UTIG's approach to managing polar aerogeophysical data in the field: philosophy and examples from fixed wing and helicopter surveys

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Abstract

This report documents UTIG's approach to managing aerogeophysical data in the field. This approach to fieldwork has taken shape in the course of over 20+ years of polar campaigns based out of over 10 Antarctic stations. Aerogeophysical survey is not simply about the act of making measurements and observations. A key component of conducting surveys is managing data as it is collected and providing feedback for quality control. We want to document that institutional knowledge for the benefit of researchers who are continuing in this work as well as for the users of our data.

While this document focuses on data management in the field, we start by providing the context for a typical aerogeophysical campaign and describe how the work is broken up amongst teams. We then discuss the philosophy behind field data processing, with a focus on what the goals are for preliminary processing and how it differs from the final products. With that motivation, we describe how the Base Operations team typically meets those goals, along with case studies of how we have applied this approach when based at a variety of stations and field camps, with the differing logistical challenges imposed by each.

Companion documents focusing on instrumentation and airborne operations are forthcoming.

Overview/Context of Field Operations

The current team at UTIG conducting polar aerogeophysical survey can trace its operational lineage to 1991, when The Ohio State University equipped Twin Otter CF-SJB fixed-wing aircraft with instrumentation and surveyed in Antarctica. This team transitioned to UTIG, and since then, the UTIG team has also equipped a variety of Basler DC-3T and Airbus AS-350 helicopters, and trained personnel at other institutions to conduct this type of scientific survey.

While the aircraft used and places visited have changed through the years, many operational aspects related to data management, and continuous monitoring and feedback remain constant. As a result, the general approach to team management and daily operational cycle has persisted.

Campaign general structure

In general, aerogeophysical surveys follow a predictable life cycle. At the home institution, needed equipment is packed and shipped to the field site, then personnel travel to the field site. Setup of observational instruments and data processing equipment occurs, then the survey campaign can begin. With luck, surveying starts and a daily survey rhythm takes shape. Then, as the allotted time frame draws to an end, equipment must be disassembled, unpacked, and prepared for shipment home. At each of these stages, we draw upon the experiences of experienced team members for planning, but at the same time listen to newer members to provide room for improvement and innovation.

Team Organization

To provide time and space for focused discussion, we organize the overall field team into *groups* with overlapping membership, which we refer to as *group mode*. Group mode counteracts a failure mode where a big picture view of the science goals, or the need to routinely validate that instruments continue to work, falls by the wayside in an all-consuming focus on airborne operations or an obvious crisis. The group responsible for data management on the ground is known as the <u>B</u>ase <u>Op</u>erations group, or BOP, for short. Understanding BOP's operations (the focus of the present document) also requires understanding BOP's relationship to the other field groups. These include flight operations (FOP), Geophysics and Navigation (GAN), Experiment Design and Science (EDS), and Management (MGT). BOP and FOP are both highly active throughout the field expedition, given that they have the most operational responsibility; others wax and wane through expedition phases.

Base Operations (BOP)

The high level goals for BOP are to ensure that the acquired data is safe from loss, and to analyze data and determine if instruments are operating nominally. BOP may highlight operational or engineering issues for FOP to address.

BOP is often also responsible for some areas that aren't part of the core mission of securing or analyzing acquired data. Some tasks are placed in its scope because the personnel possess the most appropriate skills or placement. For example, BOP often provides software and analysis support for deciding how to prioritize the next survey targets because the analysis may come from acquired data. BOP may also operate or interface with ground instruments, especially when physical constraints make this difficult for FOP. When FOP personnel are at a location away from station management, it often falls to BOP to facilitate communication with external station personnel.

Members of the BOP group operate on a shifted schedule compared to the FOP group, starting their work after the survey flight returns.

Flight Operations (FOP)

The Flight Operations group manages details more directly related to conducting a data collection flight. This includes constructing sets of flight plans from sets of targets, communicating with external flight support personnel, and operating flight instruments before, during, and after a survey flight. FOP also implements internal procedures for reliable data collection.

FOP also often relies on customized flight planning software and metadata supported by BOP personnel. There is typically a tight feedback loop between BOP and FOP, where data from the previous flight will be quality controlled (QC'd) and any possible issues are discussed before the next flight will take off.

Geophysics and Navigation (GAN)

The Geophysics and Navigation group primarily concerns itself with engineering and maintenance of instruments used in flight. There is often overlap between the FOP and GAN group, since having a flight engineer is a valuable safety net during a survey flight. In the survey lifecycle, GAN is responsible for setting up the equipment on the aircraft at the beginning of the survey, inspecting and maintaining instruments during the body of survey operations, and removing/packing aircraft-related equipment as the survey concludes.

GAN often relies on BOP to analyze metrics generated after the flight and notice anomalies that are too subtle to be noticed in real-time monitoring displays. Additionally, while base instruments would technically fall into GAN's purview, members of BOP will often operate them if their physical location (often, close to wherever data is being processed) or temporal requirements (re-start data collection right before a flight, when GAN/FOP are occupied at the aircraft) makes that more convenient.

Experiment Design and Science (EDS)

The Experiment Design and Science group makes decisions related to the scientific objectives of the campaign. During initial planning, often well in advance of the field deployment, Principal investigators and subject matter experts participate, even if they may not deploy to the field campaign. EDS defines the experiments to be conducted and the hypotheses that will be tested. From that follows the task of identifying and prioritizing target areas, flight line orientation/coverage, and instruments (E.g. grounding zone vs upper catchment regions, along-flow vs across-flow, gravity vs radar measurements). The EDS group also collects relevant literature and related datasets before field deployment.

EDS has an important role in the field, too, ensuring that the team retains a focus on scientific objectives in the midst of logistical and technical complexities. When necessary, EDS meetings can be used to thoughtfully adjust survey priorities.

Management (MGT)

The MGT group is in charge of managing the field campaign both before and during the season. MGT deals with issues that involve the leadership at the research station or other research groups. It is also in charge of team personnel issues, such as setting the daily schedules for BOP and FOP. An important responsibility is designating points of contact, usually MGT members, who interact with station leadership and the air crew. Maintaining disciplined communication on important issues greatly reduces confusion and helps the team anticipate problems and make logical management decisions.

Daily Cycle and Tasks

Survey operations typically operate on a daily cycle, with phasing of survey flights considering diurnal trends in atmospheric weather, space weather (e.g., magnetic field), and station operations. BOP then offsets its schedule to support flight opportunities and minimize the time after the flight to accomplish its mission goals, to whatever degree practical. This often results in an 8- to 12-hour offset in personnel shift schedule between FOP and BOP.

Time	KBA Flight Crew	FOP	BOP
- 24 hr		Email 3 prioritized flight plan options to KBA, local Operations Manager	
- 4 hr		Print flight plans.	Complete media preparation; print flight notes.
- 3 hr	Check weather; select flight plan	QC review: Go/No-Go decision; review flight plan with KBA crew; inspect media for today's flight.	Media/Notes handoff to FOP; QC review.
- 1 hr	Transport to airfield	Enter DC3; ensure proper heating, power Start base instruments if at the airfield (no BOP)	*POS: Start recording POS at the base* *MAG: Maintenance (data, power)* *GRV: Record gravity tie (3 per airfield)*
- 30 min		POS: Start recording on aircraft GRV: Start recording in "V=0" mode	No duty
- 5 min	Disconnect aircraft control locks. -- Start Engines -- PWR: Start "Science Power" PWR: Remove ground power cable	GRV: Stop, save reference measurement GRV: Note pre-flight reference values on logsheet GRV: Start recording in "V>0" mode -- Note time of engine start -- PWR: Request "Science Power" from KBA. PWR: Switch from "Ground" to "Aircraft" power.	
0 hr Taxi	"Cabin secure" (seatbelts)	-- Note time of first aircraft motion – -- Confirm seat belts fastened, ready for takeoff --	
0 hr Takeoff		-- Note time of takeoff – -- Email 3 prioritized flight plans --	
~ + 3 min		-- Confirm safe to move around the cabin – -- Confirm safe to transmit radar --	
6.5 hr		Every 30 minutes: Inspect equipment, note on log.	
Landing		-- Note time of landing --	
6.5 hr Park		-- Note time of parking – GRV: Note post-flight reference values on logsheet -- Download data; mark and secure hard drives --	
7 hr	Transport to station End of crew day	POS: Stop recording on aircraft	

Time	FOP	BOP
+ 8 hr	-- Media Handoff to BOP – -- Discussion of issues in flight with BOP (e.g. P/S/T mistakes, equipment anomalies) --	POS: Stop recording at the base MAG: Maintenance (data, power) -- Initiate download, breakout, QC ---
+ 9 hr	No duty	Download complete
+ 10 hr		Breakout complete
+ 11 hr		QC complete
+ 10-15 hr		Archive complete (partially parallel operation)
+ 12-15 hr		Printing and QC review complete
+ 15-18 hr	Confirm and print flight plans.	Complete media preparation Print flight notes.
+21 hr (3 hrs before next flight)	Review flight QC Inspect media Review flight plan with KBA crew;	Handoff flight media Support QC review.
	.... repeat	.... repeat

New Flight Cycle

At a practical level, ground data processing starts with receiving the data from the survey. After taking custody of the media containing the data, BOP goes through the **download** process -- data is transferred from storage media (such as USB drives) to central storage. After it is in central storage, another copy is **archived** to a durable storage medium such as archival LTO tape. In parallel, we process data and generate plots used for **quality control** purposes. This can help identify particularly good or bad segments of data in the data acquired, or identify problems with instrument health that need to be addressed. BOP should then communicate these problems to people who can address them. After triaging the incoming flight, the BOP team then prepares the package of materials for the next flight, including empty storage media, blank flight notes, etc.

BOP Operations

Data Management

While the previous sections have discussed the general approach and tools for field data processing, this section will discuss in more detail the scope of analysis and processing that is performed in the field, and why. Generally, the processing steps performed provide feedback to the team about the quality of the data collected, and its suitability for both basic and advanced processing after the survey campaign is complete. Other goals of data processing may be to provide feedback for flight planning or making public progress reports about the field campaign.

Quality Control

In the field, we divide our quality control (QC) products into two non overlapping types: **Device QC**, and **Experiment QC**. Device QC are data products whose purpose is to determine that individual devices or components are functioning nominally, and often assist in isolating the cause of a problem to specific components. Experiment QC are data products whose purpose is to demonstrate that collected data are satisfying high-level experimental goals.

It is usually inadvisable to combine experiment and device QC into a single plot, because the processing parameters are often at odds with each other. For example, an experimental QC plot for evaluating whether we capture a continuous bed echo wants a large amount of averaging and a zoomed out view to see a holistic image and reject unrelated clutter/noise. However, device QC, which is often interested in tracing sources of noise within components, would actually want to highlight the same noise being rejected, and to plot at very short timescales. It is a scientific example of the aphorism that one man’s trash is another man’s treasure.

Some specific examples of device QC are plots that help answer the questions:

- Is the laser providing data with the expected uncertainties?
- Are instruments such as laser and radar producing data at the expected sampling rates, or are they showing evidence of timing system malfunctions?
- Is the quality of the GPS signal received (e.g., number of satellites, SNR) nominal?

Some specific examples of experiment QC are plots that help answer the questions:

- Have the ranging laser profiles collected been too obscured by cloud cover to be useful for the survey’s goals? Does the downward pointing ranging laser match with ranges from the radar or the gravity instrument?
- Is the radar capturing a strong and continuous enough radargram of the feature of interest to decide the survey’s big hypotheses?
- Is the aircraft flying the transects at the required precision (e.g., speed, cross-track-distance, altitude) for the experiment?

In the end, the answers to these questions may need to be escalated and communicated to the other operational groups, such as GAN, who has responsibility for operating the instruments, or FOP, who can adjust the flight plans as necessary, or EDS, who can weigh in when there is a tradeoff between competing scientific priorities. Communication between these groups is often difficult because there is little time overlap between shifts. This has historically been an area where there is room for improvement. Examples of decisional questions that can arise from analyzing quality control products are:

- Are instrument operating parameters within nominal values, or do they need engineering evaluation or adjustment?

- Do current engineering issues or environmental conditions require the team to change scientific priorities and targets until they are resolved?
- Do new experimental interpretations of quality control products warrant reprioritizing scientific priorities or targets?

How to make responsible decisions to these questions is beyond the scope of this paper, but in general, caution is advised when making decisions based on unvalidated data.

Early-Season QC

At the start of a season, we have a number of checks that we go through to ensure that all instruments are installed and functioning properly.

For the radar, we check that the transmit amplifier and receiver gain levels are nominal, which ensures the overall system amplitude accuracy. This ensures that data is comparable across seasons, and that the surface signal doesn't saturate.

We strive to perform a set of roll maneuvers on a test flight that provide data for characterizing the antenna beam pattern. The test has previously revealed anomalies such as a gain null, rather than a maximum, at nadir, which has previously been caused by improper device polarity. Gain asymmetries have been revealed that were caused by unexpected aircraft hardware such as a stall strip.

Additionally, it is a good end-to-end test that all components are connected and functioning properly, including both the radar, GPS, and inertial measurement unit (IMU), which senses aircraft attitude. Beyond exercising the instruments themselves, this test also exercises the end-to-end data processing workflow, since all input data streams must flow through the software to produce the beam pattern plot.

Other common tasks for the test flight are to collect data to characterize:

- The magnetometer's interaction with the aircraft. For example, some strobe light beacons will cause very noticeable 1Hz noise in the mag data; we can ask the pilots to leave those off during our flights.
- Determine the consistency of the laser measurements, or targets with known, visible variations in radar, magnetic, or gravity signatures. A rough check can be performed by flying over known significant terrain and checking that the grav signal responds. This can be challenging depending on what terrain is available for the short test flight -- in McMurdo, White/Black island works nicely.
- Collect a calibration grid for the laser. We are unable to measure its mounting bias relative to the INS with sufficient precision -- instead, we fly a grid pattern with enough crossover points to perform a minimization and recover roll/pitch biases.

Ongoing QC

During ongoing survey operations, the QC process checks that values are self-consistent and within the nominal range and identifies operational, instrumentation, and scientific issues.

On the operational side, this may involve noticing failures of the nominal procedures, and/or reminding FOP to follow them. Examples include:

- Noticing black specks in the camera images => Remind FOP to always clean the camera lens and window before flights (on the DC3's, it is mounted under the floor in an area that is rather dirty.)
- Noticing that the camera is out of focus, leading to a change in FOP procedures
- Noticing that there is periodic noise in the magnetometer, attributable to the pilots failing to turn off their strobes during the survey.
- Is the aircraft being flown in a sufficiently stable manner, with small enough roll angles such that the GPS units on the wings always see enough satellites for a good fix?
- Is the pilot achieving the required cross track error? (Are they using the autopilot?)
- Whether instruments such as the photon counting lidar provides usable data (particularly relative to events in the flight notes)
- Keeping snowmobilers away from the base magnetometer
- GPS antenna failures
- Odd noise in the radar data, attributed to multiple aircraft with the UTIG radar system operating simultaneously in nearby geographic regions.

On the instrumentation side, there is usually a feedback loop where BOP identifies a potential issue, FOP/GAN investigate (ideally before the next flight), and BOP confirms that the fix did or didn't work. Ideally, these types of installation issues will be found during the test flight, but sometimes something will break mid-season (or isn't noticed until operations have calmed down), so it is important for Device QC to be performed continually. Examples of issues in this category have included:

- The radar's beam pattern had a null at nadir; in one season, this turned out to be due to a mis-manufactured balun, so was resolved by swapping out the spare.
- one radar channel is ~20 dB below its expected gain; this was attributed to a loose connector and fixed by properly plugging in that cable.
- one radar channel is 5-10 dB below its expected gain; this was attributed to a faulty receiver. The entire receiver was swapped for the spare, and post-field debugging found the bad component.
- There is a higher than expected noise floor in the radar data; field testing did not conclusively identify the culprit, but it turned out that all 3 of the TX/RX switches had been manufactured to a lower spec than their predecessors.
- There are dropped packets in the radar data stream. A temporary mitigation was to only use the higher write-speed SSD drives until a permanent fix to the acquisition software could be made back in the lab.

- Noticing corrupt packets in the IMU’s data stream, attributed to routing its cable too close to the high-power radar cables.

Finally, BOP’s observations from looking at the Science QC products will influence the planning of future flights. These decisions include:

- analyzing diurnal trends in ongoing space weather (magnetic field), which affects the quality of radar and magnetic observations, and is used to adjust the daily timing of survey flights.
- Recovery of bed vs. flight altitude, when a choice has to be made about losing the surface or the bed (with rough surface, flying low helps a lot, e.g. Campbell glacier)
- Recovery of layers vs. flight altitude. Is the surface in the survey region rough enough that flying lower than usual is recommended?

Equipment

In the time before deploying to the field, BOP is responsible for procuring and testing whatever supplies it needs to perform its role. This includes anything from computer equipment to hard drives and flash media, to pen and paper. In addition to testing the data processing system, training operators with useful skills and refining standard operating procedures is an important pre-deployment activity.

Since 2009, the field data processing computing environment has resembled a home office, with the minimum set of equipment fitting into approximately a large suitcase, and the preferred equipment list in about 180 kg of cargo including shipping cases. Ground data processing generally uses a Linux laptop, a portable 4-disk RAID storage device, an LTO tape drive for archiving acquired data, and assorted home networking equipment. We also have a printer and scanner for producing flight plans, forms, and quality control plots, and digitizing notes.

Additionally, we carry spare devices and cables for all these items in case of failure.

BOP Philosophy

This document discusses BOP’s station-based operations as they evolved over the course of the ICECAP program. Processing data in the field isn’t accomplished simply by having a list of tasks and people to complete them; field teams are able to complete their tasks only when supported by a good framework and shared understanding of organizational management, operational rigor, and software automation.

Organizational Management

The strategy of how the field team divides into groups (group mode) as we do isn’t novel -- it follows naturally as the team seeks to divide labor. This formalism promotes focus and compartmentalization in planning meetings. In small field teams, individuals are often in more than one group, and when an urgent issue arises, one may desire to reactively discuss it in the next scheduled meeting -- regardless of whether it's the right group meeting. Formal group scopes encourage discussion of those issues in the right group, with all the relevant stakeholders. This helps to guarantee that conversations are held exactly once, avoiding the inefficiency of repeatedly circling back to an issue because a stakeholder didn't buy in.

In general, we try to organize groups to have three or more people. While not strictly necessary, especially for small field projects, this avoids impasse situations and encourages group learning. When choosing and training group members, we try to make sure that important skills are possessed by multiple members of the group. This ensures that the team is robust to things like illnesses, and also encourages productive, two-way discussions.

With these benefits of group separation, impasse-avoidance, and skills overlap, this puts practical limits on minimum total team size. For a field team with two groups, it is usually not advisable to have fewer than 4 team members.

Meeting Mode

In each group's planning meeting, groups apply the formalism of meeting mode. Meeting mode is a set of meeting principles and rules of order to promote individual empowerment and consensus-based decision making. Meeting mode consists of four phases: gathering of new issues, prioritization of the agenda, discussing the agenda, and setting the next meeting. In the first phase, all participants may list any issues of concern. In-scope issues are placed on the group's issue list, but their merits are not discussed. Once all new issues have been put on the list, all participants may propose one or more ordered lists of issues to tackle in the meeting (an agenda). Participants come to a consensus on which agenda to use, and then move to the agenda discussion phase.

In the agenda discussion phase, each issue is discussed in a series of phases. The facts and circumstances are first reviewed, with no discussion of responses. Then, participants may propose options to respond to the issue. During this phase, participants may not criticize the merits of options, they may only respond with their own counter-options. After there are no more options, or sufficient options exist (typically six), participants may discuss to decide which option to select. At this point, criticisms and comparisons of options may be discussed. When a consensus is reached, the group dispatches action items from the decision, and then moves to the next issue.

In most field campaign situations, the team is a guest in the host station or camp. Thus there is necessarily an interface with an external organization. It's important to have a unified strategy for how the group interacts with the hosts. Talking about this in advance allows the team to tailor perceptions of being prominent or low-footprint, to our advantage. This could include practices for how individual team members interact with the host station to improve communication efficiency. In the end, having these discussions should promote unified messaging to those unfamiliar with the team, and also promote communication that is culturally compatible with members of the host station, who might come from a different background.

Operational Rigor

Operational rigor starts with making sure that we bring sufficient experience to the project. This means including enough individuals with hands-on experience with previous surveys, and working on procedural plans before going to the field, and keeping them updated as conditions change through the field campaign.

Another important aspect is a data management plan. A good data management plan reduces the risk of loss starting as soon as data is collected until it arrives back at the home computer system.

The teams also develop a detailed equipment redundancy plan, having spare components for critical equipment, from large, specialty equipment like tape drives to small things like USB drives and cables. By default, we plan to have 50% equipment redundancy for critical components, rounding up. For example, if we require two laptops to perform operations, then we will have a total of three laptops on hand. But if only one tape drive is required for operations, then we will have two tape drives available.

Another part of operational planning is having good personnel plans -- arranging teams with the right skills, and making sure people are trained well enough to overlap in skills so they can cover multiple roles. Having redundancy in people and skills is as critical as equipment redundancy.

Flight planning is one of the most outwardly-visible operational planning details that happens in the field operations on the ground. Flight plans are often the basis of the survey flight crew's first impressions of the field team. Clear flight plans for the pilots builds their trust. Unclear or erroneous flight plans can jeopardize the safety of the flight crew and instrument operators, if they cause the flight crew to fly too close to hazards. For this reason, we institute a system for reviewing flight plans and training those who generate flight plans to work diligently to ensure their correctness.

Software Automation

One of the most time consuming but important aspects of ground data processing is the development of software to aid in evaluating the quality of collected data. The ground data processing software aids data processing operators through all post-flight tasks, from downloading and organizing collected data, to performing initial analyses and generating visualizations to assess quality, and aids in creating archival copies for safekeeping.

Software automation has also played an important role in flight planning. Our flight planners use QGIS with extensions and plugins customized for our workflow, to develop survey flight plans for the polar regions.

This software has been continually refined over the years to make the user's experience less error prone. This has allowed the team to work faster to process a flight, with fewer people.

It is a common misconception that once the software has been written, it's stable and should "just work," but continuous testing is always needed because of new requirements and unanticipated input data from the field campaigns.

Past/Present/Future

History

UTIG's history of polar aerogeophysical field seasons can be divided roughly into three eras: the Twin Otter era from 1991-2005, the single team DC-3 era from 2008-2015, and the multi-team seasons from 2015 to the present. Appendix B provides a complete list of UTIG's field seasons from 1991-2020.

The Twin Otter era was typified by SOAR (Support Office for Aerogeophysical Research) field seasons. These were large field teams, including multiple flight crews, that were able to support round-the-clock operations from remote field camps. Notable results from these surveys include the discovery of subglacial volcanism in West Antarctica (Blankenship1993), further identification of subglacial lakes (Siegert2005) and a thorough characterization of Lake Vostok (Studinger2003). These field operations were documented in a series of technical reports (Blankenship1995,1996; Richter1997, Magsino1998, Holt1999).

Starting in 2001, UTIG, in collaboration with NASA JPL, worked to develop and field a coherent radar system with better resolution. This radar, called HiCARS, would reach maturity in the AGASEA survey in 2004.

In 2008, UTIG adapted the scientific payload for use in a Basler BT-67. Already in use in Antarctic logistics, this aircraft was still capable of operating in a survey configuration from field camps. Its longer range allowed broader surveys and collaborating with international research partners from stations including Dome Concordia (Italy/France), Dumont d'Urville (France), Casey (Australia), Davis (Australia), and McMurdo (United States).

Finally, in recent years, the UTIG instrument suite has been modified for installation on aircraft operated by other nations' Antarctic programs. This started with outfitting the Chinese-owned BT-67 "Snow Eagle" for first operation in the 2015-2016 field season when the last "pole of ignorance” was surveyed from Zhongshan Station (Cui2020). The following year UTIG modified its radar for operation from a helicopter and performed a survey of David Glacier, based out of Jang Bogo station (Lindzey2017). With these additional platforms, UTIG began fielding up to three field teams at once to different parts of the continent.

Recent Campaigns

In this section, we focus on a few more recent campaigns starting from the end of the single-team DC-3 era and the start of UTIG’s collaborations with CHINARE and KOPRI. We discuss how BOP worked in practice in these different operational scenarios. Field procedures continue to be adapted for different concepts of operations. More recently, these have included icebreaker helicopter operations; helicopter field camps; and short “micro” seasons.

ICP5 / McMurdo Station

At right: RAC Tent at the McMurdo skiway; used both by GAN for staging instrumentation and by BOP for processing test data.

McMurdo Station is the largest Antarctic station, with a summer population of over 1000 people. This American station has an enormous amount of logistical resources, with multiple flights a week to and from New Zealand, and supports operations 24 hours per day. The team was assigned office working space at the main station, and a modest powered, heated, tented space at Pegasus airfield, about 5 km from the station and accessed via shuttle or shared truck. This is the only station that we operate out of where if something breaks it is relatively straightforward to obtain a replacement. (On the trivial end, we’ve ordered SD cards from Amazon and had them delivered within the week.)

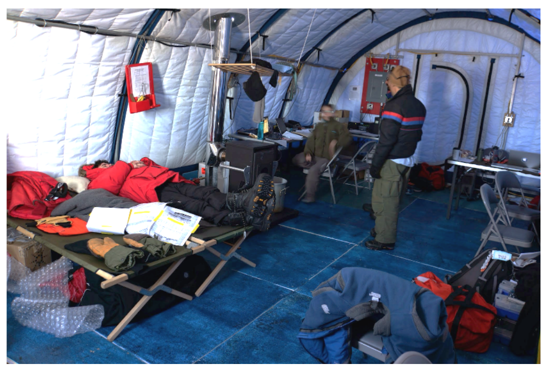
McMurdo has two airfields: a blue-ice one (Pegasus field) used for wheeled aircraft like the C-17s that provide cargo capacity to/from New Zealand; and a snow one, used by aircraft with skis, including our DC-3s. The snow runway (Williams field) is located 5-7 km from the main station, and includes basic dining facilities. Transportation between station and runways is provided by a van that runs ~every 30 minutes during the day and on demand at night.

Having the aircraft parked at a location distant from the main station leads to tradeoffs in deciding where to perform ground data processing. Setting up BOP at the airfield rather than back at Crary lab reduces the latency between when the plane lands and when data processing can begin. This can be useful, particularly during test flights when GAN may want quick feedback. However, while there are bathrooms and a mess hall at the airfield, it is typically much less comfortable than working at Crary (the RAC tents get *cold*), and the commute makes it harder to quickly get help from someone who is off duty.

In some senses, this McMurdo experience is the baseline that the rest of this discussion compares to. In both the Twin Otter and ICECAP eras -- even if the scientific survey flights were performed from more remote field camps and stations -- all aircraft buildup and test flights were performed at McMurdo. This added the operational complexity of transit flights from McMurdo to the operational area, which can be challenging due to requirements for good weather across the continent, but allowed us to benefit from the unmatched logistical support and frequent flights to and from New Zealand.

ICP6 / WAIS Divide, Byrd Station

Seasons ICP5 and ICP6 in 2012/2013 and 2014/2015 involved working out of large field camps established by USAP. In these camps, the aircraft was parked within walking distance of the main camp, and post-flight data processing was performed in a heated tent large enough for 10 people to work. Each person slept in individual mountain tents, and ate meals prepared by a full-time cook in a large communal dining tent.



*(**Left**) WAIS Divide field camp, showing the Pilot's quarters (blue), mess hall (yellow), UTIG operations (green) mechanic's shed (tan), and the aircraft. (**Right**) Interior of the tent used for operations. It was spacious, if cold.*

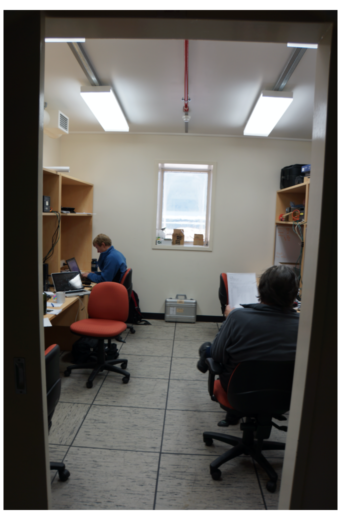
For BOP, operating out of the remote field camp meant even more careful pre-deployment attention to spare and contingency plans, and in-field attention to temperature and power management. BOP supplemented weather observations by downlinking satellite weather imagery from the NOAA APT satellite system. While there was good satellite phone reception, there was no internet connectivity and email delivery only twice a day. So, in addition to thinking about physical spares, we also made sure to prepare a set of reference materials for BOP (e.g. mirroring Stack Overflow).
Given the remote location, we were unable to rely on station infrastructure for GNSS or magnetic base stations, and BOP team members operated both of those. One novel issue was the need to locate the magnetic station within easy walking distance, but also far enough to keep other station members from inadvertently corrupting observations by snowmobiling nearby.

Unlike at McMurdo, at a camp like this you at least know everybody's face, and the logistical footprint of airborne operations becomes a lot clearer. A significant number of the USAP staff are dedicated to tasks directly supporting: managing fuel, grooming runways, handling communications, etc. Part of everybody's job is being seen to pitch in around camp, which helps to make the relationship between science and support run much more smoothly.

ICP7 / Casey Station

In ICP7 (2015/2016), the ICECAP field campaign was carried out entirely from Casey Station, with logistical support provided by the Australian Antarctic Division (AAD).

At Casey Station, the main station is about 6 km from the airfield, typically a 30 minute drive. The allocated science office is one of a few labs in a separate building from the Big Red Shed (where the dorms and mess hall are), and is accessible in all but the worst of weather. It has enough room for six people to work, with space for computer equipment and meetings. This is where all post-flight data processing occurs.. Given the distance from the airfield to the main station, FOP team members operated a GNSS reference station at the airfield, and made all gravity reference measurements. BOP also archived data from the permanent GNSS reference station at the main station operated by Geoscience Australia.



The science office at Casey Station

After almost a decade in the USAP system, we found the smaller, more relational nature of the AAD to be a cultural adjustment.
The UTIG team has usually operated on a 24-hour shift system to maximize scientific impact, ensuring that all data from the previous flight will be processed and QC'd before the next flight takes off. Team members often work 12-16 hours per day. With McMurdo's 24-hour operations, these practices go largely unnoticed, and dorms are set up with the expectation that neighbors may be on different shifts. However, since the AAD stations typically operate only on an 8 or

12-hour daytime workday, BOP's overnight work and long hours were more noticeable to others. Poor sound insulation in the West Wing sleeping quarters in particular means that opening a drawer can wake up your neighbors at 3am, and their 3pm socializing can wake up a BOP member on the night shift. If possible, schedule expectations should be brought up when room assignments are discussed with station management.

Like in the deep field camps, smaller stations expect science participants to pitch in with the work required to keep the station running. At Casey this takes the form of each person being assigned one daytime shift of assigned household chores roughly every two months. Team management recognized the goodwill value of this and worked with the station management for everyone to fully participate, while minimizing the impact for those on night shift. Participating in station life extends beyond chores, and we have found that being more social at this station and other small stations had a much greater effect on professional relationships than at McMurdo.

Our previous communication strategy of designating a single person as a point-of-contact also had to be adjusted. McMurdo is large enough that official interactions with the station's representatives only happen when we seek them out, and the bureaucracy of saying, "it's not my place to answer that question" is well-tolerated. At Casey, where everybody gets together in the same smallish room for meals multiple times a day, social and professional interactions are very blended.

It's common for a friendly station leader to ask how things are going. How is the data looking? Will the team need more time to fix equipment or review data? At Casey, it is often helpful to anticipate and proactively brief senior team members, and anticipate upcoming decisions. Senior ICECAP team members tend to be expected to respond, even if in our internal organization another team member is the point of contact for an issue.

The single-point-of-contact communication strategy arose in USAP as a result of a history of significant negative outcomes from propagating mixed messages. It's always good to have unified messaging, but compared to USAP's transactional nature, the more relational, fluid culture at AAD resulted in fewer negative outcomes from a shifting plan.

Practically speaking, the shift to Australian 240VAC power, metric paper systems, and driving on the left side of the road were mundane details that had to be adapted to.

CHA1, CHA2, CHA3 / Zhongshan Station

*(**Left**) skiway camp at Zhongshan. This included multiple dorms, a kitchen, and a trailer for GAN/BOP. (**Right**)* Interior of the yellow trailer; the front room was used for BOP's data processing, and the back provided storage for spares.

Expeditions CHA1-CHA3 in 2015-2017 marked the beginning of the UTIG collaboration with the Polar Research Institute of China (PRIC), as part of the Chinese National Antarctic Research Expedition (CHINARE). On a superficial level, navigating the Chinese-English language barrier was a new challenge. The organizational culture at Zhongshan and PRIC is more focused on hierarchical decision making, and understanding this was important in creating a team that engaged in consensus-based decision making and meeting mode.

Working at Zhongshan more resembles working at Casey than at McMurdo, in terms of scope, scale, and infrastructure. However, here, data processing was generally set up at a skiway camp, since this was a more significant commute time (up to 1 hour). However, if needed, the data processing equipment could be packed and moved to the station as required.

In CHA1-CHA3, UTIG sent only two people per season, a GAN specialist and a BOP specialist, and so this was extremely challenging for workload. In this situation there is little redundancy and everyone is working to their limit.

KRT1 + KRT2 / Jang Bogo Station

Jang Bogo Station is a relatively compact station operated by the Korea Polar Research Institute (KOPRI) on the northern end of Terra Nova Bay. The helipad is a short two-minute walk from the main station, which has the science office and living quarters. The short travel times greatly facilitated handling when operating multiple two-hour flights per day. The science office, shared with other researchers, serves well for ground data processing but not as a private meeting space. We often used the single conference room on the main floor for full team meetings, or took advantage of BOP members sharing the same dorm room for smaller meetings.

Future

Aerogeophysical survey has changed significantly from its beginnings in the 1980s. In the evolution from the 80s to now, improving technology and expectations mean that survey teams accomplish more while using fewer resources. But some operational principles remain invariant through the years. Having an appropriate level of redundancy, and good quality control feedback mechanisms are always important.

In the future, we expect more international collaborations to increase the reach, and promote scientific data collection, even if it isn't collected by UTIG. Being able to work effectively in this environment means that we must focus on promoting diversity and inclusion at all levels, from scientific planning through field teams, to run effective field campaigns, which will almost certainly involve collaborations with people and organizations we have never worked with before.

Appendix A: Procedures

Attached to this paper are examples of procedures, illustrating those used for several field campaigns. [UTIG Field Data Processing Appendix Docs]

A1. SRH1 (2018) Example Procedure Documents

These documents show a representative workflow for the full suite of aerogeophysical instruments operated on the DC-3 C-GJKB. They contain a manual to remind operators the details of the procedures to be done, and a checklist to assist them in managing the processing of a flight from start to finish.

A2. CHA2 (2016) Example Procedure Documents

These documents illustrate a representative workflow developed for DC-3 C-FGCX. This aircraft has a slightly different suite of instruments and theater of operations, so the procedures are adjusted accordingly.

A3. ASE3 (2019) Example Procedure Documents

These documents show a representative workflow for the suite of aerogeophysical instruments operated with the AS350 radar helicopter, operated from the R/V Araon.

A4. Example Quality Control Documents

BOP_Quality_Control.pdf shows examples of the data quality control data products and review process.

A5. Base GNSS siting procedures

These documents describe some of the environment and considerations for setting up a GNSS monument for differential GNSS processing. (ec023.pdf)

Appendix B: Previous Field Seasons

Acknowledgments of individual significant contributions to BOP practices in narrative form; things prior to the 2016 field season.

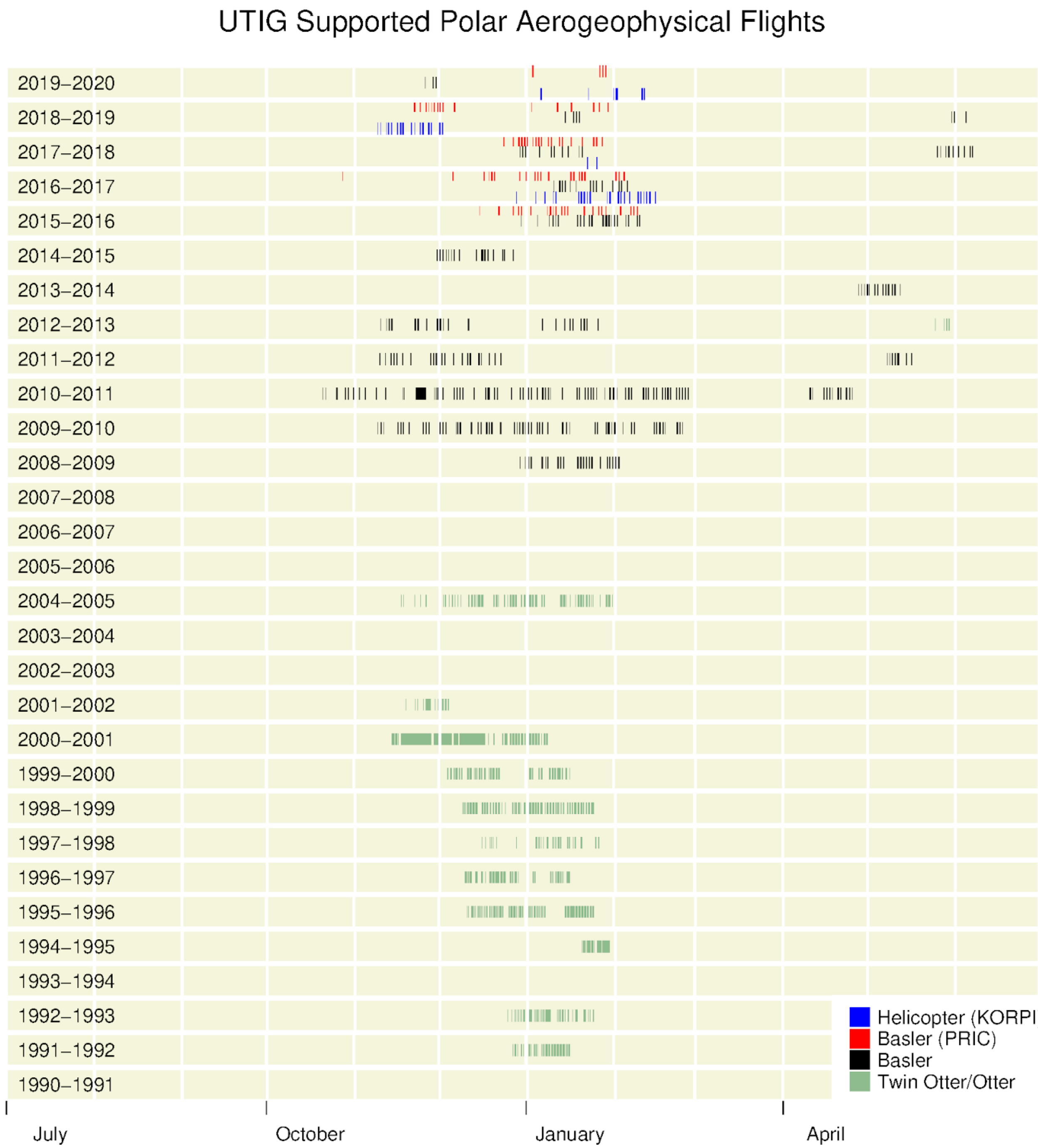


Figure B1: UTIG supported aerogeophysics over the last 30 years. UTIG transitioned from short-range Twin Otters with up to three flights per day and 24 hour operations and large teams, through a single long range Basler with one flight per day and extended seasons, to supporting multiple platforms with smaller teams.

Antarctic Expedition List

Below is a list of field campaigns throughout the years, including the stations visited, and participants and collaborators.

Year	**Season (Project)**	**Bases of Operation**	**Field Participants**
2019-2020	ASE3 (LIONESS)	RV Araon (KR), Thwaites Glacier field camp	Lucas Beem Dillon Buhl Anja Rutishauser Natalie Wolfenbarger
	ICP11 (ICECAP II / AAP 4511)	Casey (AU)	Jamin Greenbaum Jason Roberts (AAD) Lenneke Jong (AAD) David Brown (Self-employed)
2018-2019	CHA4 (ICECAP2)	Zhongshan (CN)	Jamin Greenbaum
	KRT2 (K-Route)	Jang Bogo (KR)	Lucas Beem Gregory Ng Kristian Chan
	ICP10 (ICECAPII / AAP 4346)	Davis (AU), Casey (AU), Zhongshan (CN)	Enrica Quartini Dillon Buhl Gonzalo Echeverry Shuai Yan
2017-2018	CHA3 (ICECAP 2)	Zhongshan (CN)	Jamin Greenbaum Wei Wei Jingxue Guo (PRIC) Lin Li (PRIC)
	ASE2 (LIONESS)	RV Araon (KR)	Lucas Beem Dillon Buhl Thomas Richter
	ICP9 (ICECAP / EAGLE)	Casey (AU)	Gregory Ng Chad Greene Lenneke Jong (AAD) Felicity McCormack (U.

			Tasmania) Wilma Huneke (U. Tasmania) Gonzalo Echeverry
2016-2017	CHA2 (ICECAP 2)	Zhongshan (CN)	Jamin Greenbaum Feras Habbal
	KRT1 (K-Route)	Jang Bogo (KR)	Dillon Buhl Enrica Quartini Laura Lindzey
	ICP8 (ICECAP/EAGLE)	Casey (AU)	Duncan Young Gregory Ng Lenneke Jong (U. Tasmania) Felicity McCormack (U. Tasmania) Jason Roberts (AAD) Lucas Beem Wei Wei
2015-2016	CHA1 (ICECAP 2)	Zhongshan (CN)	Jamin Greenbaum Laura Lindzey Jingxue Guo (PRIC) Xiangbin Cui (PRIC) Bangbing Wang (ZJU)
	ICP7 (ICECAP / EAGLE / SPICECAP)	Casey (AU), Davis (AU), Dome Concordia (FR/IT), Dumont D'Urville (FR)	Duncan Young Gregory Ng Enrica Quartini Feras Habbal Carly Tozer (U. Tasmania) Jason Roberts (AAD)
2014-2015	ICP6 (GIMBLE)	McMurdo (US), WAIS Divide (US)	Duncan Young Enrica Quartini Jamin Greenbaum Feras Habbal Gregory Ng Laura Lindzey Gonzalo Echeverry Tom Richter Gail Gutowski
2012-2013	ICP5 (ICECAP/OIB; GIMBLE; SIMPLE)	McMurdo (US), Casey (AU), Byrd Camp (US), Casey (AU)	Duncan Young Jamin Greenbaum Gregory Ng Jason Roberts (AAD) Roland Warner (AAD)

			Laura Lindzey Cyril Grima Chad Greene Evelyn Powell Tom Richter
2011-2012	ICP4 (ICECAP/OIB; SIMPLE)	McMurdo (US) Dumont D'Urville (FR) Casey (AU) Dome Concordia (FR/IT)	Duncan Young Jamin Greenbaum Gregory Ng Enrica Quartini Gonzalo Echeverry Cyril Grima Kirsta Soderlund Anatoly Mironov Donald Blankenship Thomas Richter
2010-2011	ICP3 (ICECAP/OIB; ICECAP/IPY)	McMurdo (US) () Rothera (UK) Casey(AU) Troll (NO) Ushuaia (AR)	(Photo 2010-11-28) Jamin Greenbaum Gregory Ng Dustin Schroeder Duncan Young Svetlana Stadnik (now Burris) Jason Roberts (AAD) Bruce Fredrick Britney Schmidt Anne Le-Brocq (Exeter) Don Blankenship Scott Kempf
2009-2010	ICP2 (ICECAP/OIB; ICECAP/IPY; ICEGRAV)	McMurdo (US) Marambio(AR) Halley (UK) Teniente Marsh (CL) Casey (AU) Dumont D'Urville (FR) Dome Concordia (FR/IT) Rothera (UK)	Dustin Schroeder Gregory Ng Jorge Alvarez Jamin Greenbaum Duncan Young Andy Wright (Edinburgh) Thomas Richter Donald Blankenship Julian Dowdeswell (SPRI) Jack Holt Scott Kempf
2008-2009	ICP1 (ICECAP/OIB; ICECAP/IPY; ICEGRAV)	McMurdo (US)	Jamin Greenbaum Dustin Schroeder Duncan Young Gonzalo Echeverry Donald Blankenship

			Martin Siegert (Edinburgh) Jack Holt Issac Smith Scott Kempf
2004-2005	ASE1 (AGASEA)	McMurdo (US) Thwaites Camp (US)	Matt Peters Scott Kempf Gonzalo Echeverry Don Blankenship Theresa Diehl David L. Morse Irina Filina Jack Holt Anatoly Mironov Duncan Young Erick Leuro Thomas Richter Janessa Link J. Michael Tritchler John Gerboc
2001-2002	2001 (ATRS)	McMurdo (US), On-D Camp (US)	Matt Peters Scott Kempf Donald Blankenship David L. Morse Anatoly Mironov Jack Holt
1991-2003 (SOAR)	CTZ2 (91-92; CASERTZ) RTZ2 RTZ3 RTZ4 RTZ5 RTZ6 RTZ7 RTZ8 (98-99 - South Pole) RTZ9 (99/00 - Wilkes Basin) VTZ1 (00/01 - Vostok)		Donald Blankenship John Gerboc Mark Maybee Maureen Noonan Scott Kempf Thomas Richter Marcy Davis Bob Arko Eric Robison Dwight Melcher Sammantha Magsino Effie Jarrett Ken Griffiths Jennifer Eigenbrode

Arctic Expedition List

Year	Season (Project)	Bases of Operation	Field Participants
2019	SRH2 (SEARCH^{Arctic})	Resolute, Canada	Anja Rutishauser Dillon Buhl Enrica Quartini
2018	SRH1 (SEARCH^{Arctic})	Resolute, Canada	Lucas Beem Natalie Wolfenbarger Gregory Ng Thomas Richter Anja Rutishauser (Alberta)
2014	GOG3 (CAGE; ICEE)	Qaanaaq, Greenland	Duncan Young Julian Dowdeswell (SPRI) Steven Palmer (Exeter) Anja Rutishauser (Alberta) Jamin Greenbaum Gregory Ng Feras Habbal Thomas Richter
2012	GOG2 (GROGG)	Qaanaaq, Greenland	Duncan Young Julian Dowdeswell (SPRI) Steven Palmer (SPRI) Poul Christoffersen (SPRI) Jamin Greenbaum Gregory Ng
2011	GOG1 (GROGG)	Ilulissat, Greenland	Duncan Young Donald Blankenship Julian Dowdeswell (SPRI) Steven Palmer (SPRI) Poul Christoffersen (SPRI) Jamin Greenbaum Gregory Ng Svetlana Stadnik (now Burris)

Key Developments in Field Data Processing

Through the years, many individuals contributed to developments for our ground data processing systems.

In the AGASEA season (ASE1, 2004), Duncan Young developed the basis for the data quality control architecture using the Generic Mapping Tools (GMT) project, which remained the basis for graphical quality control products through 2016.

Scott Kempf has developed and maintained software related to the ELSA and photon-counting lidar data formats, and the variety of archival tape systems from ASE1 to the present.

Gregory Ng also worked on interfaces with many data formats, in addition to streamlining and maintaining command line scripts that automate the tasks of ground data processing, translating them from shell scripts, to Perl, and eventually Python, through the years, with a focus on making them robust against unexpected situations, and clear in their usage.

In 2010, Jason Roberts selected the QNAP network-attached storage system that brought enterprise-level data reliability in a very portable form factor, and has proven useful and reliable. He also developed software in Matlab (pik1) that has proven very useful for radar quality control.

Also around this time, in ICP3, Jamin Greenbaum performed an unmatched feat, which was to perform tasks for both ground data processing and flight operations for flights, for weeks at a time. Jamin's experience confirmed the existing belief that this should not be standard practice. On a more general level, Jamin's attention to procedural reliability influenced field data processing and made it better, especially where it interfaces with flight operations.

During her time at UTIG, Laura Lindzey led the shift that moved the data processing ecosystem into the world of SciPy and Matplotlib, from the prior world of internally-developed tools in C. While the prior tools are still in use, her work created a foundation that effectively made C tools considered legacy software. The culmination of this migration was Deva/RadarFigure, which replaced Xevas, and is frequently used for picking features in radargrams.

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