DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2014/7

# High resolution airborne hyperspectral Spectroscopy in Central East Greenland 2012 - Data acquisition and pre-processing

Leif Thorning, Nicolai Nørtoft Christensen, Símun D. Olsen, Peter Riisage,
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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

GEUS

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G E U S

**Content**

# 1. Abstract

The purpose of this report is to document the acquisition and basic processing of data in the HyperEast 2012 project, covering two remote sensing (hyperspectral, LiDAR, photography) data sets from central East Greenland; the Carlsberg Fjord hyperspectral survey and the Kap Simpson hyperspectral survey.

Both surveys were flown in August 2012 by NERC ARSF[1] in accordance with the survey design laid out by GEUS, using a Dornier aircraft fitted with instrumentation for hyperspectral airborne scanning, LiDAR laser scanning and digital photography. The aircraft and the ARSF team were in Iceland for another project and flew to Nerlerit Inaat (Constable Pynt) Airport on the East Coast of Greenland. This remote airfield served as the base for seven flights acquiring all the planned HyperEast 2012 data before returning to Iceland.

The Carlsberg Fjord Survey comprises 4426 line km of data covering approximately 2620 km$^2$ (3,44 terabyte as delivered from ARSF); the Kap Simpson Survey comprises 1310 line km of data covering an area of approximately 664 km$^2$ (0,88 terabyte of data). Altogether seven flights were needed, see Appendix 1.

The first, basic processing of the data took place at the Plymouth office of ARSF. The data were then shipped to GEUS on external hard disk drives; the first delivery was a test file enabling GEUS to start up the tuning of processing software; the actual delivery of data processed to ARSF standards took began November 2012 and the last digital data file was delivered on April 2013.

The processing at GEUS encompassed the calculation of a new DEM based on the LiDAR data and resampling, georeferencing, and atmospheric corrections of hyperspectral data. Interpretation of data from special target areas for exploration companies was also started up soon after the delivery of the first data, but will not be described here.

With the conclusion of the processing described in this report, new GEUS data sets have been created, available for purchase and further use by interested parties according to standard GEUS conditions for use of GEUS' digital data. Recommended form of references for data sets is (example):

- *"Multisensor airborne survey of the Carlsberg Fjord region, central East Greenland, flown August 2012:* ***Processed hyperspectral data. GEUS data set id 1, version 1.0, 15 May 2013."***

See section 9 of this report for further details.

The version and date stamp may be changed if future (corrected or enlarged) versions of the data sets are released.

[1] Natural Environmental Research Council, Airborne Research and Survey Facility

# 2. Synonyms and abbreviations

| | |
|---|---|
| ARSF | *Airborne Research and Survey Facility, NERC, England.* |
| BGS | *British Geological Survey.* |
| GEUS | *Geological Survey of Denmark and Greenland* |
| LiDAR | ***Li**ght **D**etection and **R**anging or **L**aser **I**maging **D**etection and **R**anging. Distance to and some properties of the target are measured, from the air or from a point on the ground.* |
| LADAR | *Laser Detection and Ranging, similar to LiDAR, but often used in military contexts. The term "laser radar" is sometimes used, even though LiDAR does not employ microwaves or radio waves and therefore is not radar.* |
| GPS | ***G**lobal **P**ositioning **S**ystem.* |
| NERC | ***N**atural **E**nvironment **R**esearch **C**ouncil. United Kingdom's main agency for funding and managing research, training and knowledge exchange in the environmental sciences.* |
| HyMAP | *A commercial airborne hyperspectral imaging sensor that is manufactured by Integrated Spectronics.* |
| MINEO | ***M**onitoring and assessing the environmental **I**mpact of mi**n**ing in Europe using advanced **E**arth **O**bservation Techniques. An EU-funded project.* |

# 3. Introduction

This report concerns the HyperEast 2012 project, giving a brief documentation of the acquisition and basic processing of the data. The HyperEast 2012 project includes three remote sensing data sets: (i) hyperspectral data; (ii) LiDAR data; and (iii) aerial digital photography. The HyperEast 2012 data sets will be exploited in several on-going or future studies, the results of which will be published later as they become available, or delivered to exploration companies, which have commissioned the studies.

The processing of hyperspectral and ancillary data described in this report is typical for such data and objectives. The amount of data is quite large and has led to delays in the processing scheme at ARSF and at GEUS pointing towards required improvements in the computer set-up and data management required to carry out the processing. There will be further processing to do in relation to classification and interpretation of data but that will be reported elsewhere. In most cases, this report and the references herein should provide a sufficiently detailed account of the basic processing for the generally interested user of interpretational results.

# 4. Project and outlook

***Project title**: Use of hyperspectral and LiDAR data for the discrimination of lithological and structural features in alpine arctic terrain.*

The project encompassing new airborne hyperspectral and LiDAR surveying in Greenland was initiated by GEUS through a joint application with BGS for the use of the ARSF aircraft and equipment in East Greenland. The exploration company Avannaa Resources Limited was involved in the initial discussions and have supported the project throughout.

As a national geological survey, GEUS is responsible for many types of geoscientific investigations, often in co-operation with the international science community and the international exploration industry. The resulting projects produce data and information important for society, the geosciences and the international exploration industry. Starting in 2000, having mostly until then worked with satellite data, GEUS became involved in the use of modern hyperspectral data recorded from aircraft, (the MINEO project), through a multinational EU funded project aimed at using HyMAP data for assessment of environmental impact of mining operations in different climatic surroundings. On the same year, HyMAP data were acquired over several types of mineralisation in East Greenland and these sites have since been subjected to follow-up groundwork, when and where the possibility arose. In 2001, the HyMAP system was used for a survey in central West Greenland over Precambrian and Proterozoic rocks around a well-known carbonatite, in an area just then becoming interesting because of the presence of diamond bearing kimberlites; today the site is known also to have a REE potential. Late 2010, a PhD was awarded to a GEUS employee for the development of efficient classification methods for HYMAP and ASTER data, applied among other places to the Sarfartoq area.

For all of North East, East and South East Greenland with geology spanning most periods from the Early Precambrian to the present, ASTER data – and new satellites data expected to become available over the coming years - are still a possible source for interpretational studies of how to use such data in the exploration for mineral resources in Greenland. This trend is further strengthened by the emergence of more and more powerful instruments for airborne and ground work. Similarly, the new possibilities related to thermal imaging, especially well-suited to mineralogical/geological studies, are attractive for the type of exploration studies anticipated for the coming years; GEUS will be involved in fieldwork in the relevant regions in the coming years and will thus have excellent opportunities for seeking ground truth for the interpretation of the remote sensing data from aircraft and satellite, and laboratory work based on GEUS' extensive sample collections from many geological environments in Greenland can become important in the development of new methodologies, not the least such that can be operative within the time-frame of mineral exploration, despite the enormous amounts of data processing involved. Based on this background, GEUS welcomed the opportunity to initiate the HyperEast 2012 project and anticipates being involved in several additional projects over the coming years related to advanced remote sensing projects in Greenland.

This report has the sole objective of documenting the acquisition and basic processing into data sets of the data acquired by the joint GEUS/BGS/ARSF project in August 2012 in central East Greenland, so that this documentation does not have to be repeated in all future studies concentrating on interpretational issues.

GEUS' objectives for the involvement in the work with interpretation of these data types are four-fold and related to

1. Improvement of our understanding of the geology and the geological/mineralisation processes behind the formation of this geology.
2. Specific advancement of the knowledge of image spectroscopy for hyperspectral data.
3. Development of new methods using multisensory data from aircraft and satellites.
4. Preparing data and methods as a service to the industry.

# 5. Survey areas in central East Greenland

In the period 14 to 23rd August of 2012, two areas were surveyed in central East Greenland: (i) Kap Simpson; and (ii) Carlsberg Fjord. It was important for GEUS that each survey area were flown as a proper survey and not just as a few scenes, allowing GEUS to check the operability of the methods and instrumentations in relation to realistic exploration in Greenland. The two survey areas are North and South of Kong Oscars Fjord, central East Greenland, see the index map in figure 1. This report does not contain exhaustive references and descriptions of the geology of the survey areas; that will be included in future reports and publications dealing with interpretational issues. Appendix 1 contains the flight logs for the seven flights out of Constable Pynt.

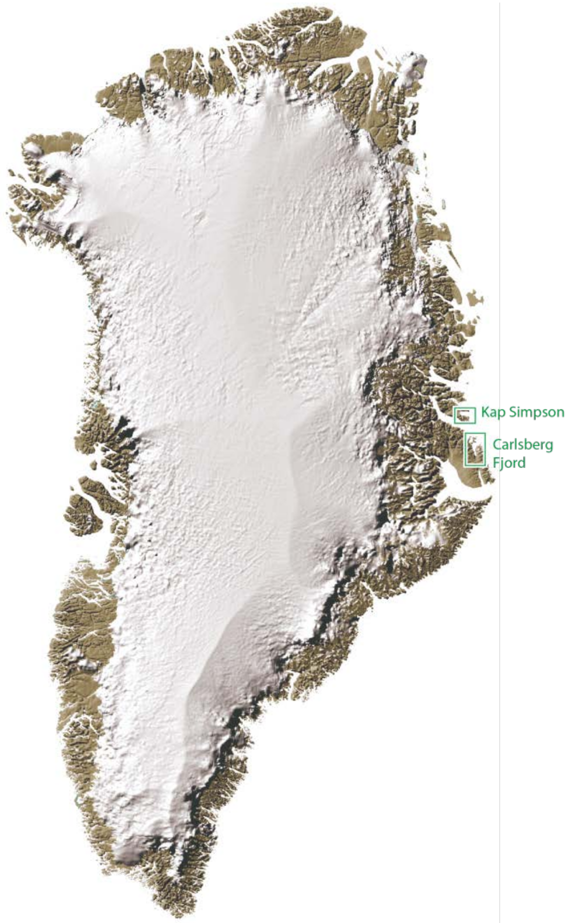


**Figure 1.** *Location of the two survey area: Kap Simpson (see Figure 2) and Carlsberg Fjord (see Figure 4) of project HyperEast 2012.*

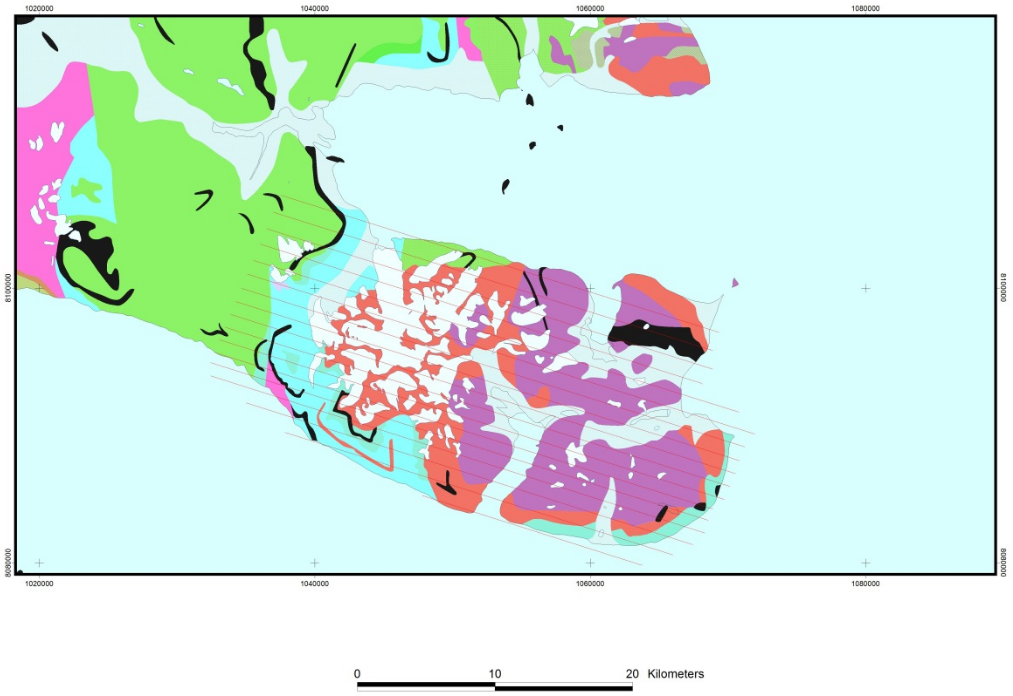


**Figure.** 2 *The Kap Simpson Survey Area.The Kap Simpson survey*

The geological targets of main interest for the Kap Simpson survey are the various components of the Tertiary,alkaline intrusions that make up most of the half-pininsula but also the border to the Mesozoic sediments to the West across a major fault system are of interest. Previous work in the area includes remote sensing projects by GEUS and private exploration companies.

The Kap Simpson survey comprises 1310 line km of data covering an area of approximately 664 km2

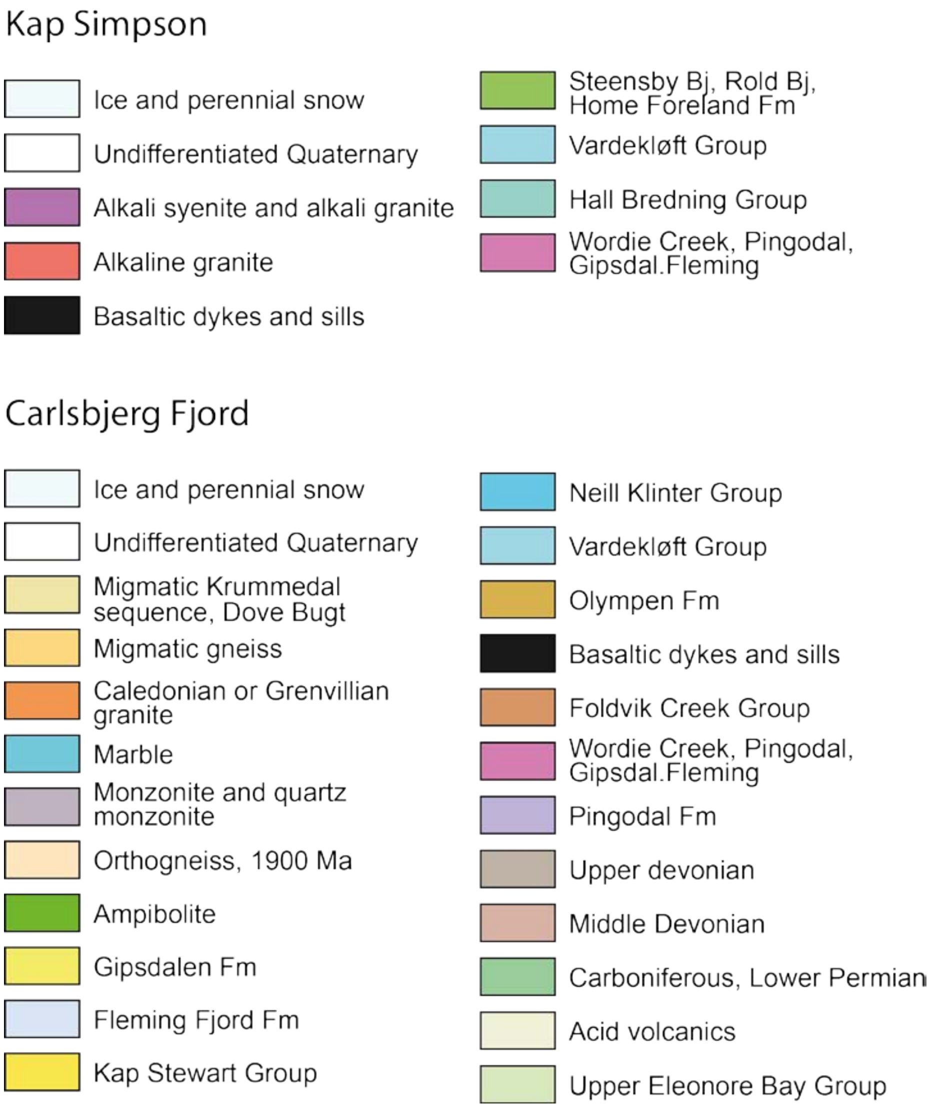


**Figure 3**. *Legend for geological maps on figures 2 and 4. The Carlsberg Fjord survey*

The main interest for the survey in the Carlsbjerg Fjord area is to identify possible strata-bound Cu-Pb-Zn mineralisations, including a Kupferschiefer-equivalent shale type which is known from the Permo-Triassic sediments of central East Greenland including the Wegner Halvø area. Many of the stratabound mineralisations was found and investigated by Nordisk Mineselskab A/S (Nordmine) in the 1970's including several high-grade occurrences – these were however never drilled.

The Carlsberg Fjord Survey comprises 4426 line km of data covering an area of approximately 2620 km2

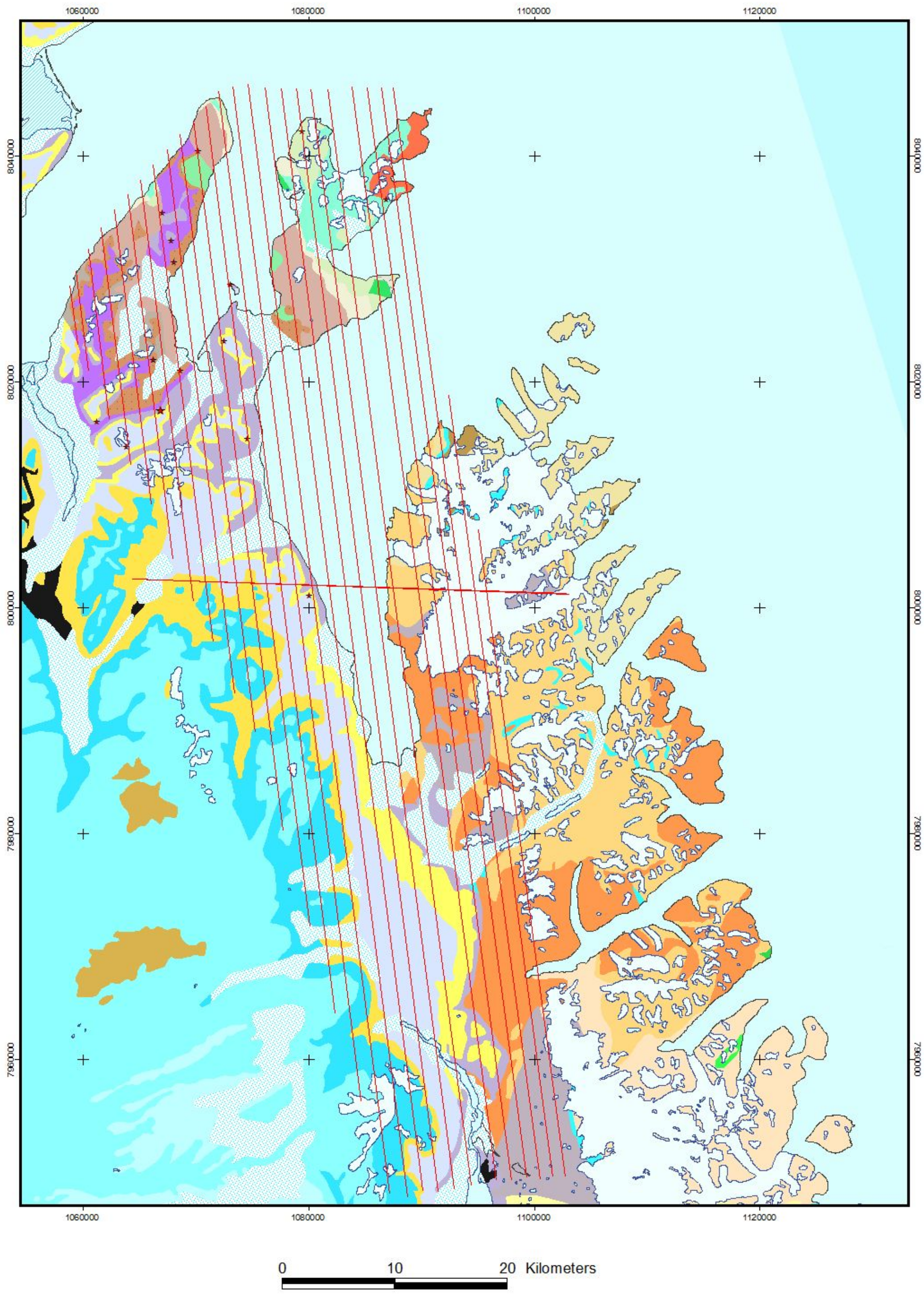


**Figure 4.** *The Carlsberg Fjord survey with lines flown; lines plotted from their start and end points only.*

# 6. Aircraft and instrumentation

## 6.1 Aircraft

The ARSF operates a Dornier 228-101 aircraft for its multiple purpose airborne survey activities for many different projects. The capabilities, endurance and flexibility make the Dornier well suited for remote sensing operations, among other types of scientific purposes. For a full description of the Dornier's specifications, see the ARSF web site, http://arsf.nerc.ac.uk/aircraft/

**Figure 2.** *The ARSF Dornier 228-101 aircraft (G-ENVR) used for the field operation in central East Greenland, August 2012. Courtesy ARSF.*

The aircraft can be fitted with a variety of instrumentation packages for different purposes. For GEUS' hyperspectral survey in central East Greenland the instrumentation described below was deployed, supported by all necessary flight and data recording/registration instrumentation.

More details on the instrumentation can be found at the ARSF web site
http://arsf.nerc.ac.uk/instruments/ .

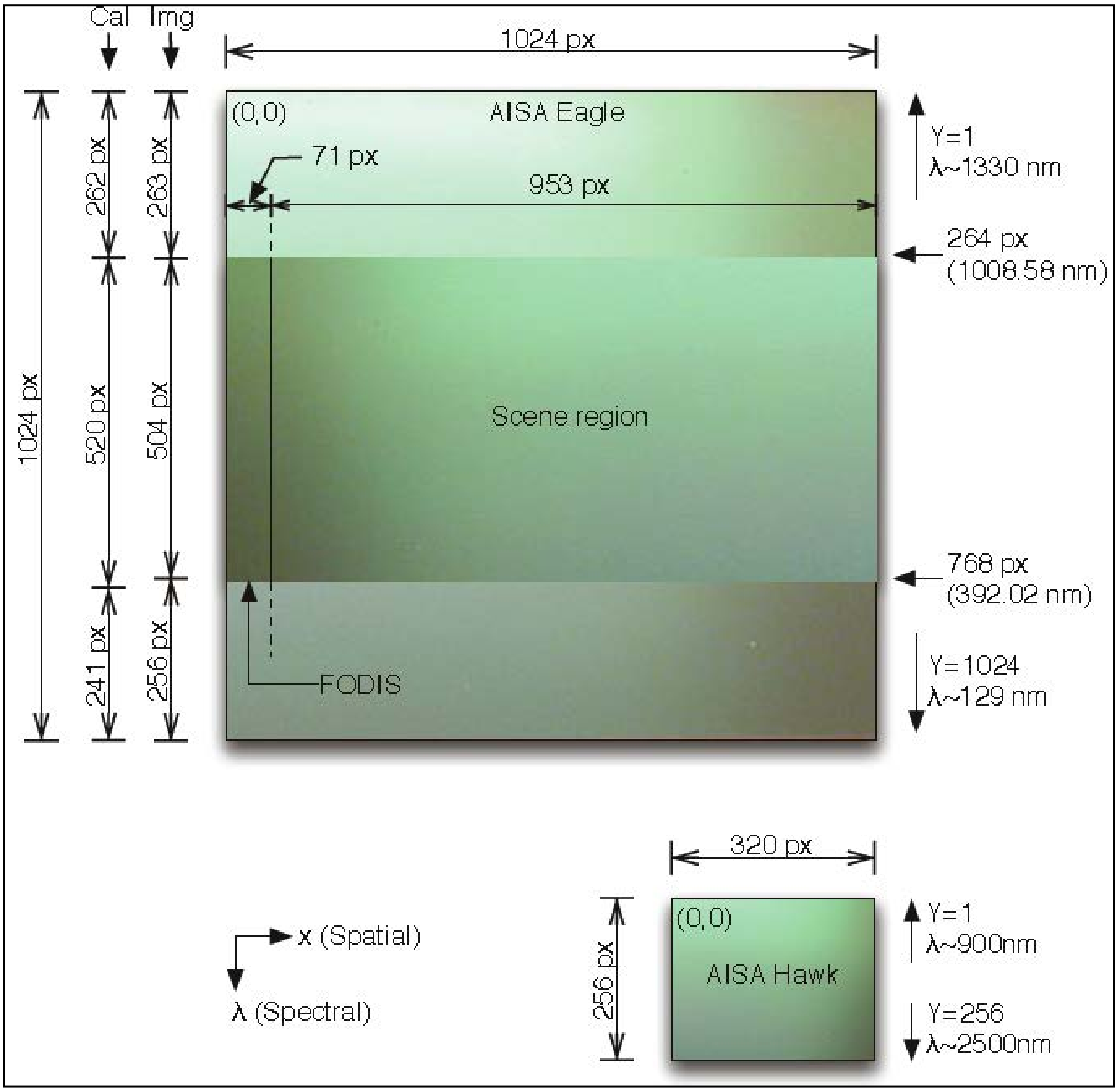


**Figure 3.** *Detector diagrams for the two hyperspectral sensors. Courtesy ARSF.*

## 6.2 Hyperspectral sensors

The aircraft carried two hyperspectral sensors, both manufactured by Specim: the 12-bit AISA Eagle covering the visible (400 to 750 nm) and near infra-red spectrum (750 to 970 nm) with a maximum spectral resolution of 2.9 nm; the 14-bit AISA Hawk covering the spectrum's short wave infrared wavelengths, 970 to 2450 nm with a maximum spectral resolution of 8 nm. The Eagle has a 1000 pixel swatch and the Hawk has 320 spatial pixels and 244 spectral pixels. The two sensors supplement each other but do not capture data synchronously. This necessitates some additional processing later in the compilation of the data.

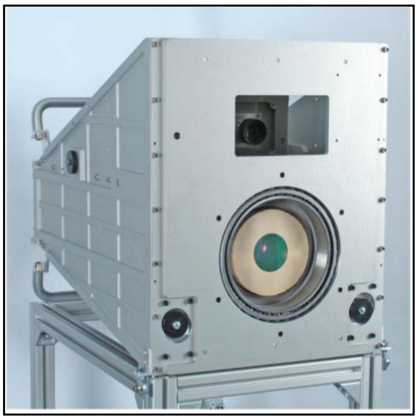

**Figure 4.** *The core parts of the hyperspectral instruments; left: Eagle and right Hawk*

## 6.3 LiDAR sensor

For acquisition of LiDAR data was used a Leica ALS50-II Airborne Laser Scanner. The integrated IPAS 20 navigation controller includes a GPS receiver and Honeywell IMU. The IPAS 20 has the 'Freebird ' upgrade to ensure navigational coupling at high bank angles. The wavelength of the radiation is 1064 nm.

## 6.4 Digital Camera

A medium-format digital camera, Leica RCD105, is integrated with the LiDAR system. The camera data are captured in compressed 12-bit files (.raw) of approximately 57MB size and various ASCII header files are generated, including time stamp information for each photograph, as well as real-time aircraft position and attitude data. The RCD system is calibrated at Leica's calibration factory. The pixel size corresponds to ~15cm resolution at 1350 m flying height. The camera’s maximum frame rate is 0.5 Hz, and the CCD is a Bayer array (raw 7162 x 5389). In the final processed TIFF, the pixels are blended and interpolated to make a full RGB grid; for more details see figure 3.

# 7. Data processing at ARSF

Data for the HyperEast 2012 project were initially processed by the ARSF-Data Analysis Node (ARSF-DAN) based at the Plymouth Marine Laboratory and later delivered to GEUS.

## 7.1 Description of processing steps

Radiometrically calibrated data (Level 1b) will be supplied in a standard, sensor independent, data format. Level 1b data are in the WGS84 geodetic coordinate system and datum. These data have location and navigational information appended to enable the user to geometrically rectify the data to a user-defined map projection (Level 3a) using supplied software (azgcorr).

To ensure that the ARSF supplies the correct navigational data, the Level 1b data are transformed into the local coordinate system and compared with existing vector data, where available. Quick-look 3-band RGB images of these corrected data are supplied. ARSF-DAN (arsf-processing@pml.ac.uk) can be contacted for information or guidance concerning data processing and data delivery.

The ARSF-DAN does not supply geocorrected data except as example jpegs. In this case all UK data are processed with respect to the British National Grid system and UTM is typically used as the default non-UK map projection.

# 8. Delivery of data to GEUS

The amount of time necessary for the initial processing of the three types of data at ARSF was a surprise for GEUS. If information from a survey in August 2012 is to be utilized for the planning of the following field season starting perhaps May 2013, and for the actual interpretation defining the follow-up positions in the field, then the processing and the interpretation should be concluded in the mid-spring. It was quickly realized that this would be difficult to achieve. In order to test GEUS software processing environment with respect to the ARSF produced data, the first delivery was therefore a test file containing a small sample of all three data types. This was delivered 21st of November 2012. The GEUS processing facilities were prepped and ready, when delivery of the final data began 30th of November 2012, and the processing could be initiated immediately. Again, the processing times turned out to be extreme; even running several machines simultaneously, it became necessary to sharpen up the specifications, change to a LINUX operative system, and use external disk devices in order to handle the large datasets and obtain a tolerable processing time. These actions did improve the turn-around time significantly, specifying the system to be used in the future.

Thus, GEUS processing took place simultaneously with the delivery from ARSF, which was concluded the 3rd of April 2013, and GEUS basic processing could then be concluded by the end of 2013.

The following were delivered:

| LiDAR data acquisition | Digital elevation model (HDF) | Flightlines (ASCII & Las1.0) | Logsheet (PDF) | Screenshots (JPEG) | Data Gigabytes |
|---|---|---|---|---|---|
| | | | | | |
| **BGS11_01-227-lidar-20121113** | BGS11_01-2012_227-lidar_ASTER-wgs84_latlong<br>BGS11_01-2012_227-lidar_ASTER-wgs84_utm | 18 ASCII files<br>18 Las1.0 files | BGS11_01-2012_227-Carlsberg | 5 | 35 |
| **BGS11_01-228a-lidar-20121114** | BGS11_01-2012_228a-lidar_ASTER-wgs84_latlong<br>BGS11_01-2012_228a-lidar_ASTER-wgs84_utm | 18 ASCII files<br>18 Las1.0 files | BGS11_01-2012_228a-Carlsberg | 5 | 47 |
| **BGS11_01-228b-lidar-20121119** | BGS11_01-2012_228b-lidar_ASTER-wgs84_latlong<br>BGS11_01-2012_228b-lidar_ASTER-wgs84_utm | 4 ASCII files<br>4 Las1.0 files | BGS11_01-2012_228b-Carlsberg | 5 | 31 |
| **BGS11_01-230-lidar-20121213** | BGS11_01-2012_230-lidar_ASTER-wgs84_latlong<br>BGS11_01-2012_230-lidar_ASTER-wgs84_utm | 11 ASCII files<br>11 Las1.0 files | BGS11-2012_230-Carlsberg | 5 | 70 |
| **BGS11_01-231-lidar-20130108** | BGS11_01-2012_231-lidar_ASTER-wgs84_latlong<br>BGS11_01-2012_231-lidar_ASTER-wgs84_utm | 13 ASCII files<br>13 Las1.0 files | BGS11_01-2012_231-Carlsberg | 3 | 66 |
| **BGS11_01-236a-lidar-20121204** | BGS11_01-2012_236a-lidar_ASTER-wgs84_latlong<br>BGS11_01-2012_236a-lidar_ASTER-wgs84_utm | 21 ASCII files<br>21 Las1.0 files | BGS11_01-2012_236a-East_Greenland | 3 | 46 |
| **BGS11_01-236b-lidar-20121122** | BGS11_01-2012_236b-lidar_ASTER-wgs84_latlong<br>BGS11_01-2012_236b-lidar_ASTER-wgs84_utm | 14 ASCII files<br>14 Las1.0 files | BGS11_01-2012_236b-East_Greenland | 5 | 28 |

**Table 1.** *The delivered data from the LIDAR data acquisition*

| CAMERA data aquisition | Image events file (Excel) | Photograph files (TIFF) | Thumbnail files (JPEG) | Spatial index file (KML) | Data Gigabytes |
|---|---|---|---|---|---|
| **BGS11_01-227-camera-20121113** | RCD105-BGS11_01-2012227-ImageEvents | 1073 | 1073 | BGS11_01-2012_227 | 233 |
| **BGS11_01-228a-camera-20121123** | RCD105-BGS11_01-2012228a-ImageEvents | 1321 | 1321 | BGS11_01-2012_228a | 287 |
| **BGS11_01-228b-camera-20121126** | RCD105-BGS11_01-2012228b-ImageEvents | 606 | 606 | BGS11_01-2012_228b | 132 |
| **BGS11_01-230-camera-20121128** | RCD105-BGS11_01-2012230-ImageEvents | 1893 | 1893 | BGS11_01-2012_230 | 412 |
| **BGS11_01-231-camera-20121228** | RCD105-BGS11_01-2012231-ImageEvents | 2154 | 2154 | BGS11_01-2012_231 | 469 |
| **BGS11_01-236a-camera-20121113** | RCD105-BGS11_01-2012236a-ImageEvents | 1564 | | BGS11_01-2012_236a | 340 |
| **BGS11_01-236b-camera-20121121** | RCD105-BGS11_01-2012236b-ImageEvents | 938 | 938 | BGS11_01-2012_236b | 204 |

**Table 2.** *The delivered data from the aerial photography*

| HYPERSPECTRAL data acquisition | Elevation model (HDF) | Flightlines(HDF): Level1b, fodis, line information, mapped & navigation | Logsheet file (PDF) | Project Info file (XML) | Screenshots file (JPEG) | Sensor FOV vectors (HDF) | Data Gigabytes |
|---|---|---|---|---|---|---|---|
| **BGS11_01-227-hyperspectral-20121126** | BGS11_01-2012_227-ASTER | EAGLE & HAWK 434 files | BGS11_01-2012_227-Carlsberg | BGS11_01-2012_227-project | 39 | 8 | 255 |
| **BGS11_01-228a-hyperspectral-20121126** | BGS11_01-2012_228a-ASTER | EAGLE & HAWK 217 files | BGS11_01-2012_228a-Carlsberg | BGS11_01-2012_228a-project | 21 | 6 | 401 |
| **BGS11_01-228b-hyperspectral-20121127** | BGS11_01-2012_228b-ASTER | EAGLE & HAWK 97 files | BGS11_01-2012_228b-Carlsberg | BGS11_01-2012_228b-project | 11 | 6 | 172 |
| **BGS11_01-230-hyperspectral-20121129** | BGS11_01-2012_230_ASTER | EAGLE & HAWK 265 files | BGS11_01-2012_230-Carlsberg | BGS11_01-2012_230-project | 25 | 6 | 463 |
| **BGS11_01-231-hyperspectral-20121220** | BGS11_01-2012_231-ASTER | EAGLE & HAWK 277 files | BGS11_01-2012_231-Carlsberg | BGS11_01-2012_231-project | 26 | 7 | 441 |
| **BGS11_01-236a-hyperspectral-20121106** | BGS11_01-2012_236a-ASTER | EAGLE & HAWK 505 files | BGS11_01-2012_236-East_Greenland | BGS11_01-2012_236a-project | 45 | 6 | 229 |
| **BGS11_01-236b-hyperspectral_20130322** | BGS11_01-2012_236b-ASTER | EAGLE & HAWK 337 files | BGS11_01-2012_236b-East_Greenland | BGS11_01-2012_236b-project | 31 | 8 | 141 |

**Table 3.** *The delivered data from the hyperspectral data acquisition*

# 9. Processing of data at GEUS

GEUS processing has been aimed at homogenising the data from the various instruments, improving the accuracy of the terrain model and the atmospheric correction. The objective was to produce the basic datasets that could be used as the starting point for further work involving mapmaking, classification, interpretation and utilization of the data, and which could be offered to the industry holding mining exploration licenses in the region. The data were split into two datasets by geographical sorting: The Carlsberg Fjord Survey and the Kap Simpson Survey. The following subsections of the report briefly list the stages of processing.

## 9.1 Base Maps and Digital Terrain Models

The two survey areas were covered by existing digital mapping in scale 1:250.000 (the DANCEA project; See Figures 2 and 4).

## 9.2 LiDAR data

The LiDAR data formed the basis for the DTM but has hitherto not been further processed at GEUS.

## 9.3 Hyperspectral data

The HyperEast 2012 hyperspectral data was delivered to GEUS as radiometrically calibrated sensor data (Level-1b), and several steps of low-level processing were carried out at GEUS to bring the data to level-3 (i.e. ready for geological information extraction). The majority of the low-level processing steps carried out at GEUS used the Airborne Processing Library software provided by NERC

(http://arsf-dandev.nerc.ac.uk/trac/wiki/Processing/aplquickstart),

and interacting with the software through the aplGUI graphical user interface. The final step of low-level processing, involving atmospheric correction, was carried out using the Atcor4 software

(http://www.rese.ch/pdf/atcor4_manual.pdf).

In the following five subsections all major processing steps carried out at GEUS are described. The following figures are taken from the aplGUI interface, note the tabs at the top.

### 9.3.1 Step 1: Masking bad data

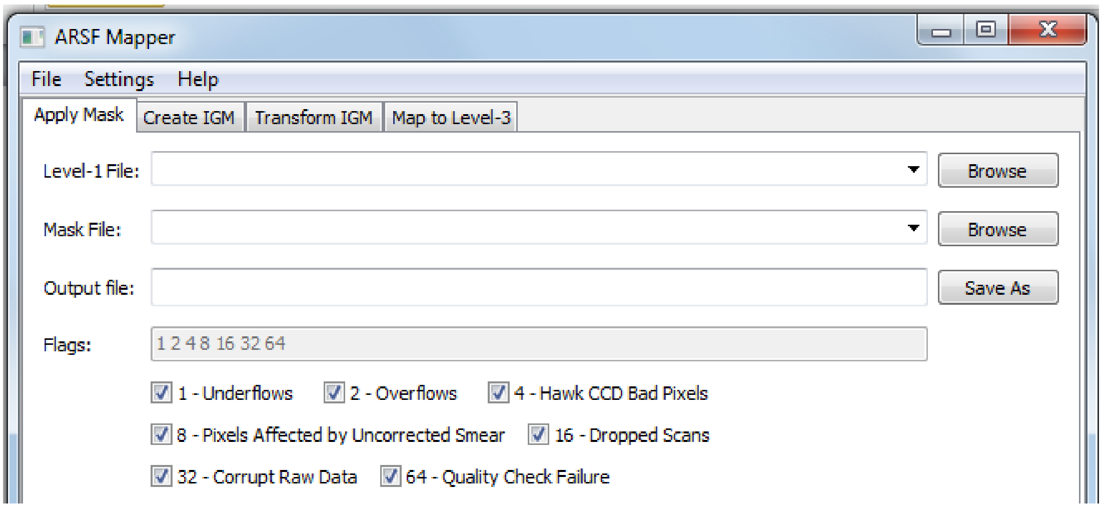


**Figure 8**. *Apply Mask. The inputs required are the **Level-1 File** and the **Mask File**. The user must specify the **Output File** as well. Under "flags" the user can select or unselect specific mask features. This step was performed on all original data masking all types of bad data.*

The first processing step is designed to mask "bad data" in all Level-1b flight line files, so that potentially erroneous data is removed before further analysis. Together with each Level-1b data file, ARSF-DAN supplied a separate mask file containing a record of all bad pixels. There are several reasons why a pixel in a hyperspectral image can be in error – Figure 8 lists seven potential causes, in the boxes.

The input for this processing step is (see also Figure 8): (i) The **Level-1 file** which is the original Level-1b data file supplied by ARSF-DAN. Note that there are two files for each flight line, e.g. one file for each of the two sensors; (ii) The **Mask file** that contains a record of "bad data"; (iii) The **Output File** that is the processed file used in the next Step 2 processing.

We chose to mask all marked errors: Underflows, Overflows, Hawk CCD Bad Pixels, Pixels Affected by Uncorrected Smear, Dropped Scans, Corrupt Raw Data, Quality Check Failure (i.e. all boxes are checked in Figure 8).

### 9.3.2 Step 2: Georeferencing

Next step is to create an IGM (input geometry file) file which is used to relate every single recorded level-1 pixel to a unique Geographic location (defined by its Latitude, Longitude, and Height).

The input for this processing step is (see Figure 9): (i) The **Navigation BIL file** that contains the aircrafts deviations from the course as well as its pitch, roll and yaw for a given flight line; (ii) The **Level-1 BIL file**, which is the masked Level-1 data file created in the previous Step 1 processing; (iii) The **DEM file**, that is the digital elevation model, which in our case is defined by the HyperEast 2012 LiDAR data; (iv) The **Sensor Field of View** which is a file containing information on what the sensor can "see" – There is a single Field of View file for each of the two sensors; (v) The **Output IGM file** that is the file resulting from the processing.

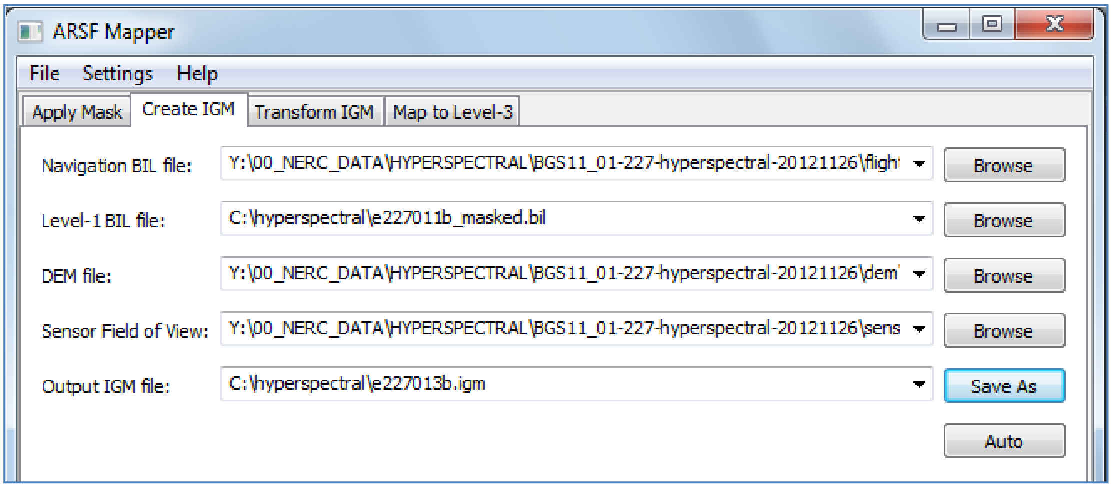


**Figure 9**. *Create IGM. The inputs required are the **Navigation BIL file** containing the planes trajectory, the masked **Level-1 BIL file** (the output file from step 1), the digital elevation model **DEM file**, and the **Sensor Field of View** file. The user must specify the **Output IGM File** as well. This step was performed on all flight lines.*

### 9.3.3 Step 3: Changing the projection of the IGM file

The IGM file produced in Step 2 is in a simple Geographic Latitude and Longitude projection. Using the "Transform IGM" option in aplGUI software, we reproject the IGM into an UTM zone 27N projection, still using the WGS84 ellipsoid (Figure 10). The reprojection is performed using the program AplTRANS, which, in principle is a wrapper for the open-source PROJ4 program.

The input for this processing step is (see Figure 10): (i) The Input IGM file (produced in step 2); (ii) Output **Projection** which in our case is UTM WGS84, (iii) **UTM Zone** which in our case is 27N.

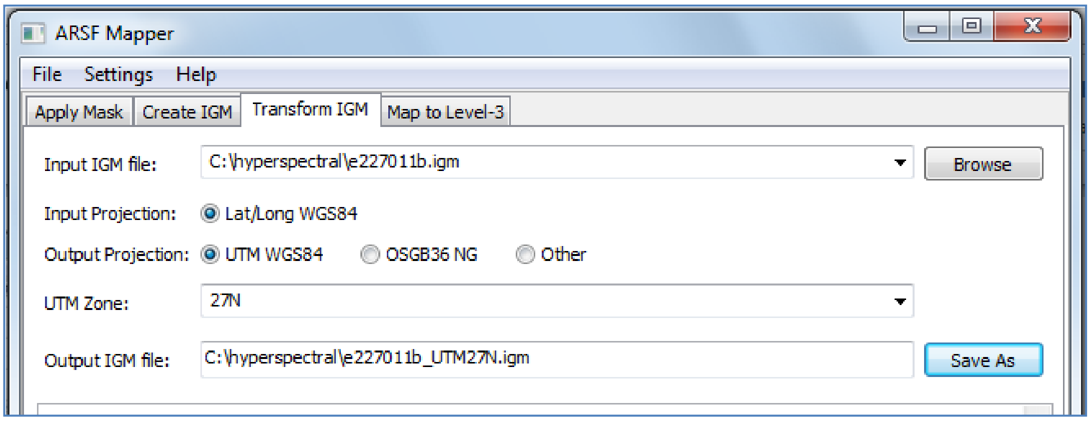


**Figure 10.** *Transform IGM. The inputs required are the **Input IGM file** (produced in step 2), and the chosen **Output Projection** which in our case is UTM WGS84 Zone 27N. The user must also specify the new reprojected **Output IGM File**. This step was performed on all flight lines.*

### 9.3.4 Step 4: Mapping the data

Mapping the data is the final processing step using the APL software. Using the IGM file in UTM 27N projection (Step 3) we now turn the recorded hyperspectral images (i.e. the masked level-1b data; Step 1) into maps.

The input for this processing step is (see Figure 11): (i) The **IGM File** produced in Step 3; (ii) The **Level-1 file**, which is the masked Level-1 data file created in Step 1; (iii) The output **Mapped file**, that is the Level-3 file resulting from the processing. We set the number of bands in the **Band list** to be all the bands, and the spatial resolution is set to be 2*2 meters.

Given a total area for the two surveys of 3284 km$^2$, a 2*2 meter spatial resolution results in a total of 821 million pixels for the entire mapped area, and considering that 486 spectral bands are recorded for each pixel, the total mapped dataset contains close to 400 billion data.

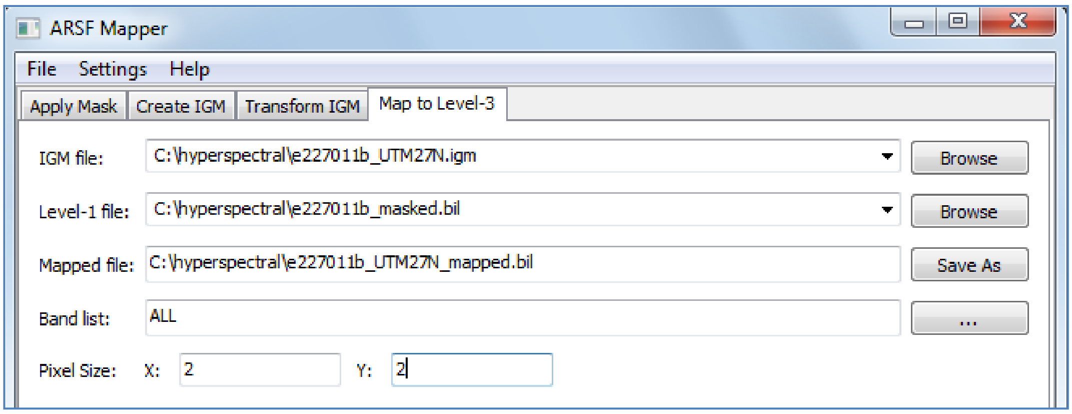


**Figure 11.** *Map to Level-3. The input files are the re-projected (UTM 27N) **IGM file** and the masked **Level 1 File**. The user can select which bands to map; we use the default setting of all bands. Pixel size is set to 2x2 meters.*

### 9.3.5 Step 5: Hyperspectral data cube

The mapped VNIR and SWIR are combined into a three-dimensional hyperspectral data cube for processing and analysis. The mapped VNIR and SWIR data were combined to a hyperspectral data cube by using the Layer Stacking facility of the ENVI/IDL software. The resulting hyperspectral data cube has 485 spectral bands from 407.8 nm to 2468.9 nm.

### 9.3.6 Step 6: Atmospheric correction

The atmospheric correction is an important prerequisite to most airborne hyperspectral Imagery data analysis approaches. The hyperspectral data cube of the mapped 'at sensor radiance' data needs to be corrected for atmospheric effects and be turned scaled surface reflectance data.

This analysis was first performed using FLAASH (Fast Line of sight Atmospheric Analysis of Spectral Hypercube), which is a MODTRAN4-based atmospheric correction software package developed by the Air Force Phillips Laboratory, Hanscom AFB and Spectral Sciences, Inc. Unfortunately, for our purposes, it turned out that FLAASH did not perform well, most likely due to the strong topographic relief. We therefore chose to use the Atcor 4 atmospheric correction program package for airborne hyperspectral imagery (http://www.rese.ch/products/atcor/atcor4/). The Atcor 4 performs the atmospheric correction taking the topography and the more complex illumination conditions into consideration. The Atcor 4 atmospheric correction may be enhanced using the empirical line calibration if the ground target spectra are available.

## 9.4 Aerial Photography

A total of 7043 coloured aerial photographs were collected from the Carlsberg Fjord area and 2498 from the Kap Simpson area during the survey together with LiDAR and Hyperspectral data. The Imagery was collected using a Leica RCD105 Digital Frame Camera. Specifics of the camera are given in the Data Quality Report – 2012 (Appendix 4) and information on camera calibration is given in the camera RCD105 Calibration Certificate. Aerial photographs were delivered to GEUS in a non-referenced format as RGB-tiff images, while Information of position and attitude of the aircraft and how the camera was oriented (omega, phi, kappa), when the photographs were acquired, was supplied in an excel spread sheet.

### 9.4.1 Preparing the images for geological and structural interpretation

The GEUS Photogrammetry Laboratory has a long tradition of using aerial photography for geological and structural interpretation. The laboratory is at present equipped with three-modern digital photogrammetric workstations running the photogrammetric software package SocetSet 5.5 from BAE systems. In order to prepare the images for geological and structural interpretation within the 'GEUS system' a number of processing steps was undertaken. These steps are summarized below.

1. A SocetSet project named Hypereast was set up using UTM 27, WGS 84 and WGS 84 ellipsoid as vertical reference to comply with ALS and hyperspectral data.

2. Images were imported into SocetSet as Bingo Frames in a tiff-tiled format. By doing so a so-called support file (internal file used by SocetSet) for each image was generated. Naming conventions for the support files was to omit the first part of the filename as illustrated below.

RCD105-BGS11_01-2012227-00001 was renamed to 227-0001.

3. An automatic tie-point measurement routine was set up within SocetSet. In this step tie points, that is common points between aerial photographs, are measured automatically using an evenly distributed 148 point strategy. The ALS derived DTM was used to aid the image-matching (this is not a prerequisite).

4. Identified tie-points were used to triangulate the aerial photographs into two coherent blocks, one for the Carlsberg Fjord area and one for the Kap Simpson area. The triangulation was solved using the Bingo-F bundle block adjustment software. A summary of the main statistics for each triangulated block is given in Table 4.

5. Transformation from photo space into absolute space using GPS and IMU data.

6. Updating Bingo triangulation within SocetSet. Once this step is completed, the images are prepared for geological and structural interpretation as well as for further processing/production of for example orthophotos.

| | **Carlsberg Fjord** | **Kap Simpson** |
|---|---|---|
| **# of used points** | 73273 | 42254 |
| **# of used photos** | 7022 | 2293 |
| **Max. Photo rays per point** | 21 | 14 |
| **Max. Photo measurements per point** | 28 | 15 |
| **Used points per photo - minimum** | 1 | 10 |
| **Used points per photo - median** | 74 | 214 |
| **Used points per photo - maximum** | 172 | 4928 |

**Table 4.** *Statistics of the triangulation*

### 9.4.2 Notes on triangulation result

A full report of the triangulation process is given in the Bingo triangulation report (Appendix 5) while a summary of calculated errors are given in table 5.

| **Residuals of photo measurements in photo space (1:1000)** | **Carlsberg Fjord** | | | **Kap Simpson** | | |
|---|---|---|---|---|---|---|
| | **x´** | **y´** | | **x´** | **y´** | |
| **RMS** | 2,1 | 2,1 | | 7,6 | 7,8 | |
| **MAX** | 10,6 | 10,8 | | 33,0 | 32,4 | |
| **GPS residuals (1/1000)** | | | | | | |
| | **x** | **y** | **z** | **x** | **y** | **z** |
| **RMS** | 1221 | 891 | 306 | 1140 | 753 | 575 |
| **Maximum** | 5645 | 6777 | 3004 | 3964 | 3100 | 3078 |
| **Imu residuals (1/1000)** | | | | | | |
| | **Phi** | **Ome** | **Kap** | **Phi** | **Ome** | **Kap** |
| **RMS** | 45,4 | 49,8 | 215,8 | 2413 | 1546 | 524 |
| **Maximum** | 294 | 619.6 | 813.4 | 39258 | 14301 | 5722 |

**Table 5.** *Summary of calculated errors; full details in Appendix 5*

Because of relatively large image overlap, automatic identified tie-points are generally measured in multiple images. This gives a well-defined and stiff geometry of the triangulated blocks. Calculated errors are randomly distributed for both surveys areas as illustrated in figure 14 and 15. The calculated image space errors amount to 2.1 microns for the Carlsberg Fjord survey area and 7.6 microns for the Kap Simpson survey area. For the Carlsberg Fjord survey area this is approximately 1/3 of the Leica RCD105 image sensor pixel size (6.8 microns) and within what would be expected. For the Kap Simpson survey area the calculated error is larger than what would be expected. This is likely a result of missing tie-point error elimination or insufficient measurement accuracy. Further work on eliminating gross errors is likely to lead to a decrease in the calculated image space error for the Kap Simpson survey area.

Absolute positioning of the aerial photographs only relies on transformation of GPS and IMU data. No control points were measured during the triangulation process.

The calculated errors based on GPS data is approximately 1 m in x-y and 0.5 m in z for both survey areas and are generally randomly distributed as illustrated in figure 9 and 10. It is noted though, that some deviation from this is found toward the margins of the blocks which is expected and in ice-covered fjords which is likely due to bad image correlation in these areas. The calculated error on the IMU measurements is much higher for the Kap Simpson survey area than for the Carlsberg Fjord area. The reason for this is not clear and further work would be needed to resolve this.

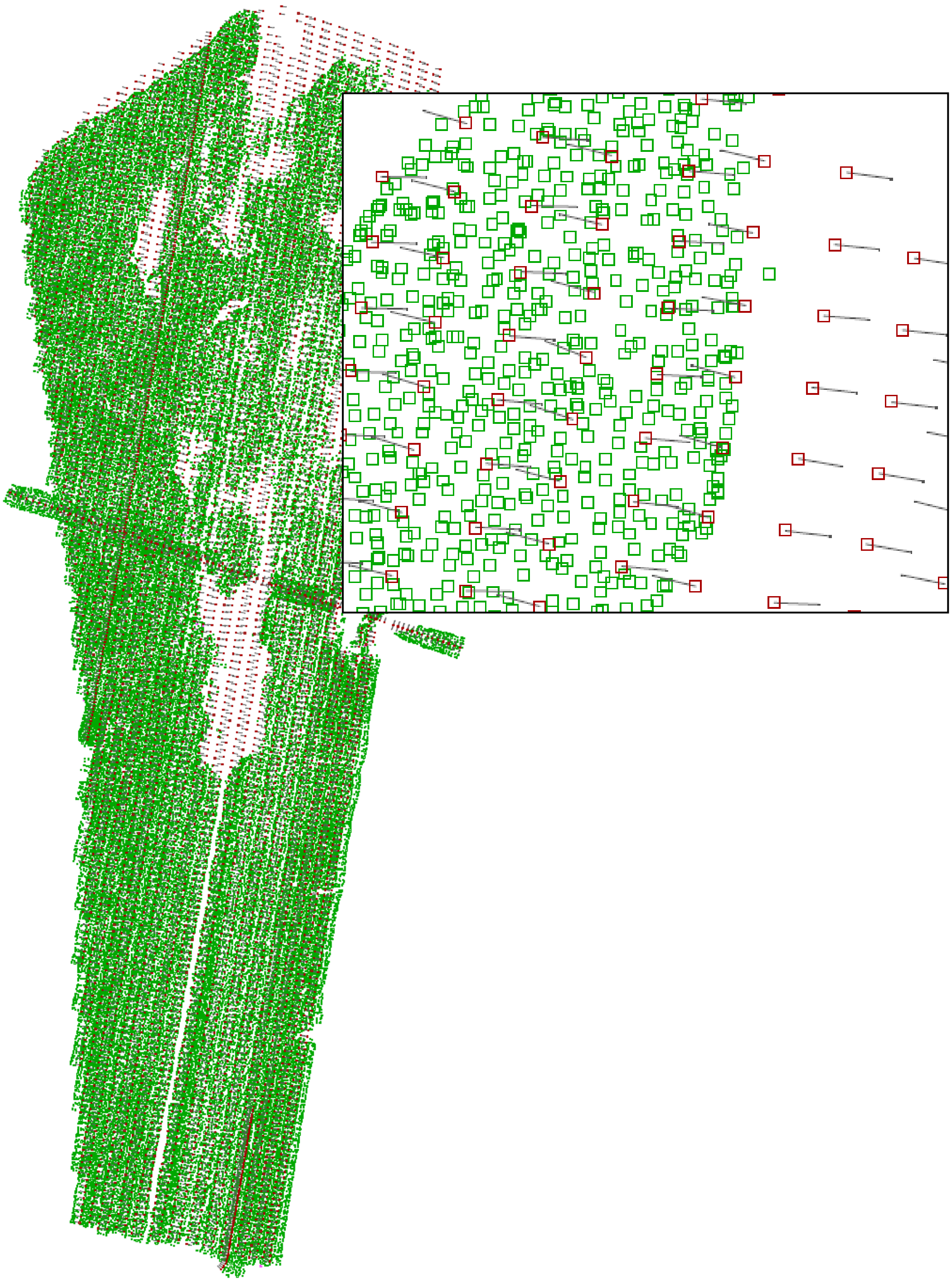

**Figure 12**. *Carlsberg Fjord Survey distribution of tie points (green squares) and camera positions (red squares). Insert show enlargement of a small area in the NW- corner of the survey.*

**Figure 13.** *Kap Simpson Survey distribution of tie points (green squares) and camera positions (red squares).*

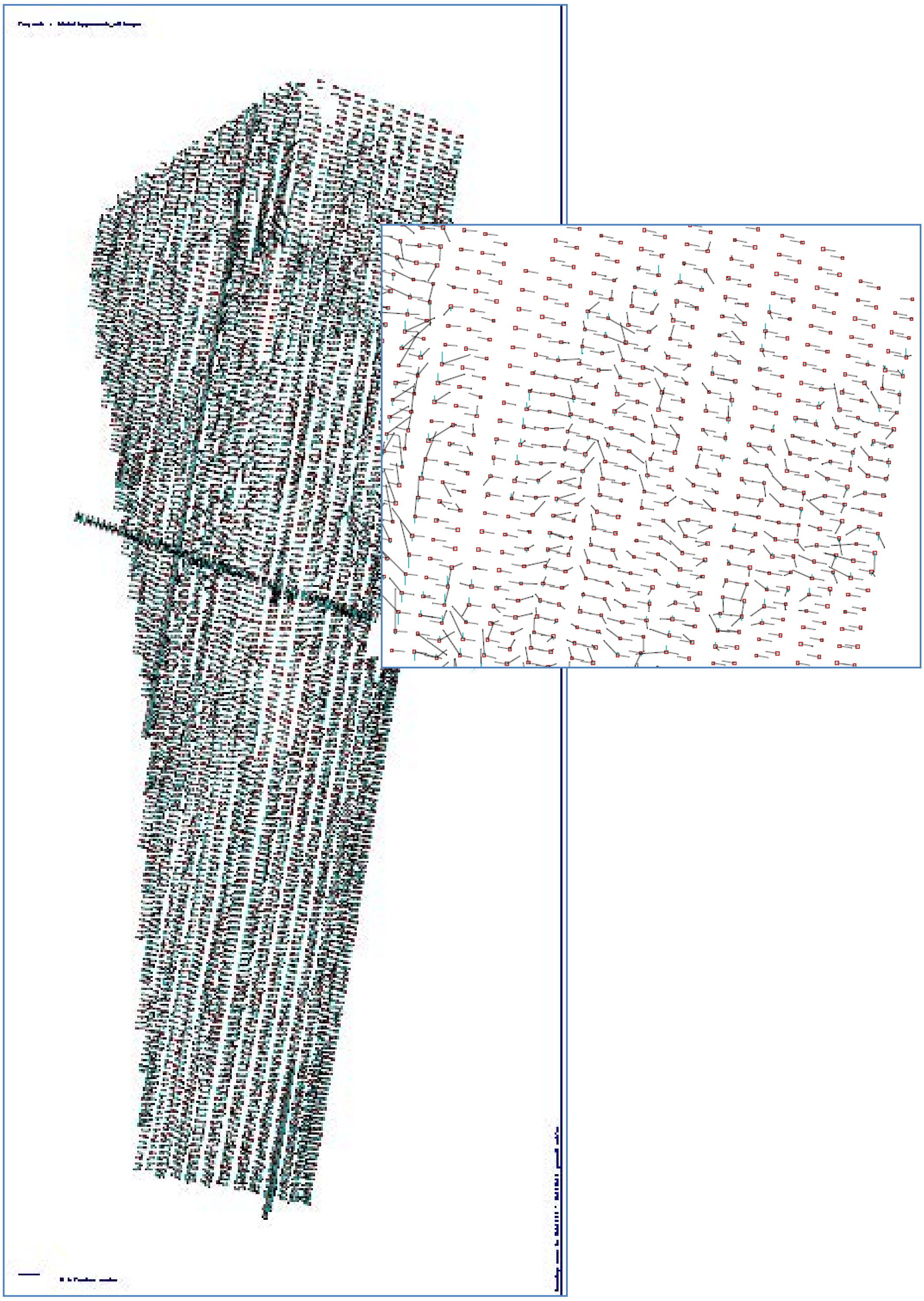

**Figure 14.** *Carlsbjerg Fjord absolute errors based on GPS.*

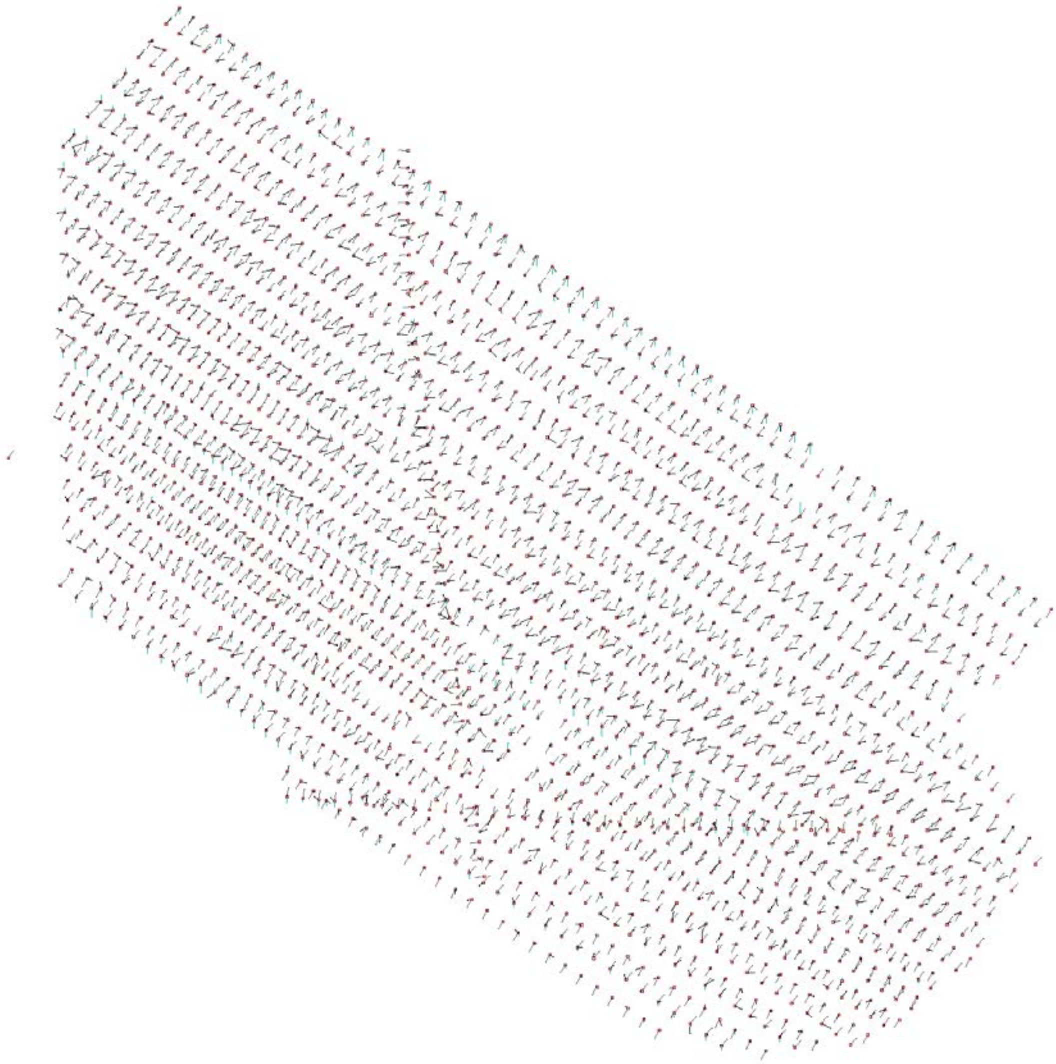

**Figure 15.** *Kap Simpson absolute errors based on GPS.*

## 9.5 Databases and storage

The geometrical corrections are an essential part of working with geodata. The procedure is a time consuming process. Mapping to level 3 takes a lot of space, one file takes up about 160 gibabytes of space, and the process is repeated 10-16 times for each subset. The space needed for storage is considerable and can pose a problem.

At the time of writing the processed data take up 12.5 TeraBytes

## 9.6 Description of data sets

The following datasets have been defined for the HyperEast surveys of August 2012, Central East Greenland.

GEUS data sets are identified by a title, a type, an id number, a version number, and a date. The first three datasets (listed below) are hyperspectral, LiDAR, and aerial photography data from the Carlsbjerg Fjord Survey (Fig. 4). The following three datasets are similar data from the Kap Simpson Survey (Fig. 2). All data are processed to GEUS standard. Normally, the GEUS standard data sets (or a sub section thereof) will be used for further work.

- *"Multisensor airborne survey of the Carlsberg Fjord region, central East Greenland, flown August 2012:* ***Processed hyperspectral data. GEUS data set id 1, version 1.0, 15 May 2013."***
- *"Multisensor airborne survey of the Carlsberg Fjord region, central East Greenland, flown August 2012:* ***Processed LiDAR data. GEUS data set id 2, version 1.0, 15 May 2013."***
- *"Multisensor airborne survey of the Carlsberg Fjord region, central East Greenland, flown August 2012:* ***Processed aerial digital photography. GEUS data set id 3, version 1.0, 15 May 2013."***
- *Multisensor airborne survey of the Kap Simpson region, central East Greenland, flown August 2012:* ***Processed hyperspectral data. GEUS data set id 4, version 1.0, 15 May 2013."***
- *"Multisensor airborne survey of the Kap Simpson region, central East Greenland, flown August 2012:* ***Processed LiDAR data. GEUS data set id 5, version 1.0, 15 May 2013."***
- *"Multisensor airborne survey of the Kap Simpson, central East Greenland, flown August 2012:* ***Processed aerial digital photography. GEUS data set id 6, version 1.0, 15 May 2013."***

For each title, a listing of files with the data is given, together with a print of the metadata attributes below.

| **Unique ID:** | **1** | **Notes** |
|---|---|---|
| Name: | *Multisensor airborne survey of the Carlsberg Fjord region, central East Greenland, flown August 2012:* ***Processed ARSF hyperspectral data.*** | |
| Sho_Name: | Carlsberg Fjord Hyperspectral Survey | |
| Version: | 1.0 | |
| of_date: | 15 May 2013 | |
| Description: | Text | |
| History: | Text | |
| Projection: | | |

Type:

Specification (type dependant):

File_name(s):

File_size_total:

Contact:

The above titles, list of files, attributes are for the unique identification of a dataset. In addition, there must be a number of attributes for the handling of the datasets, such as price, number sold or delivered, list of customers, dates for updates etc. The exact number and type of attributes depends on how and at what detail the department (GEUS) wants to register the distribution, price and income for each attributes. The required metadata are not complicated, but need to be defined in accordance with the procedure

# 10. Acknowledgements

The professional skills and enjoyable co-operation with the the NERC Airborne Research and Survey Facility (ARSF), Gloucester, UK,  and the NERC Plymouth Marine Laboratory Data Analysis Node (ARSF-DAN), Plymouth, UK made this successful data acquisition possible.

The data acquisition was carried out by the NERC Airborne Research and Survey Facility (ARSF) and the NERC Plymouth Marine Laboratory DATA ANALYSIS NODE (ARSF-DAN) preprocessed and made the data available for further research and collaboration between GEUS and the British Geological Survey, Environmental Science Centre, Keyworth, Notthingman, UK.

The exploration company Avanaa Resources Limited is thanked for their support to the data acquisition project.

# 11. Appendix 1: Flight Logs

These are the original ARSF logs of the seven measuring flights, 14 – 23 August 2012.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Proj No. | BGS11-01 | Proj Name | Carlsberg Fjord | PI | | Do-228 | G-ENVR | Date | 14-08-12 | Day | 227 | Land | 18:40 |
| Pilot | Carl Joseph | Co Pilot | James Johnson | Op | Phil Goy | Base | Constable | Sortie | | Log | | Take off | 14:55 |
| Observer | | Weather | 30 degree sun angle | | | | | QNH | Mb | OAT | °C | Total | 03:45 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site parameters required | | PPP | Backup | Resolution | | WILD RC-10 | | Ipas20 | Card A | ALS | 500GB | Eagle | | Chock Time | |
| Gnd speed kts | 8300 | Start | 14:35 | Eagle | 1.64 | Filter | y | MPIA | | Scan F | 32.2 | RHD | F | Engine's | |
| Alt ft amgl | 135 | End | 18:40 | Hawk | 3.28 | Fstop | 5.6 | SPIA | Yes | PRF | 49.5Khz | Spec | Spat | On | 14:30 |
| **Acquisition Complete** | | Station | | Lidar | 0.7 | Film | Agfa Colour | FOV | 24 | Laser % | 75 | 4 | 1 | Off | 18:55 |
| | | Station | | RCD | 17-28 | Shutter | 320 | Stereo | Yes | Cloud % | 0 | Hawk | | Align in | 14:38 |
| THERMAL | | HAWK | X | Ipas20 | X | Cassette | | FCMS File | | Shadow % | Min | RHD | C | Align out | 18:43 |
| RCD | X | LIDAR | X | AIMMS | | Film | | Wave | No | Illumination % | 4 | Spec | Spat | Base Station | |
| EAGLE | X | RC10 | | Grimm | X | Science hrs | 3:08 | Transit hrs | 0:37 | Data quality | 8 | 1 | 1 | Arsf + Fixed | |

| General nav. information | | | | GPS Quality | | PRF | Laser I | Scan | Fov | Return | Time (GMT) | | Frames | Eagle | | | Hawk | | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Dir | GPS Alt ft | Spd kts | PDOP | SV | Khz | % | Hz | Deg | % | Start | Stop | | File | FPS | IT | File | FPS | IT | |
| 36 | 227 | 8382 | 135 | 2.4 | 13 | 50 | 75 | 32 | 24 | 100 | 15:19 | 15:21 | 15-26 | 1 | 30 | 15 | 1 | 30 | 14 | 2 x 360 deg |
| 37 | 28 | 8382 | 135 | 1.4 | 16 | 50 | 75 | 32 | 24 | 100 | 15:23 | 15:26 | 27-45 | 2 | 30 | 15 | 2 | 30 | 14 | Pre X |
| 38 | 227 | 8382 | 135 | 1.4 | 16 | 50 | 75 | 32 | 24 | 100 | 15:29 | 15:33 | 46-71 | 3 | 30 | 15 | 3 | 30 | 14 | Post X |
| 39 | 28 | 8382 | 135 | 1.4 | 13 | 50 | 75 | 32 | 24 | 100 | 15:35 | 15:39 | 72-103 | 4 | 30 | 15 | 4 | 30 | 14 | |
| 40 | 227 | 8382 | 135 | 1.3 | 15 | 50 | 75 | 32 | 24 | 100 | 15:42 | 15:47 | 104-142 | 5 | 30 | 15 | 5 | 30 | 14 | |
| 41 | 28 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 15:50 | 15:56 | 143-185 | 6 | 30 | 15 | 6 | 30 | 14 | |
| 42 | 227 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 15:58 | 16:05 | 186-231 | 7 | 30 | 15 | 7 | 30 | 14 | |
| 43 | 28 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 16:07 | 16:15 | 232-284 | 8 | 30 | 15 | 8 | 30 | 14 | |
| 44 | 227 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 16:17 | 16:25 | 285-343 | 9 | 30 | 15 | 9 | 30 | 14 | |
| 45 | 28 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 16:28 | 16:36 | 344-407 | 10 | 30 | 15 | 10 | 30 | 14 | |
| 46 | 227 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 16:39 | 16:48 | 408-476 | 11 | 30 | 15 | 11 | 30 | 14 | |
| 47 | 28 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 16:50 | 17:01 | 477-549 | 12 | 30 | 15 | 12 | 30 | 14 | |
| 48 | 227 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 17:04 | 17:14 | 550-627 | 13 | 30 | 15 | 13 | 30 | 14 | |
| 49 | 28 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 17:16 | 17:27 | 628-709 | 14 | 30 | 15 | 14 | 30 | 14 | |
| 50 | 227 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 17:30 | 17:40 | 710-795 | 15 | 30 | 15 | 15 | 30 | 14 | |
| 51 | 28 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 17:42 | 17:55 | 796-888 | 16 | 30 | 15 | 16 | 30 | 14 | |
| 52 | 227 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 17:58 | 18:10 | 889-985 | 17 | 30 | 15 | 17 | 30 | 14 | |
| 53 | 28 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 18:13 | 18:27 | 986-1087 | 18 | 30 | 15 | 18 | 30 | 14 | |
| | | | | | | | | | | | : | : | | | | | | | | |
| | | | | | | | | | | | : | : | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Notes<br><br>Flight lines 36 -53<br>Limited shadow from high cirrus. No cloud below aircraft | Data Download Completed | | Database Update | | Backup Complete | | QC | |
| | Eagle | | Hawk | | Lidar | | Thermal | |
| | RC10 | | RCD | | Applanix | | Rinex | |
| | GPS | | FCMS | | IPAS | | Aimms | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Proj No. | BGS11-01 | Proj Name | Carlsberg Fjord | PI | | Do-228 | G-ENVR | Date | 15-8-12 | Day | 228a | Land | 15:08 |
| Pilot | Carl Joseph | Co Pilot | James Johnson | Op | Phil Goy | Base | Constable | Sortie | | Log | | Take off | 11:10 |
| Observer | | Weather | 30 degree sun angle | | | | | QNH | Mb | OAT | °C | Total | 03:58 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site parameters required | | PPP | Backup | Resolution | | WILD RC-10 | | Ipas20 | Card A | ALS | F | Eagle | | Chock Time | |
| Gnd speed kts | 8300 | Start | 11:00 | Eagle | 1.64 | Filter | y | MPIA | | Scan F | 32.2 | RHD | E | Engine's | |
| Alt ft amgl | 135 | End | 15:10 | Hawk | 3.28 | Fstop | 5.6 | SPIA | Yes | PRF | 49.5Khz | Spec | Spat | On | 10:50 |
| **Acquisition Complete** | | Station | | Lidar | 0.7 | Film | Agfa Colour | FOV | 24 | Laser % | 75 | 2 | 1 | Off | 15:15 |
| | | Station | | RCD | 17-28 | Shutter | 320 | Stereo | Yes | Cloud % | 0 | Hawk | | Align in | 11:04 |
| THERMAL | | HAWK | X | Ipas20 | X | Cassette | | FCMS File | | Shadow % | Min | RHD | B | Align out | 14:37 |
| RCD | X | LIDAR | X | AIMMS | | Film | | Wave | No | Illumination % | 6 | Spec | Spat | Base Station | |
| EAGLE | X | RC10 | | Grimm | X | Science hrs | 3:05 | Transit hrs | 0:53 | Data quality | 8 | 1 | 1 | Arsf + Fixed | |

| General nav. information | | | | GPS Quality | | PRF | Laser I | Scan | Fov | Return | Time (GMT) | | Frames | Eagle | | | Hawk | | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Dir | GPS Alt ft | Spd kts | PDOP | SV | Khz | % | Hz | Deg | % | Start | Stop | | File | FPS | IT | File | FPS | IT | |
| 54 | 207 | 8382 | 135 | 2.4 | 13 | 50 | 75 | 32 | 24 | 100 | 11:40 | 11:55 | 129-349 | 1 | 30 | 25 | 1 | 30 | 15 | 2 x 360 deg |
| 55 | 028 | 8382 | 135 | 1.4 | 16 | 50 | 75 | 32 | 24 | 100 | 11:58 | 12:13 | 350-473 | 2 | 30 | 25 | 2 | 30 | 15 | Pre X |
| 56 | 207 | 8382 | 135 | 1.4 | 16 | 50 | 75 | 32 | 24 | 100 | 12:16 | 12:33 | 474-607 | 3 | 30 | 25 | 3 | 30 | 15 | Post X |
| 57 | 028 | 8382 | 135 | 1.4 | 13 | 50 | 75 | 32 | 24 | 100 | 12:35 | 12:53 | 608-748 | 4 | 30 | 25 | 4 | 30 | 15 | |
| 58 | 207 | 8382 | 135 | 1.3 | 15 | 50 | 75 | 32 | 24 | 100 | 12:55 | 13:15 | 749-896 | 5 | 30 | 25 | 5 | 30 | 15 | |
| 59 | 028 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 13:18 | 13:37 | 897-1053 | 6 | 30 | 25 | 6 | 30 | 15 | |
| 60 | 207 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 13:39 | 14:02 | 1054-1214 | 7 | 30 | 25 | 7 | 30 | 15 | |
| 61 | 028 | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 14:04 | 14:25 | 1215-1380 | 8 | 30 | 25 | 8 | 30 | 15 | |
| 165X | | 8382 | 135 | 1.3 | 16 | 50 | 75 | 32 | 24 | 100 | 14:45 | 14:45 | 1381-1461 | 9 | 30 | 25 | 9 | 30 | 15 | |
| | | | | | | | | | | | : | : | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Notes<br><br>Flight lines 54 -61<br>Clear sky | Data Download Completed | | Database Update | | Backup Complete | | QC | |
| | Eagle | | Hawk | | Lidar | | Thermal | |
| | RC10 | | RCD | | Applanix | | Rinex | |
| | GPS | | FCMS | | IPAS | | Aimms | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Proj No. | BGS11-01 | Proj Name | Carlsberg Fjord | PI | | Do-228 | G-ENVR | Date | 15-8-12 | Day | 228b | Land | 18:35 |
| Pilot | Carl Joseph | Co Pilot | James Johnson | Op | Phil Goy | Base | Constable | Sortie | | Log | | Take off | 16:29 |
| Observer | | Weather | 25 degree sun angle | | | | | QNH | Mb | OAT | °C | Total | 02:06 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site parameters required | | PPP | Backup | Resolution | | WILD RC-10 | | Ipas20 | Card A | ALS | 500GB | Eagle | | Chock Time | |
| Gnd speed kts | 8300 | Start | 16:20 | Eagle | 1.64 | Filter | y | MPIA | | Scan F | 32.2 | RHD | A | Engine's | |
| Alt ft amgl | 135 | End | 18:40 | Hawk | 3.28 | Fstop | 5.6 | SPIA | Yes | PRF | 49.5Khz | Spec | Spat | On | 16:15 |
| **Acquisition Complete** | | Station | | Lidar | 0.7 | Film | Agfa Colour | FOV | 24 | Laser % | 75 | 2 | 1 | Off | 18:45 |
| | | Station | | RCD | 17-28 | Shutter | 320 | Stereo | Yes | Cloud % | 0 | Hawk | | Align in | 16:25 |
| THERMAL | | HAWK | X | Ipas20 | X | Cassette | | FCMS File | | Shadow % | Min | RHD | C | Align out | 18:27 |
| RCD | X | LIDAR | X | AIMMS | | Film | | Wave | No | Illumination % | 4 | Spec | Spat | Base Station | |
| EAGLE | X | RC10 | | Grimm | X | Science hrs | 3:05 | Transit hrs | 0:53 | Data quality | 8 | 1 | 1 | Arsf + Fixed | |

| General nav. information | | | | GPS Quality | | PRF | Laser I | Scan | Fov | Return | Time (GMT) | | Frames | Eagle | | | Hawk | | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Dir | GPS Alt ft | Spd kts | PDOP | SV | Khz | % | Hz | Deg | % | Start | Stop | | File | FPS | IT | File | FPS | IT | |
| 62 | 207 | 8382 | 135 | 2.4 | 13 | 50 | 75 | 32 | 24 | 100 | 16:40 | 17:03 | 20-199 | 1 | 30 | 25 | 1 | 30 | 16 | 2 x 360 deg |
| 63 | 028 | 8382 | 135 | 1.4 | 16 | 50 | 75 | 32 | 24 | 100 | 17:05 | 17:30 | 200-382 | 2 | 30 | 27 | 2 | 30 | 18 | Pre X |
| 64 | 207 | 8382 | 135 | 1.4 | 16 | 50 | 75 | 32 | 24 | 100 | 17:56 | 17:56 | 383-563 | 3 | 30 | 28 | 3 | 30 | 18 | Post X |
| 64 | 028 | 8382 | 135 | 1.4 | 13 | 50 | 75 | 32 | 24 | 100 | 18:06 | 18:16 | 564-644 | 4 | 30 | 28 | 4 | 30 | 18 | |
| | | | | | | | | | | | : | : | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Notes<br><br>Flight lines 62-64<br>Clear sky | Data Download Completed | | Database Update | | Backup Complete | | QC | |
| | Eagle | | Hawk | | Lidar | | Thermal | |
| | RC10 | | RCD | | Applanix | | Rinex | |
| | GPS | | FCMS | | IPAS | | Aimms | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Proj No. | BGS11-01 | Proj Name | Carlsberg Fjord | PI | | Do-228 | G-ENVR | Date | 17-8-12 | Day | 230 | Land | 14:05 |
| Pilot | Carl Joseph | Co Pilot | James Johnson | Op | Phil Goy | Base | Constable | Sortie | | Log | | Take off | 09:10 |
| Observer | | Weather | Clear and bright | | | | | QNH | Mb | OAT | °C | Total | 04:55 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site parameters required | | PPP | Backup | Resolution | | WILD RC-10 | | Ipas20 | Card A | ALS | 500GB | Eagle | | Chock Time | |
| Gnd speed kts | 8300 | Start | 09:00 | Eagle | 1.64 | Filter | y | MPIA | | Scan F | 32.2 | RHD | A | Engine's | |
| Alt ft amgl | 135 | End | 14:10 | Hawk | 3.28 | Fstop | 5.6 | SPIA | Yes | PRF | 49.5Khz | Spec | Spat | On | 08:56 |
| **Acquisition Complete** | | Station | | Lidar | 0.7 | Film | Agfa Colour | FOV | 24 | Laser % | 75 | 2 | 1 | Off | 14:20 |
| | | Station | | RCD | 17-28 | Shutter | 320 | Stereo | Yes | Cloud % | 0 | Hawk | | Align in | 09:04 |
| THERMAL | | HAWK | X | Ipas20 | X | Cassette | | FCMS File | | Shadow % | Min | RHD | C | Align out | 13:53 |
| RCD | X | LIDAR | X | AIMMS | | Film | | Wave | No | Illumination % | 6 | Spec | Spat | Base Station | |
| EAGLE | X | RC10 | | Grimm | X | Science hrs | 3:05 | Transit hrs | 0:53 | Data quality | 8 | 1 | 1 | Arsf + Fixed | |

| General nav. information: Line No. | Dir | GPS Alt ft | Spd kts | GPS Quality: PDOP | SV | PRF Khz | Laser I % | Scan Hz | Fov Deg | Return % | Time (GMT) Start | Stop | Frames | Eagle File | FPS | IT | Hawk File | FPS | IT | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | 227 | 8382 | 135 | 1.9 | 13 | 50 | 75 | 32 | 24 | 100 | 09:09 | 09:42 | 20-200 | 1 | 30 | 25 | 1 | 30 | 17 | 2 x 360 deg |
| 66 | 208 | 8382 | 135 | 1.9 | 14 | 50 | 75 | 32 | 24 | 100 | 09:44 | 10:07 | 201-383 | 2 | 30 | 27 | 2 | 30 | 17 | Pre X |
| 67 | 227 | 8382 | 135 | 1.3 | 17 | 50 | 75 | 32 | 24 | 100 | 10:09 | 10:32 | 384-567 | 3 | 30 | 27 | 3 | 30 | 17 | Post X |
| 68 | 208 | 8382 | 135 | 1.3 | 13 | 50 | 75 | 32 | 24 | 100 | 10:34 | 10:57 | 568-750 | 4 | 30 | 27 | 1-2 | 30 | 17 | 2 x 360 deg |
| 69 | 227 | 8382 | 135 | 1.9 | 14 | 50 | 75 | 32 | 24 | 100 | 10:59 | 11:22 | 751-932 | 5 | 30 | 27 | 1-3 | 30 | 17 | |
| 70 | 208 | 8382 | 135 | 1.9 | 13 | 50 | 75 | 32 | 24 | 100 | 11:25 | 11:46 | 933-1110 | 6 | 30 | 27 | 1-4 | 30 | 17 | |
| 71 | 227 | 8382 | 135 | 1.9 | 13 | 50 | 75 | 32 | 24 | 100 | 11:49 | 12:11 | 1111-1290 | 7 | 30 | 27 | 1-5 | 30 | 17 | |
| 72 | 208 | 8382 | 135 | 1.8 | 15 | 50 | 75 | 32 | 24 | 100 | 12:13 | 12:36 | 1291-1468 | 8 | 30 | 27 | 1-6 | 30 | 14 | |
| 73 | 227 | 8382 | 135 | 1.8 | 15 | 50 | 75 | 32 | 24 | 100 | 12:38 | 13:01 | 1469-1649 | 9 | 30 | 27 | 1-7 | 30 | 14 | |
| 74 | 208 | 8382 | 135 | 1.8 | 15 | 50 | 75 | 32 | 24 | 100 | 13:03 | 13:26 | 1650-1836 | 10 | 30 | 27 | 1-8 | 30 | 14 | |
| X | | 8382 | 135 | 1.7 | 17 | 50 | 75 | 32 | 24 | 100 | 13:37 | 13:47 | 1837-1917 | 11 | 30 | 27 | 1-9 | 30 | 14 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Notes<br>Hawk Crash 10:15 restart 10:16 | Data Download Completed | | Database Update | | Backup Complete | | QC | |
| | Eagle | | Hawk | | Lidar | | Thermal | |
| | RC10 | | RCD | | Applanix | | Rinex | |
| | GPS | | FCMS | | IPAS | | Aimms | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Proj No. | BGS11-01 | Proj Name | Carlsberg Fjord | PI | | Do-228 | G-ENVR | Date | 18-08-12 | Day | 231 | Land | 13:25 |
| Pilot | Carl Joseph | Co Pilot | James Johnson | Op | Phil Goy | Base | Constable | Sortie | | Log | | Take off | 08:18 |
| Observer | | Weather | 30 degree sun angle | | | | | QNH | Mb | OAT | °C | Total | 05:07 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site parameters required | | PPP | Backup | Resolution | | WILD RC-10 | | Ipas20 | Card A | ALS | 500GB | Eagle | | Chock Time | |
| Gnd speed kts | 8300 | Start | 08:07 | Eagle | 1.64 | Filter | y | MPIA | | Scan F | 32.2 | RHD | F | Engine's | |
| Alt ft amgl | 135 | End | 13:35 | Hawk | 3.28 | Fstop | 5.6 | SPIA | Yes | PRF | 49.5Khz | Spec | Spat | On | 08:02 |
| **Acquisition Complete** | | Station | | Lidar | 0.7 | Film | Agfa Colour | FOV | 24 | Laser % | 75 | 2 | 1 | Off | 13:40 |
| | | Station | | RCD | 17-28 | Shutter | 320 | Stereo | Yes | Cloud % | 0 | Hawk | | Align in | 08:12 |
| THERMAL | | HAWK | X | Ipas20 | X | Cassette | | FCMS File | | Shadow % | Min | RHD | C | Align out | 13:17 |
| RCD | X | LIDAR | X | AIMMS | | Film | | Wave | No | Illumination % | 4 | Spec | Spat | Base Station | |
| EAGLE | X | RC10 | | Grimm | X | Science hrs | 4:30 | Transit hrs | 0:37 | Data quality | 8 | 1 | 1 | Arsf + Fixed | |

| General nav. information: Line No. | Dir | GPS Alt ft | Spd kts | GPS Quality: PDOP | SV | PRF Khz | Laser I % | Scan Hz | Fov Deg | Return % | Time (GMT) Start | Stop | Frames | Eagle File | FPS | IT | Hawk File | FPS | IT | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 75 | 28 | 8382 | 135 | 1.6 | 15 | 50 | 75 | 32 | 24 | 100 | 08:28 | 08:50 | 18-208 | 1 | 30 | 29 | 1 | 30 | 18 | 2 x 360 deg |
| 76 | 227 | 8382 | 135 | 1.6 | 15 | 50 | 75 | 32 | 24 | 100 | 08:52 | 09:14 | 209-394 | 2 | 30 | 29 | 2 | 30 | 18 | Pre X |
| 77 | 28 | 8382 | 135 | 1.6 | 15 | 50 | 75 | 32 | 24 | 100 | 09:16 | 09:38 | 395-579 | 3 | 30 | 29 | 3 | 30 | 18 | Post X |
| 78 | 227 | 8382 | 135 | 1.6 | 15 | 50 | 75 | 32 | 24 | 100 | 09:40 | 10:02 | 580-769 | 4 | 30 | 29 | 4 | 30 | 18 | |
| 79 | 28 | 8382 | 135 | 1.6 | 15 | 50 | 75 | 32 | 24 | 100 | 10:04 | 10:27 | 770-961 | 5 | 30 | 29 | 5 | 30 | 18 | |
| 80 | 227 | 8382 | 135 | 1.6 | 15 | 50 | 75 | 32 | 24 | 100 | 10:29 | 10:50 | 962-1207 | 6 | 30 | 29 | 6 | 30 | 18 | |
| 81 | 28 | 8382 | 135 | 1.6 | 12 | 50 | 75 | 32 | 24 | 100 | 10:53 | 11:14 | 1208-1405 | 7 | 30 | 29 | 7 | 30 | 18 | |
| 82 | 227 | 8382 | 135 | 1.6 | 12 | 50 | 75 | 32 | 24 | 100 | 11:18 | 11:39 | 1406-1601 | 8 | 30 | 29 | 8 | 30 | 18 | |
| 83 | 28 | 8382 | 135 | 1.6 | 12 | 50 | 75 | 32 | 24 | 100 | 11:40 | 11:58 | 1602-1753 | 9 | 30 | 29 | 1.1 | 30 | 18 | |
| 84 | 227 | 8382 | 135 | 1.6 | 12 | 50 | 75 | 32 | 24 | 100 | 11:59 | 12:15 | 1754-1905 | 10 | 30 | 29 | 1.2 | 30 | 18 | |
| 85 | 28 | 8382 | 135 | 1.6 | 12 | 50 | 75 | 32 | 24 | 100 | 12:17 | 12:32 | 1906-2053 | 11 | 30 | 29 | 1.3 | 30 | 18 | |
| 86 | 227 | 8382 | 135 | 1.6 | 12 | 50 | 75 | 32 | 24 | 100 | 12:35 | 12:48 | 2054-2180 | 12 | 30 | 29 | 1.4 | 30 | 18 | |
| X | 28 | 8382 | 135 | 1.6 | 12 | 50 | 75 | 32 | 24 | 100 | 12:59 | 13:08 | 2181-2261 | | | | | | | Lidar only |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Notes<br>Line 82 Hawk failure at end of line<br>Restarted Hawk for line 83 | Data Download Completed | | Database Update | | Backup Complete | | QC | |
| | Eagle | | Hawk | | Lidar | | Thermal | |
| | RC10 | | RCD | | Applanix | | Rinex | |
| | GPS | | FCMS | | IPAS | | Aimms | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Proj No. | BGS11-01 | Proj Name | Kap Simpson | PI | | Do-228 | G-ENVR | Date | 23-8-12 | Day | 236b | Land | 18:15 |
| Pilot | Carl Joseph | Co Pilot | James Johnson | Op | Phil Goy | Base | Mestervig | Sortie | | Log | | Take off | 14:24 |
| Observer | | Weather | Minor cloud at Eastern end of site | | | | | QNH | Mb | OAT | °C | Total | 03:11 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site parameters required | | PPP | Backup | Resolution | | WILD RC-10 | | Ipas20 | Card A | ALS | A | Eagle | | Chock Time | |
| Gnd speed kts | 8300 | Start | 14:21 | Eagle | 1.64 | Filter | y | MPIA | | Scan F | 32.2 | RHD | A | Engine's | |
| Alt ft amgl | 135 | End | 18:20 | Hawk | 3.28 | Fstop | 5.6 | SPIA | Yes | PRF | 49.5Khz | Spec | Spat | On | 14:19 |
| **Acquisition Complete** | | Station | | Lidar | 0.7 | Film | Agfa Colour | FOV | 24 | Laser % | 75 | 2 | 1 | Off | 18:25 |
| | | Station | | RCD | 16-28 | Shutter | 320 | Stereo | Yes | Cloud % | 0 | Hawk | | Align in | 14:49 |
| THERMAL | | HAWK | X | Ipas20 | X | Cassette | | FCMS File | | Shadow % | Min | RHD | C | Align out | 17:23 |
| RCD | X | LIDAR | X | AIMMS | | Film | | Wave | No | Illumination % | 6 | Spec | Spat | Base Station | |
| EAGLE | X | RC10 | | Grimm | X | Science hrs | 2:05 | Transit hrs | 1:06 | Data quality | 8 | 1 | 1 | Arsf + Fixed | |

| General nav. information | | | | GPS Quality | | PRF | Laser I | Scan | Fov | Return | Time (GMT) | | Frames | Eagle | | | Hawk | | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line No. | Dir | GPS Alt ft | Spd kts | PDOP | SV | Khz | % | Hz | Deg | % | Start | Stop | | File | FPS | IT | File | FPS | IT | |
| 23 | 144 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 15:04 | 15:13 | 14-100 | 1 | 30 | 17 | 1 | 30 | 16 | 2 x 360 deg |
| 24 | 322 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 15:15 | 15:24 | 101-184 | 2<br>1.1 | 30 | 17 | 2 | 30 | 16 | Pre X |
| 25 | 144 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 15:27 | 15:35 | 185-267 | 1.2 | 30 | 17 | 3 | 30 | 16 | Post X |
| 26 | 322 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 15:37 | 15:47 | 268-349 | 1.3 | 30 | 17 | 4 | 30 | 16 | 2 x 360 deg |
| 27 | 144 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 15:49 | 15:58 | 350-430 | 1.4 | 30 | 17 | 5 | 30 | 16 | |
| 28 | 322 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 15:59 | 16:08 | 431-510 | 1.5 | 30 | 17 | 6 | 30 | 16 | |
| 29 | 144 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 16:11 | 16:19 | 511-588 | 1.6 | 30 | 17 | 7 | 30 | 16 | |
| 30 | 322 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 16:22 | 16:30 | 589-662 | 1.7 | 30 | 17 | 8 | 30 | 16 | |
| 31 | 144 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 16:32 | 16:39 | 663-730 | 1.8 | 30 | 17 | 9 | 30 | 16 | |
| 32 | 322 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 16:41 | 16:48 | 731-793 | 1.9 | 30 | 17 | 10 | 30 | 16 | |
| 33 | 144 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 16:50 | 16:57 | 794-850 | 1.10 | 30 | 17 | 11 | 30 | 16 | |
| 34 | 322 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 16:59 | 17:05 | 851-900 | 1.11 | 30 | 17 | 12 | 30 | 16 | |
| 35 | 144 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 17:07 | 17:12 | 901-930 | 1.12 | 30 | 17 | 13 | 30 | 16 | |
| X | 292 | 8382 | 135 | 2.0 | 12 | 50 | 75 | 32 | 24 | 100 | 17:15 | 17:19 | NA | 1.13 | 30 | 17 | 14 | 30 | 16 | Manual X |
| | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Notes<br><br>Line 24 Eagle fail<br>No Eagle data 30km – 36km on line | Data Download Completed | | Database Update | | Backup Complete | | QC | |
| | Eagle | | Hawk | | Lidar | | Thermal | |
| | RC10 | | RCD | | Applanix | | Rinex | |
| | GPS | | FCMS | | IPAS | | Aimms | |

# 12. Appendix 2: ARSF on hyperspectral data


## Hyperspectral Data

### Project Details

| | |
|---|---|
| Site Location: | East Greenland |
| Principal Investigator: | TapsaTukiainen |
| ARSF Project Code: | BGS11/01 |
| Date of Flight: | 23 August 2012 |
| Julian Day of Flight: | 236a |

## Introduction

This file has been generated specifically for your Airborne Research and Survey Facility (ARSF) project and includes important information about your data. Please make sure you read it fully before trying to use your data.

## Delivery Contents

The following files are contained on the distribution medium: Filename Description Read_Me-20121106.pdf This PDF document

| | |
|---|---|
| dem | Directory containing a Digital Elevation Model generated for processing your data |
| doc | Directory containing information on the processing and quality of your data |
| flightlines | Directory containing the level1b data sets |
| flightlines/fodis | Directory containing averaged FODIS data for |
| each Eagle flight line e236axx1b_FODIS.bil | Averaged FODIS data BIL file for line xx |
| e236axx1b_FODIS.bil.hdr | and header file. |
| flightlines/level1b | Directory containing radiometrically cali- |
| brated level1 image data e236axx1b_mask.bil | Bad pixel mask BIL file for Eagle line xx |
| e236axx1b_mask.bil.hdr | and header file. |
| e236axx1b.bil | Radiometrically calibrated level1b BIL |
| file for Eagle line xx e236axx1b.bil.hdr | and header file. |
| h236axx1b_mask.bil | Bad pixel mask BIL |
| file for Hawk line xx h236axx1b_mask.bil.hdr | and header file. |
| h236axx1b_mask-badpixelmethod.bil | Bad CCD pixel method identifier BIL |
| file for Hawk line xx h236axx1b_mask-badpixelmethod.bil.hdr | and header file. |
| h236axx1b.bil | Radiometrically calibrated level1b BIL |
| file for Hawk line xx h236axx1b.bil.hdr | and header file. |
| flightlines/line_information | Directory containing ISO XML infor- |
| mation for each flight line e236axx1b.xml | ISO standard XML file for Eagle line xx |
| h236axx1b.xml | ISO standard XML file for |
| Hawk line xx flightlines/mapped | Directory containing |
| mapped hyperspectral data | |
| e236axx3b_mapped_PROJ.bil | Mapped data for Eagle line xx in projection PROJ |
| e236axx3b_mapped_PROJ.bil.hdr | and header file |
| h236axx3b_mapped_PROJ.bil | Mapped data for Hawk line xx in projection PROJ |
| h236axx3b_mapped_PROJ.bil.hdr | and header file |
| flightlines/navigation | Directory containing post-processed |
| synced navigation data e236axx1b_nav_post_processed.bil | Post-processed nav- |
| igation BIL file for Eagle line xx e236axx1b_nav_post_processed.bil.hdr | and header file. |
| e236axx1b_nav_post_processed_quality.bil | Post-processed navigation quality flag |
| file for Eagle line xx e236axx1b_nav_post_processed_quality.bil.hdr | and header file. |
| h236axx1b_nav_post_processed.bil | Post-processed navigation BIL |
| file for Hawk line xx h236axx1b_nav_post_processed.bil.hdr | and header file. |
| h236axx1b_nav_post_processed_quality.bil | Post-processed navigation quality flag |
| file for Hawk line xx h236axx1b_nav_post_processed_quality.bil.hdr | and header file. |
| logsheet | Directory containing flight log sheet |
| project_information | Directory containing ISO XML de- |
| scription of the project screenshots | Directory containing example screen- |
| shots of Level 3 data sensor_FOV_vectors | Directory containing the Eagle/Hawk |
| Field of View vectors | |

The image filename identifiers are structured as "sdddfnn1b", where • s is the sensor id (a=ATM, c=CASI, e=Eagle, h=Hawk),• ddd is the Julian day of the data acquisition, • f distinguishes between multiple flights on the same day ("a" being the first flight) and • nn is the flight line number

However, please note that the nn flight line numbers do not necessarily reflect the flight line numbers denoted in the flight log sheet. The following table shows the mapping of file identifier to flight line name as shown in the logsheet.

| Logsheet flightline name | Eagle file identifier | Hawk file identifier |
|---|---|---|
| 003 | e236a011b | h236a011b |
| 004 | e236a021b | h236a021b |
| 005 | e236a031b | h236a031b |
| 006 | e236a041b | h236a041b |
| 007 | e236a051b | h236a051b |
| 008 | e236a061b | h236a061b |
| 009 | e236a071b | h236a071b |
| 010 | e236a081b | h236a081b |
| 011 | e236a091b | h236a091b |
| 012 | e236a101b | h236a101b |
| 013 | e236a111b | h236a111b |
| 014 | e236a121b | h236a121b |
| 015 | e236a131b | h236a131b |
| 016 | e236a141b | h236a141b |
| 017 | e236a151b | h236a151b |
| 018 | e236a161b | h236a161b |
| 019 | e236a171b | h236a171b |
| 020 | e236a181b | h236a181b |
| 021 | e236a191b | h236a191b |
| 022 | e236a201b | h236a201b |
| UL001 | e236a211b | h236a211b |

## Data processing details

### Level-1 data

These data are delivered as Level 1b ENVI BIL format files with metadata as ISO standard XML which means that:

- radiometric calibration algorithms have been applied
- navigation information has been synced to the image data.

Level 1b files have been supplied to provide maximum flexibility in image processing your data. Hence, Level 2 products (such as atmosphere corrected products) can be created before geocorrection.

These Level 1b (or Level 2) files can be geocorrected with the Airborne Processing Library (APL) software suite to produce a Level 3 file. Instructions on how to do this are provided in a later section of this document, and also in the apl_mapping_guide.pdf which can be downloaded from the same place as the APL software.

### Level 3 / Georeferenced data

ARSF DAN is also delivering georeferenced data to users. These files have been processed with the APL software to a final mapped image allowing users to get quick access to their data in a mapped form. The level-1 data will have had the mask applied and all data bands will have been mapped using nearest neighbor interpolation. Pixel size will have been determined based on information from the entire flight day, with each line mapped to the same pixel size unless large variances of flight altitude occur.

To save disk space, the level 3 delivery data may have been zip compressed, details of the filesize before zipping are included in unzipped_filesize.csv file. This means the data will need to be unzipped before it can be accessed; a range of freely available tools exist to do this.

If you wish to reduce the size of these files further you can use the free tool '[gdal_translate]' to crop out an area of interest or bands of interest. An example command follows that demonstrates how to crop a file by both band and area:

```
gdal_translate -of ENVI -co INTERLEAVE=BIL -projwin 445319.2 8054184.8
451584.8 8049351.2 -b 62 -b 63 -b 64 e236a013b_mapped_utm27n.bil
e236a013b_mapped_utm27n_cropped.bil
```

This will create a new file called e236a013b_mapped_utm27n_cropped.bil which contains data from the bands: 62, 63, 64 restricted to the area described by 445319.2, 8054184.8, 451584.8, 8049351.2

## Downloading APL (aplmask , aplcorr , apltran , aplmap )

In order to ensure that you have the latest version of the software, please either visit the ftp download site:

*ftp://sw:nogwugAk7@ftp.nerc-arsf.ac.uk/*

or the http download site:

*http://arsf-dan.nerc.ac.uk/trac/wiki/Downloads*

(username "sw", password at the time of writing is "nogwugAk7")

You will need to download all of aplmask , aplcorr , apltran and aplmap . Currently there are builds that support 32-bit MS Windows and both 32-bit and 64-bit Linux distributions.

If you wish to get the most up to date versions, please download an update from one of the above sites. As soon as we create a newer version, it will be available for download.

## Quality and issues with data

While the data have been corrected to account for alignment of the sensors, small errors may remain or accumulate from other sources and will manifest as roll, pitch and heading features. If the standard accuracy is insufficient, please contact arsf-processing@pml.ac.uk to discuss the inaccuracy and methods for correcting.

Some bands show missing (or constant) pixel lines where the instrument has bad pixels.

Eagle and Hawk lines 007 and 013 (e236a051b.bil, e236a111b.bil, h236a051b.bil and h236a111b.bil)

have a few dropped scans, these will appear as zero data in the level 1 files.

## Hawk pixels of unreliable quality

During calibration of the Hawk sensor we have tested the quality of the response of the sensor for each of its pixels. This testing has given us a list of pixels which are deemed to be of lower quality.

This list has been provided in your delivery within the mask files (see below) so that you may mask out the bad pixels if you desire.

For further information on the tests used to detect these unreliable pixels please see the data quality report.

## Mask files

As part of the processing of your data to level 1, mask files are generated that contain information about pixels that have been adversely affected. These include pixels that may have underflowed, overflowed, are missing (i.e. dropped scans), be affected by incorrect Eagle smear correction (due to overflows in higher bands) or deemed to be bad pixels during calibration. The values in the mask file denote:

0 = Good data.

1 = Underflows.

2 = Overflows.

4 = Bad CCD pixels.

8 = Pixel affected by uncorrected smear.

16 = Dropped scans.

32 = Corrupt raw data.

64 = Quality control failures.

The mask files have the same dimensions as the calibrated BIL files with a one-to-one mapping between them. Software is available to mask the data as part of the APL package. See Example mapping commands section for example commands.

## ASCII view vector list

As part of the delivery, a readable text list of the sensor field of view vectors for the data has been provided. This is a 'binned and trimmed' version of the binary sensor FOV files, such that it is a one-to-one mapping for each sample of the provided level 1 data. The given value is to the centre of the CCD pixel.

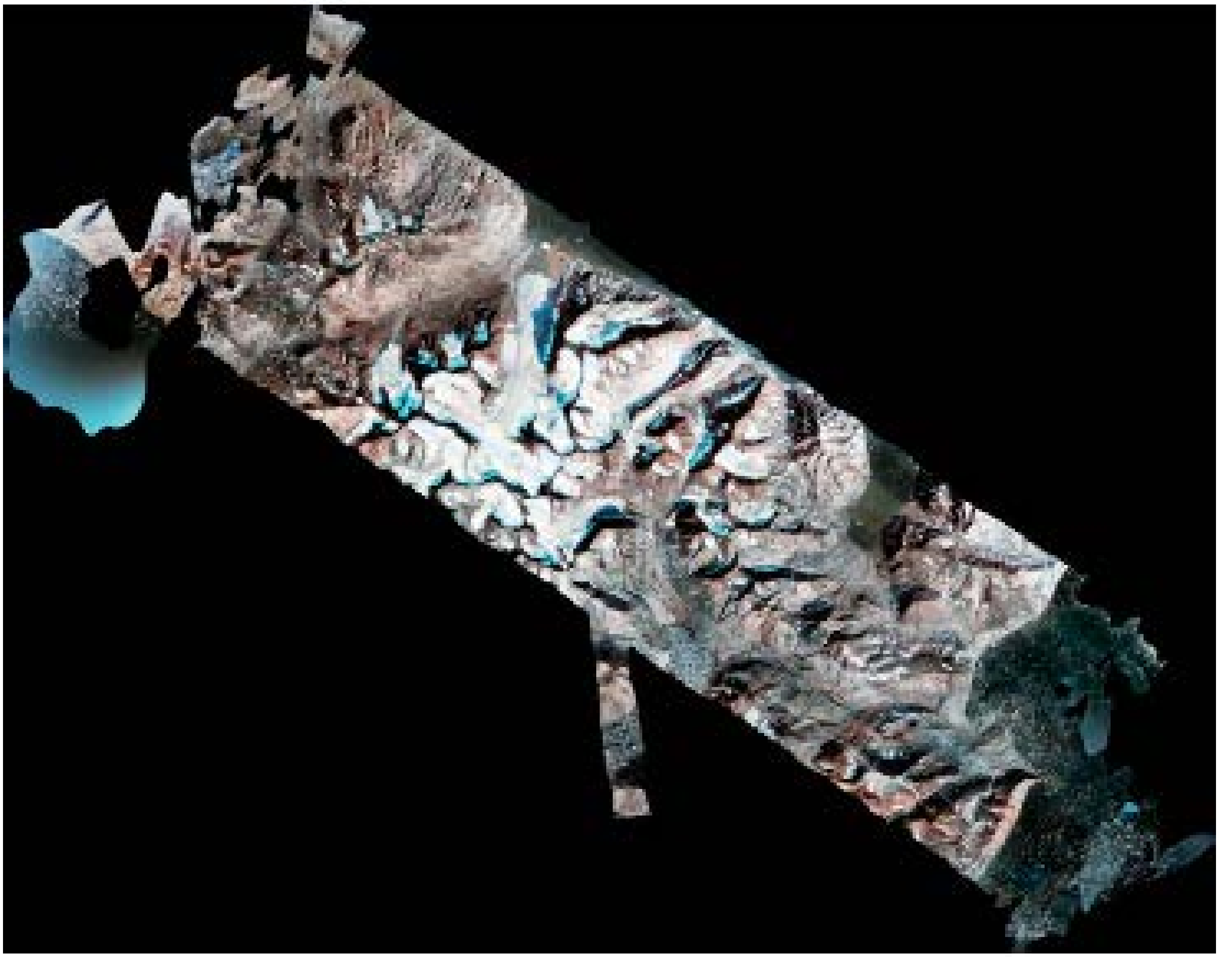


Figure 1: Mosaic of Eagle data

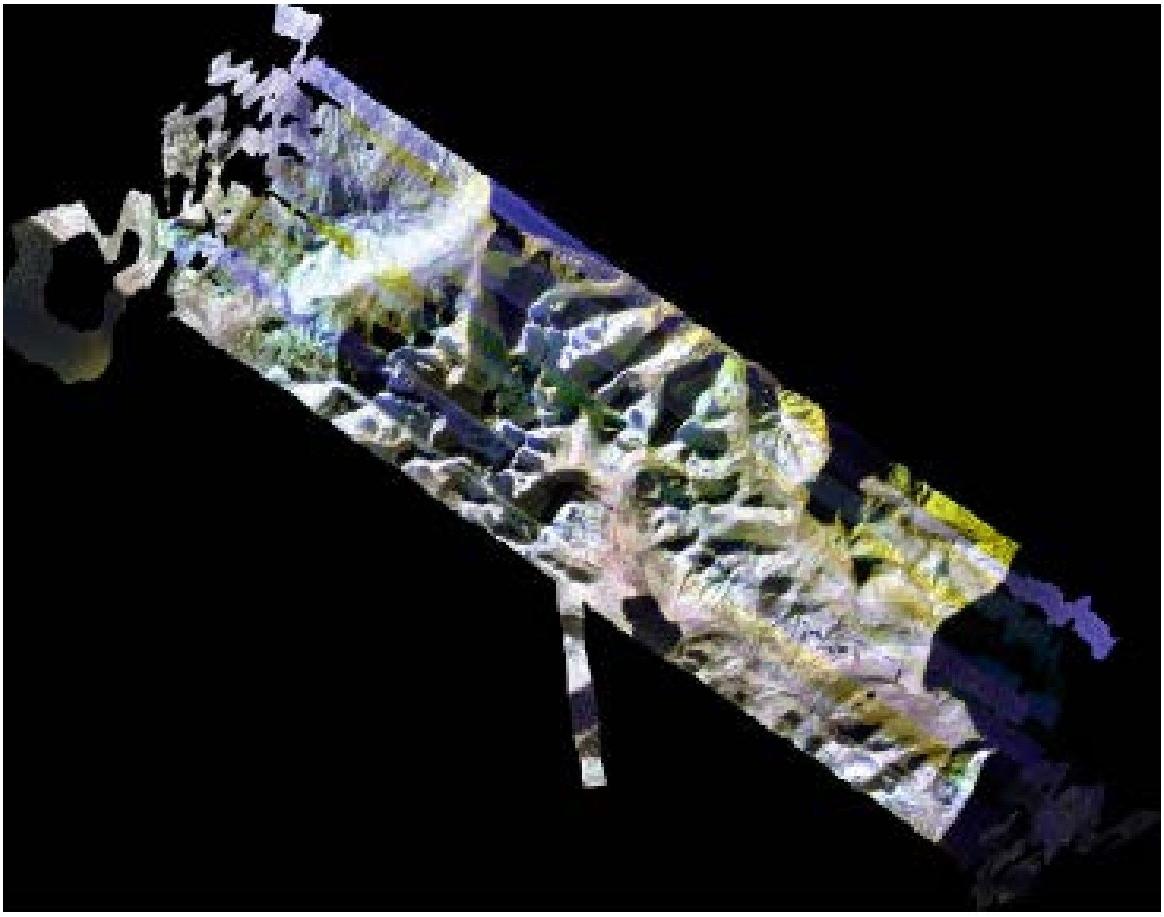


Figure 2: Mosaic of Hawk data

## Digital Elevation Models

As part of the data pre-processing the ARSF Data Analysis Node produce Digital Elevation Model (DEM) maps from various sources. This is to ensure that any navigation corrections include the influence of topography. Where licensing terms allow, these maps have been included with the imagery. However, it should be stressed that these DEMs may be inadequate for your analyses since their use for navigation pre-processing requires only part of the DEM to be of high quality (i.e. the navigation is checked only where the DEM is of good quality). Hence, it is recommended that you use your own DEMs where available as these will have characteristics known to you.

The DEM used for processing this imagery came from NASA's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) GDEM. An appropriate coverage was downloaded and converted to the aplcorr format and this file has been included. The resolution of ASTER DEMs is 1 arc second (30m) with an estimated vertical accuracy of 20m.

Additionally, ASTER data is measured against the geoid, but the supplied DEM will have been offset such that it now references the WGS-84 ellipsoid surface.

*EOS data archive*

*Japan's Ground Data System*

- data access

*http://asterweb.jpl.nasa.gov/ ASTER GDEM Validation Summary Report (pdf)*

- information about ASTER

*https://lpdaac.usgs.gov/lpdaac/products/aster_policies*

- requested acknowledgements if the DEM is used as part of a publication

Also note that processing without a Digital Elevation Model (DEM) will result in substantial inaccuracies for any non-flat terrain. DEMs for the UK for academic use are available from NEODC (NEXTMap dataset) - see *http://www.neodc.ac.uk/* If a LIDAR dataset was also captured at the time of flight, this can be converted to an appropriate DEM for aplcorr - please read the manual and contact us for assistance.

However, you should get a Digital Elevation Model included in your project, although due to licencing restrictions this is likely to be derived from free sources such as from SRTM or ASTER data.

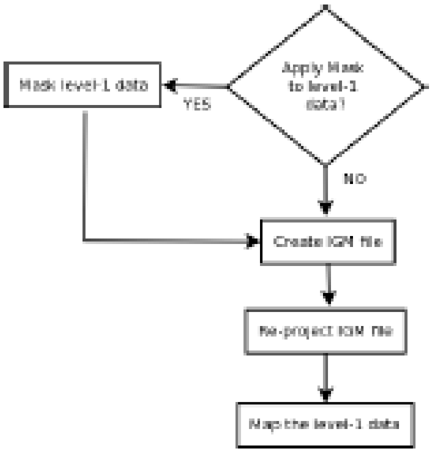
## Example mapping commands

For more detailed information on using the mapping software, please see the apl_mapping_guide.pdf which is available for download with the APL software. Please note that the example command should be entered on a single line.

For help using the Graphical User Interface please consult the web page

*http://arsfdan.nerc.ac.uk/trac/wiki/Processing/apluiquickstart*

## Processing flow




## aplmask

Prior to mapping the data or using the level-1 as input to other algorithms you may wish to mask the data. This can be done using the aplmask software. An example command is:

aplmask -lev1 flightlines/level1b/e236a011b.bil -mask flightlines/level1b/e236a011b_mask.bil -output flightlines/level1b/e236a011b_masked.bil

## aplcorr

An example of the aplcorr commands used to generate an IGM file to test the processing of this dataset is:

aplcorr -lev1file flightlines/level1b/e236a011b.bil -igmfile e236a013b.igm -vvfile sensor_FOV_vectors/eagle_fov_fullccd_vectors.bil -navfile flightlines/navigation/e236a011b_nav_post_processed.bil -dem dem/BGS11_01-2012_236a-ASTER.dem

This command creates an IGM file, i.e. a per-pixel latitude / longitude file, using the Eagle field of view files together with the navigation contained in e236a011b_nav_post_processed.bil and the level1 data contained in e236a011b.bil.

## apltran

The IGM file will be in WGS-84 Geographic Latitude / Longitude. To re-project it into a more suitable projection use the apltran software. An example command is:

```
apltran -inproj latlong WGS84 -igm e236a013b.igm -output
e236a013b_utm_wgs84N27.igm -outproj utm_wgs84N 27
```

This command re-projects the IGM file from WGS-84 Geographic Latitude/Longitude into Universal Transverse Mercator projection with zone: 27.

## aplmap

To map the level1 data using this IGM file use the aplmap software. An example command is:

```
aplmap -igm e236a013b_utm_wgs84N27.igm -lev1 flight-
lines/level1b/e236a011b_masked.bil -mapname
e236a013b_mapped_utm27n.bil
-pixelsize 4 4 -bandlist ALL
```

This command uses the re-projected IGM file together with the level1 data file to map all bands using a pixel size of 4m. The resulting file e236a013b_mapped_utm27n.bil is in ENVI BIL format.

If your project contains multiple flight lines which are flown at significantly different heights, you will need to vary the pixel size used.

See *http://arsf-dan.nerc.ac.uk/trac/wiki/Processing/PixelSize* for details on the selection of appropriate pixel sizes.

## Outputting image data

The mapped data are output as ENVI BIL files. These can be transformed to a different format, such as GeoTIFF, using GIS packages (such as ArcGIS, GRASS, ENVI) or the Open Source GDALTranslate software which can be downloaded from:

*http://www.gdal.org/gdal_tra
nslate.html*

More details can be found from the GDAL web pages *http://www.gdal.org/*

For example, to produce a GeoTIFF from the Level 3 BIL generated above (using all bands for RGB), do:

```
gdal_translate -of GTiff
        e236a013b_mapped_utm27n.bil
        e236a013b_mapped_utm27n.tif
```

## Using image data

The BIL files can be viewed directly in ENVI or can be converted to GeoTIFFs (as above) and viewed in most GIS tools such as ERDAS Imagine.

Flight metadata (such as the date and time of flight, altitude, airspeed and direction) are stored in the ISO XML files. These can be viewed with any text editor or web browser.

## Imagery for general use

You may wish to have images of the ARSF aircraft for use in presentations. A few images are available from our FTP site at *ftp://ftp.rsg.pml.ac.uk/arsf/user_images*, please feel free to use these as you wish (crediting ARSF appropriately).

## Contacting ARSF and reporting problems

If you have any problems of data access, software installation or data processing, please ensure the following is supplied so that ARSF can help you quickly and efficiently.

For all problems:

- ARSF project code - to enable more specific help

For software installation:

- the error that occurred when attempting to run

For data processing:

- a copy of the command line used to run the program
- any output text from the run would be useful

If you encounter any problems, or if you have any other queries relating to data processing then consult the help desk web page *http://arsf-dan.nerc.ac.uk/trac/wiki/Help*. If this fails to help then please contact ARSF using the details below.

### Email: arsf-processing@pml.ac.uk

Tel: +44 (0)1752 633100

(Plymouth Marine Laboratory switchboard, ask for ARSF helpdesk, Ben Taylor, Mark Warren, Emma Carolan, Kevin Paxman, Mike Grant or Steve Groom).

If you wish to discuss other issues, such as matters relating to the service, please contact: Carl Joseph

NERC-ARSF Operations Centre

Firfax House

Meteor Business Park Cheltenham Road East Gloucester

GL2 9QL

Tel: +44 (0)1452 859945

Fax: +44 (0)1452 713219

Email: cjos@nerc.ac.uk

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## ARSF Hyperspectral Data

The ARSF collects hyperspectral data[2] using two instruments, both of which are manufactured by Specim:

- Eagle for visible and near infra-red wavelengths (~400nm to 970nm)
- Hawk for short wave infra-red wavelengths (~1000nm to 2500nm)

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[2] Hyperspectral processing using the Airborne Processing Library

The Airborne Processing Library (APL) is an open source software package that has been developed by ARSF-DAN at Plymouth Marine Laboratory. It has been specifically designed to process the ARSF Eagle and Hawk data from the raw data collection stage through to end-user geocorrection and mapping. The following gives a description of how ARSF-DAN use APL to process the hyperspectral data upto the point of dispatching the data to the end-user.

The raw data format from these sensors is ENVI band interleaved by line (BIL) files, which is a simple binary data format. Each BIL file comes with an accompanying header file in a human readable text format. The header file contains information about the BIL file format and specifications of the sensor at time of data capture. The Eagle raw data files contain data 12-bit data (0-4095) stored as 16-bit integer, whilst the Hawk raw data are 14-bit (0-16383) stored as 16-bit integer. The first pixel of the first band of each raw file is the frame counter pixel, which is essentially a frame id tag that increments by 1 through out the file. At the end of the raw file, after data capture for this flight line, a number of lines of data are captured with the shutter closed. These lines are refered to as "dark lines" and give sensor ccd values for when no light is present.

When ARSF-DAN receive hyperspectral raw data, it enters the processing chain which consists of the following stages:

- Initial checks and re-formatting project structure
  - This includes Digital Elevation Model (DEM) generation
- Aircraft position and navigation post processing
- APL Hyperspectral chain
- Delivery creation
- Delivery checking
- Dispatch Dispatch

After the data has been dispatched to the PI, the project directories will be tidied up and the data archived at the NERC Earth Observation Data Centre (NEODC). The data will then be available for use by other parties after an initial embargo period of 1 year after dispatch.

## Stage 1: Radiometric calibration

The first stage of processing is to apply a radiometric calibration to the raw data and generate a mask file. This can be summarised as follows:

### Normalise the data.

The captured dark frames are used to generate a per CCD pixel (i.e. per sample per band) average value which can be used as an effective "0" value. That is, it gives the value of the pixel when no light is shining on the CCD. This is therefore a measure of the noise of the system at time of capture. The raw data is then normalised to this by subtracting the corresponding average dark value. If the value would drop below 0 after subtraction it is set to equal 0.

## Smear correct Eagle data

The Eagle uses a CCD that shifts data out line by line at the end of a frame. While this readout process is quick, additional light still falls onto the detector during the readout period. The Eagle data therefore needs to be corrected for any light that is coming from the other bands as the data is extracted. The formula used for this is:

$I_{ic} = I_i - f*Sum_{j<i}(I_j)$

where $I_{ic}$ is the smear corrected image band i, $I_i$ is the image band i, f is the frame smear correction scalar, $I_j$ is the image band j.

## Apply gains

At the start and end of the flying season the Eagle and Hawk instruments are "factory" calibrated. Since 2011 this has been done in-house by ARSF and FSF. One of the products of the instrument calibration is the gain multipliers. This is a per sample list of scalars that convert the sensor captured data value into a "real world" at-sensor radiance value. The image data is multiplied by the corresponding gain value to give the at-sensor radiance value.

### Calibrate FODIS if Eagle data

The FODIS collects down-welling light, and is stored on the first 71 pixels of the Eagle CCD. This is calibrated in the same way as the other raw data. When calibrated, the FODIS pixels for the same scan line are averaged together to further reduce random noise.

### Insert Missing Scans

Occasionally the sensor "drops" a scan line. This can be identified by examining the frame counter through the raw file and observing where it increases by more than 1 between consequetive scans. If a missing scan is identified in the raw image, a dummy scan line of 0s is output to the calibrated image.

### Flag Pixels over/under flown, bad, missing

A mask file will be created at the same time that the radiometric calibration is applied. This is a file of the same dimensions as the raw data file that contains the status of each calibrated pixel. The values in the mask file are as follows:

0 - good data
1 - underflown data - the raw value after normalisation is less than 0.
2 - overflown data - the raw value is equal to the maximum (4095 for Eagle, 16383 for Hawk).
4 - bad pixel - usually refers to a Hawk CCD pixel that is considered untrustworthy. Is also used for first 2 pixels of band 1.
8 - Smear affected - a longer wavelength Eagle band has overflown causing the smear correction for this pixel to be incorrect by an unknown quantity.
16 - Dropped scan - a missing scan has been detected and inserted here.
32 - Corrupt raw data - scan lines that are corrupt at raw stage (e.g. contain values higher than allowed maximum)
64 - QC Failures - pixels deemed bad at quality control visual check

### Flipping data and writing

The calibrated data, FODIS and mask files are stored in ENVI BIL format. Prior to writing out, the image data and mask data are reordered. The Eagle data is "flipped" spectrally such that the first band is the lowest wavelength and the last band is the highest (i.e. such that wavelengths are ordered blue to red). The Hawk data is "flipped" spatially such that each scan line is reversed (i.e. pixel 1 becomes pixel 320). This is done because the Eagle and Hawk are mounted backwards to each other and flipping allows targets to be more easily compared between the two sensors data prior to geocorrection.

## stage 2: Navigation - Image syncronising

The second stage of the hyperspectral data processing is concerned with matching up the image scan lines with the sensor orientation and position. The data from the onboard navigation system (currently a Leica IPAS system) are post-processed such that the position and attitude data are blended together to create either a SOL file or SBET file. These files basically contain a list of times together with corresponding GPS location and IMU attitude values.

The Eagle and Hawk sensors also feed off the IPAS navigation system and receive timing pulses. These pulses are used to create a message (sync message) when the sensor starts collecting data, and is stored in the sensor real time navigation file.

APL takes as input these SBET and real time navigation files, together with the calibrated image header information and uses a spline interpolation to get sensor position and attitude for each scan line. It also applies the given sensor boresight and lever arm offset values to the navigation data.

The Eagle and Hawk sensors can suffer from inaccurate timing of the order of ~0.1 seconds. This means that the navigation data and scan lines can be out of sync, which manifests itself as a "wobbly" image. See here for an example. This is currently corrected by eye at ARSF-DAN, processing using time offsets with accuracies of 0.01 seconds.

## Stage 3: Geocorrection

This stage of the hyperspectral data processing involves generating a per-pixel list of latitude and longitude values. This is currently only done at ARSF-DAN for quality control and to check the correct navigation syncing has been used. A Digital Elevation Model (DEM) is required to get accurate geocorrection information. The format of the DEM file should be an ENVI file (either BIL or Band sequential (BSQ)) with geographic projection in WGS84 latitude and longitude. The heights should be referenced against the WGS84 spheroid. This is because the GPS navigation is referenced in WGS84 latitude/longitude projection and all other inputs should also be given in this projection to allow direct comparisons.

For each pixel of the scan line, a CCD pixel-to-ground view vector needs to be constructed. This is made up from the sensor view vector and the navigation attitude (which includes the boresight offset). This vector has origin at the sensor, which is given by the synced position since the lever arm offset has been applied. The vector is traversed from the origin until it intersects the DEM surface, at which point the latitude, longitude and height are recorded.

The geocorrection information is written out as a 3-band BIL file (referred to as an IGM file) where the bands are: longitude, latitude and height.

## Stage 4: Re-projection

Prior to generating a mapped image it may be best to reproject the data into a more suitable projection, e.g. Transverse Mercator. APL makes use of the open source PROJ libraries for doing reprojection. If the data is collected in the UK and wants to be in Ordnance Survey (OS) National Grid projection, then there is a grid-shift file available to download from the OS website which can be used with PROJ. Typically ARSF-DAN will use either the OS National Grid or Universal Transverse Mercator projection for quality control of the data. The output file has the same format as the previous stage - a 3- band BIL file.

## Stage 5: Mapping

The final stage of the hyperspectral data processing is to generate a mapped image. The calibrated image data is taken together with the (reprojected) IGM file so that the image data can be resampled to a regular grid based on the IGM data. The user specifies the pixel size of the output grid and which bands of the image to map.

The mapping is performed in 2 stages. The first of which is to import the IGM file into a tree-like structure to allow more efficient searches based on geographic location. The second stage is to create a regular grid based on the pixel size and IGM projection information, and to iterate across it filling in each cell. The cell is filled with a value based on interpolation of particular image points with regards to distance from the centre of the cell. For example, if nearest neighbour interpolation is used, the nearest image point to the centre of that cell is used to fill the cell.

The map is output as an ENVI BIL file.

# 13. Appendix 3: ARSF on LiDAR data

This appendix contains three ARSF notes on the LiDAR system and its use; the notes have only been changes typographically to fit them into the format of this report, with permission from ARSF.

## Overall system design and comments of note

System is a Leica ALS50 (phase II) LIDAR.

The integrated IPAS 20 navigation controller includes a GPS receiver and Honeywell IMU. The IPAS 20 has the 'Freebird ' upgrade to ensure navigational coupling at high bank angles.

There are also some associated control and display devices for operator and pilot us-

age. The wavelength of the radiation is 1064nm

## How it works

The LIDAR works by firing a (4ns or 9ns) laser pulse downwards and measuring the roundtrip time for the light pulse to return, then converting this to a distance. The pulse isn't modulated by a carrier - it's just an on/off pulse. There are four timing cards ("range cards R1-R4") running for a pulse, so up to 4 returns can be detected (R4 actually detects the last return rather than the 4th?). The system has a "MPiA" (Multiple Pulses in the Air) mode, which fires two pulses evenly separated, rather than waiting for the first to come back before firing another [SPiA mode, times out in case the pulse is eaten]. To measure this, there are actually two banks of timing cards (bank A and bank B, both with R1-R4 cards), so there are 8 timing cards in total.

A minimum time separation between two returns means the minimum distance between two returns must be at least 2.7m for them to be counted as independent. The expectation for the number of returns is 1 return ~100%, 2 returns ~10%, 3 returns ~1%, 4 returns
~0.1% of points - obviously this varies with the terrain. When there are 4 returns, each range card measures the time of the return pulse. When there are less than 4 returns, R4 is a second measurement (not a copy of) of the last pulse - i.e. if there are 2 returns, you will have R1, R2 and R4 (= re-measurement of R2).

The intensity of a return is measured only for the first 3 returns (R1-R3), and is an 8 bit value (0=dark (water), 255=bright) relating to the reflectivity of the illuminated surface. The value is amplified by an automatic gain controller, and is not related to a physical measure (can it be?). The intensity can be used in various processing algorithms to help distinguish transitions between surfaces. The AGC tries to keep the intensity in the range 100-150 or so.

The laser is scanned across a (up-to) 75 degree swath by an oscillating mirror. Due to the acceleration/deceleration of the mirror, this produces a sinusoidal pattern to the trace on the ground, with the highest density of points at the peak and trough of the sine wave (i.e. at the edges of the swath). If the swath width is set to less than 75 degrees (45 degrees recommended), there's a roll compensation mechanism that tries to smooth out small roll movements by using the remaining freedom of motion. The scan rate of the mirror is dependent on the FOV angle (36Hz for 40 degree FOV, 24Hz for a 75 degree FOV,
calculate with 412.33 * $FOV^{-0.6548)}$.

The laser is an 8W class 4 laser, operating in the infrared range. The divergence results in approximately a 22cm spot on the ground when fired from 1000m up.

Controllable parameters:

- laser intensity (0 -> 8W output), controlled by operator as a percentage output. Includes an eyesafe cut out if the light intensity at the ground could cause eye damage.

- altitude - minimum of ~650 up to ~2000m (after 2km, you start getting poor returns on forests, etc, the real limit is up to about 6km in ideal conditions)
- ... pulse frequency, scan angle, MPIA/SPIA , Full-waveform settings
- Automatic Gain Control ramp up/down parameters or fixed gain

The intensity of a return is measured (R1-R3) as an 8 bit value (0=dark (water), 255=bright) relating to the reflectivity of the illuminated surface. The value is amplified by an automatic gain controller to keep it within 8 bit range. The value of the AGC is also measured as an 8 bit value and is recorded per pulse as the "gain control voltage" in the raw files. Typical values are 110-180.

The AGC is controlled automatically in our LIDAR, but operates on a threshold basis. If there are N low intensity points in a row, the AGC will step up one level. If there are M over bright points in a row, the AGC will step down. This may lead to visible steps in the image intensity.

## RCD camera

The system has a 39 megapixel digital camera, referred to as the "RCD", with the following characteristics:

- 7216x5412 resolution, 12bit [=~57MB raw]
- 60mm lenses (changeable), with 44.2 degree x 34 degree FOV
- pixel size 6.8microns (= ~15cm ground resolution at 1350m)
- 1/4000 exposure time, 2.2s per frame
- serial number 21
- shutter is curtain style, taking 8ms to open and close, so there's a 4ms time

difference between the top and bottom of the CCD stopping acquiring light

Log files contain various handy info, notably the image event file contains GPS time, pos/ att and picture id

Calibration files are required and supplied by Leica (dark, gain and camera parameters).

File name convention is: `DDHHMMSSXXXXXXGN.raw`

- DD = day of month
- HHMMSS = timestamp
- XXXXXX = incrementing picture id
- G = gain (1-4)

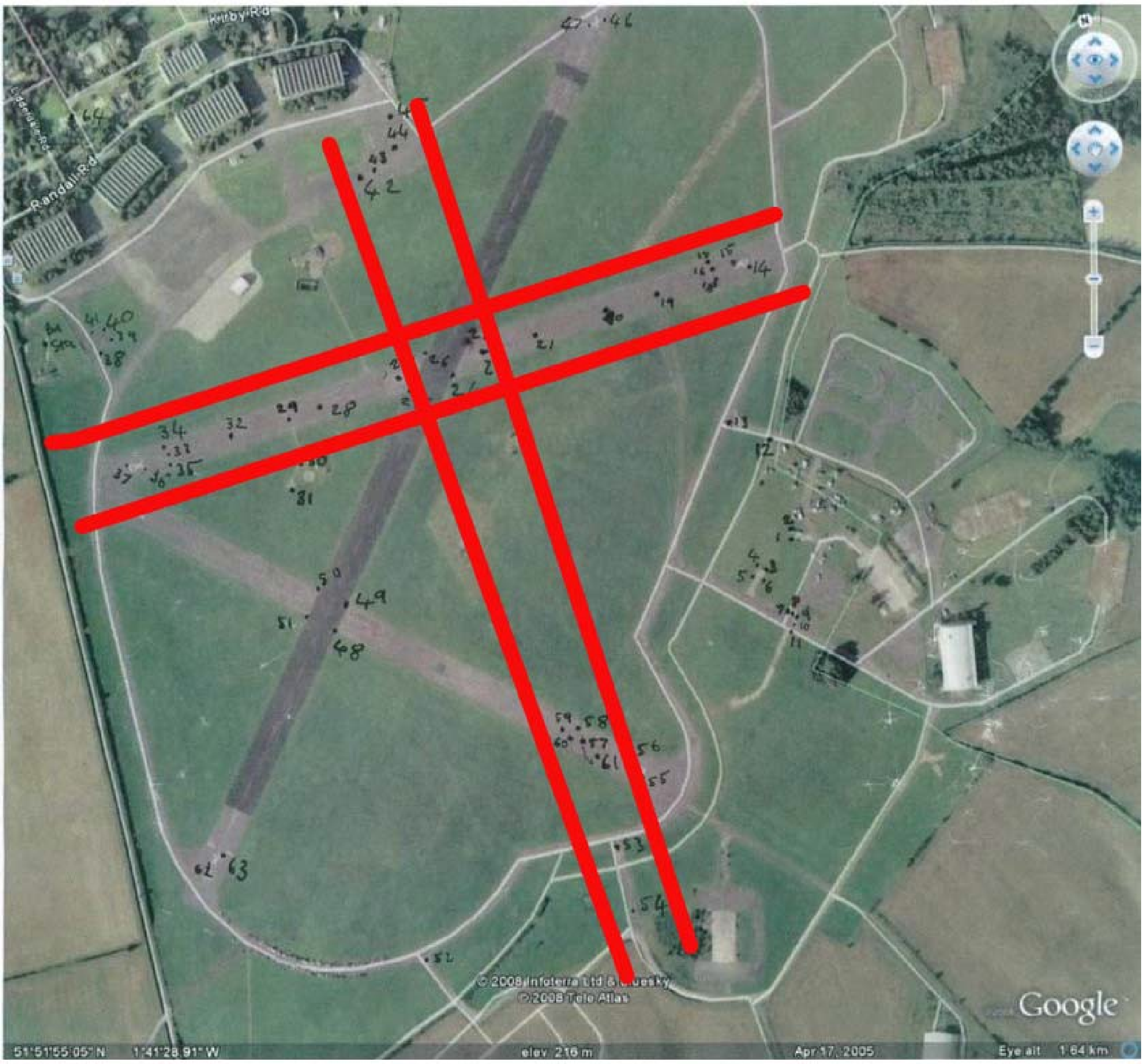
## Recommendations

Perform calibrations frequently at the start of the period to get a feel for how they hold. Reduce down to fit circumstances over time.

-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
-

## Calibration of the Leica ALS50 II LIDAR

This page describes the procedure for calibrating the ARSF LIDAR. The procedure is performed in 3 main stages: Boresight, Range correction and Validation




## Boresight

The first stage of calibrating the LIDAR is to calculate the boresight angles. These are the angles in pitch, roll and heading that describe the pointing direction of the laser scanner with respect to the nadir. Using incorrect boresight parameters will result in georeferencing errors and gross errors will be obvious when comparing overlapping flight lines, especially lines flown in varying directions. The boresight calibration is performed using data taken at 3 altitudes: 750m, 1350m and 2300m. The flight lines are acquired in 'cross formations' and parallel lines with a sizeable overlap.

### Pitch

To correct pitch we take opposing flight lines. If there is a pitch error, the lidar will be sensing pulses ahead/behind (along track) the nadir point. There will be a small overall range error, but the main effect will be that the data is shifted backwards/forwards of where it should be.

### Roll

If there is a small roll error, surfaces will be tilted up on one side of the swath and down on the other. In opposing lines, these errors will be on different sides. Vertical displacements due to roll error will be most noticeable at the edges of the swath. For small errors, the nadir point will be roughly the same, for large ones, there will be some across-track shift, but that will be much harder to measure than the vertical errors.

### Heading / Yaw

If there is a heading error, the left side of swath will move backwards while the right side will move forwards (or vice versa). If you reverse the direction of flight (ie. with opposing flight lines), these errors will overlap (left side down in one direction matches right side up in the other) and not be visible. Instead, take two parallel flight lines with 30-50% overlap

### Pitch error slope

The mirror will not be mounted exactly flat to the laser so, as the mirror moves, the pitch of the beam will change by a small amount. The resulting errors are along-track offsets just like the pitch errors, but varying, with no error at nadir and maximum error at the edges of the swath.

## Procedure

The main procedure in the boresight correction is:

- Process Navigation
- Process raw scan to attune files in ALS Post Processor
- Use Attune to calculate boresight parameters
- Analyse in LAG - reprocess if necessary

Copy the folder structure under /users/rsg/arsf/backups/windows_software/leica_lidar/leica- original_dvds/dvd1/Software/WorkStation/Directory\ Structure\ -\ ALS\ Calibration/RevD_Cal/ to the processing directory.

For calibration procedure information from Leica check under /users/rsg/arsf/backups/windows_software/leica_lidar/ for the latest updates.

Leica will send a set of files including a reg file, IBRC file and a calibration report. These are usually saved under /users/rsg/arsf/doc/leica/$YEAR. Check the values in the reg file match against those in the calibration report. If a dual IBRC file is used ensure the TPR range offset is set to 0.

1. Process the Navigation as per usual using IPAS Pro and Grafnav

2. In ALS Post Processor:
   - Load up the calibrated reg file (received from Leica) to get correct scanner settings
   - Set the pitch, roll and heading values to 0
   - Check the output as attune files in the outputs dialog
   - Add all the flight data into the ALSPP, including the BIT mode data.
   - Run the Rangecardcal program from the utilities menu. Select the use all SCN files option when prompted.
     - Enter range offset A1 as 0 since it is unknown (if a good Range card value is known it should be used instead of zero)
     - Enter the output Range offsets into the range corrections dialog of AL-SPP.
   - Run Compute Scanner Offsets
     - check the values are close (=/-500) to the Scan Angle Correct value
     - If not then take the average value and use that instead.
     - If you change the value make a note on the ticket as it will not match the calibrated value given to us by Leica
     - Ask Ops to check the value at the next available opportunity (http://arsf-dan.nerc.ac.uk/trac/wiki/Procedures/NewSeason#Scanencoder)
   - For Attune a minimum of 6 flightlines should be used: 2 orthogonal at mid altitude, 2 orthogonal a high altitude, 1 opposed at high altitude and 1 parallel at high altitude (30% overlap)

   - Uncheck the BIT mode data (we don't need to process this) and any flightlines not needed for Attune - run the ALSPP processing
   - Look at the filesizes of the output data. If the ATN.LAS files are over 400MB in size then Attune will not run. If this is the case re-process with only the part of interest of the line.
     - Part of interest will be the area where all flight lines overlap.

3. Converting the ATN.LAS files to bin files. Ground classification needs to be performed on the files before tie pointing in Attune. To do this we need to first import the ATN.LAS files into Attune to convert them to .bin files. To do this we need to start the Attune software
   - We do this so that we only use points on the ground in the tie pointing (since we don't want errors due to perspective or shadowing)
   - In Attune - Add ALS data -> add the real ATN.LAS files from the ALSPP output
     - The suggested pixel sizes (from top level calibration pdf) are 0.3m for 750m, 0.4m for 1350m and 0.8m for 2300m.
   - View the image pngs to make sure no data holes. (Some are OK. Re-load

using a different resolution if too many holes. e.g. Try 0.35m for 750m)
    - 'a' centres the image
    - '+/-' to zoom in/zoom out
  - There should now be some files with .bin extension- they are created automatically alongside the .pngs.

4. Ground classify the bin files. Run ground_classify_las_bin.sh in a directory containing only the .bin files created in the above step. The classified files will be created in a ground_classified/ subdirectory.

   Manual way. To ground classify the *.bin files, we use lasground from LASTools. This tool has a 1.5million point limit so the *.bin files need to be split up first into smaller files.
   - run las2las with the option -subseq: e.g. las2las -i lasfile1.bin -subseq 0 1500000 -o lasfile1_a.bin; las2las -i lasfile1.bin -subseq 1500000 3000000 -o lasfile1_b.bin etc.
   - run lasground.exe -i lasfile1_a.bin -o lasfile1_a_gr.bin
   - run lasmerge -i lasfile1*gr.bin -o ground_classified/lasfile1.bin
   - las2las -i ground_classified/lasfile1.bin -o ground_classified/lasfile1.LAS

Check the ground_classified LAS files in LAG to make sure that the classification has worked as expected. If doing it manually, you can alter the settings used in lasground e.g. using -step, -spike. See the lasground Readme for more info. When satisfied, replace the attune created *.bin files with the ground classified ones.

5. Tie point the data
   Once the data have been ground classified re-start Attune and tie point the data
   - Now select tie points. We use streets for tie points since these should be on the ground so no (little) effects due to look angles and also has slow varying topography
     - Open tie point editor in Attune.
     - Press 'm' to measure a point and then click where you want it. Do this for each image (selecting the same point). Then press 'sample all' to record the locations.
     - To change one, re-measure it and then just click 'sample point'. accuracy.
   - Save the project after selecting 50-100 points. (Attune is very crashable, save often)
   - Select points on roads with uniform intensity. Use lines of roads and field boundaries to get the same place in each image. Don't use buildings as markers due to perspective/shadow.
   - Edit project file properties.
     - Torsion constant =-100,000
     - Image observation Weights 0.2, 0.2, 0.1
     - Atmosphere same parameters as in the ALSPP processing
     - Set class as ground = 2 (ground is usually class 2)
     - Adjustment criteria maxiter=50, angular (?)=1.00e-08
   - Click Solve Calibration parameters and deselect Torsion, just want

to solve roll, pitch and heading.

- Analyse adjustment
  - A good result would have aposteriori reference of between 1 and 2.
  - No. of observations of 300 is good
  - Standard deviations of around 0.00001 for Roll and Pitch, 0.00005 for Heading.
  - Average residuals of 25cm for X and Y, 5cm for Z is good.
- If the above criteria are not met (roughly...they are only guidelines)
  - Analyse results and remove or adjust any points with large residuals
    - Open all the images + point editor and then can select a point from the solution list and zoom to it on the images
    - You could just remove the point from one or two images (especially the high altitude images) or from all images. Then recalculate the network adjustment and iterate until Aposteriori reference is approx 1-2 and average residuals are 0.25,0.25 and 0.05.
    - Can remove the points from the lower resolution images if it will help. We want more measurements in the higher resolution images than the lower ones if they are unclear to measure in (so don't just measure in them for the sake of it)
  - When happy save the solution - also note down roll, pitch and heading values in case of crashes

6. Return to ALS Post Processor
   - Add the Pitch, Roll and Heading values into the boresight calibration dialog.
   - Change output to LAS (not attune)
   - Change output directory
   - Additional flightlines should be processed to check the validity of the calibration (not just the 6 used for Attune)
   - Re-run the processing

7. Now analyse the results in LAG or TerraScan
   - Check profiles etc for misaligning flightlines.
   - To load all flightlines will probably need to use a fence (this is like a region of interest)
   - To check the Roll accuracy – check opposing flights and look at cross sections at either end of the swath for a tilt (across track).
   - To check the Pitch accuracy – check along track on slopes for offsets
   - To check the Heading accuracy – check the parallel lines for offsets

- Also possible to check for errors by re-ordering points by elevation

8. The boresight parameters can be manually twiddled (rather than using Attune) by reprocessing in ALS, changing the R,P,H values one at time. Only process parts of the flightlines for speed benefits.

9. When happy with the results save the ALS Post Processor settings to a .reg file for future reference.

## Range Calibration

The second stage in the calibration process is to calibrate the range offsets.

Can do range correction if the boresight results are good. This is a 2 stage process:

- 1. Nominal offset determination A1
- 2. Define relative differences for A2,A3,A4 and B1,B2,B3,B4
- 3. Check if an offset exists between bank A and bank B

points have approx. the same range error within +/-7 degrees of Nadir, so we look only at this region firstly.

Note: You need to have the program RangeCardCal in your windows SentTo folder [located at C:\Documents and Settings\$user\SendTo ]

## Procedure

1. Start up ALS Post Processor
   - In filters dialog set the angles to +7 and -7 degrees
   - Change the output directory (to 02a_Roff+-7deg if using suggested directory structure)
   - Run the processing on the 4 low altitude flight lines.

2. Calculate the A1 nominal range offset. This can be done using LASTools or TerraScan. The GCPs for Little Rissington are available here
   - LASTools:
     - Copy the GCP's to the 02a_ROff_+-7Deg folder. You may need to edit this file to remove some points.
     - Run lascontrol.exe -i *.LAS -cp gcp_points.txt -parse xyz (you may need to edit the parse command depending on the format of the GCP's you are using)
     - Scan the output and remove any bad points from the gcp file and re-run

     - Look at the average (abs) value, this is used for the nominal range offset A1. This value should not change dramatically from season to season
     - Note: if there are negative values in the lascontrol output then calculate the average value yourself (lascontrol gives the average absolute value)
     - Save the output to a text file
   - TerraScan:

- Load the results into TerraScan and use the 30-40 GCPs of the calibration site.
- Tools -> Output Control Report
- Browse -> GCP file and remove bad points (maybe an error occurred in the surveying of a certain point)
- Look at the dz value, the average dz is used for the nominal range offset A1.
- Save the text file.

3. Preferably using data including areas of forest (little riss should do) and the BIT mode data, run Rangecardcal (from ALSPP tools menu) on all flightlines. (on ~45 degrees?).
    - Enter the average dz value as A1 to get the other offsets.
    - Add the outputs to the ALSPP dialog and save the settings reg file (to a new name)

4. Analyse the results
    - Check these results and re-run using the full FOV (~45 degrees) on the low flightlines again (remember to change output back to normal folder)
    - Check average dz is less than 1cm or so, and standard deviation <5cm using lascontrol or TerraScan control report. Save the output from this check as it is used in the Data Quality report. Note for lascontrol output you will need to calculate the average dz value.
    - Check the flightlines in LAG/TerraScan (also look at cross sections)
    - Process the 4 high altitude flights in ALSPP and check in LAG/TerraScan (around nadir and swath edges) (looking at absolute height).
    - Run lascontrol/TerraScan control report for the high altitude flightlines and check for reasonable values. Save the output as it is used in the Data Quality report. Note for lascontrol output you will need to calculate the average dz value.
    - Finally load in all flights into LAG/TerraScan (within a fence if memory issues) and check them (ideally along a stream because this has a “good” profile) Can use the travel path tool in TerraScan for comparing cross sections along a path.

## Final validation

The final stage of the processing is tweaking the parameters and validating the calibration.

1. Check the torsion and pitch slope
    - To check the Torsion look at cross sections of high altitude cross flight. Flat roads and grassy areas are good. Look for “smiles” in the data. This can be done by looking at the centres of the edges of the overlapping area
    - May also be able to do this by re-ordering points by elevation

2. Check for offset between bank A and bank B
    - Leica have advised that *some* systems have an offset between bank A

and bank B. To check for an offset process a single line using only returns from bank A then using only returns from bank B (ALSPP: Filters > Pre- Proc Filters > Filter Range Bank A/B).
   - Load the results in LAG or TerraScan and check for any elevation difference.
     - If there is none then great.
     - If a consistent offset is visible then adjust all the values for bank B by this offset. Re-run the line again and check the result.

3. If full waveform data has been collected then the Trigger Delay values need to be checked
   - Use LasHistoViewer to verify that the LAS file is suitable for calibration purposes
     - check the AGC activity is not jumping around or saturated - value of ~150
     - 1 volt is good target for timing offset
     - Intensity ~ 60-80
     - waves where there is one discrete return only
   - In ALSPP > Ultilies > Load Wave Viewer
     - display by time and volts
     - the peak of the FW signal and the discrete point should coincide
     - zoom in and manually calculate the difference in time between the peak of the FW and the first discrete return
     - under Options there is a box where the trigger delay can be entered - this can be used to assist in visualising the calibration
     - repeat until an accurate result is obtained
     - check for several waves over varying parts of the flightline and calculate the average value
     - above and below TPR (transition pulse rate) are independent and calculated separately
       - below TPR, less than 100,000 Hz
       - above TPR, greater than 100,000 Hz
   - Make a note in the ticket if either of the trigger delay values have been validated

4. Save the final ALSPP options to a .reg file

# Processing

## Required items for processing

Items required from every flight:

- GPS and IMU data (including a base station if not using PPP)
- Raw laser data
- Log files from LIDAR

    - Flight log files are useful too, if the LIDAR flight planning software is used
- RCD & webcam images
- Pressure and temperature measurements at the plane position above the site [this affects how long it takes the laser light to move through the air]

Items required in general:

- calibration (see elsewhere)
- lever arm measurements

## Extraction

Use IPAS Pro to extract GPS, IMU and laser data from the raw files.

- probably worth having the real time navigation info (doesn't add a lot of processing time)
- During extraction, view the listing and verify the lever arms are correct (IMU one should never change).
- look out for data gaps (listed in log)

Most Leica systems are mounted "laser backwards" (cables will be at the rear if this is so) - ensure that z=180 in the IPAS Pro aircraft tab.

### 13.1.1.1 Navigation processing

See other pages on navigation processing as they cover this already.

## General processing

The general processing procedure is as follows:

- Trajectory processing
    - see the pages on GrafNav and IPAS processing
- ALS post processor to convert raw LIDAR scan data to binary LAS point cloud
    - see the page on the ALS post processor
- QC of the processed data
    - check % of first returns - should be >95% in most cases
    - check intensity images look ok (like real world, no streaking etc)
    - check neighbouring flight lines match up well
    - basic classification or filtering to remove noisy points

# QC

## Things that may go wrong

### In flight

Flying too low - if the LIDAR detects that the laser power may be too high for eye safety, it will cut out the laser automatically (if you're a seagull looking up, bad luck, it only accounts for ground height).

Flying outside the "range gate" (acceptable ranges of distances) may cause similar effects. Going too high will tend to make the edges of the swath drop out first (due to path length).

Automatic gain control issues - the measured intensity is returned via an AGC which may step up or down depending on the returns from the ground. Measured return intensity should only be used as a guideline rather than a real measurement.

Laser power too high - if the intensity overflows (reaches 255), the intensity based range correction will probably be wrong. For example, a freshly asphalted road with bright white reflective (overflowing) strips may appear with the strips appearing to float up to
20cm above the road surface.

Water absorbs IR, so expect poor returns from wet surfaces. Ideally one should wait for a whole dry day after rain.

### In processing

Most Leica systems are mounted "laser backwards" (cables will be at the rear if this is so) - ensure that z=180 in the IPAS Pro aircraft tab.

Initial QC for when data first arrives for processing - raw scan data files should all be the same size, except for the last file.

### Other error sources

Atmospheric effects; the light path may bend due to atmospheric refraction, density effects, etc causing the laser to hit the ground earlier or later than expected, or in a different position. This will be most noticeable at the edges of the swath where there are longer path lengths (and more atmosphere to pass through) and may look like the swath curls up or down at the edges (path length error), or may look like compression or stretching of the edges (if there is horizontal divergence). The error was claimed to be a fraction of a meter at 6km altitude (i.e. not well bounded). Measurement of temperature may help with this effect, but was said to be a minor value.

Range correction error; if the range correction is wrong, the electronics will measure the path length incorrectly. Points at nadir will be in error vertically only and points at the edge will have a vertical and horizontal error. The error will make a flat piece of land look like a smile and the nadir point will be below the expected land surface (one can only get "late" measurements?).

Torsion (of mirror) error; the mirror may be out of the expected position at the edges of the swath due to it bending under high acceleration. There will be no error at nadir (no acceleration) and errors at the edges, inducing a smile effect again, but with the nadir at the correct height. Range errors should be corrected before working on the torsion error, and the nadir point should be used for the range correction as there will be no mirror torsion effect there.

MPiA mode errors: if a seagull gets in the way of the second pulse before the first pulse has returned, things will mess up. On an edge of a very unluckily placed cloud, this would look a bit like the cloud merging into the ground. Presumably rare or minor.Initial QC

See if the lines are too short or if the point cloud has poor return %s. If so, check the following (look at webcam images for hints):

- clouds
- height problem ("range gate" issue)
    - eye safe shutoff (too close to ground)
    - too high may give dropouts
    - find altitude over ground (measured GPS alt - geoid-spheroid height) and see if it's within the min & max ranges
- check the speed they were flying at is not too fast
- check the images in TerraScan
- look at start/stop times of points at end of flight line – do these match the flight log sheet

Also check if suspiciously large number of return %s for R2, R3 and R4. This could be due to flying in hazy conditions (check the webcam images). When you view the data check for extra surfaces (e.g. 200m above the terrain - will be obvious), and view by echo to see where the high number of R2, R3, R4 occur.

Laser power too high - if the intensity overflows (reaches 255), the intensity based range correction will probably be wrong. For example, a freshly asphalted road with bright white reflective (overflowing) strips may appear with the strips appearing to float up to
20cm above the road surface.

- filter out incorrect points (based on high intensity and height difference from locality?)
- also, if you observe odd spikes, check for intensity over 150 - this may indicate a two-peaked response with the first peak being 150 (and being the detected one) and the second being 255 (overflow), causing the effect above

## Full QC procedures

The general processing data QC-ing should primarily take the form of viewing the intensity images to check for striping and to see if they look “correct” i.e. Does it look like the area surveyed. The data should be loaded into TerraScan and checked that all the flight lines line up OK both spatially and vertically (check cross sections around the image).

The main things are:

- profiles
    - profiles along averaged areas
    - profiles along a track (e.g. following a ditch / feature in the surface)
    - narrow profiles across features where swaths overlap
    - try to select profiles over flat hard features (roads, runways, etc) to lessen perspective effects
- comparisons against GCPs
    - Requires the point cloud to be converted to a surface - also useful if no local DEM available for hyperspectral instrument processing.

We may want to do some initial classification (or filtering) of points to remove noisy points, but we shouldn't do a full classification. See classification procedure below.

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## Calibration

Calibration procedure is bore sight first, then range correction and finally checks, validation and fine tuning

## Parameters needing calibration

Bore sight parameters (pitch, roll and heading).

- Angle between straight-down and what the sensor thinks is straight-down, as it's mounted in the plane.
    - Angle between a line from the sensor head (mirror centre) to the point on the ground at the centre of the swath and a line from the sensor head to the
      centre of the spheroid (or the reference frame's Z axis?).
- Measured in calibration procedure

  Pitch error slope.

- The mirror will not be mounted exactly flat to the laser so, as the mirror moves, the pitch of the beam will change by a small amount.
    - Roll and yaw either have no error slope (laser position central? geometry means no effect?) or a negligible effect (presumably, as there's no parameter)

- Measure pitch at nadir and at swath edges to determine how the pitch changes - the first order for this is is the pitch error slope.
- Measured in calibration procedure
    - Correct pitch error (at nadir) first

Lever arm measurements:

- IMU -> sensor head (centre of mirror?)
    - Measured in the factory and provided by Leica

- IMU -> measurement point [front left corner of the casing]
    - Measured in factory and provided by Leica

- measurement point -> GPS antenna centre

Range offset correction (+range card calibration).

- Correction for the slightly different timing of the 4 range cards in both banks in the system.
- At a set distance, the range cards should all return the same result.

- **Measured by Leica but also measured and verified in calibration procedure.** (see below)

Mirror torsion parameter.

- This measures how much the mirror flexes at the edges of the swath, when under high acceleration, putting it out of position.
- Later Leica mirrors (including ours) are much stiffer and apparently do not flex.

- Fixed very high (negative) value (-100,000 N?) meaning "no measurable flex".
- Can be measured during the calibration procedure, but should never be necessary.

## Factory calibrated

Intensity Based Range Correction (IBRC).

- A range correction based on the reflectivity of the target object ("reflections are slower on darker objects"? perhaps this is more that a lower intensity return may take longer to be detected - i.e. takes longer for enough photons to come back to exceed the detection threshold).
- Measured in factory and provided by Leica.

Transitional Pulse Rate.

- 2 pulse widths are used (4ns and 9ns) depending on the pulse frequency (higher frequencies require a shorter pulse time), with the system switching over to a shorter pulse at a set frequency (around 120 KHz). This parameter measures the

time difference for the pulses' return.
- In our system, this distance is of the order of 11cm.
- Measured in factory and provided by Leica.

Encoder Offset (scan angle correction).

- The rotating mirror has an optical shaft encoder attached that tells it the position of the mirror. The mirror will not be mounted exactly at nadir relative to the shaft encode and this value measures the offset between the centre of the scan pattern and the centre point of the encoder.
- The value is measured in "ticks" and will appear quite high as the shaft encoder has a high resolution (order of millions of ticks).
- Measured in factory and provided by Leica.
- Can be easily checked on the ground by following this procedure:
    - Start up the system on the ground (no GPS or installation required)
    - run BIT mode
    - turn off 'Position In' switch on the front panel - this will allow to snap the mirror on the centre
    - Read F4's tick column, it should show real scan offset and it should be within +/- 500 ticks from the -10800 value
    - turn on 'Position In' switch when finished

## Calibration site requirements

Calibration flight pattern consists of:

- 2 crosses at different heights (700m and 1350m)
- A line, opposing line and a parallel line (at 2300m)
- The parallel line should have a "sizeable" overlap

(50%?) The features required for a perfect cal site are:

- Need a source of multiple returns - tallish (15m) trees in a forest are best. Try to include a treed/forested area in some parts of the flight lines (doesn't have to be in all, nor in the central area). The multiple returns are required for the range card calibration (see below).
- Straight, flat areas made of a hard substance that'll generate only one return pulse. Roads or runways ;) These are used in the boresight (roll) and range calibrations.
- Sloping areas are used to detect pitch and heading errors in the boresight calibration.
    - A road running up a hill is good for pitch (vertical change in surface easily found in the image). These are good for measuring along-track shifts.
    - Slopes with peaks (house rooftops are ideal) with the peak cutting across the line of flight ( `--->` `/\` ). Again good for measuring along-track shifts.
- An accurate ground survey (see below).
- Slow over flight for maximum point density.

### For range offset calculation

GCPs required, ideally 1cm vertical accuracy

Around 30-40 GCPs should be within the area covered by a 14 degree swath (+/- 7 degrees either side of nadir) taken at an altitude of ~750m [= ground swath width of about 180m].

### General accuracy measurements

Other GCPs should be scattered around a wider area within the full swath width - typically run at 45 degrees [=620m wide on ground @ 750m alt] or to a max of 75 degrees [=1150m], though 75 degrees will introduce more errors..

### Quality, accuracy, etc

A nominal quality of 5-10cm (vertical) is suggested as a reasonable output. If one has GCPs, it should be possible to do better

## Bore sight calibration

The basic method is similar to the imaging instruments, but exploits the measurement of range. A set of flight lines and data points are chosen, in a particular order, such that specific calibration parameters are isolated.

## Manual procedure and QC of automatic procedure

### Pitch

Take opposing flight lines. If there is a pitch error, the Lidar will be sensing pulses ahead/behind (along track) the nadir point. There will be a small overall range error, but the main effect will be that the data is shifted backwards/forwards of where it should be.

Search for areas close to nadir where the height of the surface changes in an clear and predictable fashion, with reasonable sampling density (e.g. a road leading up a hill, or rooftops with their peaks going along-track).

Take along-track profiles on both opposing flight lines.

- If there is no pitch error, there will be no offset and the resulting profiles will coincide (the hill profiles will overlay and look like /).
- If there is a pitch error, the profiles will be offset along track and the resulting profiles will not coincide (the hill profiles won't overlay and will look like /

/). By measuring the along-track offset, one can estimate the pitch error.

One must use profiles close to nadir to avoid being affected by the pitch-error-slope parameter (see below).

Repeat until the pitch error has been removed.

## Roll

If there is a small roll error, surfaces will be tilted up on one side of the swath and down on the other. In opposing lines, these errors will be on different sides.

- Take opposing flight lines.
- Find flat surfaces going across the swath (e.g. a road going across-track).
- Take across-track profiles on the flat surfaces
- If there is a roll error, the profiles will not align with one another and will have a X shape rather than an overlapping - shape (the flatter the X, the smaller the error)

Vertical displacements due to roll error will be most noticeable at the edges of the swath. For small errors, the nadir point will be roughly the same, for large ones, there will be some across-track shift, but that will be much harder to measure than the vertical errors.

## Heading / Yaw

If there is a heading error, the left side of swath will move backwards while the right side will move forwards (or vice versa). If you reverse the direction of flight (ie. with opposing flight lines), these errors will overlap (left side down in one direction matches right side up in the other) and not be visible.

- Instead, take two parallel flight lines with 30-50% overlap (more overlap = less chance of detection)
- Along the mid line of the intersection, find areas where the height of the surface changes in an clear and predictable fashion, with reasonable sampling density (e.g. a road leading up a hill, or rooftops with their peaks going along-track).
- If there is an along-track shift between features, there is a heading error (size of shift proportional to error)
- If there is no error, features should overlap
- Adjust until lines up

## Pitch error slope

The mirror will not be mounted exactly flat to the laser so, as the mirror moves, the pitch of the beam will change by a small amount. The resulting errors are along-track offsets just like the pitch errors, but varying, with no error at nadir and maximum error at the edges of the swath.

To correct this, first correct the pitch error at nadir (the overall pitch error), then determine the pitch error at the edges of the swath. This will let you compute an error slope (first order linear).

- Straight, flat areas made of a hard substance that'll generate only one return pulse. Roads or runways ;) These are used in the bore sight (roll) and range calibrations.
- Sloping areas are used to detect pitch and heading errors in the bore sight calibration.
  - A road running up a hill is good for pitch (vertical change in surface easily found in the image). These are good for measuring along-track shifts.
  - Slopes with peaks (house rooftops are ideal) with the peak cutting across the line of flight ( ---> /\ ). Again good for measuring along-track shifts.

## Mirror torsion error correction

This shouldn't need to be done with newer LIDARs, but included here in case. Leica suggests checking for torsion errors if there seem to be problems in the bore sight calibration and reporting to them if found.

Visible sign of torsion error is a smile

effect. Detect torsion by:

- choose highest altitude pair of crossing lines
- pick a point at nadir on one swath and at the edge on the other
  - torsion will be at max for the edge swath and at 0 for the nadir swath
- take cross sections to see if there is any consistent vertical difference

## Automatic method (using Attune)

**Note that Attune apparently crashes if you use >400MB files, and crashes plenty anyway - save often! Do an initial run with just a few tie points to make sure the lines will work.**

*PROCEDURE:*

- In ALSPP uncheck the “average last returns” option in the settings dialog.
- Check the output as attune files in the outputs dialog
- Add all the flight data into the ALSPP, including the BIT mode data, and run the RangeCardCal program from the utilities menu. Select the use all SCN files option when prompted.
  - This gets the differences for range card banks A & B. Takes differences R1-RL and averages them. Similarly for R2-RL, R3-RL, R4-RL.
- Enter range offset A1 as 0 since it is unknown.

- Enter the output Range offsets into the range corrections dialog of ALSPP. Only need R1 for A and B for now.
- Uncheck the BIT mode data (we don't need to process this) and run the ALSPP processing.
- Look at the filesizes of the output data. If the LAS files are over 400MB in size then Attune will not run. If this is the case re-process with only the part of interest of the line.
    - Part of interest will be the area where all flight lines overlap.
- GROUND CLASSIFICATION NEEDS TO BE DONE HERE
    - See the notes on ground classification
    - we do this so that we only use points on the ground in the tie pointing (since we don't want errors due to perspective or shadowing)
- Start up Attune
- Add ALS data -> add the real ATN.LAS files from the ALSPP output
    - The suggested pixel sizes (from top level calibration pdf) are 0.3m for 750m, 0.4m for 1350m and 0.8m for 2300m.
- View the image pngs to make sure no data holes. (Some are OK. Re-load using a different resolution if too many holes. e.g. Try 0.35m for 750m)
    - 'a' centres the image
    - '+/-' to zoom in/zoom out
- Now select tie points. We use streets for tie points since these should be on the ground so no (little) effects due to look angles and also has slow varying topography see *HINTS* below

- Open tie point editor in Attune.
    - Press 'm' to measure a point and then click where you want it. Do this for each image (selecting the same point). Then press 'sample all' to record the locations.
    - To change one, re-measure it and then just click 'sample point'.
- Save the project after selecting 50-100 points. (Attune is very crash-able, save often)
- Select points on roads with uniform intensity. Use lines of roads and field boundaries to get the same place in each image. Don't use buildings as markers due to perspective/shadow.
- Edit project file properties.
    - Torsion constant =-100,000

- Image observation Weights 0.2, 0.2, 0.1
- Atmosphere same parameters as in the ALSPP processing
- Set class as ground -> 2 (ground is usually class 2)
- Adjustment criteria maxiter=50, angular (?)=1.00e-08

- Click Solve Calibration parameters and unselect Torsion, just want to solve roll, pitch and heading.
- Then analyse the adjustment
    - A good result would have aposteriori reference of between 1 and 2.
    - No. of observations of 300 is good
    - Standard deviations of around 0.00001 for Roll and Pitch, 0.00005 for Heading.

    - Average residuals of 25cm for X and Y, 5cm for Z is good.
- If the above criteria are not met (roughly...they are only guidelines)
    - Analyse results and remove or adjust any points with large residuals
        - Open all the images + point editor and then can select a point from the solution list and zoom to it on the images
        - You could just remove the point from one or two images (especially the high altitude images) or from all images. Then recalculate the network adjustment and iterate until Aposteriori reference is approx 1-2 and average residuals are 0.25,0.25 and 0.05.
        - Can remove the points from the lower resolution images if it will help. We want more measurements in the higher resolution images than the lower ones if they are unclear to measure in (so don't just measure in them for the sake of it)
    - When happy save the solution
- Return to ALSPP and add the Roll, Pitch and Heading values to the bore sight calibration dialog. Change the outputs to LAS not Attune. Change the output directory too. Re-run the processing.

- Analyse the results in TerraScan
    - Check cross sections etc for misaligning flight lines.
    - To load all flight lines will probably need to use a fence (this is like a region of interest)
    - To check the Roll accuracy – check opposing flights and look at cross sections at either end of the swath for a tilt (across track).
    - To check the Pitch accuracy – check along track on slopes for offsets
    - To check the Heading accuracy – check the parallel lines for offsets
- The bore sight parameters can be manually twiddled (rather than using Attune) by reprocessing in ALS, changing the R,P,H values one at time. Only process parts of the flight lines for speed benefits.

After completing the Attune process, save the parameters as a reg file (for reference - you will need to manually transfer the numbers to avoid overwriting other parameters). Then check the bore sight parameters using the manual procedure above and adjust if required.

## HINTS

It may be useful (proved so in calibration site of little rissington) to copy the PNGs generated by Attune and draw onto them. Use a noticeable colour (e.g. red) and draw straight lines along features which will not change (or only negligibly) between images. For example, draw along field boundaries into, and over, the roads or along runways from the centre of the white cross to the centre of the cross at the other end of the runway. Also draw along road edges at junctions to create crosses where you can select the centre as a tie point. Doing this on each image will allow much better precision of selecting tie points.

### Selecting tie points

- Better to have fewer good tie points than many bad ones
- Focus mainly on the lower altitude lines
    - Place tie points on the higher altitude lines only when you're really sure of them - they will always have a greater error due to the pixel size.
- Tarmac roads are good, but:
    - avoid paint on road (intensity problems and height difference)
    - choose continuous homogeneous areas
- Avoid:
    - building corners (perspective)
    - grass (multiple returns, moves)
    - cars/people (moves)
    - areas with streaky intensity (likely to have ranging errors)

- Try to select areas where you can use the nearby geometry to help you
    - e.g. follow straight road edges to where they intersect another feature, so you have more than just one pixel to guide you to the intersection point in other images

- avoid using building edges (perspective shifts)

- Location of tie points
    - Focus mainly in the core intersection area
    - Points around nadir
    - Points around the edges of the swath
    - Some generally scattered around
    - Some outside the core intersection area
    - Try to include some on slopes(?)

### Range offset calibration

Range offset correction (+range card calibration) is to correct for the slightly different timing of the 4 range cards (R1-R4) in both banks (A & B) in the system, and to correct any overall ground offset.

Two datasets are required:

1. A real dataset with:
    1. a source of multiple returns, such a forest (for step 1 below)
    2. a strip with well known distances (for verification)
2. BIT (Built-In Test) mode data, where the range cards are all electronically fed with identical fake data representing the same distance. All cards should give the same result, so differences are used to calibrate each card against the others.

First, we need to determine the timing differences between the 4 range cards (R1-R4) in each bank. To do this, we use a dataset with multiple varying returns present - we need combinations of 2-4 returns (forests are good for this, being tall and porous enough to give multiple returns). When there are less than 4 returns, R4 is a second measurement (not a copy of) of the last pulse - i.e. if there are 2 returns, you will have R1, R2 and R4 (= re-measurement of R2). This is exploited to compute the difference in timing between R2 and R4 (averaging many 2-returns). Similarly 1-return and 3-return pulses are used to measure R1-R4 and R3-R4 differences. The end result is a set of timing differences between all the cards in a bank.

Second, we need to establish the timing differences between bank A and bank B. As with the first step, we need the timing cards to measure exactly the same instant. To do this,
we use BIT mode data, where R1 in both bank receives the same electronically generated pulse at the same instant and are thus measuring the same event. Averaging these numbers gives the timing offsets between the R1 cards, which can be combined with the first measurements to establish timing between all cards.

*PROCEDURE:*

Can do range correction if the bore sight results are good. This is a 2 stage process:

- 1. Nominal offset determination A1
- 2. Define relative differences for A2,A3,A4 and B1,B2,B3,B4

points have approx. the same range error within +/-7 degrees of Nadir, so we look only at this region firstly.

- In ALSPP filters dialog set the angles to +7 and -7 degrees, change the output directory (to 02a_Roff+-7deg if using suggested directory structure) and run the processing on the 4 low altitude flight lines.
- Load the results into TerraScan and use the 30-40 GCPs of the calibration site.
- Tools -> Output Control Report
- Browse -> GCP file and remove bad points (maybe an error occurred in the surveying of a certain point)
- Look at the dz value, the average dz is used for the nominal range offset A1.
- Save the text file.

Preferably using data including areas of forest and the BIT mode data, run RangeCardCal (from ALSPP tools menu) and enter the average dz value as A1 to get the other offsets. Add the outputs to the ALSPP dialog and save the settings reg file (to a new name)

To check these results re-run using the full FOV (~45 degrees) and check average dz is less than 1cm or so, and standard deviation <5cm in TerraScan control report. (Also look at cross sections)

Then process the 4 high altitude flights in ALSPP and check in TerraScan (around nadir and swath edges)

Finally load in all flights into TerraScan (within a fence if memory issues) and check them (ideally along a stream because this has a “good” profile) Can use the travel path tool in TerraScan for comparing cross sections along a path.

### Final validation and fine tuning

- check the torsion and pitch error slope
- To check the Torsion look at cross sections of high altitude cross flight. Flat roads and grassy areas are good. Look for “smiles” in the data. This can be done by looking at the centres of the edges of the overlapping area (Figure 3).
- We could create a surface model using one of the opposing flight lines, and then difference the other flight line against this to show if there are any roll effects [or maybe torsion etc]. Do this as well as the cross sections.

When finished save all the results to a reg file in ALSPP

## Ground classification

Classification is the process of labelling the points in the point cloud by type. Ground classification specifically refers to labelling points that are considered to be part of the ground(!) This is a required step for the automatic bore sight procedure.

Steps:

- remove very low, noisy points from consideration first
    - e.g. remove groups of up to 3 points > 1m below neighbours (iterate a few times so it settles)
- classify groups of low points as ground (run N times to settle), takes account of neighbours
- repeat with singletons
- remove isolated points (>5m from any other point)
- manually "add points to ground" for areas that should be ground but haven't been classified as such (e.g. peaks of hills) and rerun process above

Run as a macro. Terra->tools->macro->new.

*PROCEDURE:*

- This is an iterative procedure to take points from default classification to ground classification.
- Classify from default classification to ground.
- Max terrain slope – if lots of man made structures then use 88-90 degrees, else estimate from the natural terrain and add 10-15 degrees.
- To classify, both the vertical distance and angle between points are tested against.
- It’s better to classify too few points to ground than too many.
- It’s good to pre-classify more difficult areas first. [i.e. classify large buildings and steep hill tops].
- The tie points that you will later select will presumably avoid areas such as trees, so you don't need to really worry about these when classifying
- In TerraScan load in a LAS file.
- Before ground classification we should remove noisy points.
    - Default -> low points classification.

    - Do this for group of points and then single points.
    - We can set up a macro to do this.
- Set up the Macro
    - Tools -> Macro
    - any -> default
    - default -> low (group)
    - default -> low (single)
    - isolated points -> any -> low
    - To run on large projects use “selected files” instead of reading all into memory.
- Run the macro and check result. Update distances etc used in the classifications if needed.
- Now to classify the ground points:
    - Classify->Routine->ground
    - use measurement tool to get max building size (horizontally) in area. Also for terrain slope can view elevation and use cross section tool to measure/estimate it.
    - Initial points = aerial low and ground
    - iteration angle = 6 degree to start with
    - iteration distance = 1m to start with
- Then add ground classification.
    - Default -> ground.
- The Add point to ground tool can be used to add points to the classification that have been missed.

*Aside:*

- Can get Model Key Points
    - Routine -> Model key points
    - from ground -> model key points
    - These are the points which can be used as a model (?)

---

## Random snippets

SCN file, DC=delta counter (time in ms since last GPS-second tick), ANG=angle in ticks. R1-R4 is the ranges in metres of the returns. R4 is always the last return. There is no intensity values for R4

If there are less than 4 returns then R4 is an INDEPENDENT measurement of the last pulse received

- This allows the “average last return” option to be used to give a better measurement (in the ALSPP)

Minimal detectable distance between R1-R2, R2-R3, R3-R4 is 2.7m

---

# 14. Appendix 4: ARSF on digital photography


## Digital Photography

### Project Details

| | |
|---|---|
| Site Location: | East Greenland |
| Principal Investigator: | Tapsa Tukiainen |
| ARSF Project Code: | BGS11/01 |
| Date of Flight: | 23 August 2012 |
| Julian Day of Flight: | 236a |

## Introduction

This file has been generated specifically for your Airborne Research and Survey Facility (ARSF) project and includes important information about your data. Please make sure you read it fully before trying to use your data.

## Delivery Contents

The following files are contained on the distribution medium:

| Filename | Description |
|---|---|
| Read Me-20121114.pdf | This PDF document. |
| BGS11 01-2012 236a.kml | Google Earth file showing locations of each photograph. |
| doc | Directory containing documents describing the instrument and |
| data. eventfile | Directory containing an image event file, describing photo- |
| graph timing | and position, in CSV format. |
| photographs | Directory containing full resolution images in TIFF format. |
| thumbnails | Directory containing thumbnails of each photograph in JPEG |
| format. | |

The image filenames are structured as: RCD105-PPPP PP-yyyydddf-nnnnn.tif where:

PPPP PP is the project code for your data
yyyy is year the data was acquired
ddd is the Julian day of the data acquisition
f is the flight letter indicating that day's collection ('a' is first)
nnnnn is the image number

## Data details

Please read the supplied data quality report for important information about your data.

During the processing of the photographic data, some images may have been removed due to over/under exposure or if they do not correspond to the area of interest (for example photographs used to test the exposure settings prior to surveying).

The data are supplied as 16-bit TIFF images with additional meta-data in TIFF tags. Where possi- ble, the TIFF tags comply with the TIFF and EXIF standards used for digital cameras. The standard geolocation tags have been added so that the photographs will appear in the right world position correctly in album software. Note this is not the same as orthorectification or full georeferencing - this merely locates where in the world the photographs were taken.

Some additional information has been placed in XML in the ImageDescription tag (see below for an example). This includes:

- Original Filename - raw camera filename that the photograph was produced from
- Project Code - ARSF Project Code
- Flight Day - Julian Day of Flight
- Location Name - Site Location
- Position Information
  - Latitude - latitude of aircraft when image taken
  - Longitude - longitude of aircraft when image taken
  - Height - height of aircraft when image taken
- Exterior Angles
  - Omega - rotation about x-axis
  - Phi - rotation about y-axis
  - Kappa - rotation about z-axis

The tags can be read using free software such as exiftool, available from:
http://www.sno.phy.queensu.ca/~phil/exiftool/, freeware, Windows/Mac/Linux

Sample output from exiftool

ExifTool Version Number : 8.90
File Name : RCD105-BGS11 01-2012236a-00001.tif
Directory : photographs
File Size : 223 MB
File Modification Date/Time : 2012:11:13 12:26:36+00:00
File Permissions : rwxr–r– File Type : TIFF

MIME Type : image/tiff
Exif Byte Order : Little-endian (Intel, II) Subfile Type : Full-resolution Image Image Width : 7212
Image Height : 5408
Bits Per Sample : 16 16 16
Compression : Uncompressed Photometric Interpretation : RGB
Strip Offsets : 4826
Samples Per Pixel : 3

Rows Per Strip : 5408
Strip Byte Counts : 234014976
X Resolution : 300
Y Resolution : 300Planar Configuration : Chunky
Resolution Unit : inches
XMP Toolkit : Image::ExifTool 8.90
ARSF Original Filename : 23074421100013G3.raw
ARSF Project Code : BGS11 01
ARSF Sortie : a
Decentring Distortion P1 : 0.0
Decentring Distortion P2 : 0.0
Exterior Angles Kappa : 150.91835
Exterior Angles Omega : -1.67307
Exterior Angles Phi : -2.16572
Flight Day Of Year : 236
Focal Length mm Cb : 59.799
GPS Time Of Week : 380098.563013
Heading : 119.040318964
Image Centre X : 3605.5
Image Centre Y : 2703.5
In Plane Distortion B1 : 0.0
In Plane Distortion B2 : 0.0
Location Name : East Greenland
Pitch : 2.70536295262
Pixel Size um : 6.8
Plane Orientation : top = plane forwards
Principal Point Offset mm Xp : -0.0025
Principal Point Offset mm Yp : -0.3247
Radial Distortion K0 : 8.57325E-03
Radial Distortion K1 : -2.01969E-05
Radial Distortion K2 : 5.13135E-09
Roll : -0.407533373758
UTC Time Stamp : 9:34:42.563013
Year : 2012
GPS Version ID : 2.3.0.0
GPS Latitude Ref : North
GPS Longitude Ref : West
GPS Altitude : 2561.786982 m
GPS Time Stamp : 09:34:58.563013
GPS Map Datum : WGS84
GPS Dest Bearing Ref : True North
GPS Dest Bearing : 119.040319
GPS Date Stamp : 2012:08:23
Unique Camera Model : Leica RCD105 CH39 digital camera
Camera Serial Number : 21
GPS Date/Time : 2012:08:23
09:34:58.563013Z GPS Latitude :
72 deg 24’ 16.66” N
GPS Longitude : 22 deg 53’ 20.36” W
GPS Position : 72 deg 24’ 16.66” N, 22 deg
53’ 20.36” W Image Size : 7212x5408

The event file gives you an overview of the time, location and attitude of the aircraft when each photograph was acquired. This should agree exactly with the data in the tagged tiffs, since both data are from the post processed navigation file (unless mentioned otherwise above). The event file is in Comma Separated Value (CSV) format and can be viewed using any text editor or as a spreadsheet in Excel / OpenOffice. There are 17 columns in the event file, the relevant ones are:

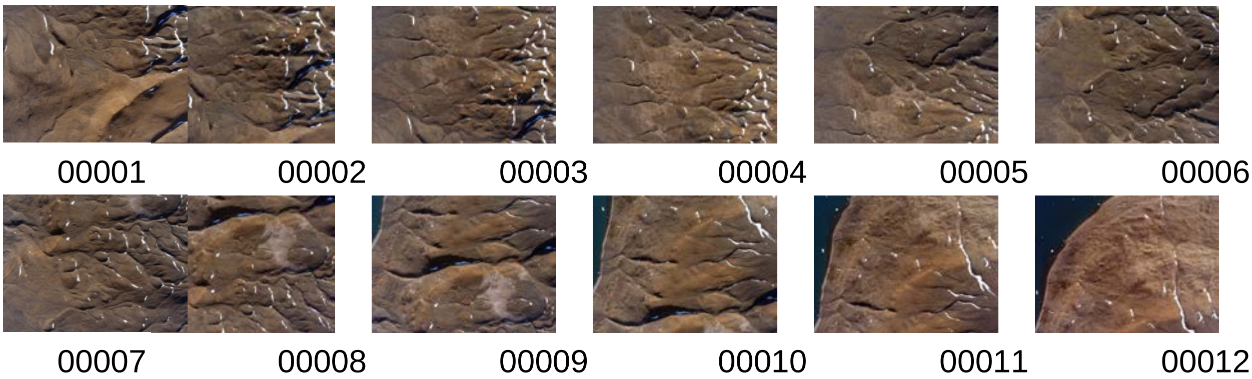
- ImageName: The filename of the photograph in question
- GPSTime: The time when the photograph was acquired
- Latitude: Latitude when the photograph was acquired
- Longitude: Longitude when the photograph was acquired
- Altitude: Altitude when the photograph was acquired
- Omega: Rotation about the x-axis
- Phi: Rotation about the y-axis
- Kappa: Rotation about the z-axis
- Pitch: Pitch when the photograph was taken
- Roll: Roll when the photograph was taken
- Heading: Heading when the photograph was taken

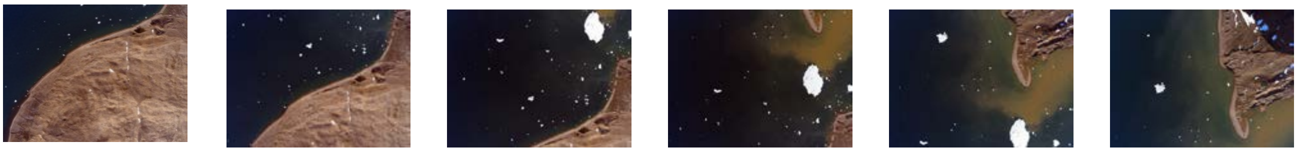
## Image Collection

The following is an overview of your photograph collection. They have been separated into flight- line coverage sections. The numbers identify, which image is shown.

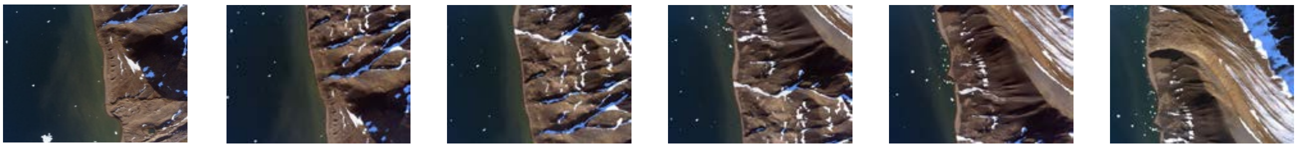
Loading the supplied KML file into Google Earth will display the photograph acquisition positions together with Eagle/Hawk swath lengths. If the thumbnails directory is together with the KML file then clicking on the push-pins in Google Earth will display the photograph thumbnail.

Line: 003

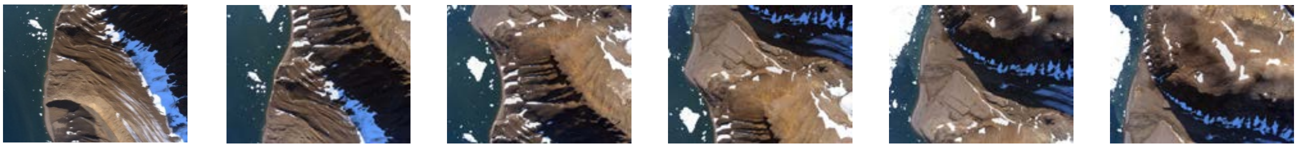




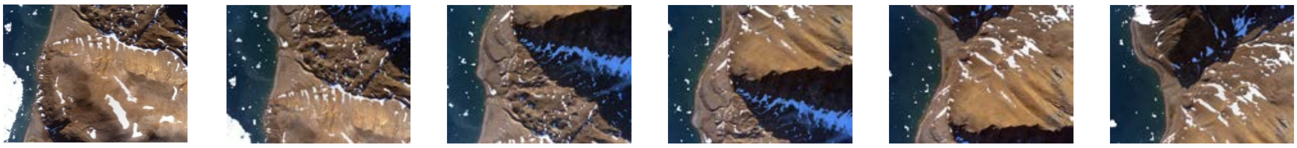
00013 00014 00015 00016 00017 00018



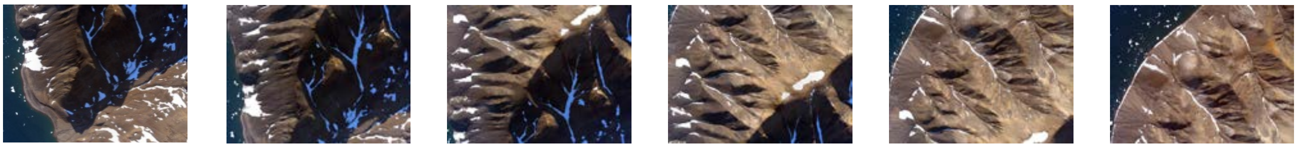
00019 00020 00021 00022 00023 00024



00025 00026 00027 00028 00029 00030

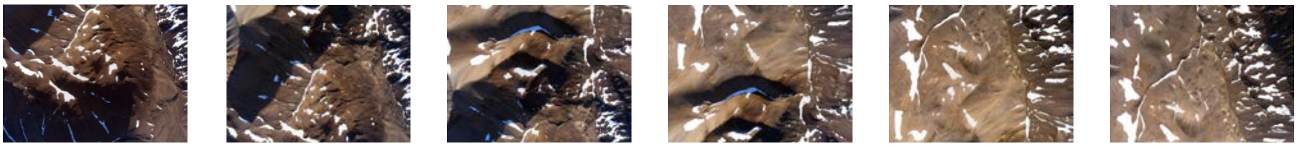


00031 00032 00033 00034 00035 00036

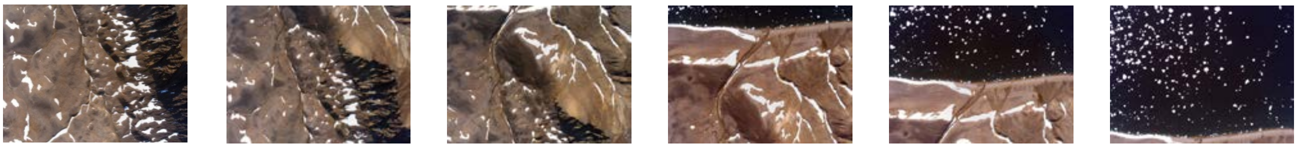


00037 00038 00039 00040 00041 00042

00043 00044 00045 00046 00047 00048



00049 00050 00051 00052 00053 00054



00055 00056 00057 00058 00059 00060

Addendum - GEUS 15 June 2013:

Similar prints are available for all photographs, but not included here because it would demand 4000 pages. The full file will be delivered in digital format when required.

Another note from ARSF:

---

## Imagery for general use

You may wish to have images of the ARSF aircraft for use in presentations. A few images are available from our FTP site at *ftp://ftp.rsg.pml.ac.uk/arsf/user images*, please feel free to use these as you wish (crediting ARSF appropriately).

## Contacting the ARSF and reporting problems

If you have any problems of data access, software installation or data processing please contact the
ARSF Data Analysis Node:
**Email: arsf-processing@pml.ac.uk**
Tel: +44 (0)1752 633432
(Plymouth Marine Laboratory ARSF helpdesk, Mike Grant, Ben Taylor, Mark Warren, Emma
Carolan, Kevin Paxman or Steve Groom)

Please include a description of the problem (attach relevant images if this may help describe any artefacts).

If you wish to discuss other issues, such as flight planning or matters relating to the service, please contact:

Carl Joseph
NERC-ARSF Operations Centre
Firfax House
Meteor
Business
Park Cheltenham
Road East
Gloucester

GL2 9QL

Email: cjos@nerc.ac.uk
Tel: +44 (0)1452 859945
Fax: +44 (0)1452 713219

## Copyright Notice

# 15. Appendix 5: Details on GEUS aerial photography processing

Carlsbjerg Fjord Survey:

BINGO 6.2 Nov. 2011

FREE NETWORK BUNDLE ADJUSTMENT FOR ENGINEERING APPLICATIONS

=========================================================================

2013, April 15., 12:02:15

```
Z:\DATA\HYPEREAST_AT\BINGO
 Names of connected files :
--------------------------
Project file      :  project.dat
Image coordinates :  image.dat
Geo input file    :  geoin.dat
Itera file        :  itera.dat
Control residuals :  reselli.dat
GPS residuals     :  gpsresi.dat
Image residuals   :  imresi.dat
Skip file         :  skip.dat
Bingo list file   :  bingo.lis

      DATA FROM IMAGE COORDINATE FILE

Selected parameters :
---------------------
Minimum no. of rays for points :           3
Listing key for photo data     :           0
Key for unit of image coord.s  :           2
Smallest valid point number    :           1
Highest valid point number     : zzzzzzzzzzzzzzz

Suppressed image numbers :
```

227-00990 230-00101 230-00102 230-00645 230-00646
230-00647 231-02119 231-02120 228a-00366 228a-00367
228a-00368 228a-00369

12 photos ignored from input

Normal number of data sets per photo is 1 (from 6759 photos)

Summary of photo data:
----------------------
No. of used points : 73273
No. of used photos : 7022
No. of used cameras : 1
Max. photo rays per point : 21
Max. photo measurements per point: 28
Used points per photo - minimum : 1
Used points per photo - median : 74
Used points per photo - maximum : 172
Max. photo index difference : 4730

START OF ITERATIVE ADJUSTMENT

Iteration no. 1

No. of unknowns : 261957

No. of observation equations : 868895

Profile of normal equation matrix N : 124204428 = 0.36%

Memory space available for N : 60000000

Average bandwidth of N : 474

Effort for factorisation (Mio mult.) : 29400.84

A priori stand. dev. of unit weight : 2.60 (1/1000)

Sigma 0 before adjustment : 2.54 (1/1000)

Stand. dev. of unit weight sigma 0 : 2.53 (1/1000)

Max. value in solution vector : 0.2619E+01

Average value in solution vector : 0.8542E-01

Iteration no. 2

Stand. dev. of unit weight sigma 0 : 2.53 (1/1000)

Max. value in solution vector : 0.5323E-01

Average value in solution vector : 0.1498E-01

Iteration no. 3

Stand. dev. of unit weight sigma 0 : 2.53 (1/1000)

Max. value in solution vector : 0.1413E-03

Average value in solution vector : 0.1063E-04

===============================================================================================

Z:\DATA\HYPEREAST_AT\BINGO

RESULTS OF ADJUSTMENT SIGMA 0 = 2.53 (1/1000)

===============================================================================================

Listing of photo orientation data suppressed.

Mean photo scale: 37.643

RMS precision values of photo orientations from Qxx matrix (X,Y,Z,phi,omega,kappa): (1/1000)

462. 479. 725. 16.5 17.0 54.2

Poorest precision values of photo orientations from Qxx matrix (X,Y,Z,phi,ome,kap): (1/1000)

8057. 6124. 48942. 48.7 48.7 194.7

Camera data

---------------------------------------------------------------------------------------------

Camera RCD105

Eccentricity ex, ey, ez : -1.5562 1.3296 2.1581

+-S (1/1000) : 13.6 18.9 384.5

Diff. angle of rotation delta : 0.2433 0.0491 1.8221
+-S (1/1000) : 0.6 0.6 2.4

Listing of object point coordinates suppressed.

RMS precision values for all object points (X,Y,Z): 118. 110. 478. (1/1000)
- for 15255 2-ray points: 210. 167. 719. (1/1000)
- for 24600 3-ray points: 155. 142. 549. (1/1000)
- for 179943 multi-ray points: 99. 98. 441. (1/1000)
Poorest precision values of object points (X,Y,Z): 713. 653. 1546. (1/1000)
(Computed from Qxx matrix)

The following neighbouring points may be identical

| Point | Point | DX | DY | DZ | 3D |
|---|---|---|---|---|---|
| | | | ( 1 / 1 0 0 0 ) | | |
| 228b-00353_10 | 228b-00353_12 | 0. | 0. | 0. | 0. |
| 228b-00312_1 | 228b-00312_3 | -9. | -18. | 188. | 189. |
| 228a-00214_12 | 228a-00214_14 | 0. | 0. | 0. | 0. |
| 228b-00444_20 | 228b-00444_25 | -49. | 19. | 221. | 227. |
| 227-01070_19 | 227-01070_25 | -79. | -8. | -299. | 309. |
| 228b-00452_7 | 228b-00453_21 | -61. | 57. | 268. | 280. |
| 228a-00532_10 | 228a-00532_26 | -51. | 29. | -169. | 179. |
| 228a-00532_3 | 228a-00532_12 | -4. | 7. | -11. | 14. |
| 228a-00532_2 | 228a-00532_11 | 0. | 8. | 79. | 79. |
| 228b-00576_19 | 228b-00576_20 | -101. | -71. | -466. | 482. |
| 228a-00542_16 | 228a-00542_19 | 25. | -77. | -197. | 213. |

| | | | | | |
|---|---|---|---|---|---|
| 228b-00562_3 | 228b-00562_20 | 10. | 12. | 87. | 89. |
| 230-017025 | 230-0170230 | -77. | 80. | 95. | 146. |
| 227-01042_5 | 228a-00149_7 | -2. | 1. | 8. | 8. |
| 228a-00147_4 | 228a-00147_15 | -41. | 10. | 247. | 250. |
| 228a-00147_5 | 228a-00147_17 | -10. | -24. | -48. | 55. |
| 230-0120318 | 230-0120325 | 0. | 0. | 0. | 0. |
| 228a-00133_8 | 228a-00133_11 | -21. | -13. | 63. | 68. |
| 228a-00130_8 | 228a-00130_10 | 19. | 35. | -22. | 46. |
| 228b-00486_6 | 228b-00487_13 | 7. | 21. | -57. | 62. |
| 230-0167710 | 230-0167715 | -34. | -18. | 171. | 176. |
| 228b-00222_3 | 228b-00223_7 | 0. | 0. | 0. | 0. |
| 227-01008_8 | 227-01008_12 | -30. | 91. | -177. | 202. |
| 230-0165211 | 230-0165214 | -48. | -32. | 392. | 396. |
| 228b-00154_4 | 228b-00200_6 | 0. | 0. | 0. | 0. |
| 230-0165117 | 230-0165118 | 27. | 106. | -48. | 119. |
| 228a-00044_2 | 228a-00044_4 | 34. | 43. | 452. | 455. |
| 230-0125410 | 230-0125412 | 0. | 0. | 0. | 0. |
| 228a-00002_4 | 228a-00003_19 | -1. | 1. | 8. | 8. |
| 228a-00348_20 | 228a-00348_27 | -42. | -62. | 6. | 76. |

Total number of detected identical points is 30

Residuals of photo measurements (x', y') in photo space: (1:1000)

| | | |
|---|---|---|
| RMS | 2.1 | 2.1 |
| MAX | 10.6 | 10.8 |

RMS residuals of all other photo measurements transformed to object space: (1/1000)

| | | | |
|---|---|---|---|
| RMS | 75. | 76. | 21. |

Frequency of photo measurement residuals N(0,1) :

```
              for x                            for y

                                               *
               **                              **
              ***                              ***
             *****                             ****
             *****                             *****
            *******                            ******
            *******                            *******
           *********                           *********
          ***********                          ***********
   **********************************    ********************************* *
 <-----------------+----------------->  <-----------------+----------------->
  - 4  3  2  1  0  1  2  3  4 +           - 4  3  2  1  0  1  2  3  4 +
```

RMS GPS residuals: 1221. 891. 306. (1/1000)

Maximum GPS residuals: 5645. 6777. 3004. (1/1000)

RMS IMU residuals: 45.4 49.8 215.8 (1/1000)

Maximum IMU residuals: 294.0 619.6 813.4 (1/1000)

(Computed from real residuals)

Test : v(T)Pv = 3.884864E+00 O.K.

l(T)Pl - n(T)x = -v(T)Pl = 3.884864E+00

Test : Sum. of red. = 606938.000 O.K.

f = n-u+d = 606938

A posteriori variance-component estimation

Test value = s(a posteriori) / s(a priori)

| Group | | Test Value | No. of Obs. | Redundancy |
|---|---|---|---|---|
| Photo coordinates | : | 0.99 | 826886 | 571320.29 |
| Photo positions and orientations | : | 1.08 | 21066 | 18860.91 |
| Photo orientation in phi | : | 0.99 | 7022 | 6216.53 |
| Photo orientation in omega | : | 1.09 | 7022 | 6167.08 |
| Photo orientation in kappa | : | 1.15 | 7022 | 6477.31 |
| Exterior orientations incl. GPS | : | 1.08 | 20943 | 16756.79 |
| GPS position in X | : | 1.41 | 6981 | 5492.71 |
| GPS position in Y | : | 1.05 | 6981 | 5342.12 |
| GPS position in Z | : | 0.68 | 6981 | 5921.96 |
| Sum of all observations | : | 1.00 | 868895 | |

Results written on ITERA FILE

END BINGO elapsed time: 17 min 8 sec

FREE NETWORK BUNDLE ADJUSTMENT FOR ENGINEERING APPLICATIONS

2013, November 06., 23:01:16

Names of connected files :
--------------------------
Project file      :  project.dat
Image coordinates :  image.dat
Geo input file    :  geoin.dat
Itera file        :  itera.dat
Control residuals :  reselli.dat
GPS residuals     :  gpsresi.dat
Image residuals   :  imresi.dat
Skip file         :  skip.dat
Bingo list file   :  bingo.lis

DATA FROM IMAGE COORDINATE FILE

==============================================================================================

Selected parameters :
---------------------
Minimum no. of rays for points :        3
Listing key for photo data     :        0
Key for unit of image coord.s  :        1
Smallest valid point number    :        1
Highest valid point number     : zzzzzzzzzzzzzzz

Suppressed image numbers :

236a-00685 236a-00844 236a-00845 236a-00846
236a-00847 236a-00848 236a-01005 236a-01006
236a-01007 236a-01008 236a-01009 236a-01010
236a-01011 236a-01012 236a-01013 236a-01167
236a-01168 236a-01169 236a-01170 236a-01171
236a-01172 236a-01173 236a-01174 236a-01175
236a-01176 236a-01177 236a-01178 236a-01179
236a-01333 236a-01334 236a-01335 236a-01336
236a-01337 236a-01338 236a-01339 236a-01340
236a-01341 236a-01342 236a-01343 236a-01344
236a-01345 236a-01346 236a-01347 236a-01457
236a-01458 236a-01459 236a-01498 236a-01499
236a-01500 236a-01501 236a-01502 236a-01503
236a-01504 236a-01505 236a-01506 236a-01547
236a-01548 236a-01553 236a-01554 236a-01556
236b-00001 236b-00002 236b-00003 236b-00004
236b-00005 236b-00006 236b-00007 236b-00008
236b-00009 236b-00159 236b-00160 236b-00161
236b-00162 236b-00163 236b-00164 236b-00165
236b-00166 236b-00167 236b-00168 236b-00169
236b-00170 236b-00171 236b-00172 236b-00173
236b-00174 236b-00175 236b-00176 236b-00177
236b-00223 236b-00323 236b-00324 236b-00325
236b-00326 236b-00327 236b-00328 236b-00329
236b-00330 236b-00331 236b-00334 236b-00335
236b-00337 236b-00338 236b-00339 236b-00340
236b-00341 236b-00342 236b-00343 236b-00483
236b-00484 236b-00485 236b-00486 236b-00487
236b-00488 236b-00489 236b-00490 236b-00495
236b-00496 236b-00497 236b-00498 236b-00499
236b-00500 236b-00501 236b-00628 236b-00629

236b-00630 236b-00635 236b-00636 236b-00637

236b-00638 236b-00756 236b-00757 236b-00758

236b-00761 236b-00762

134 photos ignored from input

Summary of photo data:

----------------------

No. of used points : 42254

No. of used photos : 2293

No. of used cameras : 1

Max. photo rays per point : 14

Max. photo measurements per point: 15

Used points per photo - minimum : 10

Used points per photo - median : 214

Used points per photo - maximum : 4928

Max. photo index difference : 960

START OF ITERATIVE ADJUSTMENT

=================================================================
==========================

Iteration no. 1

No. of unknowns : 140525

No. of observation equations : 600624

Profile of normal equation matrix N : 45289986 = 0.46%

Memory space available for N : 60000000

Average bandwidth of N : 322

Effort for factorisation (Mio mult.) : 7281.22

A priori stand. dev. of unit weight : 8.50 (1/1000)

Sigma 0 before adjustment : 8.96 (1/1000)

Stand. dev. of unit weight sigma 0 : 8.91 (1/1000)

Max. value in solution vector : 0.1279E+01

Average value in solution vector : 0.5141E-02

Iteration no. 2

Stand. dev. of unit weight sigma 0 : 8.91 (1/1000)

Max. value in solution vector : 0.1313E-02

Average value in solution vector : 0.7257E-05

==========================================================================================================

E:\236AB\NEW VERSION

RESULTS OF ADJUSTMENT SIGMA 0 = 8.91 (1/1000)

==================================================================================================

Listing of photo orientation data suppressed.

Mean photo scale: 35.677

RMS precision values of photo orientations from Qxx matrix (X,Y,Z,phi,omega,kappa): (1/1000)

594. 587. 288. 123.3 123.2 124.4

Poorest precision values of photo orientations from Qxx matrix (X,Y,Z,phi,ome,kap): (1/1000)

1049. 1049. 1049. 1049.6 1048.9 1050.0

Camera data

------------------------------------------------------------------------------------------------

Camera RCD105

Diff. angle of rotation delta : 1.9538 -1.3815 103.6214

+-S (1/1000) : 22.1 22.0 24.1

Listing of object point coordinates suppressed.

RMS precision values for all object points (X,Y,Z): 188. 189. 542. (1/1000)

- for 480 2-ray points: 263. 248. 916. (1/1000)
- for 5073 3-ray points: 220. 223. 733. (1/1000)
- for 121209 multi-ray points: 186. 188. 530. (1/1000)

Poorest precision values of object points (X,Y,Z): 1426. 770. 4367. (1/1000)

(Computed from Qxx matrix)

The following neighbouring points may be identical

| Point | Point | DX | DY | DZ | 3D |
|---|---|---|---|---|---|
| | | | ( 1 / 1 0 0 0 ) | | |
| 2804497 | 2804498 | 2. | -7. | -13. | 15. |
| 3304822 | 3304823 | 115. | 42. | -97. | 156. |
| 2115519 | 2115629 | 18. | 160. | -231. | 282. |
| 3447986 | 3448097 | 71. | -54. | -203. | 222. |
| 3034105 | 3268185 | -78. | 41. | -356. | 367. |
| 1346613 | 1347214 | 14. | -44. | 149. | 156. |
| 3086908 | 3087202 | 123. | -115. | 59. | 179. |
| 3630207 | 3702005 | -95. | 111. | 203. | 250. |
| 3787251 | 3787252 | 21. | 1. | 131. | 132. |
| 1894731 | 1894732 | 0. | 29. | -71. | 76. |
| 1633214 | 1633215 | 9. | -4. | 45. | 46. |
| 3709699 | 3710098 | 42. | 132. | -478. | 498. |
| 2525211 | 3004098 | 15. | -65. | -77. | 103. |
| 3603965 | 3725221 | 62. | 37. | 298. | 307. |
| 3338889 | 3340363 | -25. | -53. | -275. | 281. |
| 3416092 | 3536753 | -104. | -88. | 277. | 308. |
| 2079232 | 2081201 | 39. | -10. | -38. | 55. |
| 1305467 | 1305468 | -12. | -17. | 8. | 23. |
| 2438223 | 2438224 | 12. | 4. | 47. | 49. |
| 3344630 | 3344631 | -35. | -161. | -64. | 176. |

| | | | | | |
|---|---|---|---|---|---|
| 2334759 | 2334760 | 60. | -75. | 80. | 125. |
| 3124391 | 3125892 | 134. | 23. | -429. | 450. |
| 622186 | 622187 | -15. | 10. | 7. | 19. |
| 3552243 | 3554111 | 95. | -142. | 171. | 242. |
| 1288670 | 1290330 | 23. | -18. | 65. | 71. |
| 3135810 | 3135811 | -9. | 94. | 172. | 196. |
| 3193742 | 3363830 | 80. | 95. | -9. | 125. |
| 1281185 | 1281708 | 40. | 10. | 313. | 316. |
| 576900 | 576901 | 16. | -15. | -104. | 106. |
| 1954644 | 1954645 | 99. | 67. | 10. | 120. |
| 2962012 | 3150356 | -67. | 25. | 153. | 169. |
| 2957728 | 2958416 | -46. | -76. | 195. | 214. |
| 3177989 | 3181971 | 53. | -50. | 63. | 96. |
| 1795924 | 1958029 | 0. | 0. | 269. | 269. |
| 1420597 | 1420598 | -28. | 116. | 250. | 277. |
| 653296 | 789274 | -95. | -36. | -106. | 147. |
| 2643191 | 2644886 | -103. | 152. | -392. | 433. |
| 1695851 | 1695852 | 49. | 50. | -63. | 94. |
| 1525603 | 1525604 | 28. | -11. | 104. | 109. |
| 205277 | 205278 | -11. | -55. | 65. | 86. |
| 330304 | 330798 | 129. | -32. | -54. | 144. |
| 101576 | 103866 | -56. | 14. | 327. | 332. |
| 903784 | 1017635 | -22. | -69. | 116. | 137. |
| 1781554 | 1781555 | 69. | 4. | 301. | 308. |
| 1973504 | 1977254 | 20. | 21. | 129. | 133. |
| 2026068 | 2026069 | 109. | 158. | 401. | 444. |
| 762718 | 764729 | -52. | -17. | -37. | 66. |
| 668216 | 668217 | 40. | 11. | 79. | 89. |
| 762888 | 764504 | -69. | 44. | 207. | 223. |
| 1232931 | 1232932 | -2. | 14. | 23. | 27. |
| 1452207 | 1454006 | 29. | 20. | 76. | 84. |
| 450321 | 450382 | -12. | -22. | 107. | 110. |
| 225264 | 225265 | 20. | -64. | 200. | 211. |

Total number of detected identical points is 53

Residuals of photo measurements (x', y') in photo space: (1:1000)

| | | |
|---|---|---|
| RMS | 7.6 | 7.8 |
| MAX | 33.0 | 32.4 |

RMS residuals of all other photo measurements transformed to object space: (1/1000)

| | | | |
|---|---|---|---|
| RMS | 273. | 259. | 67. |

Number of skipped photo measurements: 6969  (for active points)

Frequency of photo measurement residuals  N(0,1) :

```
              for x                            for y

                *                                *
               ***                              ***
               ***                              ***
              *****                            *****
              *****                            *****
             *******                          *******
             *******                          *******
            *********                        *********
           ***********                     *************
   ********************************      *******************************
  <-----------------+----------------->  <-----------------+----------------->
   - 4  3  2  1  0  1  2  3  4 +          - 4  3  2  1  0  1  2  3  4 +
```

RMS GPS residuals: 1140. 753. 575. (1/1000)

Maximum GPS residuals: 3964. 3100. 3080. (1/1000)

RMS IMU residuals: 2413.7 1546.2 523.9 (1/1000)

Maximum IMU residuals: 39258.2 14300.8 5721.5 (1/1000)

(Computed from real residuals)

Test : v(T)Pv = 3.655334E+01 O.K.

l(T)Pl - n(T)x = -v(T)Pl = 3.655334E+01

Test : Sum. of red. = 460099.000 O.K.

f = n-u+d = 460099

A posteriori variance-component estimation

Test value = s(a posteriori) / s(a priori)

| Group | | Test Value | No. of Obs. | Redundancy |
|---|---|---|---|---|
| Photo coordinates | : | 1.04 | 586866 | 448067.14 |
| Photo positions and orientations | : | 1.69 | 6879 | 6780.48 |
| Photo orientation in phi | : | 2.43 | 2293 | 2260.38 |
| Photo orientation in omega | : | 1.56 | 2293 | 2260.36 |
| Photo orientation in kappa | : | 0.53 | 2293 | 2259.74 |
| Exterior orientations incl. GPS | : | 0.98 | 6879 | 5251.38 |
| GPS position in X | : | 1.38 | 2293 | 1556.39 |
| GPS position in Y | : | 0.91 | 2293 | 1575.11 |
| GPS position in Z | : | 0.60 | 2293 | 2119.88 |

| | | | |
|---|---|---|---|
| Sum of all observations | : | 1.05 | 600624 |

Results written on ITERA FILE

END BINGO elapsed time: 2 min 56 sec