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Bureau of Land Management
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Dear BLM,

This letter is being submitted in response to your finding that the proposed 3D seismic work covering the entire 1002 Area of the Arctic National Wildlife Refuge would have no significant impact and therefore you are not requiring a full Environmental Impact Statement for this work.

I've spent 25 years studying the impacts of climate change on the landscapes of our polar regions, 17 of those as a professor at UAF, and the last 15 of which I have been running the only long-term field program within the Arctic National Wildlife Refuge studying climate-glacier-ecosystem interactions from the continental divide to the coast (Nolan et al, 2011; Weller, Nolan, et al, 2007; Delcourt, Pattyn, and Nolan, 2007). All of my career has involved the engineering and development of new measurement techniques suitable for new cold region applications. My PhD and much of my early career was focused on developing new seismic exploration techniques in Alaska, Siberia, and Antarctica, as well as developing satellite remote sensing techniques to measure depth of ground freeze and soil moisture, and much of my later career has been developing airborne methods to measure topography at very high resolution and accuracy, all in support of understanding cold regions landscape change and evolution.

While I am not opposed to conducting seismic work within the 1002 Area, I am opposed to using the proposed seismic methods because they very clearly have significant impacts. This spring and summer I have been measuring and documenting these impacts in the Pt Thompson area -- impacts made by seismic work *last* winter by this *same* seismic company proposing to use these *same* methods in the 1002 Area *this* winter. This letter and its appendices highlight just a few of the significant impacts I am aware of and some of the gaps in our knowledge that prevent us from predicting whether other significant impacts may occur – these knowns and unknowns easily justify the requirement of a full EIS for any seismic work here, and as you will see this particular proposal should be rejected outright due to its lack of rigor and its lack of attention to necessary detail.

How much snow cover is required to prevent significant impacts of 3D seismic to the tundra and ecosystem of the 1002 Area? The application cited no research along these lines. My recent data of the 2018 Pt Thompson 3D seismic acquisitions by this same company shows that nearly 100% of their seismic lines left visible ruts in the tundra from their tracked tires and sleds more than 3 months after they were created – by anyone's definition, these ruts being 100% visible months after work was completed is 'significant'. I also measured high resolution topography of these seismic ruts twice, once in late June and once in July. Again, in both cases nearly 100% of these trails left a significant impact – depressions of 2-20 cm across trails 10-20 m wide, where I could resolve the topography of individual tire and sled tracks. These ruts were so pronounced that I could navigate my plane using them while going over 100 mph. My photographs and data in June showed that there was compressed snow left in all of the tracks, tracks which were 10-20 cm deep after melting – if there is compressed snow in depressed tracks, clearly the amount of snow was insufficient to spread the load and avoid damaging the tundra. Whether the tundra mat was broken through to mineral soil is immaterial – the tundra plant fibers obviously could not support the weight of these vehicles by virtue of the existence of these depressions within the mat and as such each and every one of these fibers were broken or bent – a significant impact by any definition. Further, these depressions, while shallow, change the permafrost hydrology (in this case, the water content within the ruts) to significantly impact the plant dynamics and species composition within these ruts, causing them to seasonally green up or brown up earlier or later than their surroundings, making them visible today as well as for years to decades afterwards as can be seen throughout the North Slope. You can read more about my measurements in the Appendices, which are PDF captures of the blogs listed there which you can find online and which also contain videos documenting these impacts. What's needed before such work can be permitted within the 1002 Area are systematic studies of the influence of snow depth on preventing these impacts. What's also needed is a systematic study of all 3D seismic conducted over the past 10 years using these same methods to determine the long-term impacts of this work, using airborne techniques like fodar to measure topography and color, and ground studies by botanists and permafrost scientists. Such studies have never been done before and it would be completely irresponsible and not at all in keeping with the public trust for you to permit the proposed seismic methods to be employed within the Arctic Refuge without such prior studies, whether part of an EIS or not, as the standard of care required by law within this Refuge is significantly higher than elsewhere in the US Arctic.

Is there sufficient snow cover in the 1002 to meet the existing standards? Having spent 15 years working in and flying over the 1002 each spring, I can say without hesitation that in many years, if not all years, there is insufficient snow cover to support the 3D seismic methods proposed, which require 20 cm on continuous snow cover as proposed. This eastern side of the US Arctic, where the mountains almost reach the coast, is subject to occasional strong winds from the south in winter which sublimate the snow away completely wherever they blow. The glacier I have studied intensively for the past 15 years, McCall Glacier, which faces the 1002, can be snow free over its lower half any day in winter, as it only takes a single storm to scour the thin snow completely. These same storms continue into the 1002 and we often find less than 50% snow cover there in April. This April, for example, our team was unable to complete a cross-country ski traverse from the glacier to the coast (over the 1002) because of the lack snow – and that was for humans on skis, let alone dozens of heavy vehicles on tracked tires towing dozens of heavy sleds! Indeed, in this paper (Nolan et al, 2015) you will find my measurements of snow depth along the Hulahula River using my airborne fodar technique which documents both our ability to measure thin snow packs as well as the lack of snow continuous cover there. What is required to do this seismic work responsibly is at least a 3 year study of snow cover – completely mapping snow depth in the entire 1002 in winter to determine the interannual variability of snow cover to determine where it is likely or unlikely to have sufficient snow cover for this seismic work. Without such information, there is no way to responsibly permit overland travel of heavy machinery. As you will see in this paper, my technique can easily map snow depth in this way, so the technology to do so exists, it is affordable, and it should be employed as part of a responsible development effort.

Are there better vibroseis techniques than the ones proposed? The permit application offered no information on the exact methods being proposed – there are many different flavors of vibroseis, each with a different impact on the tundra, none of which have been studied or documented. How do you even know what you are approving if you approve this application? While a lot of attention is paid to the tire pressures, no attention at all is being paid to the impact of the vibrator itself – this is a unit that is used to smash the ground really, really hard to generate sound waves that penetrate several *miles* through the subsurface – is it reasonable to think that such smashing units will leave no significant impact without any study at all on this terrain? Again, without systematic study of all possible vibroseis units in all possible configurations, you are being irresponsible in approving this permit without a full EIS that assesses this.

Are there better seismic methods than vibroseis? Clearly the vibroseis must only be used in winter, if at all, to mitigate the damage that heavy vehicles dragging them in summer would cause. But winter is the time that polar bears den in the 1002. And most winters there is insufficient snow cover even for current methods, which are clearly inadequate already as I have shown near Pt Thompson. The possibility of summer use of explosive methods was not considered at all in this proposal. Drill rigs slung by helicopter in summer could isolate impacts to point targets which can be remediated individually, for example, with autonomous (wireless) seismographs installed the same way. Many other options exist as well, which have not been explored at all within this permit application. Unless all possible options are considered and their impacts investigated and compared, there is no way to responsibly permit the type of seismic activity that will leave no trace.

Is a mobile four-star hotel really required for this work? The bulk of the tire and sled ruts in the fragile tundra are being caused by this 300 person hotel, complete with galleys, hot showers, laundry, internet, and recreational facilities. No justification for this mobile hotel was given in the permit application. Nearly all of this work could be completed by helicopter or by field teams living in tents and traveling by ski, for example. For you to permit the 1002 area to be permanently scarred just so that these crews can eat steak, download porn, and take hot showers every night is the height irresponsible development in my opinion. Much further work must be done to evaluate the options here, as these manpower needs have nothing to do with the impacts of the seismic methods themselves and what is proposed for living facilities is definitely not a requirement to doing the seismic work proposed. That is, there are really two damage-causing activities being proposed here -- the seismic work itself and the accommodations of the field team running it – and the impacts of these two activities must be considered independently.

Is further seismic work really needed in the 1002? The permit application offered absolutely no justification for this. How could it be approved without such justification? We have over 1400 miles of seismic work done here in 1984-85 – this was sufficient to justify drilling here, so why is this not sufficient to do that drilling? I'm not saying there are not good reasons for additional seismic work here, but the laziness and arrogance that the lack of such justification implies suggests to me that the quality of the work which will be done will be of a similar lazy and arrogant nature, and I would be shocked if the BLM thought otherwise. The application offered no justification for this work and to approve it without such justification is a violation of the public trust within the BLM in my opinion.

Is 3D seismic on a 200 m grid really needed? The permit application offered absolutely no justification on this. Most of the 1002 Area is indeed underlain by a complex series of folds and faults, however the USGS believes that most of the oil is to be found deep beneath these more shallow complex areas, within the Ellesmerian and pre-Missippian basement rocks (USGS Bulletin 1778). These rock strata are clearly and easily resolved by 2D seismic methods, and indeed have already been revealed and form the basis of the oil reserve estimates. The application offered no options on the density of this grid spacing, either in terms of the sensitivity of the landscape to overland travel or the need for such density across the entire 1002 Area. For example, the undeformed region in the northwest corner does not require as dense a grid as it is structurally much more simple and does not vary on this spatial distance. If we consider that significant impacts are a percentage of the total area being travelled over, then reducing the total area being travelled over will reduce the permanently impacted area. To illustrate this, consider that a 1 km x 1 km block with a 200 m spacing of seismic lines will create 10 km (a grid of 5 + 5 lines) of seismic trail for every 1 km^2. A 1 km grid spacing will only create 2 km (1 + 1) of trail for every 1 km^2. You can see there is a enormous reduction in potential impact based on grid spacing – over the ~6000 km^2 area of the 1002, that's a difference between 60,000 km and 12,000 km of seismic trails, all potentially leaving permanent ruts and other significant impacts. Consider that about 20 vehicles or sleds will be driving over each line, this potentially creates ~1,200,000 km (~750,000 miles) of tire and sled tracks! Because we have no studies on this we cannot predict the extent of permanent damage, but even if 'only'1% of 1 million kilometers of tire and sled tracks became permanently scarred that is a significant impact by anyone's definition, and my observations of the 2018 Pt Thompson damage is that 100% of the ruts are still visible at the end of summer. Yet no justification was given within the proposal for a 200 m grid spacing, or that a variable grid spacing could not be employed based on subsurface complexity or surface vulnerability to damage. I measured these seismic trails from the 2018 Pt Thompson work to be 20 m wide, so a 200 m grid spacing could cause 10 km x 20 m = 200,000 m^2 of crushed tundra per square kilometer – that's 20% by area covered! That is, over the entire 1002's 6000 km area, 20% of it (1200 km^2) could be covered by tire tracks in winter, nearly all of which (based on Pt Thompson) will crush the tundra by 20 cm during operations. That's a potential impact of 300,000 acres! This extent of impacted area is 150 times more than is permitted by Congress, thus to approve the activities within this permit without further constraints would be a direct violation of law. Before a permit can be granted, valid justification for grid spacing must be given and a full EIS done to determine the impacts of that grid spacing.

Is the 1002 Area more susceptible to damage from 3D seismic than NPRA? The application cited no studies on this topic, and ample evidence exists that the 1002 Area is more susceptible to damage from 3D seismic, so approving this permit without a full EIS is simply irresponsible and a violation of the public trust. The 1002 Area is not flat and featureless as so many people familiar only with the western Arctic claim, it is the steepest ground between the Brooks Range and coast for the entire US Arctic. The Sadlerochit Mountains are only 20 miles from the coast, and the rivers draining them travel through canyons up to hundreds of feet high, some even within a mile of the coast. The subsurface of two thirds of the 1002 Area is intensely folded, causing surface undulations hundreds of feet high. These undulations cause the bulk of the area to be a series of perched wetlands with very few lakes – even a cursory look at a satellite image of the North Slope will show there are almost no large lakes in the 1002 compared to the much flatter west, because the hydraulic gradient here is much steeper – that is, the ground is not flat here! Because these perched wetlands are only separated vertically by centimeters to decimeters, cutting linear grids 10-20 cm deep every 200 m x 200 m due to seismic vehicles without regard to the vulnerability of the surface hydrology has the potential to link these wetlands together, causing cascading, irreversible impacts that have the potential to significantly impact the form and function of the ecosystems here. What is needed is a comprehensive review by leading scientists to determine the vulnerabilities of this landscape to the topographic change caused by tire tracks. That is, just because a 4-cm tire track seems 'insignificant' to us in our city mindset does not mean it is insignificant to the tundra ecosystem. This study requires a digital topographic map that can spatially and vertically resolve existing topography on the scale of tussocks and ice wedges. Such technology exists and is affordable, and I am in the process of making a complete map of the 1002 Area at a spatial resolution of 12.5 cm with a vertical resolution to resolve tire and sled ruts 4 cm deep, as already demonstrated in my blogs (and attached as Appendices). Only by thorough review of such a map can we assess the vulnerability of the landscape and predict where significant impacts would occur by the proposed activities, as the terrain of the 1002 Area is simply much different and more vulnerable to significant impacts than elsewhere in the US Arctic.

What oversight, QA/QC, and remediation can we expect as part of the proposed activity? The proposal was completely silent on this. Who will measure the impacts? How will they measure them? Who will decide whether these impacts are significant or violate the terms of the permit? If hundreds of miles of tire and sled tracks are still visible after 1 year, or 2 years, or 10 years, who will be responsible for remediating this damage? How will this damage be remediated? Is this damage even remediatable? Who will determine whether the terms of the permit were complied with? That is, who will oversee whether every single vehicle operated on at least 20 cm of snow cover, and how exactly will this be measured after the vehicles have already driven over the snow and compressed that snow to less than 20 cm? To expect that a mobile four-star hotel for 300 people being dragged around by several dozen vehicles and several dozen different drivers in the dark of winter in blizzards and whiteouts will 100% of the time be driving over 20 cm of snow when we know that much of this area never has 20 cm snow anyway is simply preposterous. How will vehicles be extracted when they get stuck? Who will ensure no damage occurs then and who will measure such damage and how will such damage be mitigated? The proposal addressed none of these concerns and as such should be rejected out of hand to avoid the expense of an EIS to the taxpayers for such an incomplete and sloppy application.

I have tried to show here that we already know enough to determine that the proposed seismic measurements here will likely cause significant impacts to the landscape of the 1002 Area and that we do not have enough data to determine which methods, if any, can be employed that will not cause significant impacts. The concerns above are not the only ones, but they should justify in and of themselves that a full EIS is required before any new seismic work can be approved and that this particular application should not be considered further until it addresses many of the issues noted above.

Beyond the issue of whether an EIS should be required or not, I hope that you will consider that the power to measure and document the topographic and visual impact *of every single tire rut and every single sled rut* caused by this seismic work is now in the hands of people like me who can afford to make these measurements out of pocket and share them with the world. Should the proposed activity be allowed to proceed this winter, the resulting environmental disaster it will likely cause will be made public for all to see, and the resulting public relations backlash will likely reverse the laws that currently allow drilling. Everyone loses under this scenario – those trying to protect the Refuge from damage, those trying to extract oil, and those trying to do both. **I believe that seismic work can be done without such impacts -- *we can do better***! And I believe that you need to require we do better by not allowing any seismic work in the Arctic National Wildlife Refuge that causes *any* impact to the form and function of its ecosystems or its visual appearance.

Sincerely,

Matt Nolan

Digitally signed by Matt Nolan
DN: cn=Matt Nolan gn=Matt Nolan c=United States l=US o=Fairbanks Fodar ou=Manager e=info@fairbanksfodar.com
Reason: Manager, Fairbanks Fodar
Location: Fairbanks, AK
Date: 2018-08-20 07:03-18:00

Dr Matt Nolan
Manager,
Fairbanks Fodar

References

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USGS Bulletin 1778 (1978) “Petroleum Geology of the Northern Part of the Arctic National Wildlife Refuge, Northeastern Alaska”, Kenneth J Bird and Leslie B Magoon Eds.

Nolan, M., C. Larsen, and M. Sturm (2015). "Mapping snow depth from manned aircraft on landscape scales at centimeter resolution using structure-from-motion photogrammetry." *The Cryosphere* 9.4: 1445-1463.

Nolan, M., Churchwell, R., Adams, J., McClelland, J., Tape, K. D., Kendall, S., ... & Martin, P. (2011). “Predicting the impact of glacier loss on fish, birds, floodplains, and estuaries in the Arctic National Wildlife Refuge. *US Geological Survey Scientific Investigations Report*, *5169*, 49-54.

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Appendices

Included here are PDF captures of these two blogs that I wrote so that they will be considered an official part of this public comments to the review of the seismic application:

http://fairbanksfodar.com/detecting-tire-tracks-in-the-1002-area-with-fodar

http://fairbanksfodar.com/latest-view-of-2018-seismic-exploration-impacts-near-the-1002-area

Note that these blogs contain videos which do not translate well into print format.

See also these blogs of mine which related to my mapping of the 1002 Area:

http://fairbanksfodar.com/end-of-week-two-mapping-in-the-1002

http://fairbanksfodar.com/1002-mapping-nearly-complete

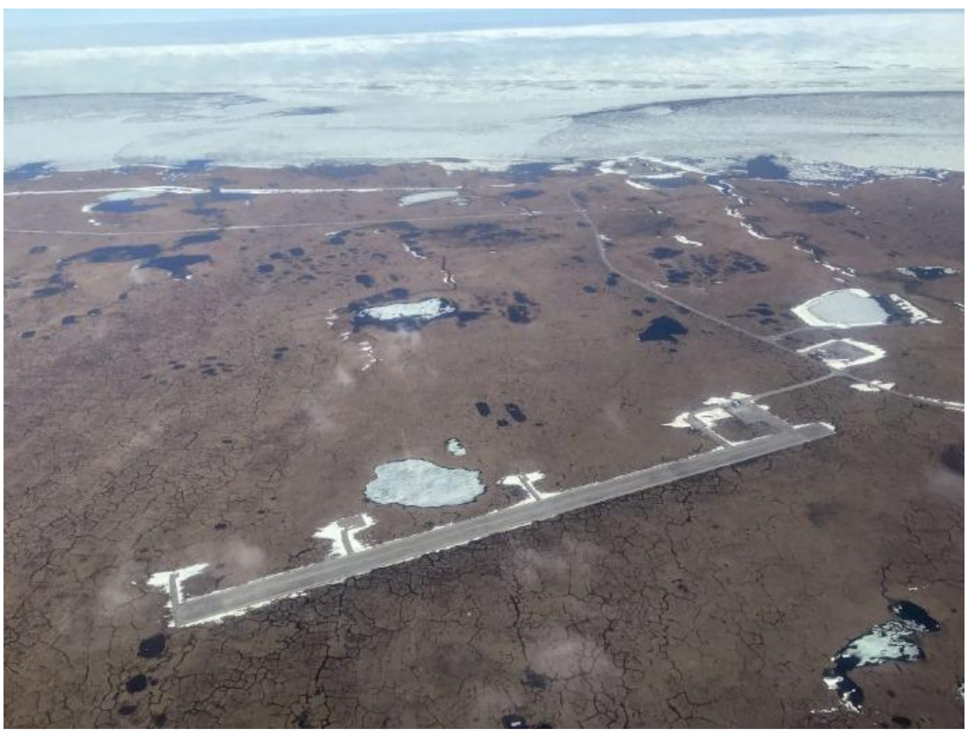
Detecting Tire Tracks In The 1002 Area With Fodar

By Matt Nolan Posted July 1, 2018 In Fodar News 0

URL: http://fairbanksfodar.com/detecting-tire-tracks-in-the-1002-area-with-fodar

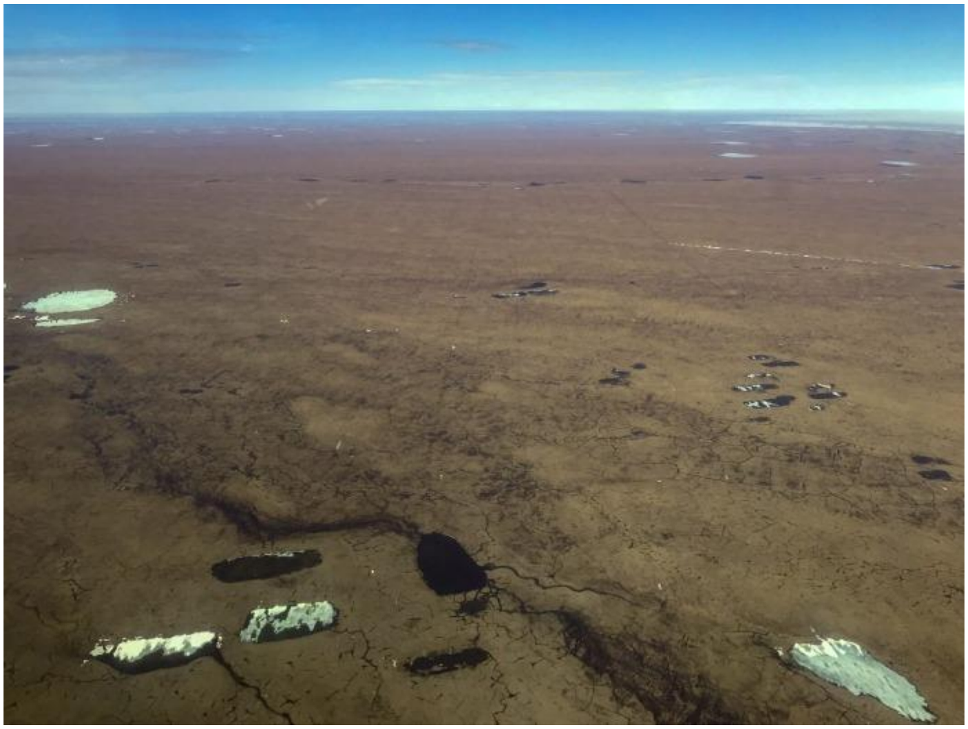
Last Sunday (24 June 2018), on my first day of creating the best topographic map ever made of the 1002 Area of the Arctic National Wildlife Refuge, I was fortunate to find that seismic exploration this past winter had reached the Refuge boundary from the oil fields to the west. I consider this fortunate because it is the potential damage caused by the tire tracks from such seismic exploration that is motivating me to make this map this summer. So here I had the opportunity to be the first person to measure and assess this damage on a wide scale at such high resolution and accuracy: not only demonstrating that I have the capability to measure these impacts but that these impacts exist and are a potential threat to the values that motivated the formation of this Refuge. You can see what these tracks look like a month later here, and learn more about my map of the 1002 Area here and here.

My goal in making this new map is not to take a stand for or against the oil exploration and drilling that Congress recently approved, but rather to make the best contribution I can towards ensuring that whatever happens out here is done as sanely and responsibly as possible. I have been making the best topographic maps of Alaska ever made for years now and have been the only physical scientist running a long-term field program in this area for the past 15 years, so the combination of this skill with this experience puts me in a unique position to make this contribution. My biggest concern about proposed operations out here is seismic exploration. This exploration uses trains of large vehicles operating on a grid pattern over the land. This work is done in winter on top of the snow cover to minimize damage to the fragile tundra and the permafrost below — but is that mitigation enough to prevent all long term impacts?



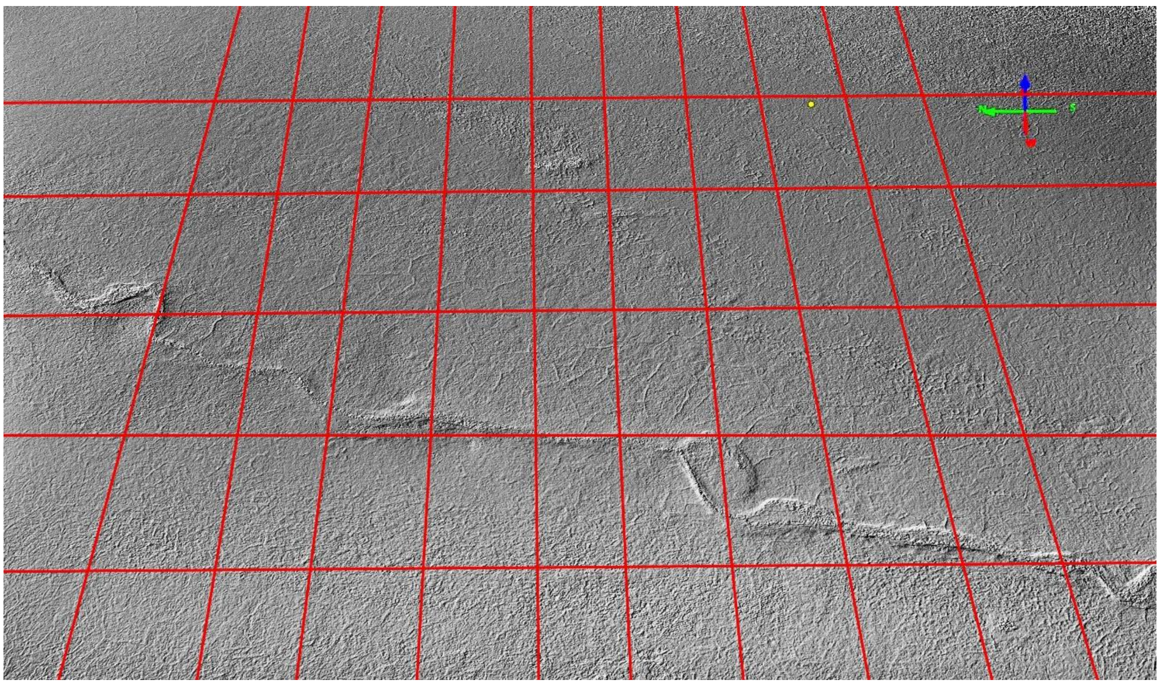
When most people think about the impacts of oil drilling in the 1002 Area, I think they are mostly thinking things like this runway and oil drilling pad at Pt Thompson, about 10 miles from the Refuge boundary. Whether you consider this an eyesore or not, it is nonetheless fairly tidy — the 'impact' is largely isolated to the gravel roads and airfields, and they do keep a tight leash on the workers there in terms of trash, vehicle oil spills, animal interactions, etc. And because it's so bloody expensive to work up here, I think we can trust that there is a strong economic motivation within the oil companies to limit the amount of such infrastructure. So while clearly this gravel infrastructure has an *impact visually and ecologically, I think those impacts are pretty obvious and something we can fairly easily decide as being acceptable or not.*

When I think about the potential impacts of oil exploration in the oil fields, it's this checkerboard that's on my mind: these are the impacts of the seismic exploration that controls where the gravel infrastructure is placed. I took this photo a few days ago. Running across the middle of the frame is the Canning River, which defines the western boundary of the Arctic National Wildlife Refuge. Above it, to the west, you can clearly see the grid lines left behind by the seismic vehicles used to map the oil field below the surface. They ran those lines literally to within feet of the boundary (the Canning River). In the foreground is the 1002 Area of the Arctic Refuge. To me, the most important question all stakeholders should be addressing right now is: Is the impact of such seismic exploration in the Arctic National Wildlife Refuge acceptable? Considering that such exploration is due to start this winter, we don't have a lot of time to address that question, which is why I'm making this map now.



Here are some of those seismic lines a few days later, after the snow melted. Even without snow on them, they are still visible. Is this an acceptable impact? That's a question for the stakeholders to answer. In the meantime, my goal is to make the measurements needed to answer the questions: Why are these tracks still visible? How will they affect the form and function of the tundra ecosystems in the 1002 Area? The intersection of these questions is: How can we improve methods of seismic exploration so that there is truly no impact? That is, with my maps, we can test the efficacy of new seismic methods towards that goal.

Here is an example of my measurements of this area from a few days ago using fodar. At left is my image mosaic and at right is my digital elevation model, shown as a shaded relief image, where I have beamed down fake sunshine at the best angle to highlight the subtle changes in topography caused by the tires of the seismic equipment. Move the slider left-right to switch between images and find the tire tracks. You have to look really closely at the topography data because the impacts are subtle, but you are looking for straight lines along a grid pattern; perhaps start with the snow covered ones and look for lines parallel to those. Note that most of the snow has melted from the tire tracks, such that most of the topographic expression seen here is not snow but a change to the tundra itself.



Here I have overlain a checkerboard grid of red lines that correspond to the location of the tire tracks of the seismic equipment that I mapped topographically. Move the slide left-right to find them yourself. Here I have demonstrated two things I find important: 1) seismic measurements made this past winter at the boundary of the Arctic Refuge left tire tracks behind in the tundra to a depth of 5-15 cm and 2) I have the capability to measure the depth and long-term impacts of those tire tracks. The view is slightly oblique so the lines converge, but my measurements show that they are quite tidily laid out on a 200 m x 400 m grid.

Anyone that's flown over the oil fields to the west can clearly see the grid pattern used by the seismic vehicles from years ago, so clearly there is some impact. Here is a great article that gives an overview of some of those impacts and how it may relate to the 1002 Area. But exactly what is that impact and should we be concerned about it? Though I am a physical scientist specializing in Arctic landscape change, I've never actually studied these questions before, but I'm pretty sure that the impact of these lines has never been measure topographically in the Arctic because no one else but me has the capability to do that. My suspicion is that the reason that these grid lines are visible for years and perhaps decades afterwards is because the weight of the vehicle does cause a topographic depression in the spongy tundra (as shown above), as well as compressing and sintering the snow beneath the tires. The compressed snow takes longer to melt in summer, insulating the ground, and causing a change in the surface energy balance. The combination of these impacts leads to the ground beneath the grid lines to be slightly soggier, which leads to different vegetation growing there or greening up sooner or later, and it is this change in color that catches our eye and makes the old trails visible years later. So along the most of the trails, there may no longer be a topographic expression of the actual tire tracks, but even briefly creating those tracks, whether by smushing the tundra or compacting the winter snow the year they were made, apparently does have a lasting impact that is visible for years or decades afterwards. So one question the stakeholders in the process (which nominally includes the general public) needs to answer is: Are we OK with seeing a checkerboard grid of 200 m by 400 m trails over this wilderness for years or decades to come?

Though it's summer, the checkerboard tire tracks from seismic work done in winter is clearly visible in this image from the oil fields further west (taken by Subankar Banerjee in 2006). Are we OK with the 1002 area looking like this next summer? Is the ecological system going to be affected?

In addition to the aesthetic values, there is also potential for these seismic grids to impact the physical form and function of this tundra ecosystem. This region of the Arctic coastal plain is different than the coastal plain further west because it is much steeper — the mountains come much closer to the coast here, so the hydraulic gradient is larger. This means there is more energy available for water to make new stream channels, utilizing any topographic lows for that purpose, such as those caused by tire tracks. This tundra is already intersected by thousands, perhaps millions, of ice wedge polygons typical of permafrost terrain. The tops of those ice wedges are often lower than the tundra, and when they intersect with each other and with any source of flowing water, small streams can develop on top of them. At some point this flow becomes vigorous enough to begin to physically eroding the ice in those wedges, causing the stream channel itself to deepen itself by meters, thereby capturing even more flow in an accelerating process, which is already accelerated because the terrain is steeper. If this new stream intersects a shallow tundra pond, that lake can be drained by this new river in a matter of hours or days. Disturbances like these, the formation of a new stream channel and the creation of dry land, then can lead the permafrost below to change temperature and the vegetation above to change in character or composition and thus change the habitat for wildlife. For example, willows love to grow in recently disturbed areas, such as the banks of new stream channels -> Rabbits, ptarmigan, beavers, and moose like to eat willows -> Wolves and bears like to eat those herbivores. Thus more stream channels means more willows which means more new animal species which means the existing species, like caribou, have more competition for resources and survival. These impacts take years to decades to unfold, but what seems like innocuous tire tracks may not be as innocuous as some like to believe.

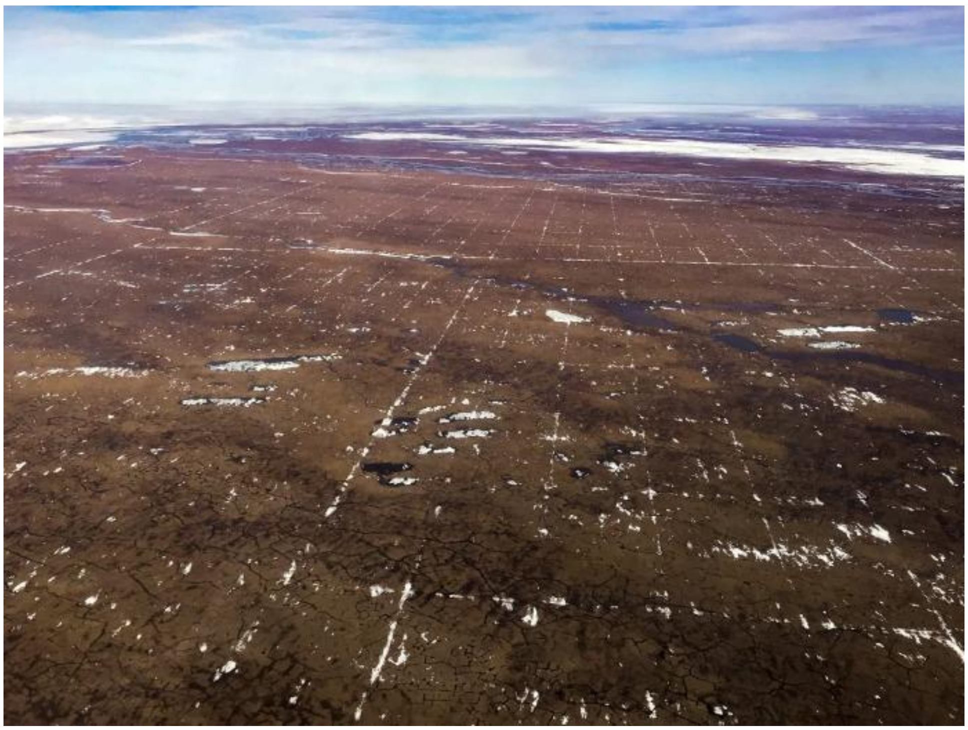
So that’s my motivation behind making this map of the 1002 Area of the Arctic National Wildlife Refuge. And after six months of planning and mortgaging everything of value that I own to afford to make it, I finally began making that map last week! Hopefully once it’s made, someone will find it valuable enough to buy…

The 1002 Area is about 6000 km2. I decided to map it at about 5″ resolution as a compromise between time, money and resolution. At this resolution, it will take me about 100 hours of flying. That’s about $20,000 in fuel alone in the Arctic. I could do the whole thing at 2″ resolution, but that would take 3 times more flying and probably 10 times the cost. I could do it at 15″ resolution, but that’s really not enough resolution to capture the processes of interest. So 5″ ground sample distance (GSD) seemed like a good optimization, and as I show here it is sufficient to see tire tracks. But even at 5″ GSD, the 10 full days of flying required may take 2 months to find given the weather, airplane issues, etc. So my plan is to give myself the whole summer to complete this.

My trip a week ago began from my home in Fairbanks on Sunday, June 24, and about four hours later I landed in Kavik, my home for the next month or two. The weather was great, so after a quick fill up of avgas, I headed out to shake down the system and start mapping! I decided to start with the area near the Canning River delta, as it was great weather for it, which is rare. The coastal zone here is notorious for fog, and if any single thing is going to delay completion of this map, it is likely to be that fog. So any time the coast is in the sun, that’s my priority.

Once out over the site, I instantly got distracted by the tire tracks I showed above. Here was an opportunity to prove to myself that my system had the capability to map these tracks without having to wait a year for the work to actually begin in the 1002! Of course after 10 years of doing this and dozens of validation studies I knew it should, but I'm always pleasantly surprised to say I told me so. So after taking a bunch of obliques with my phone, I decided to extend my flight lines to capture some of this area outside the 1002 as a proof-of-concept, which seems to have successfully worked. The flying went well, and soon I was back in Kavik downloading data and settling in.

Flying to the Canning River delta, I saw this off to the left — tire tracks in a grid pattern. My measurements showed that these grids are exactly 200 m by 400 m.



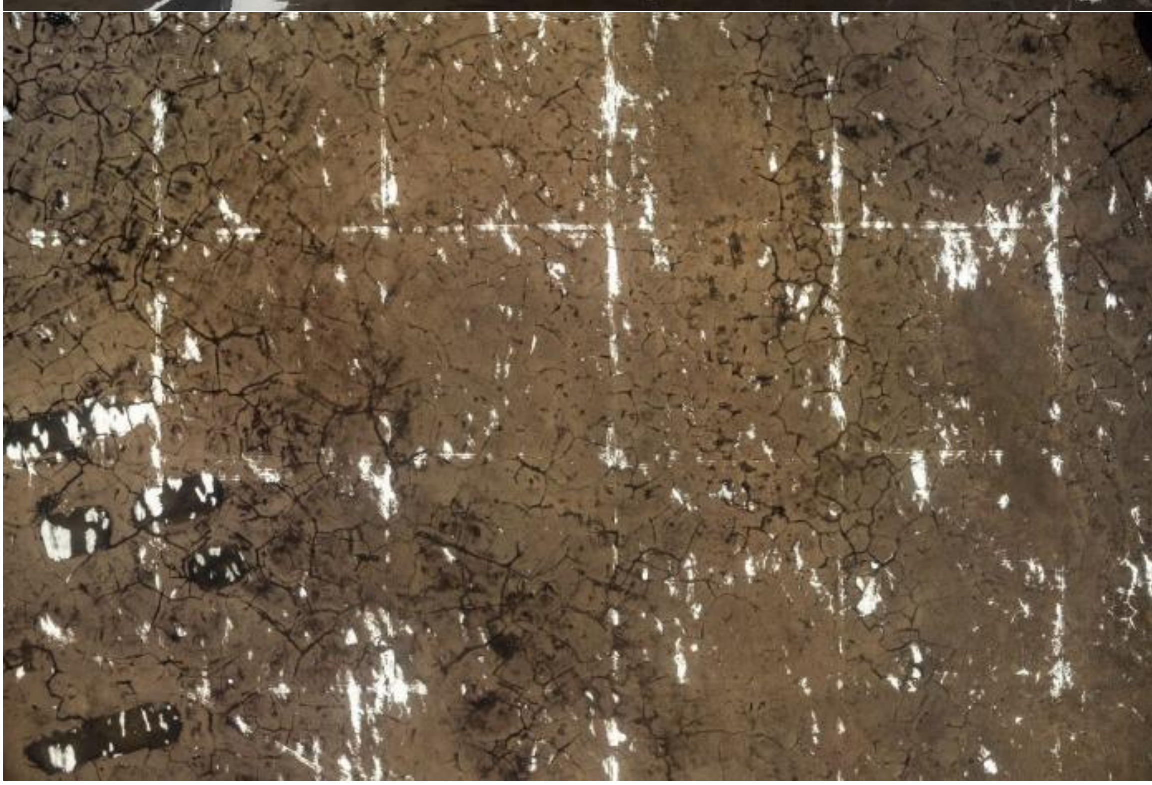
The Arctic Checkerboard. This is looking back towards the Refuge, across the Canning River and before the coast, covered in sea ice. Note: how the lines cross indiscriminately over lakes and rivers. The lakes and rivers are all frozen in winter, but the permafrost-melting process caused by the tire tracks could have major impacts in summer once the lakes and rivers open up by diverting the water along the tracks.

I think the impact of seismic tire tracks is more important on ice wedge polygons than the lakes and rivers. Here at bottom-left you can see a network of such polygons covered by water glinting in the sunshine. Should a topographic depression caused by these tire tracks lead that water in a down-slope direction, it could start the water flowing, which will thermally erode the tops of the ice wedges, melting them down into an even deeper depression, leading to a chain-reaction which could drain enormous areas in a matter of hours or days. This feedback process is well documented in the Arctic in the context of the rapid draining of tundra ponds which intersect with these ice-wedge rivers. Regardless of your opinion about whether the impacts of these tracks are good or bad, having analyzed my photos and data quite a bit now I have to say that I impressed that the operators stuck to their lines and were not out there doing donuts just for fun, so they did a great job of sticking to what they were supposed to be doing.

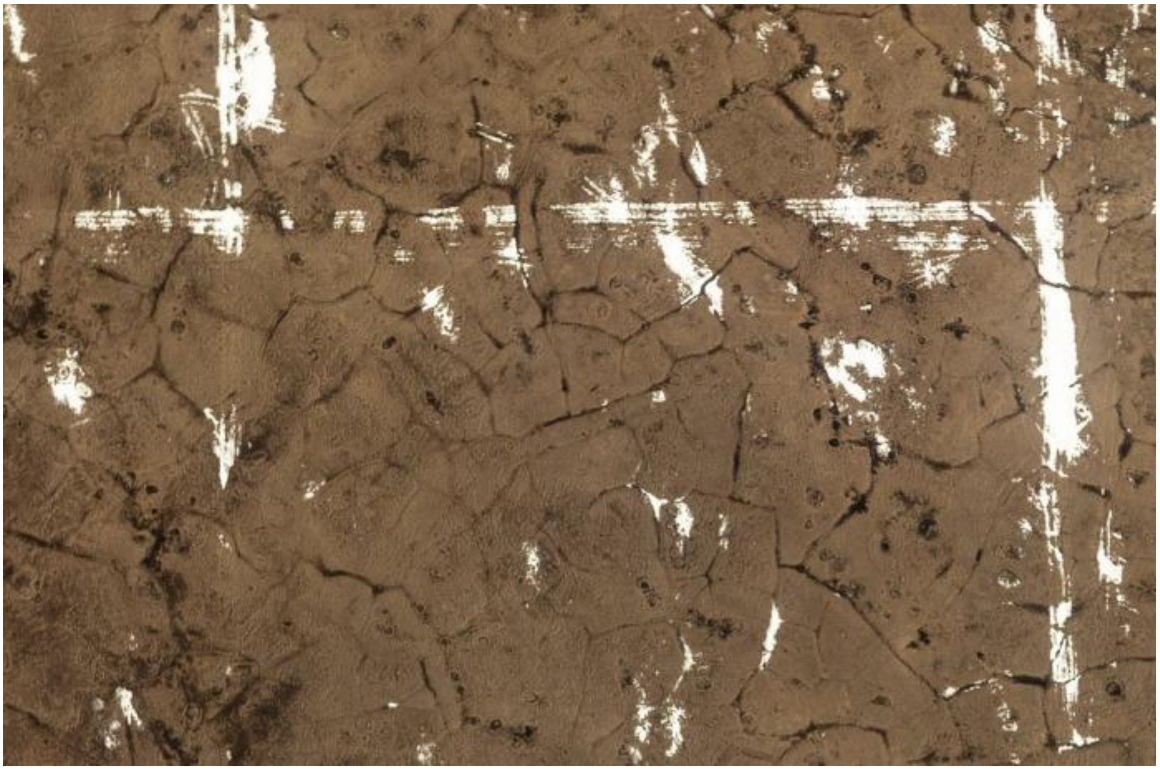
Here's a photo I took 10 years ago in the 1002 Area, showing a tundra pond that has been partially drained by the *process I described above. You can faintly see the outline of the original lake off to the left of the existing one, and the drainage channel straight ahead of it.*

Here's another photo I took a long time ago within the 1020 Area, showing a dry lake bed from a lake drained completely by this process. Perhaps counter-intuitively, this actually makes the permafrost grow thicker.

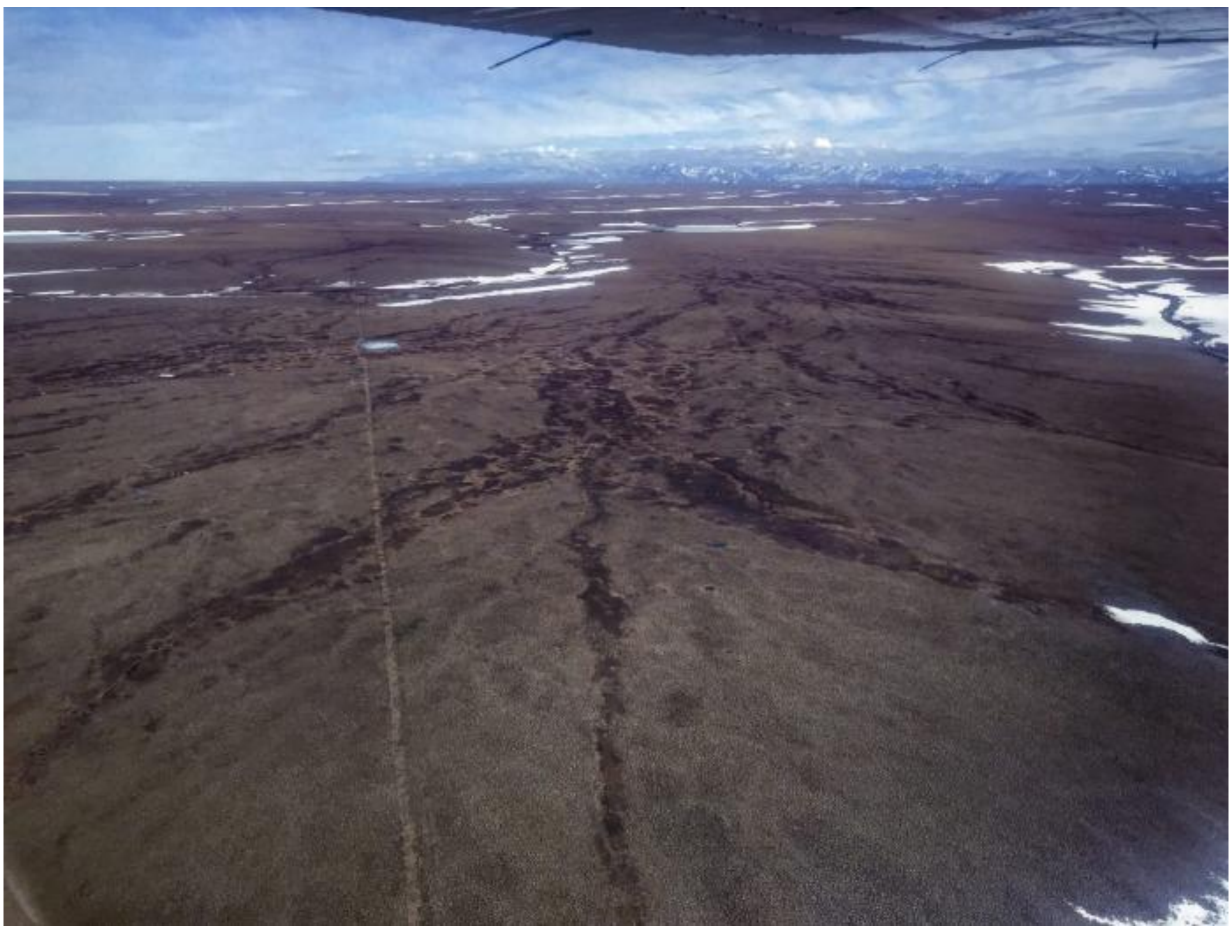
The 1002 Area is not flat, as many believe. The mountains come quite close to coast, steepening the coastal plain. This is why there are so few lakes here compared to the west side of coastal plain, which is really, really flat.



Here is an example of the vertical photography I acquired to make my map. You can clearly see the individual tire tracks that make the checkerboard.



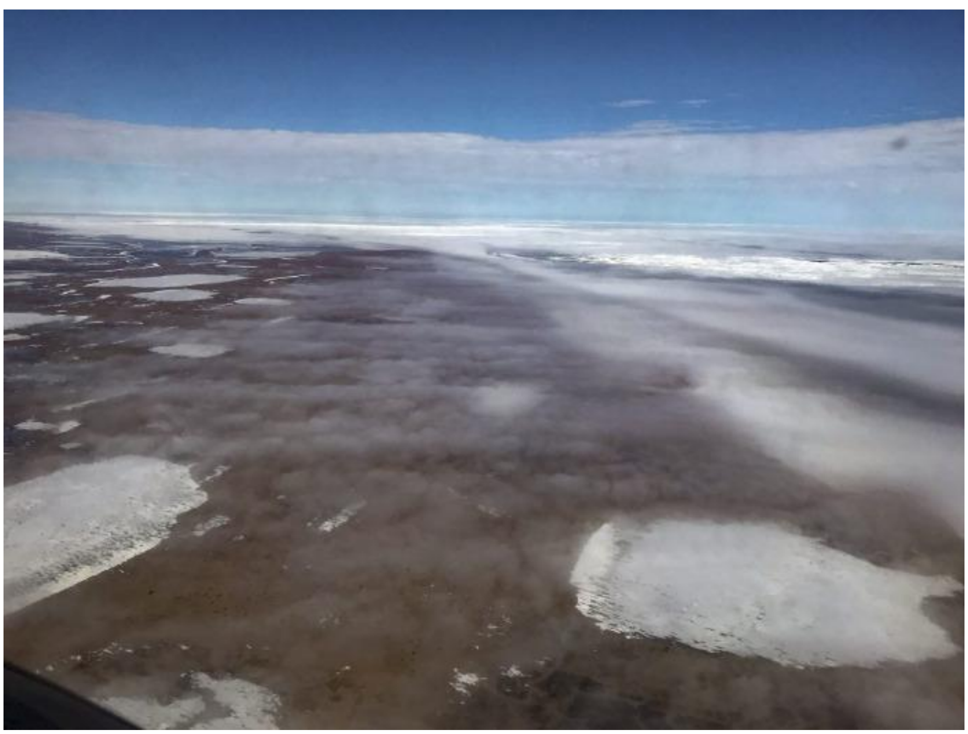
Here is a crop of the previous image. Note that you can not only see the tire tracks in the form of snow, but on the exposed tundra as well.



Here is a seismic track leftover from the 1980s. Though this is just outside the Refuge, you can find similar ones inside. They used different and more harsh methods back then, but the point remains that permanent damage *can be caused by using the best available technology of the times. The question is whether the best available technology of today is acceptable to the citizens of this country that own this land?*

Here are my flight lines, yellow, for my first day of mapping the 1002 Area, red. A long way to go, but a great start!

The next morning I was again up at 4AM, this time processing the data acquired in yesterday's late night to ensure that all was well, which indeed it was. So by about 9AM I was making my next flight line over the Canning River delta. A low fog had formed over the delta this morning, so I started working further inland, giving it a chance to burn off in afternoon, which indeed it did. In total it was 11 hours of flying taking some 13,000 photos, but the best part was knocking out one of the most troublesome weather locations on the project! Only 9 more days like that and I would be finished! So after landing, refueling, and shoveling some food in my mouth, I stumbled into my bed and dreamt of a week of perfect weather and other good things.



A low fog covered much of the coast in the morning.

I returned to refuel in Kavik mid day to find Everts' C46 topping off the tanks — 4000 gallons is enough for me! And that plane is the reason avgas here is $12/gallon… But worth every penny.

By afternoon, the coast had opened up and kept mapping until I ran out of fuel a second time. This is first year sea ice. Not that multi-year ice forms this close to the coast, but the dramatic wastage of multi-year ice further at sea is also having an equally dramatic impact on the landscape and ecology of the 1002 Area.

Another 25 year old seismic trail just outside the Refuge boundary, and also demonstrating how close the mountains are to the coast and how different this coastal plain is to the oil fields to the west.

Because of the steeper topography, there are fewer lakes here. Lake water is primary water source for ice roads used to support drilling on the west side. How will such roads be created here? The same technologies used in the west simply cannot be used here.

Another 8-9 days of weather like this is all I need! Besides a functional aircraft, lots of avgas, food and lodging, …

It was a great day! What a relief to actually start working rather than just thinking about working…

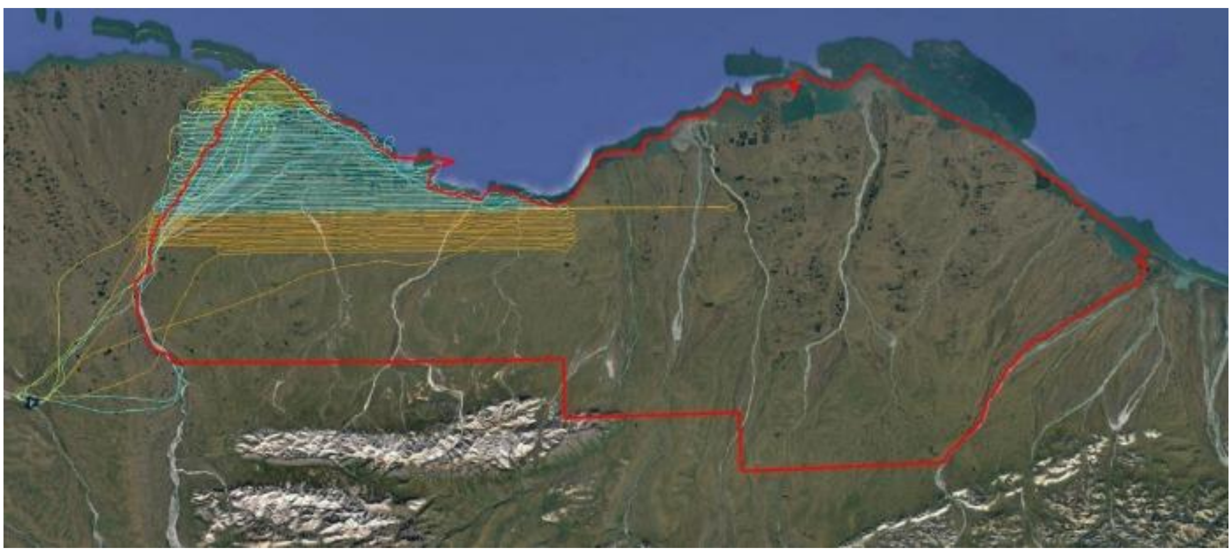
The blue lines were my second day's progress.

Having flown so late the night before, my third day of mapping (Tuesday June 27) didn't start until about noon. It was just as well as it took that long for the fog to burn off in Kavik. The forecast had called for the coast around Barter Island to open today, so I thought to map there as that location has the worst weather in the 1002 Area. But as I got close it became clear the forecast was off, so I returned to extend my lines from yesterday further inland and well outside of the coastal zone. This worked well, though I was being chased by the fog all day long. My lines run east-west and I was working my way south. The fog was coming from the north, extending inland about the same rate as my lines were moving inland. It didn't outpace me until I returned for fuel, and that pit stop allowed it to catch up a bit. But I was able to get another big wob of lines done before it overwhelmed me. "Only" an 9 hour day, but I'll take it!

I was secretly glad for the fog, gave me a chance to nap and catch up on data processing…

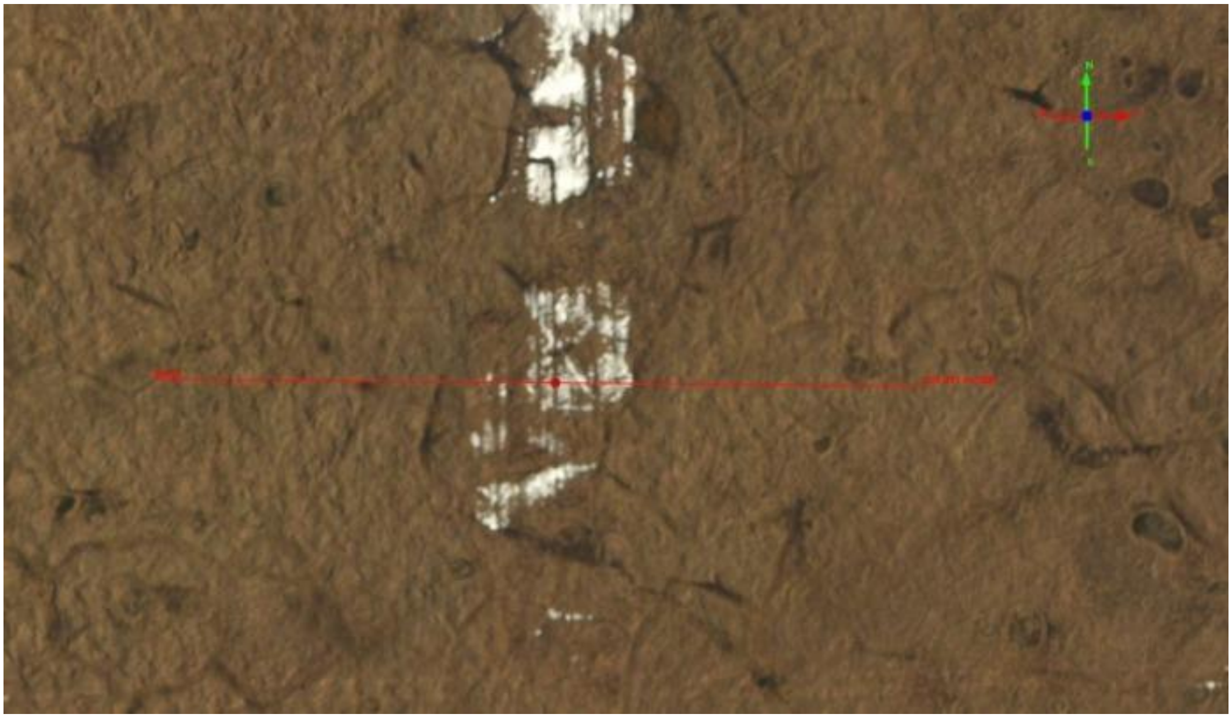
A low fog on the coast gradually followed me inland as I mapped.

It eventually caught me.

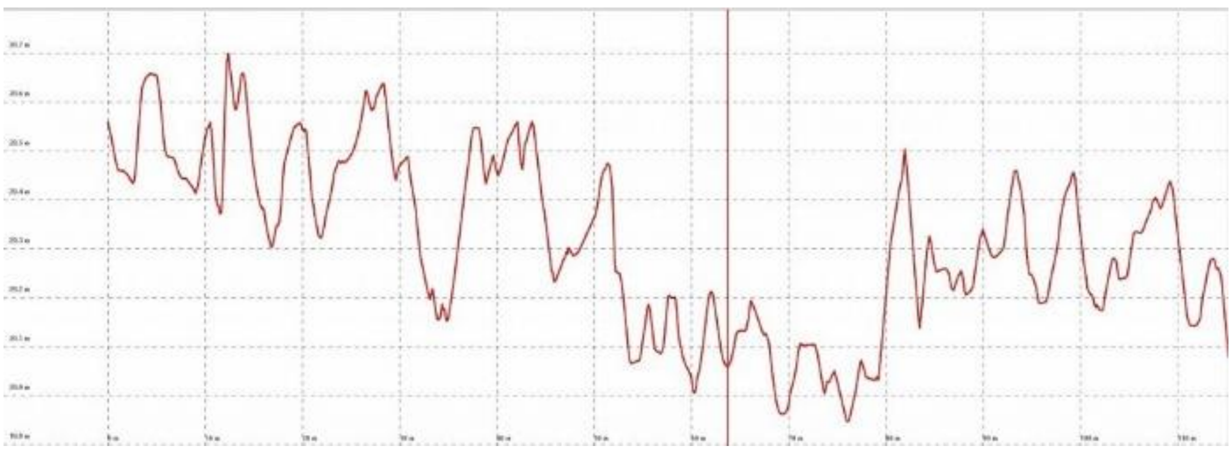


My third day's lines are in orange. Bit by bit, making progress.

The next morning I decided to leave Kavik and return home briefly. The weather forecast for Thursday and Friday were poor, and I had be back in Fairbanks to see my son's performance in Hamlet, which he had rehearsing for the past month. Plus I discovered that while taxiing back to park after fueling last night a rock put a decent-sized hole in my prop. This happened about a month earlier and cost me $9000. Fortunately this damage wasn't as severe, but it did remind me of the risks of working out here — ten thousand dollar bills are the norm and that's why it costs so much to work in the Arctic and that's why so few people do it. And by now I had acquired about 15% of area with over 25,000 photos, so it seemed like a good time to head back to Fairbanks to dig into the data deeper to ensure everything was working properly before going the distance. I spent most of that time analyzing the tire tracks just outside of the 1002.

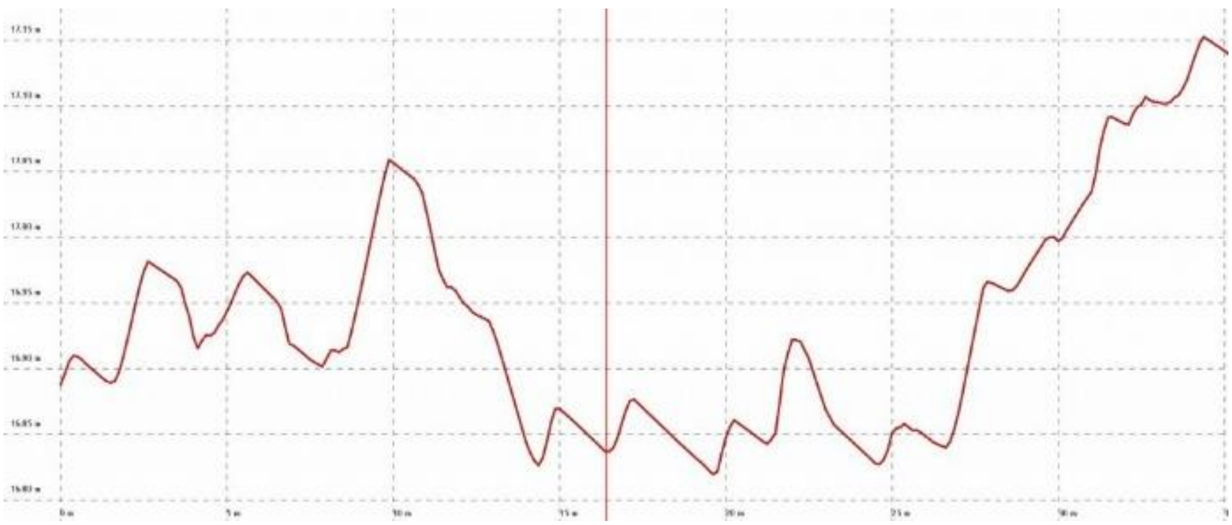


Here is a piece of one of the main seismic trails, as seen in my fodar image mosaic. When viewed in total and in detail, you can tell this one was driven over dozens of times by many vehicles, unlike many of the other lines which were used less frequently. The red line in the image is a transect I used to analyze the topographic change caused by these tire tracks. The plot below shows the topographic data along that transect.

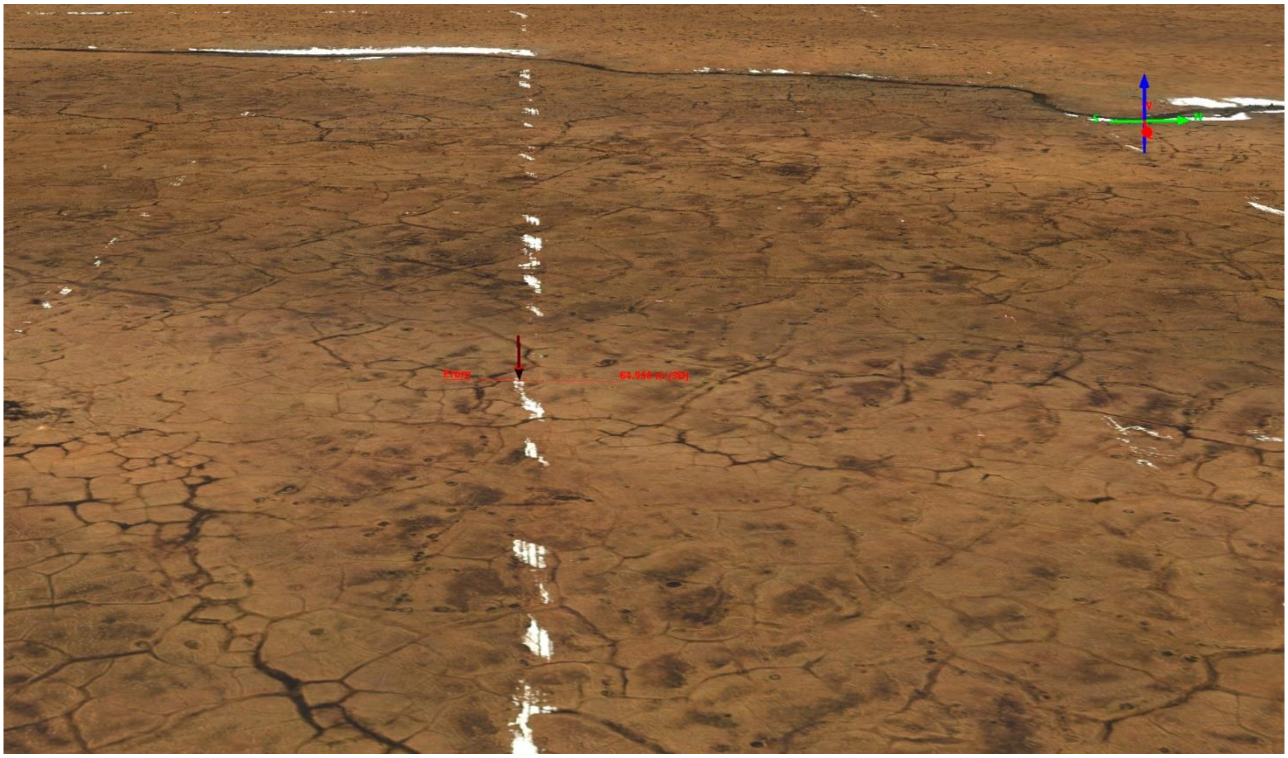


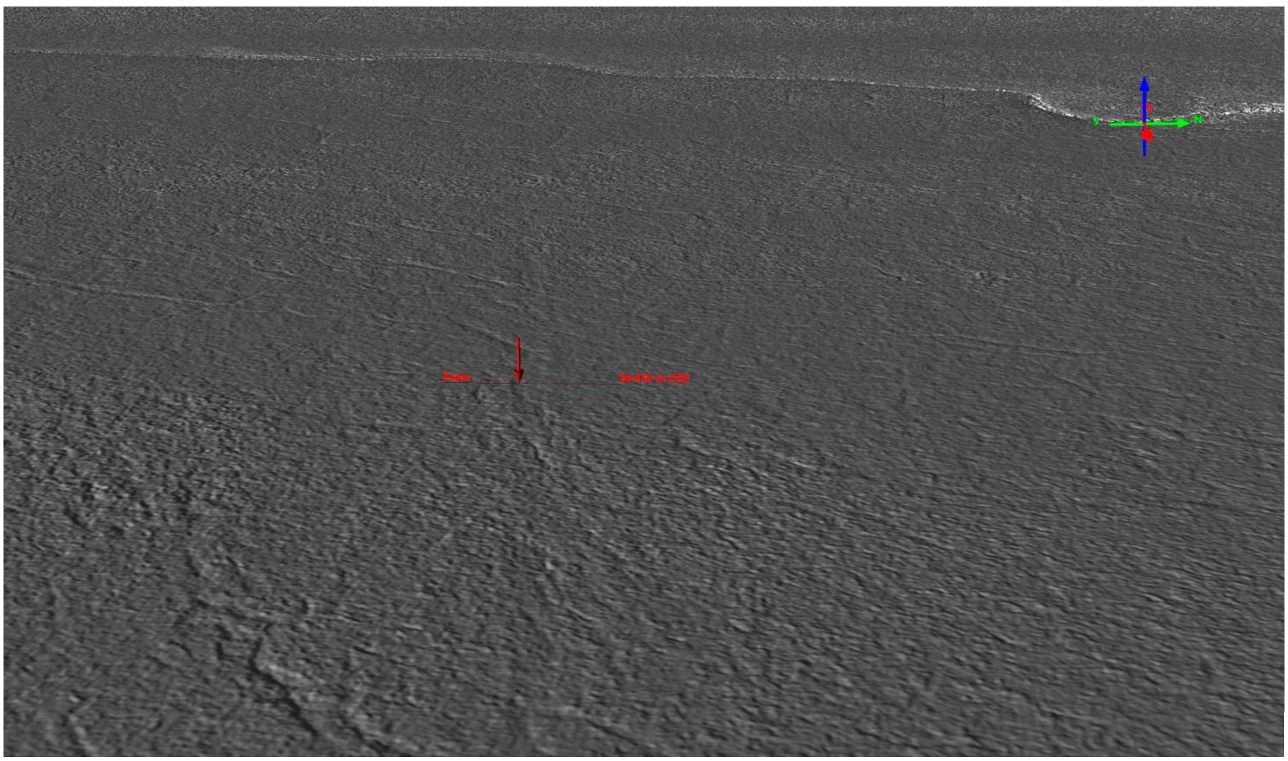
This plot corresponds to the previous image — the vertical axis is topography in meters with grid lines ever 10 cm and the horizontal axis the distance along the red line in the previous image. Here you can see that this main trail caused a depression in the tundra across it's width (from about 50 m to 80 m in this plot) of about 20 cm compared to the natural terrain. Further, you can analyze individual tire tracks to see their impacts — the vertical red line seen here corresponds to the red dot in the previous image, which in between the compressed snow of two tire tracks. That is, my data is able to resolve topographic variations on the order of single centimeters. I pulled out maybe a dozen transects along this line and all showed similar results.

Here is another similar example, see the profile plot below for the data.

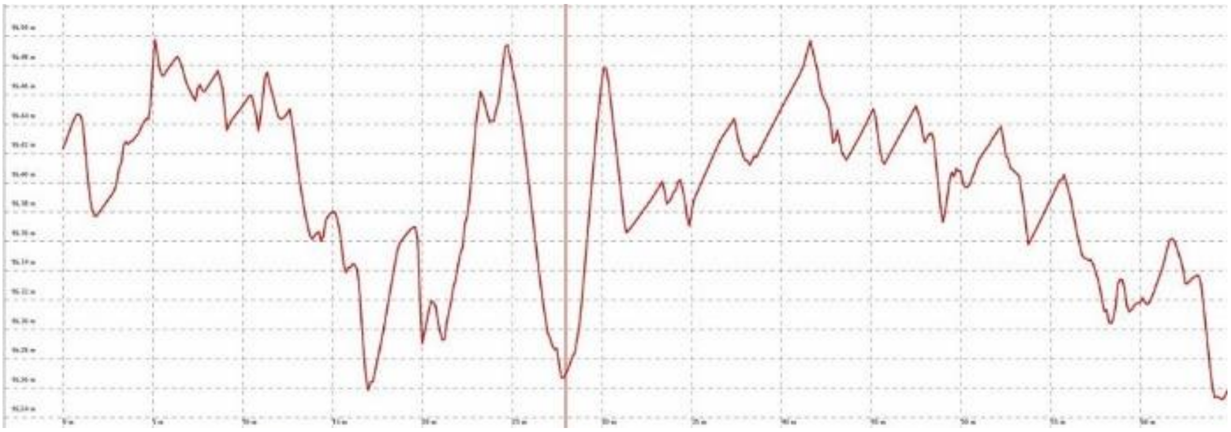


Here is the elevation profile from the previous image — note that the vertical line corresponds to the area between two tire tracks, meaning that the compressed snow is a topographic high in this case of about 5 cm. Like the previous analysis, the entire 15 m width of the trail is about 10-15 cm deep. These values of 5-20 cm are within the natural variation of the tundra surface itself, so some care needs to be taken in interpreting wiggles of this size. But from making lots of profiles like these and looking at the shaded relief imagery to see spatial consistency of these variations, signal (tire tracks) can reliably be distinguished from noise (tussock tundra, ice wedge polygons, etc).



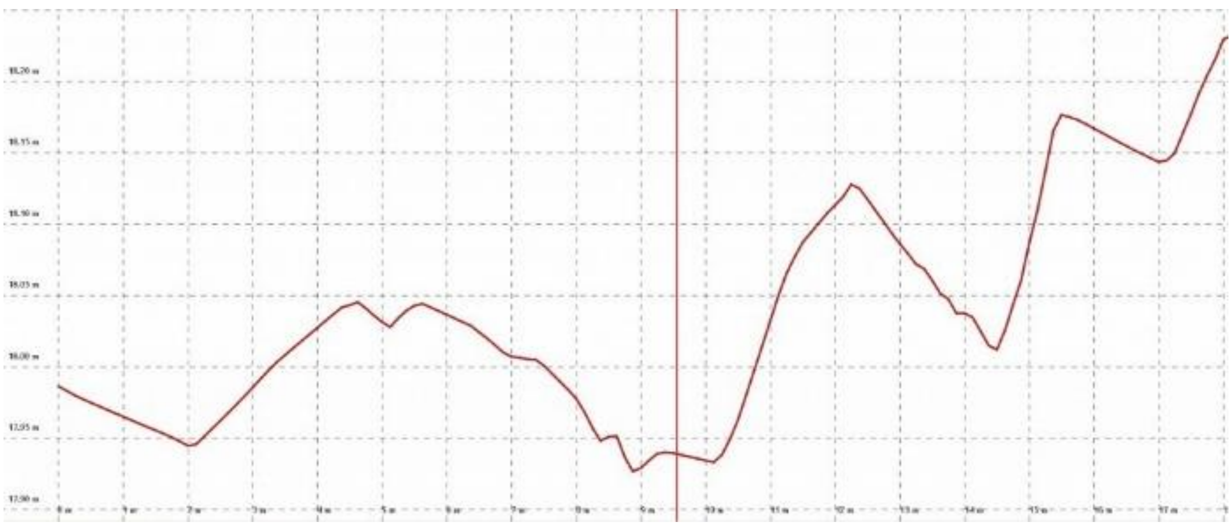


At left is the fodar orthoimage, at right is the fodar digital elevation model. By swiping left and right, you can see the spatial consistency in the topographic expression of the seismic trails — these are subtle impacts of only 5-20 cm, so you have to look closely. But even though the depth of these trails is within the noise level of variation in surrounding terrain, you can unambiguously identify the impact of the seismic work. The elevation profile is shown below.



This elevation profile corresponds to the previous image; note the horizontal grid lines here are only 2 cm apart, indicating that the depression left behind at the location indicated by the arrow in the previous image is about 20 cm.

As a final example, I explored whether the topography was affected after the snow had melted, which indeed it was. Clearly visible in the image are tire tracks with no snow in them, and as the plot below shows this visual indication has a corresponding topographic signature, in this case about 5-10 cm.



This elevation profile corresponds to the previous image, showing 5-10 cm of relief change due to the seismic tire tracks.

Here I've highlighted seismic tire tracks and the impact they may have for decades to come — we now have a means to track those changes. We now have the means to alter our plans for the future, whether for seismic exploration or anything else. For example, by making a similar map in winter, I can subtract this map from that one and directly measure snow depth. Then when seismic exploration occurs, I can make another map in summer measuring the impacts of those trails on the topography and compare this to the snow depth that I measured in winter. Perhaps I will find that when the snow depth is more than 50 cm thick there is no impact of seismic lines on tundra topography, but when snow depth is 25 cm there is an impact…or perhaps it will all have an impact. Right now, who knows? My point is that we need to be monitoring this in support of making the most rational and responsible decisions about whatever happens out there, and this is just one example of dozens of decisions that these topographic maps can assist with. This technology is just of several I have developed that could be put towards this purpose. For example, I can also measure the depth of ground freeze in winter using a different airborne technique, such that we can limit work to only those areas that are frozen to a certain depth.

In any case, that's a summary of where I'm at — about 15% of acquisitions complete and I have processed those data to demonstrate that I can measure my main signal of interest: tire tracks left behind by seismic exploration. Of course this map will be useful for a lot more than detecting future seismic tire tracks — just because I didn't feature it don't forget that I also measuring the the shape and size of every single ice wedge and polygon in the 1002, the entire coast line, every gravel bar, every snow drift, etc. The scientific uses are too numerous to list, but this map will form a baseline against which all future change can be assessed. What I find most useful about these data is that they cover a huge area at a high enough resolution not just to see the final results of change but to get at the processes causing those changes, such as tire tracks or caribou trails or climate change. When subtracting one map from another, the area that hasn't changed shows as zero elevation but those features that have changed show up as a non-zero, allowing us to easily find needles in a haystack, such that at a glance we will be able to quickly find not only tire tracks but all permafrost subsidence or thermokarst, coastal erosion, stream channel migration, polar bear dens, etc. And by detecting and tracking such small-scale processes over huge areas, we can begin to understand their causes which will allow us to model them to help us predict future impacts and perhaps how to mitigate the ones we consider negative. But I suppose I should get back to focusing on making the first map…

Though the mapping went well, the best part of my week was seeing my son Turner act in Hamlet. He had his first 7 birthdays in the Arctic Refuge during our various field campaigns, and I hope he will have many more there. And I hope when he and his kids are old enough to fly over or spend time in the Refuge on their own, they will realize I did my best to keep it from looking like a giant checkerboard…

Latest View Of 2018 Seismic Exploration Impacts Near The 1002 Area

By Matt Nolan Posted August 1, 2018 In Fodar News 0

URL: http://fairbanksfodar.com/latest-view-of-2018-seismic-exploration-impacts-near-the-1002-area

As of July 26, not only are the winter 2018 seismic tracks still visible at Pt Thompson, the depressions they left behind are still measurable topographically with fodar. I believe that it is possible to do seismic surveys in the 1002 Area without leaving any trace, but not using current methods. We can do better.

I think seismic data is cool. I think 3D seismic data is even cooler. I have a PhD in Geophysics from UAF and my thesis was on developing new methods for seismic exploration, and I've used these methods throughout the frozen landscapes of Alaska, Siberia and Antarctica. I just spent a few weeks in Kavik, where a bunch of USGS and DNR geologists were studying the rocks in the 1002 Area to better understand the oil-related geology, so I had the opportunity to see some of the latest in 3D seismic viewing technology. It's like a full body scan of a human — you can fly through the subsurface of the State in any direction and trace folds, faults, and layers, with well logs geolocated within it. What a powerful tool for understanding the formation and ongoing deformation of this unique area of the Arctic! I would love to see that for the 1002 Area.

I have a lot of experience making loud noises in cold, snowy places, in this case Antarctica.

Unfortunately, seismic exploration has a justifiably bad environmental reputation in Alaska. The seismic lines from the 1960s through 1980s stick out like sore thumbs here on the tundra, to such a degree that they are used by pilots like me for navigation. Fortunately, those methods are no longer used here; but at that time, those permitting and using those methods thought the destruction was worth the benefits because they were using the best methods of the time. Unfortunately, this is always the case — people can rationalize anything, especially where money or peer-pressure are involved. So as much as I would like to see 3D seismic done in the 1002 Area, I am adamantly against using the methods used earlier this year just outside the Refuge boundary which leave what appear to be permanent scars on the landscape, as I show in this blog. I've spent the past 15 years out there as a physical scientist trying to understand this dynamic landscape and I simply do not want to see a checkerboard placed over it due to laziness and greed after 58 years of hard-fought protection. We can do better.

Once upon a time, someone thought this was a good idea.

That river is the western boundary of the 1002 Area. The old seismic tracks outside the Refuge are so prominent they are used for navigation by pilots. These scars, many over 50 years old, may never heal; on the contrary many continue to get worse as the ice beneath them continues to melt.

While the seismic methods that created this line are no longer used, the point is that this was the best method of its day. Just because we are doing better now doesn't mean we are doing good enough for work within the Refuge.

Here's what Dan Sullivan, one of our State's Senators, recently had to say:

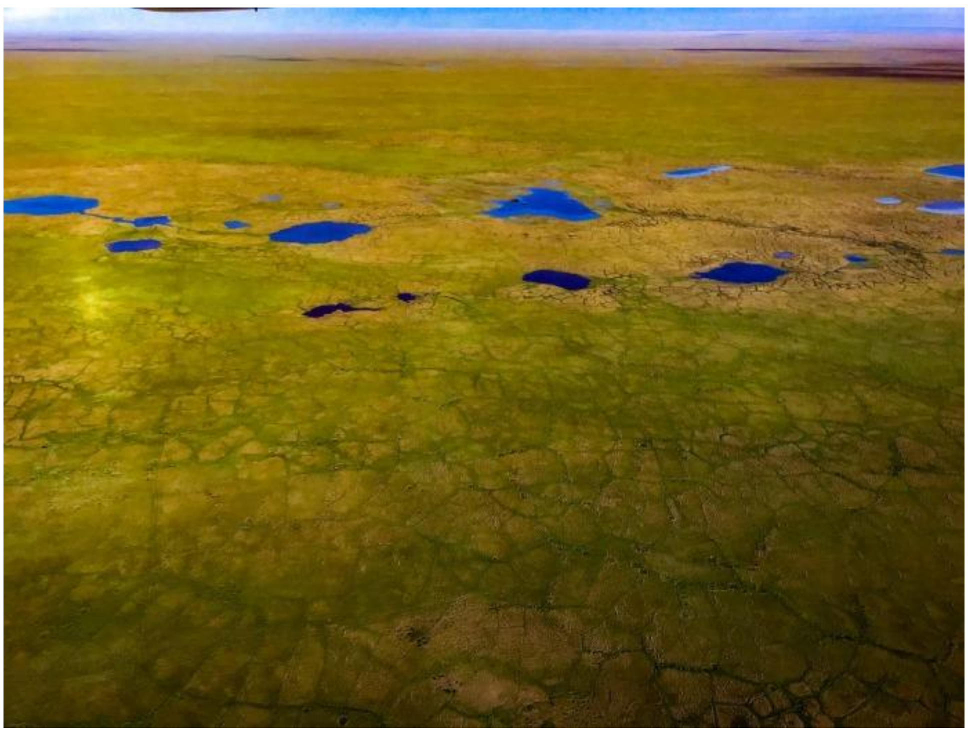
"I oversaw Alaska's environmental standards as the state's commissioner of the Department of Natural Resources, and I can say with certainty that Alaska has the highest environmental standards regarding responsible Arctic resource development in the world. Our state has a 50-year record of responsible resource development and no "impact exploration," meaning that we mandate the best available technology and require the protection of our incredible species, such as polar bears and caribou. On the North Slope of Alaska, for example, we allow for exploration activities only during the winter months. Companies are required to build ice roads across the tundra and ice pads where they put their equipment and drill rigs. They must also leave before the end of the winter. The ice pads and roads melt, leaving zero impact on the tundra. The only thing left is a small, capped well."

If you parse his statement, you see there is no mandate for "no impact" but rather for "best available technology". The seismic work of the 1960s-1980s used best available technology and those scars seen above continue to deepen over time, not heal, in the fragile arctic tundra. If he truly believes modern seismic methods leave "zero impact on the tundra", then it should be no issue at all for him to propose the following law: "Oil companies can do as much 3D seismic within the 1002 Area as they like using any methods they like, but no gravel infrastructure can be placed or drilling operations commenced until all traces or impacts of that seismic exploration are gone." This is what's called putting your money where your mouth is — if there are truly no measurable impacts of seismic exploration, then drilling can start the next summer. But if new seismic exploration creates the same scars as it did earlier this year, then it may be decades before drilling can start.

My point is… that while today's methods are much much better than yesterday's, they are still not good enough for use in the Arctic National Wildlife Refuge tomorrow. If what he said was true — that seismic exploration leaves no impact — I would entirely agree with him, but that's simply not the case, as my recent measurements reveal. I first noticed these tracks from the 2018 seismic surveys at Pt Thompson about a month ago, and described what I saw here. At the end of my trip to map the 1002 Area last week, I wanted to see how things had changed during the peak of summer at Pt Thompson.

The 2018 Pt Thompson seismic lines are still clearly visible in late July 2018, even with crappy iPhone photos through plexiglass. The tracks are deep enough to cast shadows in the low angle sun.

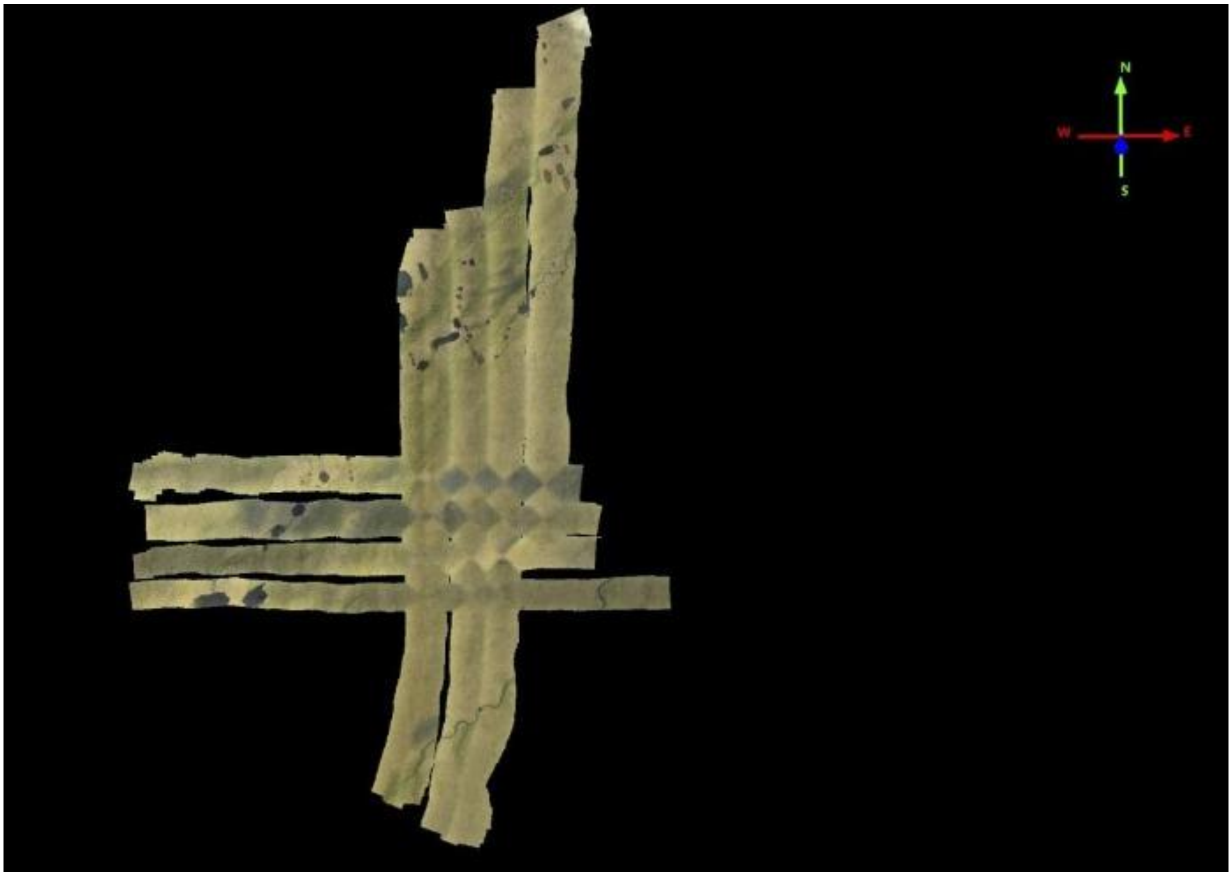
In the plane, these lines were pronounced enough that I used them to navigate by for mapping, but there were so many I got confused as to which ones to follow next when I made U-turns.



Start in the lower-left corner, and you can see the checkerboard. On the one hand, I'm tempted to bring a better camera next time, on the other hand… I'd just rather there wasn't a next time.

The lines are faint, but visible. Will they ever disappear completely given the change in vegetation they cause? A better question is…. how can we prevent these tracks from forming in the first place?

In addition to taking a few snapshots like those above, I mapped the lines topographically using my system. I have to admit that this is, by far, the worst map I've ever made; to my credit though, it is still the best map ever made of this area and still quite useful for the purpose. I'm not sure how I screwed things up, but it certainly had to do with planning this mission in my head as I flew over it, about 7AM, on my way to Fairbanks, trying to hurry to get over the mountains before the weather came down after finishing a month long mapping effort in the 1002 Area. In any case, an important plot point here is that I was using the seismic lines themselves to navigate my flight lines. That is, even at 125 mph I was able to clearly follow the lines left by the 2018 seismic work for my mapping. I just followed the wrong lines apparently and spaced my flight lines too far apart to make a pretty map…



This is by far the worst map I've made in 8 years, but still good enough for the analysis I show below. Not sure how I screwed up the line spacing, but I didn't preplan this mission, it was just on a whim on my way home, and I was using the 2018 seismic lines themselves to navigate by and I somehow forgot how far apart they were or was skipping too many of them. In any case, an important note here is that the tracks were so visible on the ground that I could use them to navigate an airplane flying 125 mph to make these perpendicular flight lines. The little diamond shapes at the intersection of the lines is caused by the change in cloud cover in the time between doing the east-west and north-south lines and the software trying to blend that together.

[Fodar measurements of seismic lines near Pt Thompson](https://www.youtube.com/watch?v=l--Xfd7J9yA) (control-click to view video)

https://www.youtube.com/watch?v=l--Xfd7J9yA

Here is a video of fodar data collected on 26 July 2018 flying over about 1.5 miles of seismic trail from the 2018 work near Pt Thompson, seen as a bunch of parallel lines near the center of the screen. The video pauses where tracks cross perpendicular the main one running through the center of the screen, about every 200 m. I didn't count them, but there were probably several dozen trails out there, each many miles long, that looked just like this one, so I'm not cherry picking the worst by any means. These larger ones like this one with multiple sets of tracks run north-south (the video is rotated with north to the right), the ones going east-west were usually much smaller often with only one set of tracks visible. So there is no doubt that the 2018 seismic work created an impact, the question is whether you consider it significant? In other words, is it ok with you if the 1002 Area gets covered by 20,000 miles of tracks like this?

[Fodar topographic measurements of seismic lines near Pt Thompson](https://www.youtube.com/watch?v=wM2PRuZVea8) (control-click to view video)

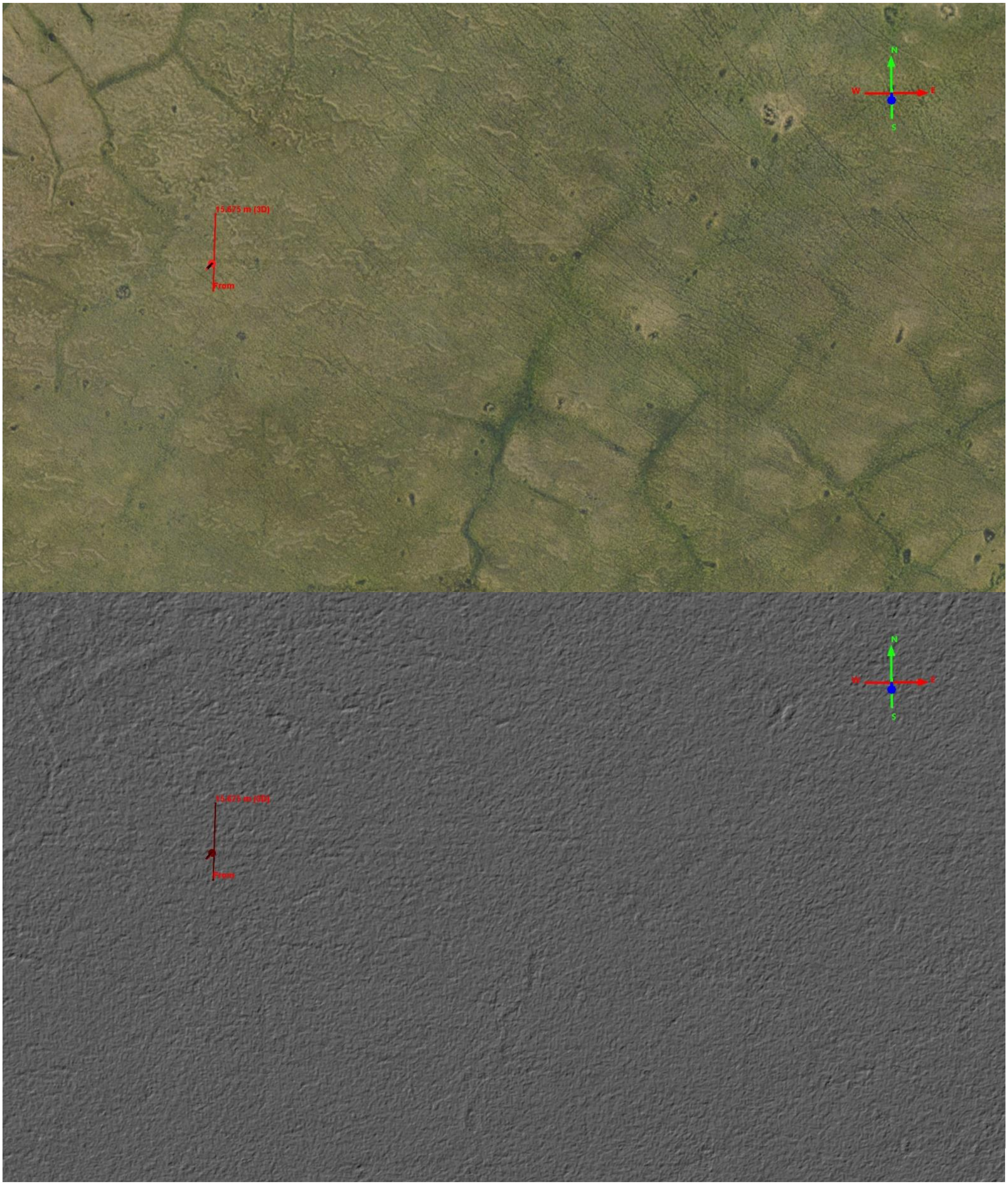
https://www.youtube.com/watch?v=wM2PRuZVea8

This is the same video as the last one, this time with topography, showing that the tracks you saw visually also have a topographic impact. What you are looking at here is a shaded relief image of the topographic data, so fake sunshine creates shadows that highlight the relief.

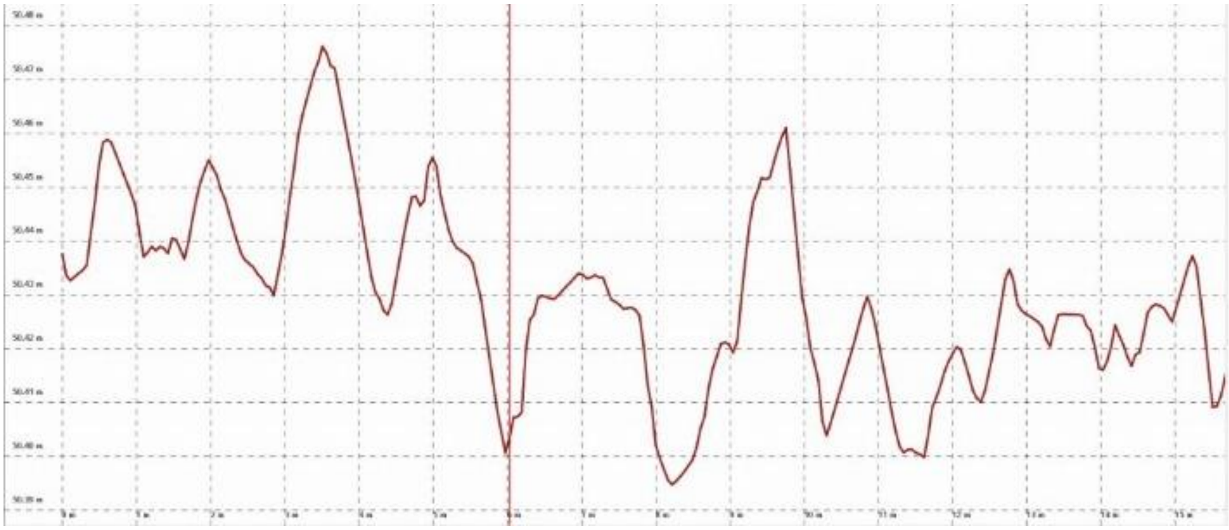
[Fodar measurements of seismic lines near Pt Thompson](https://www.youtube.com/watch?v=A9EQ0AcNA_I) (control-click to view video)

https://www.youtube.com/watch?v=A9EQ0AcNA_I

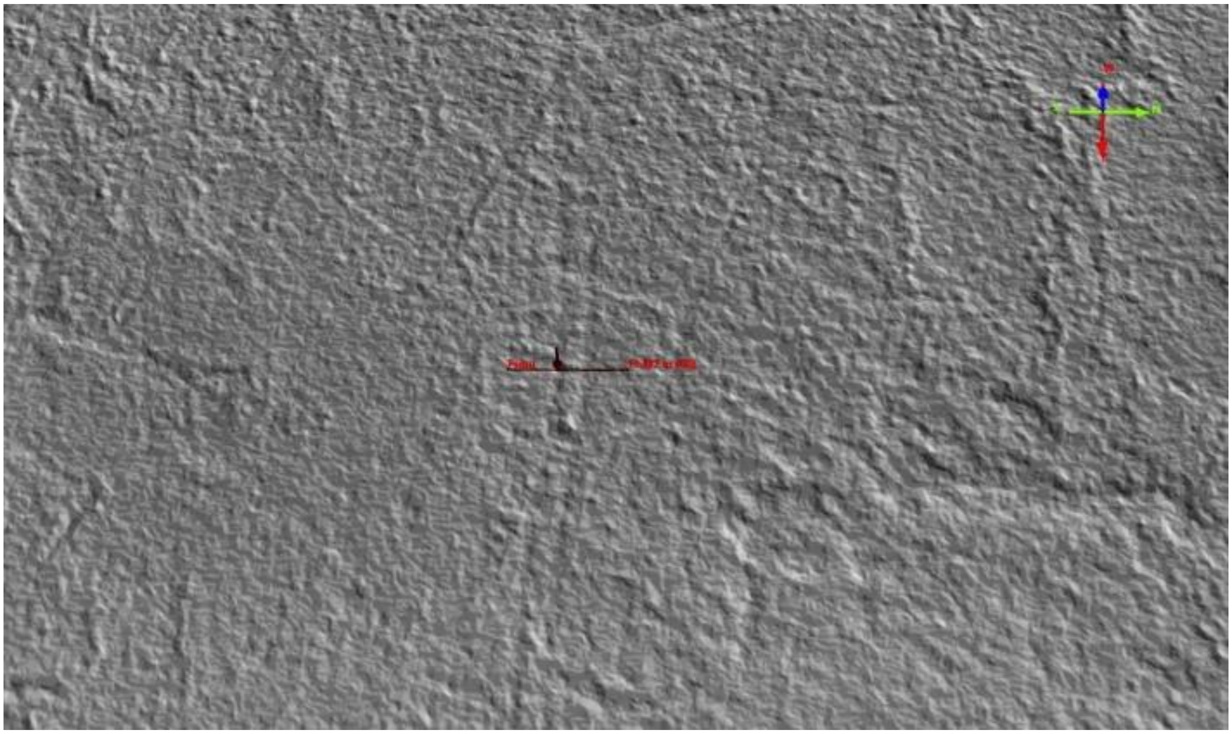
This video circles around one cell of the 200 m x 200 m checkerboard at Pt Thompson.



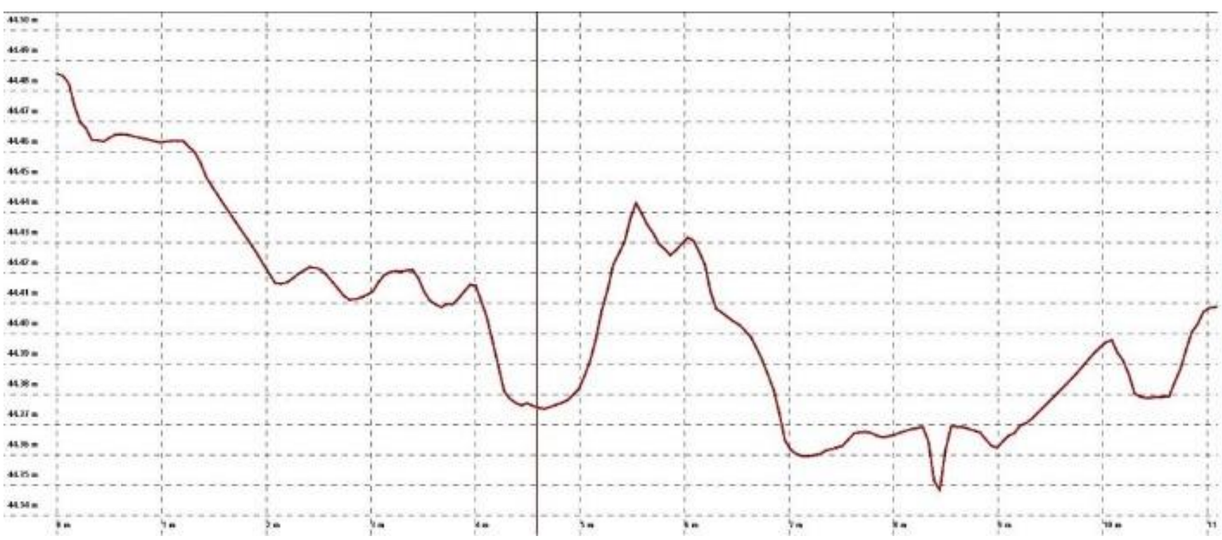
Here's a piece of that map showing my imagery on the left and my topography on right. The topography is shown as a shaded relief image, meaning that I've beamed synthetic sunshine onto digital topography to create shadows that highlight the relief. Here you can see the intersection of two seismic lines. I've run a transect over one of them, shown by the red line, and plotted the topography under that red line below; the pushpin seen here corresponds to the vertical line below.



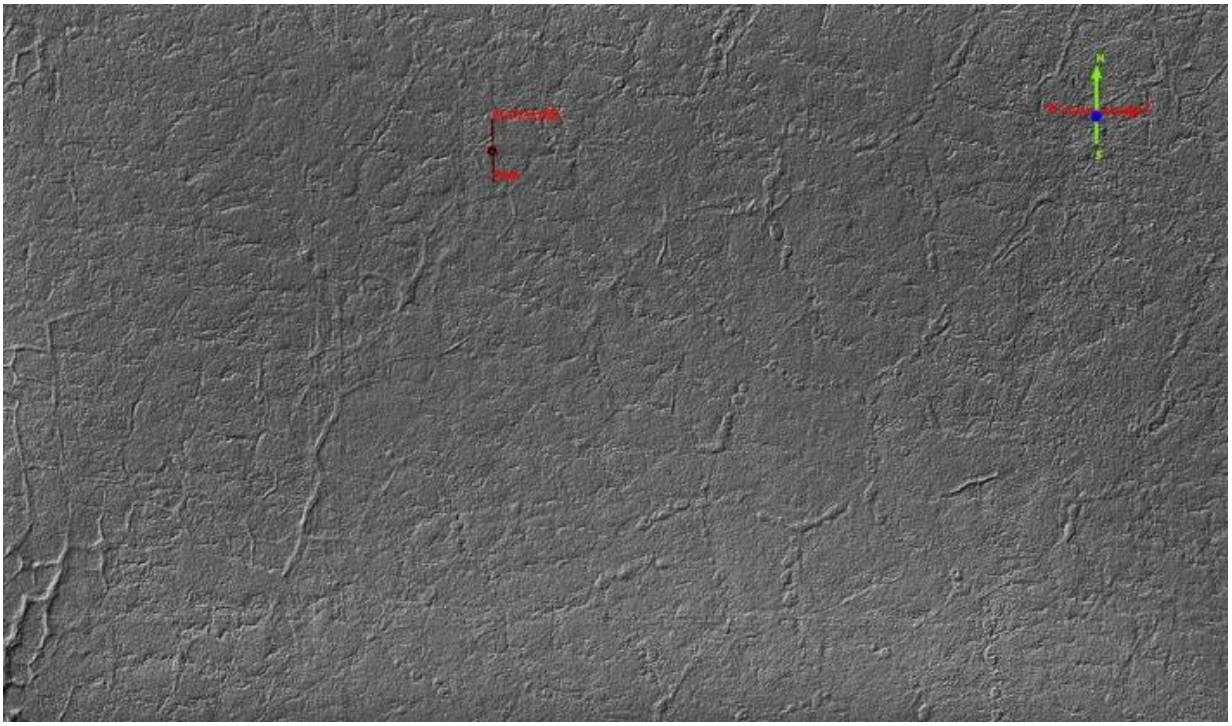
This plot corresponds to the red line in the previous image, showing the topography under that line. The vertical red line here corresponds to the pushpin in the previous image that is in one of the tire tracks. The horizontal grid lines are only 1 cm apart. Depending on what you reference to, these tire tracks are 3-6 cm deep, or about 2-3 inches. The other track is about 2 meters to the right, so this was a big vehicle or sled.



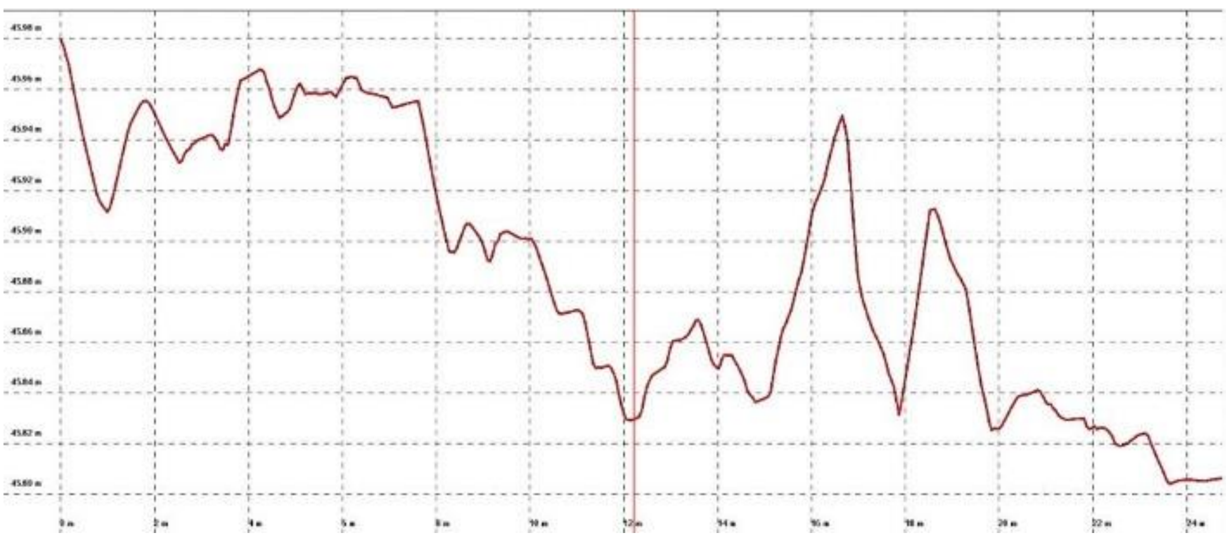
Here is a typical track along the grid lines. The red line and marker correspond to the data below. The important point with this image is not how deep it is but that you can clearly see the tracks in the topography, and that these correspond with the grid that you can see visually in the previous photos.



Here that tire track is shown to be about 5 cm deep (about 2"). This is typical of the few dozen spot checks I made. The track itself seems to be about 60 cm wide, and the next track about 2 m apart, so that's a big vehicle (or perhaps a big sled).



Here you can see a tic-tac-toe pattern of tracks if you look closely. The lines that run north-south seem to have a lot more traffic on them than those that run east-west. I've put a transect across one of the east-west lines, as it's easier to find single-vehicle tracks and measure individual tire tracks that way, like I show below.



Here it seems the tire track is about 5 cm deep (about 2"), and this is typical. The two tracks are again separated by about 2 m, indicating a large vehicle or sled caused them.

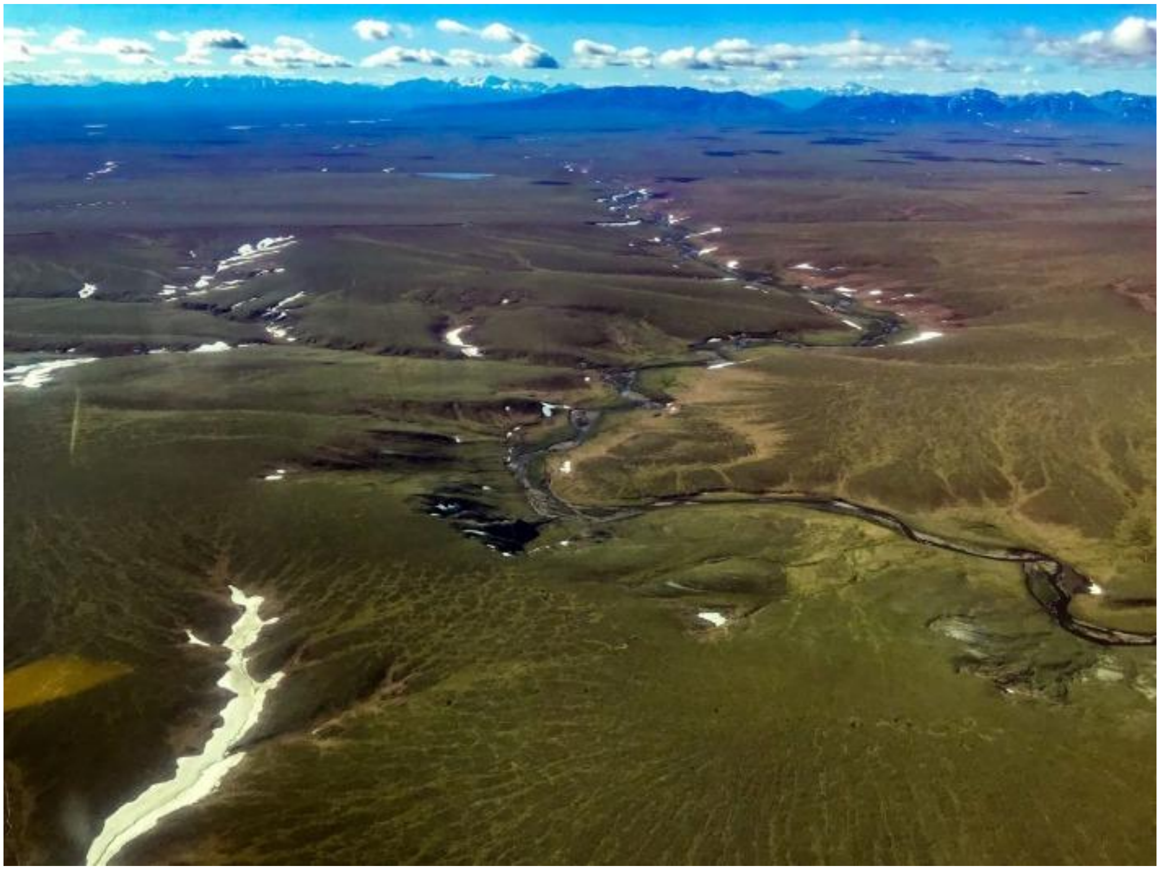
Before discussing the implications, I want to highlight two remarkable technological achievements seen in the analysis above. First, I'm able to measure tire tracks only 2″-4″ deep in Arctic tundra using a $3000 camera and some brain power. Second, the tire tracks are only 2″-4″ deep, remarkable considering how many hundreds of tons of people and gear were dragging across that landscape, such that there is almost no comparison between the impacts of the 1960's seismic and today's — it really is remarkable how far we have come. But it's simply not good enough, in my opinion, for use in the Refuge. The Refuge was set aside and zoned to be kept pristine. While it's true that when it was expanded in 1980 it was also zoned for oil extraction, but those oil-related activities still must be held to a higher standard than elsewhere. Seismically mapping the 1002 Area using 2018 methods would be a visual and potentially ecological disaster, permanently scarring the Refuge and threatening all future drilling here due to the public outrage that would undoubtedly ensure. We can do better.

Unfortunately, there is little time for doing better. Applications for permits have already been submitted to do a lot of seismic this winter in the 1002 Area, and the BLM seems to be rubber stamping it without a serious environmental review despite decades of obvious impacts. The 1002 Area is simply much different than NPRA — most of it is not really a coastal plain, it is uplands that fall directly off into the ocean, with rock outcrops and ravines a few hundred meters from the beach. The area is actively being deformed tectonically, so there is little truly flat or level area. The rivers here are not shaping the land, the land is shaping the rivers — the folds and uplifts from below are dictating their course. There is a reason the mountains come so close to the ocean here — they are actively being pushed there from the Gulf of Alaska. The Sadlerochit mountains are only 20 miles from the Arctic Ocean — 20 miles! In that 20 miles there is little that can be called flat due to the same geologic forces that created the mountains. To the east, each of the watersheds are unique. Many are shaped by a series of perched wetlands, where the perches are only decimeters apart vertically, about the same initial depth of the tracks left behind by the 2018 Pt Thompson seismic work I found in my first maps. Thus the bulk of the 1002 Area has a much stronger hydraulic gradient, in which small disturbances will have a more dynamic impact than in the much flatter NPRA. Of the few lakes out there, I don't recall seeing any that were not already connected to some lower lake, and the evidence of lakes changing shape and size over time is abundant. Same with overland flow — water tracks, beaded streams, linked ice wedges — these features are persistent everywhere. The point is that micro-topography is the dominant control on the surficial hydrology of probably 90% or more of this landscape — that is, the land in between the rivers which drain the mountain watersheds. If you do not understand that microtopography (in this case, topography on the scale of an ice wedge, or centimeter or decimeter) then you have no way to predict the impacts that a 20,000 mile network of 20 cm deep grid lines will cause. While I do have a fair amount of experience in permafrost hydrology and ecology, I wouldn't say its my specialty, but regardless I know enough to know that without a map like mine being studied intensively for at least a year we are just being reckless in terms of permitting seismic work in this region. And I don't say that to slow things down on principle but to emphasize that the comprehensive study required takes time and has not been done and apparently if the BLM has it's way it will not be done — unless we somehow change the current dynamics to allow the necessary studies to occur. It took millenia for that landscape to form, but it will only take one winter for it to get fucked up permanently.

This is the cover photo from SAExploration's permit application to do 3D seismic in the Arctic National Wildlife Refuge starting in a few months. They propose to have 300 people and their living quarters towed around by some 30 vehicles. Is it conceivable that so many vehicles towing an enormous hotel in the dark of winter won't leave an impact? Conspicuously missing from this plan is any mention of leaving scars behind or how such damage would be detected or mitigated.

Here is what a 400 m x 400 m grid looks like superimposed over the 1002 Area. I calculated that it affects over 5% of the total area of the 1002 Area, or roughly 300 km2 (75,000 acres). That's way more than the 2000 acre limit of impact required by law. And that's only half as dense as proposed by SAExploration…

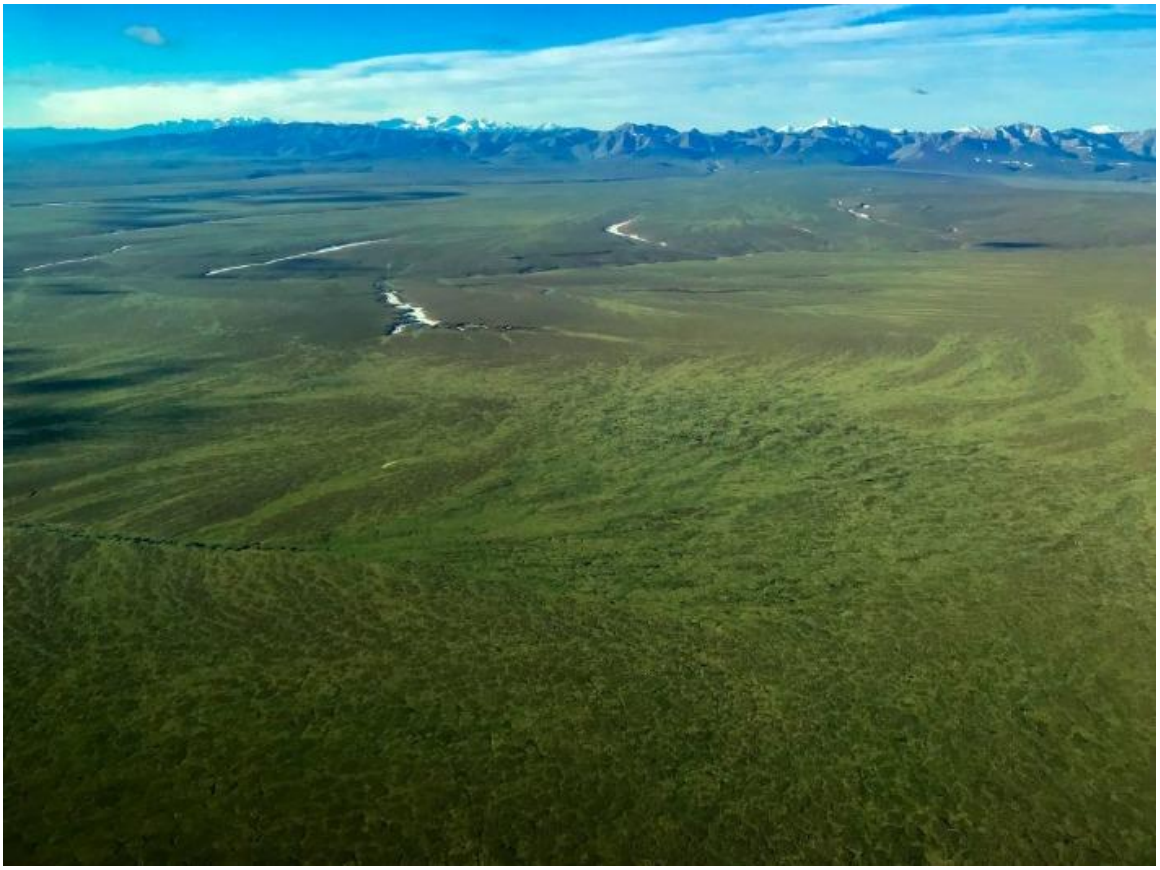
Here's what it looks like more close up. Do you really want to see such a grid etched into the tundra?
We can do better.



This is what much of the 1002 Area looks like. Would you call this a coastal plain? I wouldn't. Don't even try to tell me you can drag a 150 person man-camp across that without getting stuck a dozen times…

There are no large lakes here because it's NOT flat. This is not NPR-A!

The geology here is super cool. I look forward to learning a lot more about it.



Putting miles of linear tire tracks over this terrain would likely be a hydrologic disaster.

Here the geology shapes the rivers, not the other way around.

Apparently official federal government policy at this point is to call the 1002 Area a coastal plain, because, as I've been told by those required to call it that, it sounds like a wasteland just waiting around to be drilled. Hardly, it's a geological and ecological wonderland.


Permafrost hydrology in action — water tracks coalescing into a river channel.

This is just east of the Jago River on a smoky day — here you can actually see the folds of the soft geologic layer rumpled by the same forces that created the mountains in the distance. Again, not a coastal plain.


The 1002 has so much to offer scientists and visitors — laying a seismic checkerboard over this would be a disgrace to our country.

You can read the current seismic application here. It seems fine in general, and I don't doubt the people that wrote it were sincere. But it is all boilerplate, it basically just asking to be turned loose out here given a few guidelines, and that simply is not appropriate for the Arctic National Wildlife Refuge. From a scientific perspective, what needs to occur is develop a comprehensive plan where each line is pre-determined and approved individually, where every vehicle or boot on the ground is justified as necessary, and where every action is vetted in advance. It's no different than the Minimal Tool process used currently by the Refuge staff for permits, which somehow the oil industry managed to get a free pass on by having BLM do their permits. Reading between the lines, so to speak, of the application you can see there that they are not volunteering to do anything more than is required by law or regulation. Why would we expect them to? They are a for-profit company with shareholders expecting to see a profit — volunteering to hold themselves to a higher standard eats into those profits and gives their less scrupulous competition a competitive edge. So even if those responsible for this application wanted to do more, they really can't — unless we change the relevant laws and regulations and we hold our government accountable to enforcing these and the existing ones. Conspicuously missing from this application, for example, is any mention of measuring the impacts of all those tire tracks on the tundra or what they will do if they find such impacts, probably because there is no regulatory requirement for doing so. If no one actually attempts to measure these impacts, is it any wonder our Senators and other politicians believe that there are none?

What's needed before any regulations or laws are changed is a comprehensive, unbiased review by the leading scientists of this type of terrain — physical scientists, botanists, permafrost hydrologists, permafrost scientists, ecologists, geologists, climate scientists, biologists, and the like — to define what we know, what we know we don't know, and what we need to know before we can allow seismic exploration and drilling to occur here. I'm not saying seismic or drilling *can't* be done responsibly, but that it *should* be done rationally and responsibly, and that *requires* substantial input from the dozens of scientists working in Arctic Alaska that either understand or have the capability to understand the impacts of doing things irresponsibly. It also requires input from all stakeholders, so that scientists understand the engineering needs and vice versa. So if anything is going to get fast tracked, it should be this study process, not the actual seismic or drilling. Anything less than such a full and complete scientific review is simply shameful, and something our children and grandchildren should rightfully give us grief for not doing. Just as a simple and basic example, I'm not aware of any comprehensive study of the relationship between snow depth and tire track ruts from previous seismic work, such that we can track this over the decades to improve methods. And one simple manipulation that's never been done is to determine how deep of a tire track will cause a change in vegetation, as a function of slope and substrate, such that the tire track will leave a visible scar even if the topography heals. Or what is the long-term impact of draining a perched wetland on vegetation communities and the animal communities that eat or use them? Etc. And if nothing else, what is the impact to our national psyche when we defile our last great Arctic wilderness with a checkerboard tattoo as far as the eye can see?

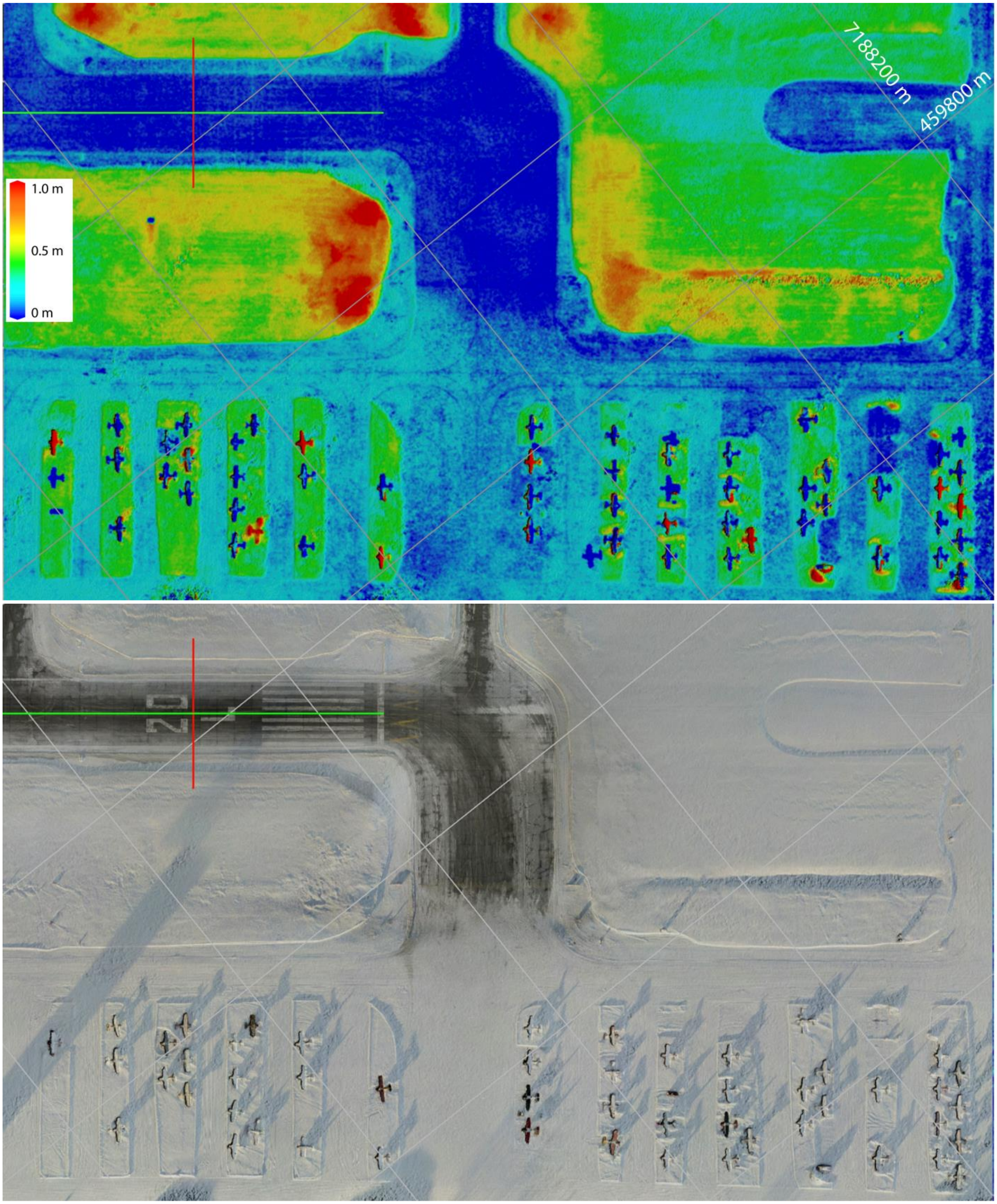
In terms of changing the law or regulation, I was really only half joking about the one I proposed earlier — that drilling operations are not allowed to start until all impacts of seismic work disappear. If there are truly no impacts using current methods, then drilling could start the next year. If there are impacts, drilling may be delayed for decades. I predict that such a put-your-money-where-your-mouth is law would lead to sweeping changes in the way 3D seismic operations are done and would eliminate the need for outsiders like me to have to propose such changes as well as eliminate the need for prescribing methodology by law — do whatever you want, but you are responsible for the "zero impact" that Senator Sullivan guarantees us. Given that's not likely right away, I felt compelled to offer a few suggestions…

One way we can improve current methods is by using fodar maps of snow depth. I have demonstrated in previous work that I can measure snow depth within the Arctic Refuge better than can be done with a guy on the ground using a probe, but covering enormous areas at high resolution. Current guidelines call for having a minimum of 20 cm snow depth, but there is little guidance as to how densely to make such measurement and essentially no oversight in it. And clearly from the 2018 Pt Thompson work seen here, 20 cm is not enough.

Using fodar to map snow depth we can:

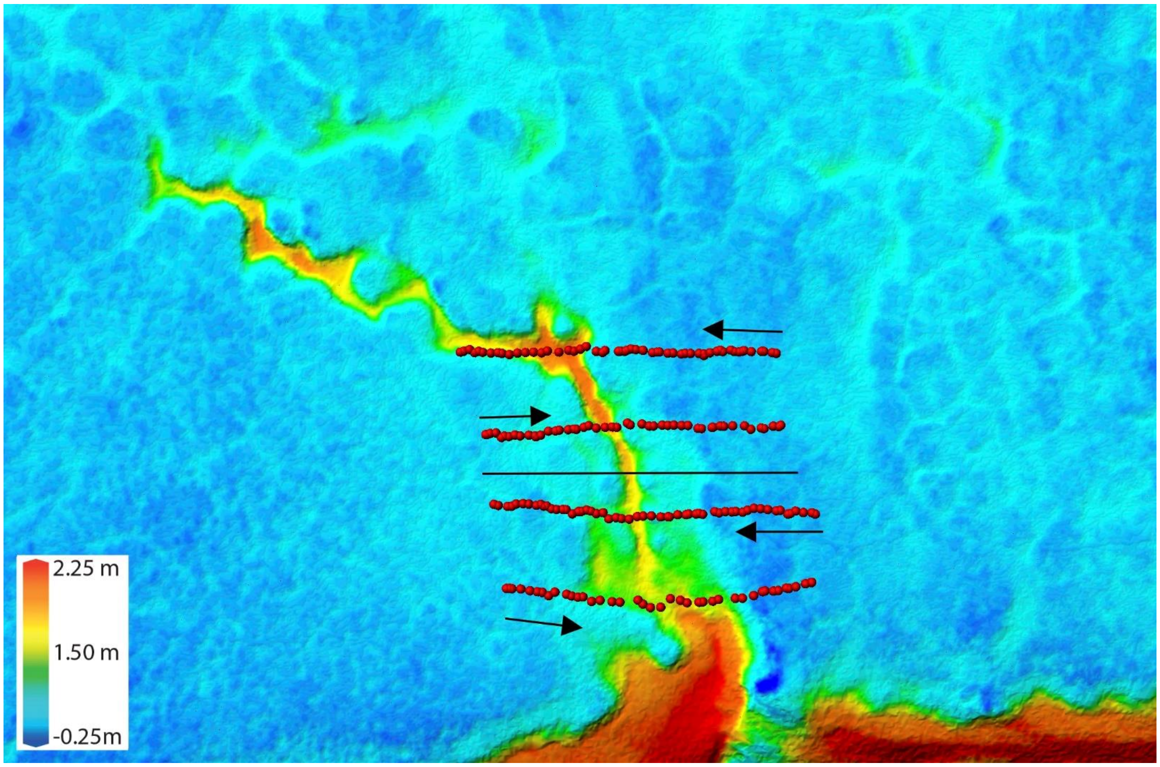
- Improve standards scientifically. By mapping snow depth before seismic work starts and mapping the tundra after snow melts, we can determine a relationship between snow depth and tundra damage. Current guidelines mandate 20 cm of snow depth, but clearly from the 2018 Pt Thomspon work whatever methods were used were inadequate to prevent measurable impacts over nearly 100% of the routes used. Using fodar to determine snow depth and a series of vehcile-load experiments (outside the Refuge) we can develop methods to determine what snow depth is required to prevent damage. Using a different method I am developing using insar, we can also map the depth of freeze of the ground from the air and perform the same set of experiments.
- Improve operations. By mapping snow depth with fodar immediately before an actual seismic campaign, we can plot routes with adequate snow coverage, where 'adequate' is based on the experiments I just described. These routes will likely not be linear, especially when ecologically sensitive areas are taken into account, but modern seismic does not require linear grid lines it's just easier and more efficient for both acquisitions and processing, and in some years there may not be adequate snow coverage, but that's life. We

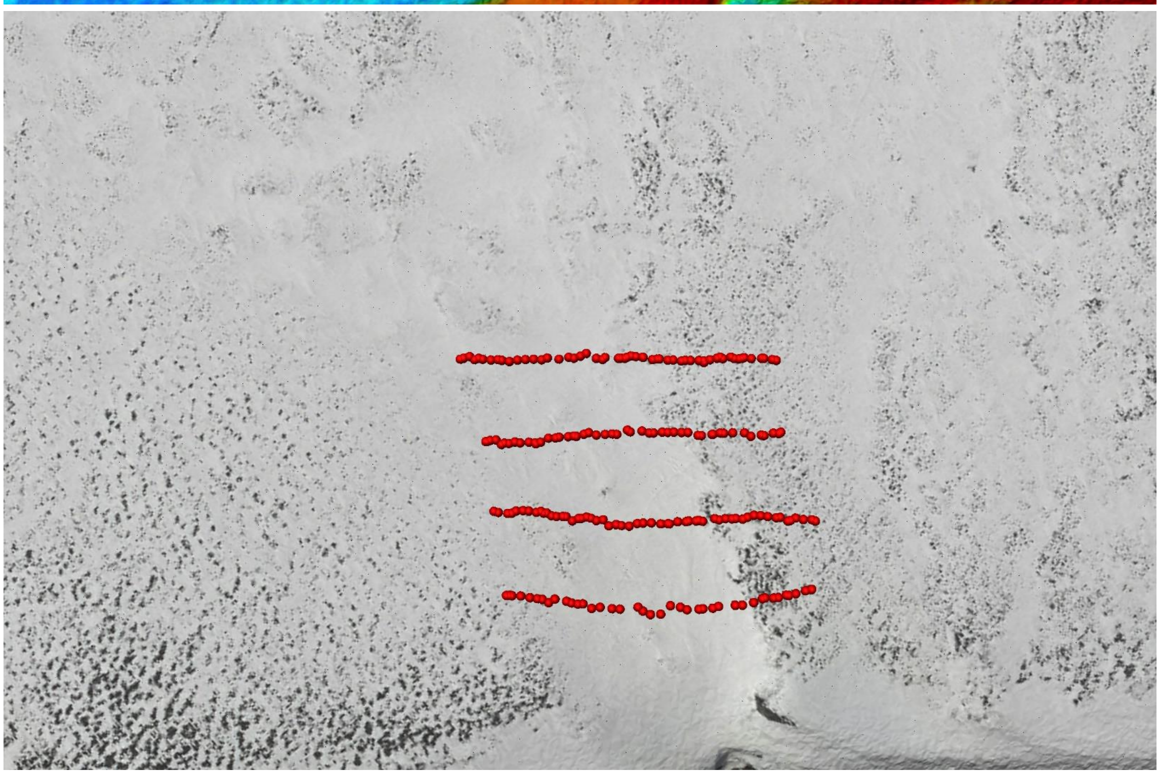
can then validate that those methods were adequate afterwards by mapping the tundra, and revising methods as needed.



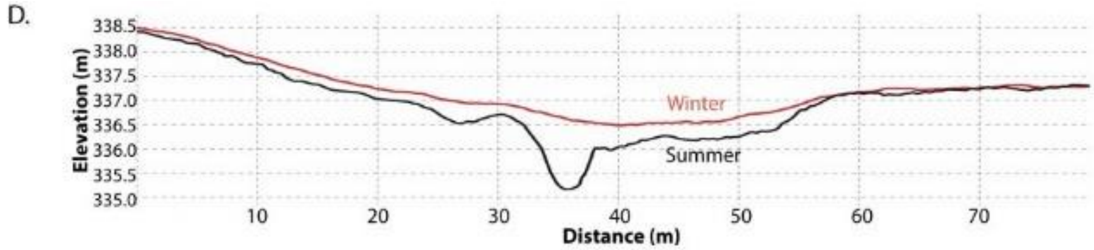
Here I've measured snow depth at Fairbanks International Airport, on the east side where the small planes park, by subtracting a summer map from a winter one. The colors are snow depth, as indicated by the scale on the left. You can see how the plow trucks don't get too close to the planes. Some of the planes have moved too, as shown by the color, so not all change is due to snow. Here I am measuring snow depth done to the single centimeter level.

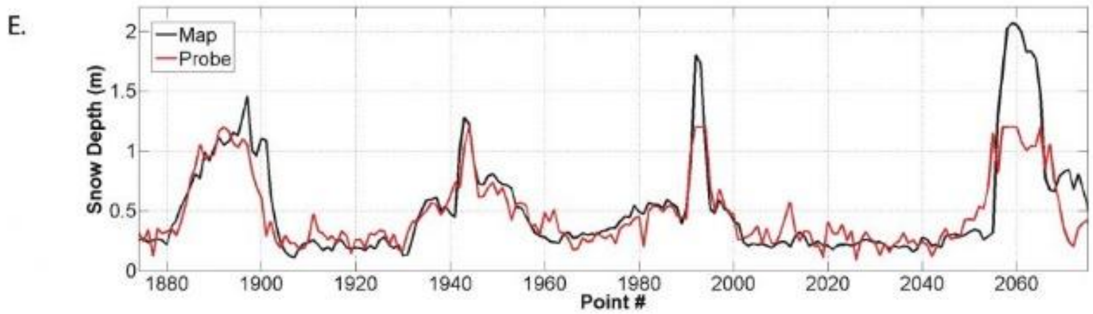
Here is a fodar winter and summer image of a gully within the Arctic Refuge along the Hulahula River. The red dots are snow probe locations from a field team. The next image pair below shows my fodar measurements of snow depth made by subtracting these two maps.



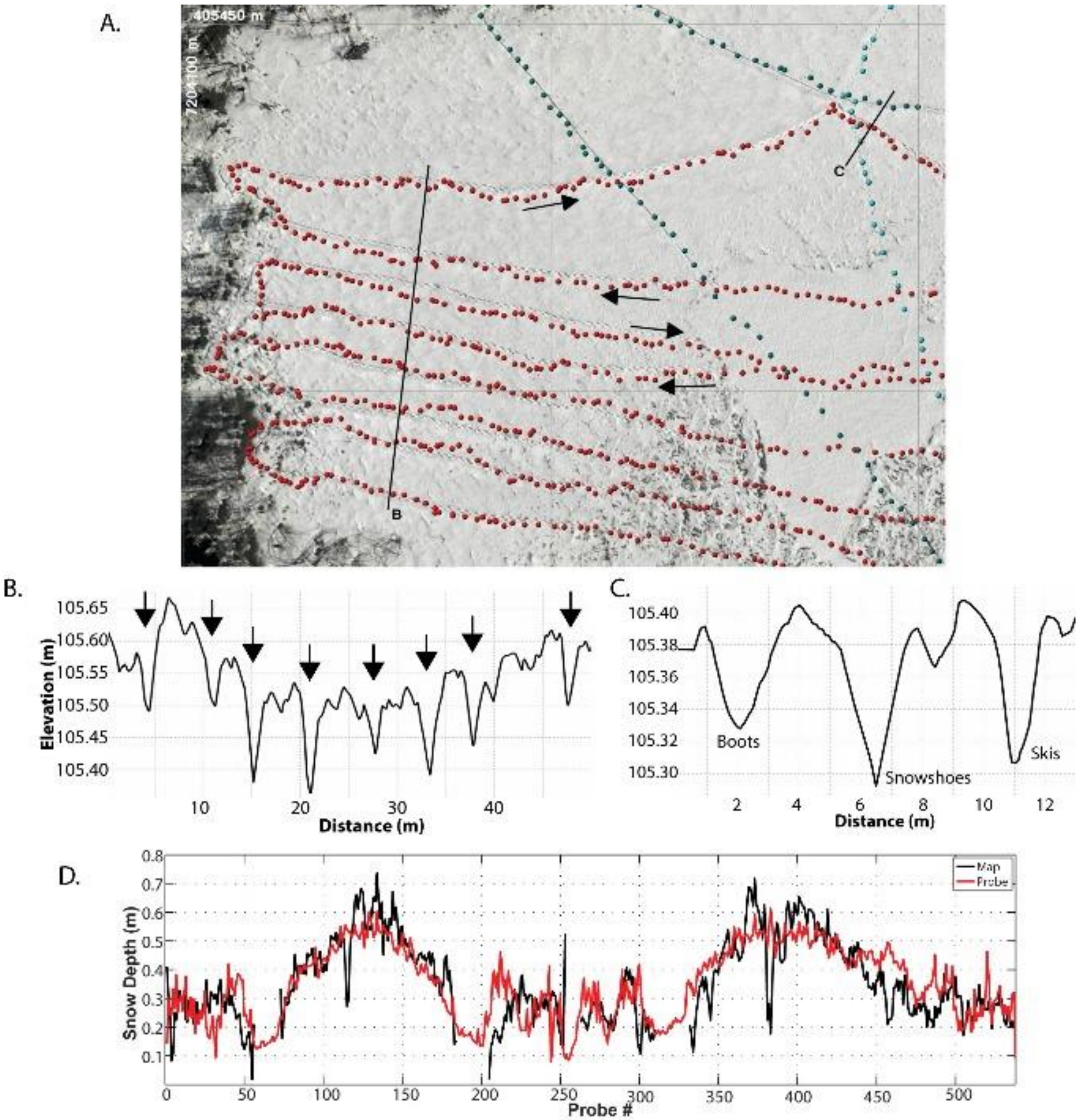


Here are the airborne fodar snow depth measurements at left, with the winter at right for reference. Note how we can actually resolve the shape of the polygons hidden under the snow through their snow depth. Note too how much bare tundra is showing even in April. Much of the 1002 Area gets blown free of snow even in the middle of winter, as warm gap winds race through the mountains from the south. I had some friends intend to ski from the mountains to the coast this spring in April, when seismic would occur, but could not because there was simply not enough snow for skiing! With fodar, we could map routes with adequate snow far better and more efficiently than could be done from the ground.





The first plot above compares winter to summer topography — the space in between is the depth of snow. The second is the point measurements from the red dots in the previous image, strung out into a single transect, such that each peak shown here is another gully-crossing. Statistically the fodar measurements are identical to the probe measurements, but because the probe was only 1.4 meters long it could not reach into the bottom of the gully. The result of our work revealed that not only was fodar better than ground measurements, but that it could cover enormous areas for a fraction of the price of field teams. You can learn more here.



Here is a fun study from that same paper, this time in Minto Flats near Fairbanks. The colored dots on the image are geolocated probe measurements made by three of us, each wearing different footwear (boots, snow shoes, or skis). The fodar map was made after the probe measurement, thus our footprints became part of the topography. You can see this in Transect B (the arrows in the plot indicate footprint crossings) and Transect C (where the three of us met up wearing different footwear). The plot D compares probe measurements to fodar along the part of the transect shown in A with red dots; the two measurements are basically identical, the differences come from vegetation measured in summer that gets compressed in winter.

While this approach would be a big improvement over current methods, all that we are really doing is tinkering with the methods of the 1960s — that is, finding better ways to drag man-camps over the tundra. It seems to me that if we truly want to eliminate impacts in the 1002 Area we need to think outside the 1960's box. That is, the only real way to guarantee there will be no tracks left behind by these vehicles is to eliminate the vehicles themselves. Modern technology offers us many new approaches to avoid the damage that draggable man-camps inevitably will cause. These suggestions may or may not be cheaper or better seismically, but that's not the point — the point is to get enough data to do the job while leaving no impacts — to act as if drilling would be delayed until the impacts disappeared. I know I'm going to get beat up for proposing these ideas, but if the oil companies have better ideas to do the same, more power to them. But if they are going to sit back on their heels and only do the minimum required by law, then they've got no right to complain when others step in to up the requirements of law, including the law I proposed earlier. Here's just a simple overview of idea of how things could be done differently to get a discussion going:

- Eliminate the mobile man camps. The vast majority of the weight being hauled by the tracked vehicles potentially causing the damage are to move people and provide them hot showers and warm beds. The bulk of these workers are doing grunt work — relocating geophones — or just dealing with running a mobile hotel itself. I understand they would like a warm dry place to eat, sleep and download porn at night, but I really don't empathize as over the past 15 years I've literally spent over a thousand nights of my life sleeping in a cold tent without internet porn in the Arctic Refuge, and I know there are hundreds, if not thousands, of intelligent, capable, trainable professionals who would volunteer for the opportunity to protect the Refuge from damage by camping in mountain tents, transporting themselves on skis, and eating dehi for dinner. Eliminating the tracked man-camp within the 1002 Area is likely the biggest thing we can do eliminate the potential for damage to the 1002 Area. Do what you want elsewhere, but here we can do better.

In Antarctica, we traveled several thousand kilometers on snow machine, mapping the bed of the ice sheet seismically.

We didn't need to haul a hotel around with us, we slept in tents. 3D seismic guys on the slope can't do the same? Really?

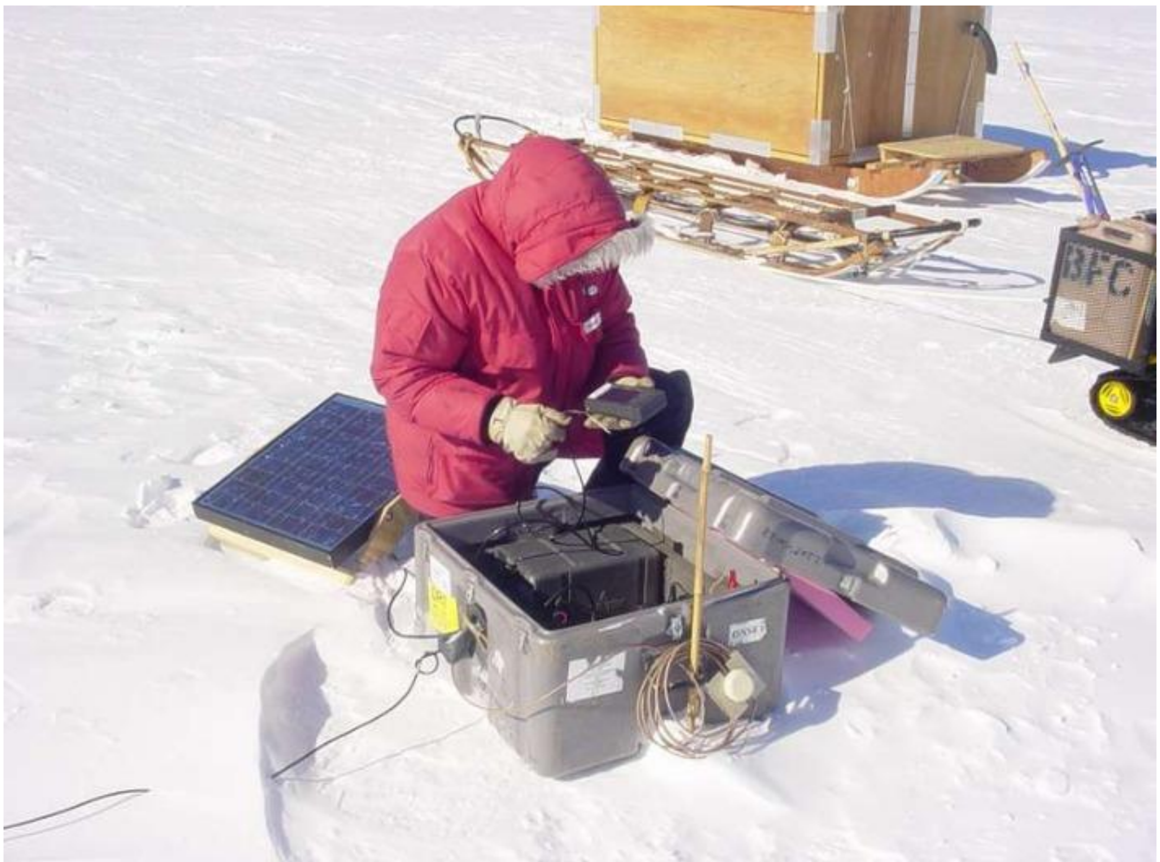
Most of seismic work consists of brief moments of frantic work in between long stretches of sitting around doing nothing. Nearly anyone can be trained for this job…

Our seismic hut is being pulled by an ancient Alpine. Why is it that the oil fields need a cat train full of Tuckers to pull their's? There's two ways to approach this problem: 1) how much equipment can we haul with a snow machine? and 2) how big a rig is it going to take to haul a cozy heated office complete with desk chairs? Yes, leaving no trace in the 1002 will be a big pain and slow down productivity, but that should be the price of playing poker here.

My son Turner had his first 7 birthdays in a tent on a glacier in the Arctic Refuge.

I don't recall him complaining once about it in all those years. If these seismic guys are so delicate that they can't do their work without solid, heated shelters complete with internet and hot showers, maybe we should find new seismic guys…

- Place all permanent camps on lakes or sea ice. Permanent camps will be needed for large jobs like this, whether in solid-walled buildings or tents. Impacts to frozen lake surfaces disappear completely, so placing those camps on lakes eliminates potential damage to the tundra. Sling all solid buildings needed onto them using helicopter and put all centralized activities onto lakes. When the lakes melt in summer, all impacts disappear forever, short of trash sinking to the bottom.
- Change the seismic shot-receiver ratio. Seismic works by making loud noises and listening for their reflections off layers in the subsurface. Usually these receivers are deployed in strings related to the source sounds, then redeployed for the next set of sounds. This means a lot of driving and thus a lot more potential impact. By investing in a lot more receivers and leaving them in place for the entire survey, each source sound gets recorded by all receivers, resulting in more bang for the buck, so to speak. Using seismographs timed by GPS and powered by battery can record continuously or be triggered to start recording via telemetry would reduce the potential of driving damage considerably and eliminate seismic shacks and local staffing at the receivers. The SAEploration application already mentions things along these lines, I'm just suggesting going all-in.



Fifteen years ago the stand-alone geophone-seismometers powered by solar and timed by GPS we used in Antarctica were home-made. Now it's something you can buy from a store. We should buy tons of them for the 1002.


With stand-alone units, you never have to worry about your cable being too short…

- Only drive over fresh snow, don't make sharp turns, and use a helicopter to get vehicles unstuck. If vehicles are used, allow them to only drive over fresh snow. A lot of the damage I've seen in my data appears to be caused by repeated use of the same track. When driving over fresh snow, the snow acts as a cushion to distribute the weight of the vehicle further. However, once its crushed and sintered it acts like a wedge being driven into the tundra when more weight is added. And any time you are driving a heavy tracked vehicle over snow you risk getting stuck, and getting unstuck is where major damage can occur, as you then have multiple vehicles pulling hard and excavating what little snow exists. Current guidelines mandate only 20 cm of snow — 8 inches! You can't get a simple snow machine unstuck here without boring down to tundra. The deepest ruts I've seen are where vehicles are making sharp turns, presumbly because the edges of the track are able to dig in because they don't remain level with the ground. Perhaps specifying a minimum turn radius, or helicopter-slung 180s, would eliminate this potential.
- Change seismic source methods. Vibroseis requires a fleet of heavy tracked vehicles, and those vehicles are where all of the potential for damage exists. If the mobile man-camps where eliminated, I could envision the vibroseis leaving no trace, though it would still be tricky. A fodar map of snow depth made immediately before driving commenced could be used to plot routes for the vibroseis vehicles. It won't be straight route, so it wont be as easy to process, but it will still be processable. These routes would also be selected with particularly fragile and vulnerable areas in mind. However, it seems to me that a better plan is to use explosives. Small drill rigs to place the explosives slung by helicopter would eliminate the majority of overland travel for the seismic sources. Shots placed in gravel bars and lake bottoms would either leave no trace inherently or those traces would be mitigatable by river action or rakes in summer. Again, shot placement would not necessarily be linear, but our priority here is to create sufficient data to do the job without creating any impact, and non-linear placement of shots satisfies that requirement, seems to me.

So I am of course not the right guy to be proposing how to actually run a 3D seismic campaign, my point here is to try to break us out of the 1960s mindset and remind ourselves that we are Alaskans, not Texans. We have the know-how and grit to do things the right way in the Arctic, we just need to apply it. The bottom line is simply this: Regardless of any new regulations or any new ideas on technical approach, if the first oil-related activity that occurs out here is permanently scarring the landscape with a 200 m x 200 m checkerboard, the justifiable public outrage could well overturn the 2017 law that allows drilling out here, in which case everyone loses. We can do better.

"I don't know Turner, are oil field workers as tough as you are? I guess we'll find out."