# Geomorphologic Mapping by Airborne Laser Scanning in the Antarctic Dry Valleys

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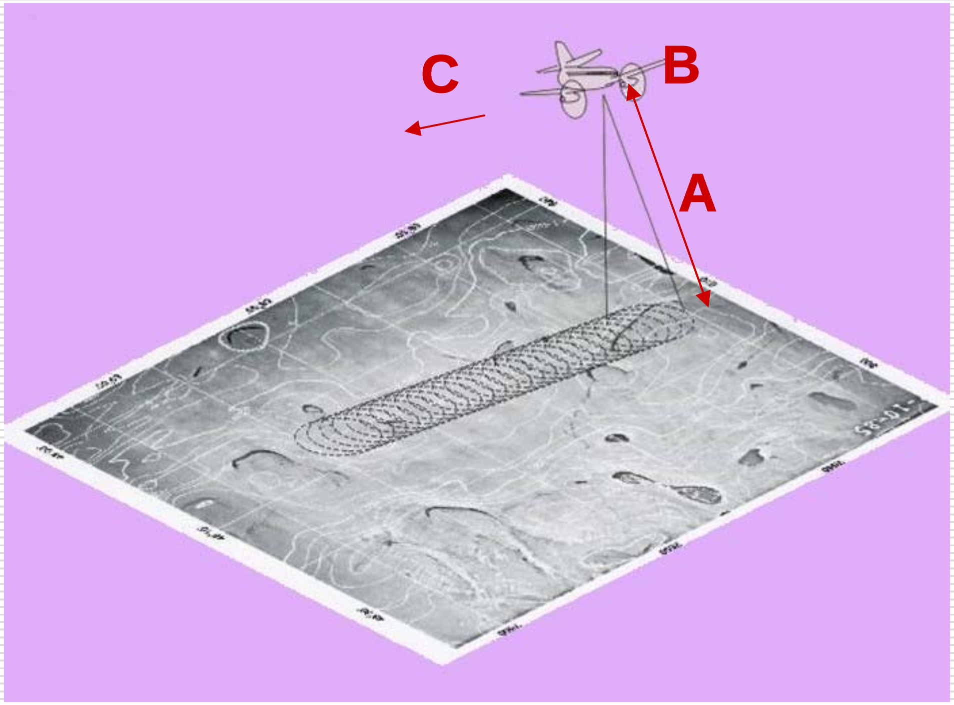
# Outline

- Overview of airborne laser mapping and polar applications
- ATM survey of the Dry Valley
  - Data acquisition
  - Data processing
  - Data dissemination
- Examples of geomorphologic mapping from DEM
  - Glacial geomorphology
  - Hydrology
  - Tectonics
  - Volcanism
- Higher level processing

# Principles of laser altimetry

- A. Distance between sensor and ground is determined from measurement of laser travel time
- B. Position of sensor is measured by differential GPS
- C. Attitude of sensor is measured by Inertial Navigation System (INS)
- A, B and C are combined with calibration values and correction factors to compute the position of the 'laser point' in a global reference system
- Result is a set 3D points
- For many mapping applications grids are computed
- Direct reconstruction of 3D surfaces is possible from the point cloud



# Why using LIDAR for cryosphere research?

- Airborne and satellite laser is ideal for polar and alpine research, because
  - fresh snow is almost a perfect Lambertian reflector
  - laser scanning provides simultaneously synoptic coverage, high spatial resolution and spatial accuracy
  - laser systems can map featureless terrain – notorious problem in photogrammetry
  - laser systems have small footprint – problem for radar systems

# History and state-of-art

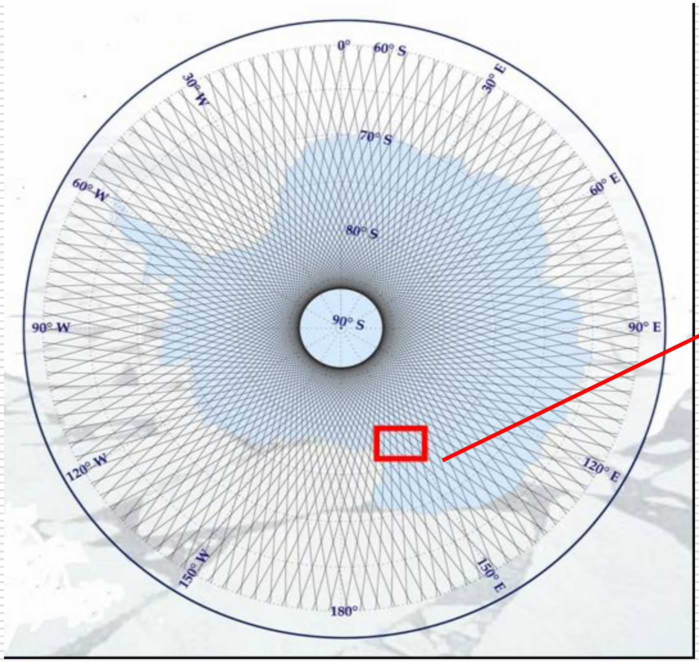
- The beginning: NASA has started a systematic mapping program in Greenland in the early 1990s
- Current status: Laser is applied routinely for mass balance and ice dynamics studies over ice sheets and mountain glaciers
- New sensors: NASA has launched the Ice, Cloud and land Elevation Satellite (ICESat) on January 12, 2003. The sole sensor of the satellite is the Geoscience Laser Altimetry System (GLAS), NASA's first terrestrial laser altimetry satellite mission. The program is in calibration/validation phase
- New applications: first surveys for glacial geomorphology

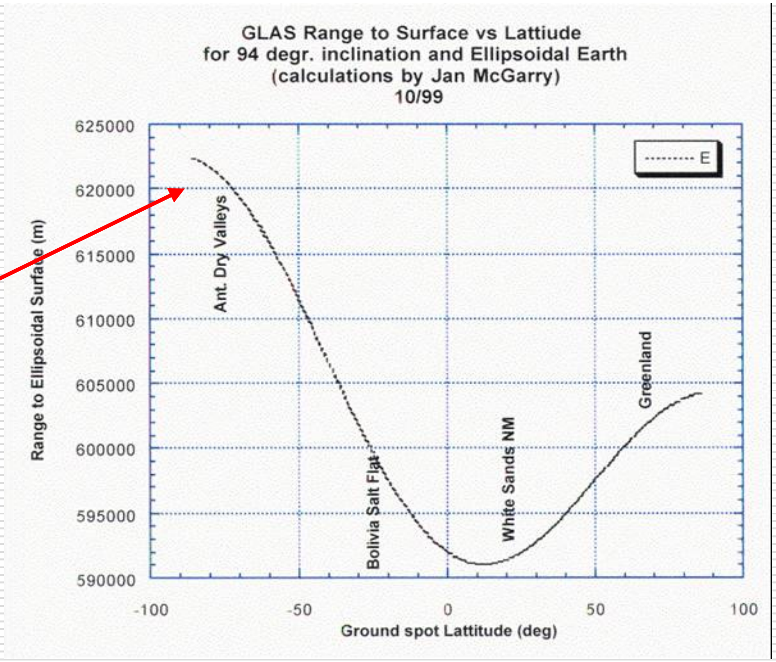
# Dry Valley airborne laser altimetry survey

- Goals:
  - obtain precise elevations for ICESat cal/val
  - assess the use of airborne laser for Antarctic mapping
- Joint project of NASA/NSF/USGS
- Data acquisition:
  - Sensor: NASA's Airborne Topopgraphic Mapper (ATM) conical laser scanning system
  - Survey: December 2001
  - Results: coverage of selected site with an average laser point density is 0.1 – 0.5 point/$m^2$

# Why did we select Dry Valleys as ICESat calibration site?

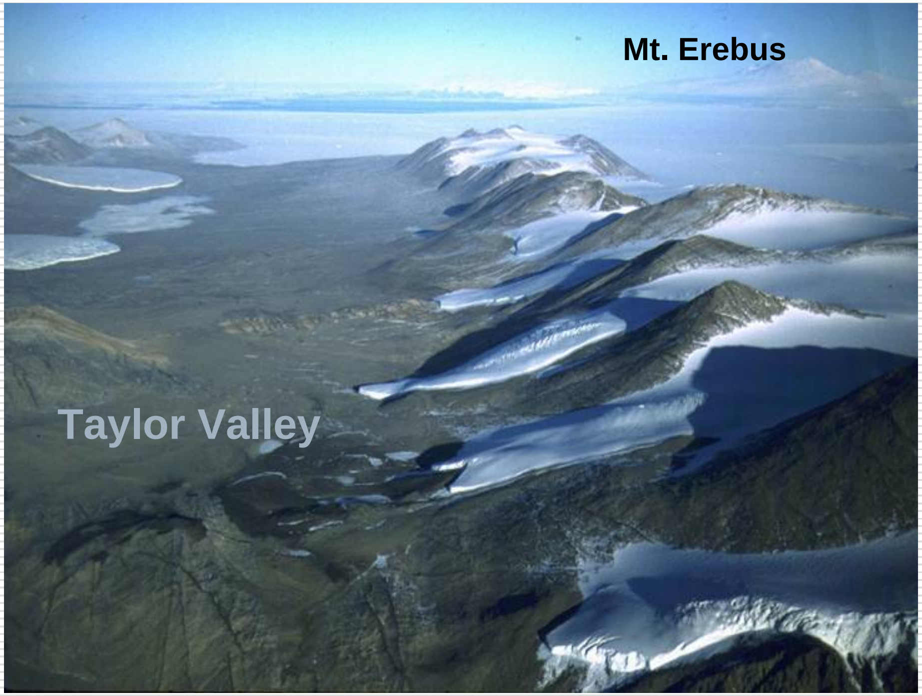
- High track density (left)
- Maximum range part of ICESat orbit (right)



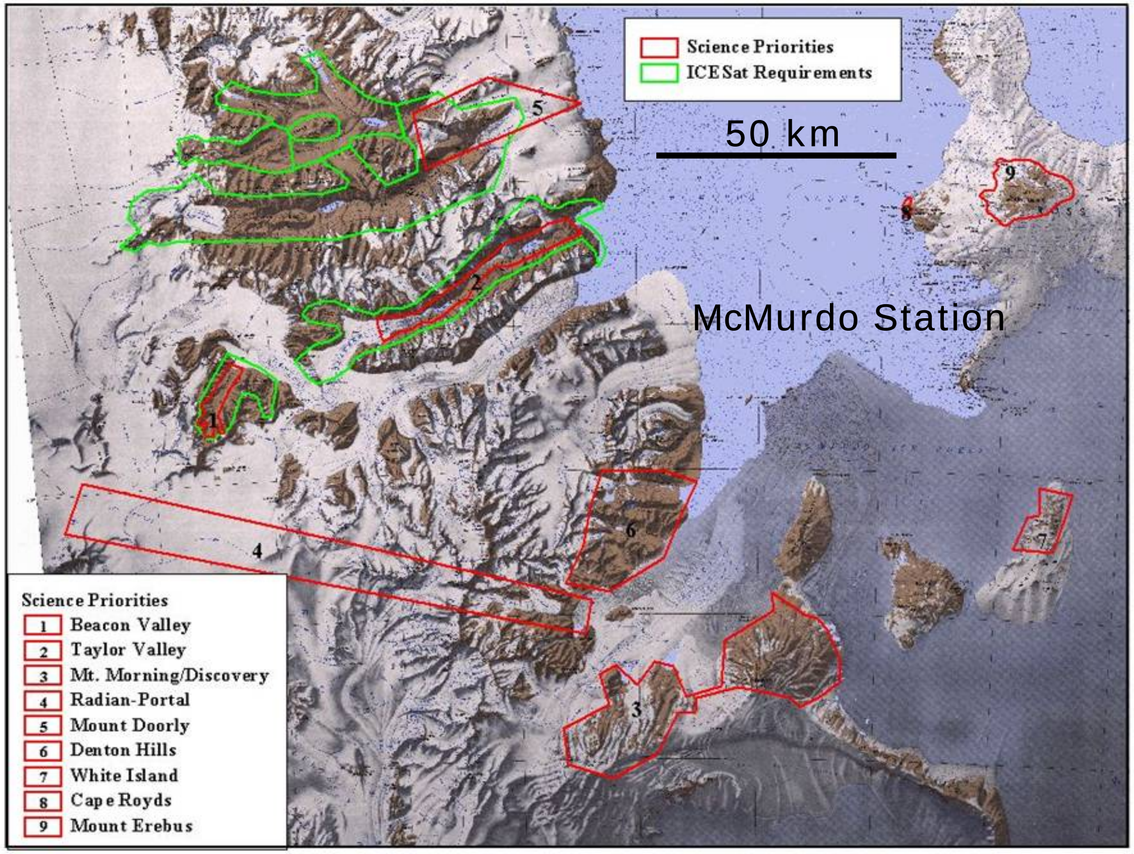
# Why did we select Dry Valleys as ICESat calibration site? (cont.)

- Small annual and interannual variability
- no vegetation, minimal snow/ice cover
- Minimal cloud cover
- Smooth surface at the scale of the ICESat footprint
- Diverse topography (slope)
- High ICESat track density
- Maximum orbital altitude
- Close to major science targets

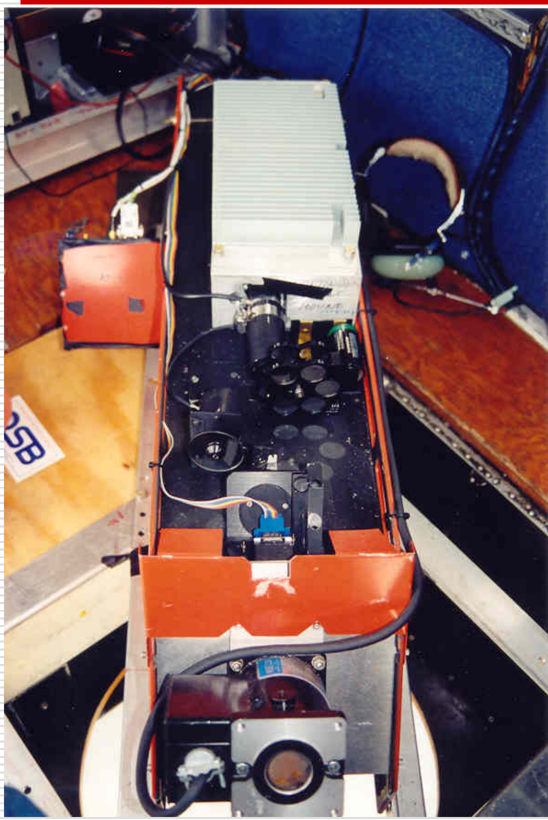



Verification and calibration of ICESat is ongoing effort. Results of cal-val and change detection were reported at AGU

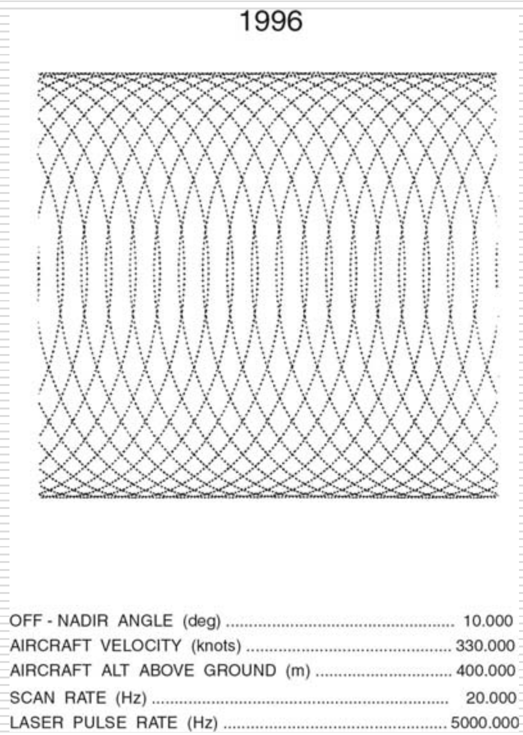
# Target areas for testing geological and glaciological applications



# Data acquisition system: Airborne Topographic Mapper, NASA/WFF



Conical scan pattern




Installed in Twin Otter aircraft (regularly used in P-3 (Orion) aircraft)

Specifications:

- Green wavelength
- Scan with nutating mirror
- Spectra Physics TFR laser
- 10-20 degree off nadir angle
- 10-15 Hz scan rate
- 5,000-20,000 pulse rate
- Installed in P3-B Orion
- Intensity + passive channel
- 1 meter footprint size
- Digital imagery also acquired

# Data Processing Steps

| | | |
|---|---|---|
| NASA WFF | Data acquisition | GPS/INS/range/intensity/.... |
| | Data processing | t/long/lat/elevation/.... |
| OSU | Database generation | flat file to relational DB |
| | DEM generation | 2m x 2m, 4m x 4m regular grid |
| | DEM quality control | relative/absolute accuracy |
| USGS | Data dissemination | DEM/'clean' laser points/.... |

# Generating Database

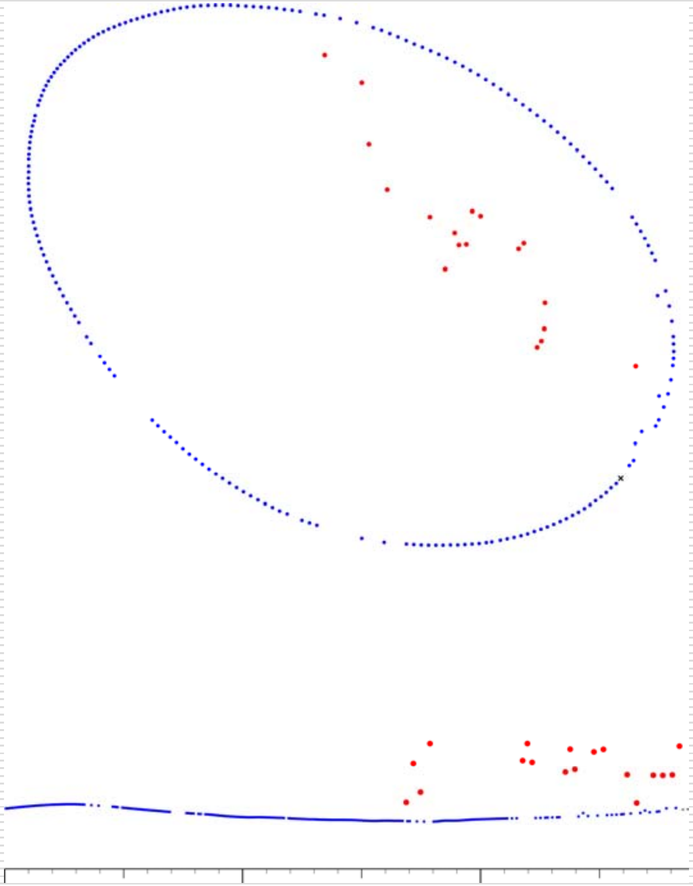
- Antarctica laser point data set contains over 1.2 billion points, stored on 23 DVDs in over 300 files, sequentially organized by flight lines
- Database required to perform queries with multiple criteria
- Oracle 9i with spatial option was selected
  - data table contains laser points and auxiliary data
  - index tables help to accelerate queries
  - disk capacity needed: approx. 90 GB
  - multiple queries possible, geared towards spatial criteria
    - find points within a specified polygon
    - find points within a search radius of a given point

# Generating DEMs

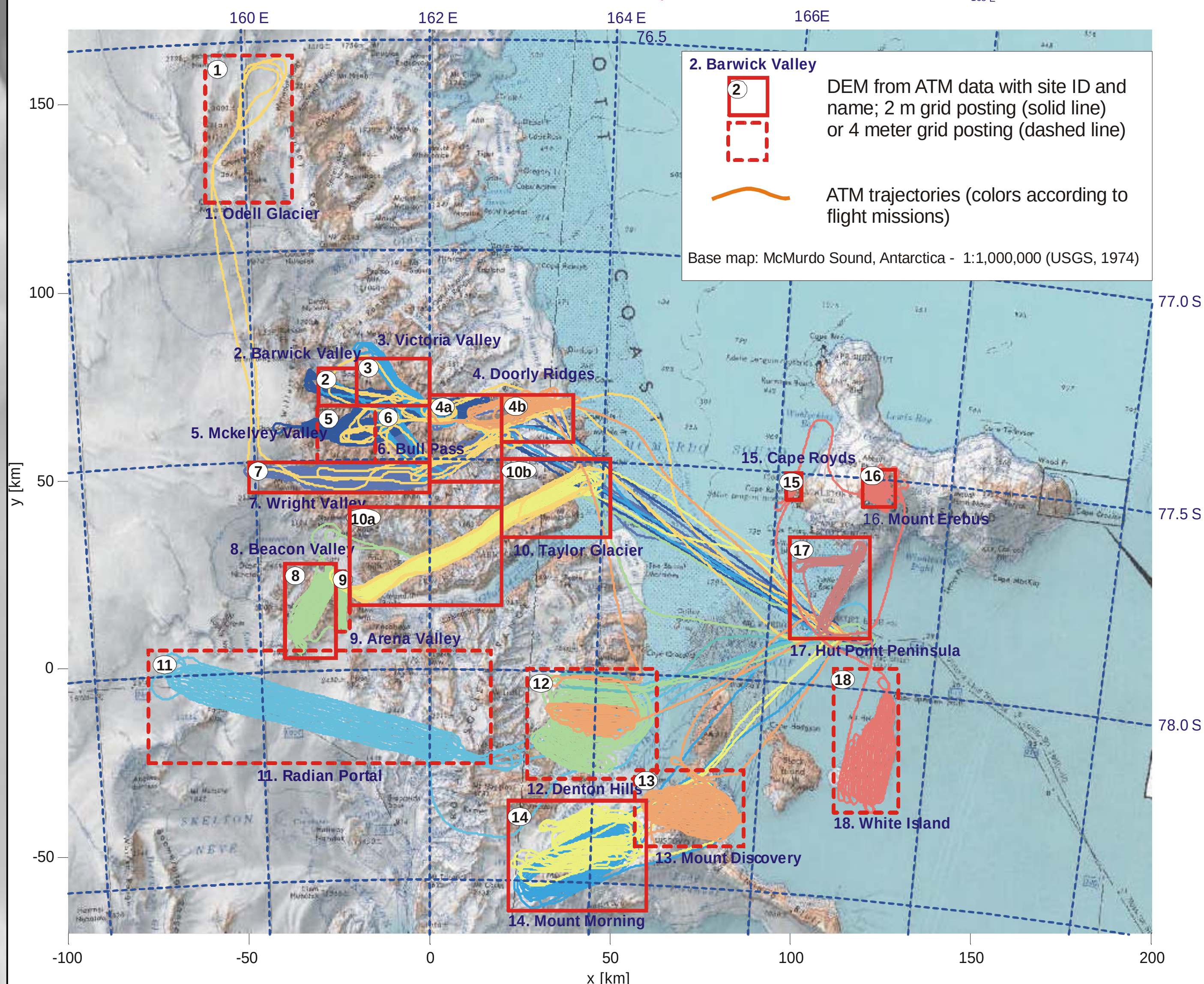
- Blunder detection
  - unusual large amount of blunders due to rapid change in albedo and atmospheric conditions
- Boundary definition
  - original laser points are organized by flight lines NOT by project sites (one flight line may cover different sites)
- Grid interpolation
  - surface fitting with robust estimator
  - label grid posts based on fitness error and point distribution
- Quality control
  - internal, e.g. fitness error during interpolation, visualization
  - external, e.g. with GPS control points

# Blunder distribution and detection

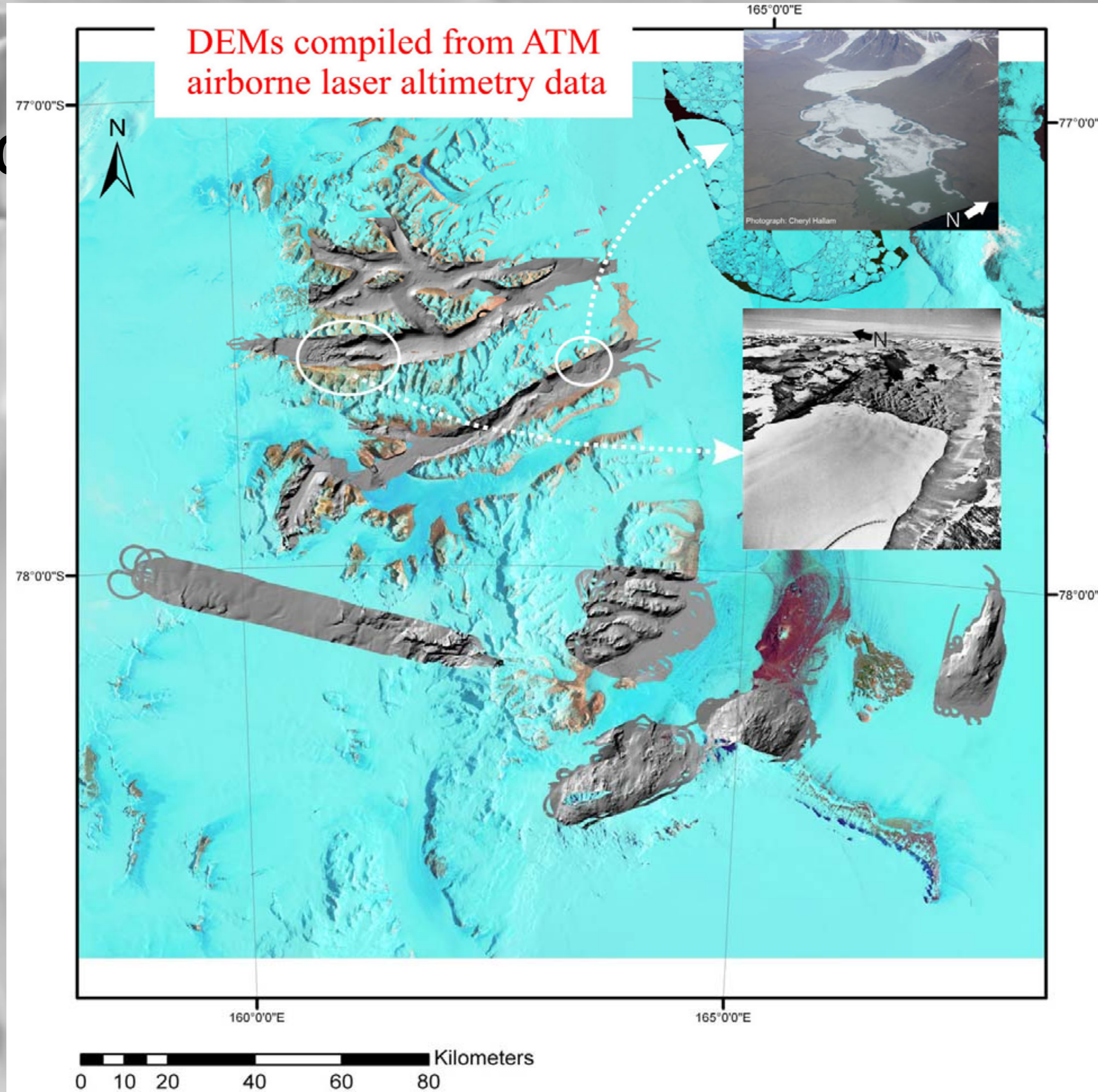
Extreme brightness contrast and atmospheric conditions resulted range errors



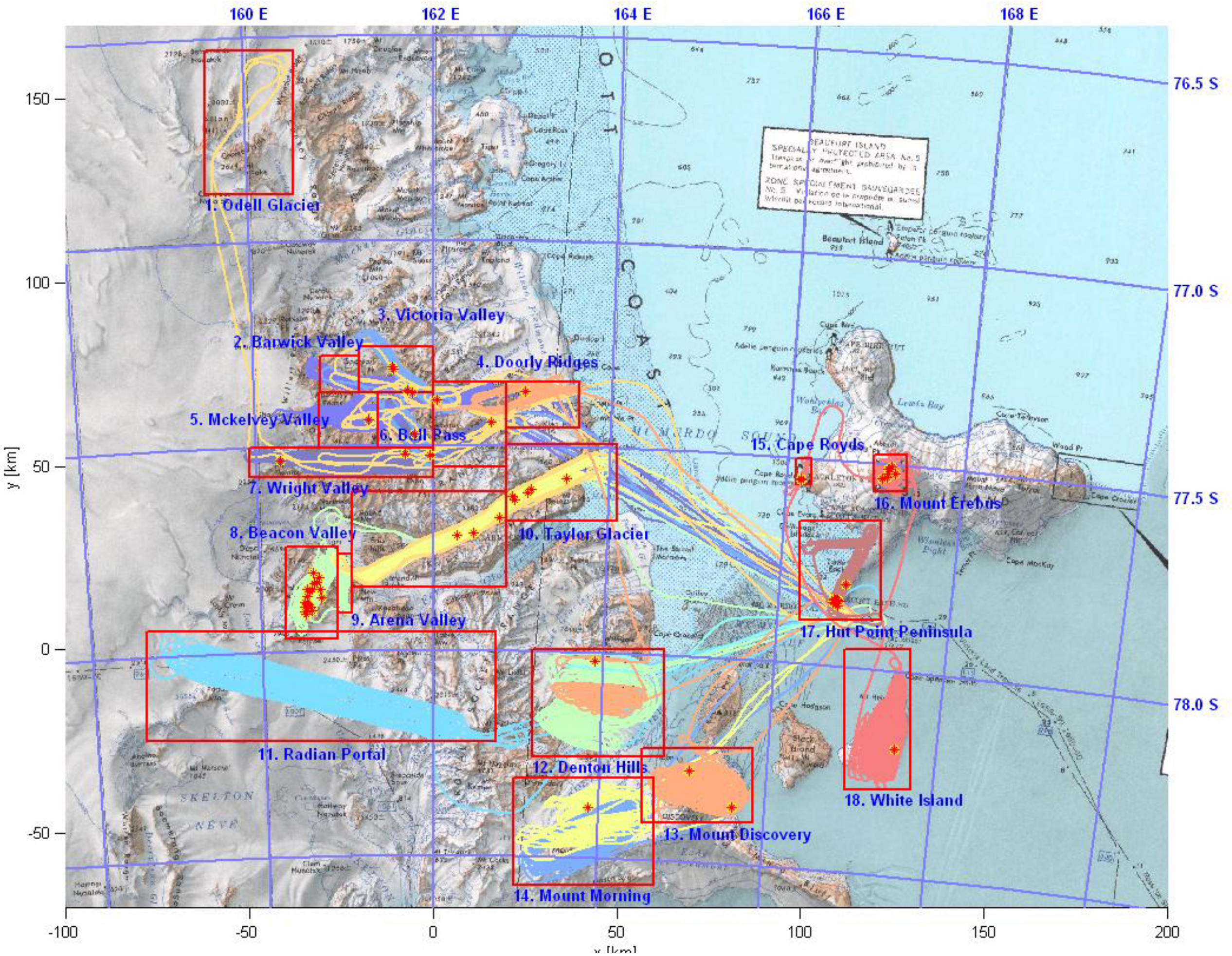
# DEMs from ATM scanning laser altimetry data around McMurdo Sound, Antarctica



# Shad

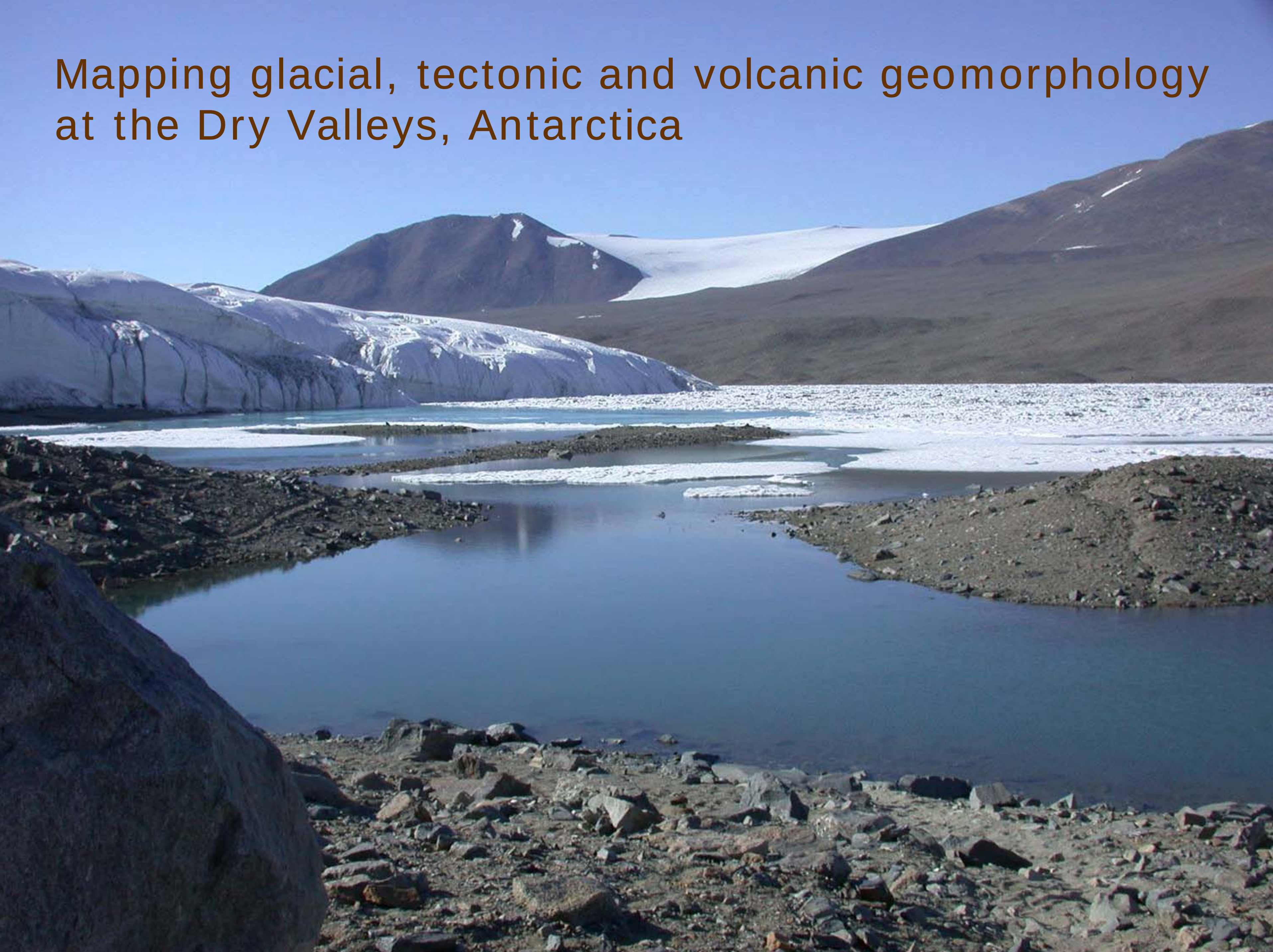

DEMs compiled from ATM
airborne laser altimetry data
N
165°0'0"E
77°0'0"S
77°0'0"S
78°0'0"S
78°0'0"S
160°0'0"E
165°0'0"E
Photograph: Cheryl Hallam
N
N
0 10 20 40 60 80
Kilometers

# Checking absolute accuracy using GPS stations




# Accuracy of DEMs and data distribution

- Accuracy of DEM
  - Internal accuracy is measured by residual of plan fitting within grid cells, and stored in a “label” matrix. For most DEM cell it is better than 10 cm
  - Absolute accuracy of 0.1+-0.5 m is estimated by comparison with 80+ ground GPS points.
    - Most of these GPS positions refer to the antenna phase center and its exact height above the topographic surface is not known. Therefore the RMS error of the DEM might be overestimated → accuracy studies are ongoing
- Data distribution:
  - For information on the data set contact Bea Csatho, OSU, csatho.1@osu.edu or visit http://www-bprc.mps.ohio-state.edu/ohglas/glid_icesat.htm
  - To obtain the data contact Cheryl Hallam, USGS, challam@usgs.gov


Mapping glacial, tectonic and volcanic geomorphology
at the Dry Valleys, Antarctica

# Research interest (several PIs)

- Taylor, Wright, Victoria, McKelvey, Balham, Beacon and Arena valleys, Bull Pass -- glaciology, glacial and periglacial geomorphology; glacier surface models, drainage patterns, patterned ground, rock glaciers, etc.,
- White Island, Mt. Morning, Mt. Erebus, Mt. Discovery -- mapping volcanic cones
- Radian Glacier to The Portal -- relationship between bedrock structure and ice flow
- Denton Hills -- fault structure and landscape analysis
- Wilson piedmont glaciers -- lineaments and bedrock structure
- Cape Royds -- Penguin rockery landscape
- Hut Point Peninsula -- volcanic landscape, McMurdo Base
- Odell glacier -- possible aircraft landing site

**Wright Valley**

**Taylor Valley 1.**

**(Canada and Common-wealth glaciers)**

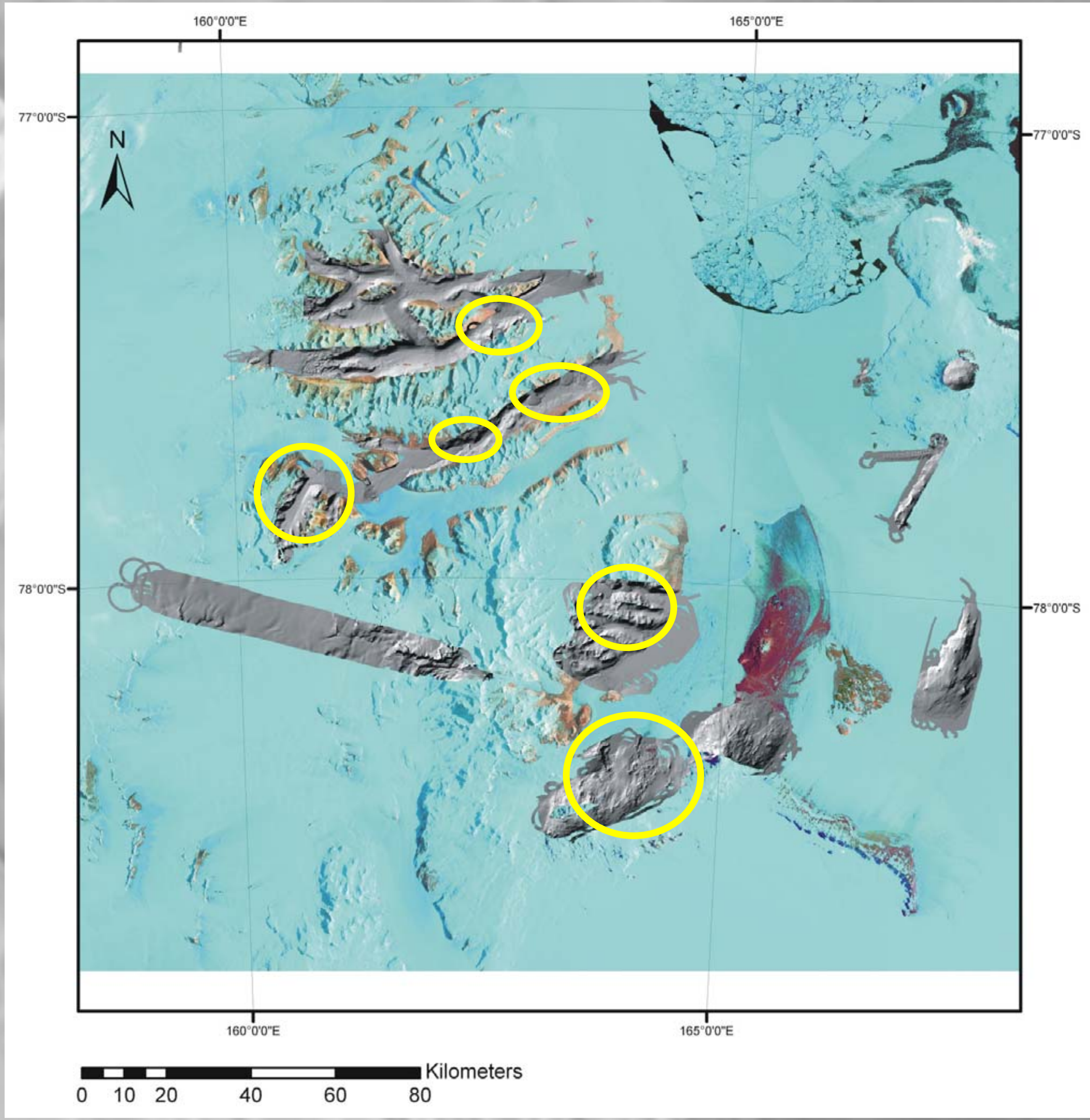
**Taylor Valley 2.**

**(Lake Bonney)**

**Beacon Valley**

**Denton Hills**

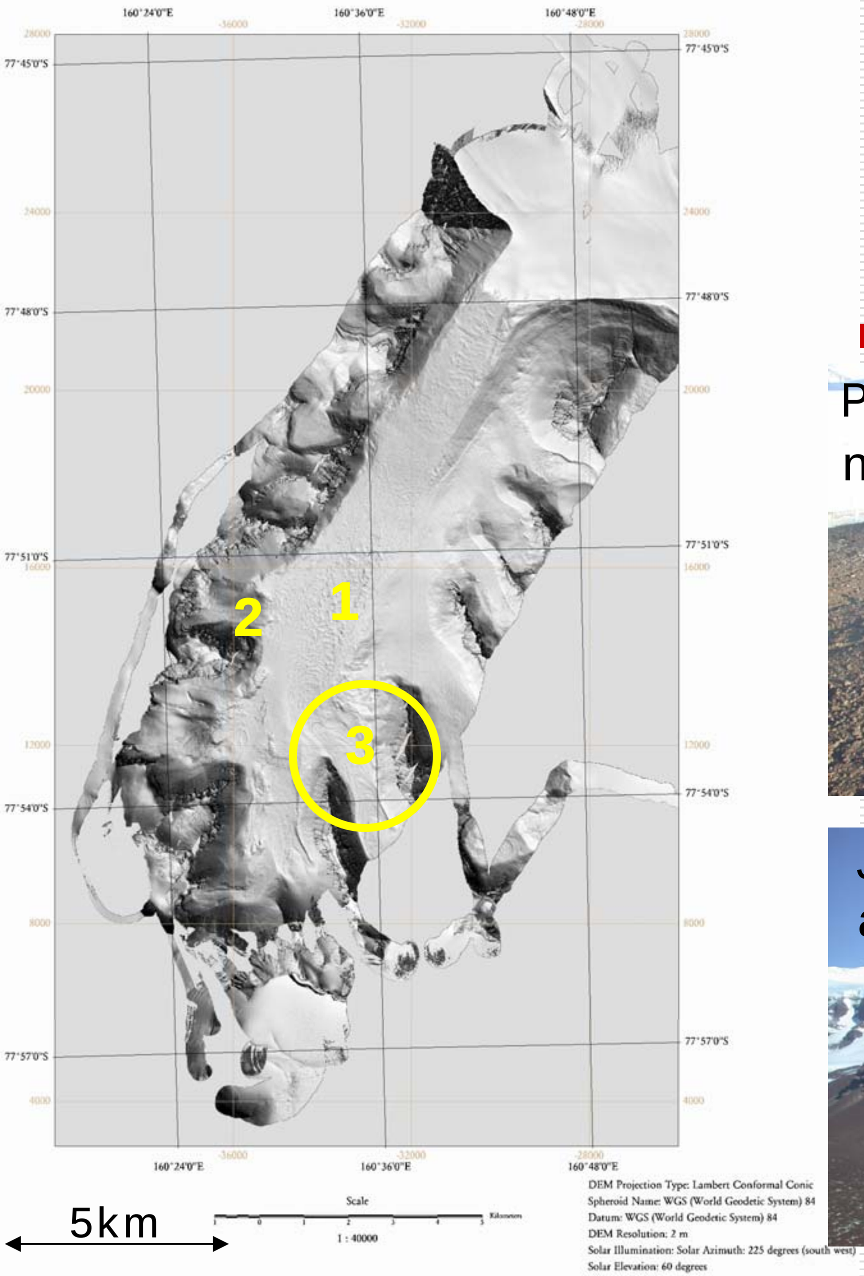
**Mount Morning**

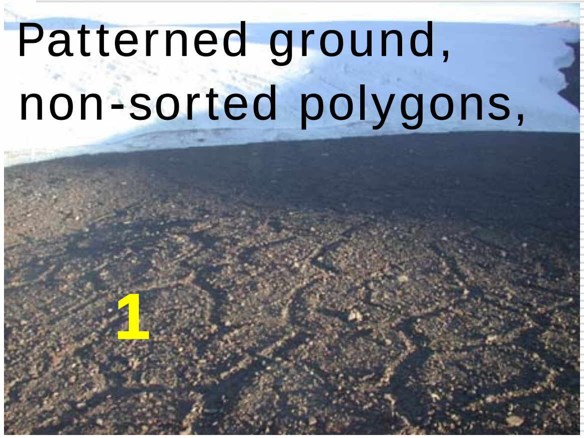


# Further data analysis and higher level processing

- Tools for mapping geomorphological features
  - Feature extraction
  - Segmentation
  - Surface reconstruction and modeling
  - Data fusion
- Provide quantitative data for landscape modeling
- Can be performed on original point cloud or from DEM

# Beacon Valley

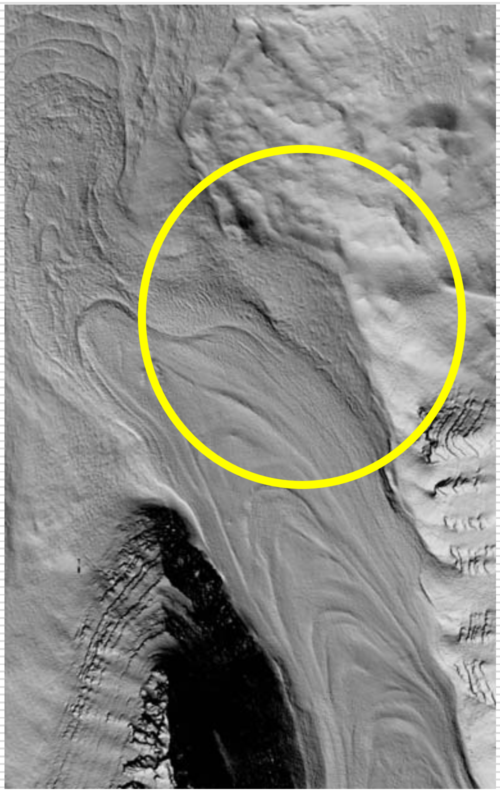


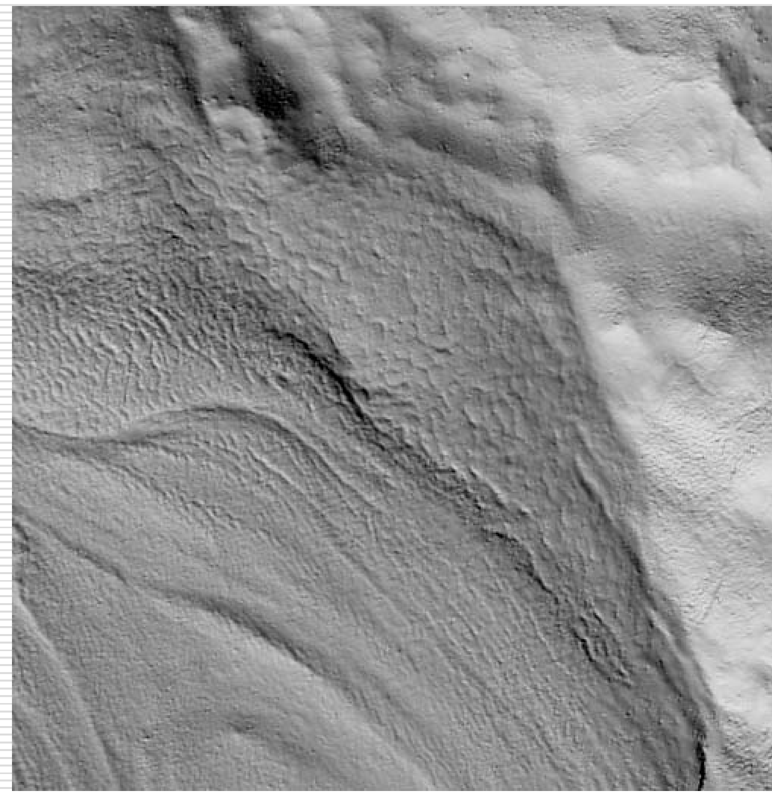





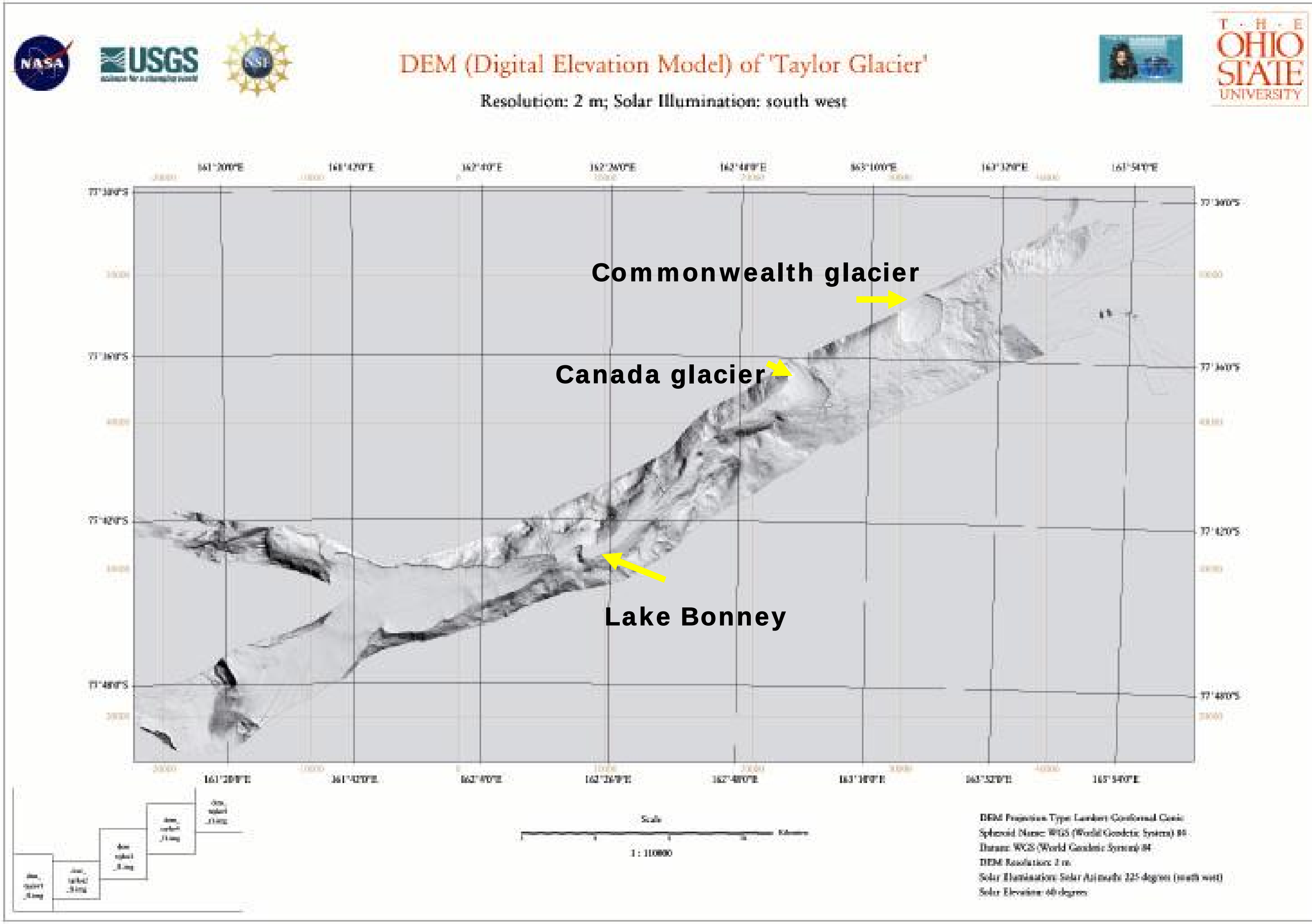
Rock glacier
surface

# Closer look at the DEM

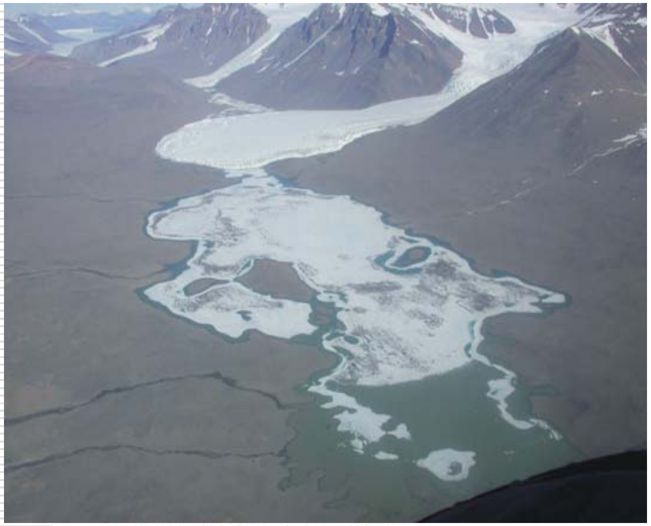




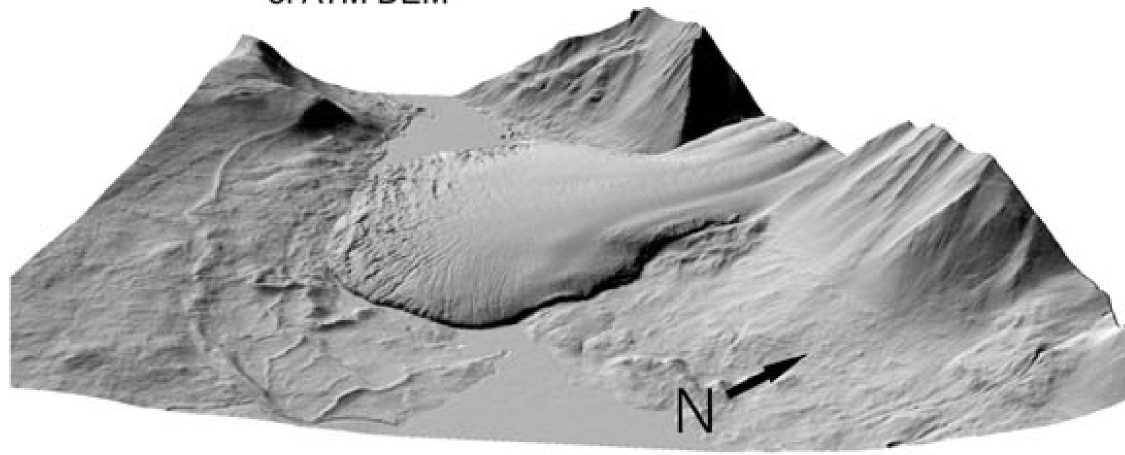
Feature extraction: polygons, rock glaciers


DEM (Digital Elevation Model) of 'Taylor Glacier'
Resolution: 2 m; Solar Illumination: south west
Commonwealth glacier
Canada glacier
Lake Bonney

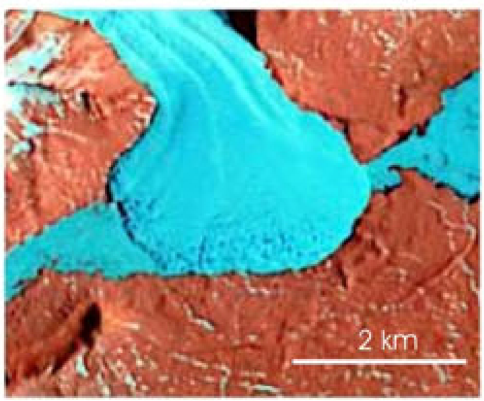
# An example: Canada glacier, Taylor Valley



3D surface view
of ATM DEM

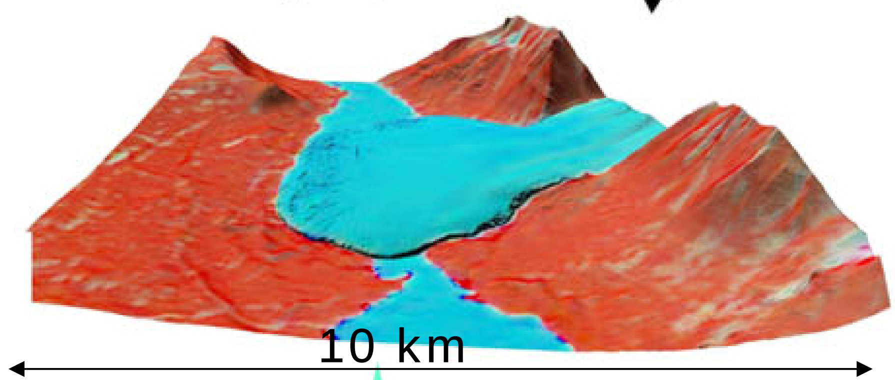



Landsat TM false color composite



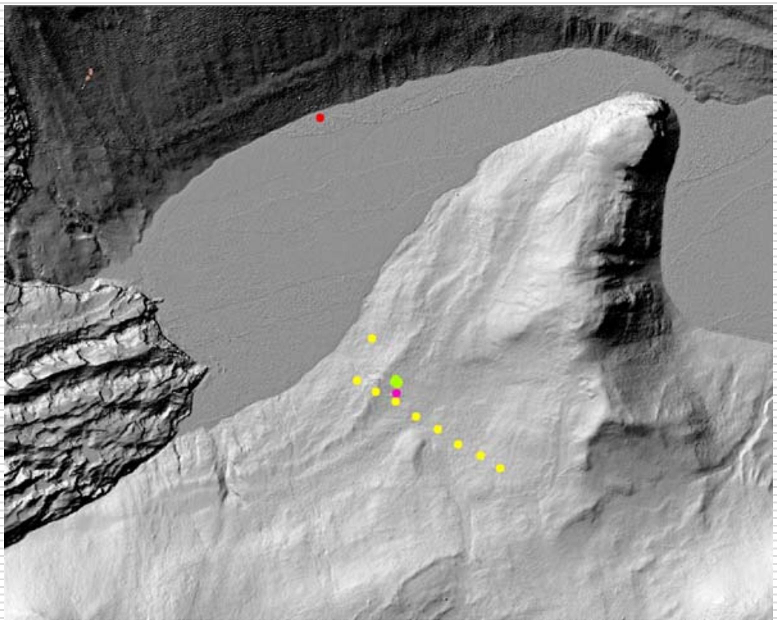

Rectified Landsat imagery from Jean-Claude Thomas, USGS

3D surface view of ATM DEM with
Landsat image draped over



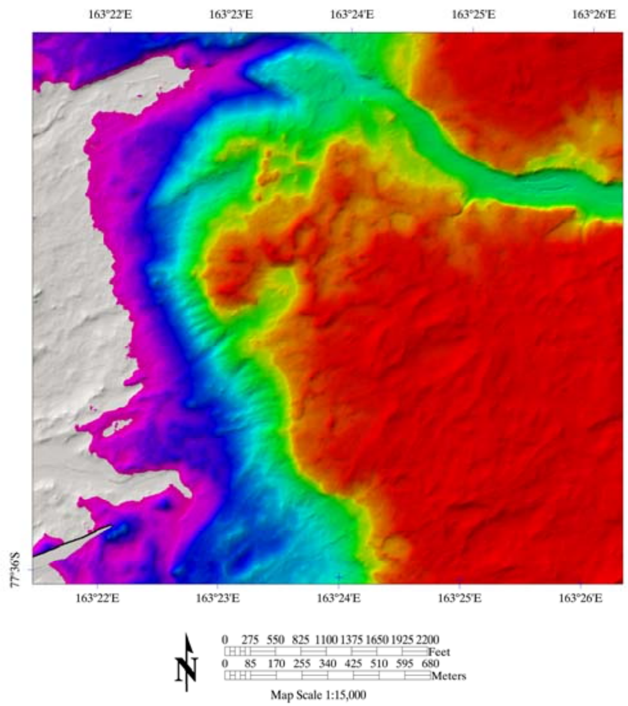

Feature extraction: drainage pattern,moraines, crevasses. Coastline, meltwater channels

# Hydrological features, drainage pattern



Evidence of temporary stream flow
S of Lake Bonney

(B. Lyons, P. Doran)

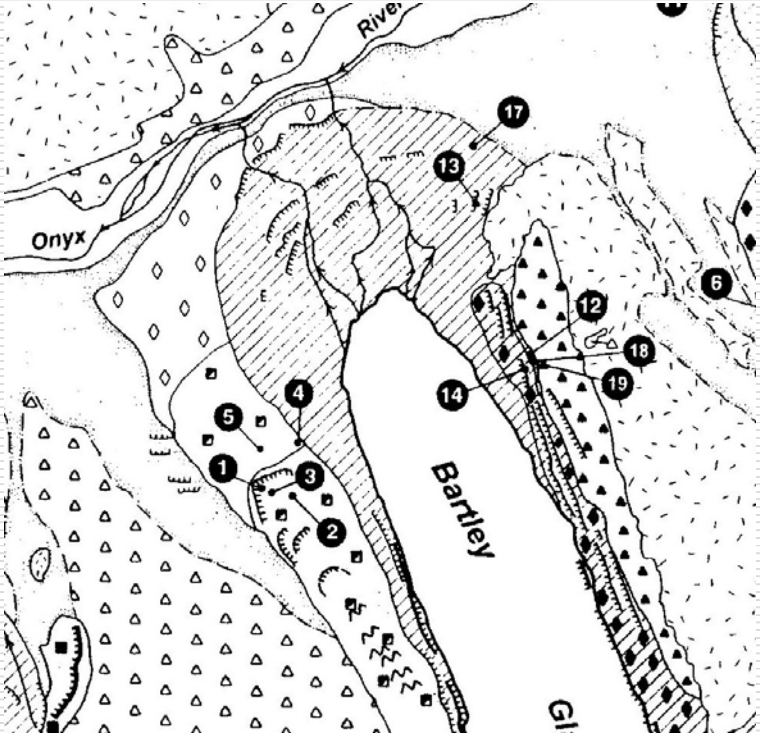



Glacial flutes S of Commonwealth glacier

Feature extraction: drainage pattern, flutes, crevasses. coastline

# Glacial geomorphological features. Bartley glacier in the Wright Valley

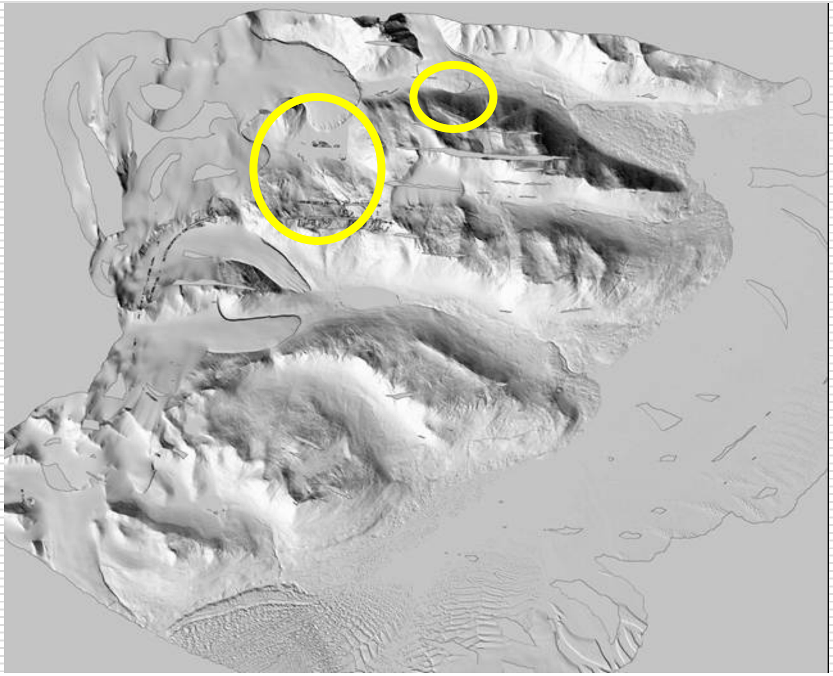
(G. McKenzie)



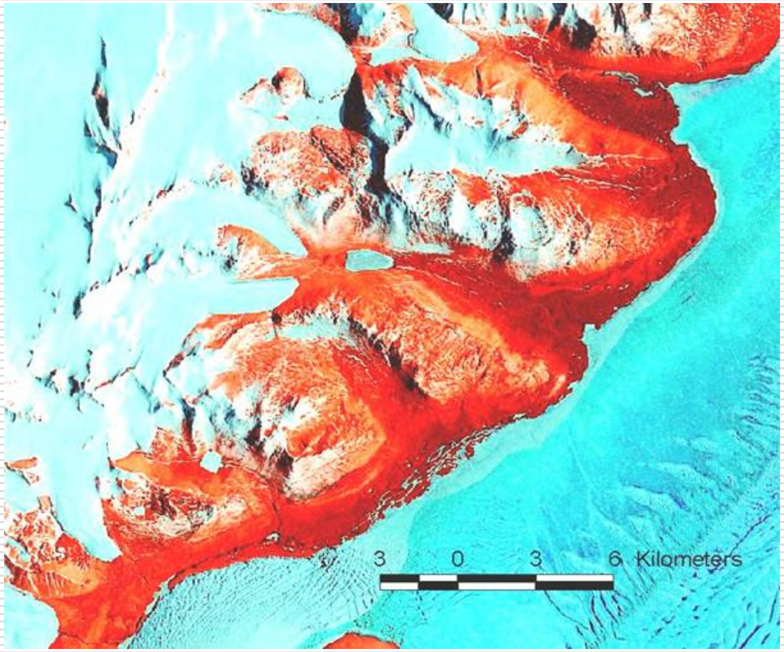

Segmentation and feature extraction: Crevasses, moraines, drifts, bedrock outcrops, streams

# Denton Hills, fault structure

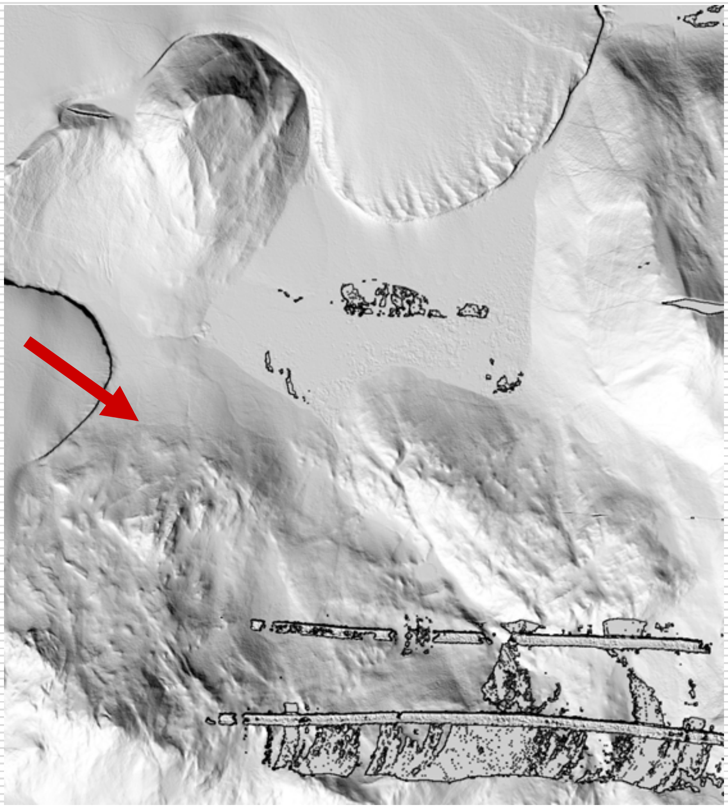
Shaded relief DEM from laser

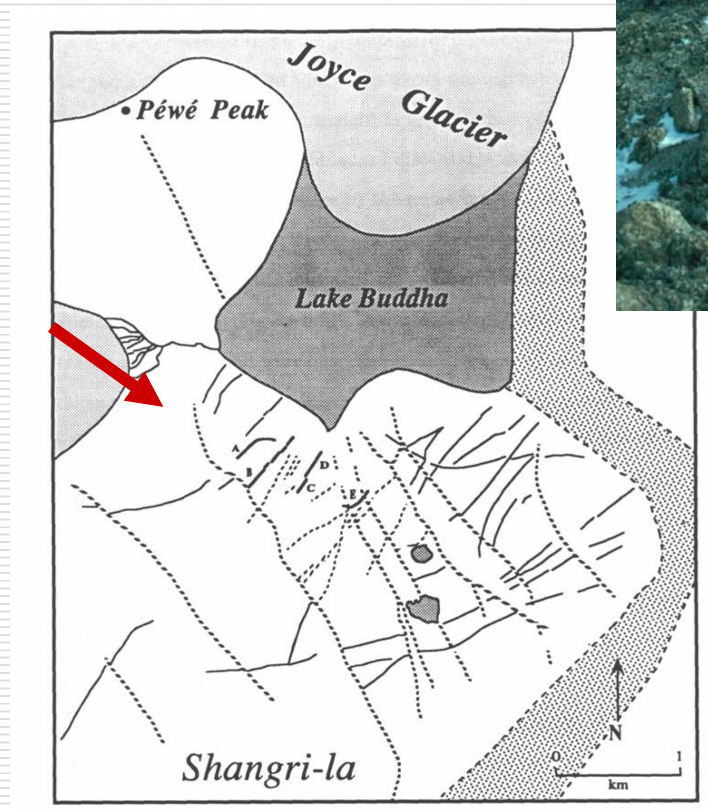


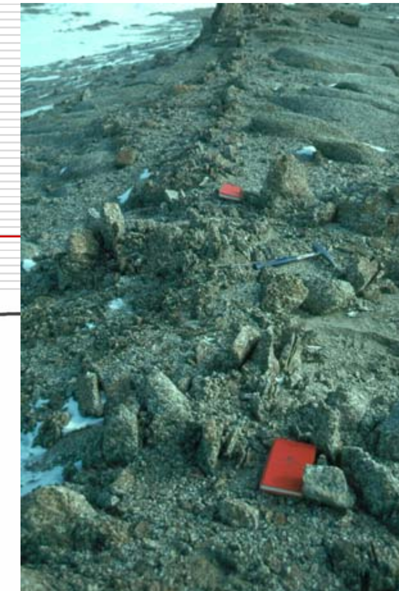
Landsat TM mosaic (USGS)



# Cross-cutting fault array
# S of Joyce glacier



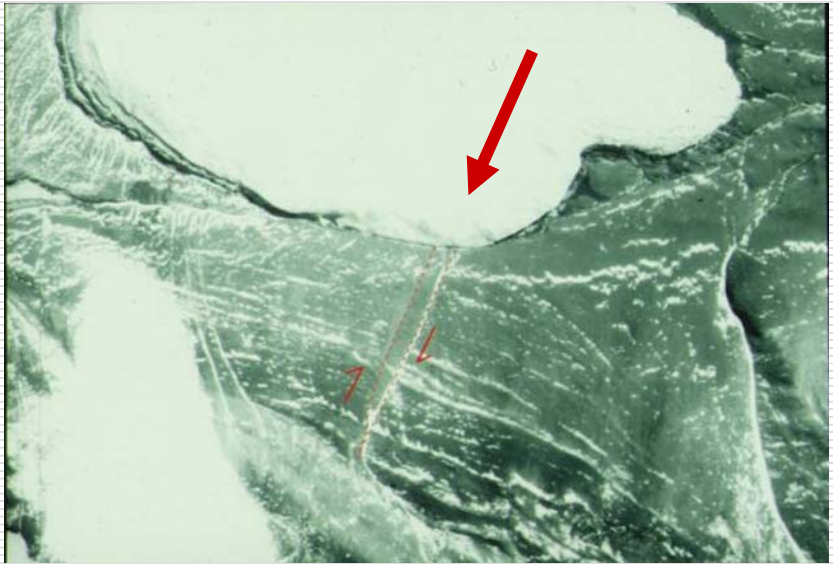


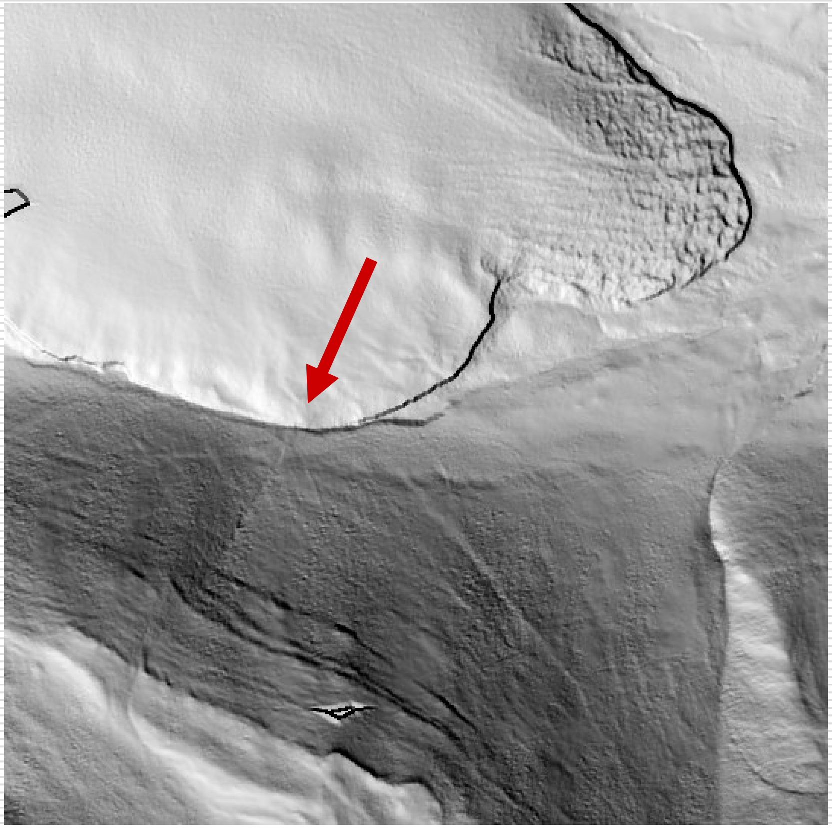
Lineament mapping

(T. Wilson)

# Quaternary fault, Garwood valley



from Jones, 1996

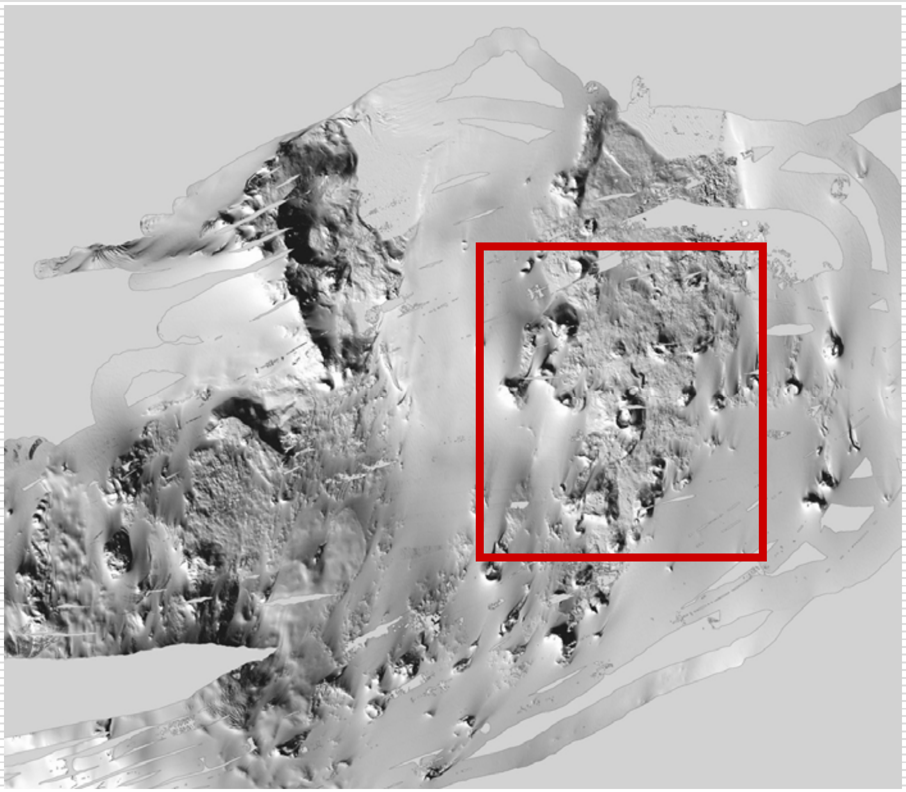


Lineament mapping

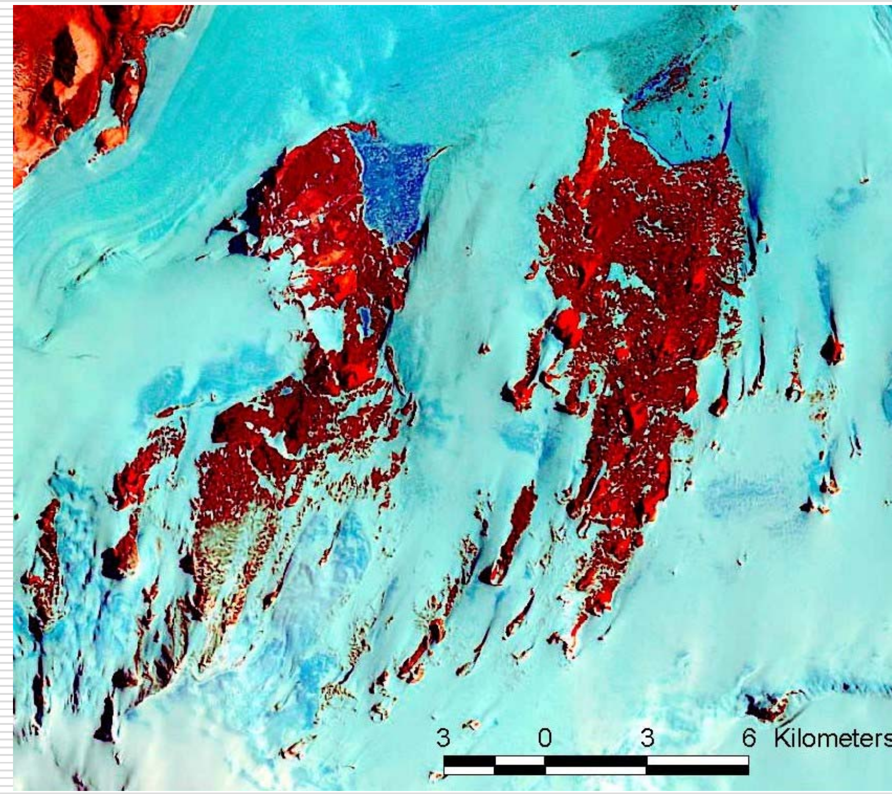
(T. Wilson)

# N slope of Mt. Morning, volcanic geomorphology

Shaded relief DEM from laser alt.

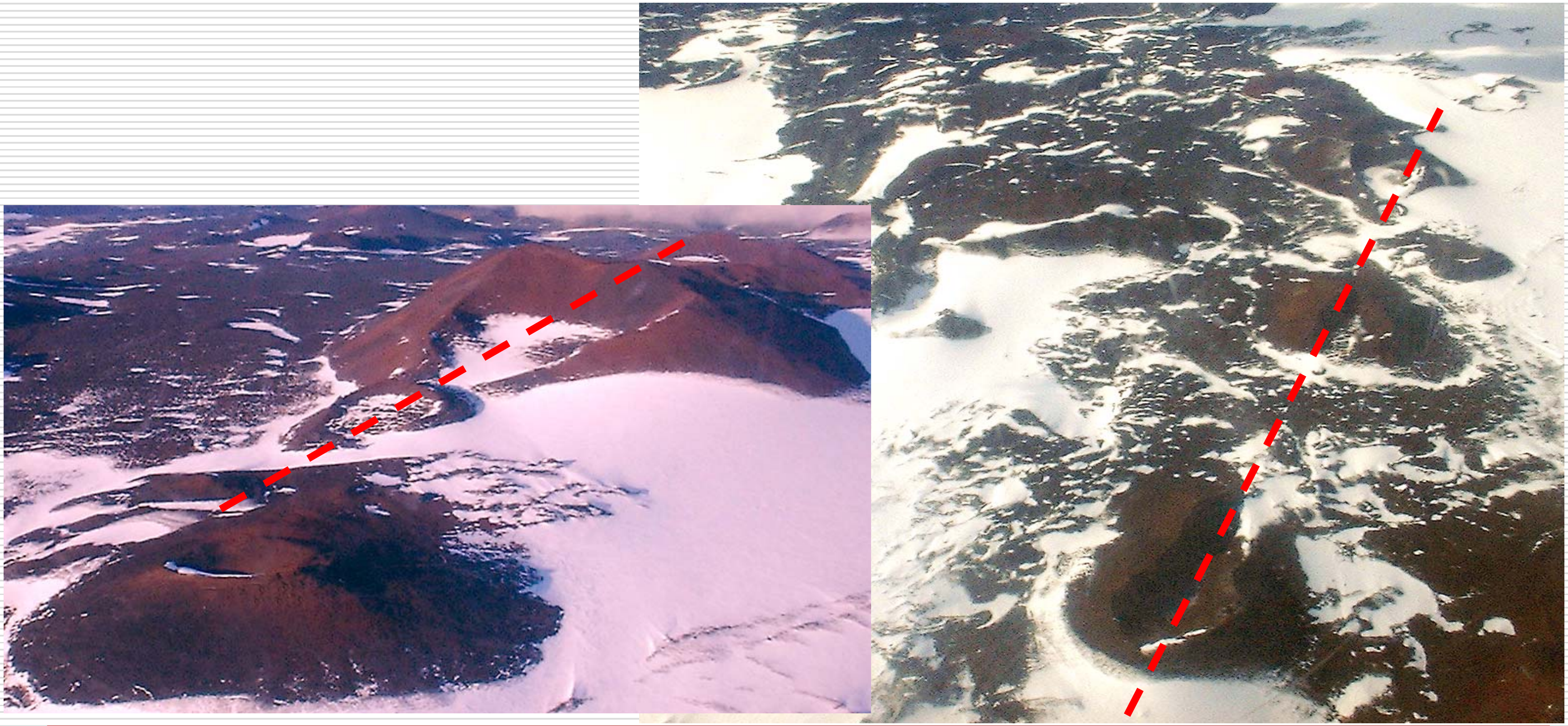


Landsat color composite



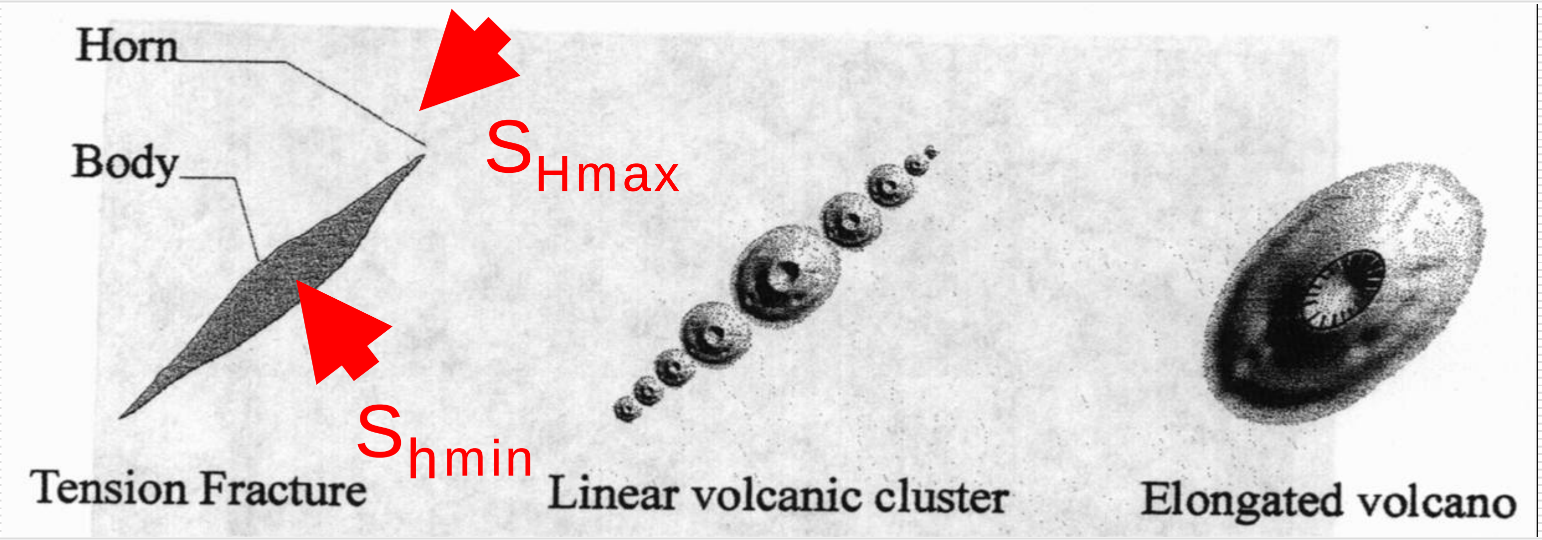
# Erebus Volcanic Province

## NE cone elongation and alignments

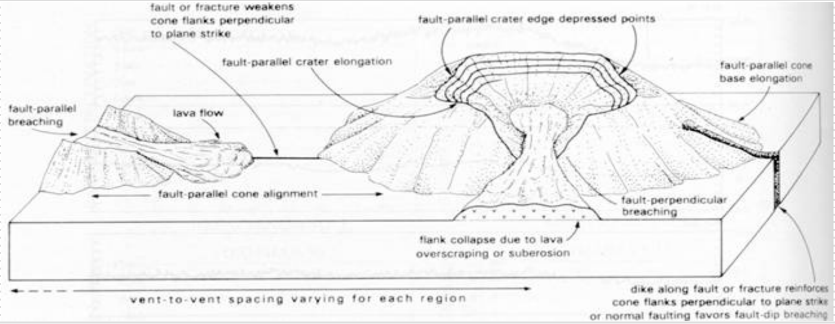


# Surface signatures of volcanic fissures

**Horizontal stress direction**



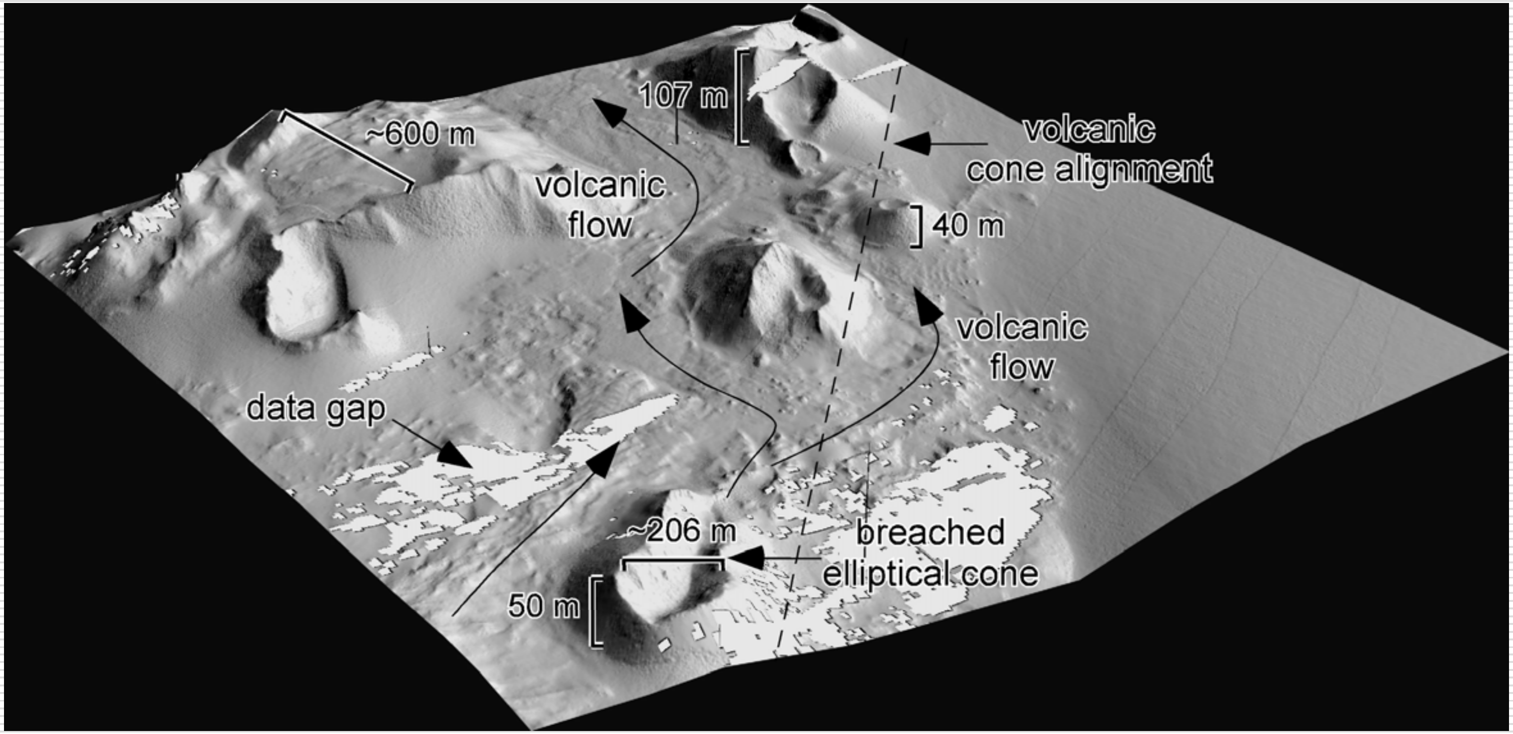

Cone morphology –
indicator of fault control




(Tibaldi, 1995)

# Close-up of volcanic cones and lava flows

(T. Wilson and T. Paulsen)




Surface reconstruction and 3D modeling: Parametric form of volcanic cone shapes determined by 3D surface fitting (cone parameter, base, crater rim); delineation of lava flows by texture based segmentation

# Conclusion, future work

- Laser mapping provides high accuracy, high resolution, repeat and regional coverage
- Data set is suitable for creating DEMs and for quantitative mapping of geomorphologic features
- Multidisciplinary effort is needed for comprehensive studies
- Techniques of different fields, such as computer vision, artificial intelligence, data fusion are needed to automate the processing steps

# Acknowledgements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- Interpretation: Terry Wilson, Garry McKenzie, Berry Lyons (OSU), Peter Doran (Univ. of Illinois) and Tim Paulsen (Univ. of Wisconsin)