University of Arkansas, Fayetteville
ScholarWorks@UARK

Theses and Dissertations

5-2018

Moulins: Down the Arctic Drain

Jonathon Nugent Carlson
University of Arkansas, Fayetteville

Follow this and additional works at: http://scholarworks.uark.edu/etd

Part of the Film Production Commons, and the Visual Studies Commons

Recommended Citation
Carlson, Jonathon Nugent, "Moulins: Down the Arctic Drain" (2018). *Theses and Dissertations*. 2784.
http://scholarworks.uark.edu/etd/2784

This Thesis is brought to you for free and open access by ScholarWorks@UARK. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of ScholarWorks@UARK. For more information, please contact scholar@uark.edu, ccmiddle@uark.edu.

Moulins: Down the Arctic Drain

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Arts in Journalism

by

Jonathon N Carlson
University of Arkansas
Bachelor of Arts in Communications, 2015

May 2018
University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

Larry Foley, Ph.D.
Thesis Director

Dale Carpenter, Ph.D.
Committee Member

Matt Covington, Ph.D.
Committee Member

ABSTRACT

This observation-style nonfiction documentary film follows a National Science Foundation expedition to the Greenland ice sheet. The bivouac lasted for 25 continuous days. University of Arkansas Professor of Geosciences Matt Covington, Ph.D. teamed up with University of South Florida Professor Jason Gulley, Ph.D. to plan, propose, and ultimately accomplish the research goals of the expedition with the assistance of Ph.D. student Celia Trunz, M.S., and experienced expeditionary team member Vickie Siegel. As an observational-style documentary film, all scientific background information imparted herein is taken directly from interviews conducted with Professor Covington, to minimize opining.

The film begins in mid-flight, as a military C-130 aircraft transports more than a dozen researchers and their equipment from Albany, New York to Kangerlussuaq, Greenland. Professor Covington introduces himself and provides a background introduction to Professor Gulley. The narrator introduces the remaining two expedition members, Vickie Siegel and Celia Trunz. An Air Greenland helicopter transports team members and their gear to the glacier, while Professor Covington gives a brief synopsis on the purpose of their experiments. A moulin is a glacial formation that allows melt water to reach the base of the ice through fissures that seasonally expand and compact. As the helicopter departs, leaving the team on the glacier, it begins to snow. The expedition team is stuck in place for the entire first week, only able to construct a weather station and send out drones to find a moulin to examine. Eventually, they are able to locate and attempt instrumentation of a moulin, which proves difficult with a lack of adequate meltwater. They are forced to abandon the effort and relocate to another moulin, which also defies instrumentation until the 24th day. Ultimately, the experiment is successful, with the data retrieved from the moulin sensors raising new questions about moulins' effect on glaciers.

© 2018 by Jonathon N Carlson
All Rights Reserved

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

EWS – Extreme Wide Shot

WS – Wide Shot

MS – Medium Shot

CU – Close-up

ECU – Extreme Close-up

INT – Interior

EXT – Exterior

POV – Point-of-view

Nats – Natural sound

V.O. – Voice over

O.C. – Off-camera

I. INTRODUCTION

I was first approached to take on this documentary thesis project by Larry Foley, the University of Arkansas School of Journalism and Strategic Media Department Head in January of 2017, at the request of Geosciences professor Dr. Matt Covington. While applying for grant funds for an arctic expedition to Greenland, Dr. Covington and his co-author Dr. Jason Gulley specifically included bringing a journalism student along to record the trip within their proposal under "broader impacts," with the express purpose of producing a feature to document and properly explain their work to the general public. The following six months were occupied by physical examinations to determine my fitness for arctic work as defined by the National Science Foundation, oral surgery to clear me for dental fitness, mountaineering training, production research, and technical preparation to provide me with the proper tools to accomplish the task.

This expedition was to feature travel in four phases: 1) take commercial flights from Arkansas to Albany, New York, 2) fly in a military C-130 transport courtesy the NY Air National Guard to Kangerlussuaq, Greenland, 3) after a two-day layover at the Kangerlussuaq International Science Support (KISS) facility to fly commercially via Greenland Air to Illulissat, Greenland, and 4) after ten days of equipment preparation the team would be flown to the bivouac site via helicopter. There, the scientists would set up a complex system of infrastructure to support their experiments, and encamp for 25 continuous days on the ice while their instruments gathered data.

The primary goal of the scientific project is to study glacial moulins over a period of three years. Moulins are a type of glacial geological formation that develop from flowing meltwater streams that encounter crevasses in the ice. During the yearly melt cycle of a glacier, meltwater will flow along the surface, creating deep channels along the way, until it encounters cracks or crevasses that allows the water to drop sharply downward. These cracks can allow the water to form drainage conduits that over time are thought to reach the bottom of the glacier itself, thousands of feet below. This water, in turn, can provide lubrication between the ice and bedrock, or water pressure that may produce lift on the glacier itself. This theory is known as the "Zwally effect," named for NSF researcher Dr. H. Jay Zwally, who first posited the water flow relationship in his 2002 paper, "Surface melt-induced acceleration of Greenland ice-sheet flow."

The proposed experiments for data gathering during the expedition included two methods of measuring the amount of water flowing into the selected moulin (a water level sensor to measure the height of the stream, and a dye trace to calculate the volume of water), coupled with an instrument inserted deep into the moulin itself to record the water pressures inside. This information will be compared over time to readings from multiple high-precision GPS units located near the moulin site, which in theory could indicate a correlation between the water flowing into the moulin, and the forward movement of the ice sheet.

II. LITERATURE REVIEW

The preliminary research phase of the project primarily consisted of personal informal interviews and email exchanges with Dr. Covington, and searches for previous documentary work on the topic of moulins and academic expeditions to the arctic. The wording of the grant award towards the role of the journalism student was specifically to translate the science behind "the Gulley Project" into terminology and phrasing that would be accessible, or understandable, to the general public at a reasonably moderate education level. Through my discussions with Dr. Covington as a primary source, I understood the basic structure of the expedition in terms of transportation, goals, and setting; with this information I generated an outline of key tasks and events to capture that were important to the execution of the project. These notes helped a great deal for identifying and prioritizing shots in a "need" list.

The outline, and accompanying standard interview questions for my film participants, sought to gain some very basic answers about the expedition: 1) who are you and what is your background in this field? 2) What is a moulin, and why it is important to climate scientists? 3) Describe the experiments involved and how they relate to the primary focus of the study. At the outset, I understood that I would be adding to those questions based on what happened during the course of production. At this stage of production, I knew that I had to begin with the idea of "take me there, and make me care" in order to draw the audience in, and part of that process in my mind had to start with the scientists themselves and their motivations.

As the science accessibility approach to the documentary was crucial, I decided to forego an in-depth presentation of glaciology in general to avoid trying to fit too much into the film for the viewer to digest. However, I took care to research the "Zwally effect," the central theory around which the project is built. As explained in the introduction, Zwally correlates the amount of water flowing into moulins with accelerated forward motion of glaciers, hypothesizing that as melt increases, glacial movement will also increase. I read Dr. Zwally's 2002 paper, and through my general search surrounding it, I found that it is the subject of some controversy. Dr. Graham Cogley, a geology professor at Trent University, outlined a few disagreements surrounding this theory in a 2010 article, "The Zwally effect: it won't go away." The article explains that multiple papers since Zwally have attempted to contend or support his research in a number of different ways; some attempt, "to explain how meltwater can find its way through more than a kilometre of ice," (Cogley, 1) while another line of inquiry, "tends to show that the Zwally effect is not the reason for dramatic increases in the speed of tidewater outlet glaciers, where the evidence favours, quite strongly, warm ocean water as the culprit." (Cogley, 1) Dr. Covington even acknowledged to me that the general thought in scientific circles was that the Zwally effect was not going to have too much impact on glacial movement, because once enough flow is introduced and the moulin pathways open up to a certain degree that water pressure will drop, and thus won't have the amount of lift that Zwally theorizes.

As I am ill-credentialed to opine on such a complex topic, I at least researched enough of the subject to become familiar with the theory and understand that disagreement exists within the scientific community, which this project team is attempting to test with their experiments. For the purposes of this film, to communicate that disagreement effectively to the audience via primary source interviews and minimal narration is sufficient to remain neutral in my telling of the expedition's story and scientific aims. To delve too deeply into competing scientific theories would defeat the purpose of my charge to make the science "accessible."

I also reviewed the video catalogue of *Yale Climate Connections*, which featured similar recent university expeditions to Greenland and other arctic environments. Though these were very short features, I noted that they all roughly contained a similar straightforward structure, which included varying shots of experimental field activities, some graphic representations of the scientific principles involved, and on-site interviews with the primary researcher to explain the science being tested. As I understood that the topic of arctic melt would be a potential minefield of partisan opinion, I also took an online EdX course from the University of Queensland entitled: "Denial 101x: Making Sense of Climate Change Denial." This provided me with a framework within which to word my narration, to avoid phrasing or 'framing terms' that may incite or exclude certain viewers. I wanted the project to be far more about the adventure and experience, "Man vs. Nature," to provide a narrative to draw in skeptics while imparting facts along the way.

While I did not search specifically for archival footage to be included in this film, I did look into scientific visualizations to assist in audience comprehension of the scientific processes being discussed. Initially, I had hoped to generate animations of my own, but I located a number of helpful topical videos available to the public via the NASA Goddard Space Flight Center Conceptual Image Lab, which were superior to my own level of skill in 3DS Max, and released for non-profit reuse at no cost.

While preparing my outline, I was also having to prepare my physical skills for the trip. Dr. Covington, Celia Trunz (Dr. Covington's Ph.D. student), and I were flown to New Hampshire in April of 2017 to learn glacial mountaineering skills from the International Mountain Climbing School in North Conway. The instructors there illustrated for me the way that crevasses form in glaciers, through the slowly flowing motion of the ice over rocky bedrock and through winding canyons. This visualization, accompanied with my training in rope harnesses and safety procedures, provided primary source material for my narration development to help illustrate hazards the team may face during our 25 days on the ice.

III. PRODUCTION NARRATIVE

Early into the production process, I determined that this film should follow the format of an "observational documentary." I would record the events as they unfolded on the ground, keeping careful notes and referring to my outline to ensure I wouldn't miss important tasks and events as defined by the scientists, who I considered my executive producers. However, I also wanted to avoid being obtrusive for practical reasons, by either placing myself too close to the action and interfering, or by prompting my subjects for a statement while engaged in a task or even during a break. If I felt the viewer needed clarification from the scientists on an interview statement, I asked for simple rephrasing; if an on-screen activity needed further explanation, I would write narration to quickly simplify what was happening. My correspondence with Dr. Covington had provided me with an overview of the expedition's goals, and so I outlined my production goals accordingly. I would record day-to-day camp activities, take great care to capture these key moments in both setting up and executing experiments, and keep my eyes open for unexpected important events.

As I also understood from experience in both video production and military maneuvers that careful plans can often change at a moment's notice, I resolved to be flexible overall with my approach to this production. I formulated questions to ask Dr. Covington ahead of time based on his explanations of the project, but I was always preparing new questions based on events as they happened. While I initially considered on-camera interviews for the rest of the camp on their backgrounds and day-to-day feelings on the ground, I ultimately decided against this later in production. Although Werner Herzog took such an approach with *Encounters at the end of the world (2007),* his goals differed from mine in that he was intending to meet and examine the people he encountered in Antarctica during brief periods of time for a glimpse into their daily routine, rather than following a single project from start to finish.

The narrative flow of this documentary needed (in my opinion) to feel less like a modern "infotainment" reality-style program such as *The Deadliest Catch (2005),* and more like the kinds of films I had grown up with, such as *The Undersea World of Jacques Cousteau* (1976), and similar productions. Primarily, the story had to flow visually, with interview audio and narration to fill in gaps. Each of my camp-mates were characters in the film, to be sure, but I felt that to continuously interview them instead of observing their natural actions might begin to influence their answers, and so would deviate from my intended *mis en scène*. Originally, I intended for Dr. Covington to be the primary interview subject, and for his Ph.D. student Celia

Trunz to be a first-person narrator, supported by smaller interviews by Dr. Gulley and Vickie Siegel (the camp manager). Celia's French-Swiss accent would have been a subtle callback to Cousteau's work, while providing a personal perspective on the narrative. Ultimately, I decided to perform all narration myself as a practical measure to prevent scheduling problems.

I selected a Canon DSLR as my camera platform of choice. This was to minimize the power requirements, space, and weight needed for my equipment, and to provide a flexible tool to produce moving and still images with a great amount of quality and precision while on the move in rugged terrain. In preparation for using this camera, I took an analogue photography course within the University of Arkansas School of Art, which gave me a refresher on the basic operations of a film camera, complete with darkroom practice. This was needed to help me return to the basics of depth of field, shutter speed, and exposure as core competencies.

Before principal photography, I decided to follow Dr. Covington around his laboratory and watch a few pre-expedition preparations he conducted with his student Brandon Conlon. They were preparing fluorescent dye for one of their experiments, and explained to me that they use the dye along with specially calibrated sensors to determine how much water is flowing in the stream. I followed Dr. Covington and Brandon to a local stream in Johnson, Arkansas and recorded them setting up the flow sensors across the stream using nylon ropes, and preparing the pumping system that would "pulse" the dye into the stream at a predetermined rate and concentration. I was lucky enough to catch a light-hearted moment when Dr. Covington found himself partially covered in dye when he attempted to "prime" the pump by blowing air into one end of the hose, getting sprayed around the mouth and on his arms. I found later that by using the external microphone that came with this particular camera kit, I had somehow recorded no audio for the day.

Because of the unexpected audio problem, I decided at that point I should bring an external audio recorder as a backup should anything like that ever happen again, and to make sure that I had multiple lavalier microphones with me that I knew worked both with the Canon camera and with the audio recorder. I also carried with me a MacBook Pro, all of which were all checked out from the school for the duration of the summer. While I also checked out a wireless microphone kit, I opted to leave it behind as final packing and weight restrictions left little room for it. I also made sure to have four working SD cards on hand at all times. With a 25-day shoot, I knew that a production outline would only take me so far in being prepared for the potential volume of events on the ground, so I also brought a large capacity external hard drive and formulated a daily review, editing, and note taking regimen. Even though I knew I would have to make most of my shots handheld, I also brought along a lightweight tripod to use when the situation allowed. Most of this gear could all fit into the standard kit backpack that came with the Canon 7D, along with other essential daily use items I would need to carry with me at all times while hiking, such as meal bars and extra layers.

For the flights to Greenland, I limited myself to only filming when inside the military transport plane. I alternated between using the Canon 7D and a GoPro camera for interior shooting, as well as capturing glimpses of the passing landscape outside the aircraft's windows. It was advantageous that I was seated near the exit door, as I was able to grab an external shot of all the scientists disembarking the plane one we had landed. While we were in Kangerlussuaq, I made certain to grab stabilized footage of the exterior of the KISS station, as Dr. Covington explained to me that we would be calling them each morning while we were in camp, and it would be a useful b-roll visual reference for the audience.

Once the expedition began, I attempted to be as helpful to the functioning of the team as I meaningfully could, but it was communicated to me that my primary responsibility was only to the documentary film. In general, I planned to follow the primary subjects (Dr. Covington, Dr. Gulley, Celia Trunz, and Vickie Seigel) during their daily activities, including camp life, forays out onto the ice sheet, and during the setup and execution of experiments. Here it must be noted that if everything had gone according to initial plans and expectations, I would have had a great deal less to film. I had these activities in my shot list and other notes from correspondence and research, but as it turned out the situation demanded an adaptable approach.

The ten days spent in Illulissat managing and staging equipment for the camp were plagued by mosquitoes each step of the way. I filmed while a representative of Polar Field Services, Kathy Young, assisted us in the Air Greenland pre-flight process, and the mosquitoes appeared in every shot as a cloud surrounding us. While the scientists appeared mildly annoyed, I had to focus to keep my shots straight and avoid filming too long with insects on my lens. I also found that the autofocus on the Canon 7D was geared towards still photography, and didn't respond nearly as quickly or reliably in video mode as camcorders would. This prompted me to continuously make the camera autofocus when switching shot depth or moving from one subject to another by using the 'push focus' button.

I was flown out to the campsite with the last helicopter load, along with Dr. Covington. I was permitted to sit in the co-pilot's seat during the flight, and captured a great deal of footage over the 25-minute journey. I had brought with me a shoulder-mounted stabilizer of my own, which showed promise initially, but during the flight I realized that the mounting angle of the camera didn't allow the focus ring of the lens to turn very quickly, so I abandoned it in favor of handheld shots for the remainder of the production.

Shortly after the camp was pitched and everyone settled in, an unexpected two feet of snow fell over the course of six hours, partially burying equipment and stymying any efforts to explore beyond the camp perimeter. Activities that would have taken place within days of landing on the ice were suspended for a week. My outline originally called for the experimental setup to be a prelude to interviews and vignettes of daily life, but as the situation began to look dire for the completion of any experiments, it became more important to capture the drama and tension of weathering the elements in anticipation of accomplishing the project's goals.

Suddenly, there were more aspects to the film than I (or anyone in camp) had anticipated. Dr. Gulley, who initially was only scheduled in camp for the first few days to assist in the setup of camp and instrumenting the moulin, was stranded with us. He had to return to South Florida University for a number of very good reasons; there was a planned second camp in the project and he was needed to continue coordinating the logistics for it, he also needed to turn in his tenure packet or miss the deadline, and he was moving apartments. While he could have requested a helicopter to take him back out, he ultimately decided that it was essential to stay behind and assist the team for as long as they needed him. He was able to make arrangements for some of his obligations back home, but couldn't get reimbursed for very expensive commercial flights he had already paid for. I was able to capture some of these moments as he came to the realization that he was stuck there, but needed to make the personal sacrifice to stay and see the project through.

As the priorities of camp changed from performing experiments on a routine expedition to cold weather survival, the tenor changed in our interactions, and most of us merely focused on passing the time. On most days in that first week when there was literally nothing to do, I would keep my camera close by and at the ready even though not much would happen. However, I kept my ears out, for any change in status, weather, or conversation. This way, I was able to catch a number of good ideas in the making, and recorded Matt, Jason, Celia, and Vickie discussing their options and potential solutions. The intense weather did preclude unnecessary recording, however; the driving wind that we were taking shelter against made the tent flap and rattle to a degree that it prevented me from attempting to catch some idle chitchat we were engaged in at the time. I did capture plenty of "thousand-yard-stare" moments among the team, with which I knew I could tamp down the natural sounds and narrate over during editing.

With the original focus of the project thus diverted, I made sure to prioritize events such as the morning weather check-in with the KISS station, and subsequent discussion among the researchers about their options. After four days of inactivity, the team had only done as much as set up the weather station on the edge of camp. Finally, Dr. Covington had the idea of using the drone vehicles that we had brought with us to perform scouting flights. It had stopped snowing to a large degree by that point, and the wind was calm enough to allow one drone, a glider, to take an aerial survey of the landscape to allow us to orient ourselves. Otherwise, the snow cover on the ground would have to melt to a point at which we could see the crevasses and streams that were beneath. To venture out blindly on a glacier is foolhardy. I filmed Dr. Covington assembling the drone, and his subsequent launches and retrievals of the Tuff-Wing™ glider the team took to calling, "The Ice Bat."

When the researchers had gathered enough information from these flights, it was decided that the second drone, a quad copter, should be sent out to take closer looks at areas they suspected the moulin would be located. I was able to capture Dr. Covington and Dr. Gulley examining the survey data, discussing it, and the moment that Dr. Covington announced his idea to use the drone in this way. I had worked with Dr. Covington before the trip to outfit the drone's GoPro camera with a flat lens to avoid the distortion typical of its standard convex wide-angle lens. These drone flights turned out to be both practical and breathtaking, and I took great care to back up those recorded files for later use once Dr. Covington had them. I also observed him closely during the footage analysis to catch visuals of his process and subsequent discussions with Dr. Gulley and Celia.

With the volume of footage growing by this point, I spent my down time viewing dailies, recording notes on the day's activities in my log, and continually assembling footage within a master chronological timeline of all raw footage in Adobe Premiere. This raw timeline was to allow me to quickly and continually view the progress of available footage. During this process, I was able to trim or eliminate unusable footage and keep a running "bird's eye view" of the unfolding situation. With the original plan firmly out the window, I developed the plot as time progressed. At this stage of production, I began to understand that this documentary would start taking the shape of a traditional dramatic narrative, which I sincerely hoped would have a happy ending. I reassured myself that if this year's expedition was a wash, I would be returning in 2018 to film something of a "comeback" successful second and third act.

Once Dr. Covington and Dr. Gulley had gathered enough information to be confident in venturing out from camp, they began to take organized treks with Celia while equipped with climbing harnesses beginning on day 5. As I was not going to accompany them, I prepared a helmet-mounted GoPro for Dr. Covington to take with him. The trio would take these hikes over three days until they found a promising moulin that was beginning to thaw enough to use in their experiments. I was able to accompany them along their trail without being attached to the rest of the team with a rope on day 8 to record them examining it. This represented a tremendous amount of excitement in camp, as their plans could begin to move forward. I accompanied the team for several subsequent trips to the moulin as they carried equipment and tools to the site, taking care not to hold up the convoy too much as I would carefully “swing wide” of the line of people in order to capture more than the back of the person in front of me.

The site was outfitted with a number of long-term installations, which required drilling holes in the ice and installing pipes several feet below the ice surface. I filmed the team setting up a water level sensor across the moulin water channel, which involved assembling a series of pipes and carefully carrying the apparatus to where Dr. Covington could safely jump across and assist Dr. Gulley in positioning it. Next, the GPS station was assembled nearby, with heavy lead-acid batteries that took many trips to transfer from camp. Some of the more tedious aspects of wiring, voltage testing, and other minutia from the setup I opted not to film in depth, as the footage started to become “more of the same.” However, I kept a close eye on the proceedings, just in case.

Once the moulin site was fully set up, the team turned their attention to transporting and installing the moulin pressure sensor cable. This four hundred pound spool of cable had sat on the edge of camp since being dropped off by the helicopter, and was impossible to move as a single object, so it was decided to unspool the wire in the direction of the site and for each team member to use their climbing harness to pull it along, positioned at one hundred meter intervals. Dr. Covington flew the quad copter drone during this process to capture an overhead view of the train of people pulling the cable. He noticed, however, after the end was detached from the spool and began moving towards the site that the cable began to curl on itself towards the middle. The movement strategy was adjusted, and so the cable was arranged in a long arc across the landscape with one end attached to the data logger situated with the GPS station, with the other end nearby the moulin.

At this stage, the last task to accomplish before data collection was instrumenting the moulin itself with the cable, which needed to be done in a slow, careful manner. Dr. Gulley instructed the team to begin drilling holes in the ice in a “V” formation so that ropes and straps could be fed through in order to make a stable anchor capable of holding the cable’s weight. Once the anchors were in place, Dr. Covington and Dr. Gulley constructed a rope pulley system to lower the cable several meters at a time, with the ability to quickly lock off further progress. Before progressing any further, the team gathered together to briefly review their plan to instrument the moulin, everyone’s roles, and safety concerns. Since we would all be spread out, adjustment instructions and warnings would be given out over the team radios.

The first attempt failed. I caught each step of the action as it proceeded, with Dr. Gulley lowering in the cable, the action of the rope pulley, and background action of Vickie relaying data updates on the data logger. Once the team was certain that something wasn’t going right, I made sure to capture all of their diagnostic moves and as much of their discussion as I could hear, though the wind made conversations even two feet apart nearly impossible. What I could get, however, was the attempt to retrieve the cable, which involved both professors pulling on the cable with all of their strength in multiple intervals of ten meter segments. Finally, a bundle of tangled cable emerged from the hole, devastatingly knotted and twisted. The day was a wash. We returned to camp, and I went about transferring and cataloging the massive amount of footage I took that day.

From this point forward, there was little to film at the campsite. While the professors figured out some technical details of the data loggers in order to make them more efficient for the instrumenting process, I was able to get a few interesting minutes of conversation. Other than this exchange, I only filmed while additional preparation was made on the dye trace experiment set up, which took several days of repetitive action. Celia and Dr. Covington would carefully dilute the dye stock to their desired concentration with locally available water, and calibrate the dye sensors. I acquired hours of this footage, knowing I would only need a select angle or two as b-roll, but having little else to do I stuck close anyway.

The next few attempts at instrumenting the moulin played out much as the first had, but I recorded the proceedings as diligently as I could each time, just in case the team would be successful. Both the third and fourth attempts were in harsher, wetter conditions, and I protected the camera with a plastic bag secured with a number of rubber bands as a shroud. I also carried several lens cloths to continually wipe the exposed parts of the camera down and keep the image clear. Little changed between events, however, and I knew when logging these clips that I would probably have to use very little of each episode in a montage rather than risk losing audience engagement by dwelling too long on individual attempts. Were this a series and not a single feature, I noted that I could probably have turned the footage on hand into a dozen or more half-hour episodes of suspense.

Finally, both lead researchers decided that it was time to locate another moulin. I caught several angles of their scouting departure on foot, as they were familiar enough with the melting landscape that little further aerial reconnaissance was needed. Several days previously, the Ice Bat had crashed on takeoff during a routine flight. The propeller had broken off at the shaft, and the nut holding it on had gone missing, rendering it useless until spare parts could arrive. Thankfully, the snow had mostly melted to this point, so the team was able to locate a second moulin safely. The new site would be only one hundred meters from camp. Nearly all equipment from the first moulin would have to be transported again, which I followed sporadically. I made sure to take several shots from camp itself observing the team members hauling items to the nearby site, zooming and panning for perspective to demonstrate the proximity to camp.

Once everything was set up at the new moulin roughly the same as before, the attempt to instrument it went badly again. There was just not enough melt to assist the sensor in reaching the depth they needed to obtain the water level data the researchers were after. After an exhausting day of continuously trying to get the cable down the moulin, Dr. Gully and Celia had to prepare to leave camp. They had to go back to Illulissat in order to assist both of his Ph.D. students in setting up the second camp of the season, leaving Dr. Covington, Vickie, and myself behind for the remaining three days.

The second moulin site had been left recording data in the farthest depth the sensor had reached, which was enough to catch Dr. Covington's attention when he checked it the following day. We decided to try the installation one more time with just the two of them, while I recorded the proceedings. I was elated to have my happy ending when the sensor finally dropped much farther down the hole, around 600 feet below the surface. The remainder of that time was spent wrapping up camp teardown, and repairing and flying the Ice Bat for one final survey of the area.

Once the remainder of the team was back in Illulissat recovering, I reviewed my notes and footage with the goal of setting up interviews for Dr. Covington and Vickie. Dr. Gulley and Celia were already back on the ice by the time we returned, and were unavailable for the remainder of the expedition while they set up the second camp's instrumentation. Interviews with either of them out on the ice would have been inundated with wind on all but the clearest of days, which were fully occupied with work. I took my list of standard questions and expanded them based on what had happened, being discrete about the difficulties but taking care to get a complete narrative. I wanted to get enough material that I would have a portrait of my subject as a well-rounded character with motivations and a background, as well as getting their personal perspective on what had happened in camp.

Given that Illulissat had ample walking trails around the hills and nearby shoreline, I decided to film the interviews next to the iceberg-filled bay. On the day of filming, Vickie didn't want to be on camera following some personal news that she was upset about, so I was only able to get Dr. Covington's interview. Though I used both the external audio recorder and a clipped lavalier, both picked up a great deal of clothing movement and bugs bouncing off of the pickups, in addition to the low grade rumbling of icebergs shifting. Overall, I was still satisfied with it, and knew that I could make adjustments in the editing room to both sound and color.

Once back in Fayetteville, Arkansas, I reviewed all of my available footage and the daily logs, and found that I had over twenty-three hours of footage, reduced in the field from far more. I read through my available textbooks on story structure typical to both documentary film and dramatic narrative film, and compared these structures with the material I had available. Ultimately, I found what I felt would be the right outline through a popular screenplay book by Blake Snyder, *Save the Cat! ® The Last Book on Screenwriting You'll Ever Need*. The author takes a careful examination of story structure used in literature, film, and television with regard to emotional beats and timing. This same structure, without consideration to pacing, is noted throughout Joseph Campbell's *The Hero with a Thousand Faces*. The "mono-myth," as it is referred to, has been used throughout human history, from *Beowulf* to *Star Wars.* Blake Snyder outlines his suggested pacing along these lines:

Opening Image Pg.1	Theme Stated Pg.5	Setup Pg. 1-10	Catalyst Pg. 12	Debate Pg. 12-25	Break Into Act 2 Pg. 25
Fun and Games Pg. 30-35	Midpoint Pg. 55	Bad Guys Close In Pg. 55-75	All is Lost Pg. 75	Dark Night of the Soul Pg. 75-85	Break Into Act 3 Pg. 85
Gathering the Team Pg. 85-110	Storming the Castle Pg. 85-110	Hightower Surprise Pg. 85-110	Dig Deep Down Pg. 85-110	Return Home with Treasure	Final Image Pg. 110

Table 1

During the process of writing the script, I also decided to field applications for a career in government work. Having been in the military when I was much younger, I had not considered such an occupation for many years, but this expedition had inspired me to venture farther out than Fayetteville to find what I needed to succeed. I was surprised to get a response back from the Department of Defense, who hired me as a multimedia specialist for the Defense Logistics Agency depot in Tracy, California. Once I informed Dr. Covington and my professors, it changed the pace of my work on both script and final edit. I was not going to return in 2018, which solidified the production of this film to center on the first expedition exclusively. With the mono-myth structure in mind, I constructed my overall plot and emotional beats in the same manner as Snyder suggests, with 110 pages cut in half to meet the roughly 55 pages or minutes needed for a standard hour-long PBS slot, which was in the language of the grant award:

Opening Titles Pg.1	Objective Stated Pg.2	Expedition Setup Pg. 1-5	Catalyst (Snow) Pg. 6	Debate Pg. 6-13	Break Into Act 2 Pg. 13
Drones to the Rescue Pg. 15-17	Midpoint Pg. 26	Moulin Difficulties Pg. 26-37	All is Lost (Drone Crash) Pg. 37	Dark Night of the Soul Pg. 37-44	Break Into Act 3 Pg. 44
Second Moulin Pg. 44-55	Jason & Celia Leave Pg. 44-55	Water Level Surprise Pg. 44-55	Success! Pg. 44-55	Return Home with Data	Final Credits Pg. 55

Table 2

I was also instructed to produce a three to five-minute short detailing the events of the expedition to demonstrate that I had a handle on the production progress, which I took the liberty of making into a fourteen minute featurette over the course of a long weekend. Having worked in detail with the material, and keeping daily notes on the progress of this production, had enabled me to find and use just the right shots from my twenty-three hour timeline to make a cohesive narrative. Dr. Covington was able to use a portion of this featurette during a presentation to the Department of Geosciences, and he also delivered some of the collected data, which I recorded with mixed success in the darkened auditorium. Following the end of the semester, I sat down with Dr. Covington for a second interview as a follow-up to see if there was anything I had missed before, and I was glad to know that there was some preliminary results from the data that had been gathered. Roughly speaking, the data suggested that there may be more evidence of the Zwally effect at thicker ice, where the conduits of melt water flow are not allowed to remain open long enough or wide enough for the water pressure to drop, facilitating more forward motion. This follow-up was recorded on an iPhone 8+ which was rated at only a few megapixels lower than the Canon 7D, though I would find later that light control was worse.

Once I had moved to Tracy, California, I settled into my new job for the first few weeks before tackling the full feature edit. With the structure outlined in Table 2, I began to construct the three-column screenplay and my timeline simultaneously, as the visuals in my timeline helped to build the backbone of the plot, while I was able to annotate narration and interview audio that would be most appropriate for each section. As I had previously planned, the film needed to work on a visual level first, as though a deaf person could still somewhat understand what was going on. Dr. Covington's interview would serve as the main pillar of exposition for the audience in his own words, while the narration would be a stopgap third person perspective for details that would round out the telling of the story, or fill in minor tidbits of scientific information. On the suggestion of colleagues with whom I shared working copies, I made sure to include sequences that explored the day-to-day life in camp that I didn't think to keep – preparing and eating meals, reading and making calculations, or just trying to stay busy.

I had already drawn upon royalty-free music tracks for the short featurette, which I decided to keep in certain segments, but once the film had most of its key emotional points built in, I scoured the internet for creative commons music that would emphasize these beats. Since the inception of the project, I had a vision of drone footage over pristine icebergs and the glacier surface set to Claude Debussy's *Claire de Lune*. Other sources I used took classical approaches to cinematic soundtracks, which I used towards the beginning and end of the film. Certain sequences I decided would need more esoteric music, especially while introducing the second moulin site and the resulting initial difficulties there.

Finally, since I had been informed from the beginning of this project that this feature was intended for an hour-long PBS broadcast, I ensured the runtime would be 56:46 as indicated in the "Red Book" production guide, including acknowledgement bumpers. To ensure I had the most up-to-date National Science Foundation logo, I contacted their production group and provided a link to my working collaboration copy on YouTube. I was given access to their FTP network to download the latest logo animation, and given instructions on what to include in the final credits. I was then also offered distribution through their national public, education, and government (PEG) channel network, their video on demand (VOD) service, and a spot on their website's multimedia gallery. I created the PBS-style bumpers according to the Red Book guidelines, complete with the traditional "viewers like you" thank-you message. I decided to call "picture lock" by March 1, 2018, and submitted it to the Hot Springs Documentary Film Festival.

IV. CONCLUSION

Change was a constant for this film project. What began as a two-year production that could have potentially become three years all together was shortened to one. What started as a routine expedition with seasoned expedition members turned into a struggle against unseasonable weather, and an uncooperative moulin. I intended the film to appear just like any other straightforward presentation that might appear in the *Yale Climate Connections* series, but it became a suspenseful drama. Though these changes caused the production process to become drastically harder, I feel as though it produced a much better product.

Moulins: Down the Arctic Drain is hardly a perfect film, however. Though I had practiced with the Canon 7D often, constant use in this environment revealed that I had to be vigilant in my settings and operation to get the best footage. Some of my shots are not as focused as I would have liked, or as stable as I tried to make them. I have a limited knowledge of sound recording that this project expanded upon, as the challenge of a constantly windy environment demanded. If circumstances had allowed, I would have interviewed each of the team members in the field after the moulin had been instrumented on a clear day with low wind – this didn't happen, but I worked with what became available to me. Much of the unrefined parts of this film could be argued to add to a "gritty" feel appropriate to making the audience feel as if they are part of the action. Hand-held shots featuring nearly excessive "camera shake" has become a recent staple of mainstream Hollywood films for this very reason, to avoid a film appearing too locked-off and slickly produced, which some audiences find distancing.

As to what I would do differently if given the opportunity to do it all again, I could have packed a larger microphone with a stronger windscreen, I would like to have had the funds available for a stabilizer of some kind, and I certainly wish I had been able to film the final interview with Dr. Covington on a device other than my iPhone and at a better location with even lighting. This was also the year I was recovering from eye surgery, and while my eyesight steadily improved over the course of the year, it certainly does show in this project and in other works I produced since that time.

Ultimately, I am incredibly grateful to have been nominated for this project, and I am confident in the film I have produced. It paints a picture of challenge and adversity that is overcome through determination and skill, which is far superior to a story where everything had gone according to plan. It allowed me to become more confident in my abilities, both in the field and in the editing room. While ostensibly being a film concerned with climate change, it presents the story as a factual exploration of a narrow aspect of it without appearing heavy-handed. This is a film I am proud to have my name on.

DOCUMENTARY SCRIPT, 3-COLUMN FORMAT

NARRATION	VISUALS	SOUND
	Fade from black	*Music:* Musway Studio – “Cinematic Epic Blockbuster 6”
	EWS POV: Icy waters ringed with icebergs rushes past the viewer (in flight), tilting upward to reveal a frozen landscape of stadium-sized icebergs. *Fade titles:* “Moulins: Down the Arctic Drain”.	Airplane engine hum
High above the Greenland coastline, more than a dozen scientists and their equipment are taking a ride in a military C-130 on their way to study the vast Greenland ice sheet.	EWS: Rocky, snow-capped landscape with C-130 aircraft engine and propellers in view.	
	MS, Panning Right: Interior of C-130, a group of travelers (scientists) are huddled in cold weather gear. An Air Force Airman walks past the camera and towards the rear of the aircraft, passing a large cargo bundle	
	EWS: A steep valley on the edge of the ocean shows a receding glacier edge	
Each of them represent different institutions, Universities, and government organizations	EWS, Trucking Left: a field of craggy icebergs on the ocean.	
	MS: Interior of C-130, the travelers are allowed to walk around, DR. COVINGTON approaches the window to see outside, as VICKIE SIEGEL looks on.	
Thanks to a special arrangement with the National Science Foundation	EWS: looking out from the C-130 window to see the	

and the New York Air National Guard, these flights are an integral part of the ongoing research into climate change.	expanse of mountain ridges covered in ice and snow. WS: landed C-130 aircraft on the tarmac, travelers departing aircraft in a line. DR. GULLEY, DR. COVINGTON prominently among them. WS, Trucking Left: view from transport bus - passing more C-130's on the tarmac MS, Zoom to CU: CELIA TRUNZ riding the bus, camera in hand. She takes a picture, puts her camera down, and looks pensive and tired.	
Here, in Kangerlussuaq, their efforts are coordinated at the International Science Support Station, or KISS for short.	WS, Panning Left: Transport bus drives out of airfield, past field of view. Shot lingers on airfield and air traffic control tower. WS: A long concrete building with drab beige and red coloring is labeled "Kangerlussuaq International Science Support"	*Music fades*
One team is here from the University of Arkansas, and the University of South Florida, to study a particular feature of glacial melt.	EWS, Panning Left: a spectacular view of Disko Bay, filled with icebergs. At the end of the pan, DR. COVINGTON is seated.	
	Lower 1/3 Title: Dr. Matt Covington, PhD	*Music:* Musway Studio – "Cinematic Ambient 2"
	MS DR. COVINGTON (interview)	DR. COVINGTON (v.o.): So, I started out as a physicist, studying galaxy

	CU, POV: DR. COVINGTON makes his way through a narrow cave, with rushing water at his feet. MS, POV: DR. COVINGTON hangs by a harness from a rope in a cathedral-like cave, water cascading all around him as he looks down at his mud-covered boots, and adjusts his harness. MS DR. COVINGTON (interview) WS EXT AIRPORT, hand-held: a woman (KATHY) is briefing DR. COVINGTON and the LOW CAMP TEAM on the plan to organize and fly all of the gear sprawled around them. An Air Greenland flight swoops in for a landing. CU, DR. GULLEY nodding *Lower 1/3 Title:* Dr. Jason Gulley, PhD. MS DR. GULLEY, KATHY, Pan Right to DR. COVINGTON CU DR. COVINGTON MS DR. COVINGTON (INTERVIEW) GRAPHICS: *Google Earth* shot of the globe spinning from the USA to Svalbard	formation, but I was also a quite obsessed caver. *Water splashing* DR. COVINGTON: I sorted out that I could be doing science a lot like physics, but use it to study caves, and eventually that bled over into glaciology, because there are caves that form in the ice and it turns out that these caves are actually quite important for determining how quickly ice sheets will melt. KATHY: Ok, this afternoon, at some point, we'll get, like, a big cart… *Jet engines roar* DR. COVINGTON (v.o.): I first met Jason at a caving convention, Jason's also a caver and he convinced me that glaciers and caves were scientifically interesting, and it certainly sounded like an intriguing environment to visit. And, so during my first post-doc I got the opportunity to go with Jason to Svalbard, in the arctic, to go glacier caving *Music:* Musway Studio – "Cinematic Ambient 3"

	PHOTO, Zooming Out: DR. COVINGTON and DR. GULLEY stand as a tiny speck on the side of an imposing arctic mountain.	
	PHOTO, Static: DR. COVINGTON lowers himself on a rope into a steep ice cave, sunlight streaming in above him.	
	PHOTO, Static: DR. COVINGTON looks downward at DR. GULLEY, within the ice cave.	DR. COVINGTON (v.o.): So, we spent quite a bit of time exploring and mapping glacier caves, as part of Jason’s PhD research.
	PHOTO, Scrolling Up: DR. GULLEY hangs from a long rope down the side of a wide crevasse.	
Joining the team is Vickie Siegel, an experienced professional in expedition field operations and logistics. She has spent several seasons in the Antarctic at McMurdo station, and was once Dr. Gulley’s graduate assistant.	MS: VICKIE talks with KATHY about their arrangements	*Music:* Musway Studio – “Inspiring Piano 2”
	PHOTOS (various): VICKIE in climbing gear, in the arctic, at the south pole	
	WS Panning Left, Airport: VICKIE inventories supply boxes as the rest of the TEAM organizes and catalogues scientific equipment in large grey containers.	DR. GULLEY: Yeah, there should be some sorta manual around here somewhere…
	MS: DR. GULLEY and CELIA TRUNZ unload long metal poles from a wooden crate.	
Also joining the team is Celia Trunz, Dr. Covington’s PhD student. She is also an	WS: DR. COVINGTON and CELIA on a craggy mountaintop	

experienced caver, with a background in hydrogeology earned in Switzerland.		
	MS, Zoom to CU: DR. GULLEY tears open a cardboard box, finds a package of beef jerky on top of a set of data-loggers. As he is reacting, DR. COVINGTON enters and grabs a yellow equipment case.	DR. GULLEY: (Scoffs) Four data loggers and one…I love grad students… DR. COVINGTON: (Laughs) Nice! Just in case you get hungry while you're setting up the weather station.
	WS, EXT: a forklift operator drives a large yellow cart into the equipment area.	
It will take four helicopter flights to bring all of the necessary equipment out to the ice sheet, so each load must be carefully weighed and balanced.	WS, INT Airport: DR. COVINGTON and DR. GULLEY wheel the cart, now full of equipment, onto the cargo scales to get weighed.	
	MS, Hand-held: DR. GULLEY and DR. COVINGTON scan their inventory lists on notepads and iPads. Mosquitoes buzz all around them.	*Music:* Philipp Weigl – "Not the streets you used to walk along"
	MS DR. COVINGTON (interview)	DR. COVINGTON (v.o.): …But he and I together have been trying to get this project funded for about four years, and finally on our fourth try with the proposal, we managed to get funded.
	ECU, DR. COVINGTON writes inventory on a notepad	
At this time of year, Greenland is under 24-hour daylight, there is no sunset, no sunrise.	WS Disko Bay: icebergs bob lazily in the rippling water	*Water lapping, birds chirping*
	WS Disko Bay: a fishing vessel speeds through the water past multiple icebergs	

	WS Disko Bay: a sailing vessel sits idly among the icebergs	
	CU, INT: a white board reads – "Greenlandic word of the day: kaagisorniarit – have a piece of cake", tilting down and panning left, the board also reads – "Gulley team to airport FLIGHT ETD 2:35 PM"	
	EWS, Panning Right: airport, a red Air Greenland helicopter is revealed, being loaded with cargo	
	Lower 1/3 Title: Day 1	
With the assistance of the Air Greenland ground crew, Dr. Covington prepares to depart with the final helicopter load, for the first of 25 continuous days camped out on the ice sheet. They will have all the food, fuel, and other supplies they need to accomplish their research.	MS: DR. COVINGTON and an Air Greenland ground crewmember load a heavy grey equipment box into the helicopter MS: DR. COVINGTON and a ground crewmember rolls a large cart full of batteries up to the helicopter MS: KATHY and DR. COVINGTON direct ground crewmembers who are assisting the load process MS: KATHY and DR. COVINGTON chat with a ground crewmember after the load is complete. He is incredulous that we are taking so much. KATHY and DR. COVINGTON exit left	
	CU, INT: helicopter cockpit. The pilot opens the door,	

	straps into his seat, and starts flipping switches and pushing buttons. WS, EXT: the helicopter begins to lift from the ground WS, INT: the helicopter maneuvers onto the runway WS, EXT: the helicopter completes its turn and prepares to depart WS, INT: the helicopter accelerates forward WS, EXT: the helicopter flies forward and out of view EWS: rocky mountain ridges with green groundcover, spots of snow and ice MS, INT: the pilot points to the glacial calving area of the approaching ice sheet EWS, EXT POV: the icebergs pass by below	 *Helicopter blades whir*
	MS DR. COVINGTON (interview) GRAPHICS[4]: Moulin cross-section video courtesy NASA Goddard Institute for Space Studies EWS: the helicopter flies over a vast crevasse field in the ice sheet. MS DR. COVINGTON (interview)	DR. COVINGTON: So, a moulin is a hole in the glacier surface where you have a stream along the surface then it goes into this hole in a big waterfall. And typically these moulins take the water fairly directly to the base of the ice. Moulins are important because the water that goes through the moulin to the base of the ice can then speed up the motion of the ice, either by lubricating the surface, or by providing water

	EWS: the horizon is completely filled with the ice sheet below and a blanket of thick cloud cover above MS DR. COVINGTON (interview) EWS: a convoluted stream channel filled with meltwater cuts through the ice sheet below MS DR. COVINGTON (interview)	pressure that actually lifts up the glacier and reduces the friction and allows it to slide forward. So, what we're trying to understand is the relationship between water going into moulins, and the forward motion of the ice.
This phenomenon, known as the Zwally Effect, was first identified in 2002 by Dr. Jay Zwally, a scientist affiliated with the national science foundation, and the NASA Goddard Institute for Space Studies. There is disagreement in the scientific community on the level of impact this effect really has on ice movement, which the team is attempting to test using a variety of experiments.	EWS: through the lower window of the helicopter, a drainage basin full of meltwater forms a craggy lake on the ice surface WS[2]: icy arctic streams PICTURE: Dr. Jay Zwally GRAPHICS: Computer-generated ice flow map of the Greenland ice shelf, courtesy NASA Goddard WS: the helicopter sits on the ice sheet, rotors spinning, as it prepares to take off	
As the last helicopter flight departs, leaving the team alone on the glacier, the first signs of trouble appear on the horizon – a white-out blizzard.	WS, Tilting up: the TEAM sits on equipment boxes as the helicopter lifts off, and flies directly overhead as they wave goodbye MS: DR GULLEY, CELIA, and VICKIE as a white-out storm approaches from behind them. DR GULLEY turns to look, as does CELIA.	*Music:* Sergey Kovchik – "One Note"

Aside from the small survival shelters the team members occupy for personal space, most of their time is spent in the domed group tent, where they prepare all meals, and perform their research.	MS DR. COVINGTON (interview) EWS, Panning: the camp, a collection of orange pup tents and a large domed group tent, is buried in snow marked with deep footsteps. WS: DR GULLEY trudges through the snow towards a cache of equipment, fuel, and food MS: VICKIE and CELIA dig out the snow buildup around the group tent WS: DR GULLEY returns from the cache, food in hand, and nearly topples over as he sinks past his knees in the snow unexpectedly MS DR. COVINGTON (interview): MS, Tilting Up: DR. COVINGTON walks through deep snow through the camp MS: VICKIE kicks snow buildup away from a connected propane tank at the rear of the group tent MS: DR. COVINGTON and DR GULLEY stand outside the group tent, preparing to erect a small storage tent to keep equipment out of the snow, which is flurrying around them	DR. COVINGTON: One of the biggest challenges for us this year, was that it was much colder than typical, and also we had a lot of snow, so a few hours after we arrived it started snowing, and at first my reaction was, ‘well, it’s the Greenland ice shelf, it snows sometimes’ we could be stuck here, maybe a day or so while we wait for the snow to melt, until it was clear enough for us to find a safe way to walk around, at this point, we hadn’t really explored around, so we didn’t know where it was safe to walk, or where there might be crevasse fields. So, the snow was really a show-stopper until it melted. But then a day passed, and another day passed, and eventually a week passed, and there was still snow! At this point we were starting to get a little bit anxious about when we were going to be able to do what we had come to do, also certainly starting to get a bit of cabin fever from being cooped up in the group tent for a week.

	MS, INT TENT, Panning Right: VICKIE is preparing a meal on the improvised kitchen setup, while DR GULLEY and CELIA are tying knots in para cord, and DR. COVINGTON works on his laptop. *Lower 1/3 Title: Day 2* MS, INT TENT: DR. GULLEY is preparing coffee while VICKIE prepares to call in to the KISS station *Lower 1/3 Title: Day 3*	DR. COVINGTON: Maybe today is not be the best day to recon the moulin. DR GULLY: Yep. VICKIE: You might find one! You might find one, the fun way… DR. GULLEY: I mean, we can't even see the ~~fucking~~ streams. DR. COVINGTON: It's like, it's a forced rest day. DR. GULLEY: (*chuckles*) Forced? You know, you got the Bataan death march, and now we have the Bataan…rest day!
Each morning, the team has to check in with the KISS station by satellite phone, to get the day's weather reports, and to coordinate their activities as a safety precaution.	EWS: Back on the ice margin, at the KISS station, viewed from down the street in a row of buildings WS: Front of KISS building CU: VICKIE is holding the satellite phone, making her morning call-in	VICKIE: Hey, Jessie, this is Vickie up at Gulley camp…We're

	MS: DR. COVINGTON and CELIA look on, pensively	doing well…um yeah, we got some yesterday, but it’s clearing up now, but getting a bit windier. We were wondering is there any kind of extended forecast? We realize that the uh, the fidelity of it would be lower, but we’re kinda curious if there’s a longer forecast
	CU: DR GULLY stares at the ice floor of the tent, pensive	
Dr. Gulley was only meant to be in camp for the first few days, and was due back in South Florida to coordinate a second camp further up the ice sheet.	MS: Vickie hangs up the phone and takes a deep breath MS: DR GULLEY, CELIA, and DR. COVINGTON listen intently	VICKIE: Ok, so, she can request a 5-day forecast, and she’ll do that, she’ll request that tonight. Um, today we’ve got wind out of the southeast, 8-15 knots, going up to 20 in the evening, drifting snow on the ground, no surprise, minus 10 to minus 2 Celsius, tomorrow is going to be cloudy, overcast, with winds out the southeast 10-15 knots, more wind in the morning, dropping off towards the evening, and then minus 5 to plus 3, Celsius.
	MS: DR. GULLEY, CELIA, and DR. COVINGTON are in stunned silence. Finally, DR GULLEY speaks up	DR. GULLEY: Well, it’s not looking good for getting that moulin instrumentation installed…
		DR. COVINGTON: What do we have to learn from you in order to be able to do it?
	CU: DR. COVINGTON	
	CU: DR. GULLEY	DR. GULLEY: Like, if stuff starts going wrong…it’s like anything else, if everything goes right,

		it’s really easy, but when stuff starts going wrong, that’s when it gets harder. I mean, after you do it once or twice, it’s really easy. But, um…would it be helpful if I stuck out and did the instrument installation with you guys?
	CU: DR. COVINGTON	DR. COVINGTON: I mean, there’s no question it would be helpful, but, you have a number of reasons to, get out of here.
		DR. GULLY: Yeah…
With their movements restricted, the team decides to handle every aspect of their mission that they possibly can at this point, including setting up a weather station on the outskirts of camp.	EWS, Panning Right: the frozen landscape is periodically broken by drifts of snow MS: DR. GULLEY and DR. COVINGTON trudge through the falling snow towards the equipment cache CU: Sled and gear pack partially buried in snow MS: equipment boxes and fuel buried in snow MS, Tilting Up: DR. COVINGTON examines a long cardboard tube from the equipment cache	
Anything that is to be installed on the ice for any	WS: in white-out conditions, VICKIE pulls food out of the deep-freeze chest outside the group tent, while CELIA and DR. GULLEY walk to the	

length of time requires drilling several feet below the ice surface. The weather station will require six feet, which calls for several flights of ice drill bits.	edge of camp to begin setting up the weather station MS, Zoom Out: DR. GULLEY and CELIA prepare to drill the hole for the weather station mounting CU: Dr. Gully's feet as the drill bit spins, biting into the snow and ice beneath. He shifts around, pushing the meter-long bit entirely into the ice, pulling it out a few times to clear it of powdery snow MS: DR. GULLEY stands by as CELIA prepares to add another meter-long flight to the drill bit already in the hole. Drilling continues as soon as she is done	
Meanwhile, Dr. Covington assembles the weather station components, and other instruments that they will need to prepare for the month ahead.	MS: DR. GULLEY and CELIA continue drilling into the ice. When DR. GULLEY is satisfied, they both pull the entire nine-foot long combined drill bit from the ice, and set it down. DR. GULLEY fist-bumps CELIA MS, INT: DR. COVINGTON is hard at work assembling the weather station components inside the tent CU: VICKIE is preparing bread and cheese as a pot of tomato soup boils behind her EWS, Panning Right: As the horizon shows signs of clearing, DR. GULLEY and CELIA break into song at the weather station, dancing as if	DR. GULLEY: Perfect! *Music:* Monplaisir - "#9" DR. GULLEY: …"Always look on the bright side of life!" (whistles)

	crucified due to the appearance of the weather station frame	
	MS, INT: DR. GULLEY enters the tent as DR. COVINGTON continues working on the weather station components	DR. GULLEY: I think we should name the weather station “Golgotha”
	MS, INT: CELIA observes DR. COVINGTON assembling the weather station	
	MS, INT: DR. GULLEY, CELIA, and DR. COVINGTON with VICKIE looking on	DR. GULLEY: We got everything kinda pulled out of the snow, so it’s not going to re-freeze, get the weather station going up, beyond that, I have, I mean, it’s…already 2, so, I think get the weather station up, get organized, then wake up and see what the weather’s like tomorrow. We might start probing around for GPS installation locations, those will probably take all day…moving 400 pounds of batteries The first thing we going to do is walk out and find where everything’s going to go, and mark it, so that we have a safe route identified. Nobody’s falling into crevasses.
	EWS, EXT: The camp and horizon, which appears clearer, with patches of clouds overhead	CELIA: Hmm? DR. GULLEY: Nobody’s falling into crevasses! VICKIE: Safety third!

With high winds approaching, Dr. Gulley and	WS, EXT: Weather station *Lower 1/3 Title:* Day 4 MS: Weather station CU: Weather station wind speed sensor spinning wildly MS, INT: DR. GULLEY talks to DR. COVINGTON as he spreads peanut butter on his pancakes WS, EXT: a pup tent partially buried in a snowdrift that threatens to become just as tall as the tent	DR. COVINGTON (v.o.): So, what was the weather forecast? It sounded like it wasn't good… DR. GULLEY (v.o): Yeah, it's not awesome… DR. GULLEY: Ah, so today is like this, but with snow… DR. COVINGTON: With snow?! DR. GULLEY: And wind. Tomorrow, ah, well, temperature minus 5 to plus 3. Tomorrow, is same temperature, but with winds 15-20, with gusts up to 40, so we're going to want to get the guy lines out. DR. COVINGTON: So, we got a couple more days of…nasty? DR. GULLEY: So basically, based on that, there's no way that we're getting any kind of instrumentation installed in a moulin before the 7th, which is my last takeout day to make my flights home. I don't even know, I don't know what to do about that. Can you pass me the maple syrup? My answer to that is that we should just…open the scotch now.

the team reinforce the tents by lashing down guy lines. This secures the tents to the ice and gives them a better chance of staying put.	WS: DR. GULLEY walks among the tents with his drill as VICKIE and CELIA are tying down the tents’ extra guy lines to protect against the forecasted wind gusts	
On the ice sheet, the tent stake of choice is a length of bamboo pole, where thickness, durability, and light weight make it an ideal anchor.	MS: CELIA ties a tent guy line	
	WS: VICKIE and DR. GULLEY grab handfuls of bamboo poles to use as extra stakes on all tents	*Music:* LesyanZ – “Inspire Me”
	MS: CELIA, DR. COVINGTON, and DR. GULLEY return from checking the weather station	
	CU: Icicles have formed on the weather station’s solar panels MS DR. COVINGTON (interview) CU, INT: DR. COVINGTON assembles the tuffwing glider	DR. COVINGTON (v.o.): So, one of the few things we could do while we were snowed in was fly some of the drone vehicles that we had, and use that as a way doing some reconnaissance of the area. So, we have a tuffwing, which is a plane that automatically flies over a grid and takes pictures…
	CU, INT: DR. COVINGTON views a topographical map on his laptop, programming the route of the tuffwing glider	…And we’re using that to map out the local area to see the shapes of the drainage basins, and drainage divides, and so on and figure out which areas are draining to which moulins…
	WS, EXT: DR. COVINGTON, CELIA, and DR. GULLEY carry the tuffwing to a clearing just outside the camp boundaries	…And so we went ahead and started that mapping process

The tuffwing glider the team has named “the Ice Bat” generates a digital terrain model of the surrounding area, superior than available satellite imagery. This mapping tool is critically valuable to the team as they try to orient themselves, and track changes to the melting landscape over time. Dr. Covington compares this to survey data they brought with them.	MS: DR. GULLEY picks up the tuffwing from the ground as DR. COVINGTON holds the remote control. The propeller spins, and DR. GULLEY releases the glider, which takes off and gains altitude MS: VICKIE, DR. GULLEY, CELIA, and DR. COVINGTON all stare up at the sky where the glider is flying WS: Glider flies overhead across the sky MS: CELIA monitors the laptop, while DR. COVINGTON holds the remote control and watches the glider WS: The glider comes in for a landing inside camp, skids to a halt on the ice WS: DR. COVINGTON carries the glider back to the group tent PICTURE: Close view of the group tent and storage tent from tuffwing flight data DISSOLVE to PICTURE, Zoom Out: Medium view of camp and surrounding terrain DISSOLVE to PICTURE, Zoom Out: Topographical view of 2km radius of camp	while we were stuck in the snow…

	MS: DR. COVINGTON holds a laminated satellite photo in his hand	
	CU: DR. COVINGTON's finger tracing a line on the map	
	MS: DR. GULLEY and DR. COVINGTON looking at a laptop screen (of tuffwing glider data results)	DR. GULLEY: Oh, I see what you're saying. So, if you're coming back towards camp, this is downstream, and that's intersecting…right.
	CU: DR. COVINGTON	DR. COVINGTON: It looks, it looks like a big enough stream, I don't know. I mean, this feature, I agree does look a lot like the one we saw.
	MS: DR. GULLEY and DR. COVINGTON	DR. GULLEY: You know, what we really need is a flamethrower
		DR. COVINGTON: Maybe call in a napalm drop. Maybe CPS does that.
		DR. GULLEY (to VICKIE): Oh hey, do you think you can order one of those for us?
		VICKIE: Sorry?
		DR. GULLEY: I said do you think you could order a napalm drop from CPS?
		VICKIE: Yeah, yeah. I'll get on that.
		DR. GULLEY (v.o.):

As daunting as the situation is, the team still has a few tricks up their sleeves	WS (various): frozen landscape with drifting snow CU, INT: DR. GULLEY MS: DR. COVINGTON EWS: ice sheet with mountains in far background MS: DR. GULLEY and DR. COVINGTON WS, EXT: fluffy snow falls on the camp as DR. GULLEY walks past the	"We know we were funded to study all this water flowing into moulins, but look at this outrageous record that we have of snow accumulating in the middle of July!" DR. COVINGTON (v.o.): We could start doing snow depth measurements… DR. GULLEY: "Day 5, the snow gets deeper…" We could set up one of those Houtin snow thermometers like back behind the tent… DR. COVINGTON: Part of it's just being here, but we do, we do want to come back. We're more likely to be able to come back if we can get some good data DR. COVINGTON: If we find an image that looks like it might be the moulin, in the tuffwing flight, we could possibly fly the quadcopter over, looking for that feature and basically we can get down really close, maybe 10 meters off the ground, to look at the, the feature. CELIA: Ok. DR. GULLEY:

	quadcopter on its' landing pad.	It didn't stop snowing, it just got fluffy! *Music:* Jon Watts – "Godspeed Thunder"
	WS: The Quadcopter takes off into the sky in dramatic fashion EWS (various): POV drone shots flying over the ice sheet, examining different stream formations WS: POV drone, approaching camp WS: Drone lands outside group tent while DR. GULLEY, CELIA, and DR. COVINGTON watch MS, INT, Tilt Up: Drone on top of supplies box, DR. COVINGTON looking at laptop with satellite photo in hand CU: Satellite photo CU: Hand on laptop keyboard	DR. COVINGTON (v.o): We also had a 3DR Solo Quadcopter, which mostly we were using for aerial filming, but it also turned out to be handy to do an initial search for the moulin. We knew approximately where the moulin was that we wanted to instrument, we didn't know exactly where it was with respect to our camp, and so we did a bunch of flights out from camp basically searching for it until we thought we found it.
	MS: DR. GULLEY, DR. COVINGTON, and CELIA all review the footage on the laptop	DR. COVINGTON: So, if we go down here, we have to cross the channel again here, to what looks like a low swampy area.
	MS: DR. GULLEY	CELIA: So, what's the plan for tomorrow?

	MS: CELIA and DR. COVINGTON fly the tuffwing	DR. GULLEY: Yeah, so, can't do much, since we don't know where the moulin is yet, so we're going to wake up, if there's no wind, Matt's going to fly a drone, try and find the moulin. Ah, if that doesn't work, we'll go see what we can find from the ground. If it does work, we'll go see what we can find from the ground, but with more direction…
	WS: the tuffwing flies across the blue sky CU: DR. GULLEY	…So, if we can find a prominent "T" depression, in the snow, we'll know that we probably found the site. I would hope that because the snow would be sagging into the moulin or something that we'd be able to pick it out, but I don't know with all the snow that's drifted into the streams around here. I mean, our original water area is completely buried under a snow bank.
	MS: DR. COVINGTON	DR. COVINGTON: It would also just be good to go out on foot, see what we see.
	CU: DR. GULLEY	DR. GULLEY: But yeah, I'd be ok running the ridge or something like that all roped up tomorrow.
	MS: DR. COVINGTON WS: Streams buried in snow and partially frozen	DR. COVINGTON: Yeah, it'd be kinda nice to be able to scout around a little bit, and you know, do something.

	Lower 1/3 Title: Day 5	
With the unknown terrain and the level of danger involved, only Dr. Covington, Dr. Gulley, and Celia will venture out from camp. Dr. Covington carries with him a helmet-mounted camera to capture the trek.	MS: VICKIE and DR. COVINGTON outside the tent, DR. COVINGTON prepares his helmet-mounted GoPro camera	
	MS: CELIA and DR. GULLEY get ready for their walk by putting on mountain climbing gear	
At any point, a team member could find themselves falling into a deep crevasse in the ice, so they will be fully connected with professional mountaineering harnesses.	CU (various): CELIA, DR. COVINGTON, and DR. GULLEY all tighten their climbing harnesses, which are covered in D-rings and climbing gear.	
	MS: the team departs camp, roped up	
	MS (helmet cam POV): DR. COVINGTON works with the climbing rope to give DR. GULLEY enough slack to move forward to investigate a glacial feature	
	WS (helmet cam): DR. GULLEY shovels snow away from a hole in the ice	
	CU (helmet cam): DR. COVINGTON investigates the opening, probing it with his ice axe	
	MS: team returns to camp, amidst blowing drifts of snow	

Over several days, the trio takes multiple journeys out onto the ice, looking for their target.	EWS: under a clear blue sky, the snowy landscape is buffeted by blowing snow WS: DR. COVINGTON and DR. GULLEY stand on opposite sides of a flowing meltwater stream *Lower 1/3 Title:* Day 8 MS: DR. COVINGTON acts as a rope anchor by sitting on a pack and holding the climbing rope, while DR. GULLEY cautiously moves forward until he is laying on his belly looking down into a moulin	
Finally, it appears they have located the moulin	MS: DR. GULLEY pushes himself up to his knees, looks back towards DR. COVINGTON and nods his head WS: CELIA carefully makes her way towards the moulin to see for herself	
Now, the real work can begin	WS: CELIA, DR. COVINGTON, and DR. GULLEY stand as a group before heading back to camp MS: VICKIE gives CELIA and DR. GULLEY an enthusiastic thumbs-up, and they all smile EWS: the midnight sun glares through a partly cloudy patch of sky with dark clouds on the horizon	

The team will install a complex system of instruments and infrastructure to support their research, which takes several days to set up.	WS: CELIA and DR. GULLEY carry bundles of long pipe across the ice WS: CELIA, DR. COVINGTON, and DR. GULLEY haul batteries on a sled, and carry all the equipment they can in a single load WS: DR. COVINGTON, DR. GULLEY, VICKIE, and CELIA all approach the fuel and equipment cache to begin unspooling a long cable MS DR. COVINGTON (interview) CU: spool of cable being unwrapped, the outer protective plastic being cut with a knife MS: DR. GULLEY and DR. COVINGTON spin the spool, unwinding the cable WS: CELIA is holding the cable end and walking towards the moulin site WS (drone): VICKIE supervises the cable spool as it continues to spin, as the rest of the team is pulling the cable out MS: CELIA, DR. COVINGTON and DR.	DR. COVINGTON (v.o): So, to study the moulins here on the ice sheet we're lowering… …water level sensors, pressure sensors, deep inside the moulins, potentially thousands of feet… …into the ice. This allows us to measure how much water is coming up in the moulin, which tells us how much water pressure there is at the base of the ice… …which is directly important for the sliding of the ice. …so we're lowering these pressure transducers in on a long, long cable that's built to withstand all the forces that it might experience in the moulin…

	GULLEY all stand next to the moulin site with the cable and sensor	DR. COVINGTON: …and then additional work, we’re looking at the water that’s flowing into the moulin…
	CU: DR. GULLEY is winding a thin cable over his elbow, holding one end in his teeth	
	MS: DR. COVINGTON (interview)	…and we’re doing that in a couple of ways.
	WS: CELIA, DR. COVINGTON, and DR. GULLEY are joining together sections of pipe with a sensor in the middle	…one of the ways is that we have sensors that can measure the height of the stream channel, the depth of the water in that stream…
	CU: DR. GULLEY adjusts the sensor at the middle of the assembled apparatus	
	WS: DR. GULLEY and DR. COVINGTON haul the assembled pipes and sensor over to the moulin stream	…and we can relate that to how much water is actually flowing into the moulin at any given time.
	WS: DR. GULLEY and DR. COVINGTON set the apparatus up across the moulin stream, DR. COVINGTON leaps back across the stream.	
	MS: CELIA and DR. GULLEY attempt to haul a very heavy battery across a frozen stream using a sled. It slides off into the water	
	EWS (drone): DR. GULLEY and VICKIE haul solar panels across a treacherous looking stream	

	MS: DR. GULLEY and DR. COVINGTON strain to pull on a large grey equipment box that appears very heavy, and barely budges CU: CELIA reads instructions on a laptop CU: Ice drill near someone's boot CU: DR. GULLEY drills into the ice, the drill and bit nearly obscuring his face, as it oscillates wildly in his hands. MS: DR. GULLEY and DR. COVINGTON as the drill continues to buck wildly as it sinks into the ice. WS: DR. GULLEY, DR. COVINGTON, and CELIA raise a long pole into the hole they just drilled (Iwo Jima style) MS: DR. GULLEY, DR. COVINGTON, and CELIA continue to set the pole until it is fully seated in the ice CU: DR. COVINGTON attaches a cymbal-looking device to the top of the pole MS: DR. GULLEY and DR. COVINGTON continue to unpack equipment. DR. COVINGTON lifts a solar panel array, and places it on another pole seated in the ice	DR. COVINGTON: Since we're interested in the motion of the ice, we're also using really high precision GPS units that are installed onto the ice in different locations, to measure how quickly it's sliding. And in particular we want to look at how the water going into the moulin impacts, whether it does impact the motion of the ice, which is being measured by those GPS's.

This particular aspect of the expedition required a great deal of planning and preparation. Several months previous, Dr. Covington and another of his students, Brandon Conlon, developed the pumping system, and carefully prepared several gallons of dye for the experiment.	MS: DR. GULLEY, CELIA, and DR. COVINGTON seal up the GPS unit WS, Panning Down: the sun peeks out between clouds as DR. GULLEY, CELIA, and DR. COVINGTON are seated around a collection of equipment boxes, laptops, test tubes, and bottles of dye CU: CELIA dumps a bottle of dye into a stream, and it spreads out with the running water WS: DR. GULLEY, CELIA, and DR. COVINGTON work with the dye. CELIA is measuring out a small amount for dilution while crouched on her knees on the ice MS, INT (flashback): DR. COVINGTON and his PhD student prepare the dye and pump apparatus for transport in his geosciences lab CU, INT (flashback): DR. COVINGTON mixes the bottles of dye in a sink in his lab MS, EXT: DR. COVINGTON watches data on a laptop as he calibrates a fluorescent sensor in a bottle of distilled water. CU: pump inside bright yellow case, slowly turning	DR. COVINGTON (v.o.): One of the ways that we're using to measure the flow in the streams on the ice sheet, specifically the streams that are going into the moulins, is using a fluorescent dye. …and we have sensors that can detect this dye at a very low concentration in the stream. And upstream, we inject the dye using a pump, we pump dye into the water at a known rate, and by measuring that concentration downstream we're able to actually calculate how much water is flowing in the stream.

Finally, the day has arrived, and the team will attempt the most crucial part of their experiment – probing the moulin with a cable more than 750 meters long.	MS: DR. COVINGTON gently sets down a pair of sensors into a low level stream to test them CU: sensors in the stream MS, Panning Right: small stream full of bright pink fluorescent dye MS: CELIA and DR. COVINGTON walk along the dyed stream, pointing out and inspecting the flow CU: sensors in the stream as the dye reaches them CU, INT: complex equations on a notepad, a hand draws more notes in the calculations MS, INT: DR. COVINGTON continues writing calculations with CELIA in the background on her laptop CU, EXT: CELIA, wearing her mountaineering helmet, cigarette dangling from her mouth, pulls on a pair of gloves. CU: DR. COVINGTON, wearing his helmet, turns to face the camera CU: DR. GULLEY, wearing his helmet, stares solemnly into the distance WS: the moulin apparatus complete with sensors is set and ready. The stream is flowing.	*Music:* Monplaisir – "#11"

DR. GULLEY examines the moulin one last time before the attempt, firmly anchored to the shoreline. He is taking no chances, as a fall into a moulin can become a thousand foot drop into a one-way waterslide.	MS: DR. GULLEY cautiously makes his way on a rope towards the edge of the moulin, braces himself, and carefully chips away at the ragged edges with his ice axe MS (drone): DR. GULLEY continues chipping away at the edge, and looks down into the abyss of flowing water	
To safely lower the cable in a controlled manner, they drill steep holes into the ice in a V-formation, feeding through nylon ropes and straps until they make a secure anchor capable of supporting the hundreds of pounds of high-strength shielded cable.	MS: DR. GULLEY and DR. COVINGTON drill holes for an anchor to support the weight of the cable MS: DR. GULLEY, CELIA, and DR. COVINGTON work together to pull a small nylon cable through the V-shaped trench they drilled, feeding in a thinker nylon strap tied to its end CU: DR. GULLEY and DR. COVINGTON both pull their V-strap anchors together to ensure that they meet at the correct point	
The cable must also be spread out over a long arc along its several hundred meters in length, to prevent it from curling on itself. As the cable is fed into the moulin, the team must watch out for the moving cable, which can be a deadly hazard if it runs out of control.	WS: DR. GULLEY, VICKIE, CELIA, and DR. COVINGTON all work together to spread out the cable so it won't curl up onto itself	
As all preparations are finalized, Dr. Gulley briefly reviews the plan with Dr.	MS: DR. GULLEY and DR. COVINGTON confer on the final preparation details before the attempt	

Covington. Once they get started, all communications will have to be by radio due to the high winds, and how far the team will be spread out. Making matters more complicated, the data they did receive from the sensor made no sense, and only updated every 30 seconds, or as the data logger was intended to function over the months it would be left on the ice sheet. They will have to figure out how to reprogram the software.	CU: water flowing through the moulin WS (drone): overhead approach view of moulin setup with sensors, cable going towards moulin DR. GULLEY with the end of the cable in hand MS: (drone): DR. GULLEY tosses the cable end into the moulin, keeping control of the cable feeding CU: rope setup assisting the feeding of cable into the moulin CU: DR. COVINGTON examines data logger and laptop MS: DR. GULLEY and DR. COVINGTON pulling the cable back out MS: DR. GULLEY, VICKIE, and DR. COVINGTON examine the tangled mess of cable, DR. GULLEY approaches it and pulls apart a section of the tangle EWS: frozen landscape with meltwater lake WS: DR. GULLEY and CELIA standby as DR. COVINGTON and VICKIE examine the laptop data CU: same	DR. COVINGTON (v.o.): So, when we first attempted to instrument the moulin, we started lowering in cable, lowering in cable, and it seemed like everything was working alright, the cable was getting heavier, but we weren’t hitting the water level, we weren’t seeing any changes on the sensor, and once we got, maybe 3 or 400 meters of cable in, we still hadn’t hit the water, and we thought that that was too far, we should have hit the water by then. And so we started trying to pull it out, and luckily we were able to pull it out, we pulled out a huge rat’s nest of cable that had all gotten tangled up.

Pouring over technical manuals, the team leads attempt to figure out the software problem.	WS: DR. GULLEY extends himself over the moulin again to inspect the formation MS DR. COVINGTON (interview) CU, Dutch Angle: DR. GULLEY removes his sunglasses in frustration WS Hand Held: VICKIE illustrates with her fingers how a rig could allow the cable to only drop straight down to avoid getting stuck. Pan Right to DR. GULLEY and DR. COVINGTON EWS: frozen landscape, frozen stream *Lower 1/3 Title:* Day 15 MS, INT: DR. GULLEY and DR. COVINGTON look over the manual for the sensor and how to program the data logger.	DR. COVINGTON: It was a little frustrating, a little bit surprising, Jason had instrumented 5 other moulins before, and everything had always basically just gone in but this time, for some reason, we weren't hitting the water, we weren't exactly sure why that was. DR. GULLEY: Yeah, but I mean, I looked at it, it's going straight down the middle…I mean, it's going exactly where I want it to go, even though it went into the side… DR. COVINGTON: So, we just need to know which sensor it is, so we need to look at the serial number. DR. GULLEY: Ok, I hope they wrote down the calibration classes… DR. COVINGTON: They're really similar

Each night it is left on the ice, the cable must be pulled out of a narrow trench it melts into, caused by its dark color under the midnight sun.	WS: VICKIE is carefully pulling the cable out of the trench it had dug for itself "overnight"	DR. GULLEY: So, we can ballpark it, in our spreadsheet *Music:* Musway Studio – "Emotional Romantic 2"
Dr. Covington takes the opportunity to fully set up his dye trace sensors across the moulin channel.	WS: DR. COVINGTON tosses CELIA a rope from one side of the moulin stream to the other	
As with the dye itself, Dr. Covington practiced these maneuvers back home in Arkansas before bringing the experiment to Greenland.	WS (flashback): DR. COVINGTON tosses a rope across a stream in Arkansas to Brad, his PhD student	
The dye sensors must float near the surface directly in the middle of the stream for the experiment to work, and stay there for several weeks while the other instruments are running.	MS: DR. GULLEY, VICKIE, CELIA, and DR. COVINGTON stand streamside, as DR. COVINGTON hoists the dye sensor down into the water	*Music:* Musway Studio – "Epic Inspiring 2"
The pump runs on a 12-volt battery, and a tank of carefully diluted dye. Dr. Covington, assisted by Brandon, gave the pumps an endurance test ahead of time to ensure that everything would work correctly.	MS (flashback): Dye pump case streamside in Arkansas	
Of course, not everything worked perfectly at first, but	MS (flashback): equipment container full of dye bottles, hoses	

this gave Dr. Covington time to work out the bugs in the system. With the dye trace running, the team can turn their focus back to their sensor problem. How do you fix software problems on the ice sheet? Just like anywhere else… …You call tech support. With the assistance of Dr. Gulley's PhD student Jessica, Dr. Covington is able to reprogram the software to	MS (flashback): Dr. Covington grinning at the camera with his mouth covered in dye MS: Dye pump case on the ice with hose leading into the moulin stream, emitting a steady pulse of dye CU: End of pump hose and dye pulse WS: DR. GULLEY, VICKIE, CELIA, and DR. COVINGTON stand near the dye pump as it sends a bright stream of fluorescent dye downstream MS: an ongoing wave of dye flows towards the moulin CU: DR. COVINGTON is hunched over the laptop, examining it MS: DR. GULLEY holds the satellite phone up to his ear, taps his foot, checks his watch	DR. GULLEY: Hey Jessica, how's it going? Yeah, good. So, it's Jason out on the ice sheet again. Yeah, we're still having some problems with the data loggers, I was hoping you could have a short chat with Matt…yeah, yeah, here you are. DR. COVINGTON: Hey, Jessica, it's Matt…doing alright…

update every 5 seconds, and gives precise readings in meters of depth. Now, they are ready to try again.	MS: DR. COVINGTON sitting on the ice, laptop across his legs, phone in hand	*Music:* Monplaisir – “#11”
	WS: DR. GULLEY and DR. COVINGTON prepare for the next attempt. DR. GULLEY pulls the sensor towards the moulin	
	MS: DR. GULLEY lowers the sensor into the moulin again	
	CU: Water rushing furiously into the stream from all sides (through holes in the bank)	DR. COVINGTON (v.o.): We decided to wait a few days and wait for a day when there was lots of melt that would maybe help to, to carry it in…That didn’t work.
	MS DR. COVINGTON (interview)	
	WS: DR. GULLEY and DR. COVINGTON pull on the cable, struggling to get it back out	
The team tries again and again with no success, and each time they have to stop and pull it out again, they are lifting hundreds of pounds of cable against the massive water pressure of the moulin water flow. They keep trying, in conditions that range from fair to blizzard, barely able to hear each other over the driving wind.	EWS: DR. GULLEY, VICKIE, CELIA, and DR. COVINGTON survey another “rat’s nest” of pulled out cable	
	EWS (drone): overhead view of DR. GULLEY and VICKIE as there is a third attempt	
	WS: DR. GULLEY, CELIA, and DR. COVINGTON pull the cable out again	

As conditions worsen again, the team begins to lose the struggle against the forces of nature. It starts to feel as though they won't succeed.	CU: VICKIE talks into a walkie-talkie MS: water flowing freely in the stream (water is up, no reason to not have enough flow) MS: DR. COVINGTON (interview) WS: DR. GULLEY and DR. COVINGTON lowering the cable with an anchor and pulley system from the opposite side *Lower 1/3 Title:* Day 16 WS: DR. GULLEY, CELIA, and DR. COVINGTON pulling the cable back out MS: DR. COVINGTON (interview) CU: DR. GULLEY lowers the sensor, wrapped in a Coleman chair seat, into the moulin CU: VICKIE looks up from the laptop, shakes her head 'no' MS: DR. GULLEY walking along the bank, trying to carefully lower the cable in small increments as snow blows all around him	DR. COVINGTON: We also tried lowering it from different angles, to see if it was getting caught somewhere, maybe if we lowered it from the other side of the moulin, maybe then it would go in… Eventually we started hitting the water, but it was never going below a few meters of depth, and then stopping at about the same depth, any way we tried to lower it. The one last thing we tried, we actually tied on the parts of a broken chair, just the cloth from a broken chair we had in camp to give it a lot of drag, so hopefully the water would pull it in… but again, we just got the same results. DR. COVINGTON (v.o.): …at this point we started to think that the whole moulin might be going into a narrow crack, a narrow crevasse, the crevasse where the moulin

	WS: DR. GULLEY, CELIA, and DR. COVINGTON pull apart another “rat’s nest”	had formed, and that the depth just hadn’t gotten large enough yet that the sensor could actually get through it, there just hadn’t been enough melt yet. So, at that point we started thinking about trying to instrument a different moulin.
Finding the next moulin might be more difficult this time, as just a few days previous, tragedy struck one of the camp’s most useful pieces of equipment.	CU: DR. GULLEY looks off into the distance despondently as freezing rain pelts the team (and camera)	*Music:* David Hilowitz – “Displaced Memories”
	WS: Weather station, camp in white-out conditions	
	Lower 1/3 Title: Day 18	
	EWS: DR. COVINGTON stands solitary against the vast frozen landscape	VICKIE: OOH! OH GOD!
The Ice Bat has crashed, breaking its propeller completely off.	MS: VICKIE releases the tuffwing into the air, which promptly crashes	
	CU: tuffwing crashes spectacularly on the ground	
Dr. Covington attempts to fix the tuffwing with Celia’s assistance, but they just don’t have the spare parts they need to get it flying again. They’re going to have to stick it out on foot with the information they have.	CU: DR. COVINGTON carefully retrieves the broken tuffwing and its propeller MS: CELIA, and DR. COVINGTON stand outside the group tent, cleaning the snow from the tuffwing CU: CELIA, and DR. COVINGTON attempt to fix the tuffwing	

Everything from the old site must be moved again and repositioned at this moulin, taking precious time away from getting this site instrumented, and recording the data the team is after. Vickie and Celia drill out the new V-anchor, and set up the lowering harness. Dr. Gulley prepares the team assignments and lays out his plan.	MS: The stream near the camp flows strongly as the sun shines down out of a clear sky WS: DR. GULLEY and CELIA join DR. COVINGTON outside the tent, and they start walking away from camp, crossing the nearby stream EWS, Zoom Out and Panning Right: DR. COVINGTON pulls one end of the sensor cable, dragging it to the new moulin site. The camp comes into view, showing how close it is. WS: DR. GULLEY and DR. COVINGTON continue to pull on the cable towards the new site MS: DR. COVINGTON sits streamside, wiring up the data logger on the new site MS: VICKIE and CELIA drill holes in the ice MS: DR. GULLEY, VICKIE, and DR. COVINGTON position the new GPS unit's solar array CU: DR. GULLEY puts on his sunglasses as VICKIE, CELIA, and DR.	DR. COVINGTON (v.o.): So, we spent a day looking around and scouting out different potential moulins to instrument, and the one we eventually decided on was really quite close to camp, only a couple hundred yards from camp, and one of the reasons for that was that we were actually starting to run out of time, and it had the advantage that if we were unsuccessful, we could pull all of the equipment and put it there in our camp to be stashed for the next year where we would try again.

	COVINGTON stand by for the plan of action MS: DR. GULLEY, VICKIE CELIA, and DR. COVINGTON	DR. GULLEY: So, Vickie will be sitting at the computer, kinda same thing as last time, just give us a shout, whenever you see like a spike in water level, and if it hasn’t been changing for a while and you’re watching us feed cable in, just keep saying ‘no change, no change, no change.’
	MS: CELIA, and DR. COVINGTON stand by at the cable anchor	*Music:* Jon Watts – “Tsunami”
	MS: DR. GULLEY lowers the sensor into the moulin MS: VICKIE at laptop CU: Following the rope that’s tied onto the cable all the way to the moulin, where DR. GULLEY is grimacing under the weight	DR. COVINGTON (v.o.): We started the next day, trying to lower the cable into that moulin, we lowered the cable until it was about 50 feet under the water, but then, it stopped going down.
	MS: VICKIE at laptop	DR. GULLEY (o.c.): No change? VICKIE: 2-1 point 4, no change.
	MS: DR. GULLEY and DR. COVINGTON pull the cable back out of the moulin, struggle up a short hill, and with a signal from CELIA that the tension is off and the cable is anchored, they let it fall to the ground	DR. COVINGTON (v.o.): …and we tried pulling it out, lowering it back in, and so on, we couldn’t get it to go beyond that point, so at this point at least we knew we were in the water, we weren’t as deep as we were hoping to be, but it was a partial success, in that we could at least capture most of the

NARRATOR: For Celia and Dr. Gulley, their time at low camp has come to an end. They have to go back in order to prepare for the second camp of the season, where Dr. Gulley will spend an additional 25 days attempting the same experiments on thicker ice. Dr. Covington finally receives the spare parts needed to repair the tuffwing glider, which he now has time to turn his attention to. However, when he checks the moulin sensor data the next day, he makes a surprising discovery.	WS: DR. GULLEY stands at the moulin hole, stunned WS: DR. GULLEY stumbles back up the short hill towards CELIA and DR. COVINGTON, both of whom have their hands on their hips, disappointed CU, INT: DR. GULLEY speaks on the satellite phone WS: DR. GULLEY, CELIA, VICKIE, and DR. COVINGTON are gathered around the cable anchor. DR. GULLEY is seated on a small pad, resting. MS, INT: DR. GULLEY, DR. COVINGTON, and CELIA are relaxing in the group tent CU: CELIA is barely awake *Lower 1/3 Title:* Day 22 EWS: a helicopter departs low camp CU, INT (various): DR. COVINGTON repairs the tuffwing EWS: partly cloudy sky with bare ice landscape (no more snow) Lower 1/3 Title: Day 24 MS: meltwater pond with heavy ripples (suggesting heavy wind)	variability of the water levels in the moulin. DR. GULLEY (v.o.): Yeah, yeah, so, ah, one of the GPS units is already in the ground, we may put some more in here, ah before we come off, one of the problems we've had, is… …we have been unsuccessful in instrumenting the moulin at low camp. We've tried, basically spent an entire week, of tossing cable in, and pulling it out, and whatnot… DR. COVINGTON (nats):

	CU, INT: DR. COVINGTON	…I mean, when you look at the rate it is increasing after that…I don't know, I'm optimistic that we might get it further in.
	WS: rippling meltwater pond, frozen landscape	
	MS: DR. COVINGTON (interview)	DR. COVINGTON: On our very last full day in camp, we had had a couple days of pretty strong melt, and the flow was really up in the stream, and we decided to give it one last try at lowering the cable
	MS: DR. COVINGTON, VICKIE discuss (inaudible) their final attempt plans	*Music:* LesyanZ – "Inspire Me"
	WS (various): DR. COVINGTON retrieves rope, sets other processes in motion for lowering	DR. COVINGTON (v.o.): …and we started lowering it, and, it went down! And we started lowering it, and it went down, and we lowered it some more, and it kept going down, it was glorious! We just kept lowering and water pressure kept going up…
	MS: DR. COVINGTON raises a triumphant fist in the air as he is lowering cable	
	MS: DR. COVINGTON (interview)	…We were able to reach the water level, a little over 200 meters or about 600 feet below the ice surface, we reached the water level…
	MS: VICKIE reads the level readings from the laptop (in meters)	VICKIE 134.7…136.3…138.1…140!
	MS: DR. COVINGTON (interview)	DR. COVINGTON: So we knew we were getting it deeper in. We were able to

		lower it around 500 feet further into the water, so at this point it was far enough in, that we were pretty sure that we would capture the full variation in water level…
	CU: DR. COVINGTON continues to feed more cable into the moulin	…We have models, mathematical models, computer models, of how flow of water beneath the glacier works…
	MS: DR. COVINGTON (interview)	…but typically, we don’t have access to the bottom of the glacier, so this project is providing data that we can use to tune and better understand how our models should work.
	EWS: frozen landscape finally starting to melt	
Before it’s time to leave, there’s one more experiment to try.	*Lower 1/3 Title:* Day 25	
	WS: VICKIE and DR. COVINGTON prep the tuffwing for its final flight of the expedition	
The Ice Bat flies again, taking one last mapping flight and bringing the summer’s expedition to a successful close. Now, it’s time to leave.	MS: VICKIE holds the tuffwing out, and it flies again. Both DR. COVINGTON and VICKIE cheer at the resurrected drone	
	WS: helicopter comes in for a landing	
	WS: DR. COVINGTON and VICKIE board the helicopter EWS: helicopter departs camp, watching the cargo cache disappear	

	EWS (various): departing shots of the glacier, ending over the icebergs in Disko Bay WS: a whale surfaces, and dives again EWS: Kangerluissat airfield, the Air Force C-130 takes off again, departing back to America EWS: University of Arkansas campus, Old Main, panning left to Gearheart Hall *Lower 1/3 Title:* University of Arkansas WS: audience of geosciences students and teachers in Gearheart hall MS: DR. COVINGTON addresses the audience	*Music:* "Claire de Lune" Claude Debussy – Recorded by Frozen Silence *Applause* Dr. Covington (nats, o.c.): Ok, so it was cold in Greenland, aha, and we think that the reason we were having all this trouble with instrumenting the moulins was a lack of meltwater… Once things started melting at a stronger rate there towards the end, we were successful. And, so we have now, several months' worth of moulin water level data from these two sites…
	MS: DR. COVINGTON (interview 2) GRAPHIC: a chart provided by DR. COVINGTON shows	DR. COVINGTON: At both of our camps, the camp at the thinner ice, and the camp at the thicker ice, we were successful at instrumenting the moulin, after some effort, and looking at the data we were a little bit surprised, particularly in what we saw at the thicker ice site. The water level was not changing very much, and also the water level was staying

	the variation in water level between the first and second camps, marked “thick” and “thin” GRAPHIC[3]: a computer generated map of the arctic, with Greenland prominently in the center, shows variation in temperature and thickness of the ice GRAPHIC[1]: a computer generated video displays a glacier flow with superimposed arrows in various colors, depicting differences in movement velocity over time	quite high during the whole period. The reason that we think that is happening is because the conduits in the ice, they can grow by melting, but they also can shrink from the pressure of the ice, the ice itself slowly flows. And so, when you drop the water pressures, it’ll start squeezing those tubes shut. The thicker the ice is, the faster it’ll squeeze shut. The general thought in recent years had been that this Zwally effect, where meltwater accelerates the ice was not going to be too important in the end, because as you introduce more meltwater, the flow paths in the ice become bigger, and eventually your water pressures drop. Our data suggests that might not be the case, as you move to thicker and thicker ice, it could be that in places where there’s very thick ice, it could be that meltwater will have a bigger impact on ice motion as melt starts to occur further and further up the ice sheet. Our data is sort of opening that question back up. Could it be that at thicker ice, meltwater will have a continued impact on ice acceleration?
Science is a difficult and demanding process. Under adverse conditions and incredible odds, the Gulley project has been a success.	*DIP to BLACK* EWS (drone): a low pass over camp, with the team lounging outside the group tent in camp chairs, enjoying the	*Music:* Jakubowski Epic Music – “Beautiful Morning”

They’ll return in the summer of 2018, to face the unknown again.	open air. The camp is visibly inundated with deep snow WS: CELIA is holding the tuffwing, with DR. GULLEY and DR. COVINGTON watching. It launches successfully, and CELIA and DR. GULLEY high-five and cheer EWS (drone): completely vertical shot (facing down) of footprints in the snow, scrolling slowly. *[Credit Title Card]* Directed & Narrated By Jonathon Carlson *[Credit Title Card]* Camera & Editing Jonathon Carlson Drone Pilot Matt Covington Additional Photography Colleen Pancake *[Credit Title Card]* Low Camp Team Dr. Jason Gulley Dr. Matt Covington Celia Trunz, M.S. Vickie Siegel *[Credit Title Card]* Music: LesyanZ – “Inspire Me” Musway Studio: “Cinematic Epic Blockbuster 6” “Cinematic Ambient 2” “Cinematic Ambient 3” “Inspiring Piano 2” “Emotional Romantic 2”	DR. GULLEY: Yay! What a great feeling of success!

	"Epic Inspiring 2" *[Credit Title Card]* Music: Philipp Weigl- "Not the streets you used to walk along" Sergey Kovchik – "One Note" Monplaisir – "#9" & "#11" Jon Watts – "Godspeed Thunder" "Tsunami" *[Credit Title Card]* Music David Hilowitz – "Displaced Memories" Claude Debussy – "Claire de Lune" Recorded by Frozen Silence Jakubowski Epic Music – "Beautiful Morning" *[Credit Title Card]* Faculty Advisors Professor Larry Foley Professor Dale Carpenter Special Thanks Kathy Young Air Greenland Mullins Library *[Credit Title Card]* Special Thanks to NASA Goddard Space Flight Center Conceptual Image Lab Staff Susan Twardy Cindy Starr Kate Ramsayer Lori Perkins Michael Starobin	

	[Credit Title Card] Recorded with Canon EOS 7D GoPro 4 iPhone 8 Edited with Adobe Creative Cloud *[Credit Title Card]* A Student Production of The University of Arkansas School of Journalism and Strategic Media *[Credit Title Card]* This material is based upon work supported by the National Science Foundation under Grant No. 1603835 Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. *Fade to BLACK* *Lower 1/3 Title:* Copyright 2018 All Rights Reserved	

INTERVIEW TRANSCRIPT 1

Subject: Dr. Matt Covington

Interviewer: Jonathon Carlson

Location: Illulissat, Greenland – Disko Bay shoreline

Date: July 25, 2017

Jon: Your background – pretty much how you got from Physics to out here in Greenland

Matt: Ok – that's a long story, so I'll tell the short version of it. SO, I started out as a physicist studying galaxy formation, but I was also quite an obsessed caver. As I was finishing my PhD in physics, I sorted out that I could be doing science a lot like physics, but use it to study caves. So I managed to switch out my career into geoscience, and mostly focused on studying caves, and eventually that bled over into glaciology, because there are caves that form in the ice, and it turns out these caves are actually quite important for determining how quickly ice sheets will melt.

Jon: Excellent. Getting a little closer here. Are they getting to you?

Matt: What? No, a little bit. Mostly they're just gnats. So they're not actually biting.

Jon: Just annoying, yeah.

(Plane crosses overhead)

Jon: Once the plane's over, we'll get into Svalbard, and Jason, and getting that conversation going.

Matt: So, I first met Jason at a caving convention. Jason's also a caver, and he convinced me that glaciers and caves were scientifically interesting, and it certainly sounded like an intriguing environment to visit, and so during my first post-doc, I got the opportunity to go with Jason to Svalbard, in the arctic, and to go glacier caving, so we spent quite a bit of time exploring and mapping glacier caves as part of Jason's PhD.

Jon: Nice. And to help transition well, how long have y'all had this project in mind?

Matt: Um…So, Jason actually came up with some of the initial ideas for this project while he was doing his PhD. But he and I together have been trying to get this project funded for about four years, and finally, on our fourth try with the proposal we managed to get funded.

Jon: ok, onto just moulin operations. First off, "what is a moulin?" – for our folks at home.

Matt: So, a moulin is a hole in the glacier surface where you have a stream that flows along the surface, and then it goes into this hole into a big waterfall, and typically these moulins take this water fairly directly to the base of the ice, where it then flows out to the base of the glacier, whether that's the ocean or the valley bottom.

Jon: Ok. And, our proposed, well…what do we think it does? Proposed effects; the effects to the glacier movement?

Matt: So, moulins are very important in terms of understanding how quickly ice sheets will melt, or glaciers will melt, because the water that goes through the moulin to the base of the ice, when it reaches the base of the ice, it can speed up the motion of the ice. Either by lubricating the surface, the boundary between the ice and the rock beneath it, or by providing water pressure that actually lifts up the glacier, and reduces the friction, and allows it to slide more quickly. And a lot of the mass lost from glaciers is actually a result of sliding, either sliding that ultimately produces icebergs that calve off into the sea, or sliding that's just bringing ice from higher altitudes to lower altitudes where it can melt more quickly. So what we're trying to understand is this relationship between water going into moulins, and the forward motion of the ice.

Jon: Awesome, very nice. Ok, so I guess now then onto the basics of the proposal and the experiment, briefly, what's been done before, and the new novel approach in this project.

Matt: So a number of people have studied moulins and glacial hydrology on the valley glacier scale, the types of glaciers you would find in the Alps, fewer people have studied it on the scale of the Greenland ice sheet, particularly when you're looking at water level changes in the moulins, and how it relates to the ice. So the new thing that we're really adding here is taking what's been learned about glacier hydrology at the smaller glacier scale, and then trying to collect some data on a very large ice sheet to understand how the moulin dynamics work here. One of the other important aspects of this is, we have models, mathematical models, computer models, of how flow of water beneath the glacier works, but typically, we don't have access to the bottom of the glacier, and so this project is providing data that we can use, to tune and better understand how our models should work, to inform the models, to constrain the parameters that control the models, we don't really know what's a realistic choice of a model. Because we can't directly observe it. That's probably a bit confusing.

Jon: No, that's ok, that's alright. I guess we would just back up and say, you know, just the components, the nuts and bolts, the sensor going down, and the water-level sensor, and then we'll get into the dye trace experiments later.

Matt: Ok, so to study the moulins here on the ice sheet, we're lowering water level sensors, pressure sensors deep inside the moulins, and potentially thousands of feet into the ice. And this allows us to measure how much water is coming up in the moulin, which tells us how much water pressure there is at the base of the ice, which is directly important for the sliding of the ice. So we're lowering these pressure transducers in on a long, long cable that's built to withstand all of the forces that it might experience on the moulin, either the falling water, or the falling ice, and then addition-work, we're looking at the water that's flowing into the moulin, and we're doing that in a number of ways. One of the ways is that we have sensors that can measure the height of the stream channel, the depth of the water in that stream, and we can relate that to how much water is actually flowing into the moulin at any given time.

Jon: Alright. Well, I guess the next two we can skip until later on…we'll have to wait on the dataset.

Matt: Like the, the findings are…we haven't had the time to process the data or think about it too much.

Jon: The next item is the dye trace experiments, for those who are completely unfamiliar with what a dye trace is…

Matt: So, one of the ways that we're using to measure the flow in the streams on the ice sheet, specifically the streams that are going into the moulins, is using a fluorescent dye. We have sensors that can detect this dye at very low concentrations in the stream. And upstream we inject the dye, using a pump, we pump dye into the water at a known rate. And by measuring that concentration downstream, we're able to actually calculate how much water is flowing in the stream. So that's our main way of measuring the discharge or the flow of the stream.

Jon: That pretty much covers that. I know I stuck some stuff in there that we can't answer until next year anyway, um, the system that we used, the testing of the system, the implementation of the system, but that can even wait until next year as well.

Matt: yeah, I can certainly talk about it, but I wonder whether you're likely to use it. I mean, I could say a little about how the system can work.

Jon: Yes, especially since I got the footage from the testing back in Arkansas…

Matt: Certainly. So, one of the things we have to do with the pumps, if we want to get accurate measure of the discharge, is that we have to make sure that they're functioning correctly, that they're pumping at the rate that we think they're pumping at. So part of this process is twice a day checking what the pump rate is, and if there's some inconsistency in the pump rate then trying to find out what's causing that. We found that we have to keep a very consistent configuration in order to be right on with the pump rate that we want.

Jon: Going on to, miscellaneous instrumentation, like the things we set up, like the weather station, the water level sensor, the gps, how it all works together…

Matt: So in addition to measuring the water flow into the moulin, we're also studying the processes that generate that meltwater, from the sun beating down on the ice and melting it, or changing amounts of snow cover on the ice causing a different amount of that solar radiation to be reflected, or different air temperatures on different days, and different wind speeds, all these things can influence the amount of melt that's generated on the surface of the ice, eventually ends up in the moulins, so we have a weather station there that's measuring all these common weather parameters so we can use that to relate that to the amount of meltwater that's produce. We're also looking at different types of drainage basins, so you have small ones, you have large ones, you have skinny ones and fat ones, and we're looking at these different shapes and different sizes, and trying to understand how that changes the way in which the water comes out, and the rates at which the water comes out of a given drainage basin. We're also using, since we're interested in the motion of the ice, we're using really high-precision GPS units that are installed onto the ice in different locations, to measure how quickly it's sliding, and in particular we want to look at how the water in the moulin impacts, whether it does impact, that forward motion of the ice, which is being measured by those GPS units.

Jon: Perfect…Now we'll kinda get into some of the nitty-gritty, but I don't know how much you want to talk about some of these things, on-the-ground events reactions, you know, when it snowed…

Matt: No, I think it's ok to talk about some of those things. We're not trying to paint an entirely cheery picture of what happened. We want to paint a realistic picture.

Jon: Yeah, we're going blow-by-blow…

Matt: I'm happy to talk about things not going as planned.

Jon: Ok, so I'll just start naming things, just things that I plopped down in there, if you think of any, we'll just bring that up as well…. (we get off-track for a moment) we may as well start from, within 6 hours of us landing, we got up to 2 feet of snow.

Matt: Ok, so, one of the biggest challenges we faced this year was that it was much colder than typical, and also we got a lot of snow. So, a few hours after we arrived, it started snowing, and at first my reaction was, 'well, ok, this is the Greenland ice sheet, it snows sometimes, we're going to be stuck here for maybe a day or so while we wait for the snow to melt, and it's clear enough for us to find a safe way to walk around. At this point, we hadn't really explored around, so we didn't know where it was safe to walk, or where there might be crevasse fields, so the snow was really a show-stopper until it melted. But then a day passed, and another day passed, and eventually a week passed, and there was still snow. At this point, we were starting to get a little bit anxious about when we were going to actually be able to do what we had come to do, also starting to get a little bit of cabin fever being cooped up in the group tent for a week.

Jon: Alright. At this point let's sing the praises of the Tuffwing and the 3DR drone, and how much that really helped us out during this time when we couldn't' really move around that much

Matt: so, one of the few things that we could do while we were snowed in was fly some of the drone vehicles that we had and use that as a way of doing some reconnaissance in the area. So, we have a Tuffwing, which is a plane that automatically flies over a grid and takes pictures, and we're using that to map out the local area to see the shapes of the drainage basins and drainage divides and so on to figure out which areas are draining to which moulins, and so we went ahead and started that mapping process while we were stuck in the snow. We also had a 3DR Solo quadcopter, which mostly we're using for aerial filming, but it also turned out to be handy to do the initial search for the moulin. We knew approximately where the moulin was that we wanted to instrument, we didn't know exactly where it was with respect to our camp, and so we did a bunch of flights out from camp basically searching for it until we thought we had found it.

Jon: Ok, let's talk about the first instrumentation attempt, pretty much we're all out there together, and then just…ran into problems?

Matt: Umm, so when we first attempted to instrument the moulin, we started lowering in cable, lowering in cable, and it seemed like everything was working alright, the cable was getting heavier, but we weren't hitting the water level, we weren't seeing any changes on the sensor, and once we got around 300-400 meters of cable in, we still hadn't hit the water, and we thought that was too far, we should have hit the water by then. And so we started trying to pull it out, and luckily we were able to pull it out, we pulled out a huge rat's nest of cable that had all gotten tangled up, and it was a little frustrating, a little surprising, Jason had instrumented five other moulins before, and everything had always basically just gone in, but this time for some reason we weren't hitting the water, we weren't exactly sure why that was.

Jon: And with the second one, I think we started maybe figured out it could be stuck in one of the T-side cracks and then so I think, I forget did we try the baffle the second or third time?

Matt: Umm, I don't remember I think maybe we…I want to say we tried, we tried in higher discharge the second time, umm…I can't remember if we changed anything else…I know we tried several things at once, and maybe that was the second time…

Jon: I think, yeah, again, I'm not nearly as…

Matt: Sorta hazy on it, I can just list some of the things we tried. So, after we recovered the cable, we decided to wait a few days, and wait for a day when there was lots of melt, so it would maybe help to carry it in, um, that didn't work. We also tried lowering in from different angles to see if it was getting caught somewhere, maybe if we lowered it from the other side of the moulin maybe then it would go in, eventually we started hitting the water, but it was never going below a few meters of depth, and then stopping at about the same depth. Any way we tried to lower it. The one last thing we tried is we actually tied on the parts of a broken chair, just the cloth from a broken chair that we had in camp, to give it a lot of drag so the water would hopefully pull it in, but again we just got the same results. At this point we started to think that the whole moulin might be going into a narrow crack, a narrow crevasse, where the moulin had formed, and the depth just hadn't got large enough yet for the sensor to actually get through it, there hadn't been enough melt yet. So, at that point we started thinking about trying to instrument a different moulin.

Jon: well that helps me, too, right there, because I'll be trying to animate some of this stuff, and sort of hypothesizing on what happened there. Umm, so ok, and then that second moulin turned out to be pretty close to the camp…

Matt: So, we spent a day looking around and scouting out different potential moulins to instrument, and the one we eventually decided on was one that was really quite close to camp, only a couple hundred yards from camp, and one of the reasons for that was we were actually starting to run out of time and it had the advantage that if we were unsuccessful, we could pull all the equipment and put it there in our camp to be stashed for the next year where we would try again. So we started the next day trying to lower the cable into that moulin, and this time we had a bit more success. We were able to reach the water level, about two hundred meters or a little over six hundred feet below the ice surface, we reached the water level, and we lowered the cable until it was about fifty feet under the water, but then it stopped going down, and we tried pulling it out a little bit, lowering it back in, and so on, we couldn't get it to go beyond that point. So, at this point, at least we knew we were in the water, we weren't as deep as we were hoping to be, but it was a partial success in that we could get at least get most of the variability of the water levels in the moulin.

Jon: And then there on the 11th hour of the very last day, just…you know Jason had already gone, and we actually got it to go…

Matt: Right, so on our very last full day in camp, we had had a couple of good days of pretty strong melt, and the flow was really up in the stream. We decided to give it one last try at lowering the cable. And we started lowering it, and it went down, and we started lowering it, and it went down, and we lowered it some more, and it kept going down, it was glorious, it just kept lowering and the water pressure just kept going up, so we knew we were getting it deeper in, and we were able to lower it around five hundred feet further into the water, and so at this point it was far enough in that we were pretty sure we would capture the full variation in water level over the season.

Jon: Alright!

Matt: It was a great way to end the expedition.

Jon: That's just about it…

INTERVIEW TRANSCRIPT 2

Subject: Dr. Matt Covington

Interviewer: Jonathon Carlson

Location: University of Arkansas campus, Gearheart Hall

Date: December 12, 2017

Jon: ok, well, just like when you were sitting out there, same questions, same topics, we don't have to go from a-z again, but if there's anything you would like to restate, so we'll go from topic area to topic area, starting with, again, background, physics to caving, climbing, cave hydrology, and then Svalbard and Jason, so… we've got a good bit before, but do you think you might state it better?

Matt: I don't remember exactly what I said, but I can give you another take of it. So my career trajectory is a little bit unusual, because I started out in theoretical astrophysics, and that was the field that my PhD work was done in, and during the time as a grad student I was also a quite obsessed expedition caver, spending a month or more every year on caving expeditions somewhere in the world. As I was finishing up my PhD in physics, it suddenly dawned on me that I could do science that was much like physics, but apply it to study caves, and at that point there was no looking back, and I was able to switch fields after my PhD, and come into geoscience, where a lot of my research focuses on caves, I got into glacier science, glaciology, also as a caver, so I met Jason through cave and CARST science, and he was also working on caves in glaciers, and he invited me to come along on an expedition in exchange for doing for doing some modeling, and that was how I really got started in glaciology, was, going along and visiting some glacier caves, and then realizing that a lot of the modeling that I do could easily be applied to study those systems as well.

Jon: So, Svalbard, I know we kind of glossed over that at first, so studying the cave formations there, was that the turning point for you to go into glaciology in general…

Matt: Right, so my first experience in glaciology was in Svalbard which is an archipelago to the far north of Norway, off to the northeast coast of Greenland, and we went there to do some work in glacial caves, mapping glacial caves and looking at the forms and trying to understand how the systems evolved over time. And that was really my introduction to glacier caves.

Jon:…Ok, the next bullet point we were going to go off were moulin operations…I don't think we got into the theory by name in the first interview, the effect.

Matt: The Zwally effect?

Jon: Yes, yes…so maybe we can start with that.

Matt: Well, a moulin is a hole in the ice that meltwater pours into where it can make its way to the base of the glacier, and we're interested in moulins specifically because the meltwater that it can deliver to the base of the ice can influence the ice motion. There was a study that was done in the early 2000s that showed that years that had more meltwater on the Greenland ice sheet resulted in more ice motion, and the thought was that this water is going down, lubricating the base of the ice, and also lifting the ice up, and causing the ice to actually accelerate. And this is important because a lot of the mass lost, a lot of the ice lost off of big ice sheets is from motion rather than from just direct melt. This effect of acceleration of ice by meltwater is sometimes called Zwally effect, after the guy that published this study in the early 2000s.

Jon: …From here we can start to roughly discuss preliminary results, like what's the early data saying, and I know that from NSF's perspective, putting that in here is pretty important, so do we have any early findings we can -

Matt: Yes! We actually know more now than we did when you talked to me last! So, umm…at both of our camps, the camp at the thinner ice, and the camp at the thicker ice, we were successful at instrumenting the moulin after some effort, and looking at the data, we were a little bit surprised, particularly with what we saw at the thicker ice site. All the other moulins that people have instrumented in the past, when you look at data variability in the water level, as the meltwater pulses come every day, it was, the water level was typically changing over 50-100 meters, but what we saw at the thick ice camp was that the water level was not changing very much, um, only by a few 10ths of meters, and also the water level was staying quite high during the whole period which suggests that the system of tunnels in the ice is not becoming efficient enough to lower those water pressures, and potentially they reduce the ice velocity. So, it looks like at the sites where the ice is thicker, the meltwater might have a more sustained impact on ice motion because the conduits in the ice were not becoming large enough to readily accept all that water.

Jon: Ok. So yeah, the melt pathways, just not capable of the output, for the flow output to continue, it just stayed at the same level.

Matt: yes, and the reason we think that is happening is because the conduits in the ice, they can grow by melting, but they also can shrink from the pressure of the ice, the ice so slowly flows, so when you drop the water pressures, they'll start squeezing those tubes shut, and umm, the thicker the ice is, the faster they'll squeeze shut, so we think at the thicker ice site, basically the squeezing in closure of the conduits is fast, that the water level's not able to drop that far.

Jon: Ok! Is there any early speculation then thicker areas vs. thinner areas, think there might be…going the other direction, there might be a runaway effect, that once the ice starts reaching a certain thickness level, that this effect will speed along…

Matt: So, the general thought in recent years had been that the Zwally effect where meltwater accelerates the ice was not going to be too important in the end because as you introduce more meltwater, the flow paths in the ice become bigger, and actually, eventually, your water pressures drop. Umm, so basically the flow system in the ice becomes very efficient and it can accept all that water and drain it away. Umm, but our data suggests that might not be the case, as you move to thicker and thicker ice it could be that in places where there is very thick ice, something like a kilometer thick, you may not be able to form these really efficient channels, and for that reason it could be that meltwater will have a bigger impact on the ice motion as melt starts to curve further up the ice sheet. It's too early to speculate at this point…

DISTRIBUTION STRATEGY

As this is a student production funded by a National Science Foundation grant, I want to be able to showcase it in as many forms as possible without violating the non-profit terms of much of the material used, including some of the Creative Commons licensed music, some of the resources from NASA, and the use of Google Earth. I have therefore planned to distribute this film in the following manner:

Priorities:

- On-campus screening with Q &A featuring myself and (ideally) one or more expedition participants as stipulated in the NSF grant
- Broadcast over AETN
- Featuring at Hot Springs Documentary Film Festival
- National distribution via Video On Demand (VOD)

Proposed / Taken Actions:

- Reserve GEAR 26 (Gearheart Hall Auditorium) for either Friday, May 11 or a Fall '18 semester date TBD (based on my availability or availability of the room) – Alternately, Mullins 108 could be reserved for smaller audiences
- Contact AETN to coordinate needs and production delivery standards
- Already submitted to HSDFF via FilmFreeway.com
- National distribution already offered via National Science Foundation
- Timing: Both AETN and NSF may have to wait until after HSDFF, as they prefer to be the "worldwide premiere" of any picture in competition.

I have obtained a letter of intent from the National Science Foundation's head of production, Cliff Braverman, indicating that he is offering to distribute this film nationally in many forms, including to PEG (Public, Education, and Government) channels, and via the NSF video on demand platforms.

GRAPHIC RESOURCES

[1]Ramsayer, Kate & Starr, Cindy. “At Glacial Speed.” *NASA/Goddard Space Flight Center Conceptual Image Lab.* March 13, 2017. Internet Resource. Retrieved 2/12/2018 from: https://svs.gsfc.nasa.gov/12476

[2]Starobin, Michael. “Arctic B-Roll in 4K.” *NASA/Goddard Space Flight Center.* November 1, 2015. Internet Resource. Retrieved 2/12/2018 from: https://svs.gsfc.nasa.gov/12034

[3]Starr, Cindy & Perkins, Lori. “Greenland Ice Sheet Mass Changes from NASA GSFC GRACE Mascon Solutions with Banded Color Scale.” *NASA/Goddard Space Flight Center Conceptual Image Lab.* March 24, 2010. Internet Resource. Retrieved 2/12/2018 from: https://svs.gsfc.nasa.gov/3687

[4]Twardy, Susan. “Accelerating Ice Sheet.” *NASA/Goddard Space Flight Center Conceptual Image Lab.* August 29, 2007. Internet Resource. Retrieved 2/12/2018 from: https://svs.gsfc.nasa.gov/20111

All photographs, music, and other elements are used under creative commons with attribution.

REFERENCES

Beers, T. (Director). (2005). Deadliest Catch [Television Series]. Discovery Communications.

Campbell, J. (1949). The hero with a thousand faces. New York: MJF Books.

Cogley, G. (2010). The Zwally effect: it won't go away. *Environmental Research Web* [Blog post]. July 19, 2010. Web Resource. Retrieved 15 February 2017 from: http://blog.environmentalresearchweb.org/2010/07/19/the-zwally-effect-it-wont-go-a/

Cook, J. [UQx Denial101x Making Sense of Climate Science Denial]. (2015 April 27). *UQx DENIAL101x 1.4.3.1 Five Characteristics of Science Denial* [Video file]. Retrieved from https://www.youtube.com/watch?v=wXA777yUndQ

Cousteau, J.Y. (Director). (1976). Voyage to the End of the World [Motion picture]. France: Les Requins associés.

Herzog, W. (Director). (2007). Encounters at the End of the World [Motion picture]. US: Discovery Films.

Sinclair, P. [Yale Climate Connections]. (2017, March 22). *Alive and Well: Microbes Add to Melting of Greenland Ice Sheet* [Video file]. Retrieved from https://www.youtube.com/watch?v=DKfP63NH4DM

Sinclair, P. [Yale Climate Connections]. (2014, September 11). *Greenland 2014: Follow the Water* [Video file]. Retrieved from https://www.youtube.com/watch?v=_PEi0Retg8A

Sinclair, P. [Yale Climate Connections]. (2016 July 2). *Gauging Greenland's Melt* [Video file]. Retrieved from https://www.youtube.com/watch?v=jGYkVAIsTIA

Snyder, B. (2005). Save the cat!: The last book on screenwriting you'll ever need. Studio City, CA: M. Wiese Productions.

Zwally H.J., et al. (2002) Surface melt-induced acceleration of Greenland ice-sheet flow. *Science* 297:218–222.