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Sandia National Laboratories

An X-band Crevasse Detection Radar for the Arctic and Antarctic

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LC-130 Flying near Mt Erebus

The Motivation for Crevasse Detection

On November 16, 1998 the left ski of an LC-130 broke through an ice bridge that covered a crevasse. The crevasse was 10 feet wide and the ice bridge was estimated as 8 feet deep. The accident occurred near field camp on the West Antarctic Ice Sheet, 80 miles SW of Siple Dome Camp.

A brief review of the accident is provided in this link to a published article from the November 22, 1998 Edition of the *Antarctic Sun*. http://www.firebirds.org/menu7/mnu7_p9.htm

Exposed and Covered Crevasses

The primary application of this SNL designed Synthetic Aperture Radar (SAR) is detection of crevasses during surveillance / mapping of deep field landing sites.

Additional applications…

An over-ice traverse route from McMurdo Station to the South Pole is an alternate to flying supplies to Amundsen-Scott South Pole Station. Hundreds of crevasses exist on the route must be found and filled before tracked vehicles can pass over them.

This particular crevasse was 7 feet wide, 107 feet deep, with a 9 foot deep bridge over the crevasse.

Solutions for Crevasse Detection

In the past, visual inspection of proposed landing areas was the primary method for crevasse detection. Development of the CDR system has added a unique crevasse detection capability. Below is short list of the methods used.

Inspection from the air

- Study best available ground truth
- Low level fly-bys for visual check
- “Light” landings to check of potential snow bridges or crevassing

Inspection from the air and ground

- Deploy a crevasse survey team with a light aircraft such as the Twin Otters or Basslers
- The team checks the proposed landing sights on snowmobiles and may use a ground penetrating radar (GPR)

Crevasse Detection Radar Method

- Generate a SAR mosaic of a proposed 5nmi x 5 nmi landing area
  - The survey area is defined by the user and the CDR Flight Planner software. A 10 nmi x 10 nmi mosaic was generated at the Fosdick site on November 7th, 2011
  - Limits exist due to radar alignment / IMU requirements.
- Study SAR imagery and compare to best available optical imagery
- Document crevasse location

Common Architecture Program (CAP)

- A common radar architecture?
  - Cost sharing
  - Reduce development time, reduce risk
  - Limited people must work on multiple programs
  - Common code, adaptability, modularity
- The benefits, as demonstrated
    - Radar Control / System Control / Phase History Processing
  - Common testing methodology
  - Reduces (& complicates) configuration management

CAP Radar Systems, Deployed

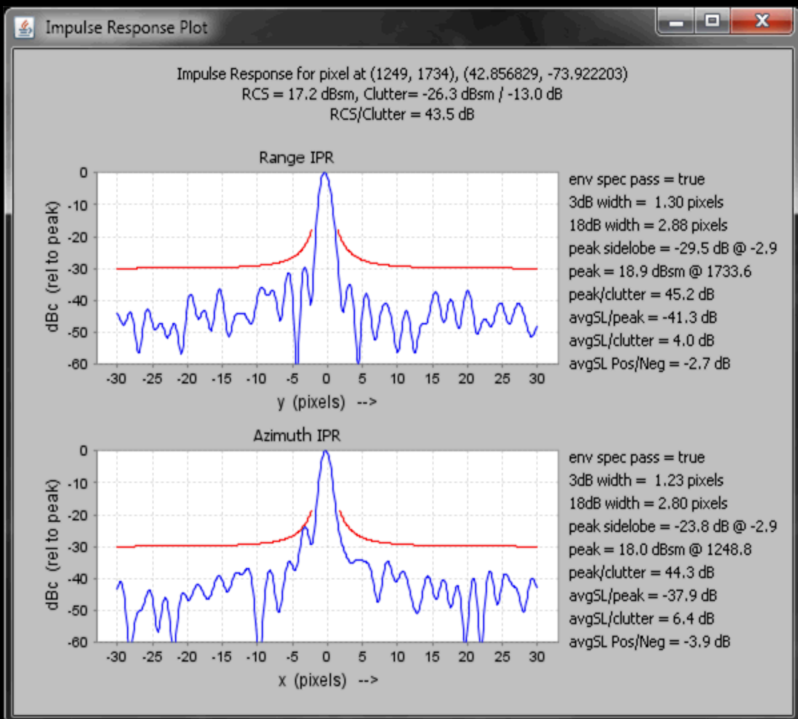
- X-Band, Ku-Band, Ka-Band
- Modes:
  - Synthetic Aperture Radar
    - Spotlight, Stripmap, Tracking*, SpotDwell*
  - VideoSAR
    - Circle, Line
  - GMTI
    - Wide Area Search GMTI*, Staring GMTI*
- Data Exploitation
  - Stripmap Mosaics
  - CCD
  - Multi-look processing

* unguided modes

Crevasse Detection Radar
System Specs

Parameter	***Value***
Frequency	**9.9 GHz**
Polarization	**VV**
Typical operating ranges	**3.3 to 5 km**
Resolution	**0.2, 0.3, 1 m**

Radar Calibration / System Characterization



- Extensive lab testing and flight testing are the primary methods for characterizing radar stability and image quality.
- Initial system testing is conducted in the lab with well defined test sets and analysis
- The CDR systems are then flight tested on Twin Otter aircraft and the LC-130, in multiple locations prior to the deployments to Antarctica.

Basic radar parameters checked during system characterization

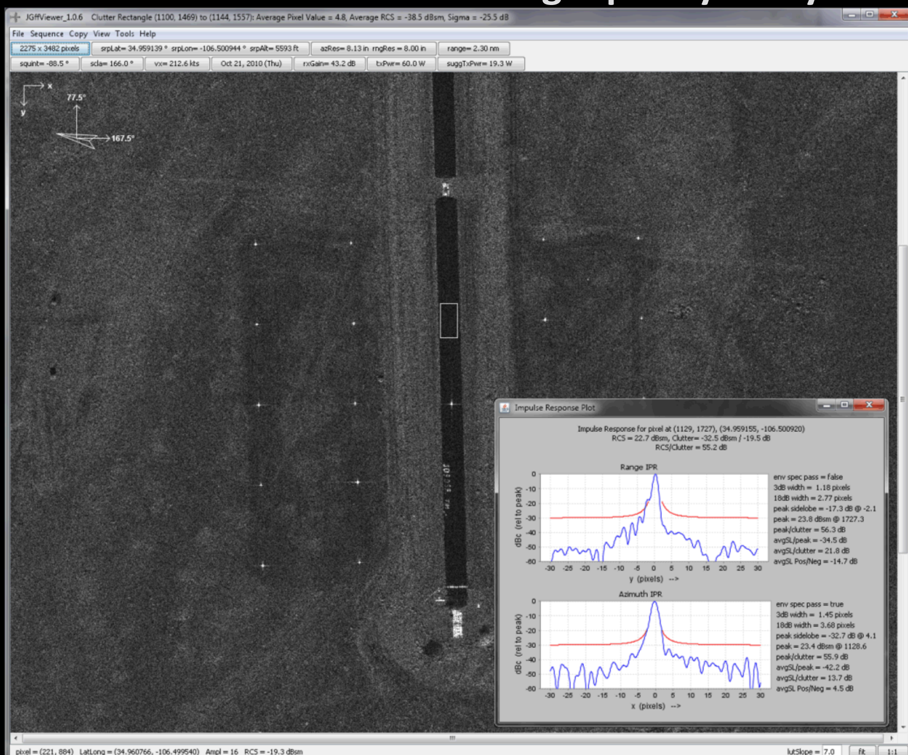
- Peak Pixel RCS
- Clutter
- IPR Plot
- Interpolation Peak
- Peak Sidelobe
- Envelope Spec Pass/Fail
- Mainlobe Width
- Average Sidelobe
- Average Sidelobe Pos/Neg

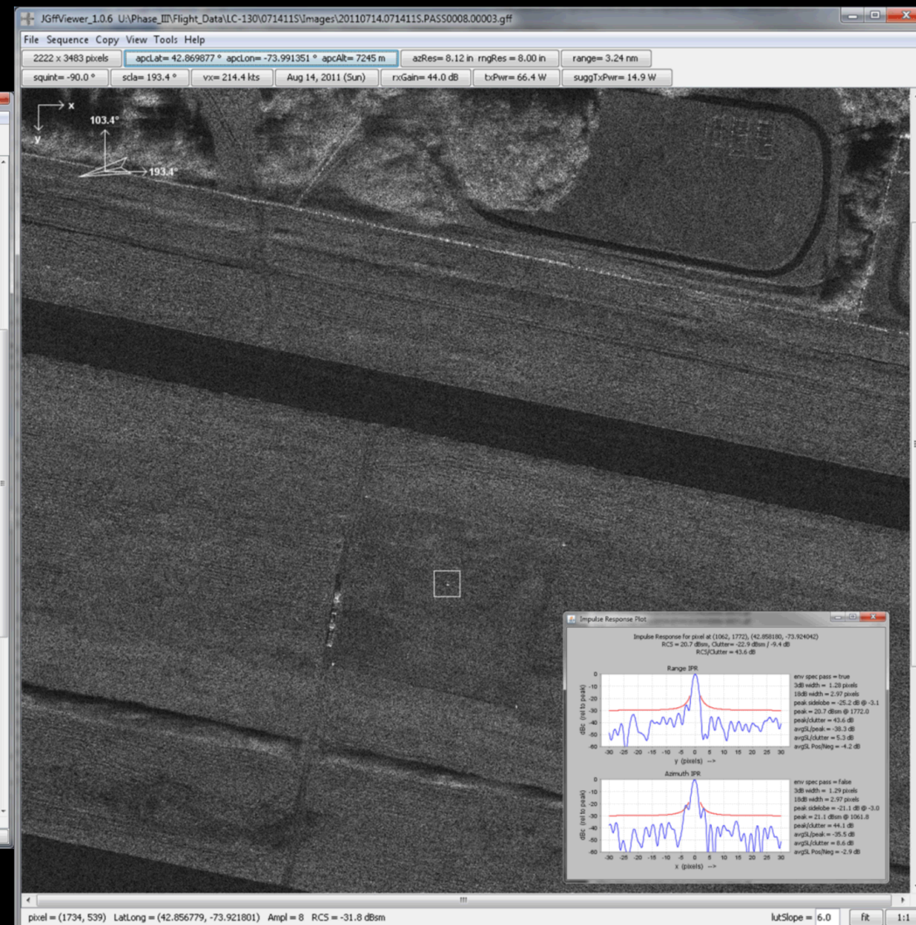
System Characterization

New Mexico, New York and Greenland

System characterization and flight crew training was conducted in New Mexico, New York and Greenland for the duration of the program.

All modes were tested and image quality analyzed.

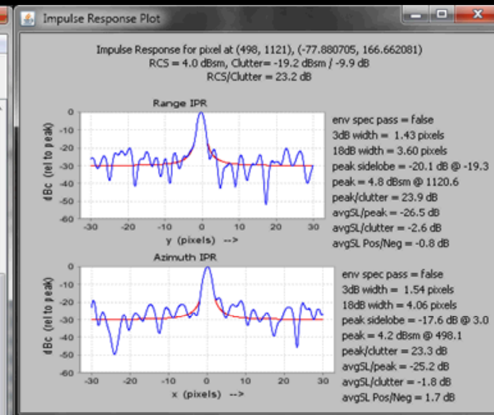




A large scale test range is located on Kirtland AFB. For remote testing corner reflectors are placed in low clutter areas – for a simple check of system IPRs.

System Characterization

Antarctica



The radars are checked out in Antarctica prior to the deep field imaging.

A corner reflector is placed on 'groomed' ice. But the groomed ice is not smooth, like the runway, as shown by the IPRs.

Crevasse Detection Radar Development

Phase I – Nov / Dec 2006

- Proof of concept – crevasse detection with an X-band synthetic aperture radar
- MiniSAR+ Radar installed on a Twin Otter
- Successfully discovered “hidden” crevasses
- Successfully found sub-surface corner reflectors

Phase II – Oct / Nov 2009

- MiniSAR+ Radar, SABIR arm, LC-130
- Successful repeat of 2006 from an LC-130
- Successful “deep field” missions

Crevasse Detection Radar Development

Phase III – Jan 2011

- SNL CAP compatible phase history generator with an X-band RF module
- GPU solution for Image Formation, Image Exploitation, and Data Recording.
  - Same volume as the MiniSAR system but with increased processing capability for VideoSAR
- 5 degrees of pitch offset built in to the Antenna Gimbal Assembly (AGA) mount
- Patch size in the range dimension (range swath) increased by 2x
  - Fewer passes required due to the larger patch sizes
- CLAW host / user interface software, developed by General Atomics
- Automated flight planner software
- Real time SAR mosaic displayed in Google Earth
- Implementation of all imaging modes

Operational Deployment, Nov 2011

- Flight Planning responsibility owned by NYANG
- Radar operation controlled from the LC-130 cockpit and the NYANG navigator
- Data transfer scripts developed and deployed

Antarctica
Flight Test History

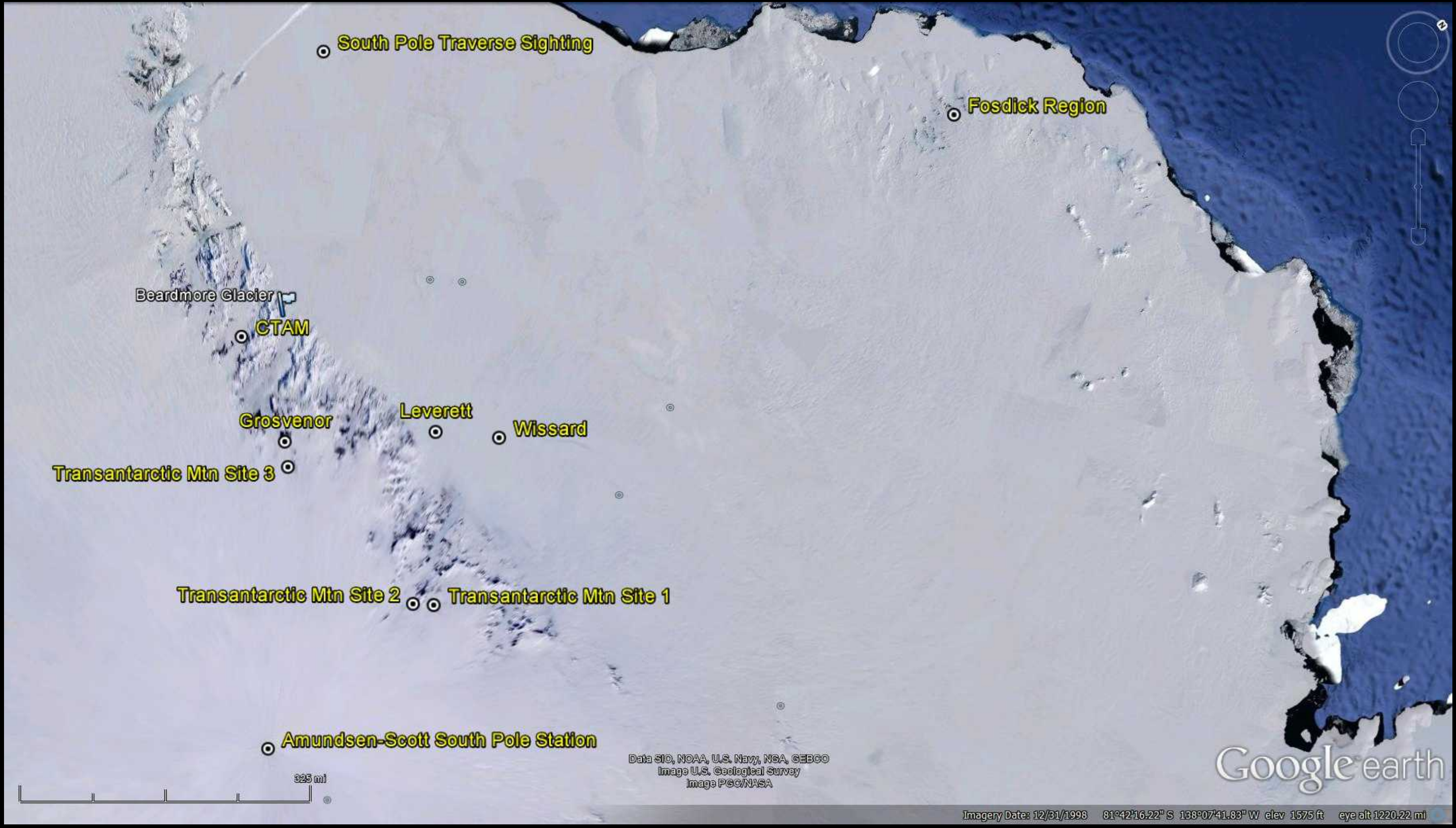
Test Date	Radar System	Flights	Locations
Dec 2006	Phase 1 CDR Modified MiniSAR	5	McMurdo, Pegasus, Shear Zone, Tres Hermanas
Nov 2009	Phase II CDR Modified MiniSAR	4	McMurdo, Shear Zone, Grosvenor, Leverett
Jan 2011	Phase III CDR CAP based	4	Pegasus, Andrill, Andrill West, CTAM, Shear Zone, Wissard
Nov 2011	Phase III CDR CAP based	3	Ice Runway, Shear Zone, Fosdick Mtns, Graves, Klein Glacier

Greenland Test Sites

Antarctica Test Sites
Ross Ice Shelf

Dec 2006, Nov 2009, Jan/Nov 2011 Deployments

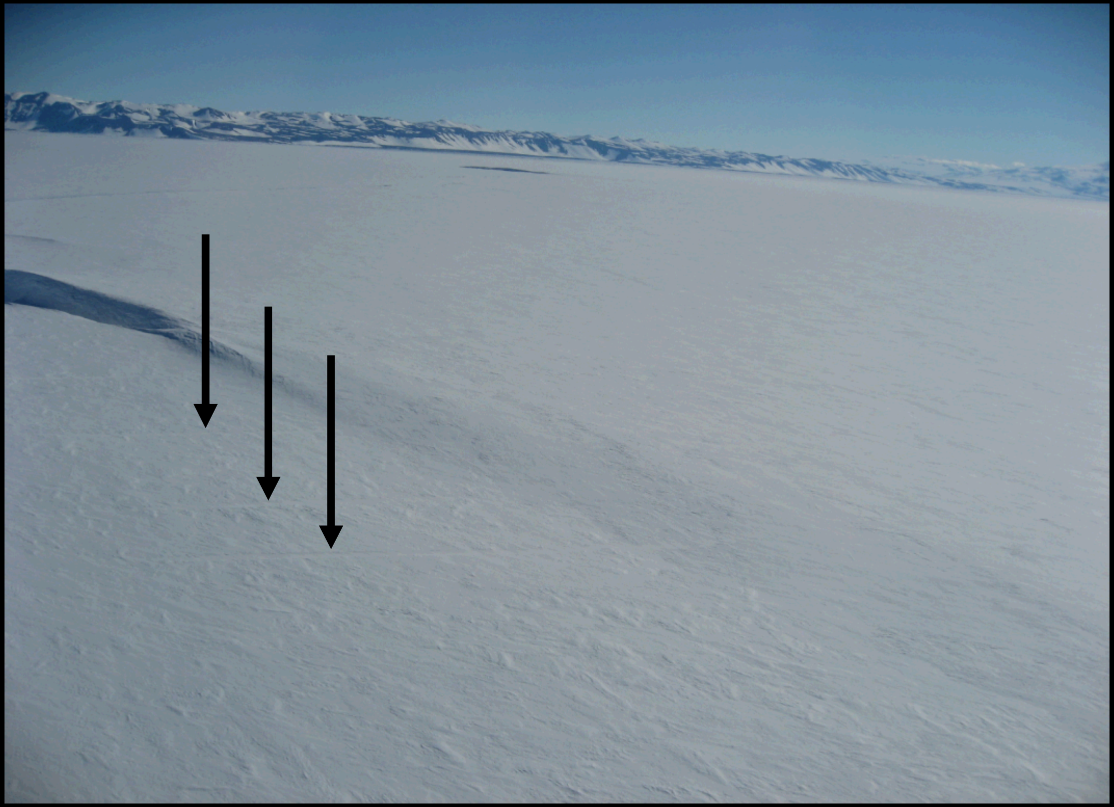
Antarctica Test Sites
Trans Antarctic Mtns
Dec 2006, Nov 2009, Jan/Nov 2011 Deployments

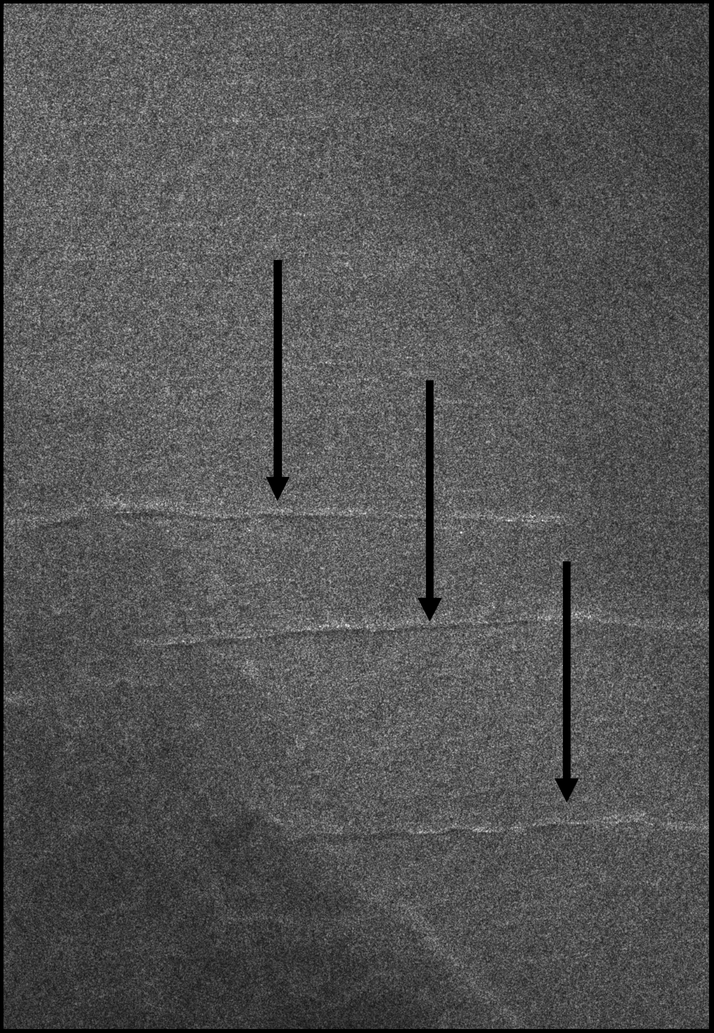


Optical Data
Antarctica

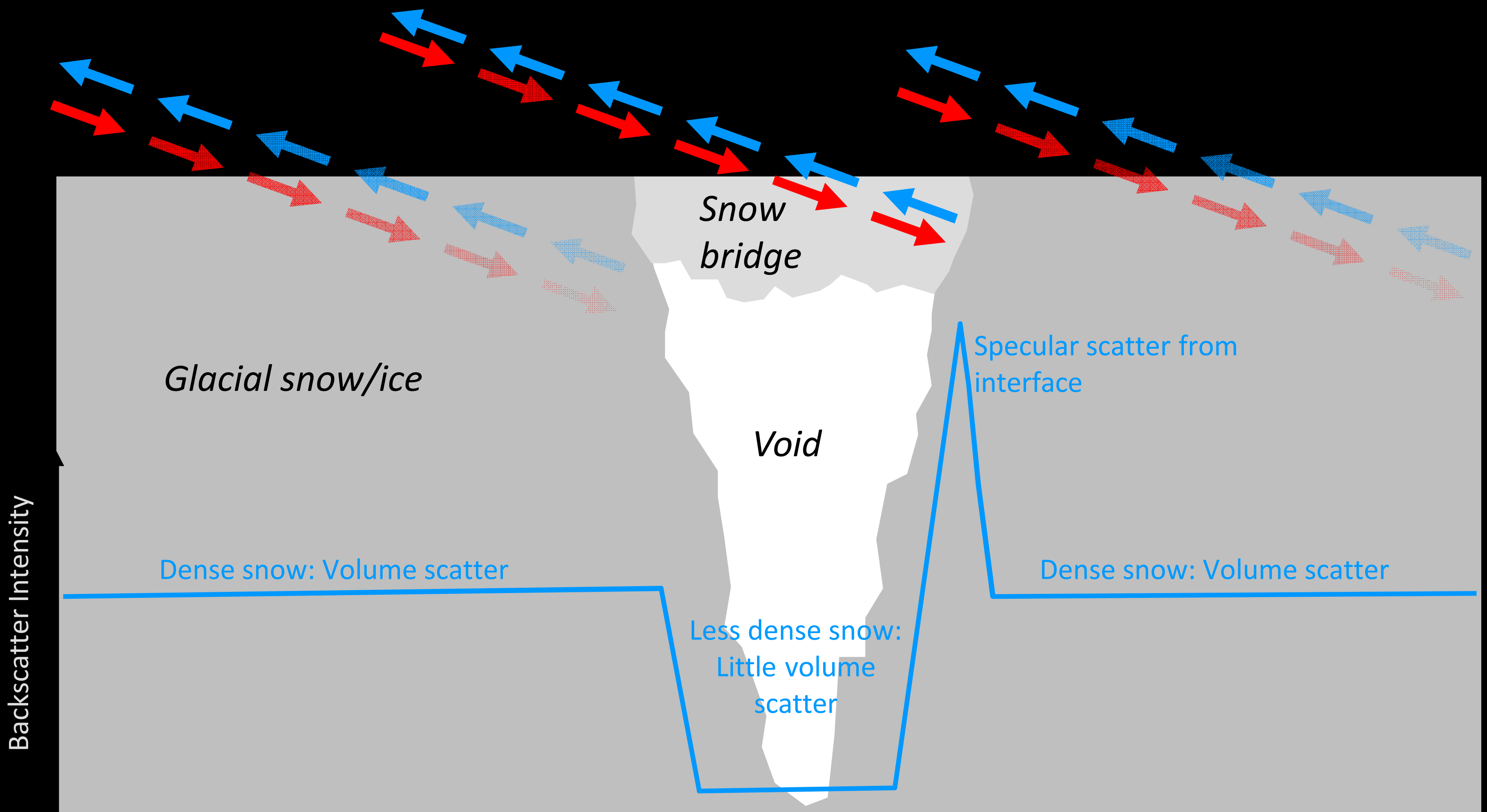
- **An optical photograph taken of three crevasses taken under optimal weather conditions and from an ideal aspect angle in Antarctica.**
  - **The crevasses were about eight feet wide covered over with a narrow snow bridge**
  - **It is obvious that crevasses can be difficult to detect even in the best of circumstances**

Optical Data vs. Radar Data
Antarctica



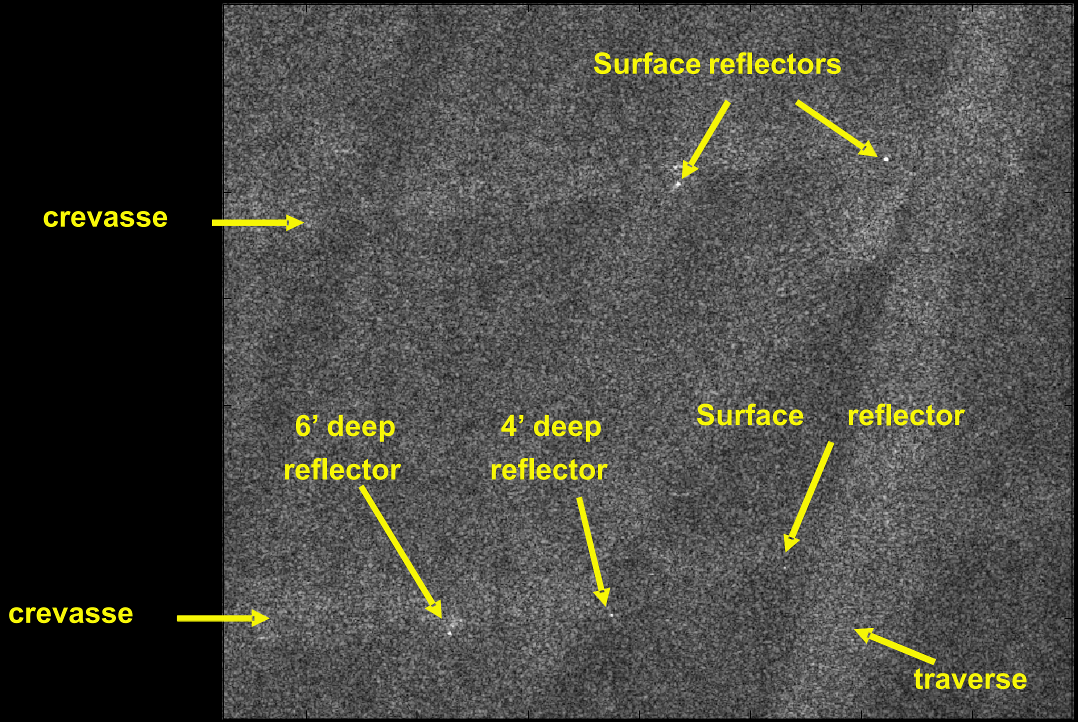


Crevasse and Radar Returns



Penetration of Snow, Experiments in Antarctica

Reflectors Inside Crevasse (8" resolution)



- An experiment in 2009 indicated that snow penetration may be possible at X-band for a shallow covering of dry Antarctic snow.
- Small crevasses were found in the Shear Zone using ground penetrating radar.
- The crevasses were opened up in a couple of spots and quad corner radar reflectors were inserted at specified depths.
- The snow bridge widths of crevasses were measured by NYANG ground personnel with support from Raytheon Polar.
- Crevasses measuring only 12" to 18" wide were detectable in the 1 foot resolution stripmap of the area.

Penetration of Snow, Experiments in Greenland

In one experiment in Greenland, radar reflectors were positioned in a snow drift to test radar penetration of the wet snow.

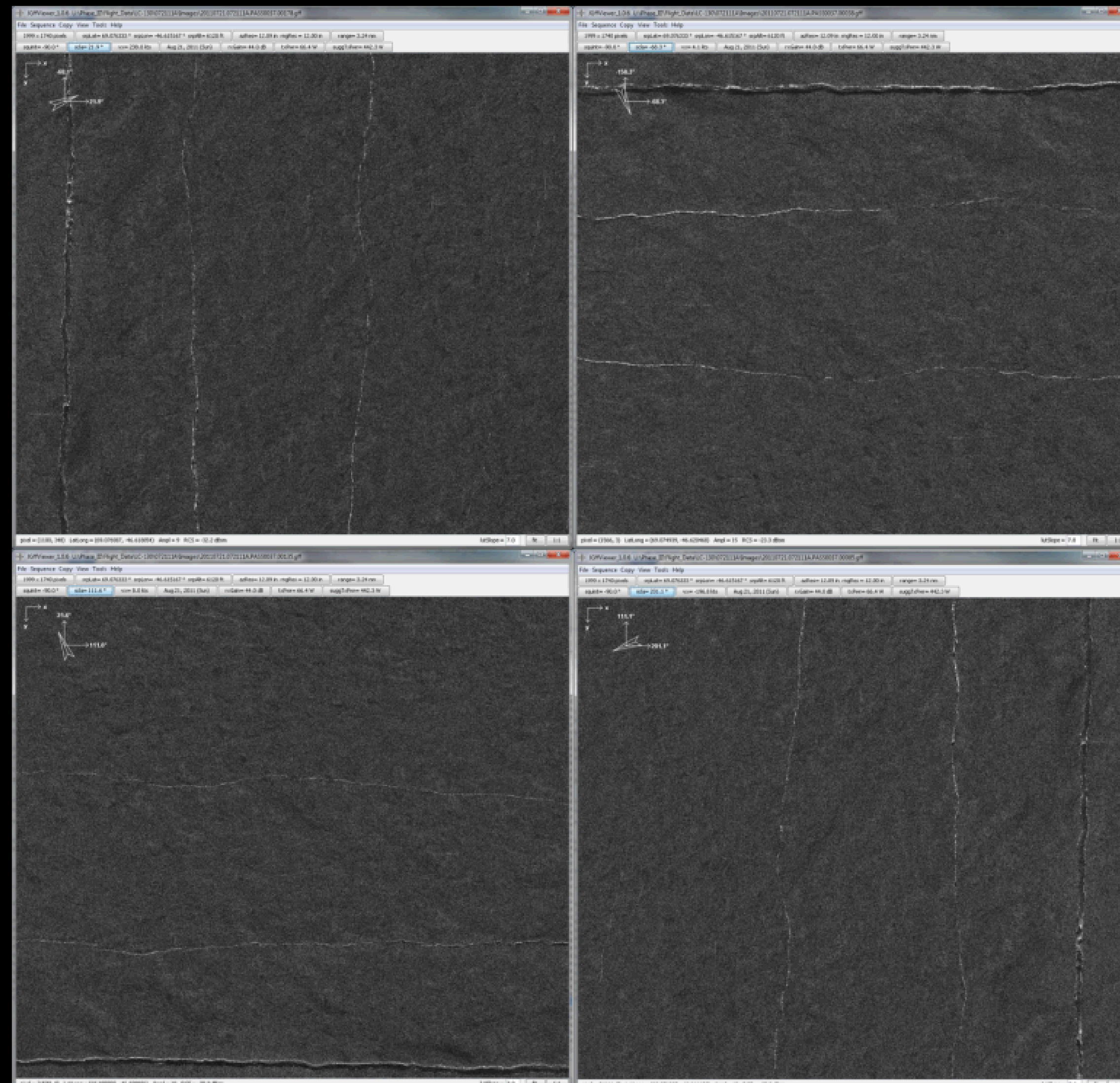
This is a single image from a 1 foot resolution VideoSAR pass on a decommissioned early warning radar site that preliminarily indicates that the reflectors are visible.

Crevasse Detection Greenland Data

The common belief is that crevasse detection capability with the CDR system is best when crevasse is parallel to the flight path, i.e., the radar is pointed perpendicular to the crevasse.

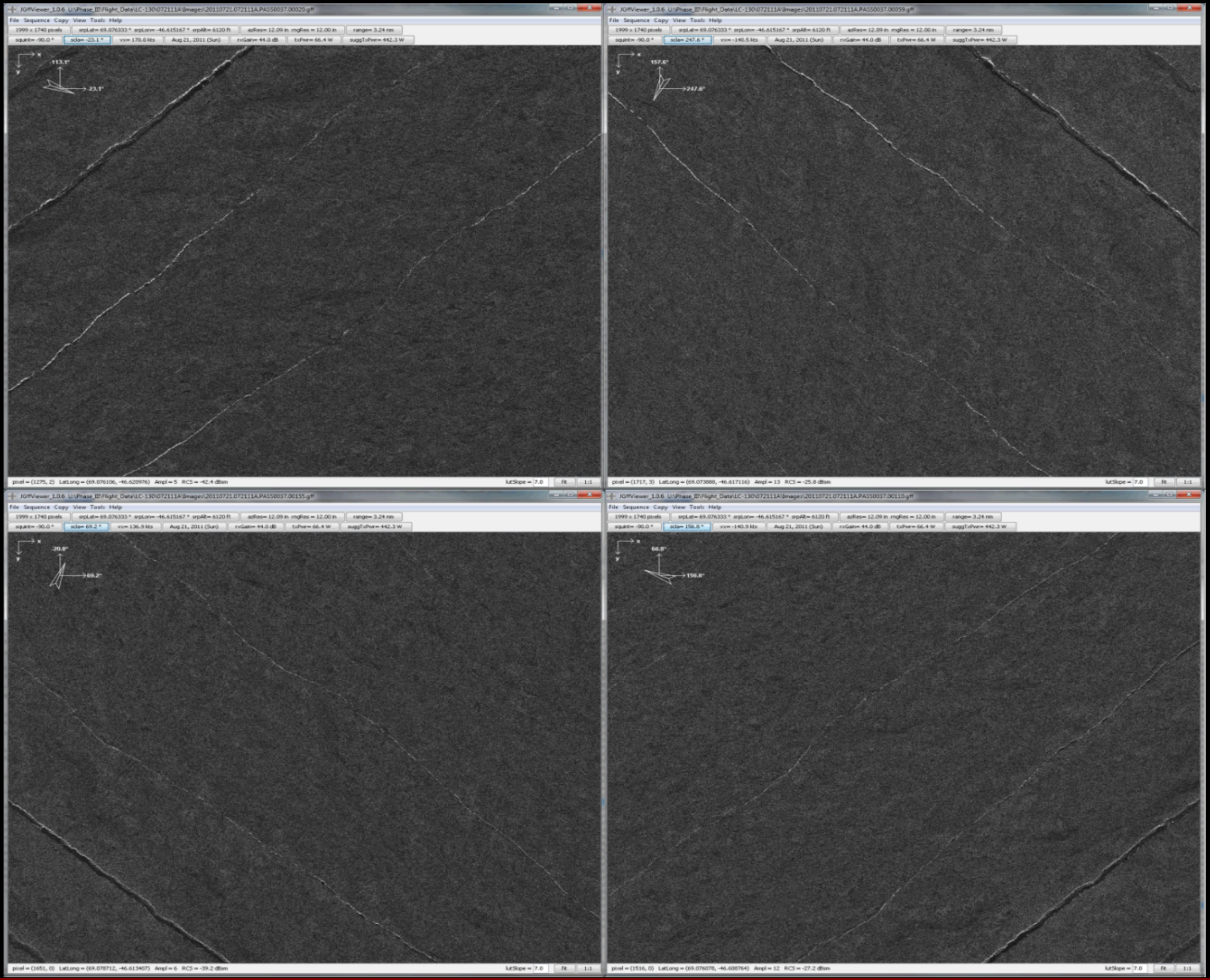
VideoSAR data shows that crevasses can be detected when perpendicular to the flight path.

In addition, the data shows that crevasse detection may be independent of the imaging geometry and a function of the local geography.

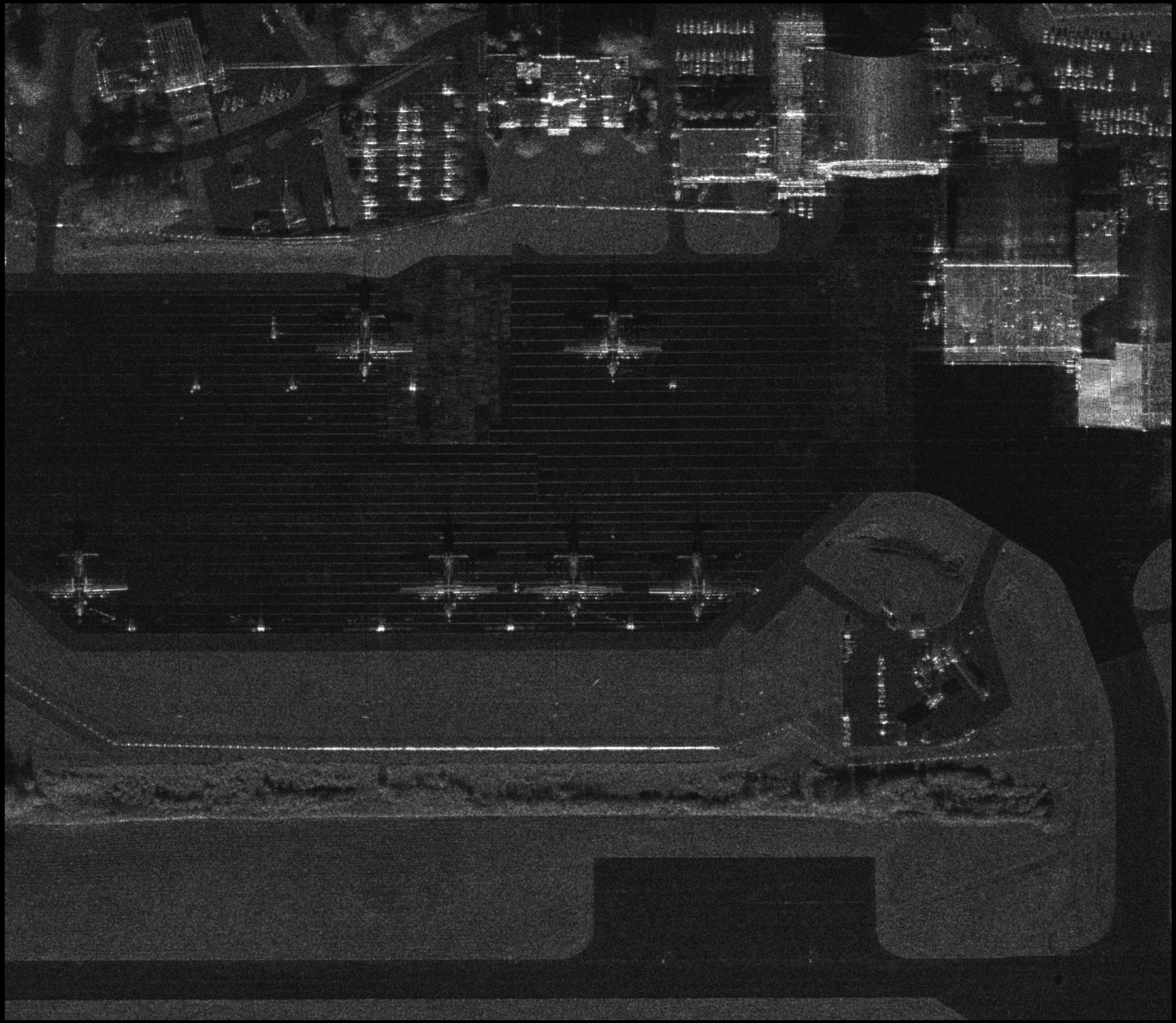


Crevasse Detection Greenland Data

As with all new applications, it is very difficult to identify the ‘best’ imaging conditions. A large set of radar data taken form a diverse set of targets is required before any ‘rules of thumb’ can be established.

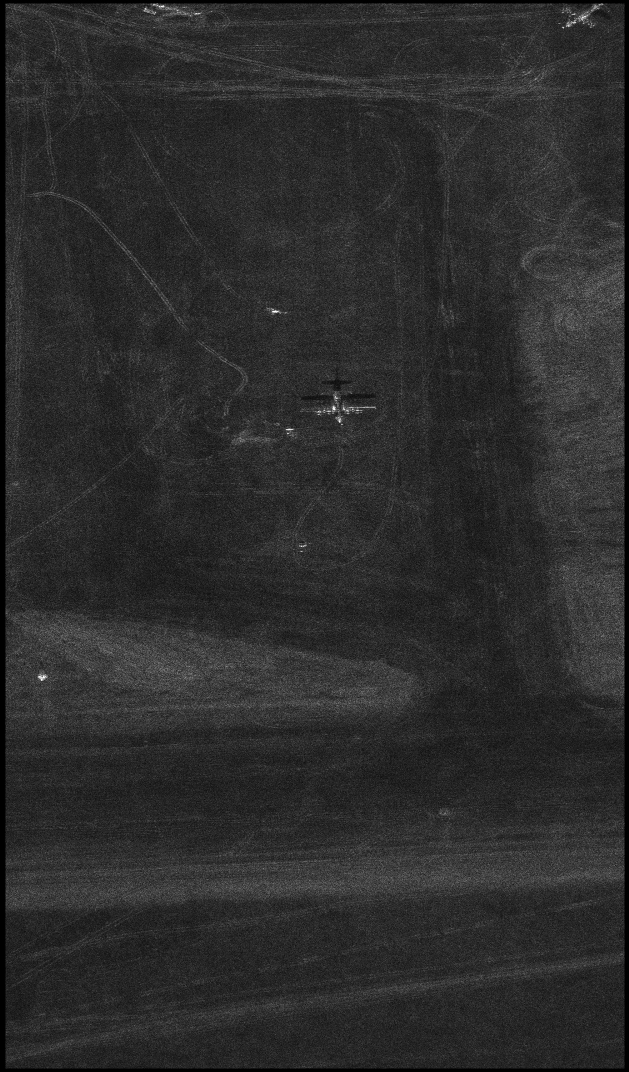


Example: CDR Image
LC-130 at Stratton AFB



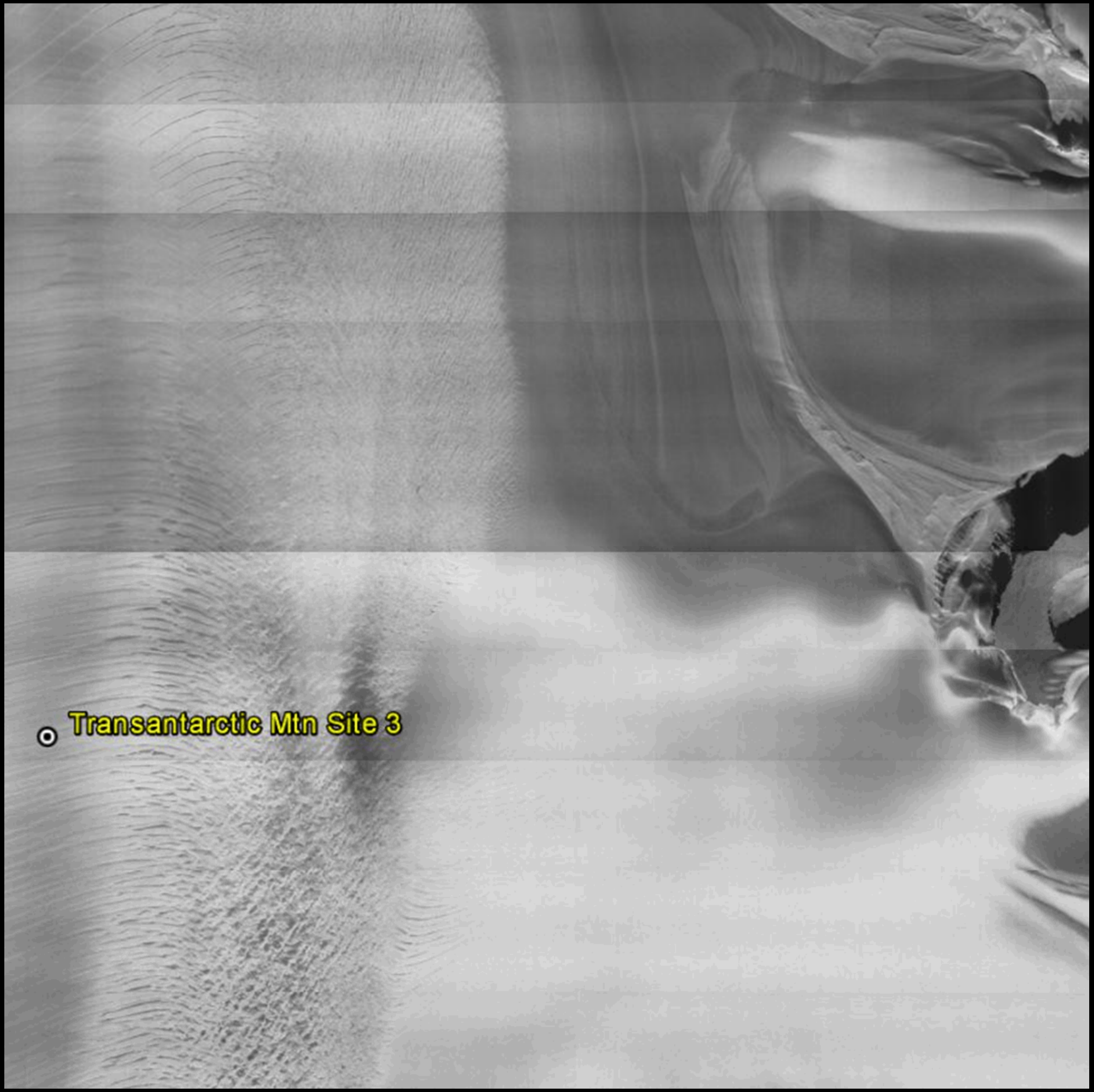
- 12” VideoSAR image
- Range: 5.8 km
- Grazing: 19.6 deg
- Patch size: 487 m x 449 m

Example: CDR Image
LC-130 on Ice Ramp



- 12” Stripmap image
- Range: 4.0 km
- Grazing: 27.0 deg
- Patch size: 332 x 954 meters

CDR Mosaics



Stripmap Mosaic

9.3km x 7.6km

Resolution

12”

Range

4.0km

Grazing

30.0 deg

Patch size

332m x 849m

Passes

10

Total Images

290

Time on Station

49 min

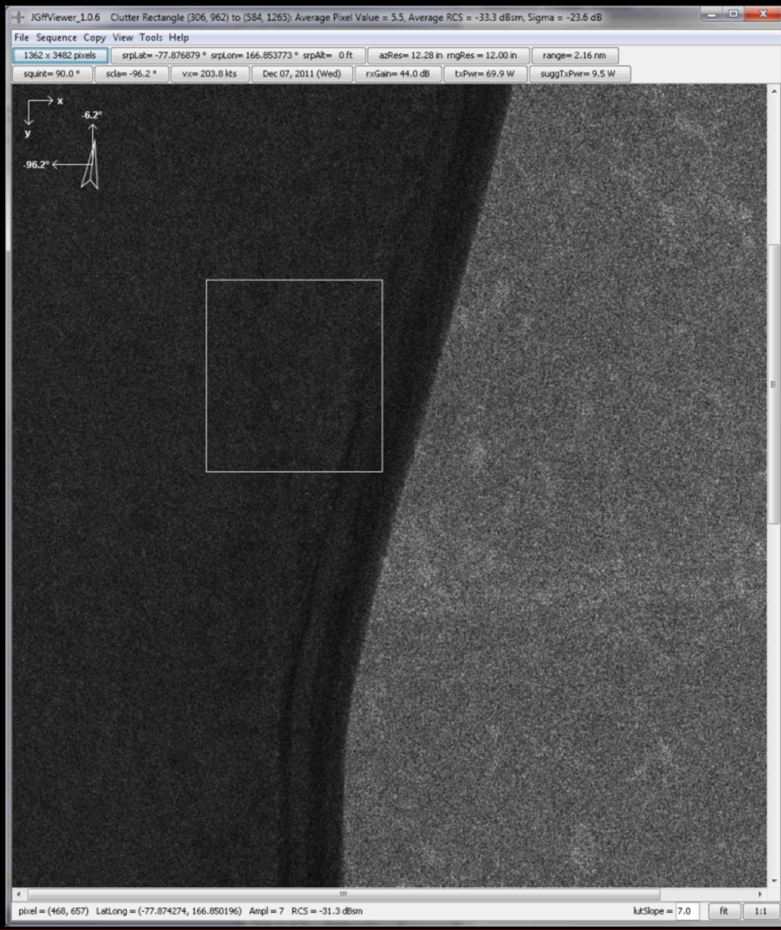
Comparison of Sea Ice & Glacial Ice Antarctica

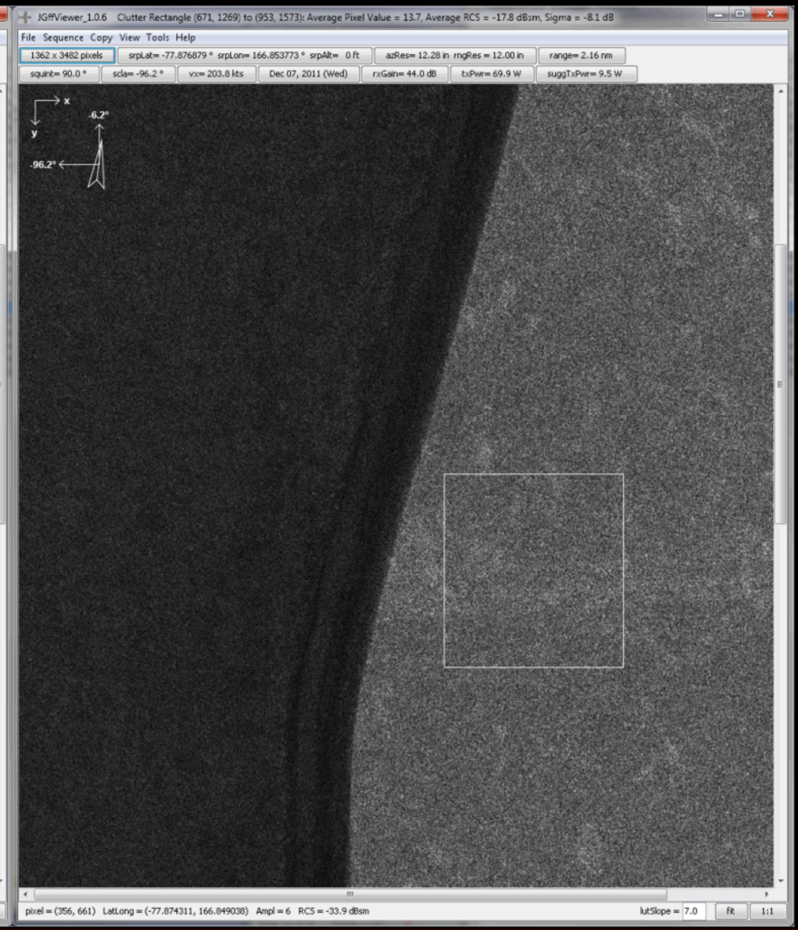
Clutter Measurement on smooth sea ice:

- **Average RCS = -33.3 dBsm**
- **Sigma RCS = -23.6 dB**

Clutter Measurement on glacial ice:

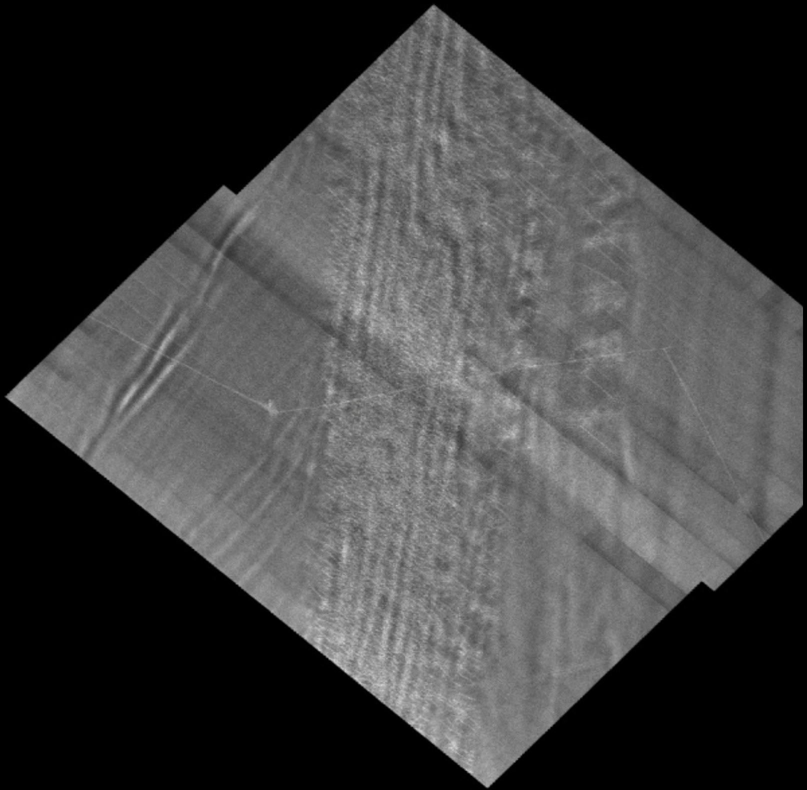
- **Average RCS = -17.8 dBsm**
- **Sigma RCS = -8.1 dB**

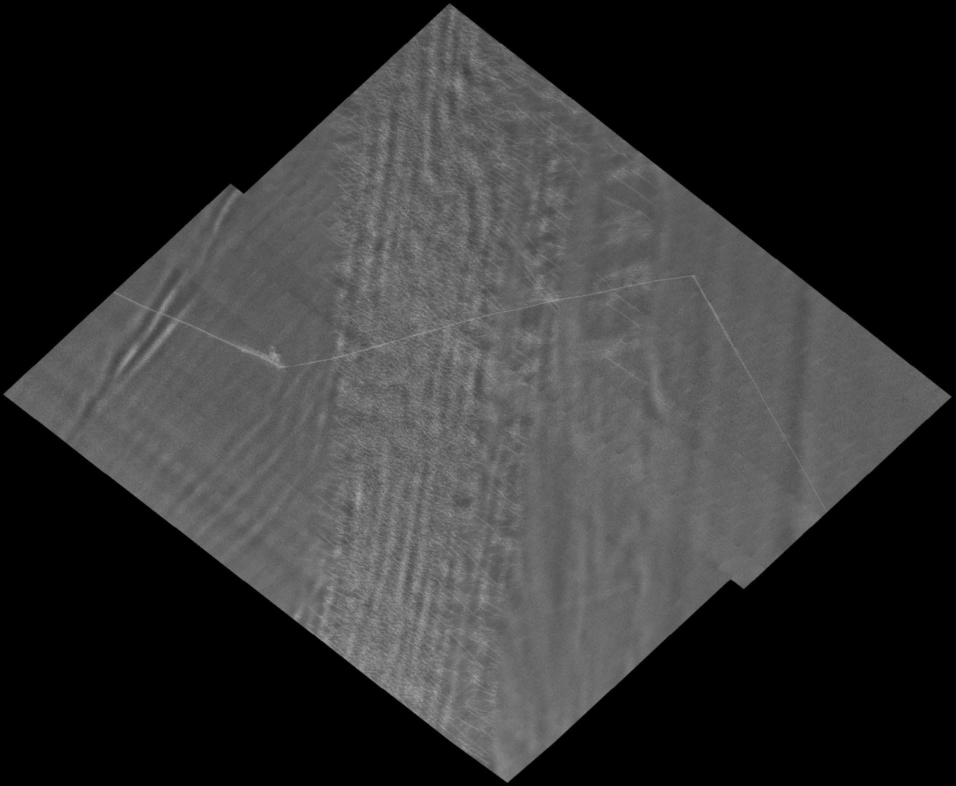




The Shear Zone Antarctica

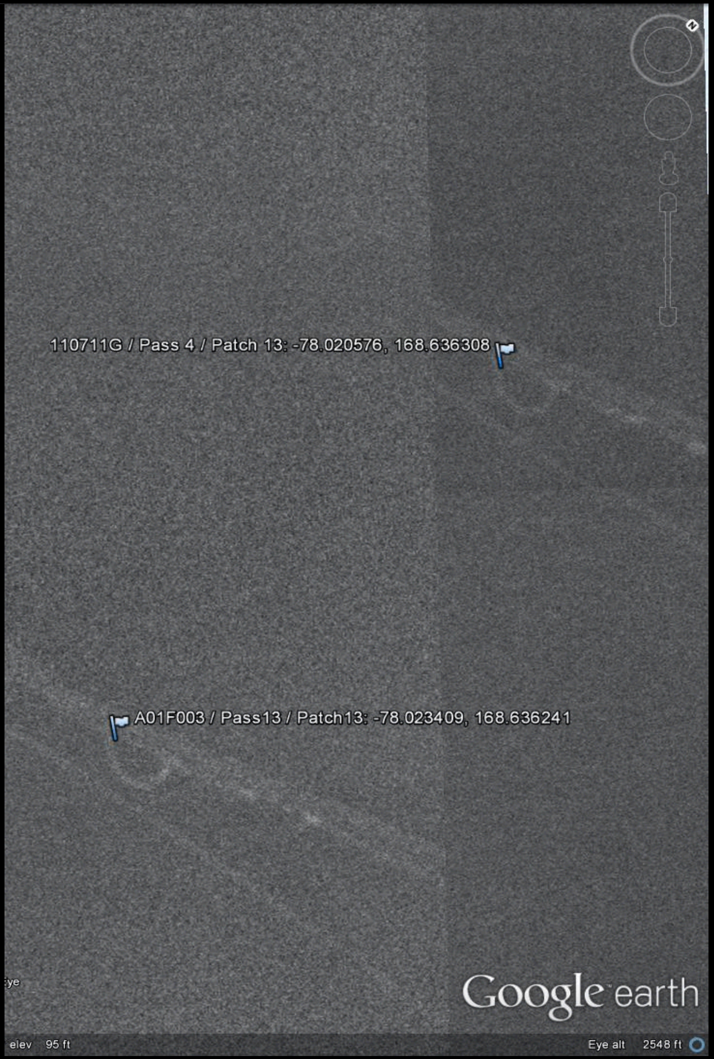
- The shear zone is located ~ 30 miles from McMurdo Station and was imaged during the four CDR deployments through 2011
- Through past surveys and local knowledge is documented that the ice moves about 3 feet per day.



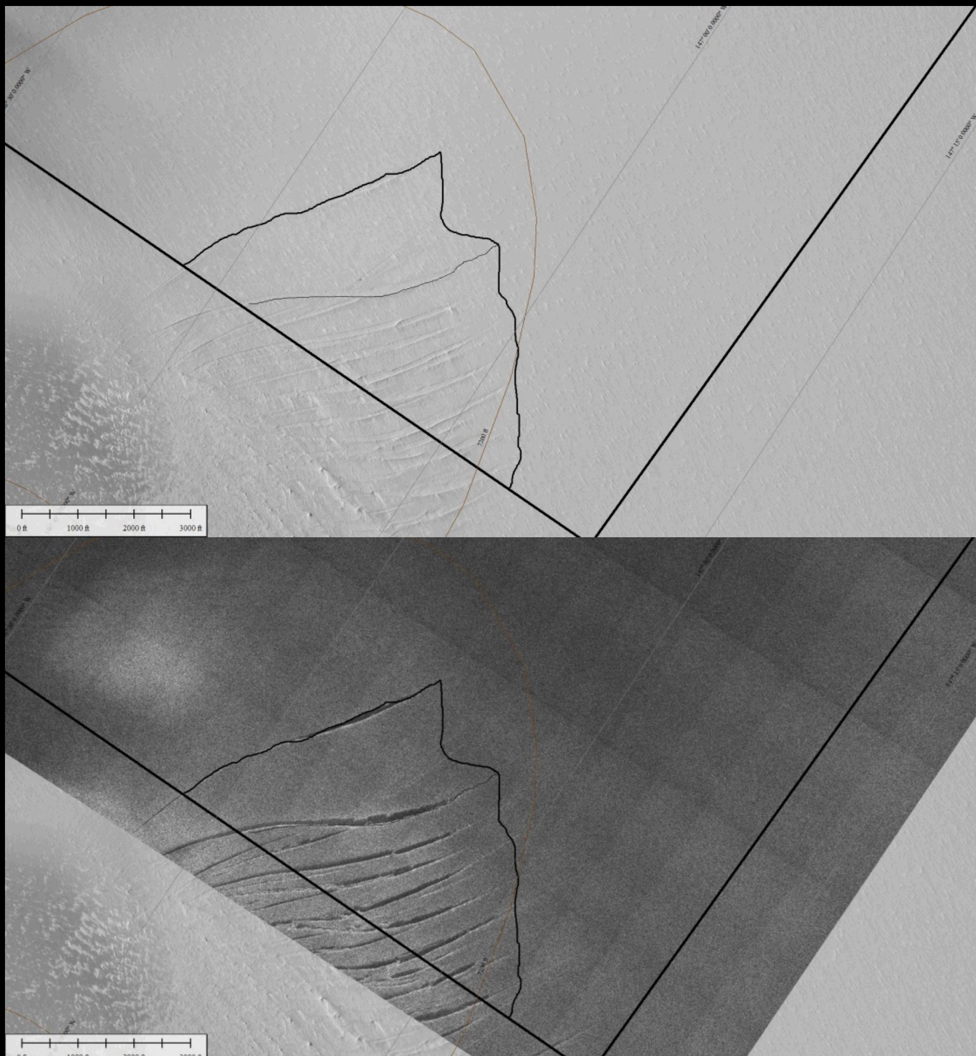


Tracking the Ice Flows Antarctica

- Overlay of two CDR mosaics at the shear zone, one from Jan 2011 and one from Nov 2011. The same point was located in both mosaics and the latitude and longitude was recorded from the SAR.
- The distance between the lat / long of the two points is 1049.6 feet, using spherical Earth approximations. This is an very large shift in the ice over an 11 month period. But the data is accurate.
  - Historical calibration data from the CDR development flights in Albuquerque shows that the CDR system has the following range and location errors:
    - range location error between -0.8 meters and 1.6 meters with an average of 0.875 meters.
    - azimuth location error between -0.1m and 0.3m with an average of 0m.
- This data is from a series of spotlight passes – but it is an example of the low error associated with the system and thus adds a bit of engineering data that the 1049.6 feet of drift is realistic.



Crevasse Detection
Proof of Capability, Antarctica

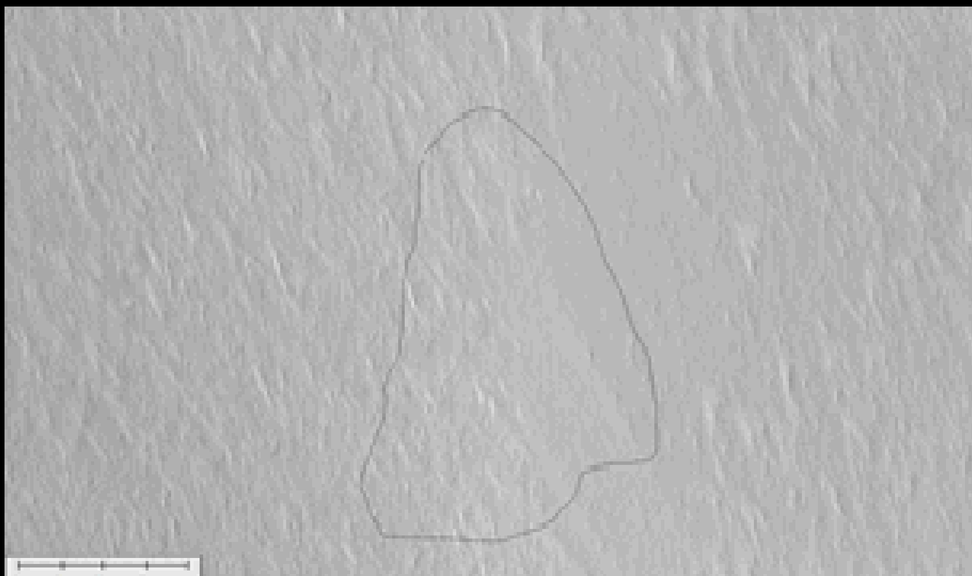


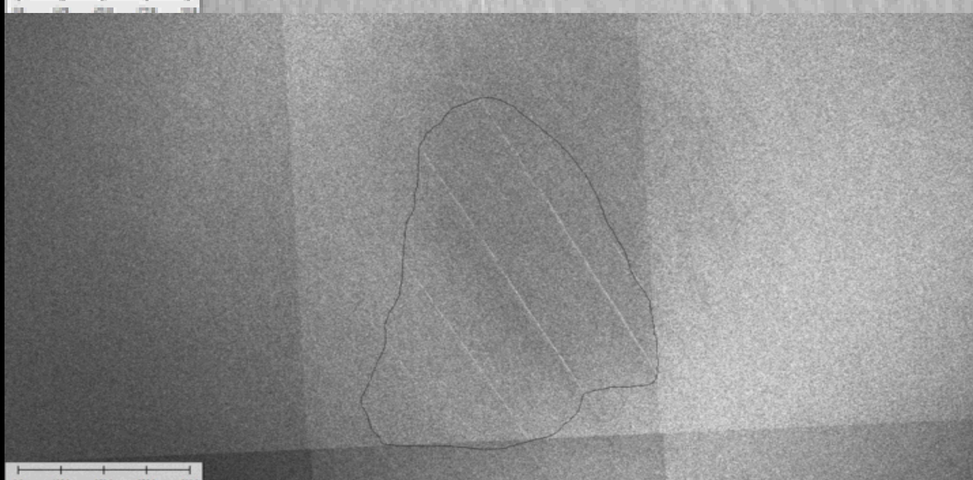
Data sets from the Nov 2011 deployment show that the CDR system detects all crevasses that are noticeable in the optical data.

Comparison of data sets at the Klein Glacier site in the Transantarctic Mountains.

*** Optical data provided by Major Josh Hicks, NYANG**

Crevasse Detection
Proof of Capability, Antarctica





- In addition many crevasses detected by the CDR system are not in the optical data.

- Comparison of the data sets at the Graves site in the Transantarctic Mountains. Three large crevasses are detected by the CDR system AND not in the optical data

* Optical data provided by Major Josh Hicks, NYANG

Conclusions

- SNL designed two variants of an X-Band Synthetic Aperture Radar to support crevasse detection in Antarctica.
- Four deployments and data collections in Antarctica have proven the capability in dry snow.
- One deployment to Greenland also generated interesting data that will aid in future uses of the X-Band capability in both the Arctic and Antarctic regions.

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