KRT1/LGV1 Season Field Report

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1. Purpose for Airborne Survey

Building on UTIG's 20 years of experience with fixed-wing aerogeophysical operations, UTIG and KOPRI have collaborated to migrate the UTIG DC-3T instrument suite to two AS-350 helicopters. UTIG's typical instrument suite consists of a VHF ice-penetrating radar, a laser altimeter, camera, magnetometer, and gravimeter, along with a number of GPS units and an Inertial Navigation System (INS) for accurate positioning. This platform migration required miniaturizing many of the acquisition electronics, designing entirely new antennas for the radar system, as well as substantial software customizations. UTIG and KOPRI first collaborated during the 2015-2016 season to test helicopter gravimetry, a project that represented the first ever deployment of a gravimeter from an icebreaker in Antarctica. The 2016-207 season marks the first time a UTIG-designed VHF radar sounder has been flown on a helicopter.

Compared to fixed-wing, the helicopters offer a particularly versatile platform for aerogeophysical survey due to the much lower infrastructure requirements, the ability to operate from an icebreaker, and the technical possibilities afforded by using a more maneuverable platform.

For the 2016-2017 season, the KOPRI aerogeophysical helicopters were supporting the following research projects:

- Locating the David active lakes for the K-ROUTE drilling project, and characterizing their subglacial hydrological context and connections to the grounding zone (Jong Ik Lee & Wonsang Lee; **Completed a 5 km x 7 km grid over targets D1 and D2**)
- Bathymetry for ocean circulation - Nansen and Drygalski cavities (Wonsang Lee; **partial coverage on a 2 km x 6 km grid**)

- Bed Topography of Campbell Glacier (Young Chul Park; **Completed a 1 km x 1.5 km grid over target region**)
- Remote detection of basal melt/freeze - Drygalski Ice Shelf (Wonsang Lee & Choonki Lee; **partial coverage**)
- Basal channel evolution - Nansen Ice Shelf (Wonsang Lee; **achieved planned flights**)
- Subglacial topography affecting the exposed layers in the Elephant Moraine blue ice area (Young Chul Han; **not flown this year**)

2. Platforms and Equipment

Two AS-350 helicopters were configured with geophysical equipment to support science operations. Both aircraft were operated by HNZ New Zealand, Ltd under their overall arrangement with KOPRI to provide helicopter support of Antarctic operations. The equipment suite in each helicopter consisted of a subset of the overall aerogeophysical suite which UTIG has developed and operated aboard fixed wing aircraft since the early 1990's and specifically aboard DC-3T aircraft in Antarctica since 2008. One helicopter was designated the "Radar / Remote Sensing Helicopter", and carried the ice-penetrating radar, laser profiler, and camera; the other helicopter was designated the "Gravity Helicopter", and carried the gravimeter.

A. Radar / Remote Sensing Helicopter

The radar / remote sensing helicopter carried three primary geophysical instruments:

- Ice-penetrating radar (custom UTIG design)
- Laser surface profiler (Renishaw laser altimeter, here abbreviated LAS)
- Visible light camera (Canon DSLR)

The primary geophysical instruments were supported by auxiliary equipment:

- GPS-aided inertial navigation (Novatel SPAN IGM-1A, here abbreviated INS)
- Dual frequency, carrier phase GNSS (Trimble Net-R9) and antenna
- System controller, user interface, and data recorder (Environment for Linked Streams Acquisition [ELSA], UTIG-developed software on National Instruments PXIe hardware)
- Electrical power equipment for conversion, conditioning, distribution, and battery backup

The UTIG-designed Environment for Linked Streams Acquisition (ELSA) provided user interface, control, and data recording functionality. ELSA timestamps data as it arrives, recording a diverse set of streams to a consistent format on both internal and external hard drives. Timestamps are provided by counter-timer hardware within the ELSA chassis, and make it possible to reference any stream to a real-time GPS recorded with the other data. The helicopter suite required substantial customizations of the existing ELSA software used on the DC-3T. The only data streams not recorded by ELSA were the camera (recorded to SD card) and the Trimble (downloaded over ethernet after each flight).

The ice-penetrating radar (IPR) is a functionally similar system to that first operated by UTIG in West Antarctica during the 2004/2005 Austral Summer then on the DC-3T platform across much of Antarctica since 2008 (60 MHz, frequency chirped, phase coherent radar). This enables straightforward comparison between this season's data and previously-performed surveys. UTIG modified the DC-3T implementation of the IPR system for the 2015/2016 summer season to record separately on each antenna, which enables phase analysis for off-nadir discrimination. This is the version implemented on the helicopter.

Ice Penetrating Radar Specifications:

- 8 kW peak pulse power; both antennas used for both transmit and receive
- 60 MHz center frequency, 15 MHz chirp bandwidth
- 1 µs pulse width (dechirped to 80 ns; yielding ~6 m vertical resolution in ice)
- 6250 Hz pulse repetition frequency; 32x hardware stacking for a data record rate of 195 Hz.
- 50 megasamples/sec digitization in receiver, 14-bit dynamic range per channel; 16 bits after stacking
- Each antenna has a separate low and a high gain receiver pathway for a total of 4 data traces per record and a total dynamic range of 120 dB

Modifications between the DC-3T installation and the AS-350 (tail number IBH) included antenna design, the addition of a transmit switch for the pilot, and an effort to reduce the size of the electronics rack.

Antennas were redesigned to fit inside existing booms that had been developed by Lake Central Air Services. These booms were originally designed for magnetometer survey and already had a Supplemental Type Certificate (STC - certification for aircraft modification). Using existing equipment enabled a faster development cycle, since we did not need to certify a new design. The new antennas remained as broadband dipoles but are end-fed rather than center-fed as on the DC-3T and incorporate a cylindrical grounding structure and top loading to fit in the booms. The antennas do not benefit from the additional 3 dB of gain that the DC-3T antennas achieve from their placement a quarter-wavelength below the large airplane wings. This year, of the three booms in the STC'd array, the front boom was empty. In future iterations of the radar design it could carry a third antenna, enabling polarimetric measurements.

(Left: Booms in-flight; Right: boom disassembly)

The electronics rack took up half of the helicopter's back seat. An operator could sit next to it for in-flight monitoring of the instruments and data.

The camera and laser were collocated on a mount to the right of the pilot's seat, taking advantage of an existing window in the helicopter. The mount shown in the below image vibrated slightly during flight. In the field, additional supports were added. The camera electronics included a remote trigger to capture an image every 3 seconds (chosen to ensure overlapping images at typical survey altitudes and speeds), and a separate GPS unit to record time and position in the recorded jpeg image. The laser records ranges at 1 kHz, and is reliable up to about 900 meters above ground level (AGL).

(Top: Laser and camera mount. Bottom: The electronics rack.)

In total, the survey instruments draw ~600W of power with the amplifier enabled, and ~460W without. In flight, the equipment is powered by the aircraft's generator via a 28 V DC survey power circuit designed by Lake Central Air Services. That DC power is converted to 120 V AC by an aviation grade inverter installed in the electronics rack. While on the ground, an aircraft ground power unit (GPU) battery pack can be plugged into the helicopter to power the instruments through the survey power circuit. The compact GPU used by HNZ had the capacity to power the instruments for approximately 45 minutes. Alternatively, and for longer ground testing, the system can be powered directly by AC station power. A UTIG-designed power distribution unit allows switching between the two sources, and an uninterruptible power supply protects against unexpected outages.

B. Gravity Helicopter

Gravity survey operations were accomplished with commercial industry standard equipment. A GT-1A three-axis stabilized dynamic gravimeter (SN007) was obtained through a cooperative agreement with CMG Operations, Perth, Australia, with whom UTIG co-owns a gravimeter. The gravimeter was installed in an AS-350 helicopter (tail number HJV) dedicated for this mission. This installation closely followed a standard, type certified installation used by commercial geophysical operators. This equipment and configuration had been initially tested with success during limited operations in the previous (2015-16) Antarctic summer season with the same helicopter operating from the RVIB Araon.

The GT-1A is an off the shelf, but state of the art, gravimeter designed for moving platform usage (ships and aircraft). It consists of a sensitive vertical axis accelerometer supported and kept aligned with local vertical by an inertial platform stabilized in all three axes, along with control and data recording subsystems. The GT-1A uses real-time GPS inputs to assist the inertial measurement unit in stabilizing the sensor platform, and recorded dual frequency carrier phase GPS data for post flight processing. The complete GT-1A suite weighs just under 200 kg and is installed in the rear seating area of the AS-350. Other than the installation of a dedicated GPS antenna, there are no external modifications to the helicopter. The only electrical interface to the helicopter is the provision for 28 VDC electrical power.

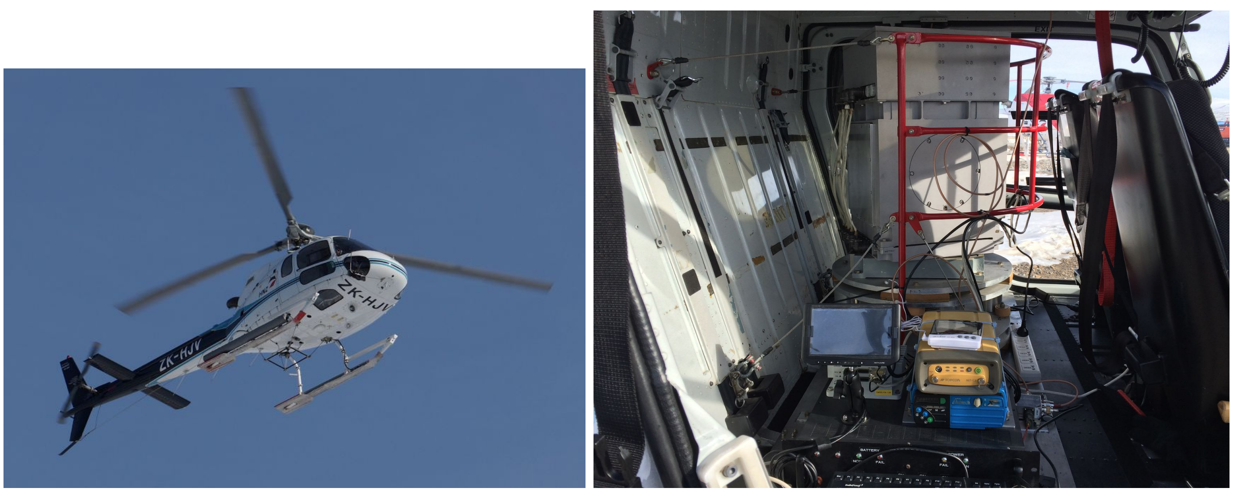
The standard GT-1A installation includes one dual frequency carrier phase GNSS receiver (Ashtech Z-Xtreme in this case) for real time inputs and to record satellite data for post processing. For our Antarctic operations, additional GNSS receivers (Topcon Net-G3A, Trimble Net-R9) were installed on the aircraft to provide hardware redundancy and some diversity in GNSS signal tracking in the difficult polar operating environment. Additional GNSS support for gravity survey operations was provided by base station GNSS receivers at Jang Bogo (Trimble Net-R9, Ashtech Z-Max). The base stations provide the capability to do differential processing of the helicopter GNSS data to provide the most accurate results, which are required as airborne gravity results are extremely sensitive to the quality of the aircraft positions and velocities as determined by GNSS.

We primarily used the Trimble Net-R9 receiver permanently installed at Jang Bogo by Choon Ki Lee. It is configured to automatically upload data every day, accessible at 192.168.34.13 on station, or externally at http://monitor.kopri.re.kr/gps. However, we found that the data quality deteriorated during the day and during busier parts of the season, possibly due to its central location (close to buildings) and interference by vehicles. Therefore, we set up a second base GPS station farther from constructions and roads. For this, we used an Ashtech Z-Max and collected data during the last week of operations. Data collected by the new base GPS station proved to be of better quality especially for gravity data processing.

(Location of second base GPS right after installation by Dillon)

One more item of support for the gravity surveys is an accurate gravity reference at the helicopter parking area. This is usually done via a gravity tie to a gravity reference monument and requires a hand portable gravimeter. This is all standard operating procedure in the commercial geophysical industry.

Initial processing of the gravity data for quality control purposes can be done on a laptop in the field with software provided as part of the GT-1A suite.



(Left: HJV in flight; Right: GT1a as installed in HJV)

3. Methods

A. Radar Initial testing: Lake Central Air Services, Ontario, Canada

The first flight test of the radar helicopter was performed at Lake Central's facility in Muskoka Canada. While we did not have access to deep ice to characterize the entire performance of the radar, collecting data over rock and water was sufficient to determine that the antennas performed as expected, and that the resulting data were similar to the previous year's DC-3T tests in the same location.

B. Gravity Initial testing: 2015-2016 KOPRI Amundsen Sea Cruise

The first deployment of the gravity helicopter was during the 2015-2016 KOPRI Amundsen Sea Cruise. In one day of operation from the Araon, three flights were performed, totaling about 900 line kilometers of gravity data. Preliminary processing indicated good internal crossovers and agreement with NASA Operation Ice Bridge data in the same area. This was the first time a gravimeter had been flown from an icebreaker in Antarctica.

C. Pre-field configuration: Helicopters New Zealand, Nelson, New Zealand

Pre-field configuration for both helicopters was performed at Helicopters New Zealand's facility in Nelson. They were transported to Antarctica on board the RVIB Araon's hangar with instruments installed.

In December, Tom Richter, Gregory Ng and Dillon Buhl (accompanied later by Don Blankenship, Laura Lindzey and Enrica Quartini) spent 10 days in Nelson for final integration of all instruments onto the radar / remote sensing helicopter. After completing a successful test flight, the booms were removed for shipping, and a second test flight was performed for INS/GNSS testing. The booms with the antennas were reinstalled in the heavy machine garage in Jang Bogo.

(Upper left: Equipment integration in HNZ's hangar in Nelson; Upper right: test flight in Nelson; Lower center: installing boom assembly in heavy machine garage at Jang Bogo)

Richter returned to Nelson in January to prepare the gravity equipment, which included installation of the gravimeter (working with HNZ personnel) into the AS-350 followed by one test flight. The schedule for gravity installation was compressed from a planned four days to two due to weather related changes to the ship and helicopter departure schedules. After installation and testing in Nelson, the helicopter was flown, with the equipment on board, to the Araon at Lyttleton where it was parked in the hangar for the trip to Jang Bogo.

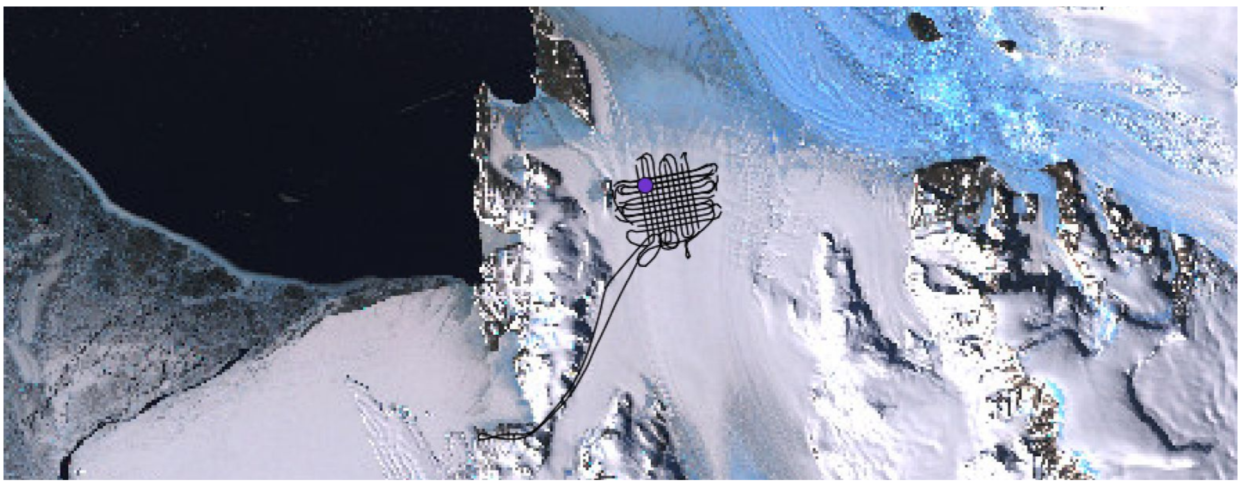
D. Calibration/Characterization

In addition to the science flights, we performed a series of calibration and characterization exercises. Some of these are repeated every year, while others were meant to explore helicopter capabilities and the new system's performance before committing to an approach for the David Lakes survey.

i. Laser Calibration

Obtaining surface elevations accurate enough for surface elevation change (dH/dt) calculations requires a precise determination of the offset between the laser's beam direction and the INS's reported frame. We followed the same procedure that UTIG typically uses:

- On the ground, with the INS running, use a digital level to measure the orientation of the sensor packages relative to gravity in as many redundant locations as possible. Use the INS's output orientation with respect to gravity and the measured LAS orientation to determine their relative angular offsets. INS measurements require that the system be initialized, which requires motion. We collected this information after F23, and archived it as event J041.
- Fly a dense grid of crossovers over a smooth, flat target at different altitudes, including some at the maximum range of the laser. A suitable grid was collected directly over the AMIGOS2 drill site in F19, yielding 150 crossovers where the same point on the ground has been measured twice. Starting with the angular offsets from the first step, we then perform a minimization over all crossovers. Ideally, at least 100 crossovers are obtained.



(F19, a 500 m grid over Nansen. Background image is LIMA mosaic, AMIGOS2 site is purple circle.)

ii . Radar Beam Pattern

In order to confirm that the energy from two antennas transmitting in parallel combined to create the expected beam pattern, we performed a number of roll tests both over open water and over snow.

- TF02 in Nelson collected information about the beam pattern with both antennas transmitting over open water.
- F23, over Campbell glacier, collected information about the beam pattern when transmitting on a single antenna and receiving on both.

This is an analysis performed every year, since it has the potential to catch a number of installation errors.

Preliminary analysis of surface reflection coefficient vs. roll angle shows that we have a maximum at about 3 degrees off nadir, and the first nulls are about 17 degrees from the max. This agrees well with our pre-field simulations. The beam pattern is not perfectly centered at nadir due to the presence of a aluminum stall strip running along the right-side boom; a redesign of the boom for next year would replace this with a non-conductive element, bringing the beam pattern maximum closer to nadir.

An additional test flight (F01) that flew the same line transmitting with only a single antenna and with both antennas was used to confirm that despite the stall strip interfering with the right antenna's input impedance and increasing mismatch loss, transmitting with both antennas results in higher total basal reflection coefficients and thus is preferable.

iii . Radar antenna and cable characterization

Optimum antenna impedance matching allows for maximum power transfer through the radar in both transmit and receive modes. We used a vector network analyzer (VNA) to measure the impedance characteristics of the antennas and RF cables. These measurements, carried out on the ground at JBS and in the air (F01), allowed us to

- be certain that the antennas and cables were properly routed and connected in the helicopter
- ensure that the antennas' input impedance characteristics were as expected from pre-season modeling and measurements.
- quantify the effect of the stall strip on the impedance of the right-side antenna

Also, the length of the RF cables used in the radar must be carefully controlled to ensure the signals from the two antennas are in the proper phase relationship to produce an optimum combined beam pattern. Because the radar antennas are fed at the ends of the antennas nearest the helicopter, rather than in the center, the voltages at the antenna terminals need to be 180° out of phase with each other. The phase difference was introduced between the two antennas by cutting one of the radar cables a half wavelength (at the radar's center frequency) longer than the other during installation of the system. We used the VNA to measure the phase of signals on the cables while trimming them, and the cables were matched to this 180° length difference within one degree.

iv . Optimal height above ground level

One of the open questions this season was what is the optimal height above ground level (AGL) for radar survey operations in a helicopter. The typical value of 600m used for DC-3T operations was not necessarily going to be optimal for the AS-350s, due to different beam patterns and platform flight capabilities. This is a tradeoff between:

- Surface scattering obscuring near-surface features and layers (flying higher increases the area of the surface illuminated by the beam, making scattering worse.)
- Radar ringdown interfering with the surface (flying too low means that energy from the initial transmission is still present in the system when the surface return arrives and is digitized.)
- What is actually realizable given the in-flight information available to the pilots. (This season, we did not have a functioning radar altimeter like we typically rely on in the DC-3Ts.)

We found that below ~300m AGL, interference prevents robust retrieval of the surface elevation using radar. This complicates generation of ice thickness products and the focusing pipeline, but it is possible to use the laser altimeter's ranges instead.

v. Radar Reflection Coefficient

In order to calculate accurate reflection coefficients using the radar equation, we need to determine the system gains and losses. This is most easily done by flying over a surface with a known reflection coefficient. As in past seasons, we will use open water for this, and TF02 included significant time spent flying ~500 m from shore.

vi. Polarimetry

Why is polarimetry interesting?

- Ice crystal fabric - Ice fabric is a critical and poorly understood control on ice flow. Some fabrics will change the polarization of the reflected energy observed in radar.
- It is thought that some features on the ice interfaces might respond more strongly to incident energy at different polarizations. An obvious example is a basal crevasse - their hyperbolae show up very strongly in radargrams, and you might expect a different reflection coefficient for an incident wave polarized parallel to the crevasse or perpendicular to it. We think that the same may also be true for subglacial features, including channels, and that this could be a useful technique for characterizing the subglacial water systems.

Both the DC-3 and the AS-350 antennas are cross-track polarized dipoles, with both antennas used for both transmit and receive. However, the helicopter's maneuverability affords an exciting chance to test techniques related to geometrical polarimetry. With this in mind, we flew a dense grid over the Campbell glacier ice tongue at three different elevations (F26) followed by "pirouettes" at the line intersections. (The pilot hovered in place while making a slow rotation about the vertical axis.) This will allow us to see the same features at two different track orientations, along with a full range of incident polarizations. The Campbell Glacier ice tongue was chosen as a site for this test due to a combination of weather constraints and its basal crevassing.

Detecting anisotropy as a matter of standard acquisition would require an additional receiving antenna, polarized differently from the primary transmit one. While this year's radar system is not able to detect this, the empty front boom could easily be used to add an along-track dipole.

vii. Gravity Tie

As with all airborne gravimeters, the GT-1A is a relative gravity instrument. Therefore, it is desirable to determine a reference (or "tie") between GT-1A measurements and a known absolute gravity measurement. A "gravity tie" measurement can be performed using a portable, relative handheld gravity meter which is operated both at an absolute "gravity monument" (that is, a location where the absolute value of gravity is known) and at the location where the airborne gravimeter is usually parked (and where it has taken repeated relative gravity measurements). A gravity tie consists of a group of three measurements, the first one taken at the absolute gravity monument, the second at the aircraft parking location, and the third back at the gravity monument to "close the tie". Multiple gravity ties are measured throughout the season in case either meter is experiencing drift.

There is a gravity monument at Mario Zucchelli Station (MZS) established by POLENET in 2011 (https://eost.unistra.fr/uploads/media/Report_2011.pdf), and Choon Ki Lee is also attempting to establish an absolute gravity monument at Jang Bogo. We performed two ties to MZS at the start and end of the season, using an L&R handheld gravity meter provided by UTIG (SN G-399). These data are archived as F02 and F08. With Choon Ki Lee and Byeong Hoon Kim's assistance, this procedure was also used to tie the superconducting gravimeter at JBS and the new absolute gravimeter to the established monument at MSZ. Additional gravity ties were subsequently measured between the absolute gravity monument at JBS and the gravity helicopter pad.

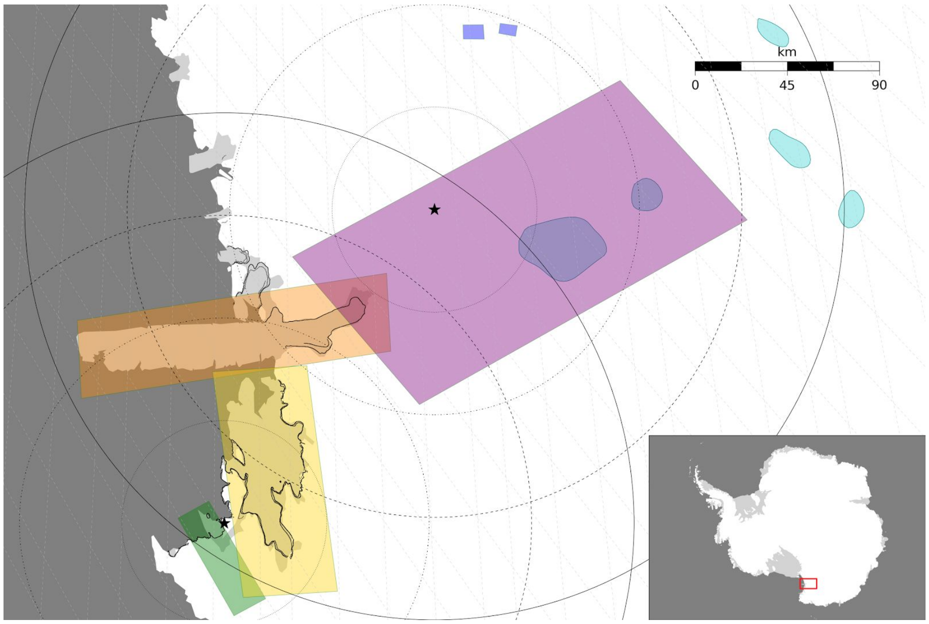
(Byeong Hoon Kim taking a measurement with the handheld gravimeter under the helicopter at MZS)

E. Helicopter Operations

This season's operations were conducted under the following constraints:

- No flight segments more than 500m over open water (HNZ requirement with the AS-350 as configured for Antarctic operations).
- A second helicopter must always be within 100 nautical miles.
- Limited to Visual Flight Rules (VFR) with a clear horizon is required, so clouds over the plateau will prevent operations. Certain types of flying (e.g. very low height AGL) impose stricter visibility requirements.
- The radar booms are only certified to a maximum of 80 knots airspeed.
- AS-350 endurance is ~2 hours, and the helicopters burn ~1 drum of fuel per hour.
- Refueling with rotors on can only be performed at < 20 knots wind speed.
- There are legal limits on daily flight hours, duty days, and cumulative flight hours.

A number of our target regions were too far away to be surveyed in a single flight from Jang Bogo, or from any already-established cache. The map below shows our target regions, along with Jang Bogo and Morris Basin as stars. Concentric circles are at 50 km range intervals from Jang Bogo; maximum flight length is <300 km.



(Target areas: Green - Campbell, Yellow - Nansen, Orange - Drygalski, Purple - David Lakes, Blue - Elephant Moraine. Concentric circles are at 50km intervals.)

i. Flight Planning:

We planned flights via a custom plugin to QGIS that allows interactive selection of waypoints shown in the context of science data and various maps. We then exported the waypoints in a format suitable for upload to the pilots' navigation units.

- Flight plans typically had a maximum of 2 hours/150 nm between stops to refuel.
- 2-4 flight segments per day was reasonable. We sometimes managed 5, where the transits were much shorter. For operations out of JBS, we planned on up to 3 flights per day, but never achieved more than 2 per helicopter in a day due to weather.
- Flights sometimes take longer than planned, whether due to wind or other factors. Therefore, we always included information about how to shorten plan length mid-flight. (While a pilot can always just return straight home, there are often ways to cut distance that are preferable from the science point of view.)

ii. Established Fuel Cache Locations:

- Morris Basin - we used this one for the radar / remote sensing helicopter in surveying the David Lakes area, and had planned to use it for Elephant Moraine.
- Tarn Flat - inaccessible with the radar booms; the wind was never calm enough for the gravity helicopter to land there.
- Cape Phillippi - not a permanent cache, but a common place to leave fuel. Both helicopters used it for surveying Drygalski.

iii. Remote Field Refueling Approaches:

Throughout the season, we used a number of different approaches for refueling:

- Take off from and return to JBS. Logistically, this is the easiest option, and it was practical for all of the Campbell and Nansen flights.
- Take off from JBS, refuel one or more times using cached fuel, return to JBS. We used this approach for the survey of Drygalski. HNZ seemed generally willing to establish a cache anywhere that we needed in order to perform a survey. This approach seems to work very well for survey regions within the 100 nm radius of JBS where there is no need for coordination with a second SAR helicopter.
- Take off from JBS with an accompanying utility helicopter sling loading up to three drums of fuel. The utility helicopter meets the survey helicopter at the end of survey lines to refuel, and can ferry fuel to/from an existing cache. We used this approach to maximize the number of science line-kilometers flown in the remote David Lakes region. This approach worked well when we would have required a SAR helicopter anyways, and is particularly valuable in regions that are severely weather-limited where it is important to make each day count.

(Refueling in the middle of the ice sheet. Photo: Fred Wunderler)

iv. Real Time Navigation:

The existing navigation units in the helicopters (Garmin Aviation units) did not provide sufficient real-time information for these types of detailed operations. This was particularly difficult for the radar / remote sensing helicopter. Gravity surveys tend to consist of long, straight lines at constant altitude, while radar surveys can consist of numerous altitude changes and turns. It is worth considering alternative systems for future work. Desired features include:

- Cross-track error was not reported until it exceeded 100 meters off line. Rather than relying on the cross-track error display, the pilots simply zoomed in on the line between waypoints and watched their GPS track. This workaround allowed the pilot to fly a good survey with 150 m line spacing.
- There was no way to display desired altitude vs. current altitude. This information was critical for the radar / remote sensing helicopter. Surface scatter is a function of height AGL; we wanted to

fly at a fixed height AGL that trades surface scatter for being high enough not to confound the surface with the antenna ringdown.

- We did not have a working radar altimeter while the IPR was operating, so "draping" (flying at a constant height AGL), like UTIG usually does in the DC-3T, was not an option. The approach this year was for the pilot to have a list of desired altitudes for each waypoint on a kneeboard, and to compare them to the GPS altitude displayed on a corner of the screen. This had high pilot workload, and did not allow for smoothly ramping altitude between waypoints.

v. Notes on science and equipment operation:

A major innovation this season is flying without a science operator or equipment engineer on board. While this had previously been demonstrated with the gravity helicopter (last season, 2015-16), it was the first time it had been tried with a the UTIG-designed radar system.

Unattended operations worked well. After the initial configuration flights, the equipment was extremely robust. Additionally, this operational model wound up being required in order for our small field team to operate two helicopters simultaneously. We had several days where both the gravity helicopter and the radar / remote sensing helicopter each made two flights from JBS, and it was crucial to not have any of our team stuck in the air.

Unattended operations only required a few modifications:

- We required a way for the pilot to enable/disable transmission since the IPR interferes with receiving VHF for helicopter-to-helicopter communications; in addition, we want to avoid transmitting with the IPR close to JBS or MZS.
- Startup/shutdown procedures for the instruments are too involved to ask the pilot to perform, so we opted to refuel with the rotors on, providing a continuous supply of power to the instruments. This has a nominal cost in fuel, but made operations much simpler and more robust.
- One downside was that the lack of an equipment operator made in-flight replanning in response to changing conditions more difficult. In traditional DC-3T operations this was a real-time dialogue between the flight crew and science operators. Instead, we had to rely on the pre-flight briefing and provide a flight plan with contingencies for shortening.

vi. Schedule Summary

The radar / remote sensing helicopter spent 56 days on continent. Of these, less than half were available for science operations:

- 26 weather days. For some of these, Campbell would have been available but we had no remaining targets there.
- 20 flight days. This includes 4-5 where only Campbell was available, and one boomerang for an attempted flight up Reeves.
- 3 days for setup (includes arrival day)
- 1 day for data analysis and an operations meeting at MZS
- 1 day for a scheduled holiday
- 3 days off due to pilot duty hour regulations / excessive air traffic

- 2 days for deconfiguration and packing

In twenty flight days, the radar / remote sensing helicopter flew a total of 95 hours and 12,300 line-km, including the test/characterization flights and transits between science lines. Note that this is hours airborne, not hours with the rotors on. HNZ bills flight hours based on the time from rotors-on to rotors-off, so flight hours and billable hours will not match. Additionally, we refueled with rotors running in order to power the science equipment.

A single flight would sometimes include lines for multiple projects, since we did our best to minimize ferry time and instead collect scientifically useful data on the way to the more distant targets. Broken out by target (omitting test flights and transit lines) we collected roughly: 810 line-km over Campbell Glacier; 1610 line-km in the Nansen grid; 410 line-km focusing on the Nansen Channel; 3540 line-km over the David Active Lakes; 270 line-km over Drygalski; and 650 line-km filling in the grid connecting the David grounding zone to the active lakes.

For the gravity helicopter, we had 21 days on continent:

- 9 weather days
- 7 science flight days; includes several boomerangs due to winds
- 3 days for setup (includes arrival day)
- 1 down day due to Gravimeter resetting itself
- 1 day for deconfiguration and packing

For the Gravity helicopter, we had 10 science flights (not including the F04 boomerang), totaling 3500 line-km and 23.5 hours at survey altitude. All of these flights were in support of the Nansen/Drygalski bathymetry targets.

In the second half of the season, katabatic winds became a significant problem. Additionally, the Italians pack up MZS before JBS operations end, which affected our operations since they operate the remote weather stations and had forecasters on staff who provided support for all HNZ operations at MZS and JBS. So, at the end of and after the Italian season, we had to operate without their weather support.

This season's deployment window was constrained by instrument and platform development/integration schedules. In the future, it might make sense to perform aerogeophysical surveys earlier in the austral summer. See Section 6 for a more detailed breakdown of the season schedule.

F. Data Processing

i. Field Processing and Quality Control

While in the field, we have limited equipment and personnel. Our goals for field processing are to make sure we collected the expected data, identify any problems with the instruments, and to archive the data.

All data is first downloaded from the in-flight media (SSD for ELSA, SDHC for the camera) to a 3TB RAID array. We used two System76 Ubuntu laptops running a custom software suite for processing the radar/remote sensing helicopter's data. For gravity, we use the CMG-provided GTNav and GTGrv Windows executables. During processing, all data is stored on the RAID. Once we have performed quality control, four copies of the data are written to LTO6 tapes for archiving. The resulting tapes are stored in at least two different buildings on station so a single mishap cannot destroy a season's worth of data.

For the radar, field processing generates a product we call "pik1" by stacking and pulse-compressing the raw radar data. This is suitable for preliminary interpretation. In some expeditions, the manual interpretation and labeling of the air/ice and ice/bed horizons is started in the field, but we had insufficient personnel this year.

ii. Post-season Processing

Typically, the bulk of the data processing occurs once the data has been downloaded to the UTIG servers. This section provides an outline of the steps required:

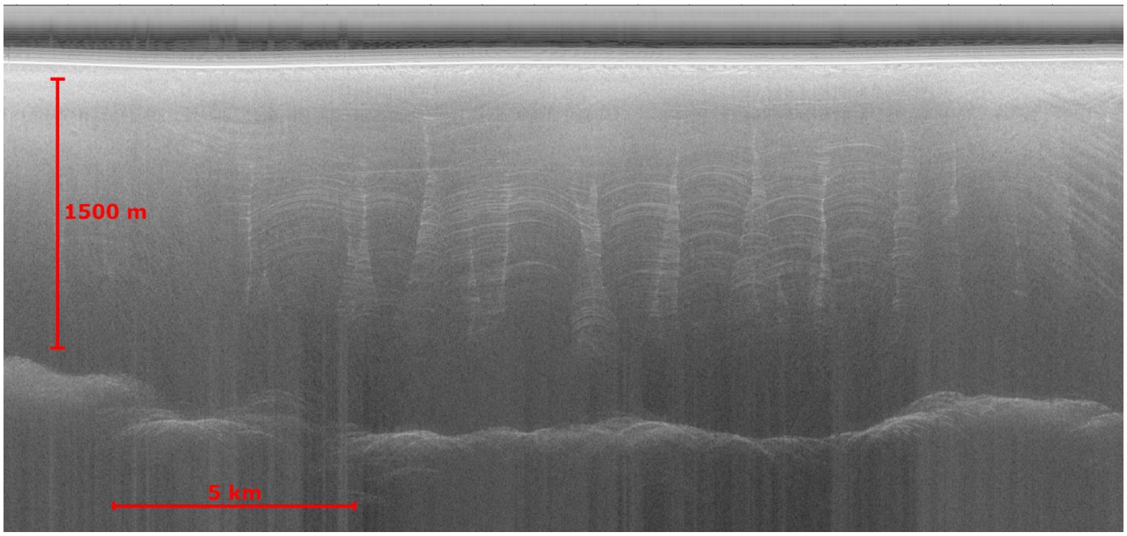
GPS & IMU post-processing: Radar data products require having a full trajectory (time, x, y, z, roll, pitch, yaw) for each flight. This is a prerequisite for any further processing. UTIG prefers the proprietary software Novatel Waypoint to obtain a solution from combined GPS and INS data streams.

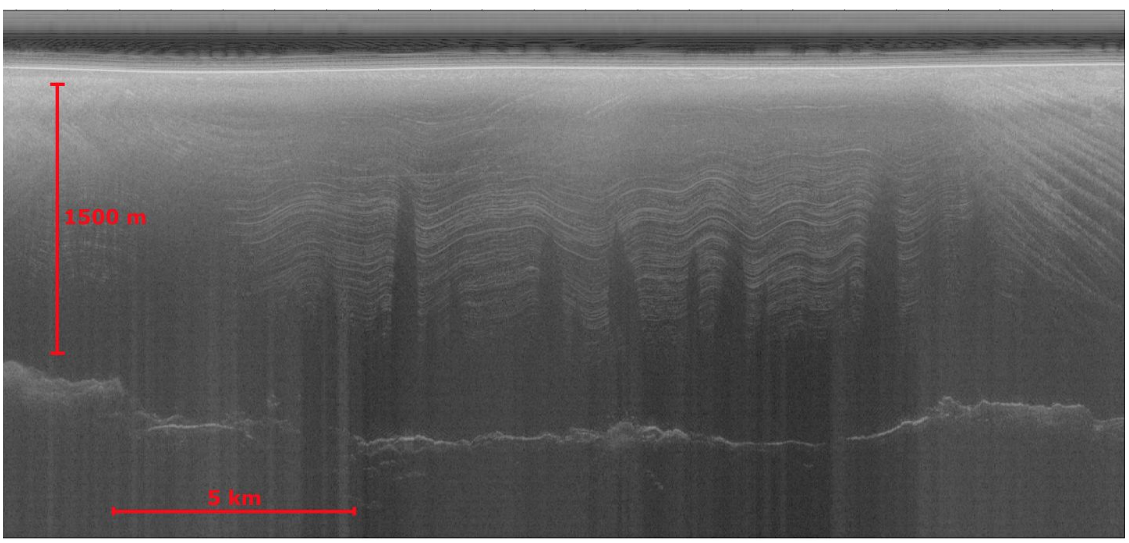
Altimetry: This season, we need laser altimetry to determine ice shelf floatation (Nansen, Drygalski), dH/dt calculations (David Active Lakes), air/ice surface determination (anywhere we flew low enough for the surface to be partially obscured by ringdown).

- The laser system used was a new sensor (1 kHz, compared to 4 Hz for the Riegl Laser used on the DC-3T), so additional post-season characterization is needed to determine its practical accuracy for this application. This includes ruling out (or characterizing) any range bias, analyzing its noise properties to determine the number of samples to average, and perhaps other issues.
- Determine the orientation offset between the laser and the inertial navigation system (INS).
- Generate along-track surface elevation data, validate using existing DEMs over slowly-changing areas.
- Integrated validated along-track data into DEMs
- Use 2017 elevation data to compute dH/dt (for ICESat reflights)

Radar Focusing: The in-field "pik1" product can be thought of as unfocused SAR. The focusing process (analogous to seismic migration) is required to obtain more accurate along-track bed slopes, improving the along-track resolution, and improving recovery of sloped layers. Additionally, it is a prerequisite for analysis of specularity, which is the ratio of horizon amplitudes for data focused with two different apertures. Focusing is performed via a custom software suite. In addition to the time needed to perform the focusing (processor-intensive calculations can require up to a week per transect), the pipeline will need to be updated for helicopter operations. Relevant differences include:

- Helicopters fly more slowly than the DC-3T (70 knots vs. 160 knots). This is good for resolution and signal-to-noise ratio, since with a constant pulse repetition frequency this translates to more measurements per line-kilometer. Optimal stacking depths will need to be determined.
- Ground speed varies more on the helicopter than the DC-3T, in both proportional and absolute terms. We will need to put in more work to ensure spatially-consistent data products with such varying sampling densities.
- For some of the surveys we flew low enough that the radar data does not contain information about the air/ice interface. We will have to use ranges from the laser altimeter instead; this technique has been demonstrated, but is not part of the typical processing pipeline.





(Radargram WSB/JKB2e/GL0292c, previously collected by UTIG over D2, demonstrating how focusing increases along-track bed resolution and enables layer tracing.
Top: field-generated pik1 product. Bottom: foc2 product.)

Radar Interpretation: After all processing is completed, both unfocused and focused radar data are interpreted so that ice thickness and surface and bed character can be quantified. To do this, ice surface and bottom elevations are extracted using a common semi-automatic method with rough localization from manual picking using software developed by UTIG. Englacial layer depths are extracted using a similar approach with commercially-available geophysical software. After these horizons have been labeled, further data products can be generated, including:

- Along-track estimates of ice thickness and bed elevations; DEMs of the same
- Hydrologic potential mapping (ideally, incorporating the more-accurate laser-derived surface elevations)
- Basal characterization using specularity

Gravity Processing: Final gravity processing is similar to what is done in the field with two usual exceptions:

- The GPS precise ephemeris is available a few days after each flight. This is not suitable for the field processing, since we require that all data be analyzed before the next flight opportunity. Therefore, processing is repeated post-season to take advantage of the improved accuracy (reduced noise) enabled by the precise ephemeris.
- More care is normally taken in post-season processing to remove sources of noise

While final gravity processing is usually performed post-season, there are no technical constraints preventing it from being done in the field, so long as there is good enough internet access to download the necessary GPS updates. This would be done on a time-available basis, after the precise ephemeris is available. Gravity processing requires a considerable amount of personnel time, which is usually not available in the field.

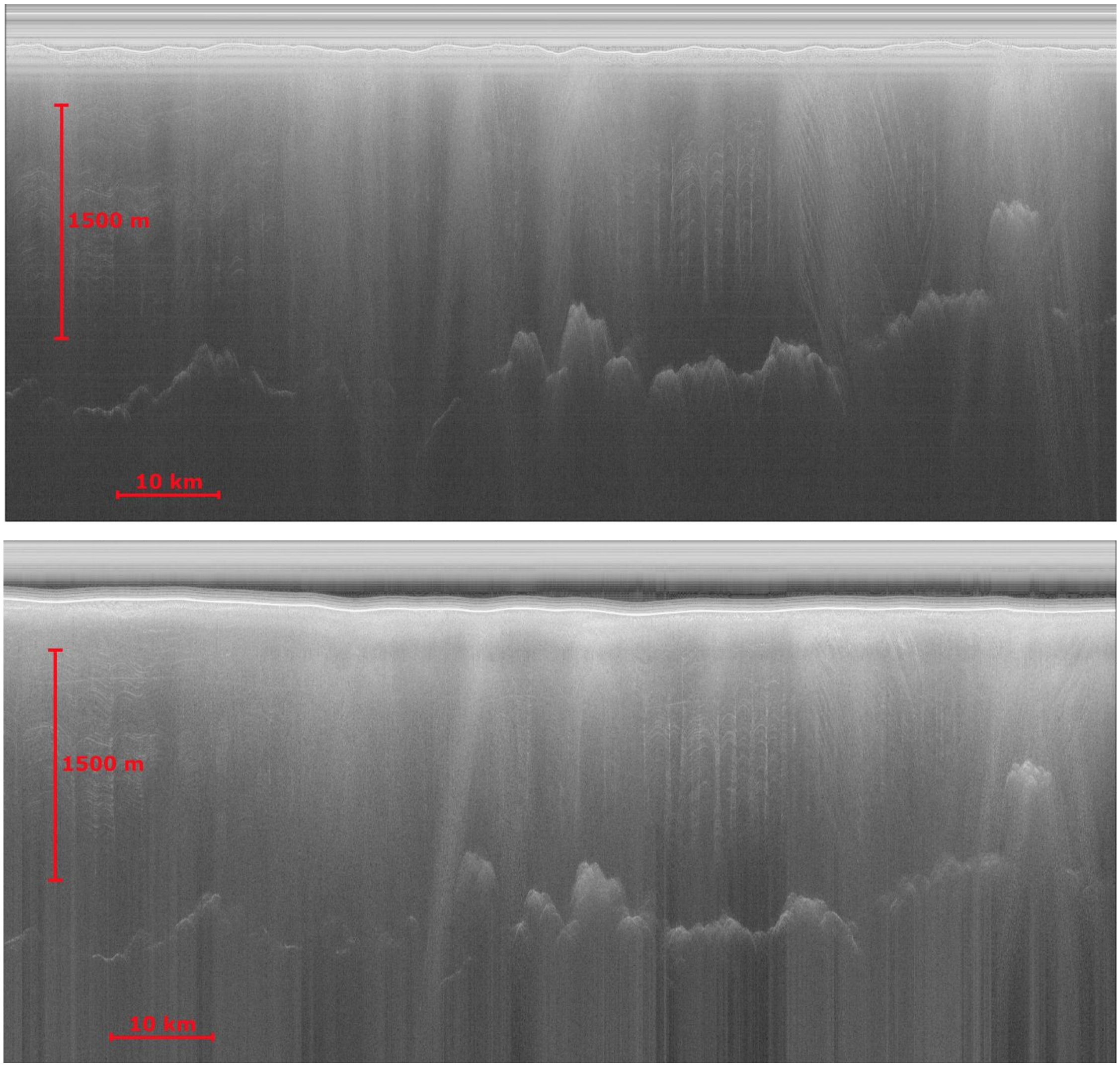
Gravity Interpretation: Ice shelf cavity bathymetry

To infer the seafloor beneath ice shelf cavities, UTIG researchers invert gravity data using ice thickness measurements from radar and constraints on depth to basement from magnetics. Typically, the largest uncertainty in the inversions is from variations in geology that can occur over short horizontal distances but result in significant changes in the vertical density distribution of the seafloor. This can result in large errors (>200 meters) in the vertical (level shifts) even if the general topography is captured.Therefore, where the ice thickness is known over grounded ice, the bedrock elevation can be used as a tie, or constraint, on the resulting gravity inversion. Magnetics data are especially useful for both visualizing changes in regional geology (where level shifts may occur) and for computing the approximate depth to magnetic basement to infer sediment layer thickness, if any. Currently, the KOPRI helicopter instrument suite does not include a magnetometer; however, magnetic constraints can be added at a later date to improve gravity inversions when magnetic data become available.

4. Preliminary Results

Preliminary interpretation suggests that the helicopter radar is qualitatively equivalent to the previous fixed-wing versions; a quantitative comparison of signal strength/noise floor is future work. This comparison is enabled by flight plans that crossed numerous UTIG radar lines, and one that re-flew a

GLAS satellite track that had previously been surveyed using the UTIG IPR and laser altimetry systems on a DC-3T.



(Radargrams along GL0292 crossing D2. Note high vertical exaggeration: the ice is ~2km thick and this section is ~100km long. Near-surface differences are a result of flying at 300m AGL vs. >700m AGL. Top: helicopter, Bottom: DC-3T.)

The following sections will discuss the preliminary results grouped by science targets. Final data products will require significant additional processing, as discussed in Section 3D.

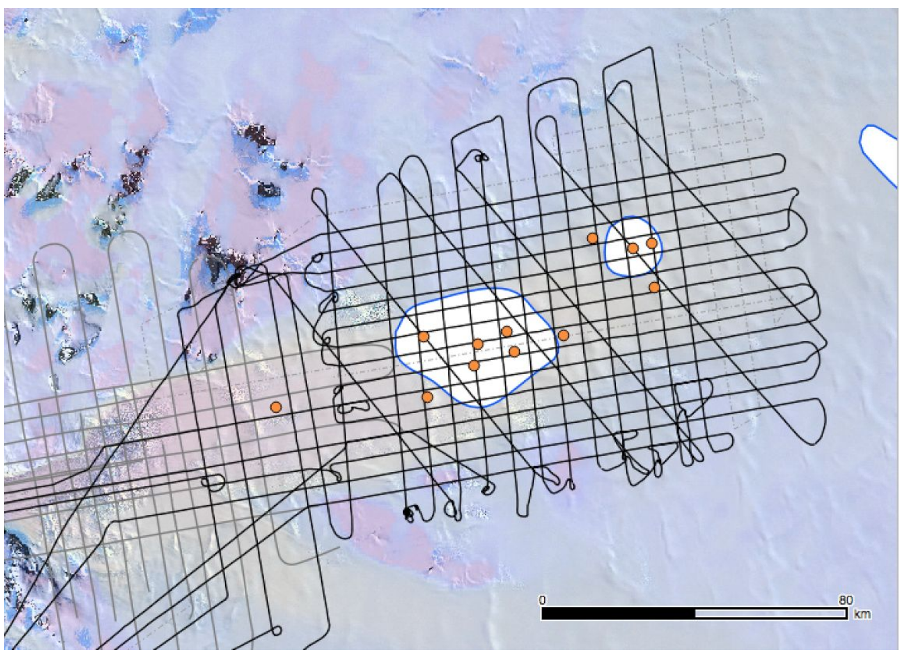
A. David Lakes

The David Active Lakes were originally identified by repeat-track ICESat altimetry, as they are features that change ice surface elevation in a pattern suggestive of a blister of water filling and draining under the ice. The particular pattern of elevation change is not easily attributable to overall acceleration and/or thinning.

- Previous research has not found a clear relationship between active lakes detected based on surface altimetry and more traditional subglacial lakes detected by their radar properties.
- Lake locations estimated from ICESat and Cryosat surface altimetry do not agree exactly.
- Choon Ki Lee has an array of GPS receivers on David Glacier. His preliminary results suggest that D1 may be a network of smaller lakes, filling and draining independently.

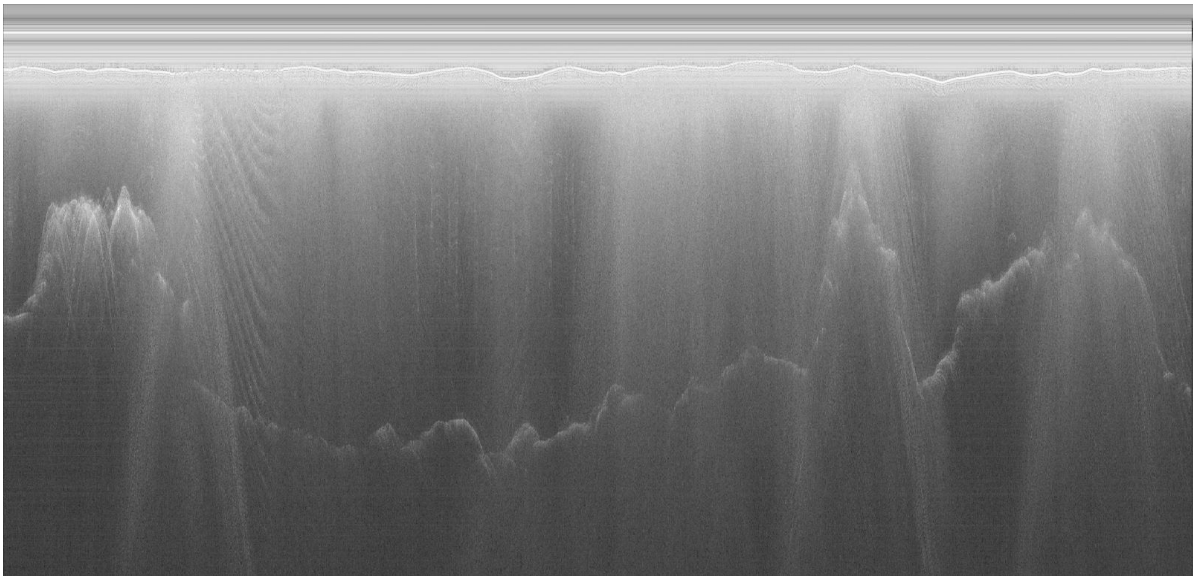
This year, we set out to perform the most comprehensive survey yet of an active lake system, with the goals of determining the best location to drill and to understand the hydrology supporting it. A survey was designed based on these constraints:

- Refly ICESat tracks: this is required in order to continue the dH/dt record, determine the phase of the lake (is it filling? draining?), and provide boundary conditions for the surface measurements.
- Interleave neatly with existing UTIG data in a way that connects the active lake region to the grounding zone.
- Orthogonal (or mostly-orthogonal) flight lines to better characterise any anisotropy.
- Extend across the shear margins to ensure that we sample the entire hydrologic system.

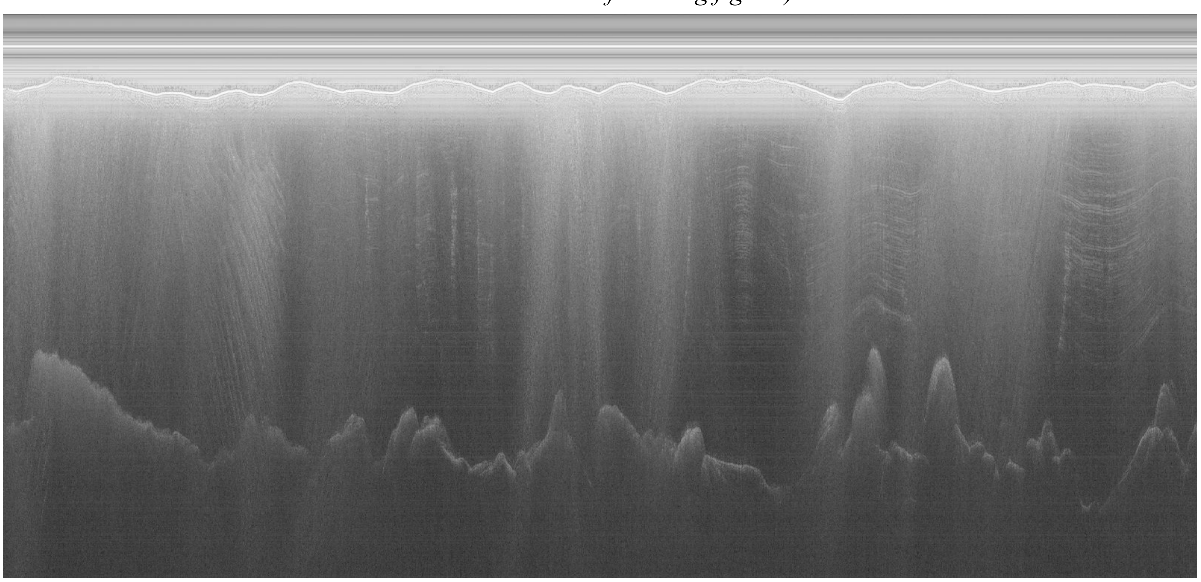


(David Active Lakes survey. This season's data is black, existing UTIG data is grey, unflown plans in dotted grey. Background is the MODIS mosaic and MEASURES velocity, with Smith's active lake outlines as white polygons and Choon Ki Lee's GPS stations as orange circles.)

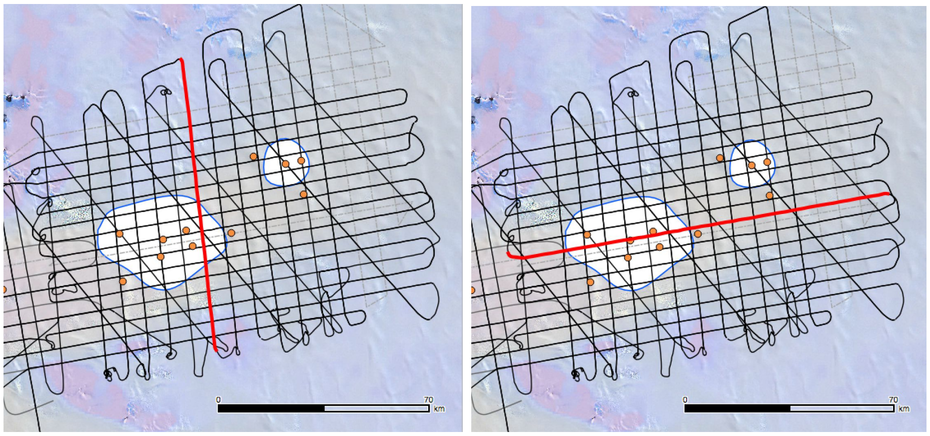
With these constraints in mind, we designed a survey that continued UTIG's along-flow lines, but used the descending ICESat tracks for the across-flow lines. Planned ICESat tracks were published at 7 km spacing, even though instrument failure meant that not all were flown. Additionally, we re-flew the ascending ICESat tracks that had time series surface data. This yielded the 5 km x 7 km grid over targets D1 and D2 shown above. With an additional day for survey, we would have filled in the far corner giving upstream context to D2. A further two across-flow lines were planned to be collected on the way to/from Elephant Moraine, but that was not possible this year.



(Radargram DVG/IBH0c/GL0938a crossing D1 from grid south to north. The ice is ~2 km thick, and horizontal extent is shown on following figure.)



(Radargram DVG/IBH0c/X20b crossing D1 from downstream to upstream. The ice is ~2 km thick, and horizontal extent is shown on following figure.)



(Context maps for above radargrams, in PS71 coordinates. Background is LIMA mosaic, Smith's lake outlines for D1 and D2 are shown in white, and Choon Ki Lee's GPS stations are orange dots. Left: DVG/IBH0c/GL0938. Right: DVG/IBH0c/X20b)

B. Bathymetry

Decoupling the gravity and radar / remote sensing instruments into separate helicopters allowed survey planning that optimizes for each instrument suite's operational constraints.

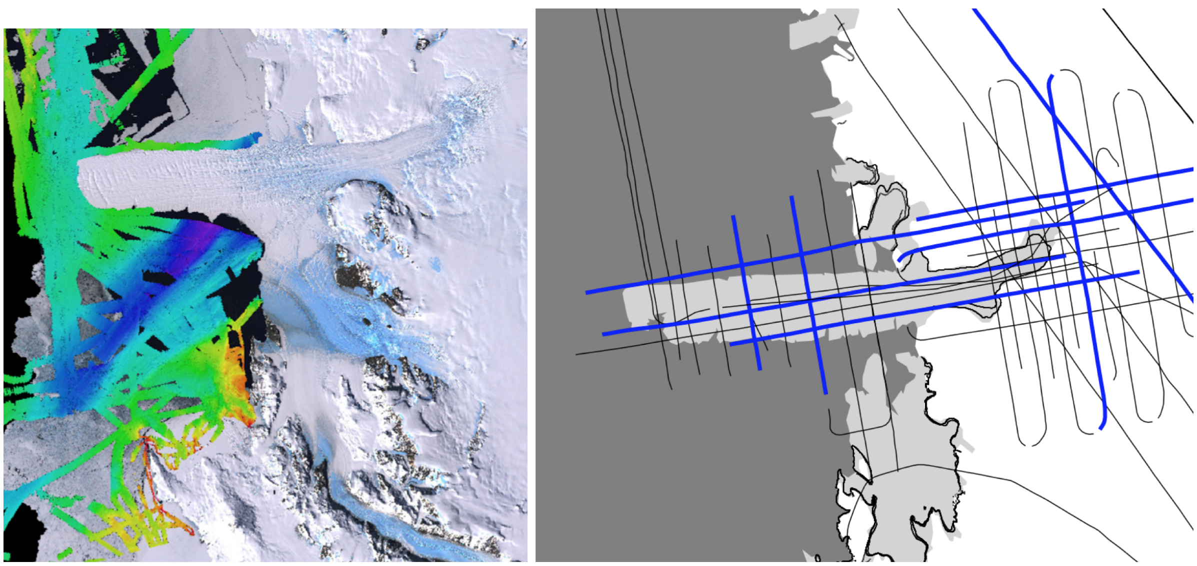
Nansen and Drygalski Bathymetry was primarily a gravity target, with associated constraints helping to determine survey layout:

- Gravity data is best when the flights minimize vertical and horizontal accelerations; therefore, long, straight lines at constant elevation are ideal. That being said, the GT-1A is more robust against platform acceleration than most gravimeters so data is likely to be recoverable from most lines and even in some gentle turns.
- Resolution is governed by either processing filter length and aircraft speed, or by the upward continuation due to the range to density anomaly (the combination of platform height and ice/water thickness).
- Given the need to cover large areas, we chose to fly at 70 kts. At this speed, we have a resolution of ~2 km; therefore, flying constant altitude at 5000 feet doesn't decrease the survey resolution, while allowing us to fly over local topography and get longer lines. Similarly, this filter-length-imposed resolution informs the minimum reasonable line spacing.
- Survey should overlap existing radar lines at the Drygalski grounding zone. For this science target, radar was only needed for a boundary condition, and this overlap with existing data meant we did not need to fly additional helicopter radar lines.
- The settling time required by the GT-1A means that the first 10 km of a line are probably unusable.
- We tried to fly neighboring lines in opposite directions to evenly distribute where the settling time causes us to lose data at the start of a line.

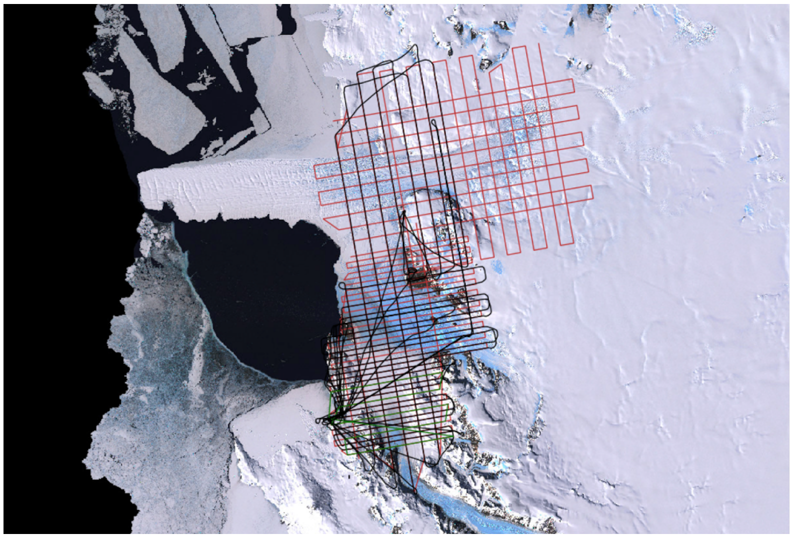
Additionally, we want to fly over locations where we know the water column thickness, ideally on both sides of the target area, to provide constraints on subsequent bathymetry inversions.

- KOPRI has extensive ship-borne bathymetry. Unfortunately, we were unable to cross any of it due to the 500 m open water restriction. In future seasons, if we are able to start operations before the sea ice to the geographic South of Drygalski breaks up, we would be able to obtain excellent ties to those multibeam lines.
- This year an active seismic experiment was performed which deployed a line of receivers across Nansen. The line intersected our survey area and could provide sediment layer thickness in addition to constraints on water column thickness; both are important for bathymetry inversions.
- We had hoped to use the AMIGOS2 deployment as a ground truth for water column deep in the cavity, but they only deployed ~300 m of line, so we only have a minimum depth.
- It is useful to fly across grounding zones where radar data provides a constraint on the location of the ice/rock interface. With a known ice density, this gives a constraint on substrate density.

Given the above, we opted to fly a 2 km x 6 km grid over Nansen, and to continue the existing 5 km x 5 km grid over the Drygalski grounding zone.



(Left: Existing multibeam bathymetry data from KOPRI; Right: black lines are pre-2016 UTIG radar flight lines in TNB; blue indicates the line also has acceptable UTIG gravity data)

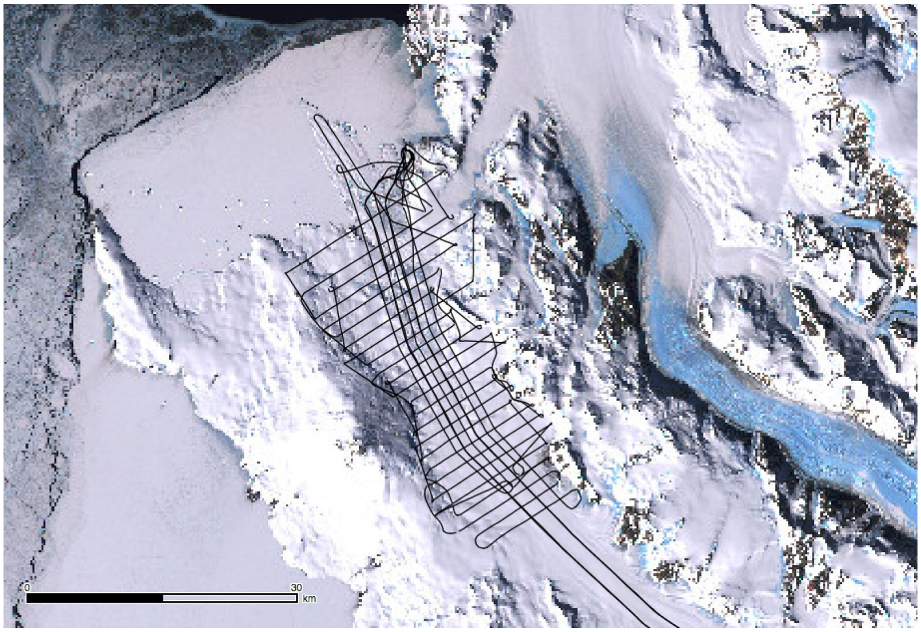


(Red: planned gravity survey; Black: achieved flights)

This season, we achieved excellent coverage over Nansen, and sparser coverage on Drygalski. Finishing the survey as planned would require a minimum of three additional flight days, assuming three flights per day. This assumes that we incorporate old UTIG gravity data where it exists (non-ideal since it was flown at a different altitude), and assumes that every line we flew this year will yield acceptable data. We think this assumption is optimistic since a number of flights flown this year were very turbulent; this will be evaluated in post-season processing.

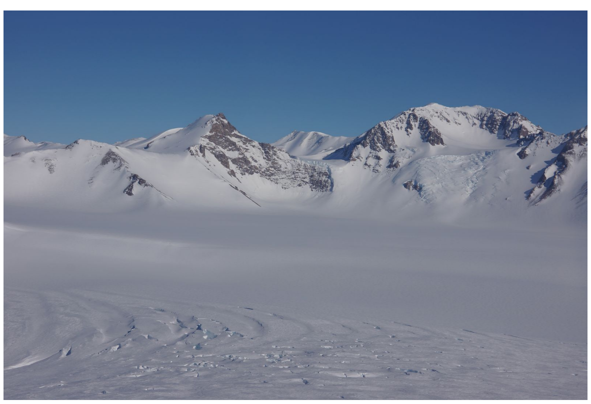
C. Campbell Glacier Topography

Campbell Glacier is a challenging target due to its geographical setting as a steep valley glacier. With an airplane, we would have been limited to flying a flow line or two down its centerline; with the helicopter, we were able to plan and complete a dense grid in the region of interest.



(Black lines show flight paths; background is the LIMA Mosaic)

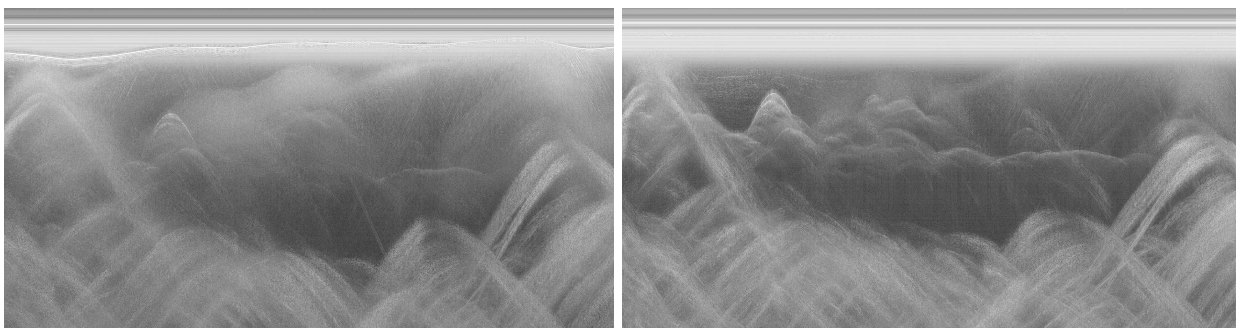
Additionally, it is a challenging radar target both due to off-nadir clutter and surface scattering. The wide beam pattern means that it is possible for an off-nadir object to reflect energy and appear as a bed reflection. Flying low helps to combat subaerial clutter (decreases distance to ice/rock interface while leaving helicopter to mountain distance unchanged), but has much less of an effect on any clutter from subglacial mountains.



(Left: steep mountains bound Campbell Glacier; Right: Campbell Glacier's rough surface)

For regions with significant surface scattering, successfully recovering the bed reflection (and, therefore, ice thickness and bed characteristics) depends strongly on height above ground level (AGL). Flying higher creates a larger radar footprint on the ice surface, causing correspondingly higher levels of noise due to surface scatter. On the other hand, flying too low can cause a shallow glacier's ice/rock interface to be obscured by resonating energy from the original high-power transmission. Based on prior work by UTIG at Byrd Glacier, flying very low (e.g. less than 60 m AGL) may be good for shallow layers but actually worse for recovering the ice/rock interface, while 60 to 200 meters AGL could improve bed recoverability beneath highly crevassed ice. Additionally, flying low prevents recovering the air/ice interface in the radar data; instead, ice thicknesses would then be computed using the laser surface and the radar bed.

Thus, it is difficult to know the ideal height AGL for surveying a given region of Campbell until it has been flown once. It would appear that the Eastern flank of the glacier is shallower, and less of that bed was recovered. Additionally, given the lack of a working radar altimeter and the coarse resolution of existing DEMs, the only way to fly a line at a known height AGL was to fly it once, use the laser ranges to reconstruct the true surface, and then re-fly using those altitudes. We used that technique to re-fly lines from a test flight, and the results are shown below.



(Two flights of the same along-flow section on Campbell. Left: 300-500m AGL; Right: 20-100m AGL)

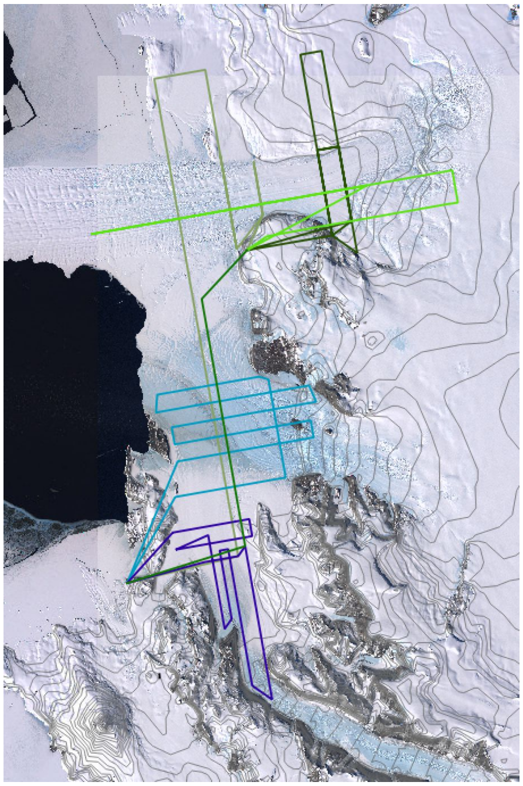
In many of the radar lines, we see a horizon that we preliminarily interpret as the bed. However, careful analysis of surface DEMs and the relative phase recorded by each antenna will be required to conclusively determine whether that radar horizon corresponds to the true bed at nadir.

D. Drygalski melt/freeze

This season, we planned to use Drygalski as a location to test our ability to discriminate melt/freeze at the base of an ice shelf using airborne radar data. Choon Ki Lee has identified hypothesized areas of melt/freeze under Drygalski based on ice flow divergence.

Remote characterization of melt/freeze depends on accurate reflection coefficients, which in turn require an accurate estimate of how much radar energy is lost at the surface due to scatter. We hypothesize that flying the same line at different altitudes will enable characterization of the $1/r^2$ and $1/r^4$ scattering components, and thus, accurate basal reflection strengths. Therefore, we planned to fly a grid at three different altitudes. Minimum experiment would be one line along-track and four across (1 x 4), but 3 x 6 across would be better.

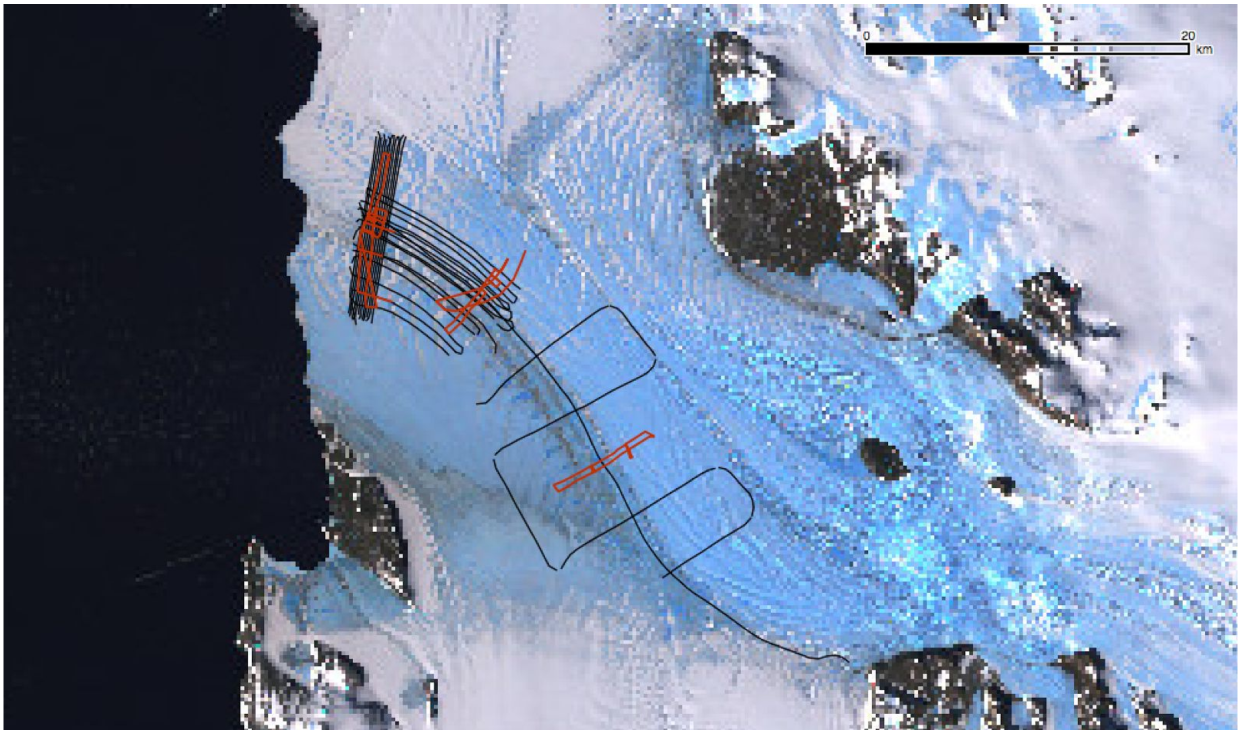
We achieved a 3 x 4 line grid, but only at a single altitude. Weather did not allow us to return to Drygalski to finish the experiment; instead, we collected a small grid at three different altitudes over the Campbell Glacier Tongue (F26) that will allow us to continue working on developing processing techniques.



(Unflown radar flight plans over Nansen and Drygalski. Green plans would finish the baseline Drygalski melt/freeze experiment in one day of flying with 2 refuels at Cape Phillippi; blue would finish filling in the 2km radar grid over Nansen with two flights out of JBS.)

E. Nansen Ice Shelf Basal Channel Evolution

The goals for these flights were to better understand basal channel evolution from the grounding zone to the shelf edge and to generate a complementary dataset to the GPR data collected by Dr. Christine Dow. We increased cross-channel coverage in areas that were too dangerous to reach with GPR, and re-flew some of Christine's lines to enable comparisons between the two instruments.



(Black lines show flight paths; red lines are Christine Dow's GPR tracks; background is the LIMA Mosaic. Nansen calved after the mosaic was created, and the new terminus is where flight lines are densest.)

Another goal was to remotely characterize the ice-ocean interface and obtain ground-truth information for its geometry, roughness, and melt/freeze distribution using sonar and CTD data from a submersible. Dense coverage near the shelf edge was meant to enable comparison between the radar data and planned Gavia Autonomous Underwater Vehicle (AUV) routes.

Unfortunately, the Gavia AUV only penetrated ~200 m beyond the ice front. We have radar data along the track Gavia had planned to follow for this mission, as well as a line crossing the track.

F. Elephant Moraine

Due to weather, we were unable to reach Elephant Moraine this season. A single day would be enough to collect a small grid over the region of interest.

5. Participants

(Field team for Antarctic helicopter operations in bold)

UTIG Personnel

Donald Blankenship
Duncan Young

Tom Richter
Gregory Ng
Dillon Buhl
Enrica Quartini
Laura Lindzey

KOPRI Personnel

Lee, Won Sang	PI for V3: Nansen & David hydrology
Lee, Jong Ik	PI for K-ROUTE: David Lakes
Lee, Joohan	
Eom, Joo Young	Postdoc w/ Wonsang (gravity)
Joo, Hyeon Tae	3rd year PhD student w/ Joohan
Lee, Choon-Ki	
Park, Young Chul	Seismologist: Campbell
Han, Young Chul	Geochemist: Elephant Moraine

HNZ Personnel

Phil Robinson	Antarctic Pilot - Radar / Remote sensing
Rob McPhail	Antarctic Pilot - Gravity
Fred Wunderler	Antarctic Engineer

6. Lessons Learned / Future Work

Radar:

- Need non-conductive stall strip on right boom
- More easily removable booms (requirement for operating from the Araon)
- Isolate the ice radar from the AS-350's radar altimeter so they do not interfere.

Laser:

- Collocate LAS & INS
- Sturdier LAS mount to reduce vibration

Navigation:

- HNZ pilots have requested a better real-time display

Magnetics:

- Should install a magnetometer on the gravity helicopter to provide constraints on bathymetry inversion.

Operations:

- Consider earlier deployment. This would help with forecasting (MZS schedule), weather (late-season katabatics) and gravity across known bathymetry (more sea ice).

Base GPS:

- Install additional base GPS at JBS with less obstructed view of sky.

7. Additional Information

a. Daily events for radar / remote sensing helicopter:

Date	**Flight**	**Comments**
Dec. 25		Arrival at Jang Bogo
Dec. 26		Setup/Configuration
Dec. 27		Setup/Configuration
Dec. 28	F01	Reeves test flight: transmit pattern, laser performance
Dec. 29		Data analysis, ops meeting at Mario Zuchelli
Dec. 30		Weather
Dec. 31		Weather
Jan. 1		Holiday
Jan. 2		Weather
Jan. 3		Weather
Jan. 4	F02	Reeves test flight – ICP4 crossovers for performance validation, test IGM + LAS reconfiguration
Jan. 5		Weather
Jan. 6		Weather

Jan. 7	F03, F04	Nansen and Campbell test flights – IGM configuration, working on navigation procedures
Jan. 8		Weather
Jan. 9		Weather
Jan. 10	F05	Reeves test flight – boomerang due to weather
Jan. 11	F06, F07	Campbell and Reeves test flights – determining optimal height AGL for survey
Jan. 12		Weather
Jan. 13		Weather
Jan. 14		Weather
Jan. 15		Weather
Jan. 16		Weather
Jan. 17		Weather
Jan. 18		Weather
Jan. 19	F08, F09	Campbell and Nansen survey flights (including site-selection for Amigos2); first flight without any science operators
Jan. 20	F10	David survey flight
Jan. 21	F11	David survey flight
Jan. 22	F12	Nansen survey flight
Jan. 23	F13	David survey flight
Jan. 24		No flying – pilot duty hour regulations
Jan. 25		No flying – pilot duty hour regulations
Jan. 26		Weather
Jan. 27		Weather
Jan. 28		Weather
Jan. 29	F14	Nansen survey flight
Jan. 30	F15	David survey flight

Jan. 31		Weather
Feb. 1		Weather
Feb. 2	F16	David Lakes
Feb. 3		No IBH flights – AMIGOS 2 camp move-in
Feb. 4	F17, F18	Campbell survey flights
Feb. 5		Weather
Feb. 6	F19, F20	Laser calibration flight, Nansen survey
Feb. 7		Weather
Feb. 8		Weather
Feb. 9	F21, F22	Nansen and Campbell survey flights
Feb. 10	F23	Campbell test flight – ringdown and beam pattern
Feb. 11		Weather
Feb. 12		Weather
Feb. 13	F24, F25	Nansen survey flights concentrating on channel
Feb. 14		Weather
Feb. 15	F26	Campbell test flight – polarimetry and scattering
Feb. 16		Deconfiguration / packing
Feb. 17		Deconfiguration / packing
Feb. 18		Departure from Jang Bogo

b. Daily events for gravity helicopter:

Date	**Flight**	**Comments**
Jan. 28		Rob and HJV arrive at Jang Bogo
Jan. 29		Gravimeter setup
Jan. 30		Gravimeter setup
Jan. 31		Weather

Feb. 1		Weather
Feb. 2		Setup - GT1a power cycled forcing 12-hour reinitialization
Feb. 3	F01	Test flight
Feb. 4		Weather
Feb. 5	F02	Weather; F02 has data for 1st MZS gravity tie
Feb. 6	F03, F04	Nansen survey
Feb. 7		Weather
Feb. 8		Weather
Feb. 9	F05, F06	Nansen/Priestley survey; boomerang from Nansen/Reeves
Feb. 10		Weather
Feb. 11	F07, F08	Nansen/Priestley survey (Reeves too windy); F08 is 2nd MZS gravity tie
Feb. 12	F09, F10	Nansen and Drygalski survey; unable to refuel with rotors on due to wind, so couldn't complete Drygalski lines.
Feb. 13	F11, F12	Nansen and Drygalski survey
Feb. 14		Weather
Feb. 15	F13	Attempted Nansen survey
Feb. 16		Weather
Feb. 17		Deconfiguration / packing
Feb. 18		Departure from Jang Bogo