1), 1-8.
- Karlsson, N. B., Binder, T., Eagles, G., Helm, V., Pattyn, F., Van Liefferinge, B., & Eisen, O. 2018. Glaciological characteristics in the Dome Fuji region and new assessment for “Oldest Ice”. *The Cryosphere*, 12(7), 2413-2424.

Scheinert, M., Eagles, G., & Tinto, K. 2017. Airborne Platforms Help Answer Questions in Polar Geosciences. *Eos*, 98.

Scheinert, M., Ferraccioli, F., Schwabe, J., Bell, R., Studinger, M., Damaske, D., . . . Leitchenkov, G. 2016. New Antarctic gravity anomaly grid for enhanced geodetic and geophysical studies in Antarctica. *Geophysical Research Letters*, 43(2), 600-610.

Schroeder, D. M., Dowdeswell, J. A., Siegert, M. J., Bingham, R. G., Chu, W., MacKie, E. J., . . . Winstein, K. 2019. Multidecadal observations of the Antarctic ice sheet from restored analog radar records. *Proceedings of the National Academy of Sciences*, 116(38), 18867-18873.

Winter, A., Steinhage, D., Creyts, T. T., Kleiner, T., & Eisen, O. 2019. Age stratigraphy in the East Antarctic Ice Sheet inferred from radio-echo sounding horizons. *Earth System Science Data*, 11(3), 1069-1081.