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SAND2010-5229
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2009 Antarctica X-Band MiniSAR Crevasse Detection Radar: Final Report

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Antarctica X-band MiniSAR Crevasse Detection Radar: DRAFT Final Report

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ABSTRACT

This document is the final report for the 2009 Antarctica Crevasse Detection Radar (CDR) Project. This portion of the project is referred to internally as Phase 2. This is a follow on to the work done in Phase 1 reported on in [1]. Phase 2 involved the modification of a Sandia National Laboratories MiniSAR system used in Phase 1 to work with an LC-130 aircraft that operated in Antarctica in October through November of 2009. Experiments from the 2006 flights were repeated, as well as a couple new flight tests to examine the effect of colder snow and ice on the radar signatures of “deep field” sites.

This document includes discussion of the hardware development, system capabilities, and results from data collections in Antarctica during the fall of 2009.

ACKNOWLEDGEMENTS

This work was funded by the Air National Guard, who will be the primary beneficiary of this work. Support from the National Science Foundation's United States Antarctic Program was provided for execution of the test. Walter Hallman and Mark Armstrong provided experiment definition and ground support. Joe Harrigan was a great help in the EMI test coordination. Raytheon Polar Services Corporation provided support in helping to define and execute the Technical Event (T-event). Ross Neyedly, not only provided support for the arm, but also helped with logistics support and photography. Doug Jordan, from Sandia, provided the antenna vibration analysis presented in this report.

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Executive Summary

Approximately 10 years ago the National Research Laboratory and the New York Air National Guard first approached Sandia National Laboratories' Synthetic Aperture Radar departments about the possibility of building an X-Band SAR system in Antarctica for the purpose of detecting crevasses in remote landing zones. Recently, technology developments incorporated in Sandia National Laboratories' MiniSAR system made a demonstration in Antarctica feasible. The Crevasse Detection Radar (CDR) was built in 2006.

The technical concept of using the SNL MiniSAR for crevasse detection was proven with flight tests against actual crevasses in Antarctica on a Twin-Otter during November through December, 2006. This document covers the Phase 2 of the crevasse detection radar project. In Phase 2, the radar was moved to an Air National Guard LC-130 which was flown in Antarctica during October through November, 2009. Results of Phase 2 are presented.

1. Introduction

In March, 2006, a project was initiated by the New York Air National Guard (NYANG) for Sandia National Laboratories to develop an X-band variant of the MiniSAR radar to demonstrate the capability of this radar for crevasse detection in potential landing areas in Antarctica. This portion of the project culminated with a data collection in Antarctica of known crevasse sites using the SNL MiniSAR flown on a Twin-Otter aircraft [1].

During the follow-on part of this project, known internally as Phase 2, the SNL MiniSAR was modified to operate on an NYANG LC-130 aircraft. The modifications were proven out in field tests, culminating with field experiments with the radar operating on an LC-130 against crevasses in Antarctica.

There were two main purposes of the Phase 2 portion of the crevasse detection radar (CDR) project. First, the SNL MiniSAR needed to be shown to be capable of operating on an LC-130 aircraft to support field missions in Antarctica. Second, the LC-130 has longer “legs” than the Twin-Otter; therefore it was desirable to see if crevasses could be detected that were colder, higher in altitude, and drier than those flown in the Shear Zone and the Taylor Dome areas during 2006. For this, the radar was flown against crevasses in the “deep field”.

2. Hardware Development Effort

2.1 Radar Modifications

The main radar modifications for this effort were to support the arm and the electronics on the LC-130.

2.2 Brief discussion of the arm

The antenna and radome assembly for this phase of the Crevasse Detection Radar (CDR) project were mounted on a sabir arm which in turn attaches to the door near the aft of the LC130. The arm was developed by Airdyne Corporation, and a picture of the arm and antenna assembly are shown in the following figure. The arm is lowered for imaging, and raised for landing.



Figure 1: Arm with mounted CDR antenna/radome assembly on side of LC130

2.3 Vibration

The arm does introduce unwanted vibration into the radar assembly; however, testing showed that the motion measurement system was able to provide the information necessary to remove the vibration during processing. The CDR impulse responses for corner reflectors did not show any ill-effects. The vibration was visible from the door window and from an internally mounted camera. The vibration seemed to increase in amplitude with increasing aircraft speed.

A power spectral density plot of the y-acceleration (horizontal, towards/away from plane) from accelerometer measurements is shown in the figure below. The plots were taken from data recorded during the 08Nov2009 flights in Antarctica. The plots show with arm deployed (down) and with it up. The peak vibration appears to be around 6 Hz, with the arm deployed.

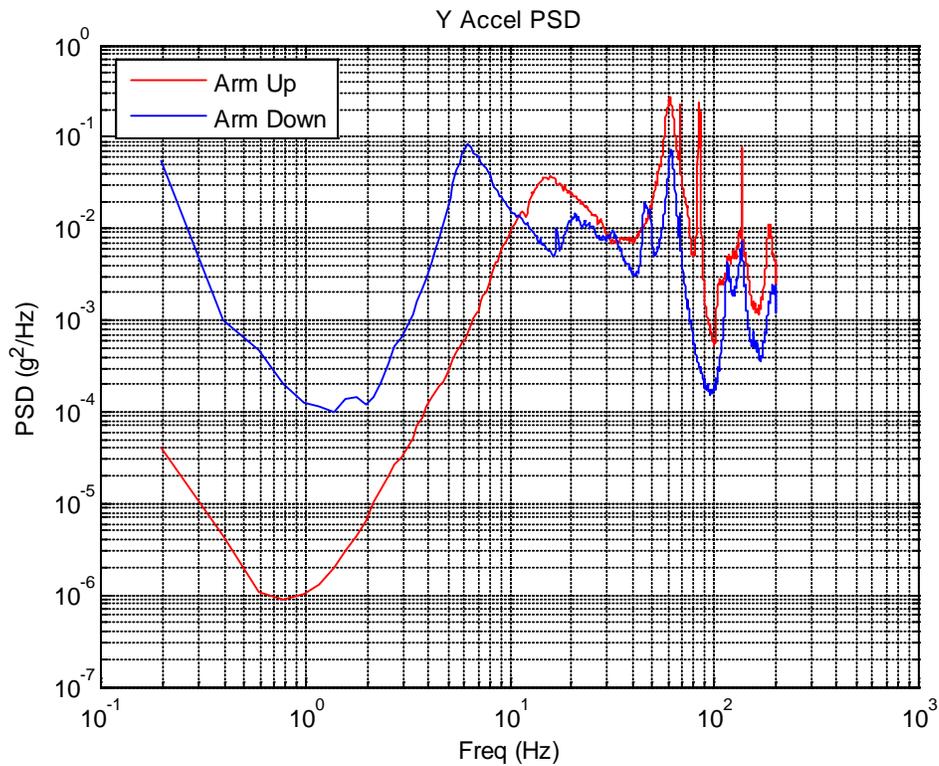


Figure 2: Y-acceleration PSD plot showing arm vibration

2.4 Other information

Platform velocity increase effects on the SAR were a concern for the LC130 compared with the Twin-Otter. To investigate this, both laboratory and flight experiments were

conducted. The flight experiments were first conducted on the Twin-Otter, and then on the LC-130 in Albuquerque, NM. During both the laboratory, and the Twin-Otter flights, the PRF was artificially inflated to force the radar to think it was operating at a higher velocity. The results of the experiment showed that the radar would be able to operate at the higher speeds of the LC130.

3 System Capabilities

Since the radar modifications did not affect the radar performance, the radar parameters are the same as in [1]. These are repeated here for completeness of this document.

Band: X-Band (9.9 GHz Center frequency)

Polarization: VV

Resolution: ~8 inch

Sigma_n: -30 dB or better

Range: 3.3 km (Note, this is near the minimum range of the radar in SAR mode)

Patch Size: Range: ~336 m Azimuth: ~300 m

High-Resolution SAR Spotmap Mode:

Band: X-Band (~9.9 GHz Center frequency)

Polarization: VV

Resolution: 1 ft or coarser

Sigma_n: -30 dB or better

Range: 3.3 km (Note, this is near the minimum range of the radar in SAR mode)

Typical Patch Size: Range: ~505 m Azimuth: ~300 m

4 Data Collections in Antarctica in 2009

As mentioned above, the purpose of the data collections in Antarctica were to: 1) prove in the radar operation on an LC-130; and to 2) investigate crevasse detection in the “deep field”. The first task was performed by repeating many of the experiments from 2006 [1]. These flight tests included: 1) tests against a reflector array at Pegasus; 2) RFI testing at McMurdo Station; 3) repeat mapping of the 5 nmi by 5 nmi area at the Tres Hermanas shear zone; and 4) repeat mapping of the 5 nmi by 5 nmi area along the South Pole Traverse site on the shear zone. New tests for the “deep field” included: 1) mapping a 5 nmi by 5 nmi crevassed area referred to at Grosvenor; and 2) mapping a 2 nmi by 5 nmi along the South Pole Traverse referred to as Leverett.

In the following, each of the flight tests are discussed and results are presented.

4.1 Pegasus

The October 30, 2009, Pegasus flight is somewhat of a repeat from [1]. The main purpose was to make sure that the radar was working properly after shipping, and installation. A radar reflector array was set out as shown in Figure 1. Figure 2 shows a photograph of the area. Figure 3 shows a radar image of the area. Drifting snow and ice dampened the response of some of the reflectors. Figure 4 shows that snow accumulated in the reflectors during a storm that hit between the time the reflectors were put out and the time that the radar was flown. Not all reflectors were as full of snow as shown in this figure.

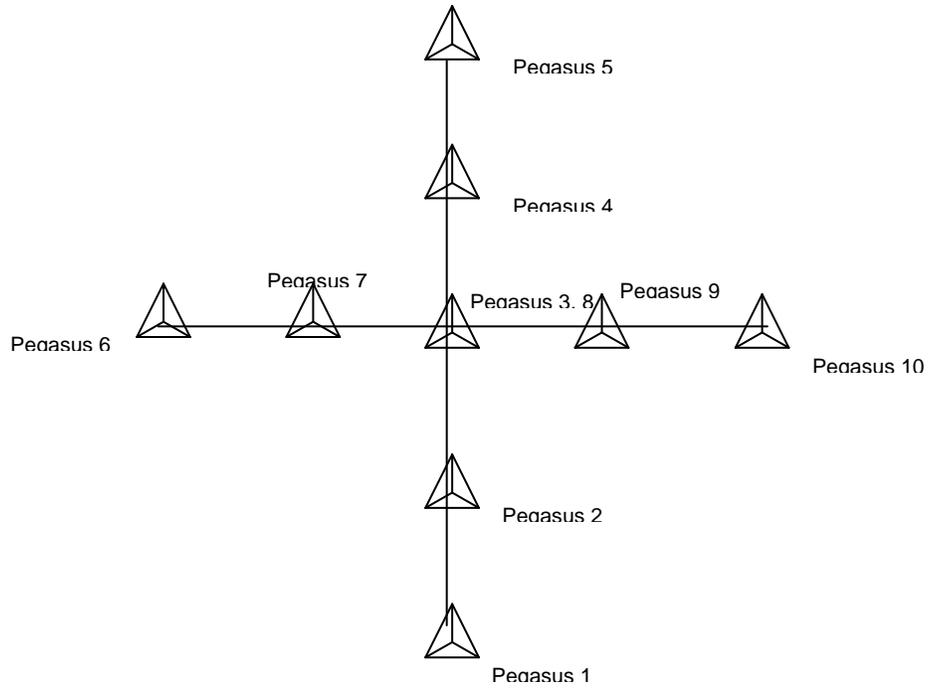


Figure 1: Approximate Layout of Pegasus Wreck Site Imaged October 30, 2009



Figure 2a: Aerial photo of Pegasus wreck site with radar reflectors visible (courtesy Ross Neyedly)



Figure2b: Portion of the radar array being setup

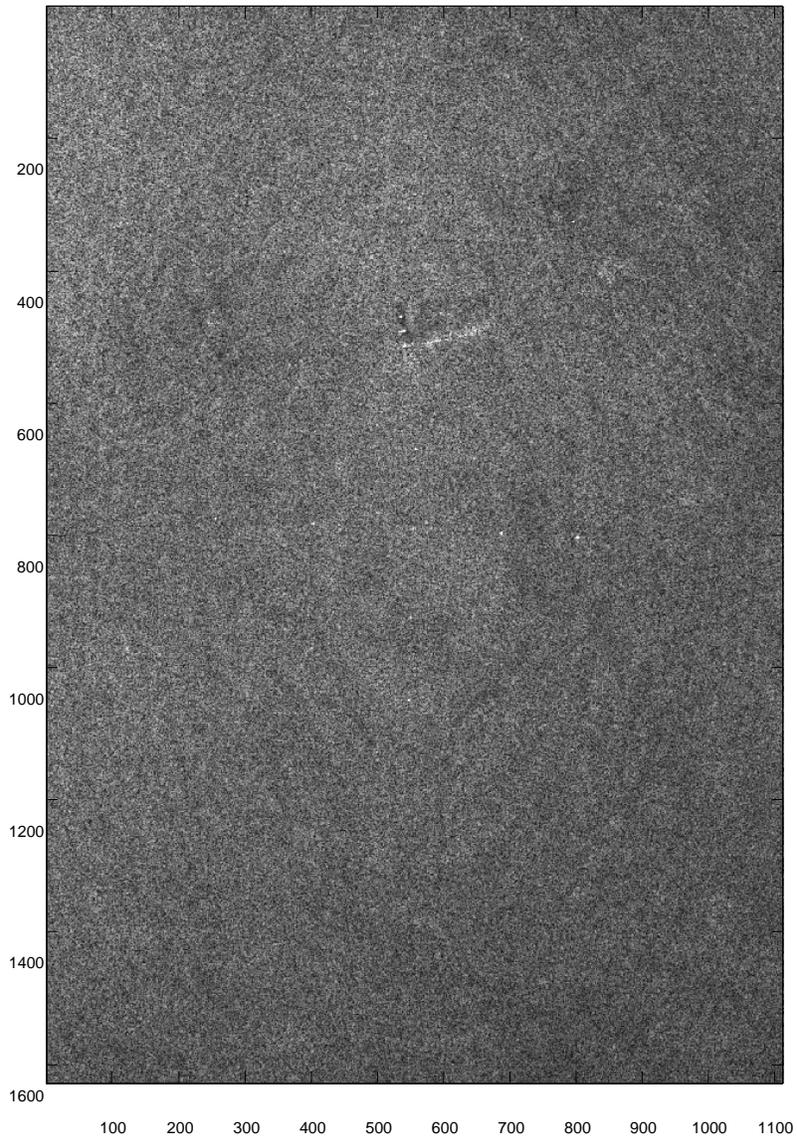


Figure 3: SNL SAR image of reflector array at Pegasus wreck site



Figure 4: Photograph of radar reflector at Pegasus drifted full of snow

4.2 Tres Hermanas

On October 31, 2009, the 5 nmi by 5 nmi Tres Hermanas area was remapped as a repeat of the mapping performed in [1]. This was to validate that we were still observing the crevasses that we had observed in 2006. Note that the Tres Hermanas site is in the Shear Zone. This area has glacial ice moving up to 3 ft. per day. The area moved significantly in the 3 years between imaging, although we attempted to map the same coordinates as in 2006. The 3 crevasses we nicknamed the “tres hermanas” were still visible in 2009.

Figure 5, is repeated from [1], and shows the approximate area that was mapped again in 2009.

A photograph of the area from taken from the LC-130 is shown in Figure 6.

Figure 7 shows the mosaic of the Tres Hermanas site mapped during the 2009 collect.

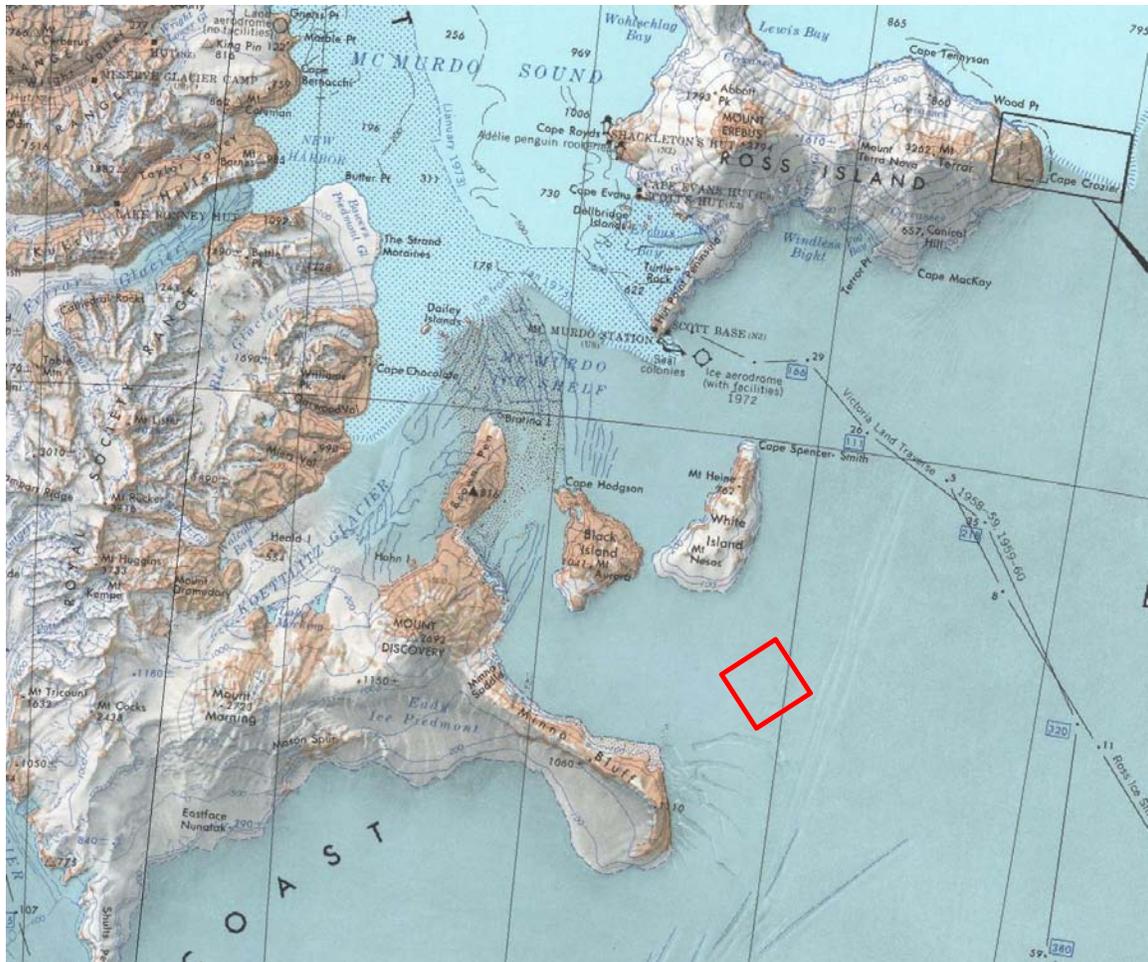


Figure 5: Approximate Location of 5 nmi by 5 nmi Area Imaged during Tres Hermanas Collect on Dec. 6, 2006 and again on October 31, 2009.



Figure 6: Photograph taken of the Shear Zone Tres Hermanas site (courtesy of Ross Neyedly)

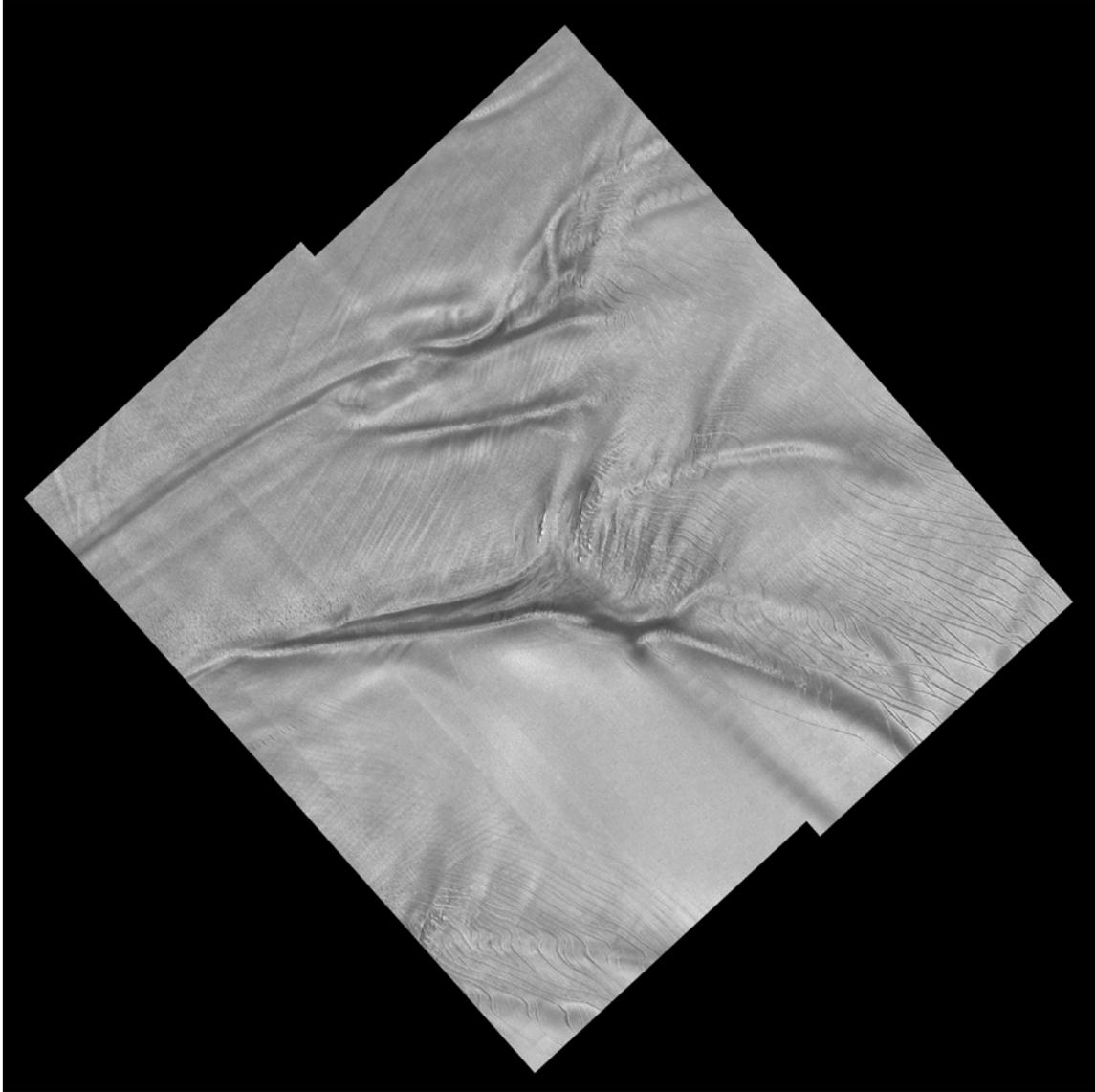


Figure 7: SNL SAR Mosaic of 1 foot resolution SAR imagery of the Shear Zone at the Tres Hermanas site on October 31, 2009.

2.1 South Pole Traverse – Shear Zone

On November 3 2009, the 5 nmi by 5 nmi Shear-Zone along the South Pole Traverse area was remapped as a repeat of the mapping performed in [1]. Figure 8, is repeated from [1], and shows the approximate area that was mapped again in 2009. When we got down to Antarctica, we found that the South Pole Traverse route had been re-instituted. Crevasses on the South Pole Traverse site had been well mapped by Raytheon Polar Services. Walter Hallman and Mark Armstrong worked with Raytheon Polar Services to identify small crevasses (12” to 18” wide) to see if we could detect these with the radar. They also worked with the mountaineer staff to place radar reflectors near and inside of

these crevasses. Appendix A includes Mark Armstrong's notes on the crevasses and reflectors at this site.

Figures 9 and 10 show the mosaics of the Shear Zone South Pole Traverse site from 2009 and 2006, respectively. As with the Tres Hermanas site, the glacial ice moving up to 3 ft. per day. Most of the features are the same between the images, but have moved due to the aforementioned motion of the glacial ice. The most obvious example of the motion is the South Pole Traverse road, which is the bright, piece-wise linear feature which cuts across the crevasses and spans the middle portion of the mosaic. It is obvious that this feature has moved north (up) in the images from 2006 to 2009. The right side of the road has moved faster than the left side, causing an increased cant in the image, as well.

Photos were taken of this area from the LC-130 but are flat, white, and featureless, so focusing was difficult, and these photos are not included in this report. The ground support personnel also reported that at ground level, the area around the traverse looks flat, white, and featureless.



Figure 8: Approximate Location of 5 nmi by 5 nmi Area Imaged during South Pole Traverse Collect on Dec. 6, 2006 and again on November 3, 2009.

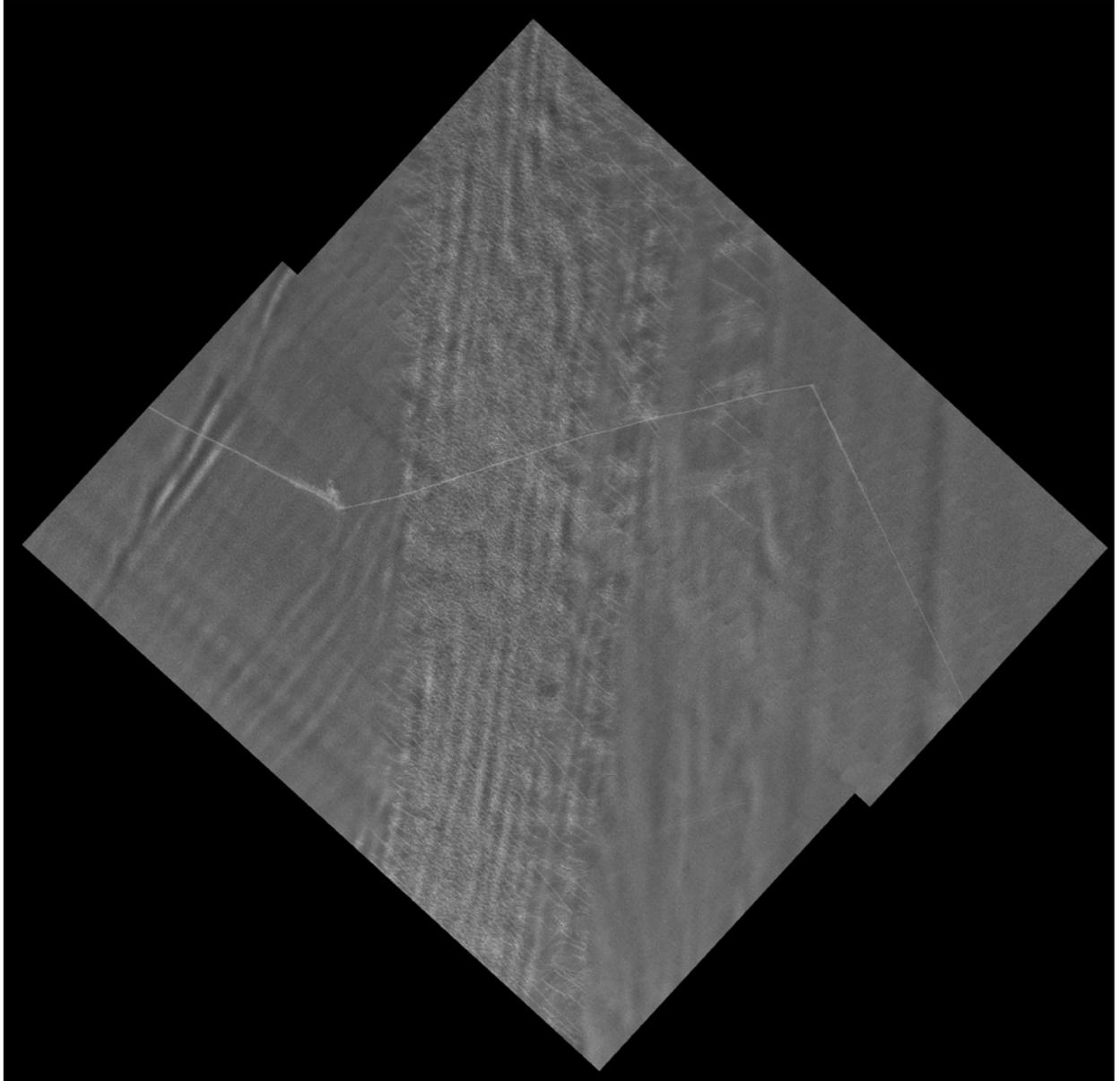


Figure 9: Mosaic of the SNL SAR 1 foot resolution imagery from the Tres Hermanas site in the Shear Zone imaged on October 30, 2009

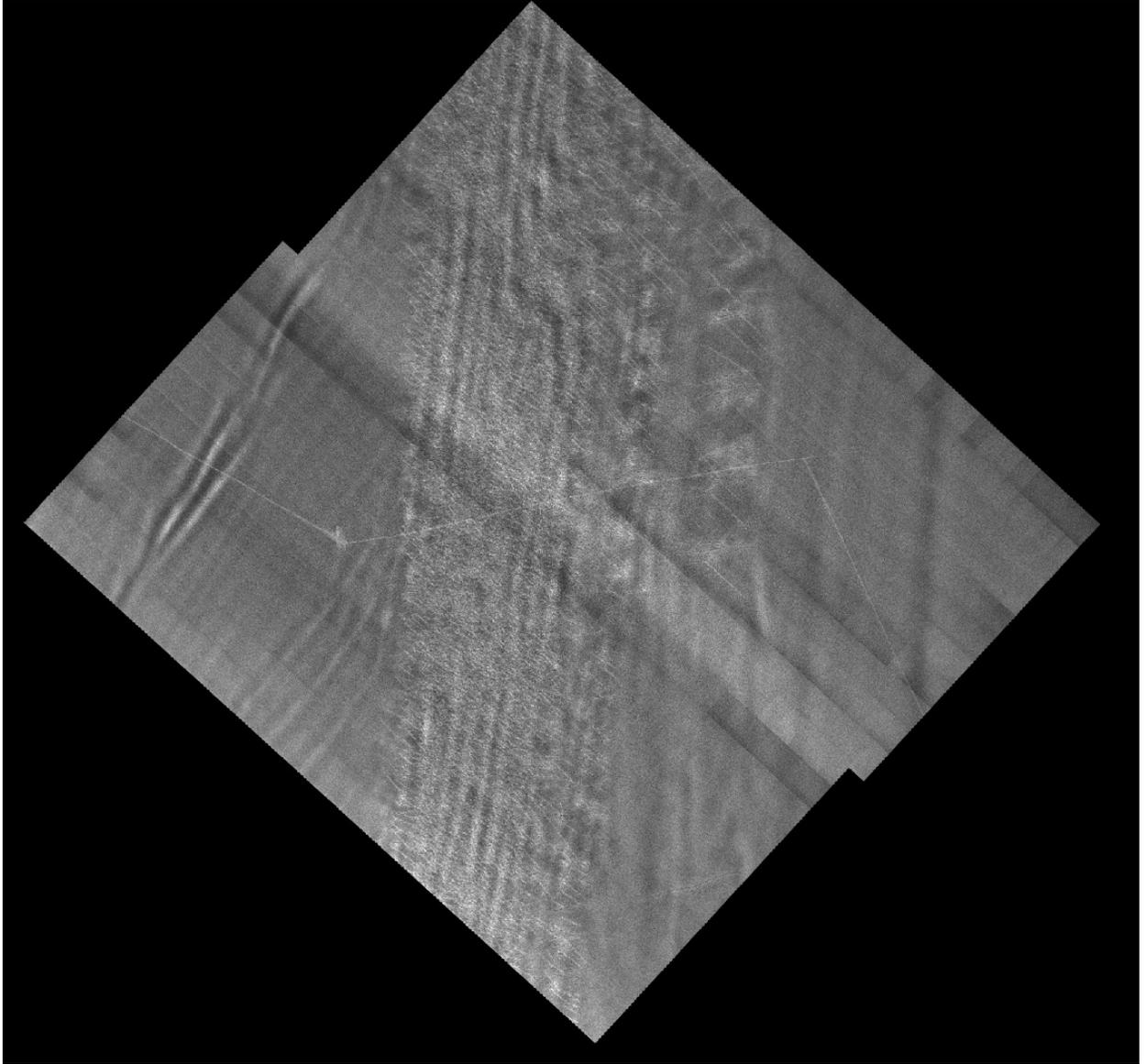


Figure 10: Mosaic of the SNL SAR imagery from the Tres Hermanas site in the Shear Zone imaged in December 6, 2006.

The small crevasses of interest are shown in Figure 11. They appear as straight, very bright lines, as opposed to alternating bright and dark crooked lines that we observed in Tres Hermanas crevasses [1]. Figure 12 shows that these crevasses appear to be newly developed since 2006.

Figure 13 shows an 8" resolution spotlight mode image taken around the 12" to 18" crevasses in the shear zone. In this image, the buried reflectors are evident as well.



Figure 11: SAR images of 12" to 18" crevasses of interest (in red circle at about 11 o'clock) in South Pole Traverse Shear Zone, November 3, 2009.



Figure 12: SAR images from 2006 of same site as Figure 11, showing the small crevasses were not present then

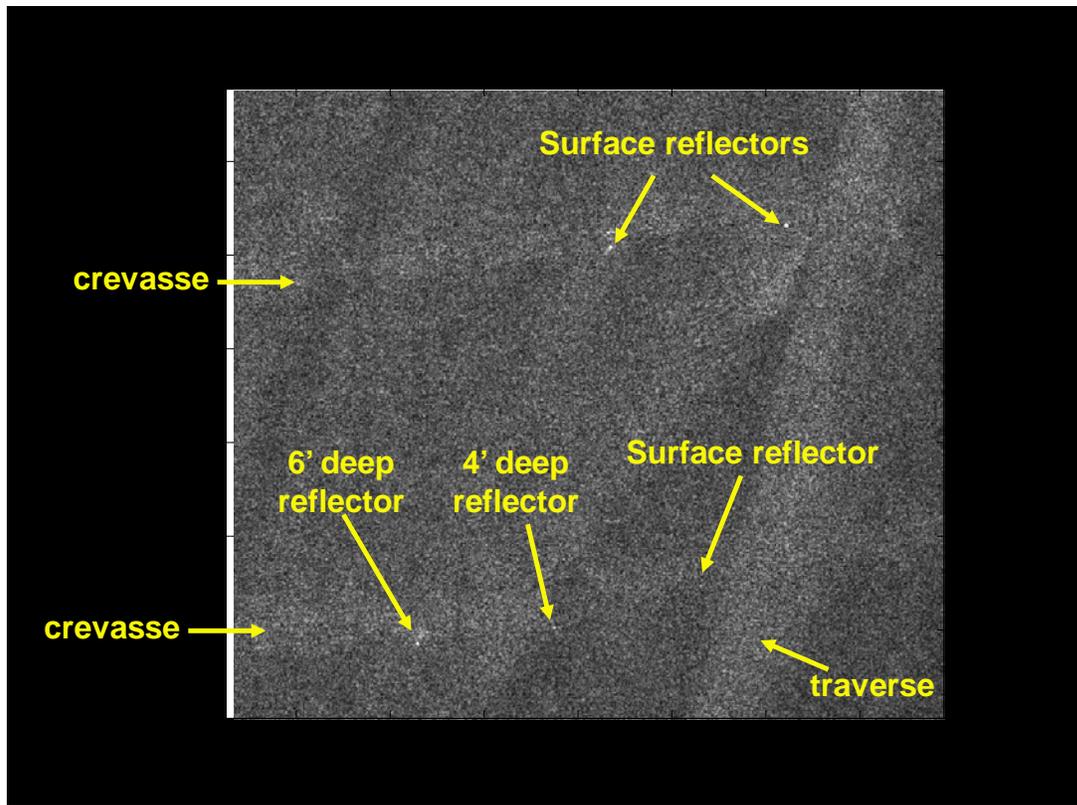


Figure 13: 8'' resolution image of the crevasses which show the buried reflectors along the South Pole Traverse in the Shear Zone

2.2McMurdo station EMI testing

On November 6 2009, the Sandia crevasse detection radar imaged McMurdo station as part of EMI testing to see if there would be any interference of sensitive RF equipment by our radar. This was a repeat of the test flown on December 5, 2006. In both 2006 and 2009, the flight tests were coordinate with the managers of key Antarctica RF systems. In both 2006 and 2009, the managers reported no issues with the CDR radar while it was operational.

Appendix C shows the information that was sent to Pat Smith at NSF/OPP prior to receiving his approval for the EMI flight test. In addition, the EMI test plan is included in Appendix D.

It should be noted that Joe Harrigan, RPSC, was a huge help in coordinating and facilitating this EMI test.

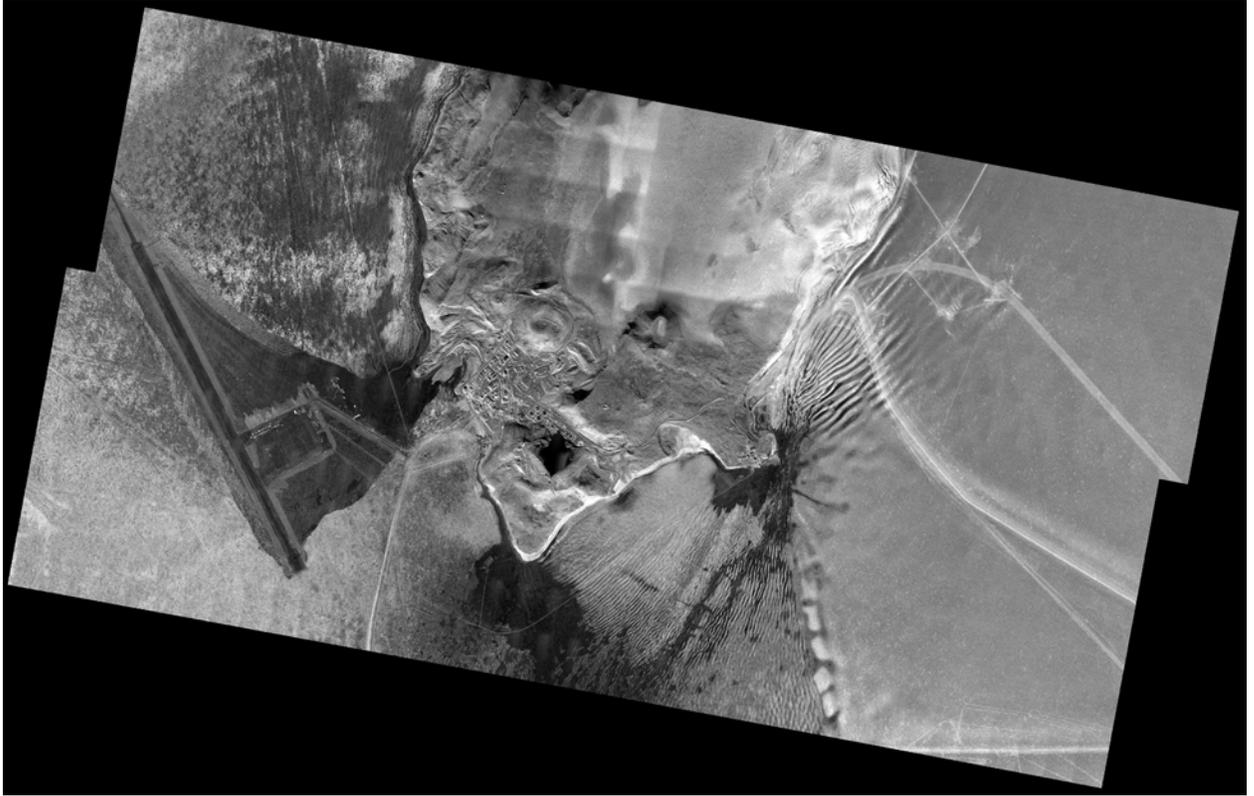


Figure 14: Mosaic of the 1 foot SAR imagery of McMurdo station including the ice runway (to the left) and the pressure ridge (to the right) from the November 6, 2009 EMI test of the CDR

2.3 Grosvenor and Leverett

On November 9 2009, the Sandia crevasse detection radar imaged deep field sites at Grosvenor and the South Pole Traverse at Leverett. The purpose of these collects was to investigate the performance of the CDR for higher and drier ice locations. Both locations are near the 85th parallel. Figure 15 shows the location of the Grosvenor and Leverett sites.

Figure 16 shows the Grosvenor 5 nmi by 5 nmi mosaic of the 1 foot resolution CDR data. A region of severe crevassing is obvious in the upper right corner of the image. In addition, smaller crevasses are evident when the image is zoomed in. The patchiness in the mosaic is due to pointing issues that were more prevalent on this day than on other flights. Figures 17 and 18 show close-ups of crevasses in the Grosvenor data.

Figure 19 shows an approximately 2 nmi by 5 nmi mosaic of CDR 1 foot resolution imagery of the South Pole Traverse at Leverett. The traverse road is evident in the image even though it had rarely been used, and not for a year. The crevassing is much more subtle in this imagery. Figure 20 shows that there are a couple of crevasses that cross at about a 45° angle to the traverse road and a couple more that appear to nearly perpendicular to the road. One of these latter two crevasses seems to cross the road and the other comes right up to the road, but does not cross. In addition, several crevasses off to the side of the road are visible in Figure 19.

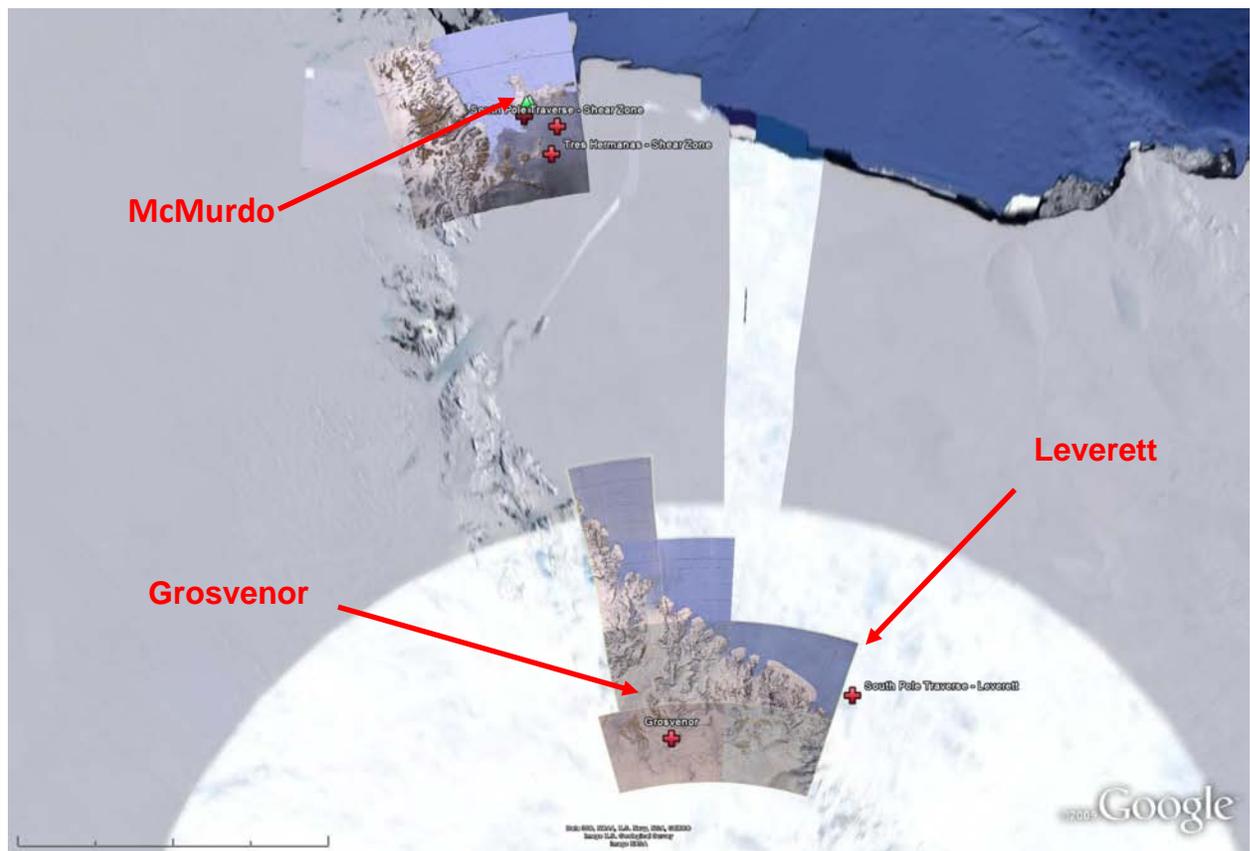


Figure 15: Location of Grosvenor and Leverett sites relative to McMurdo station

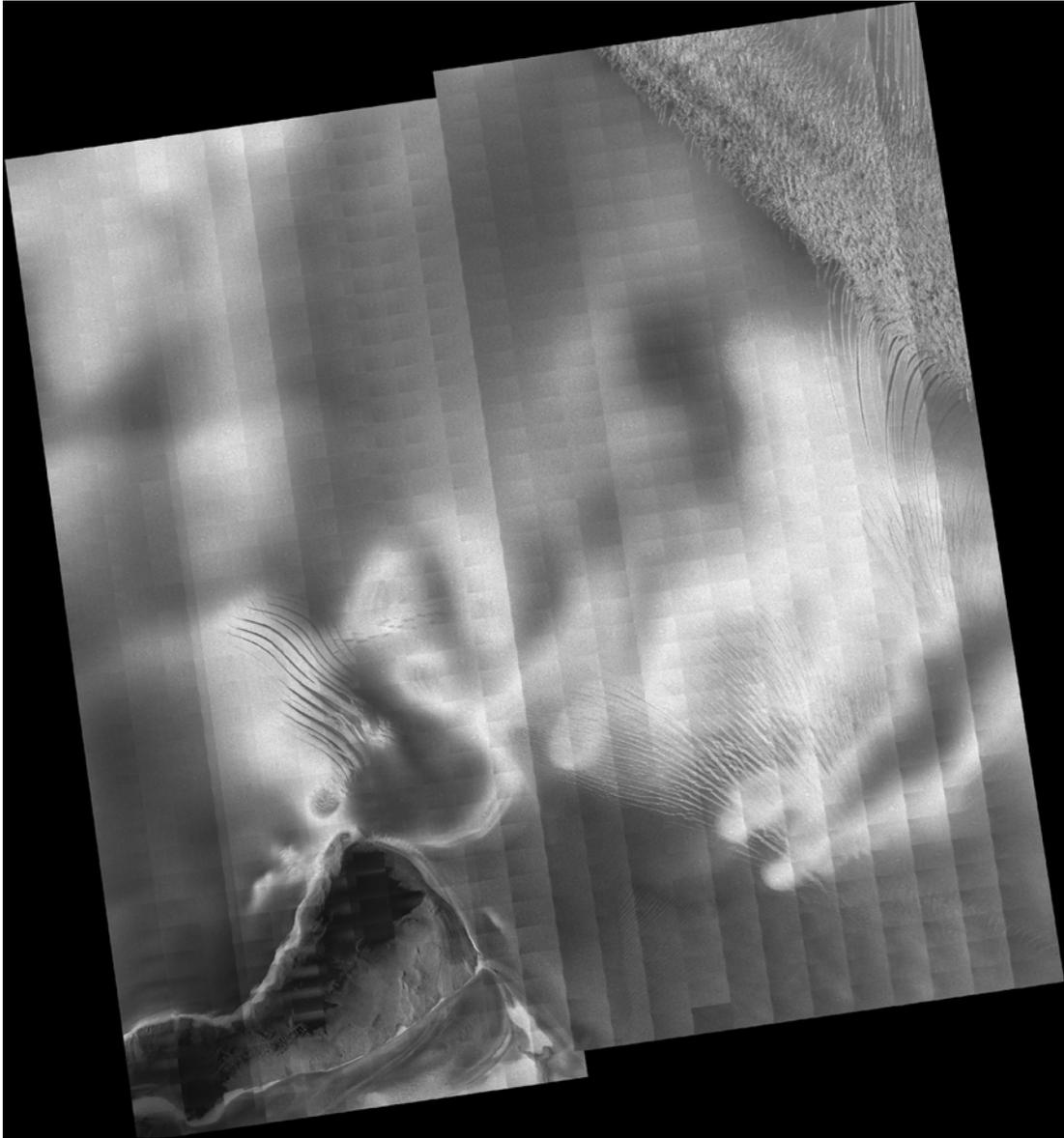


Figure 16: Mosaic of the Grosvenor CDR 1 foot resolution data over a 5 nmi by 5 nmi area

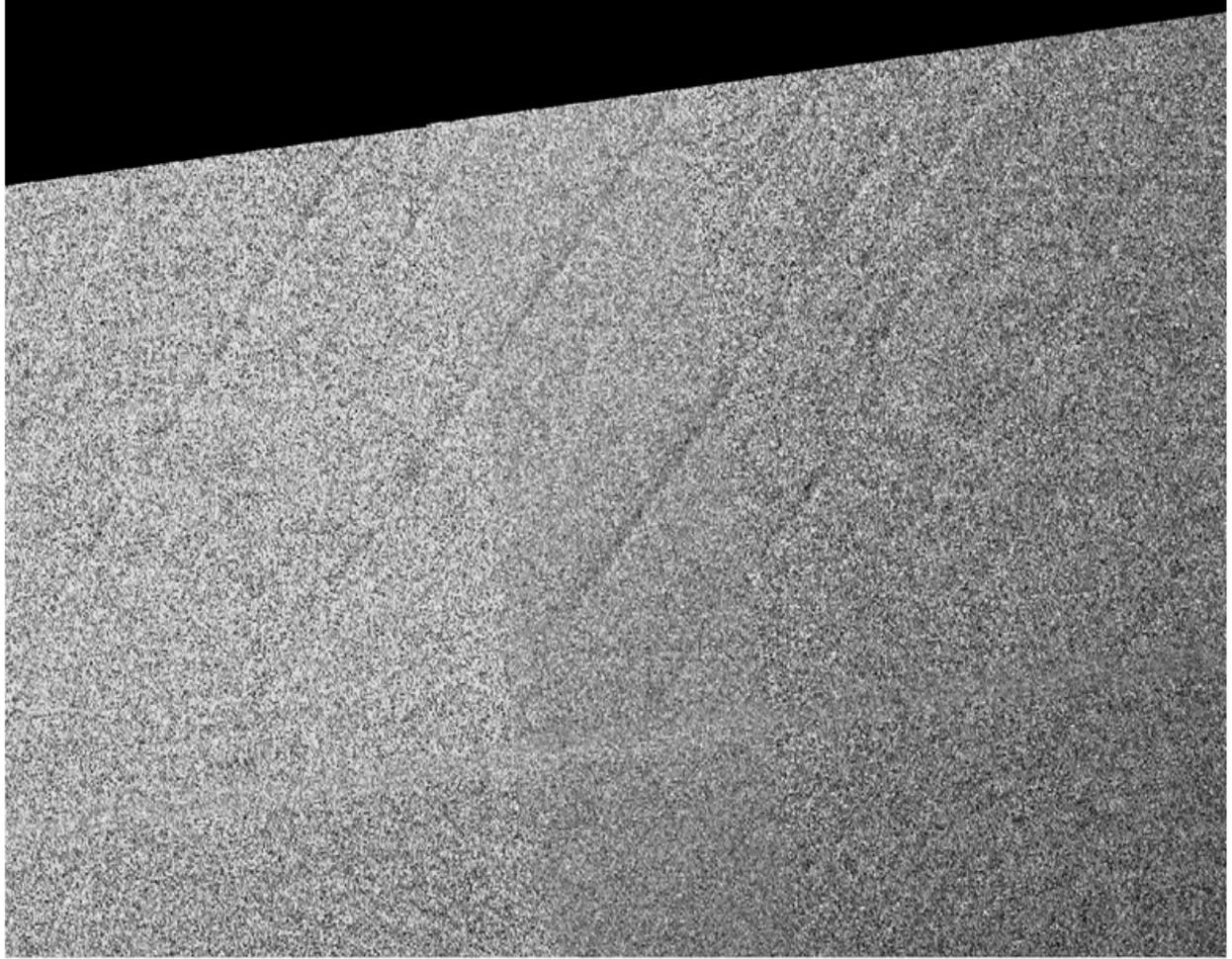


Figure 17: Close-up of crevasses from the upper middle of Figure 16

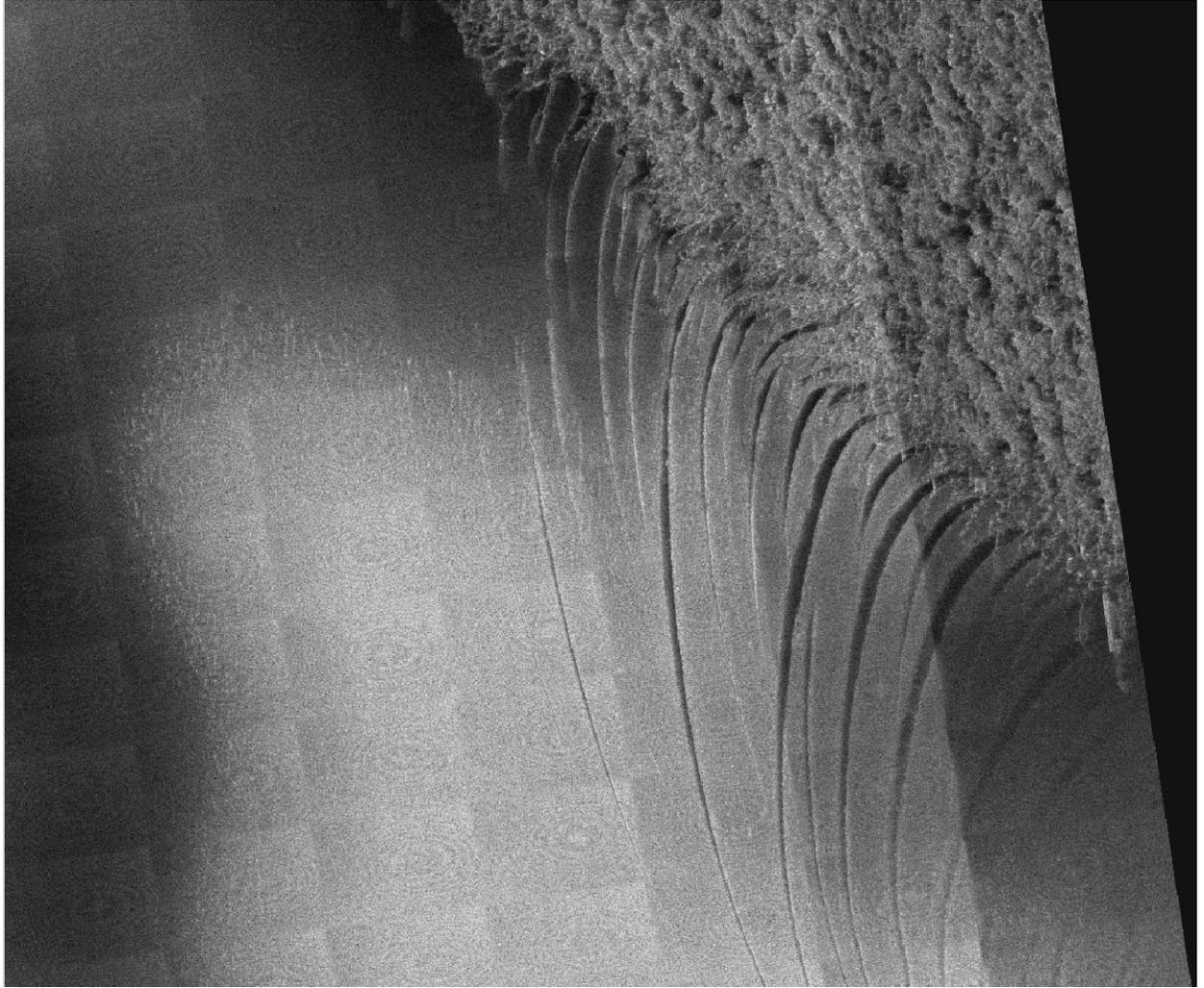


Figure 18: Close-up of more crevasses from the middle right part of Figure 16

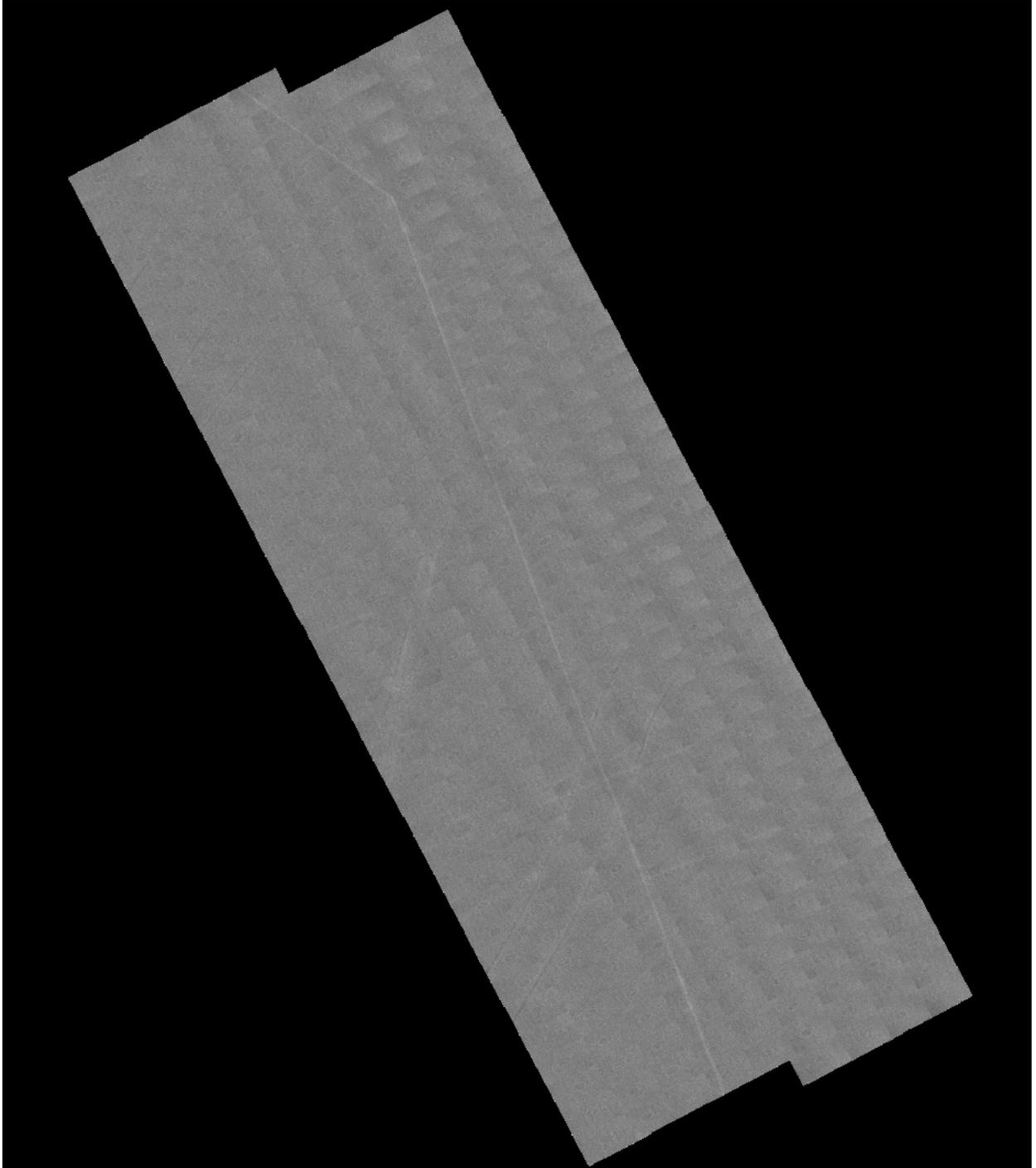


Figure 19: Mosaic of the Leverett CDR 1 foot resolution data over a 2 nmi by 5 nmi area along the South Pole Traverse

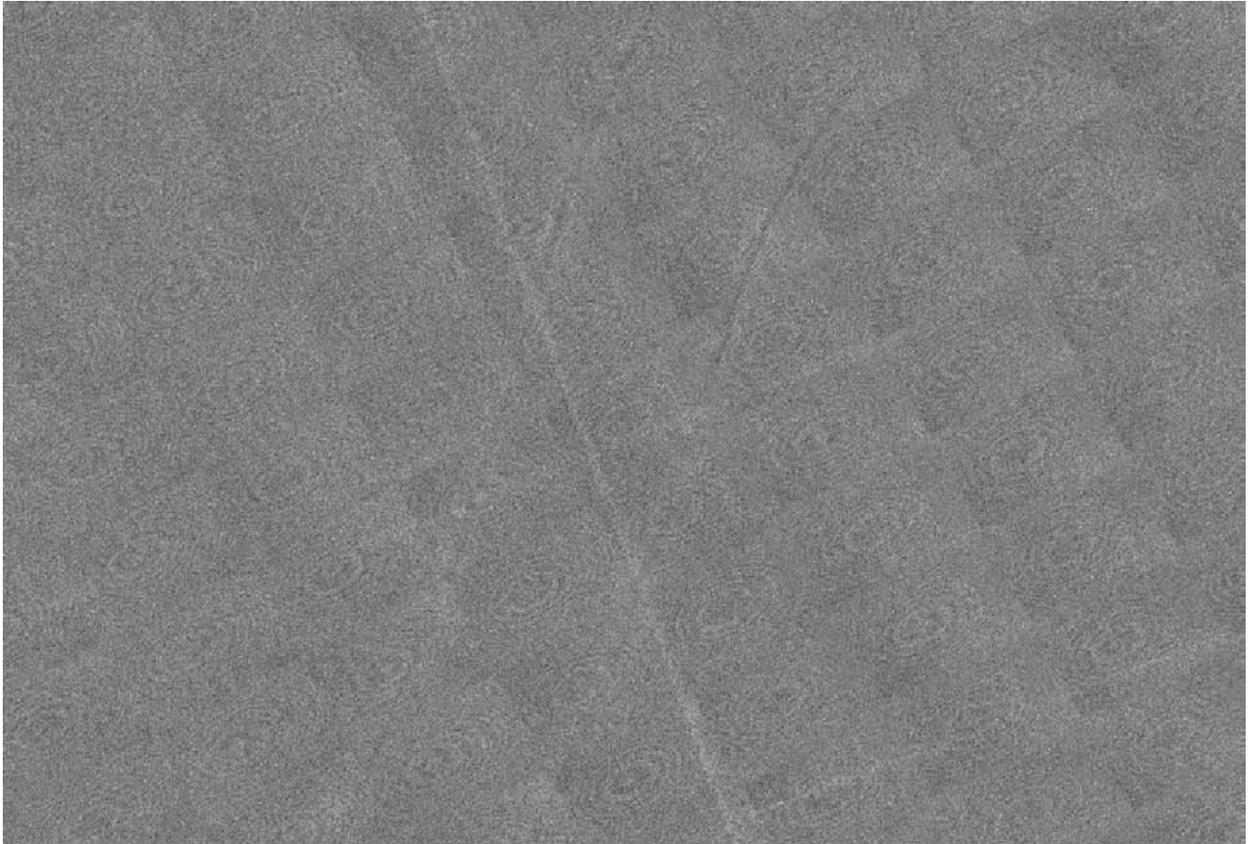


Figure 20: Closeup of crevasses in lower third of Figure 19

3 Conclusions

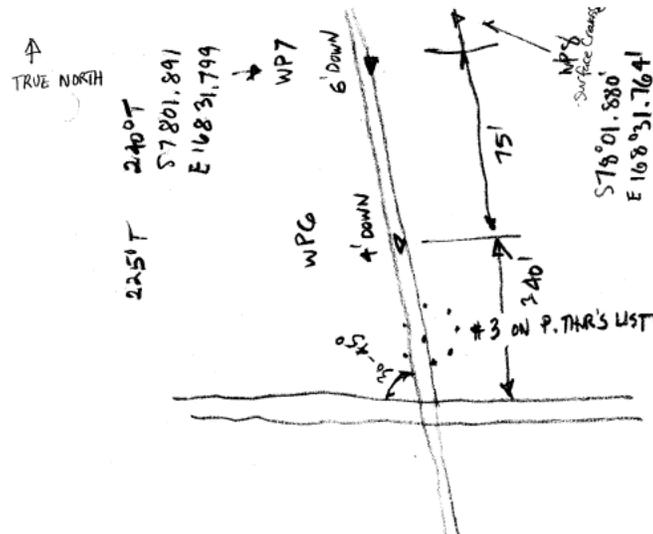
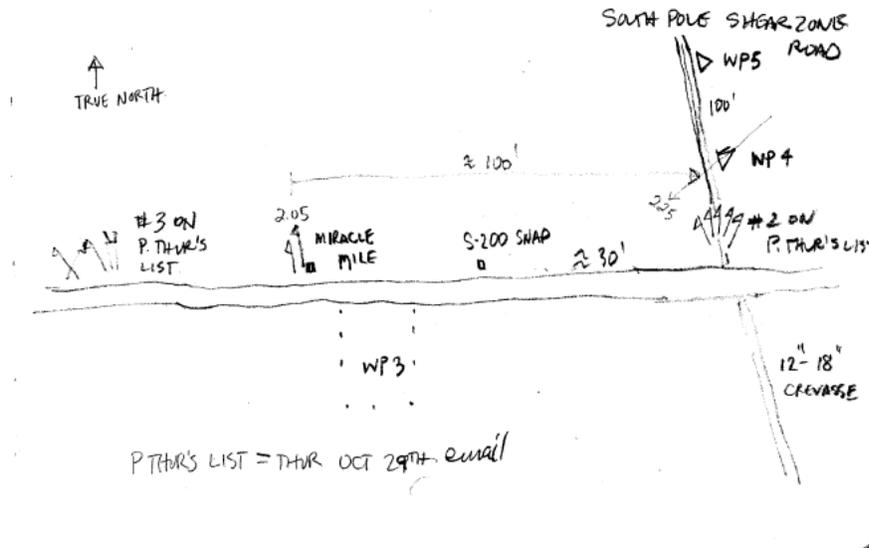
The SNL MiniSAR was successfully extended to operate on the NYANG LC-130. Flight tests and results from the 2009 Antarctica mission were presented in this report.

4 References

- [1] G. J. Sander, and D. L. Bickel, *Antarctica X-Band MiniSAR Crevasse Detection Radar: Final Report*, SAND2007-3526, September, 2007.

5 Appendix A: Notes on Shear Zone South Pole Traverse Site

The following information were Mark Armstrong's handwritten notes on this site.



ASTAR DROP OFF \approx 0940 @ WP3
INSTALLED TWO REFLECTORS \approx 1330 S 78 01.911'
LUNCH ENDS 1425 E 168 31.953'

↑
TRUE NORTH

#3 ON
P. THUR'S
LIST.

P. THUR'S LIST

Rough recollections by Mark Armstrong were that the 12" to 18" wide crevasses were at least 30 to 40 foot deep with approximately 18 to 20" snow bridges covering them. The following photograph shows the opened up snow bridge.

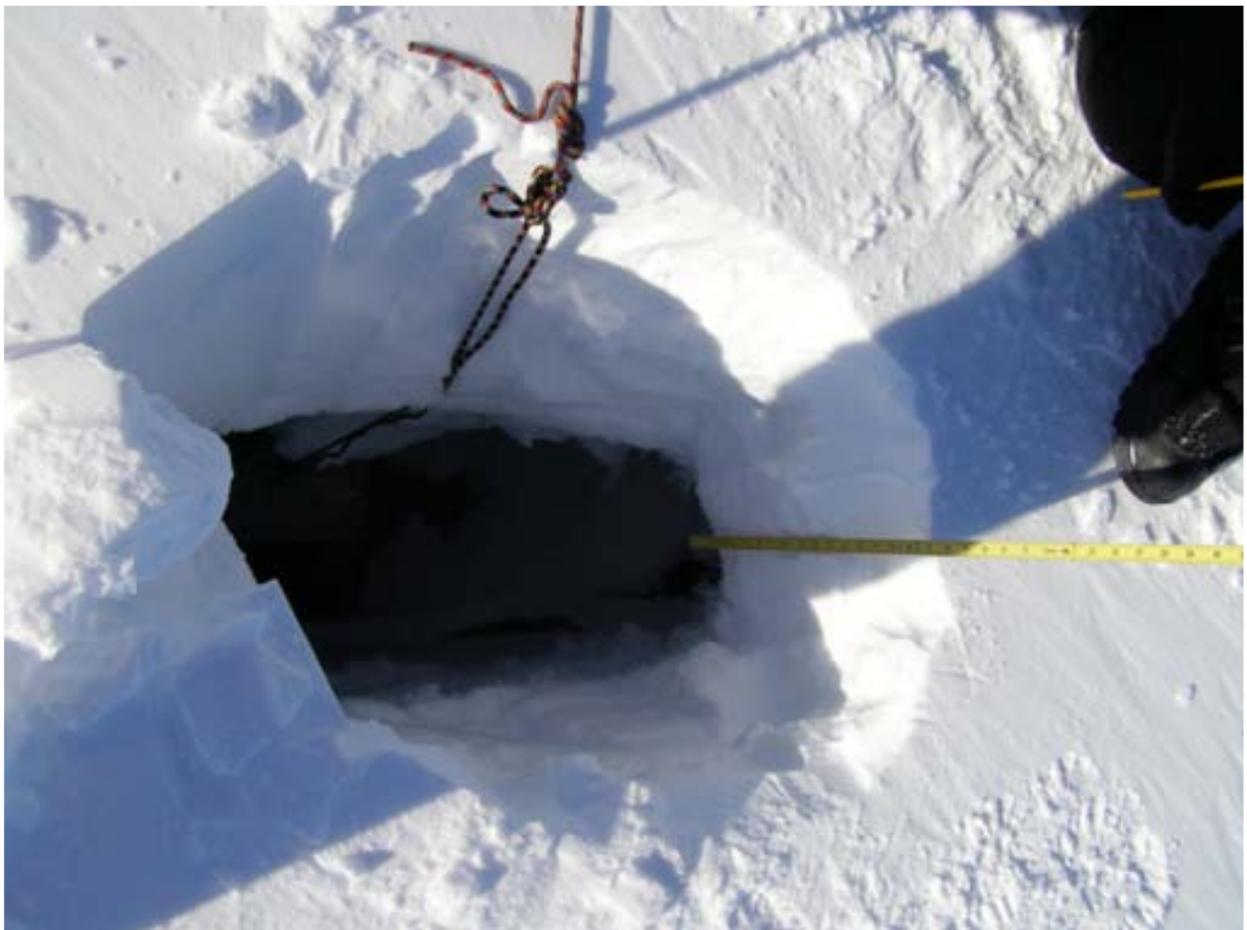


Figure A1: Snow bridge over small crevasse.

The photograph shown below shows the radar reflector placed inside the crevasse.



Figure A2: Radar reflector placed inside the crevasse.

6 Appendix B: Rough Coordinates of Areas Imaged

The following is a list of the rough coordinates that outline the areas imaged:

Grosvenor:

(85° 30' 52.54" S, 172° 20' 03.94" E),
(85° 31' 00.84" S, 171° 15' 44.04" E),
(85° 36' 18.53" S, 171° 15' 55.65" E),
(85° 36' 10.75" S, 172° 20' 15.22" E)

Leverett:

(84° 43' 03.31" S, 163° 07' 15.59" W),
(84° 44' 21.27" S, 163° 23' 36.26" W),
(84° 48' 05.19" S, 162° 42' 27.25" W),
(84° 46' 48.55" S, 162° 26' 11.70" W)

Shear Zone:

(77° 59' 08.18" S, 168° 28' 44.17" E),
(78° 02' 53.29" S, 168° 46' 50.08" E),
(78° 06' 18.86" S, 168° 29' 27.98" E),
(78° 02' 33.43" S, 168° 11' 15.95" E)

Tres Hermanas:

(78° 18' 33.43" S, 167° 53' 37.01" E),
(78° 22' 17.89" S, 168° 12' 11.31" E),
(78° 25' 43.92" S, 167° 54' 21.40" E),
(78° 21' 57.95" S, 167° 35' 40.82" E)

McMurdo:

(77° 49' 12.44" S, 166° 31' 09.53" E),
(77° 49' 29.59" S, 166° 56' 19.45" E),
(77° 52' 17.97" S, 166° 55' 00.98" E),
(77° 52' 01.99" S, 166° 29' 45.55" E)

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