Airborne Remote Sensing in Greenland

Icebridge Gravity and Icepod

New Tools For Ice Ocean Interactions

TEAM GRAVITY : Robin Bell, Kirsty Tinto, Jim Cochran, Dave Porter, Alex Boghosian
TEAM ICEPOD: Robin Bell, Nick Frearson, Kirsty Tinto, Chris Zappa

Lamont Doherty Earth Observatory
Columbia University

IcePod

Recovery Act Funding

Goal Instruments, Data and Platform for Community Us
through Piggyback Missions and Dedicated Flights

April 2013 Kanger

A Troop Door

An Arm

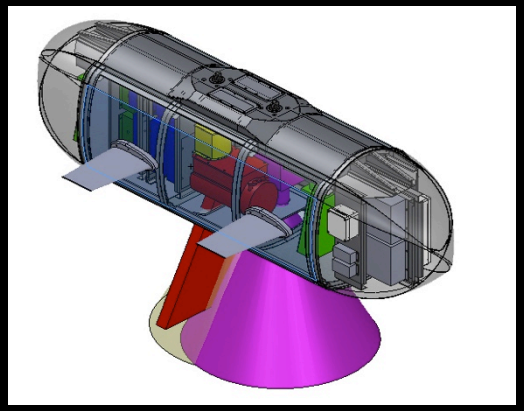
A Data Acquisition Rack

A Sensor Pod

A Skilled Team Including the Guard

IcePod Instrumentation

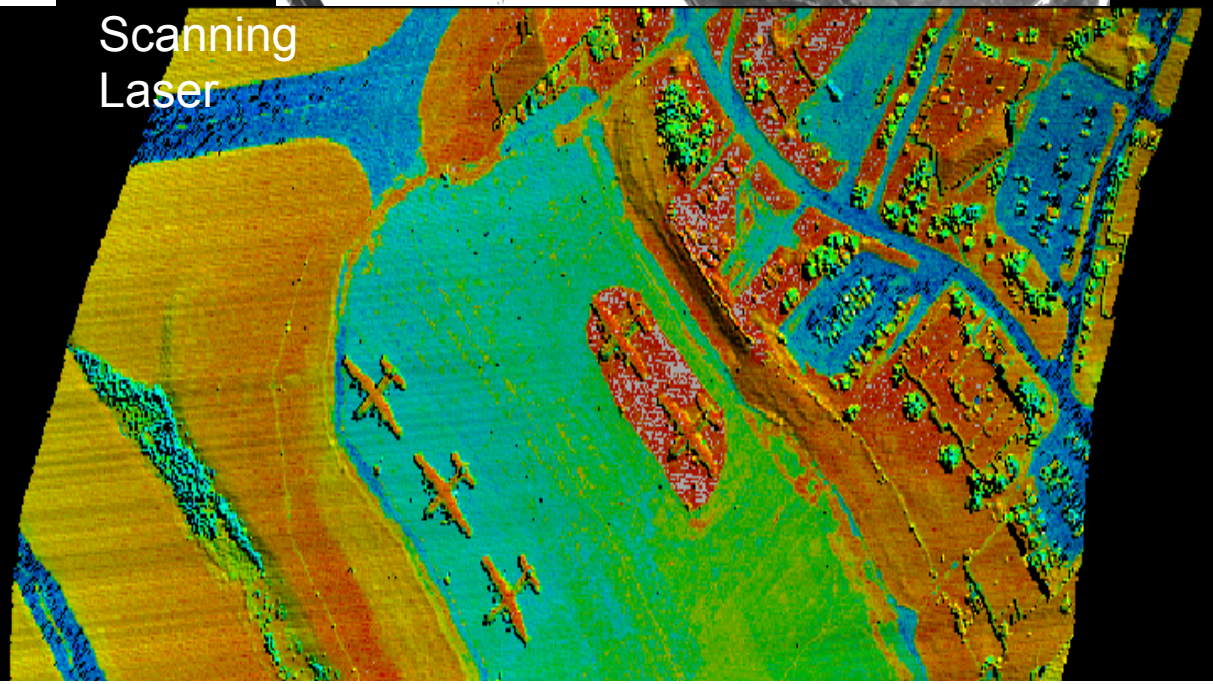
- Optical Instruments
  - IR Camera
  - Pyrometer
  - High Res Vis Wave Camera
  - Scanning Laser
- Radar
  - Deep Ice
  - Shallow Ice [100m]
- Georeference
  - GPS
  - IMU



Visible wave

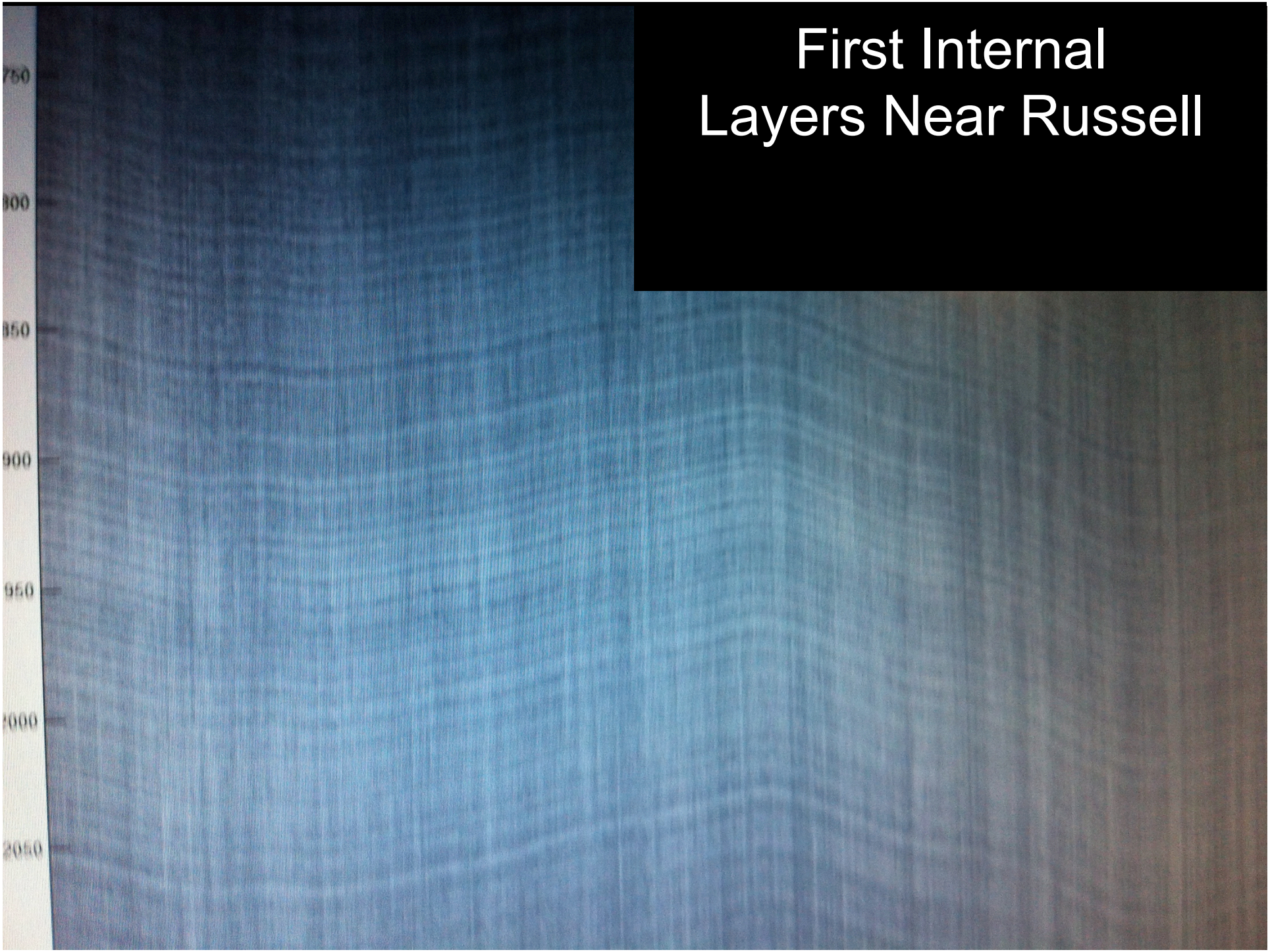
Infra-Red

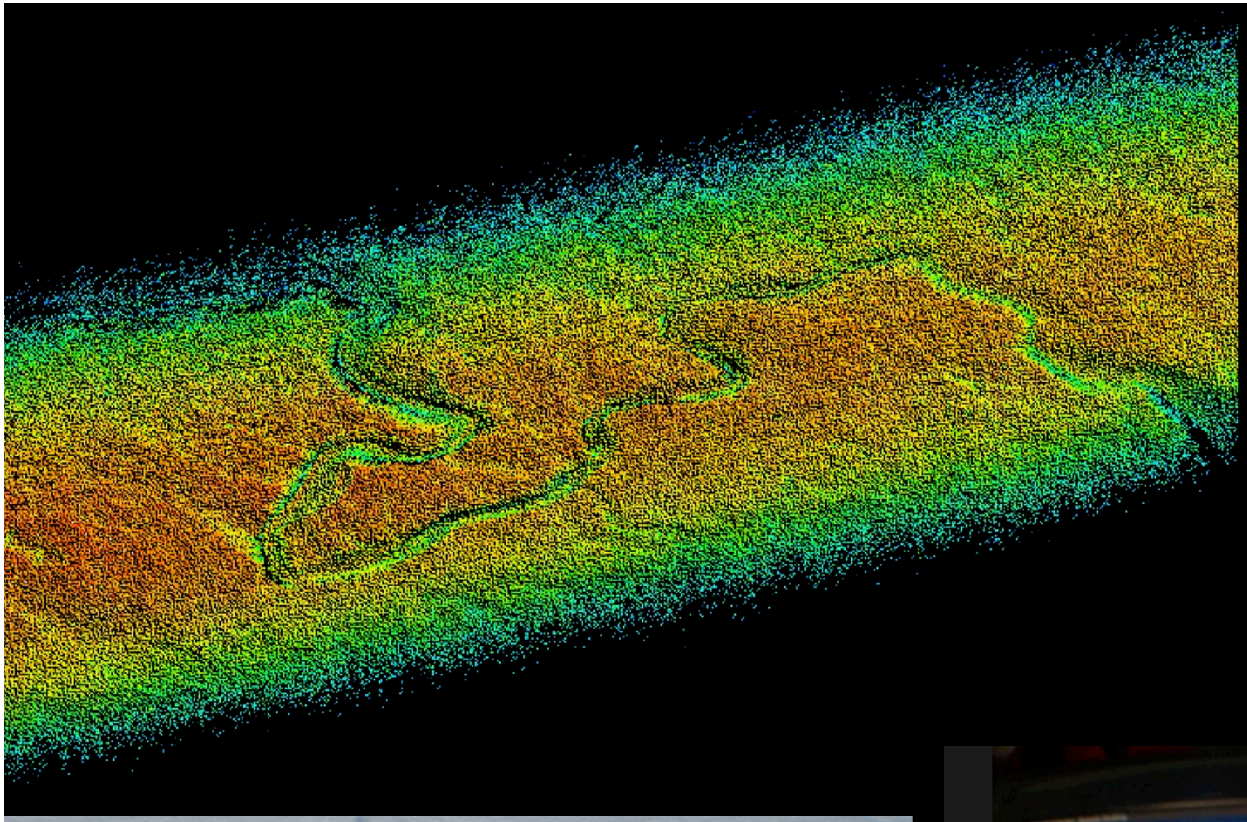
Scanning
Laser



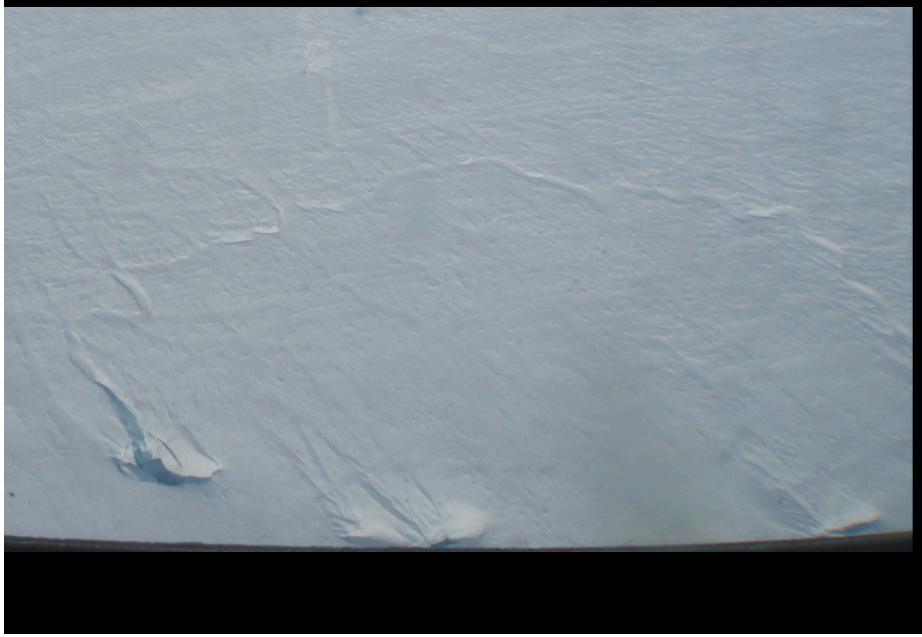
Lab Installation to Flight Ready in 2 days

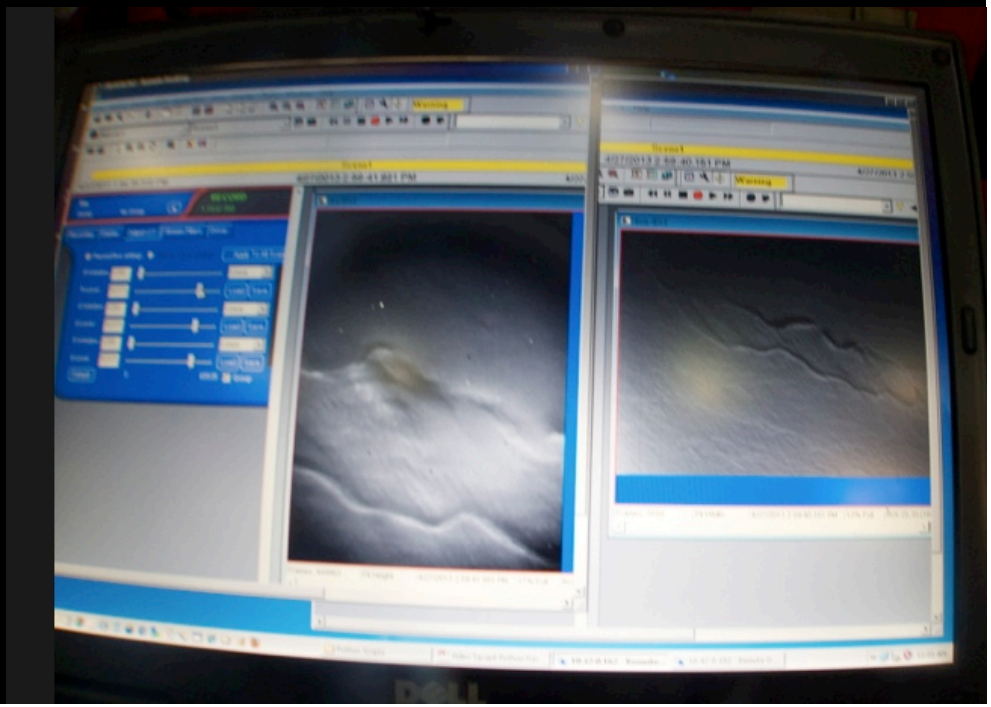
1. Disassemble and pack system: ~3h
2. Unpack and install system: ~4h
3. Test System: ~2h

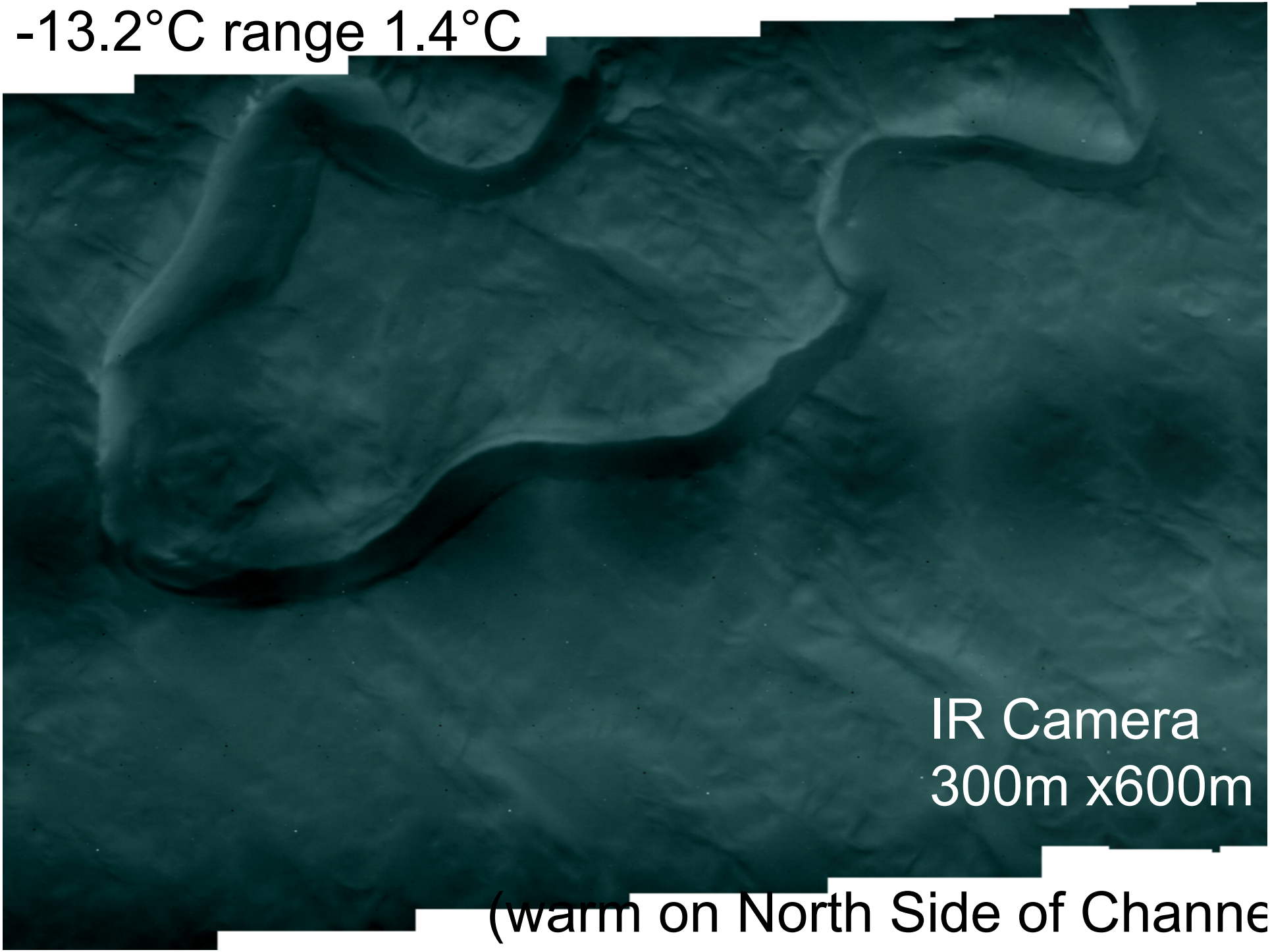

First Internal
Layers Near Russell

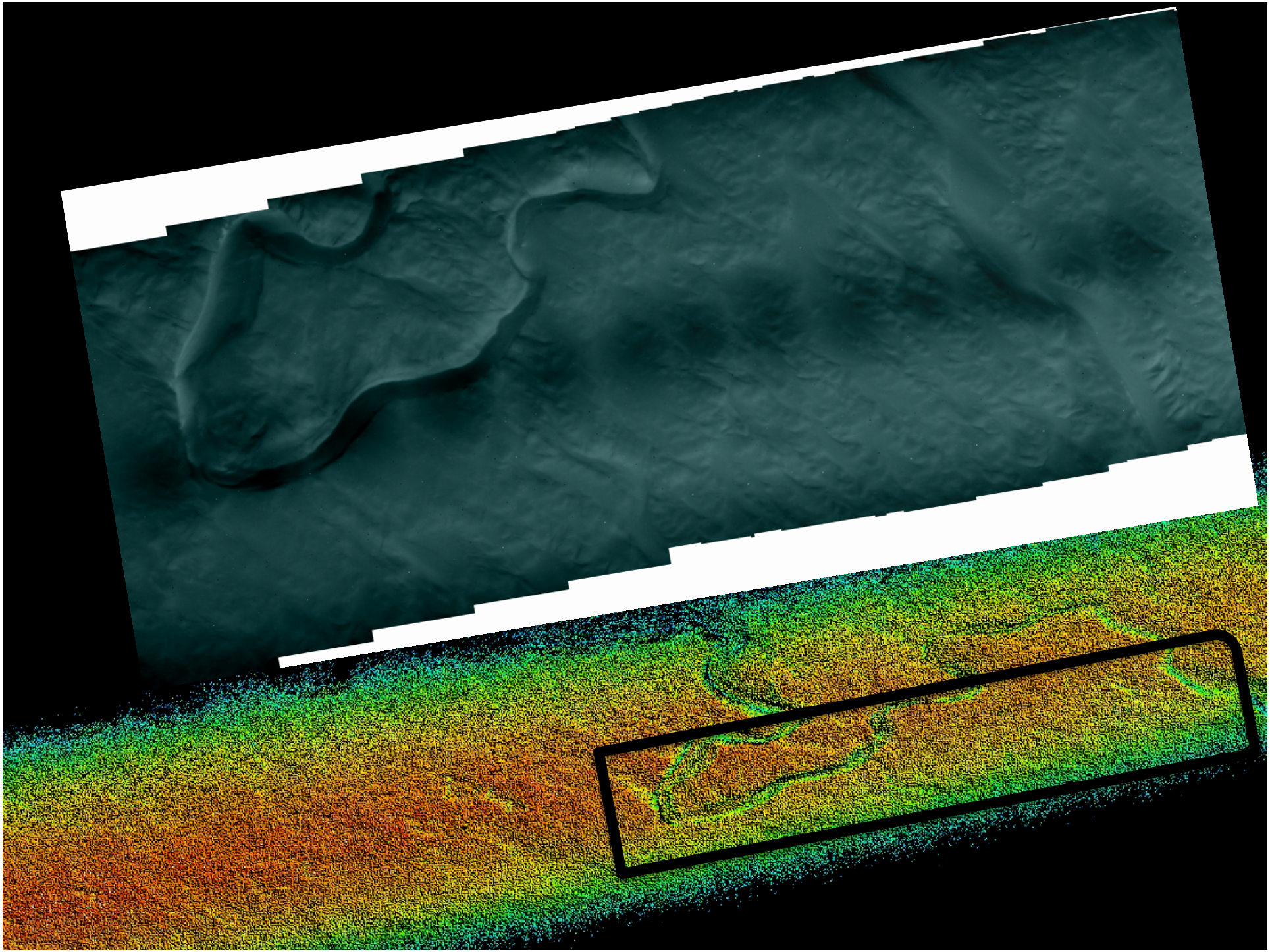


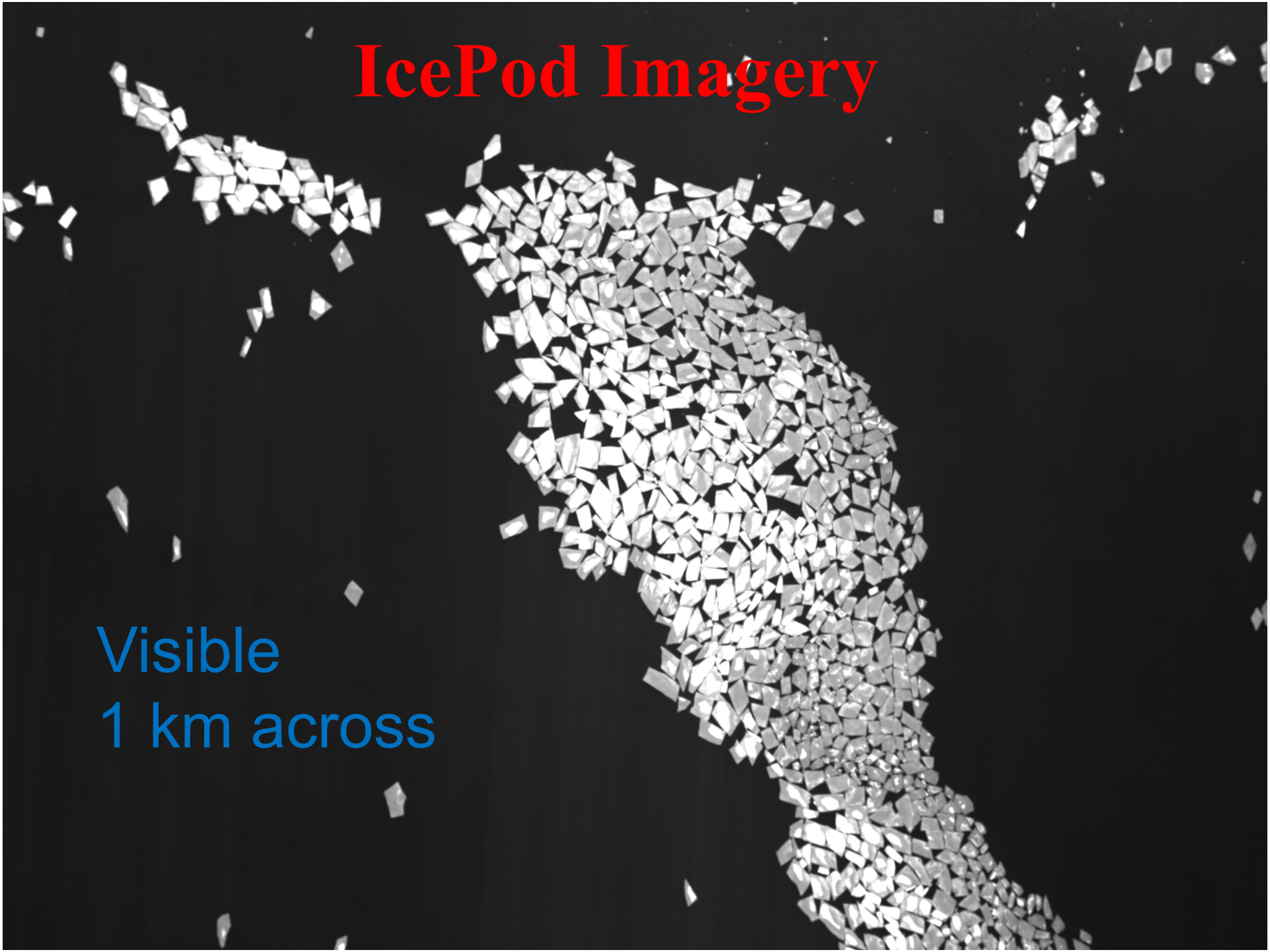
Melt Channel On the Fly



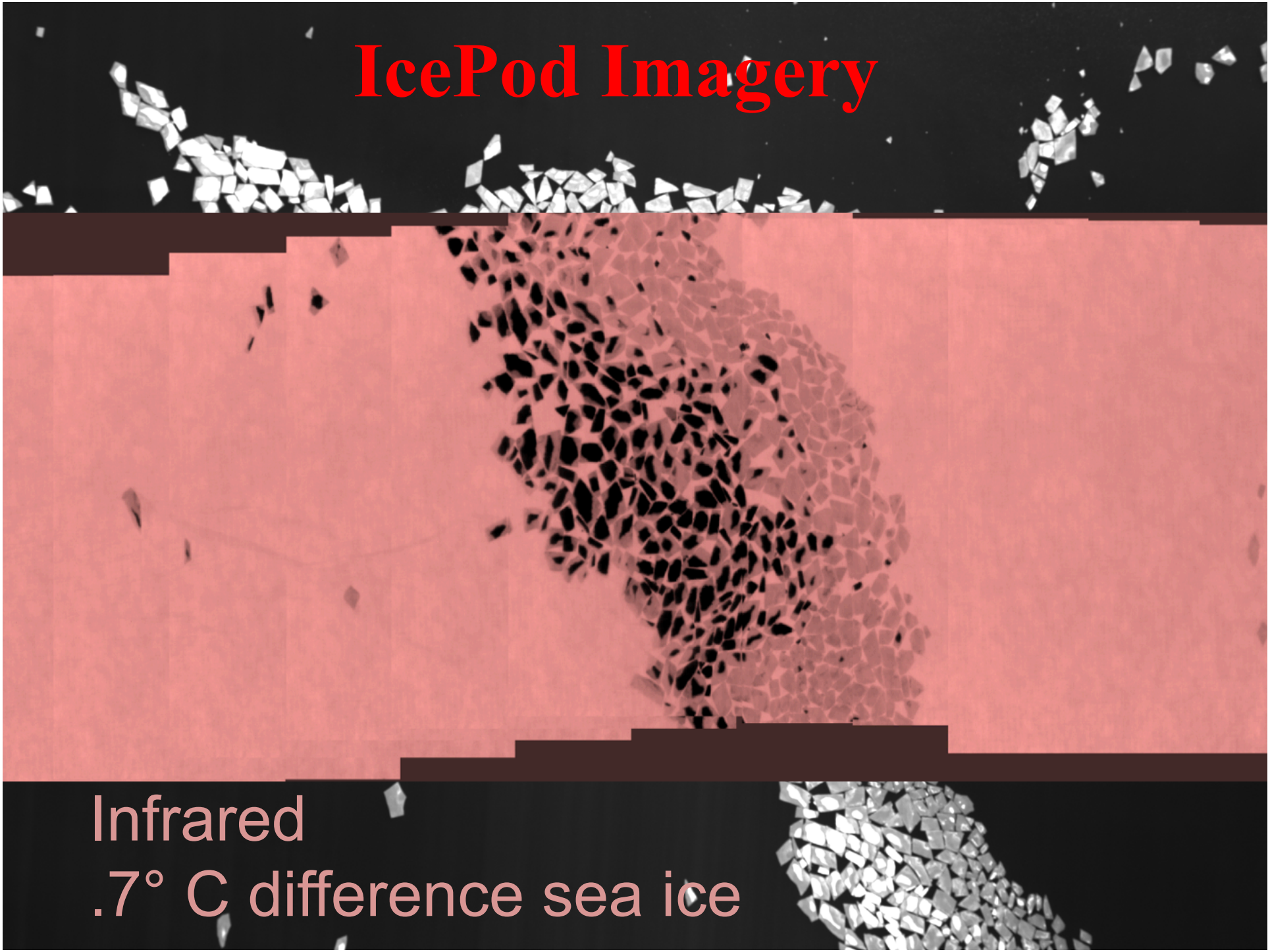


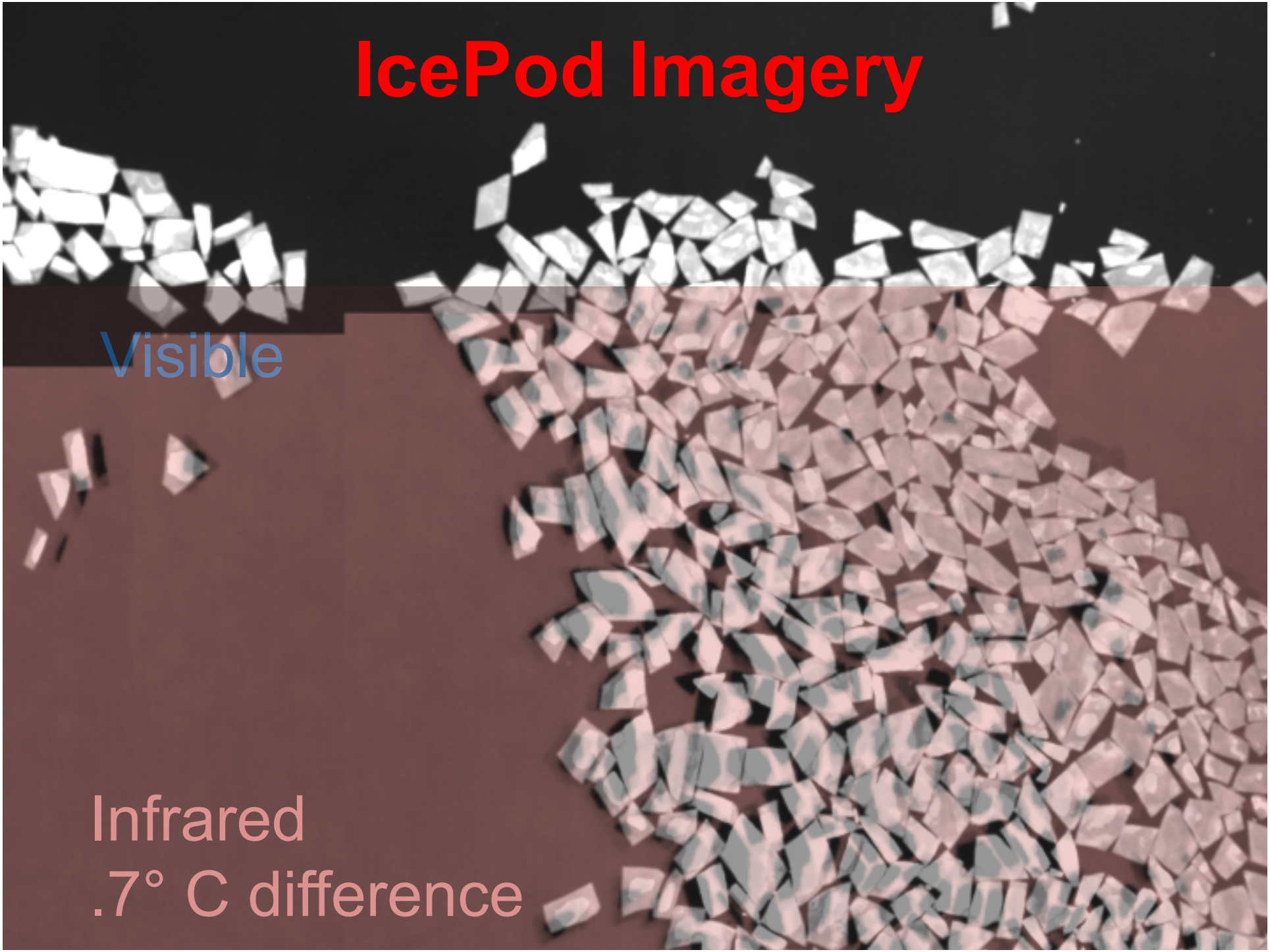

-13.2°C range 1.4°C
IR Camera
300m x600m
(warm on North Side of Channe




IcePod Imagery
Visible
1 km across

IcePod Imagery




IcePod Imagery
Visible
Infrared
.7° C difference

Capturing
The Seasonal Melt Cycle

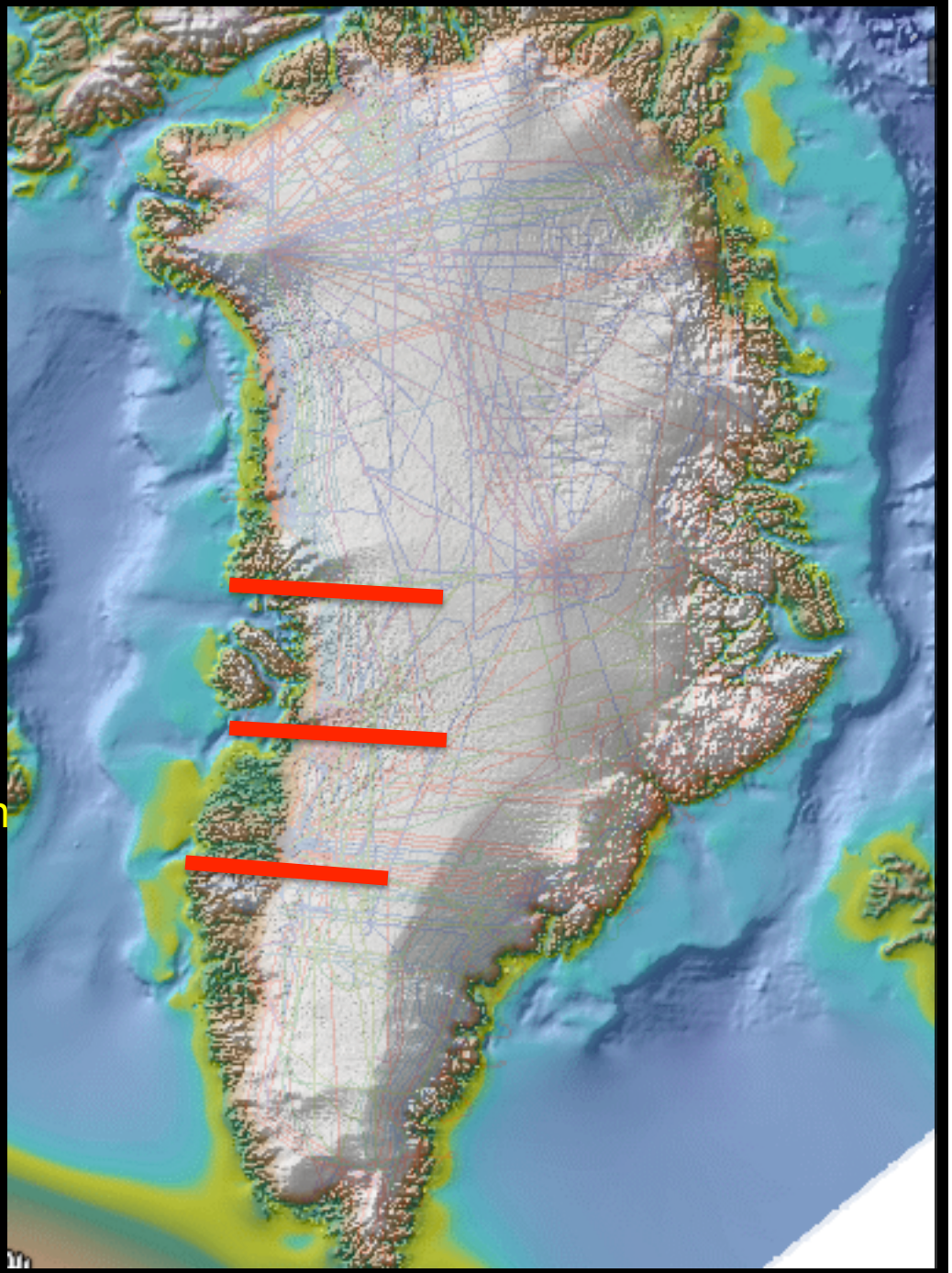
Piggyback Missions on NYANG Missions

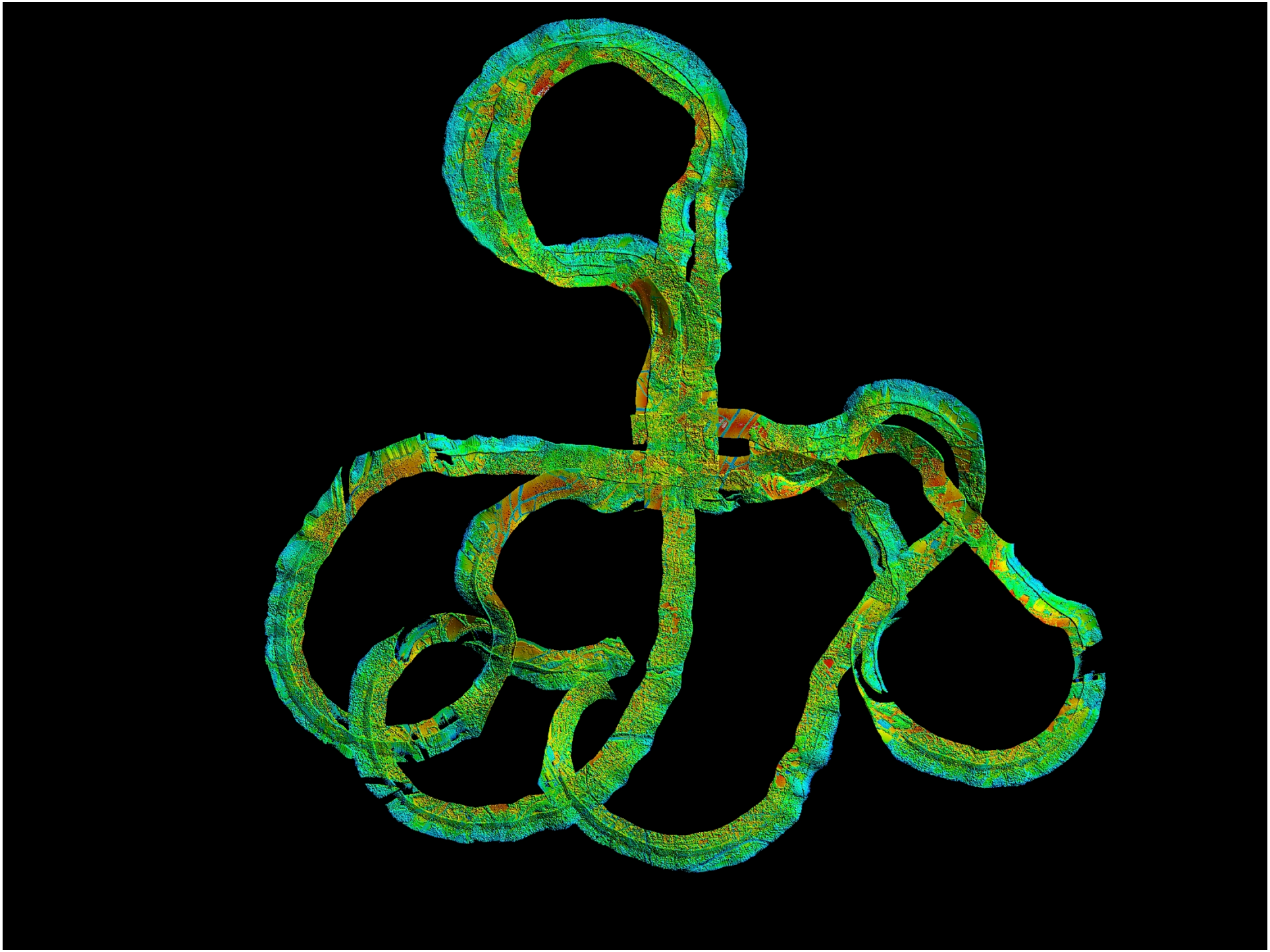
April-August

Benchmark Lines

- Summit to the Coast (Rink??)
- Jakobshavn
- Russell Glacier – Return from Raven

Ice Surface Elevation
Surface Temperature
Surface Imagery
Shallow & Deep Radar
Plume Structure
Flow in Fjords





Airborne Remote Sensing in Greenland

Gravity and Icepod

New Tools For Ice Ocean Interactions

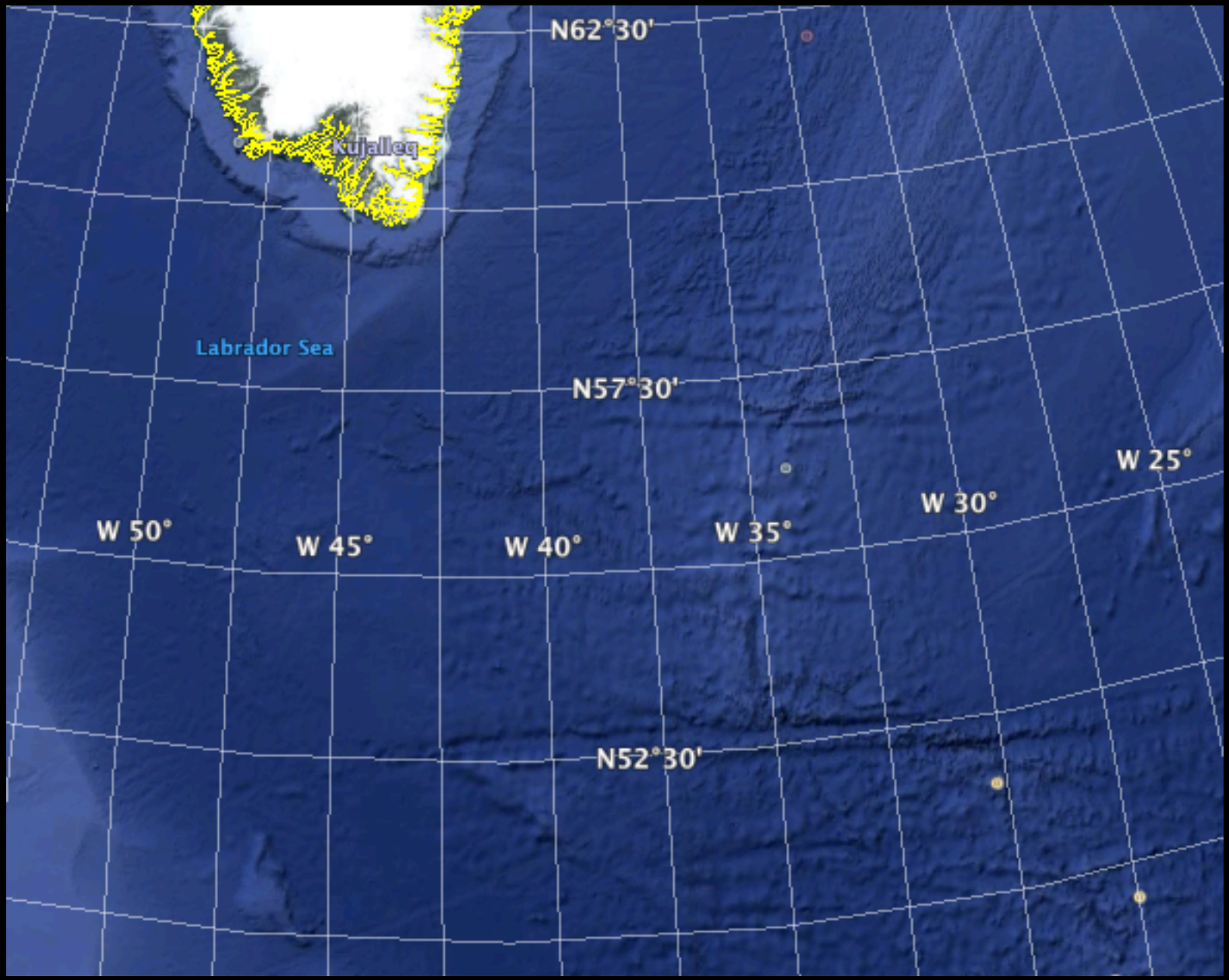
TEAM GRAVITY : Robin Bell, Kirsty Tinto, Jim Cochran, Dave Porter, Alex Boghosian
TEAM ICEPOD: Robin Bell, Nick Frearson, Kirsty Tinto, Chris Zappa

Lamont Doherty Earth Observatory

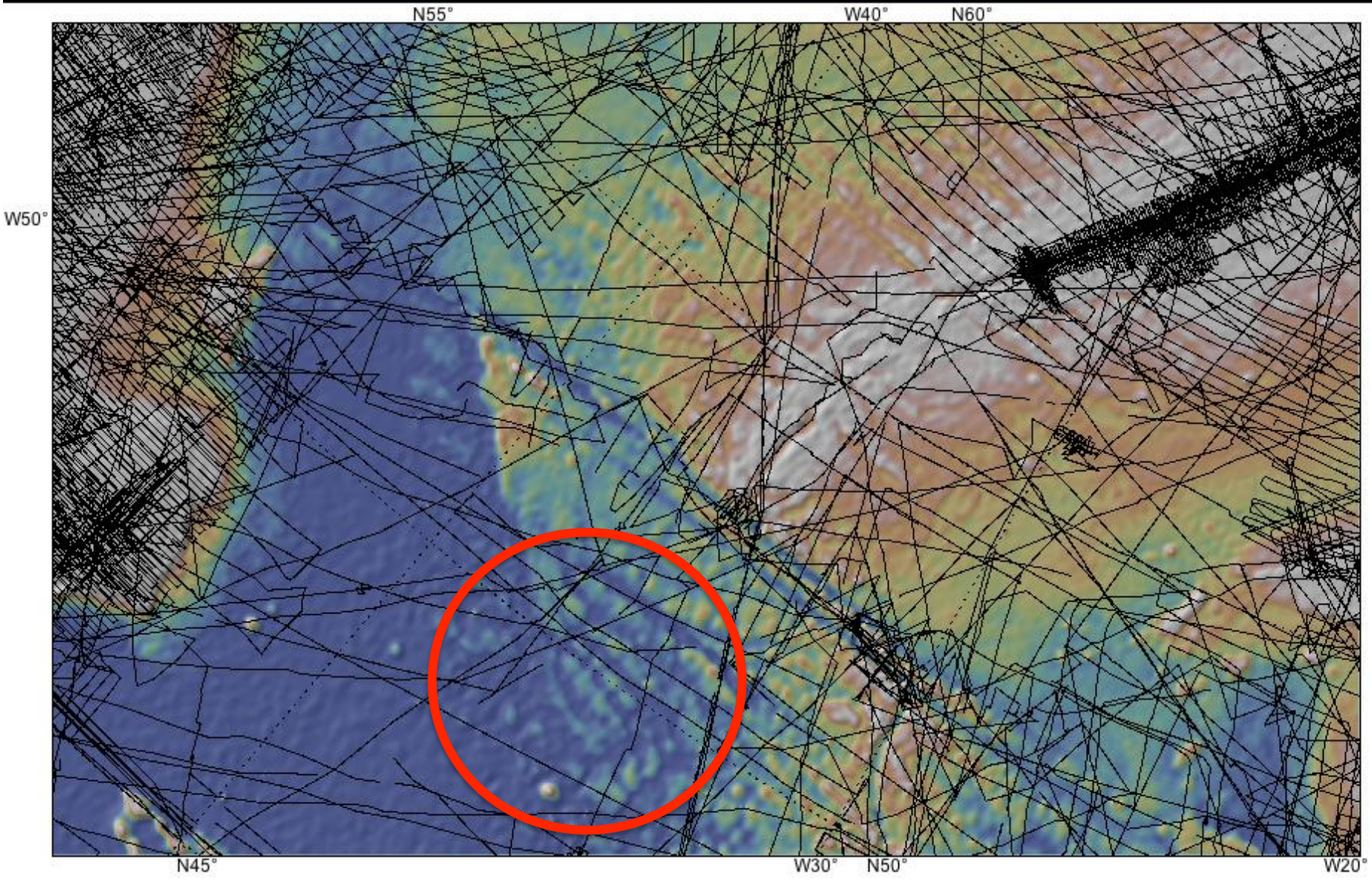
Gravity
Different Problems Different Approaches

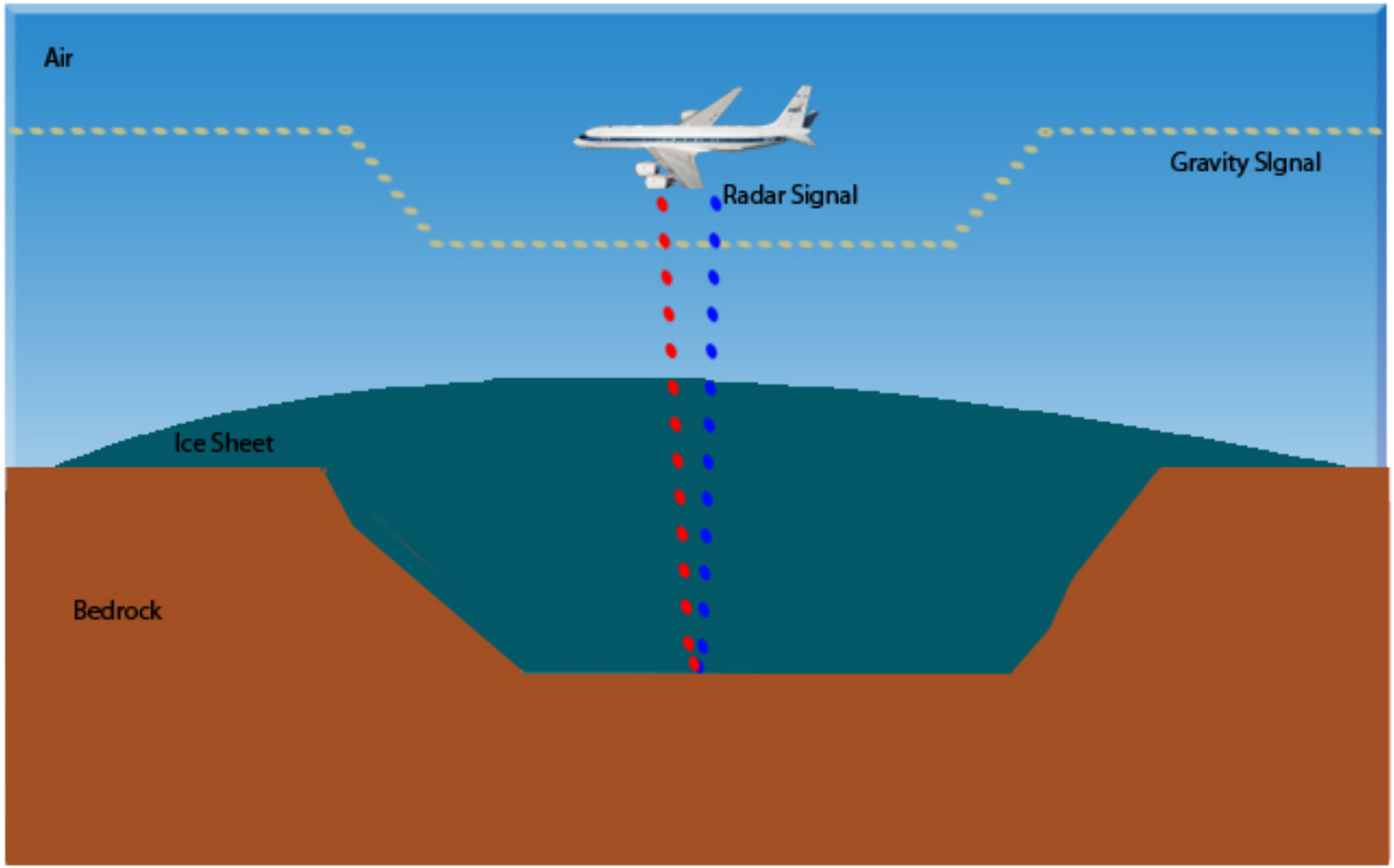
- Morphology Beneath Ice Shelves
- Constraining Sills
- Estimating Basal Conditions
- Fjord Geometry

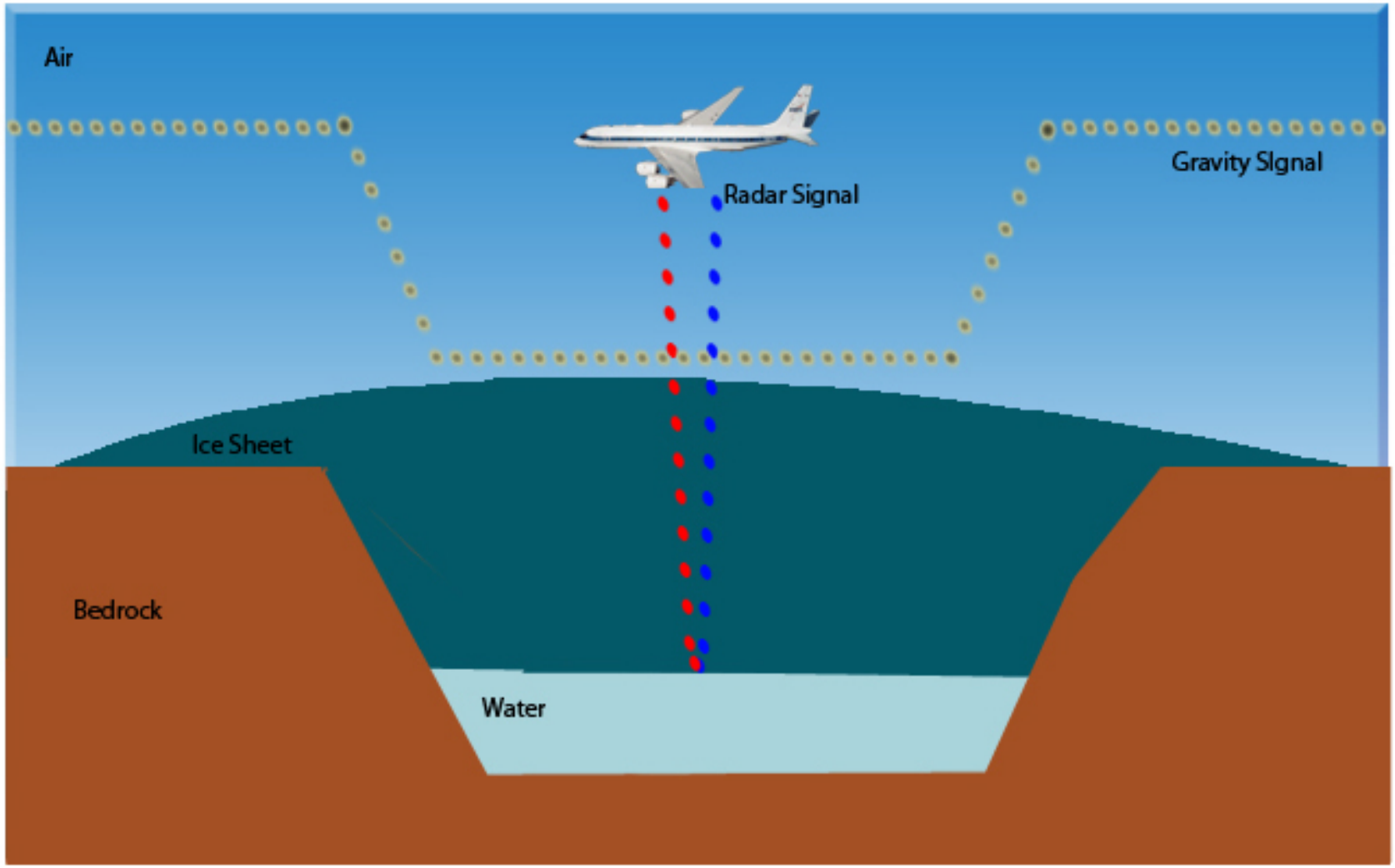
- Also OIB Magnetics constrain" geologic noise"


N62°30'
Kujalleq
Labrador Sea
N57°30'
W 25°
W 30°
W 50°
W 45°
W 40°
W 35°
N52°30'

Smith and Sandwell




Air
Gravity Signal
Radar Signal
Ice Sheet
Bedrock


Air
Gravity SIgnal
Radar Signal
Ice Sheet
Bedrock
Water

Sander Geophysics AIRGrav

- Three orthogonal accelerometers
- Three-axis gyro-stabilized, Schuler-tuned table
- Differential GPS to remove airplane acceleration
- Specifically designed for airborne surveys
  - Capable of collecting data on draped flights

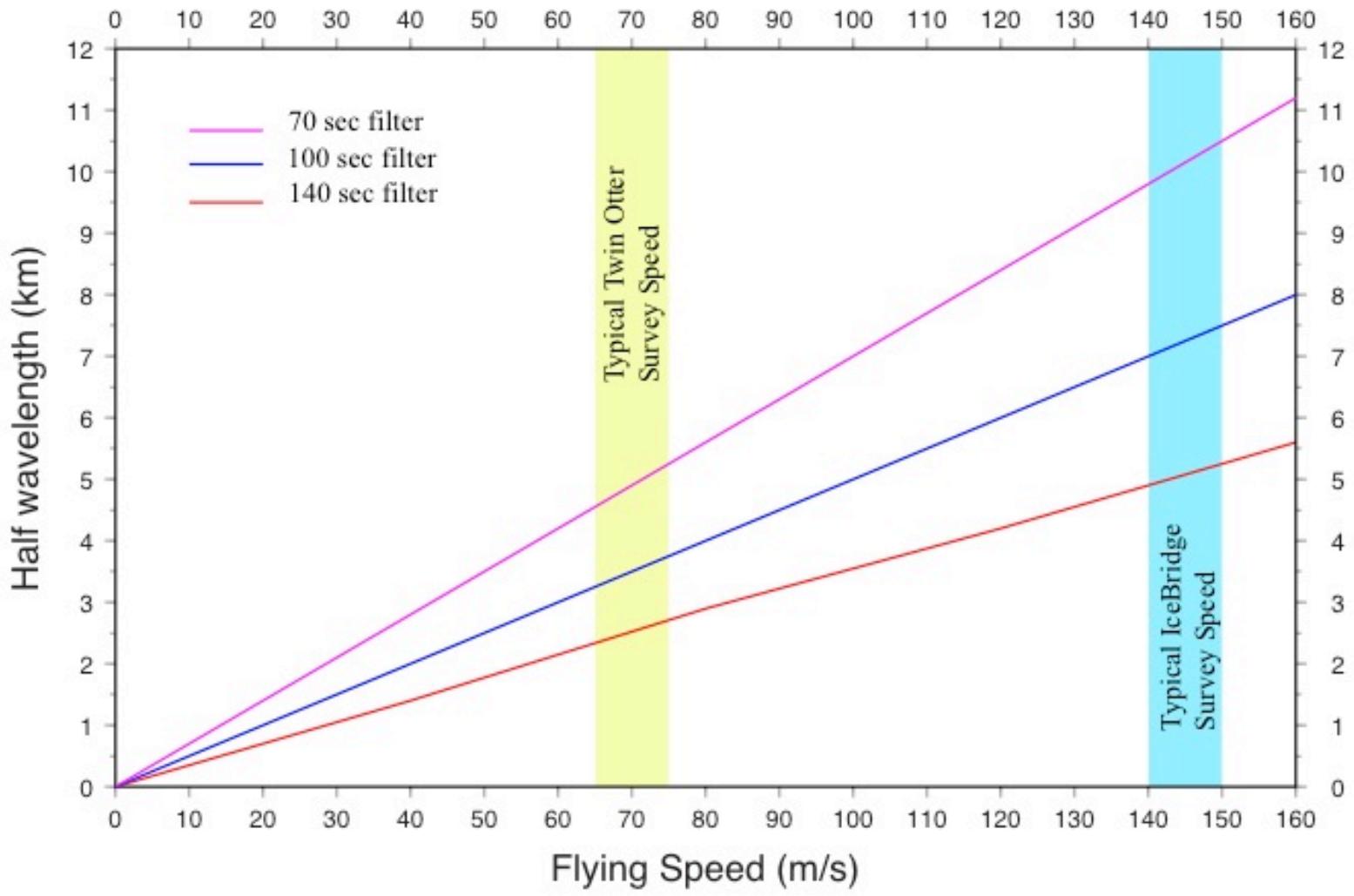
Factors Affecting Gravity Data

- Resolution Issues
  - Aircraft Speed
    - Filtering is in time, not in space
  - Elevation
    - $1/r^2$ is real
    - Short wavelengths attenuate faster, so lose resolution
- Aircraft Maneuvers
  - Elevation Changes
    - AIRGrav system designed to deal with draped lines
  - Turns
    - introduce accelerations that appear in gravity values
  - Turbulence

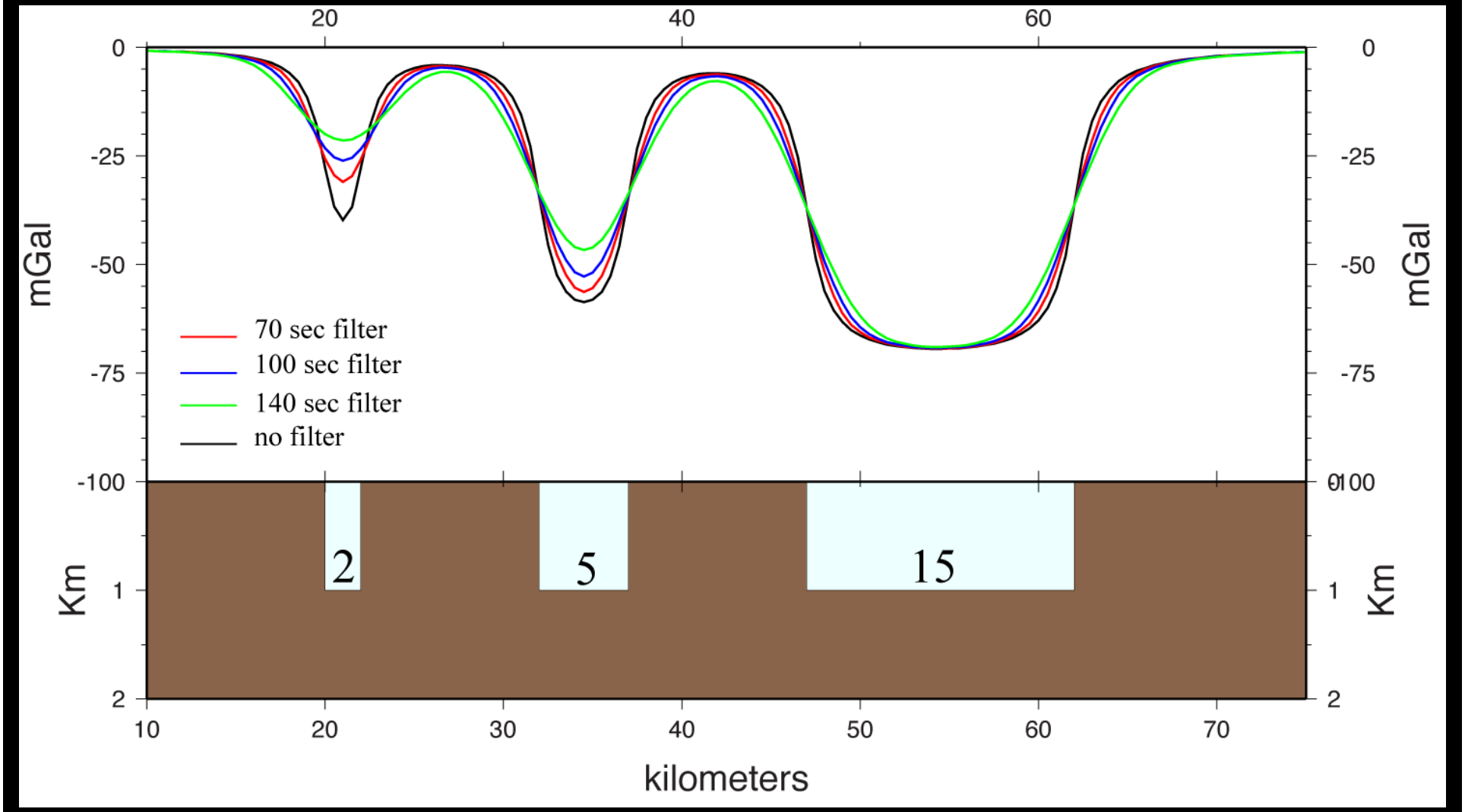
Factors Affecting Gravity Data

- Resolution Issues
  - Aircraft Speed
    - Filtering is in time, not in space
  - Elevation
    - $1/r^2$ is real
    - Short wavelengths attenuate faster, so lose resolution
- Aircraft Maneuvers
  - Elevation Changes
    - AIRGrav system designed to deal with draped lines
  - Turns
    - introduce accelerations that appear in gravity values
  - Turbulence

Filter Length as a Function of Aircraft Speed



Effect of Filters on Measured Gravity Anomalies



Factors Affecting Gravity Data

- Resolution Issues
  - Aircraft Speed
    - Filtering is in time, not in space
  - Elevation
    - $1/r^2$ is real
    - Short wavelengths attenuate faster, so lose resolution
- Aircraft Maneuvers
  - Elevation Changes
    - AIRGrav system designed to deal with draped lines
  - Turns
    - introduce accelerations that appear in gravity values
  - Turbulence

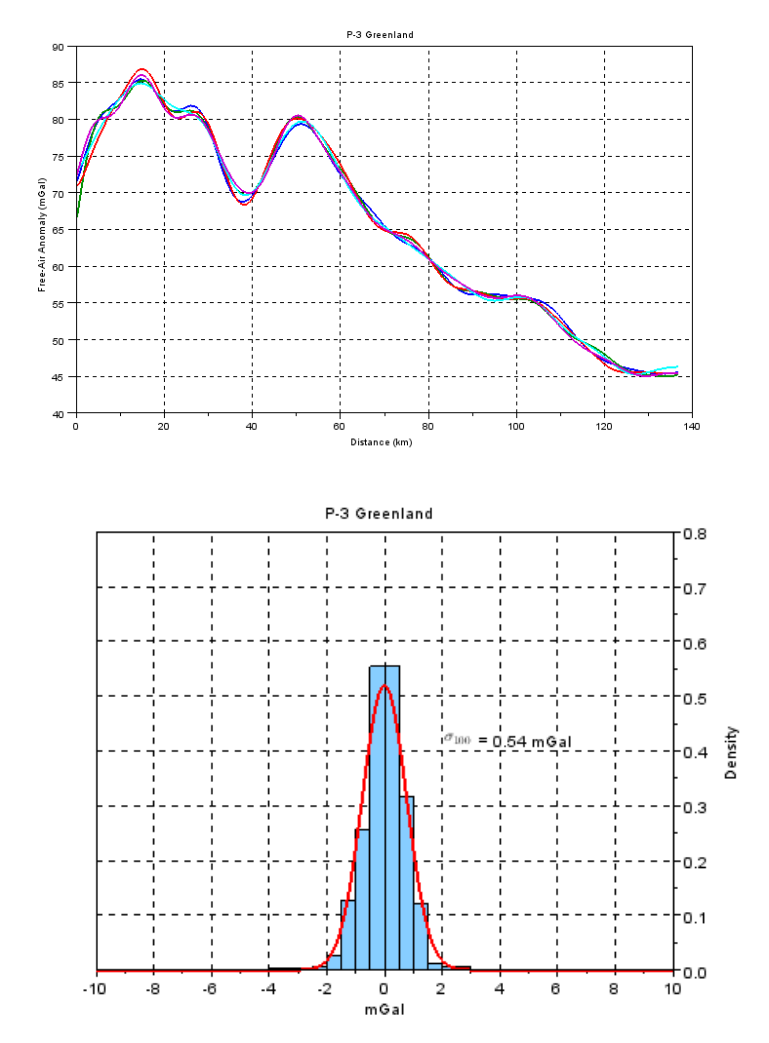
Airborne Gravity Accuracy Assessment Methods

- Intersection (Crossover) Analysis
  - Identify flight path intersections
  - Establish an elevation difference criteria
  - Method is subject to directional filtering
- Repeat Line Analysis
  - Establish horizontal and vertical offset criteria
  - Identify repeat line segments that satisfy criteria for at least a specified time (10 minutes)

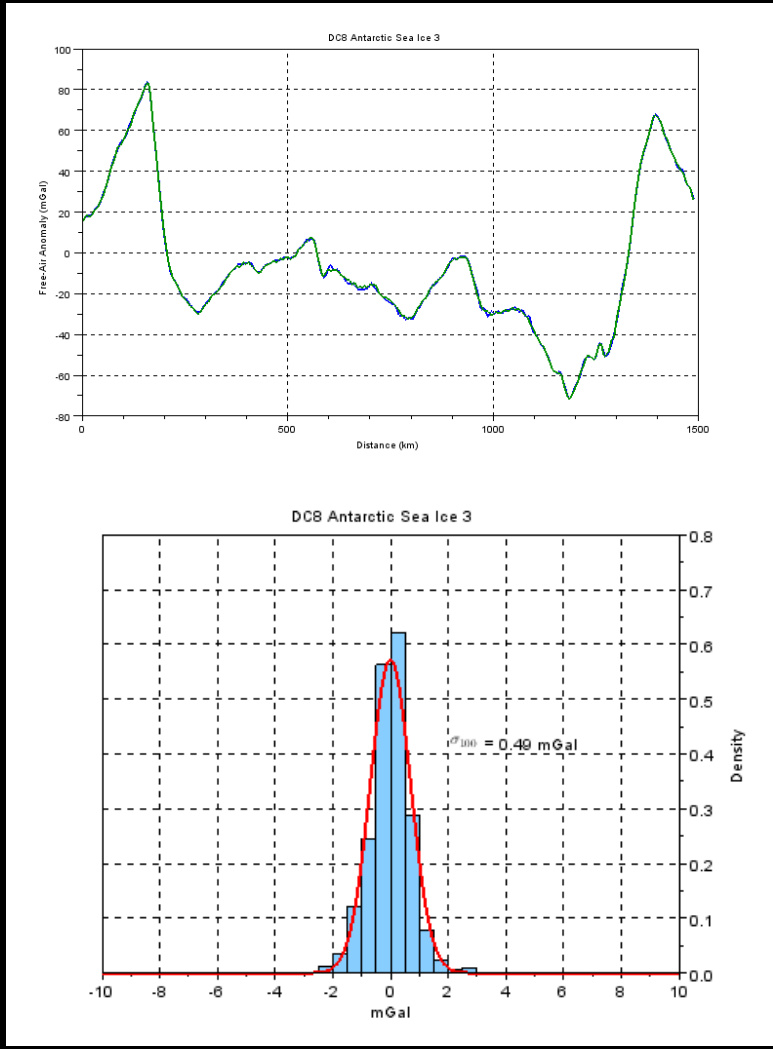
Airborne Gravity Accuracy Assessment Methods

- Intersection (Crossover) Analysis
  - Identify flight path intersections
  - Establish an elevation difference criteria
  - Method is subject to directional filtering
- Repeat Line Analysis
  - Establish horizontal and vertical offset criteria
  - Identify repeat line segments that satisfy criteria for at least a specified time (10 minutes)

Repeat Line Analysis



Thule – Camp Century (5 lines)
0.54 mGal (100 sec filter)



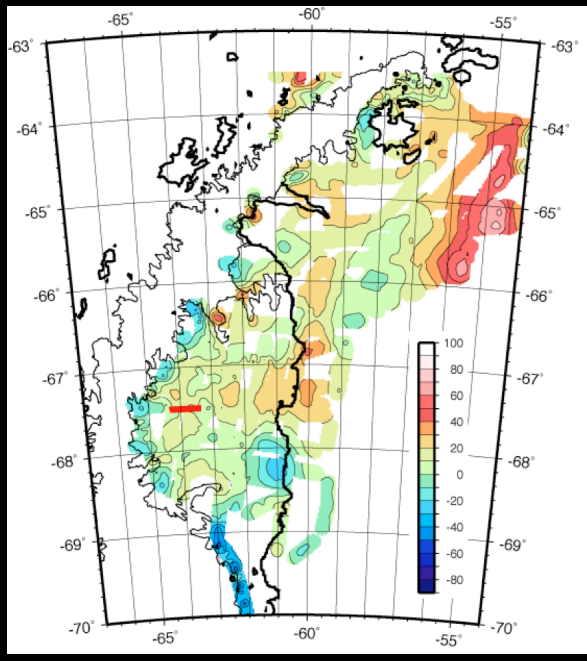
Antarctic Sea Ice
0.49 mGal (100 sec filter)

Airborne Gravity Accuracy Assessment Methods

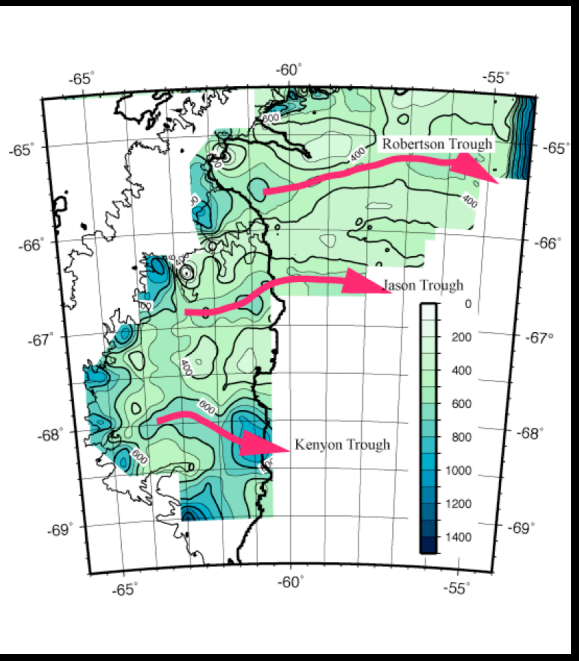
- Intersection (Crossover) Analysis
  - Identify flight path intersections
  - Establish an elevation difference criteria
  -
- Repeat Line Analysis
  - Establish horizontal and vertical offset criteria
  - Identify repeat line segments that satisfy criteria for at least a specified time (10 minutes)

Uncertainties in Derived Products
Formal Inversions - Larsen Ice Shelf

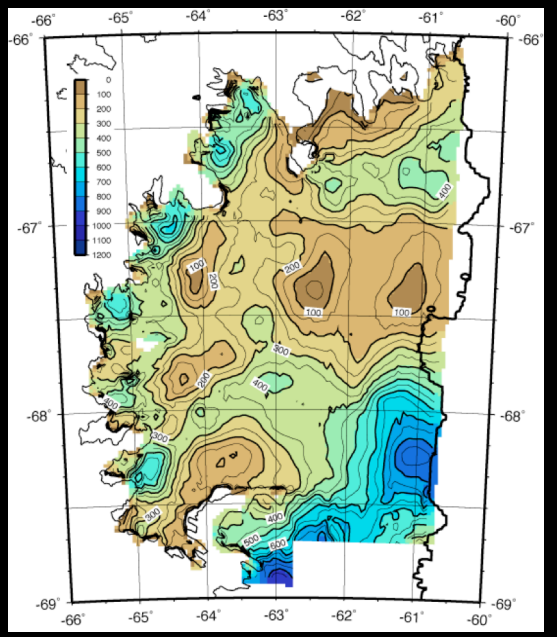
Free-air gravity anomalies



Derived shelf Bathymetry



Water cavity thickness



Cochran and Bell JGR

Inversion free parameters are:

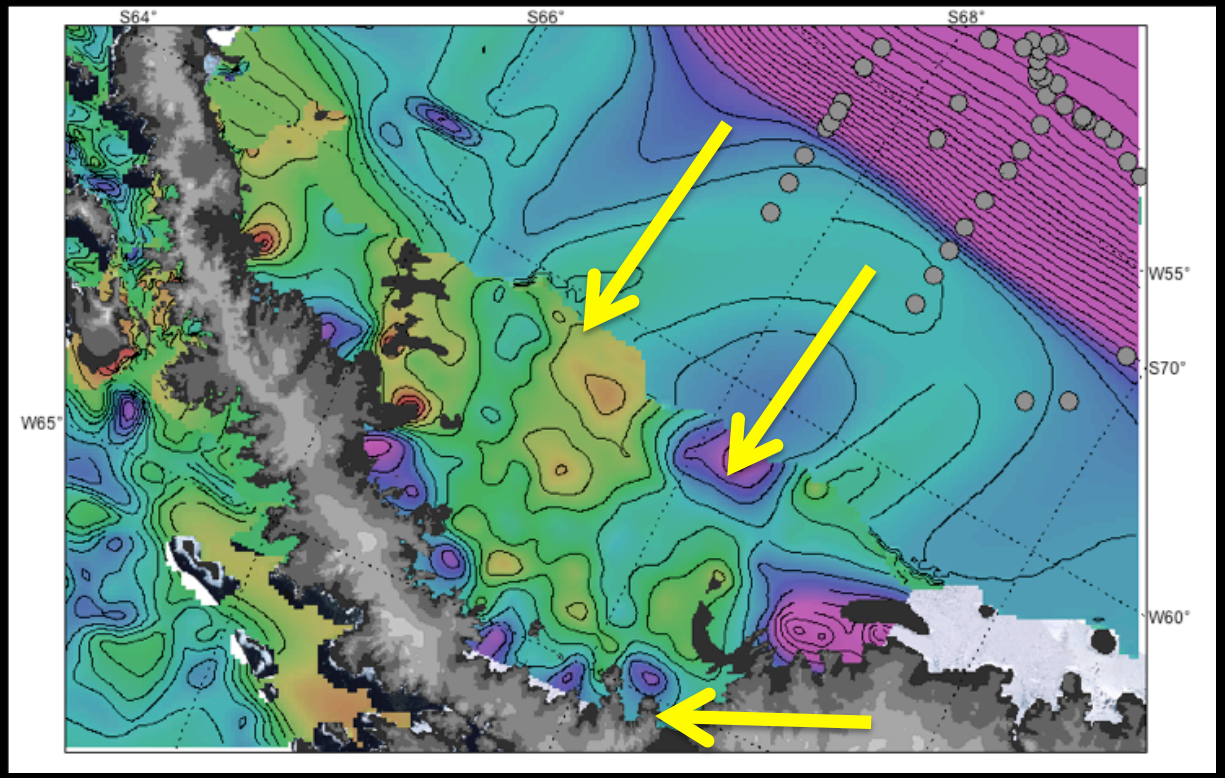
- Bed Density
- Average Depth

Larsen C
Cochran et al

Maximum change is ± 30-35 meters
(in deepest and shallowest regions)

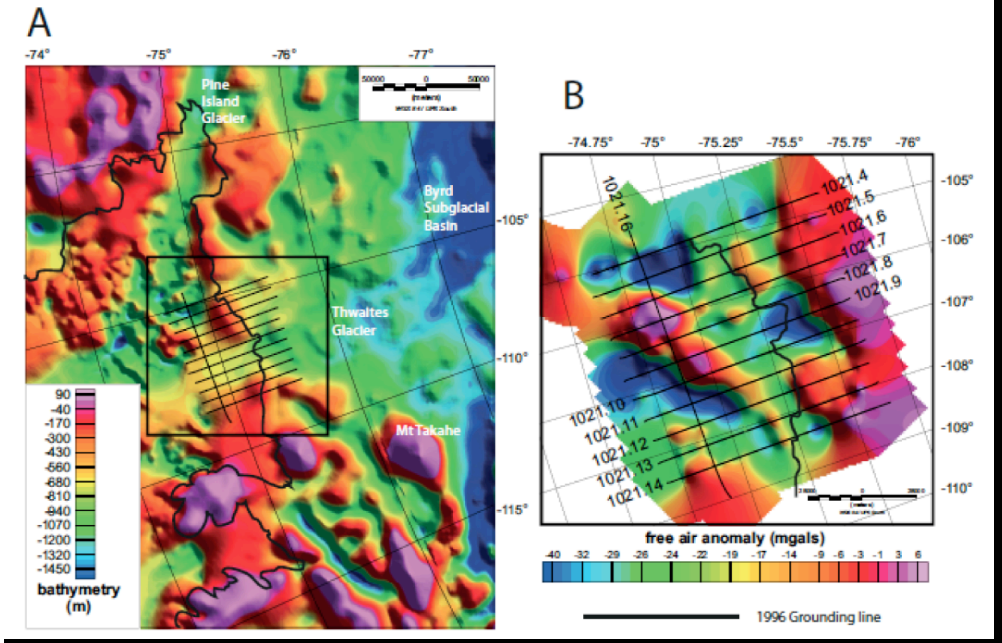
Change through most of region is
+15 to -15 meters

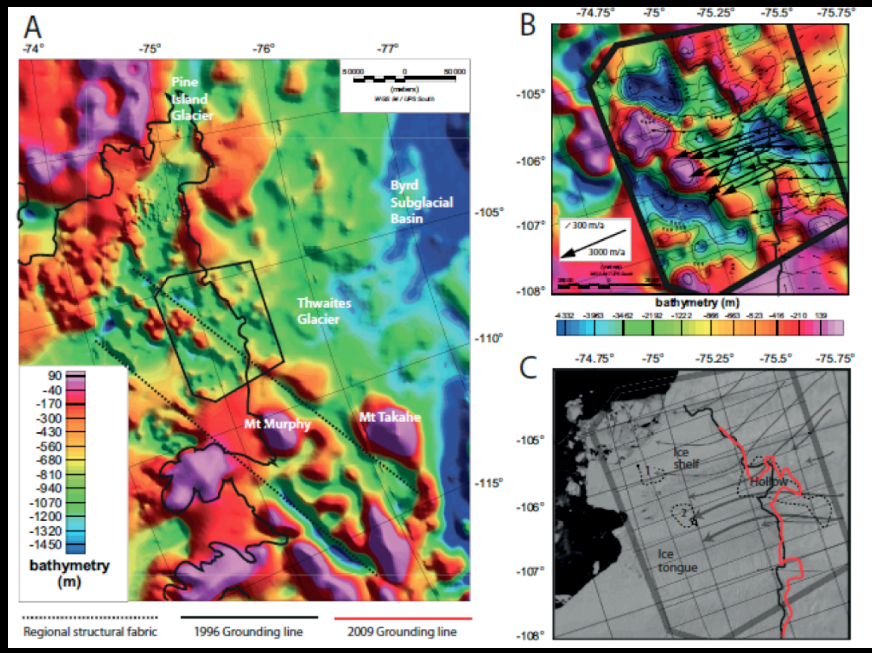
- Large Area – Coarse Grid Size
- Constraints Marine and Ice Shelf Geophysics



- BEDMAP
- ICEBRIDGE
- Overdeepenings
- Shelf Transverse Troughs

Uncertainties in Derived Products
Forward Modeling – Thwaites Glacier





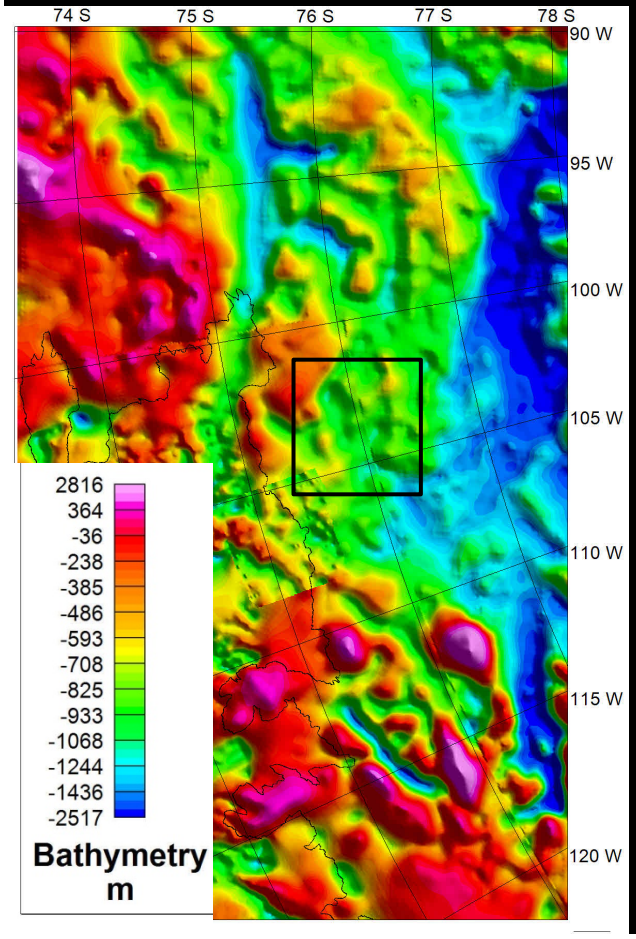
Line by line modeling of IceBridge gravity lines

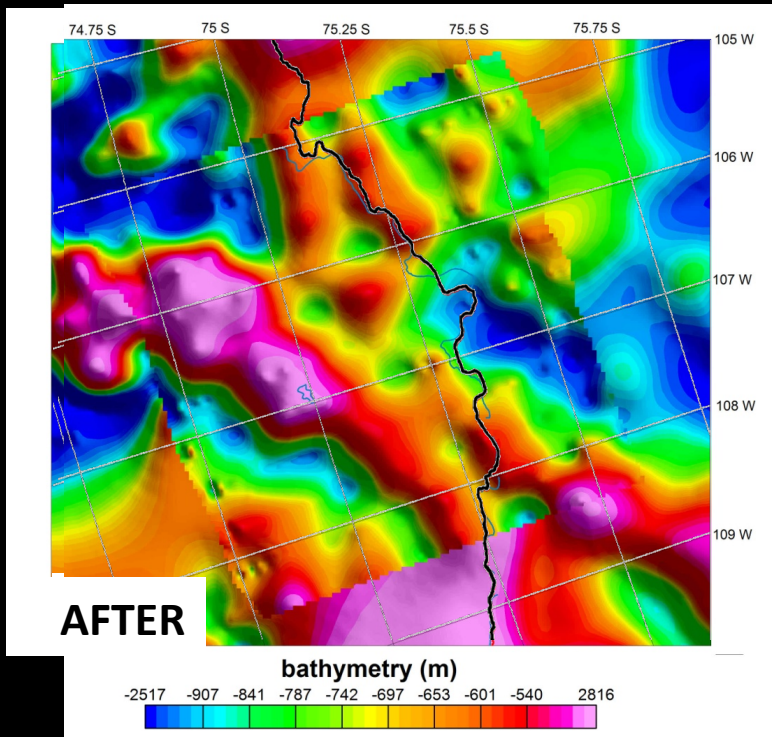
Constraints provided by:

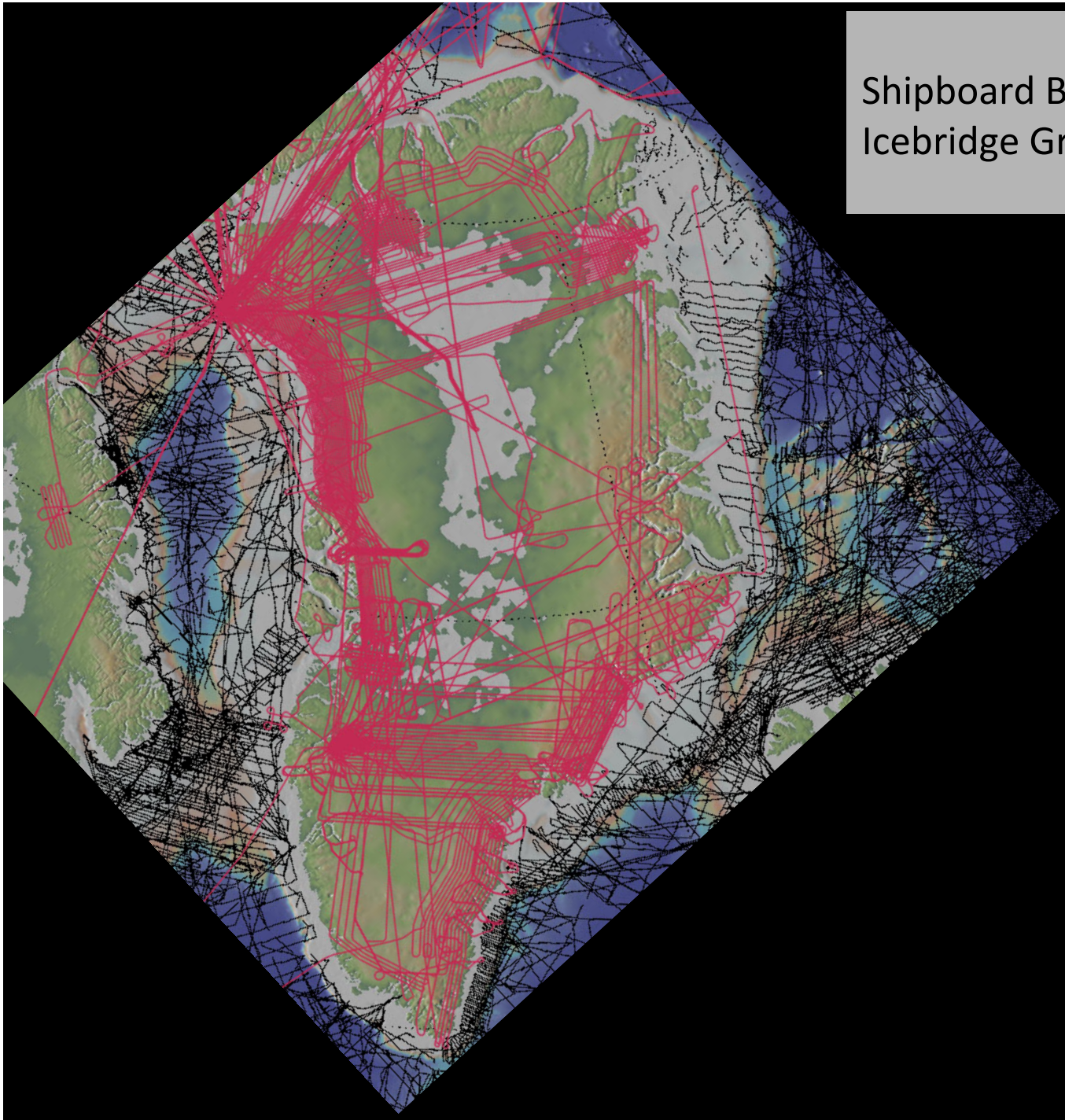
- ATM and MCoRDS data – define base of ice and bed where ice is grounded
- Marine bathymetry data – define water depths seaward of ice tongue
- Local rock outcrops – constrain rock density

Thwaites
Tinto et al

- Smaller Area (1/10 the size)
- Finer Line Spacing (10 km)







Shipboard Bathymetery – Black
Icebridge Gravity Coverage - Pink

Conclusions

- 1) Uncertainty in OIB gravity measurements, as determined from repeat flights, is about 0.5 mGal.
- 2) All airborne gravity measurements are subject to uncertainties arising from directional filtering
- 3) OIB gravity data can be used to determine bathymetry under floating ice to ± 50-200 meters

Conclusions

Gravity Capture Bathymetry in Ice Covered Waters

Understand Water Budget and Summer Melt High Resolution Seasonal Observations - ICEPOD

More Information:
http://www.ldeo.columbia.edu/res/pi/icepod/