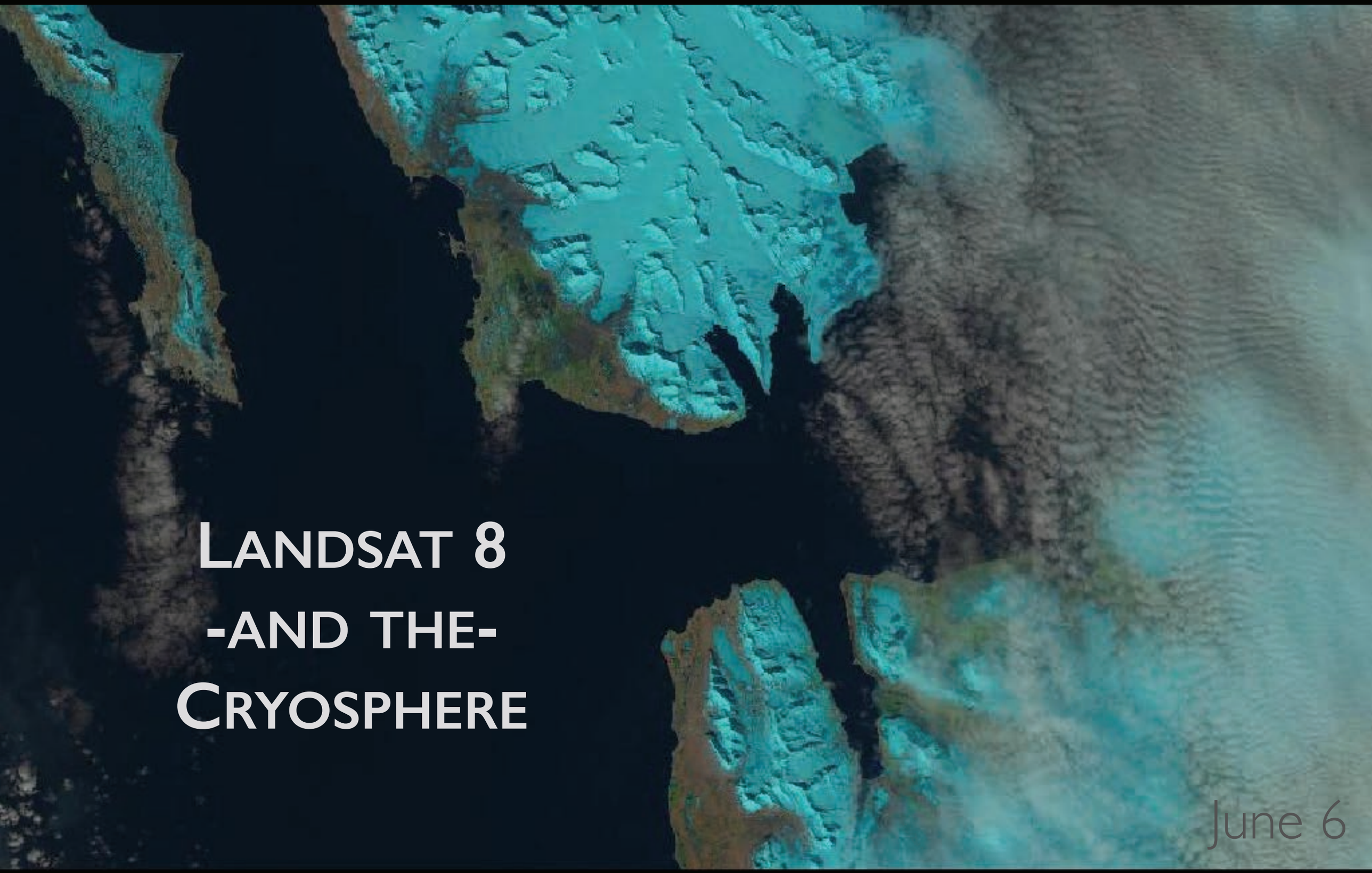


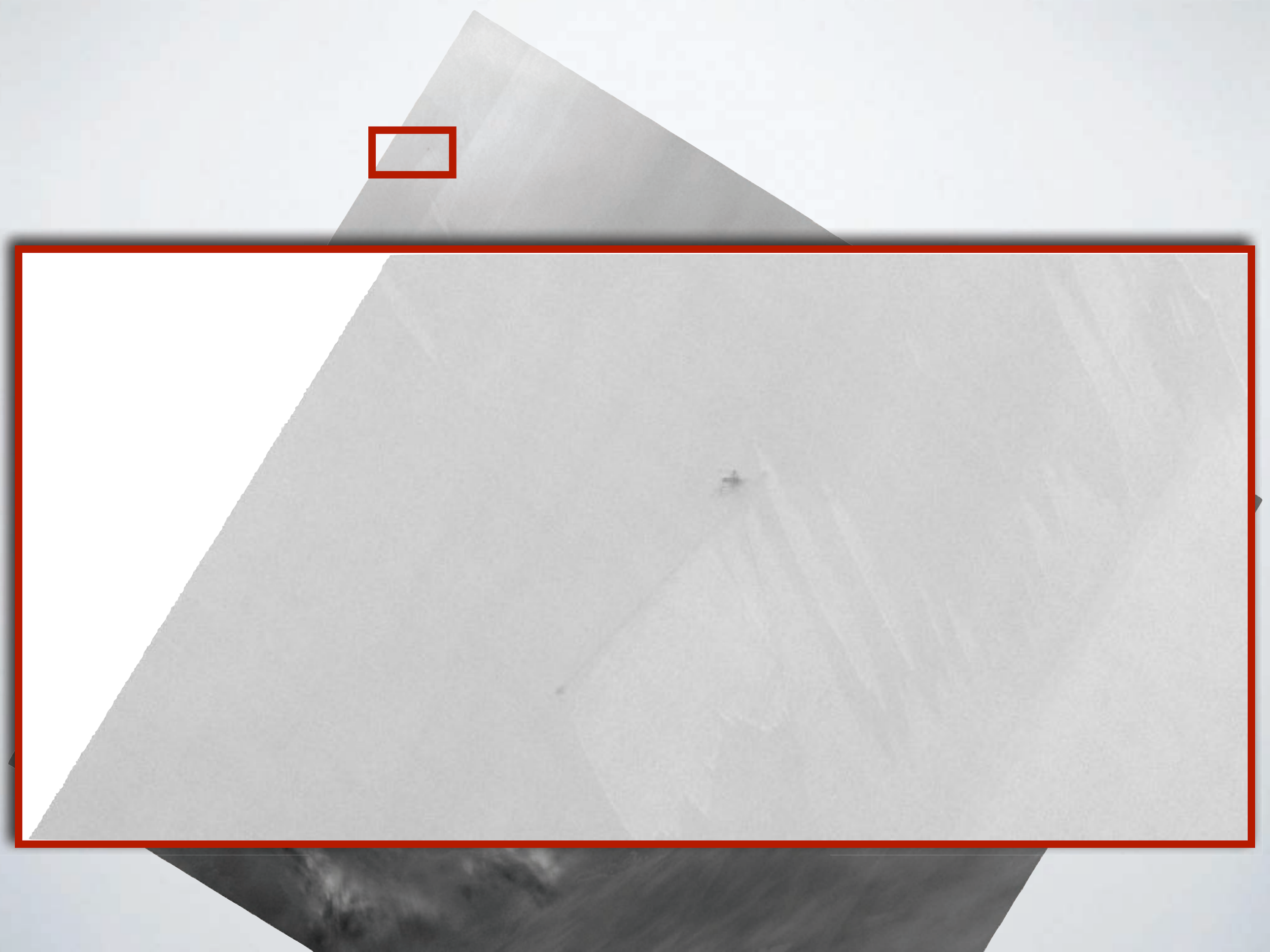
Landsat 8
-and the-
Cryosphere

June 6

Landsat 8
-and the-
Cryosphere

May 14

Who Am I?



Landsat 8

The Cryosphere is...

...all of Earth's frozen regions (either seasonally or annually).
From cryos/krios (cold) and sphaira (ball/globe).

It Includes...

Snowcover
Sea ice
Lake / river ice
Icebergs
Permafrost & seasonally frozen ground
Ground ice
Ice masses (glaciers, ice caps, ice fields, ice sheets, ice shelves)

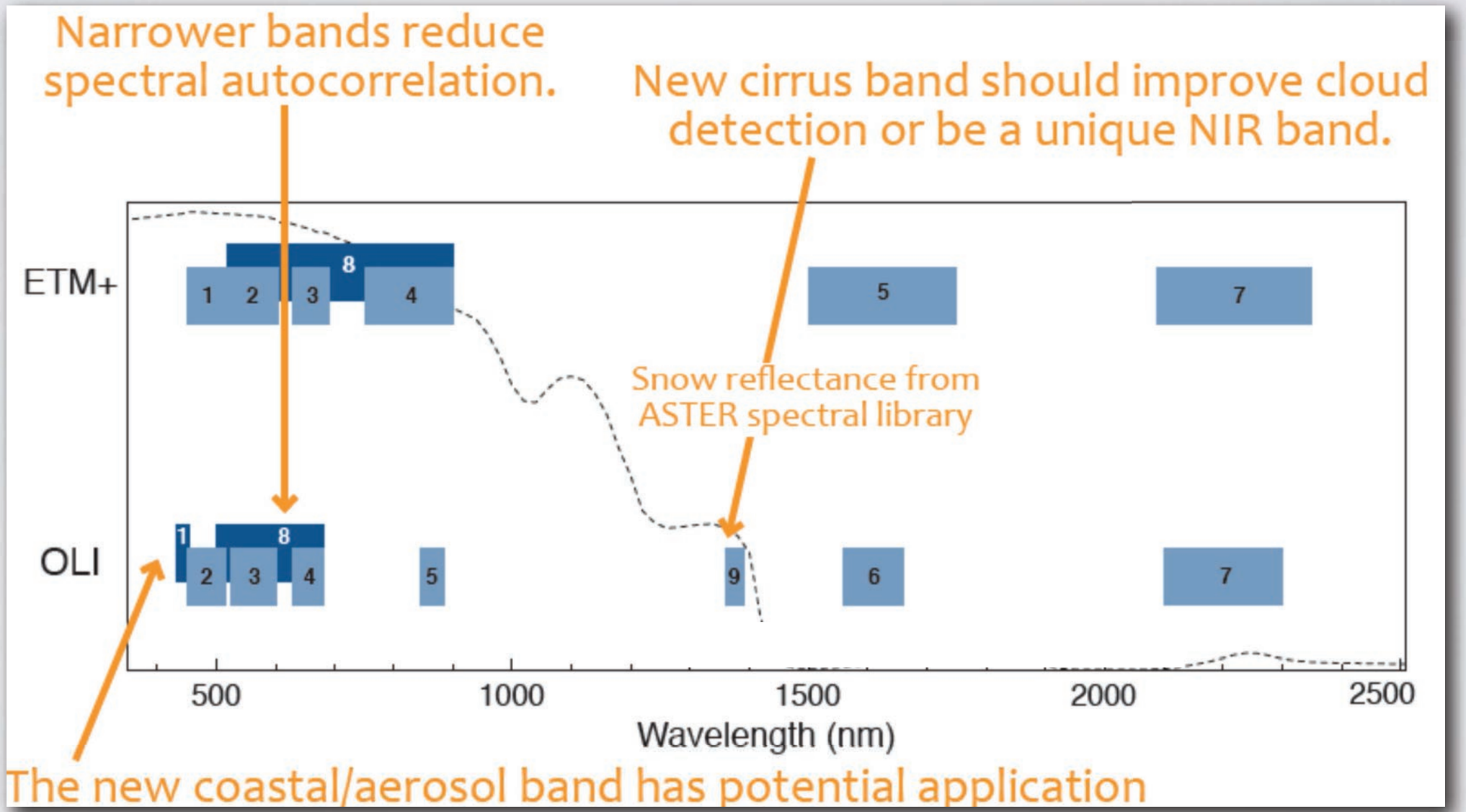
What do we know about Landsat

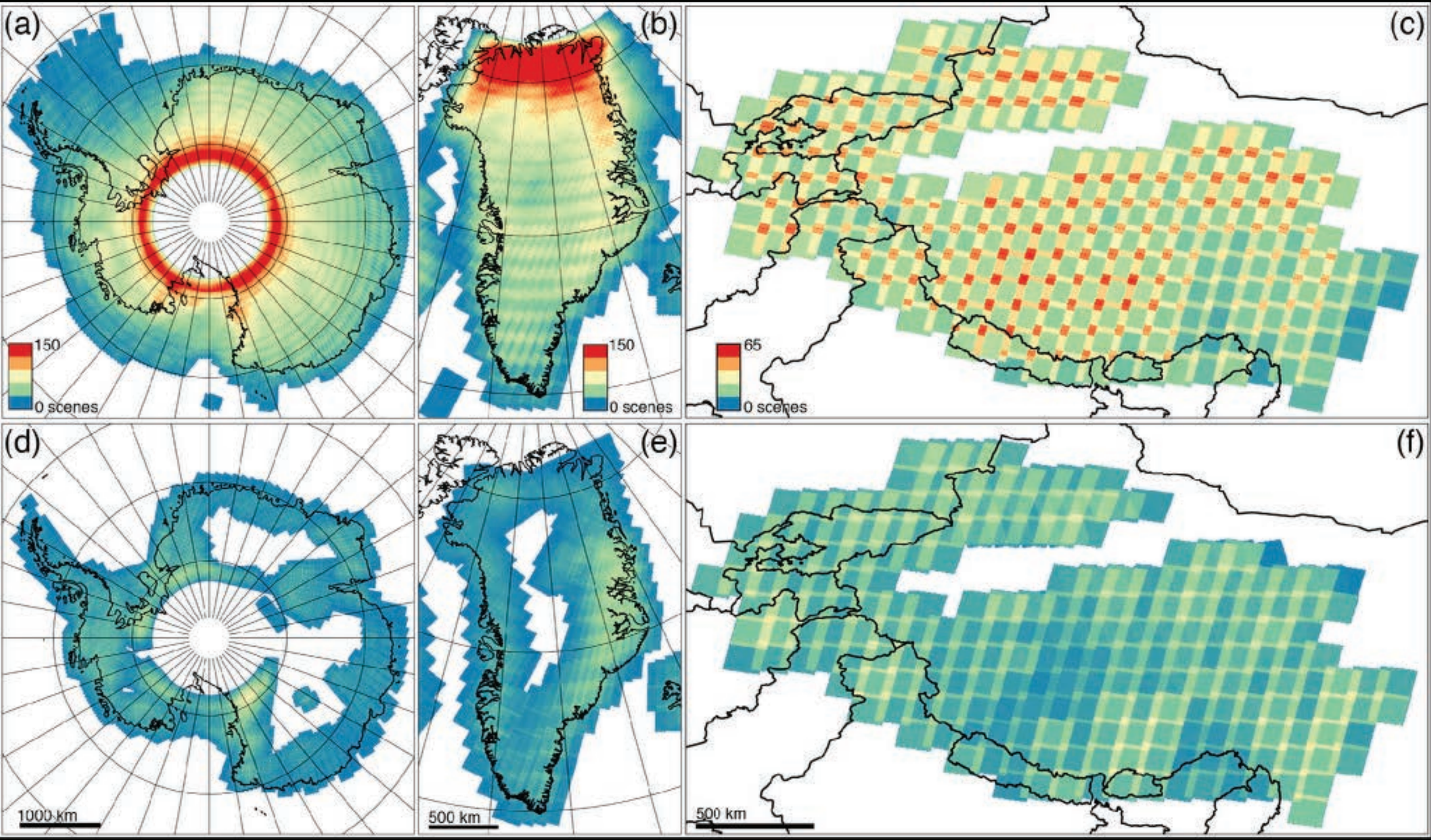
?

LANDSAT 8

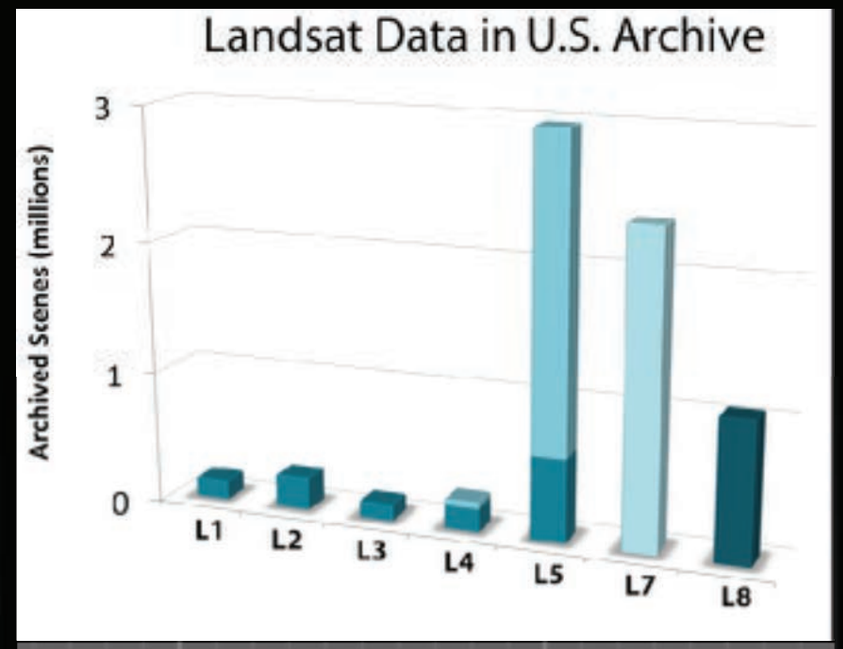
LANDSAT 8

- 12-bit radiometry means little/no saturation
- High geolocation accuracy (despite only L1GT some places)
- **High image acquisition rates**

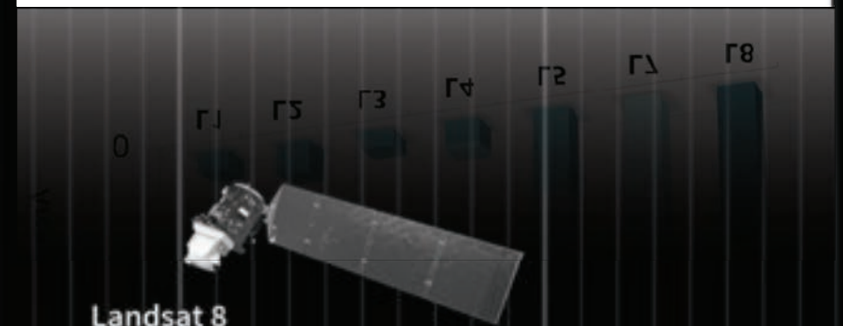



(a)
150
0 scenes
(b)
150
0 scenes
(c)
65
0 scenes
(d)
1000 km
(e)
500 km
(f)
500 km

BUILDING ON THE LANDSAT LEGACY



As of Sept 2017



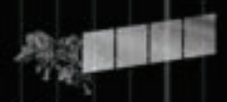
Landsat 1
1972-1978

Landsat 4
1982-1993

Landsat 2
1975-1982

Landsat 5
1984-2013

Landsat 3
1978-1983



Landsat 6
1993

Landsat 7
1999 –

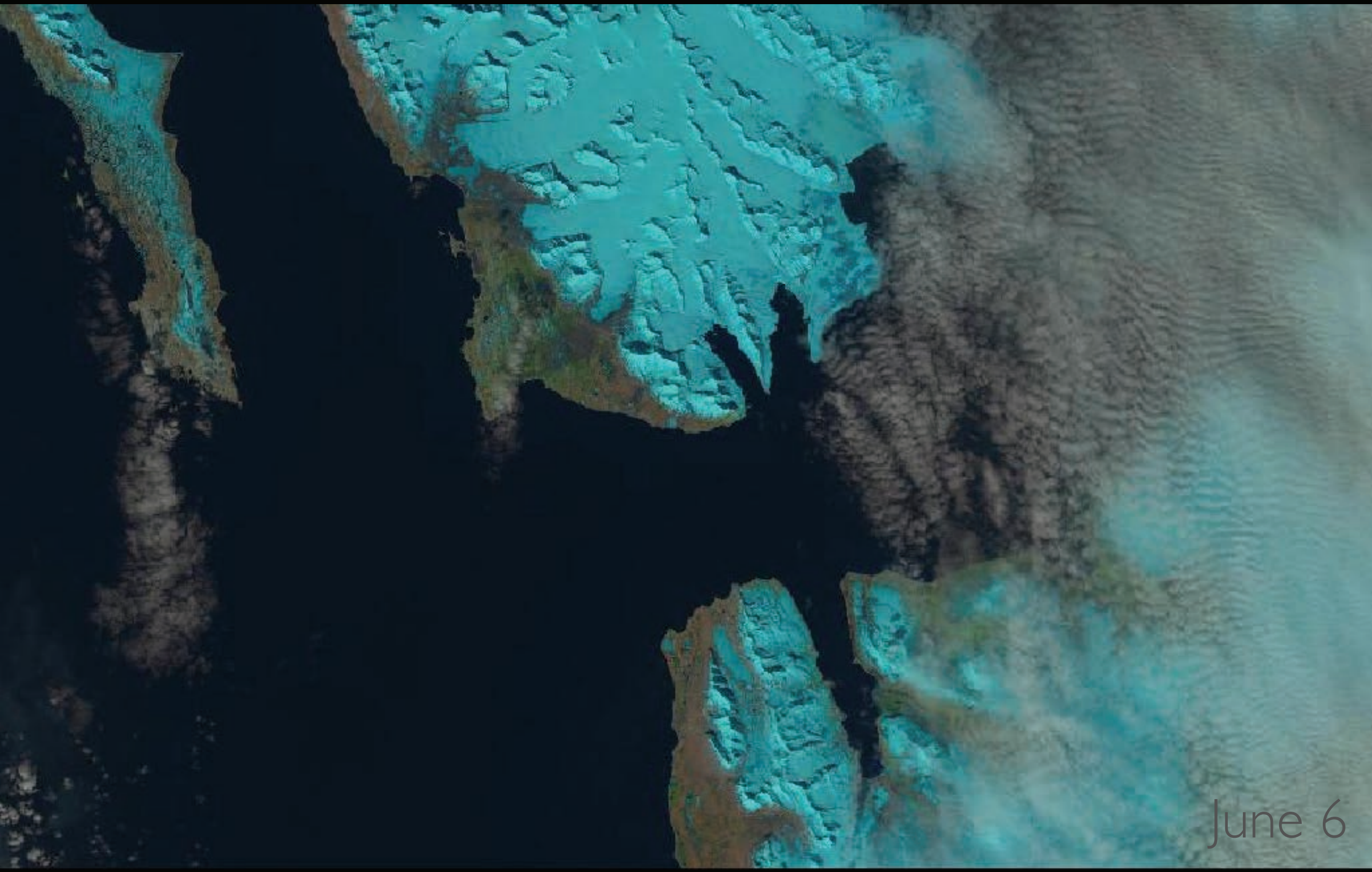
1972 1980 1990 2000 2010 2020 2030

USGS / NASA

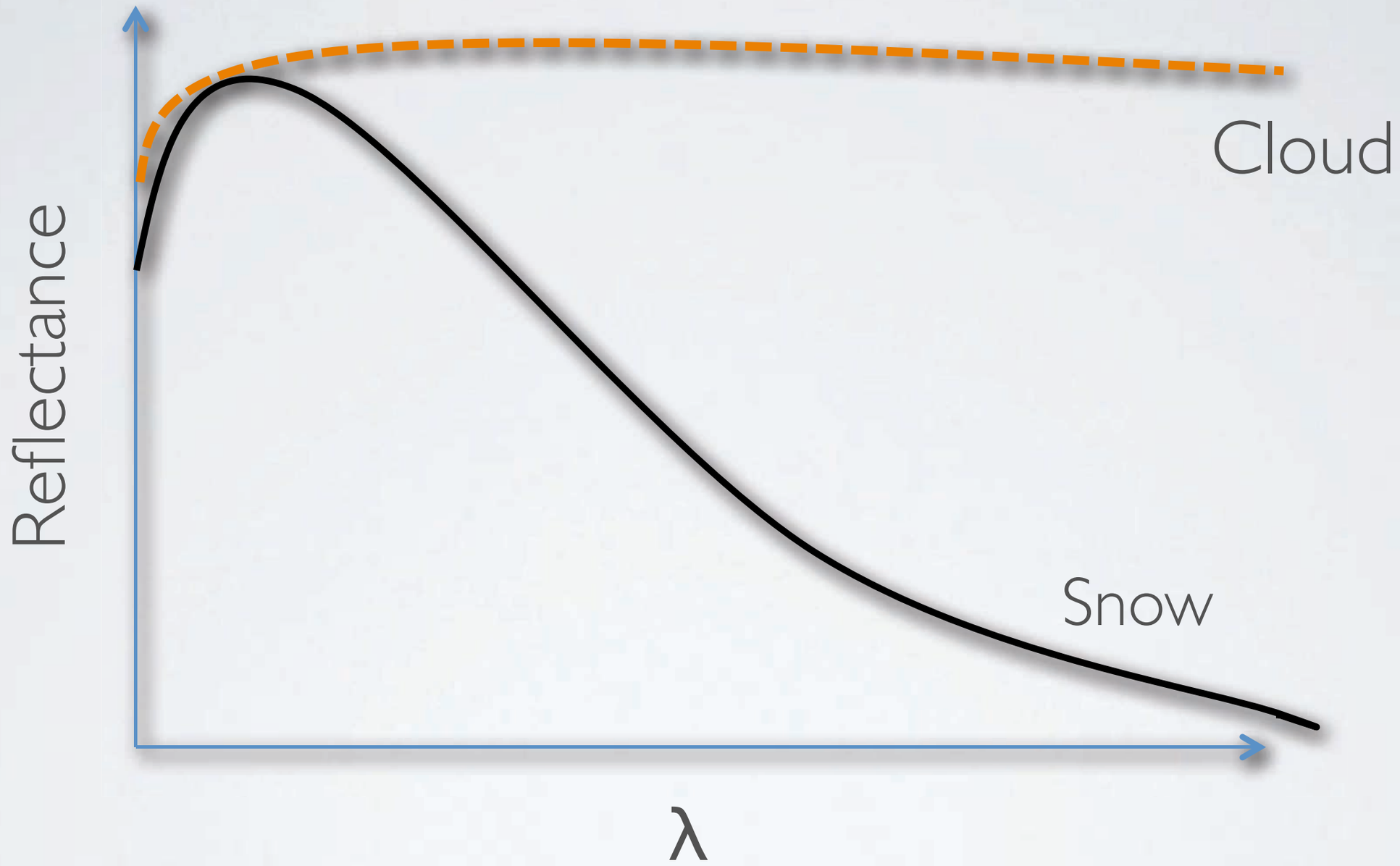
Snow/cloud discrimination with Landsat

Bands 3 2 1 (red, green, blue)

Bands 5 4 2

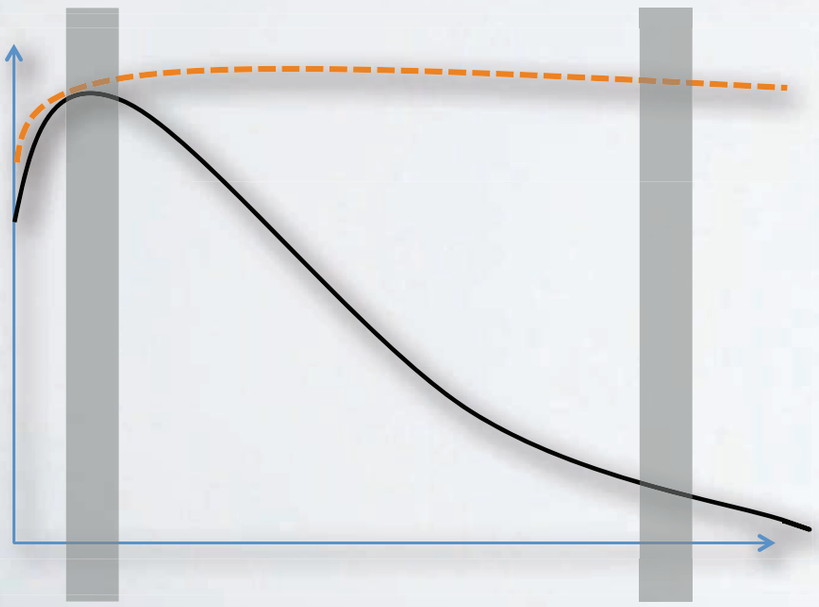


June 6


Reflectance
Cloud
Snow
λ

Normalized Difference Snow Index

$$NDSI = \frac{R_{Green} - R_{SWIR}}{R_{Green} + R_{SWIR}}$$



Snow/cloud discrimination with Landsat

Bands 3 2 1 (red, green, blue)

Bands 5 4 2

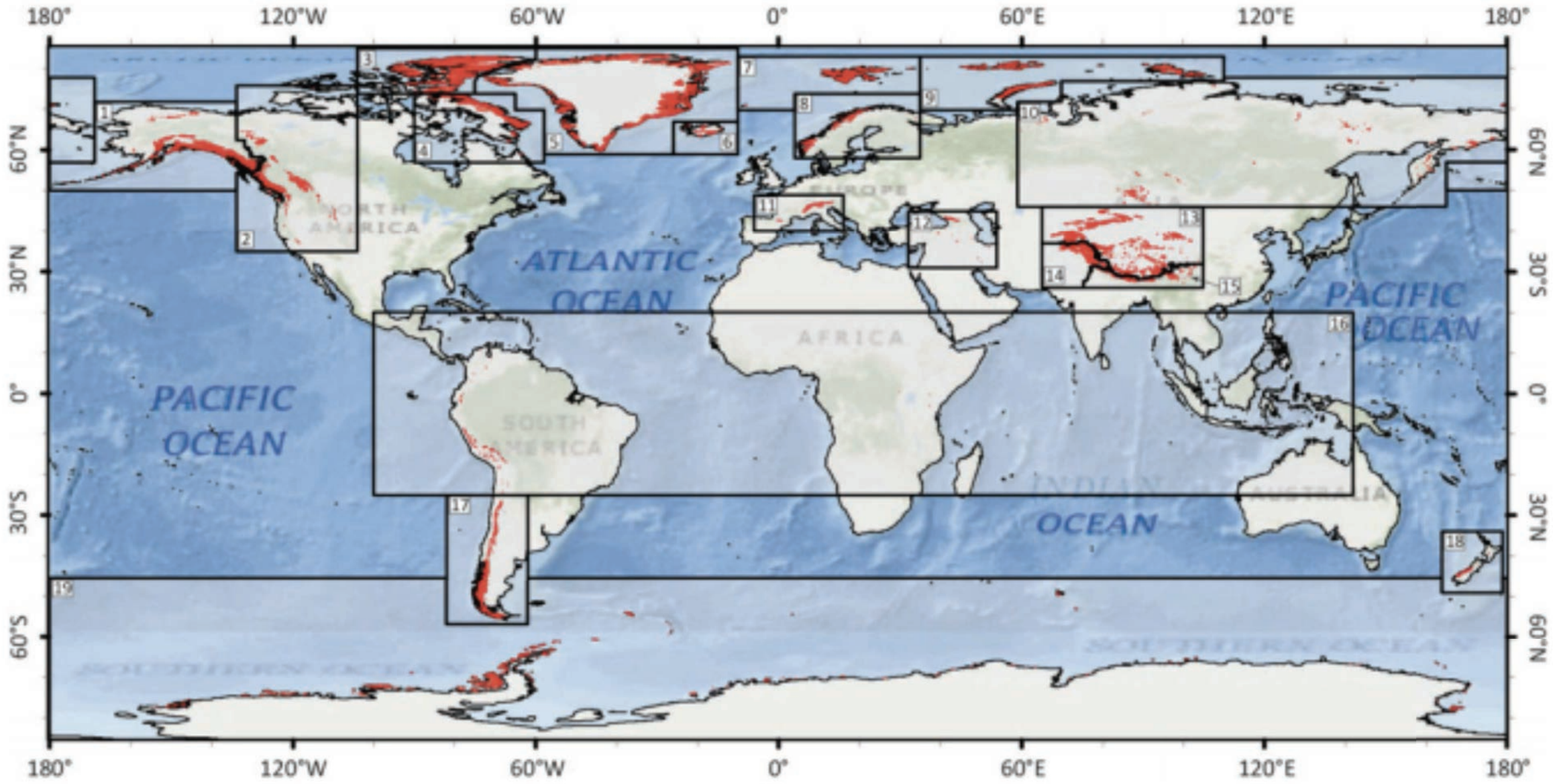


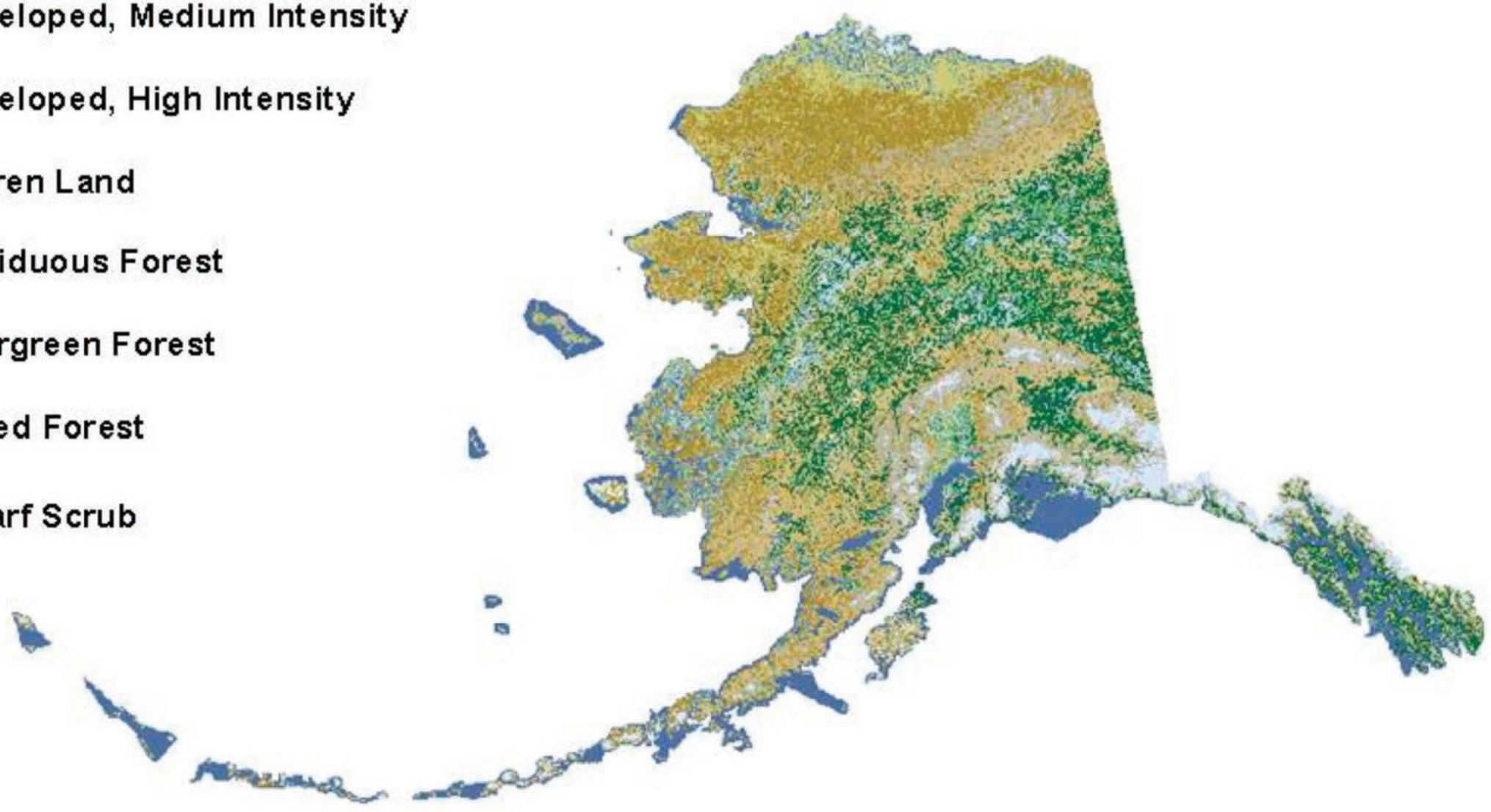
Fig. 1. First-order regions of the RGI, with glaciers shown in red. Region numbers are those of Table 2. Cylindrical equidistant projection.

Pfeffer et al., 2014

NLCD Alaska Land Cover: Classes and Percent Cover

Numbers in legend boxes indicate percent cover for the state of Alaska.

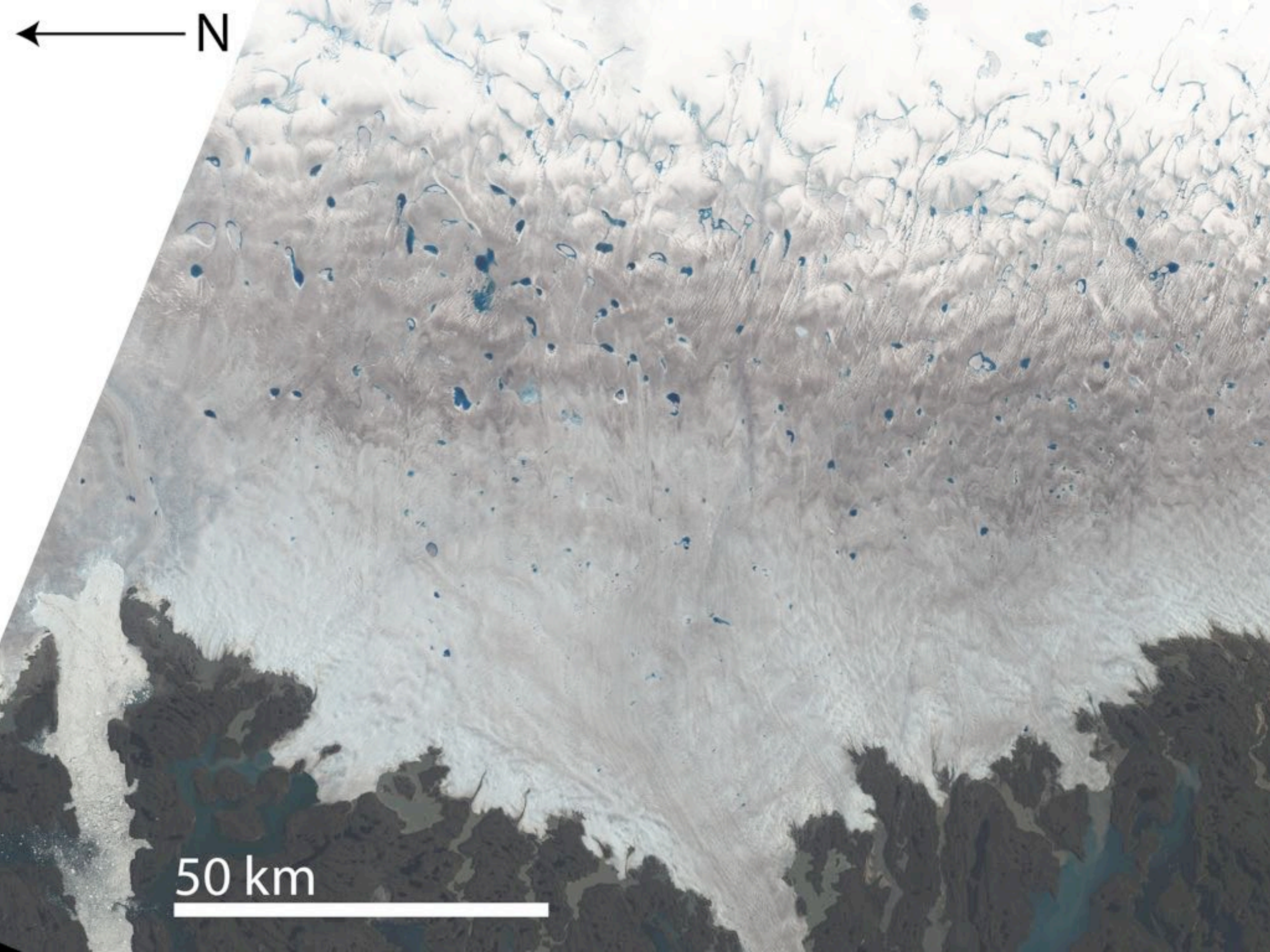
14.2	11 - Open Water
4.3	12 - Perennial Ice/Snow
.02	21 - Developed, Open Space
.06	22 - Developed, Low Intensity
.007	23 - Developed, Medium Intensity
.003	24 - Developed, High Intensity
7.7	31 - Barren Land
3.4	41 - Deciduous Forest
15.5	42 - Evergreen Forest
3.5	43 - Mixed Forest
17.2	51 - Dwarf Scrub
21.2	52 - Shrub/Scrub
0.8	71 - Grassland/Herbaceous
5.7	72 - Sedge/Herbaceous
.03	74 - Moss
.003	81 - Pasture/Hay
.02	82 - Cultivated Crops
3.5	90 - Woody Wetlands
2.9	95 – Emergent Herbaceous Wetlands



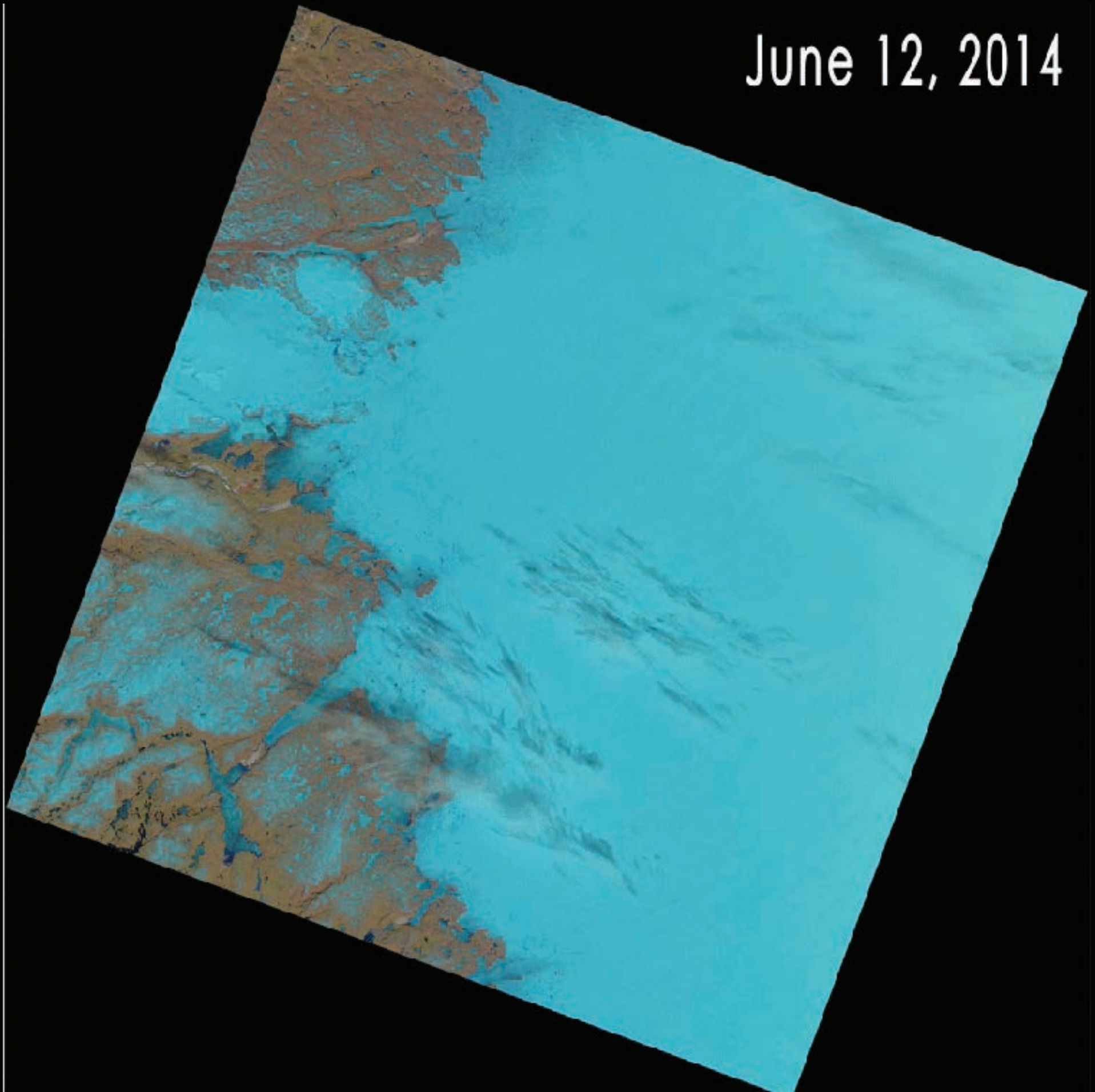
Estimating Supraglacial Lake Depth With Landsat 8

Allen Pope,
Ted Scambos, Mahsa Moussavi,
Marco Tedesco, Mike Willis, Dave Shean, and Shane Grigsby

Photo: Ian Willis


N
50 km

June 12, 2014



Method 1

Based on 1 band (usually green), physically based, widely used

Lake Depth

Reflectance of Optically Deep Water

Water Absorption Coefficient

$$z = -(\ln(A_d - R_\infty) - \ln(R_{lake} - R_\infty)) / g$$

Bottom Albedo

Reflectance of Lake Pixel

e.g. Sneed & Hamilton 2007

Method 2

Relatively new method for glaciology, uses 2 bands, empirical

Empirical Coefficients from earlier regression

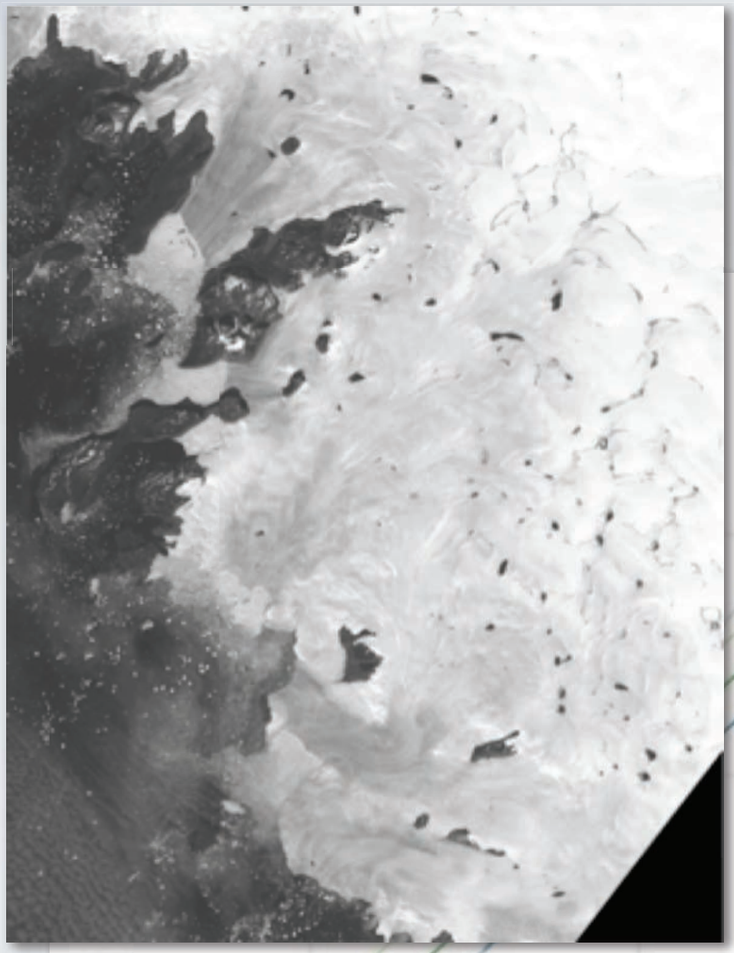
Lake Depth → $z = a + bX + cX^2$

$X = \ln(R_1 / R_2)$

Band Reflectances

Legleiter et al. 2013

Lake Volume



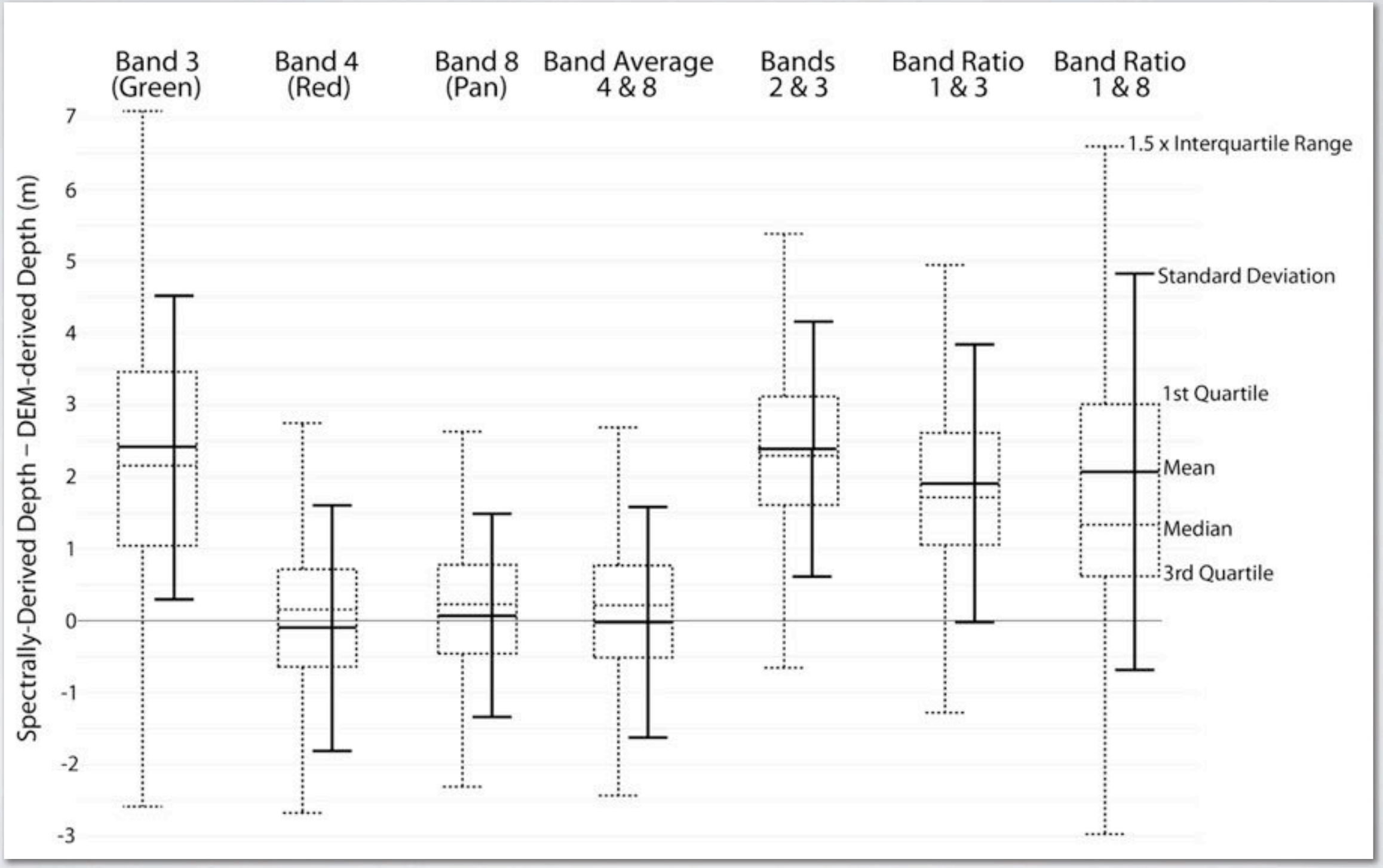
Band 3
Band 4
Band 8
Band Ratio 1 & 3
Band Ratio 1 & 8
Bands 2 & 3
Band Average 4 & 8
2x+
200M
150M
100M
50M
Total Lake Volume (cubic meters)
1 July
10 July
20 July
1 August
10 August
20 August
Day of Year, 2013

WorldView Stereo DEMs

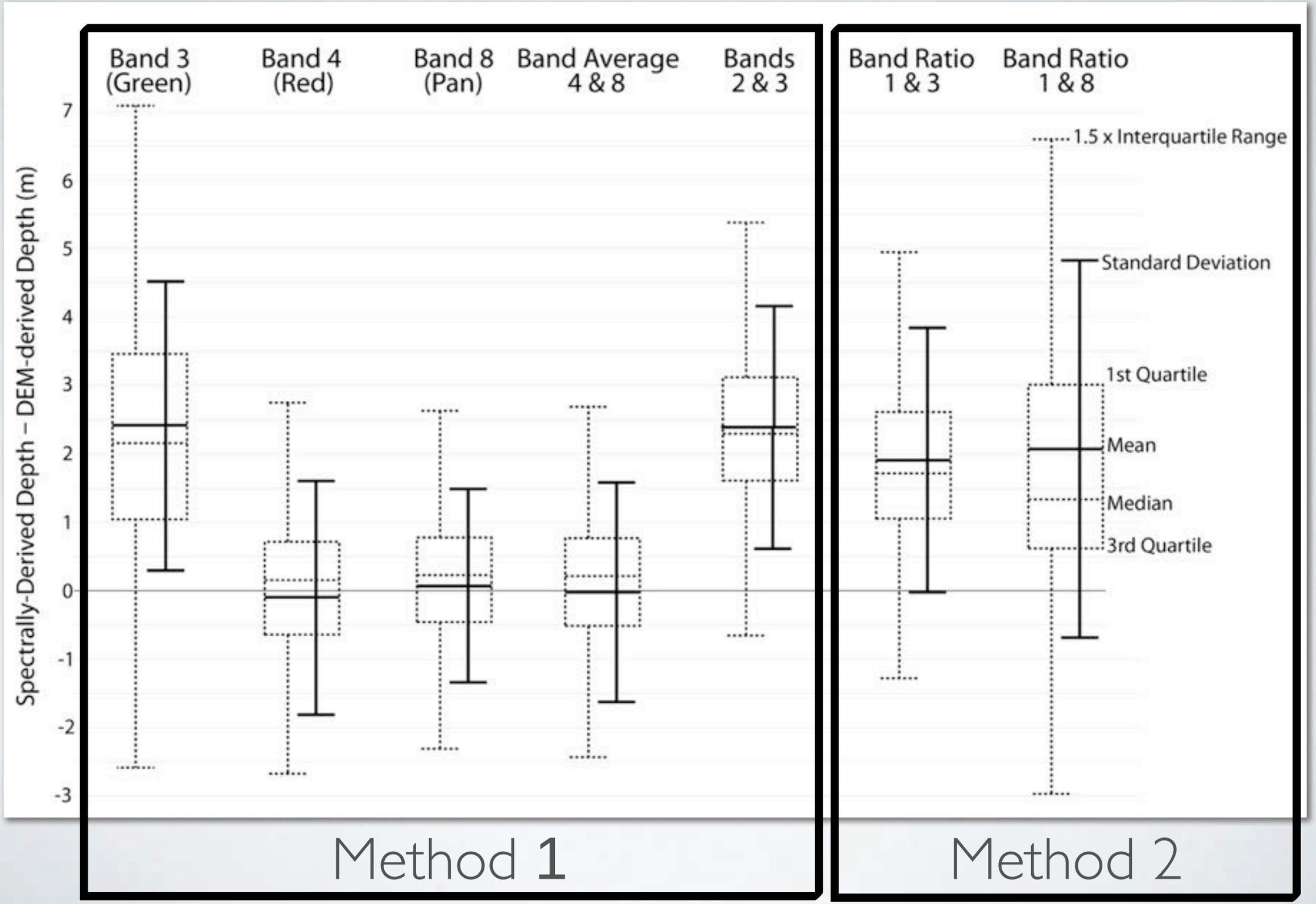
- Spring and Fall 2013
- 6 days in NW Greenland
- 6 days in Jakobshavn area
- Total of 250,000+ comparison pixels

WorldView data via UMN PGC

SPECTRAL – DEM COMPARED



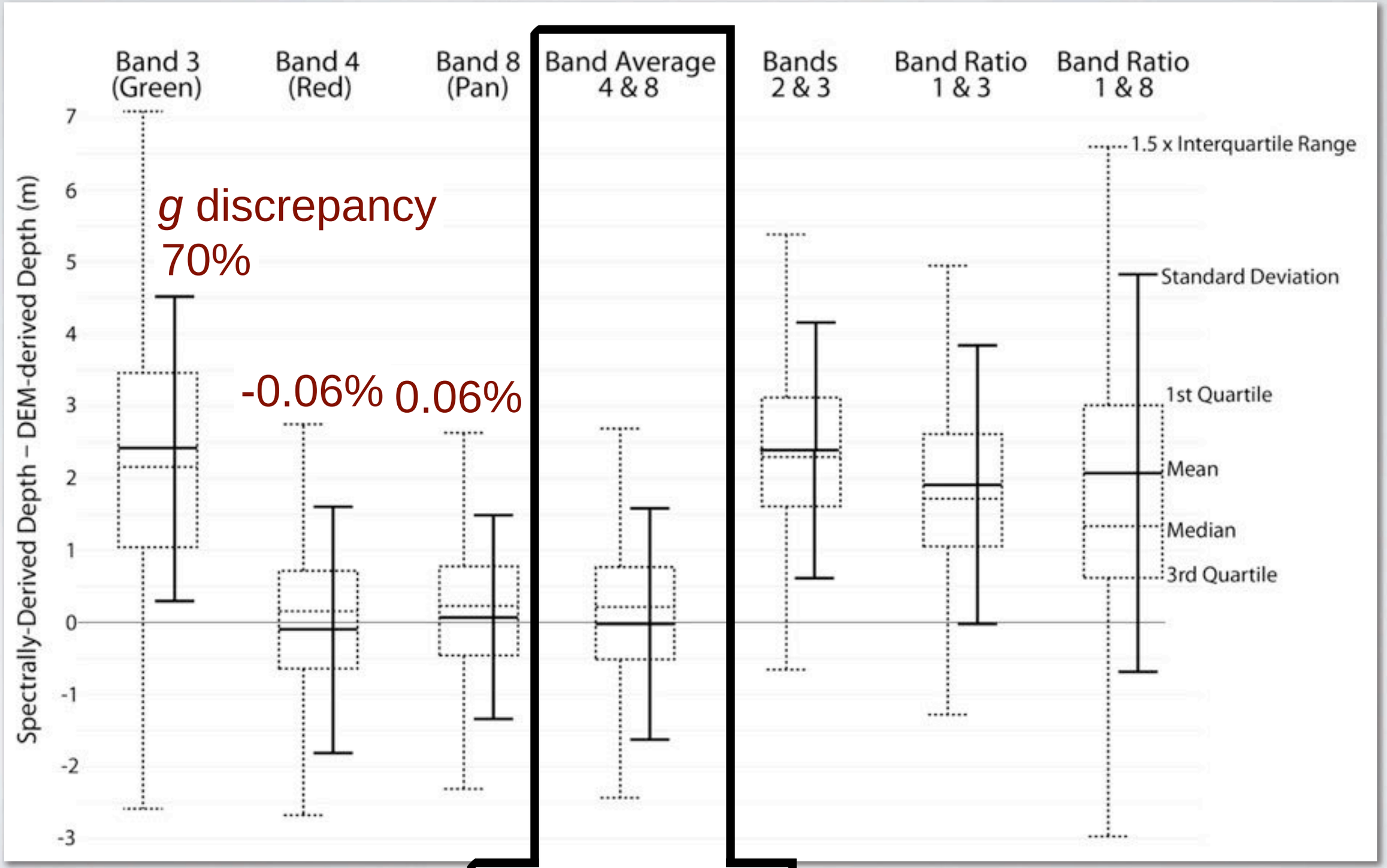
SPECTRAL – DEM COMPARED



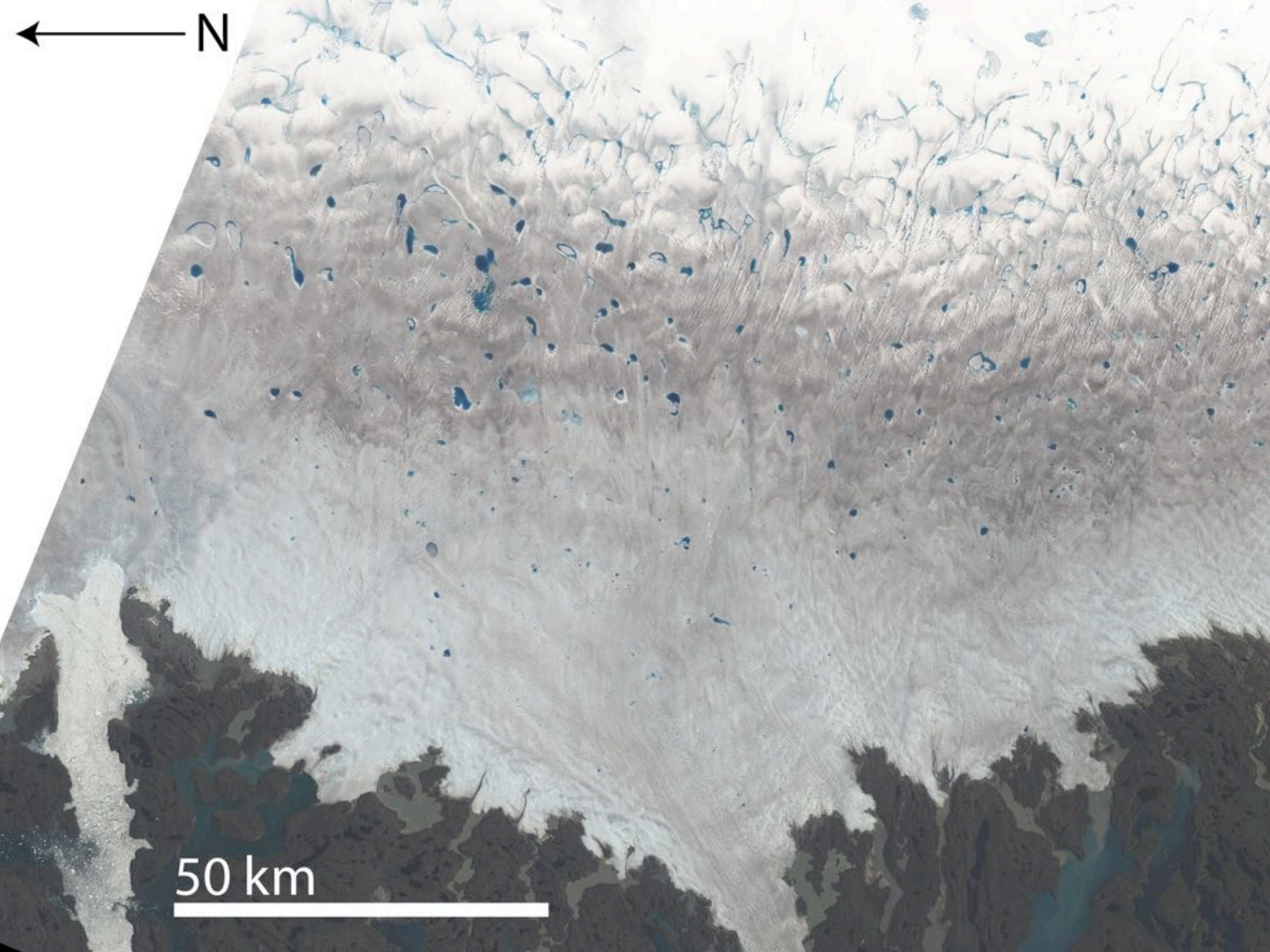
Method 1
Water Absorption Coefficient

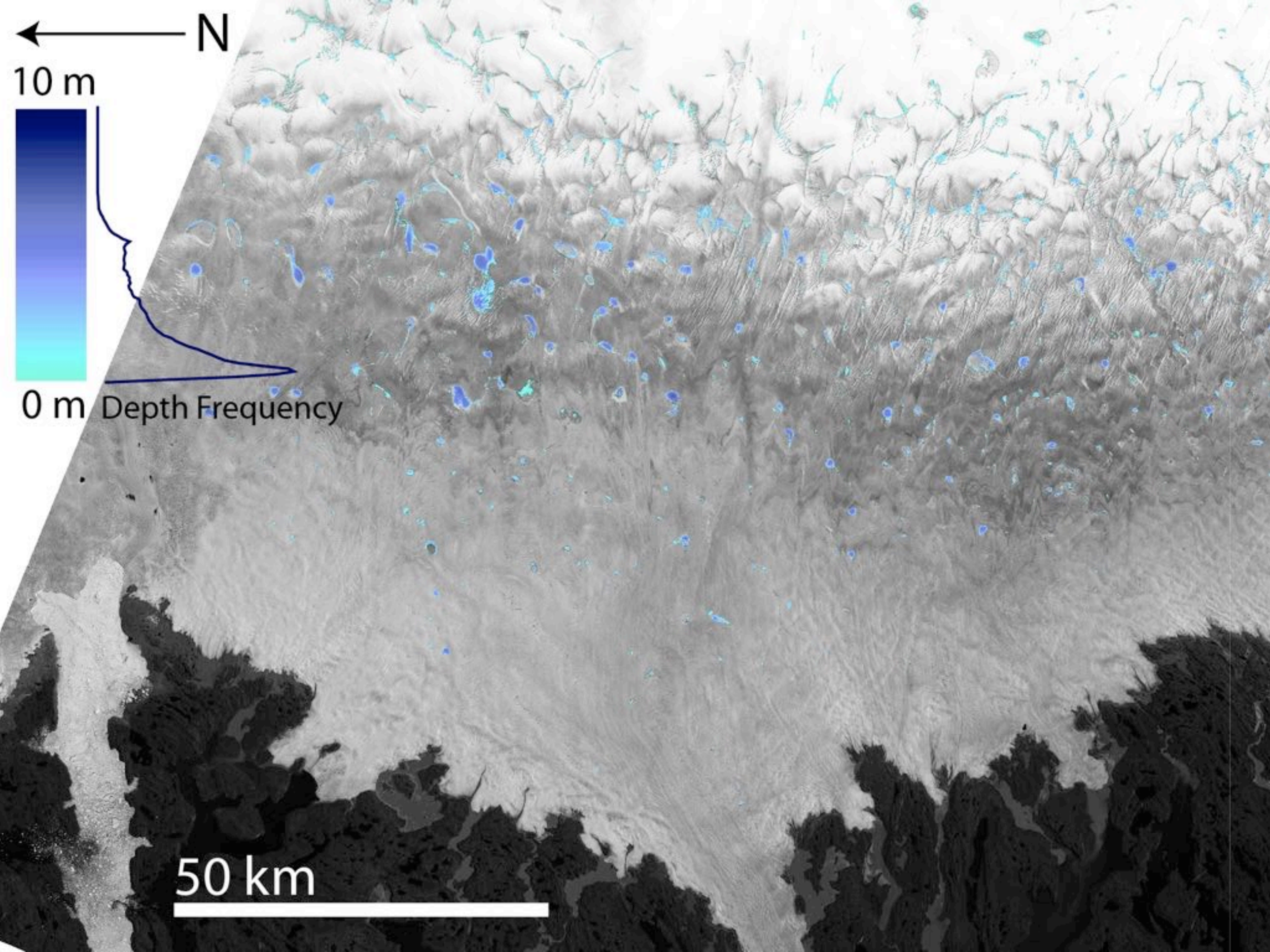
	Theoretical g	Regressed g	% Difference
Band 3 / Green	0.17	0.1	70%
Band 4 / Red	0.75	0.8	-0.06%
Band 8 / Pan	0.38	0.36	0.06%

SPECTRAL – DEM COMPARED



~0 ± 1.6 m


N
50 km


N
10 m
0 m
Depth Frequency
50 km

009 / 011

008 / 011

008 / 012

010 / 011
009 / 012

007 / 012

006 / 012

007 / 013

006 / 013

006 / 014

007 / 014

006 / 015

70°

69°

68°

67°

66°

65°

64°

Latitude

Ice Elevation

2000 m

1800 m

1600 m

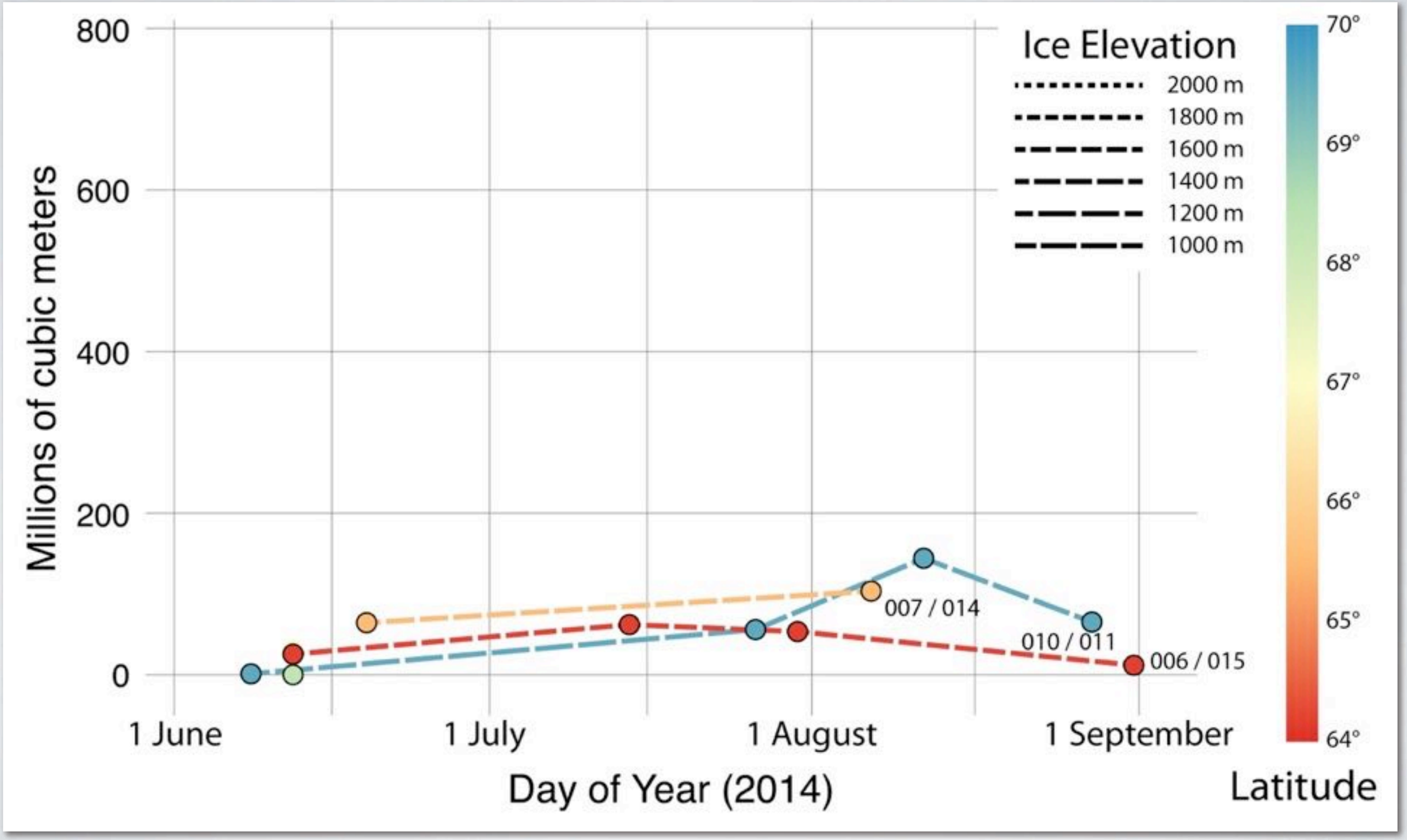
1400 m

1200 m

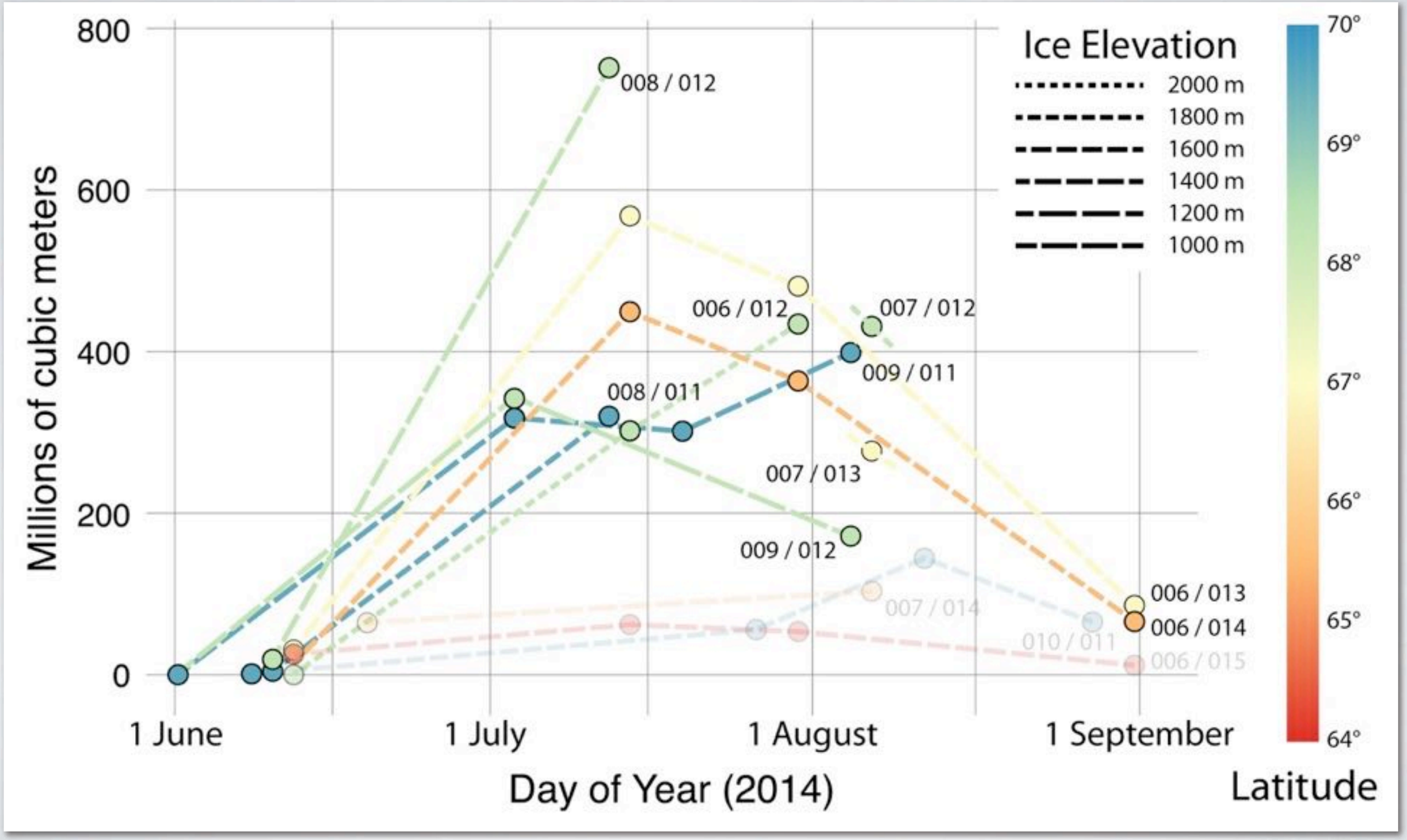
1000 m

GIMP DEM courtesy BPRC
Glacier Dynamics Research
Group, Ohio State University

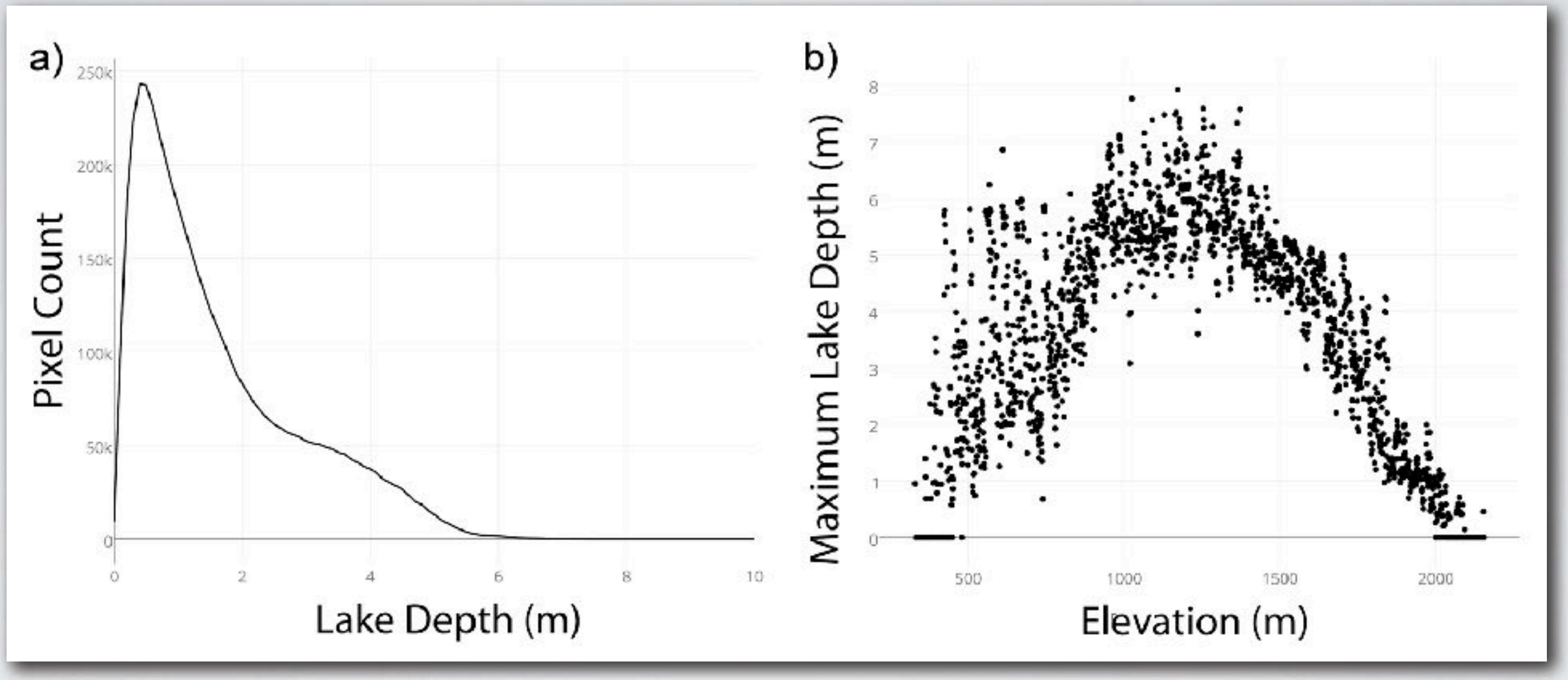
WATER VOLUME BY PATH/ROW



WATER VOLUME BY PATH/ROW



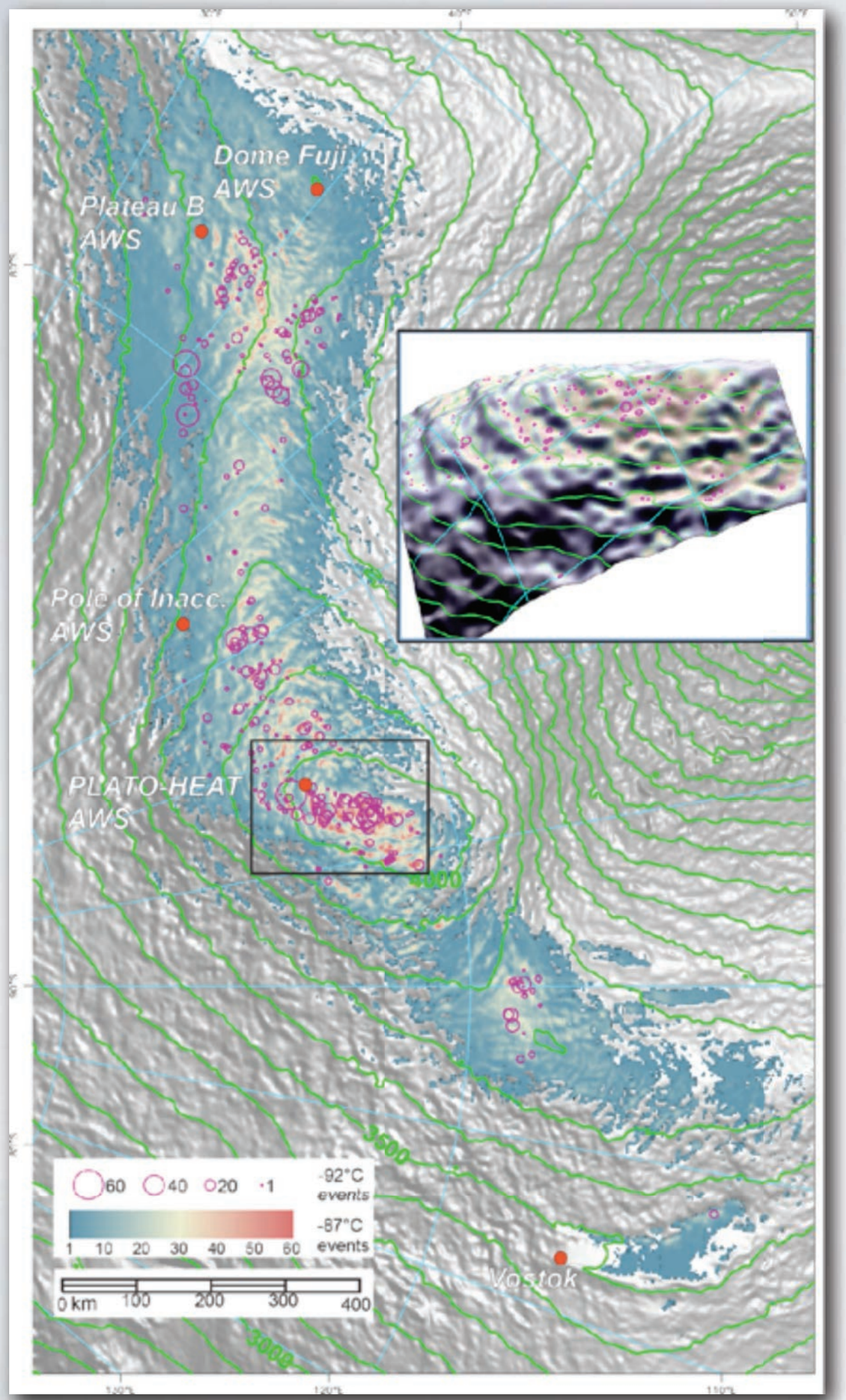
Lake Depths & Elevations



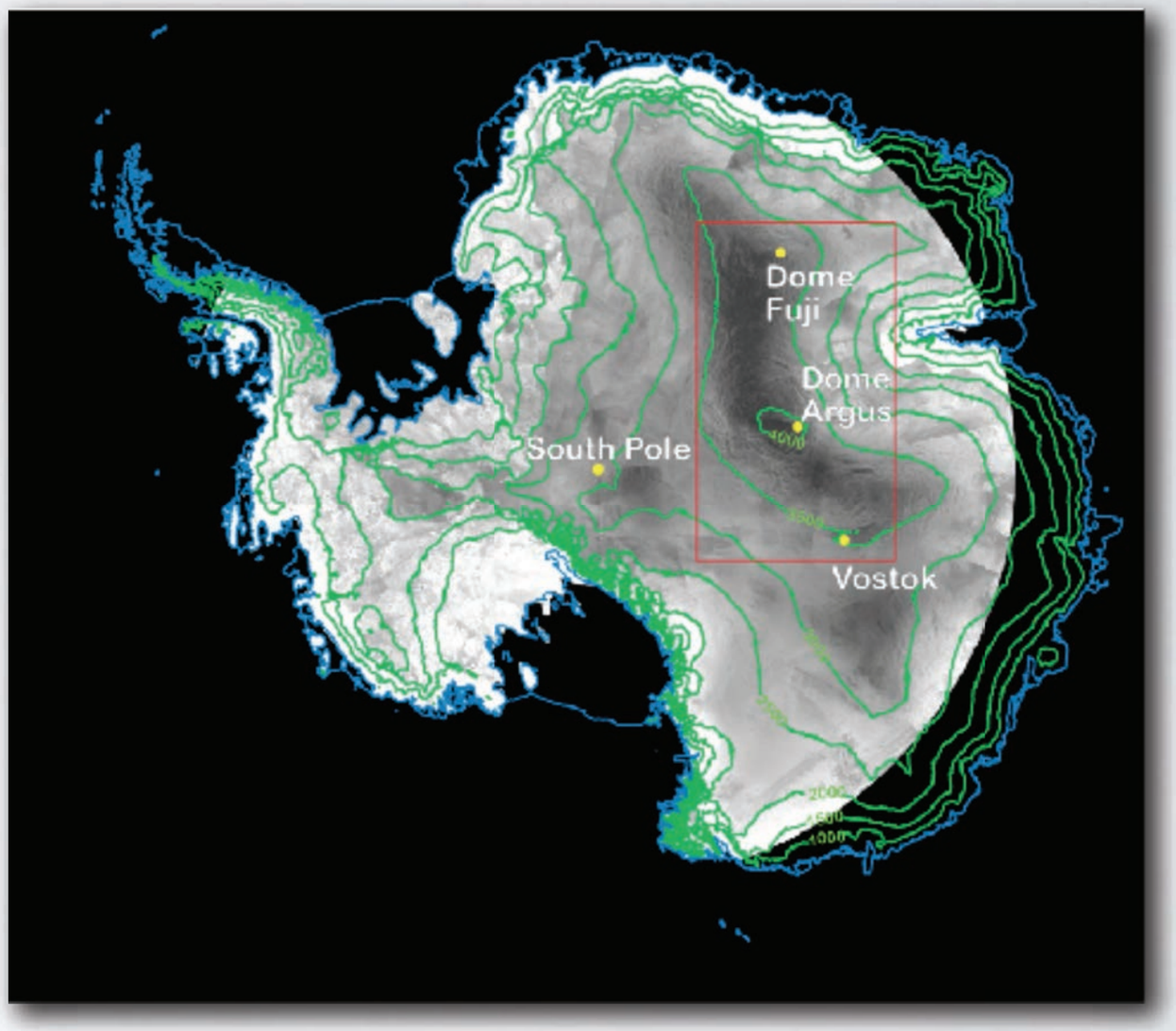
Take-Away Points

- Used *in situ* data to test idealized capability of Landsat 8 to estimate supraglacial lake depth
- Identified the best bands / band combinations for application
- Applied to two sets of Landsat observations and compared with WorldView DEM-derived lake depths
- Relative patterns of lake depth/volume are consistent, but magnitudes are inconsistent over a factor of 2
- Landsat 8 OLI Bands 4 (Red) and 8 (Pan) perform best when the results from single-band lake depth retrieval are averaged together

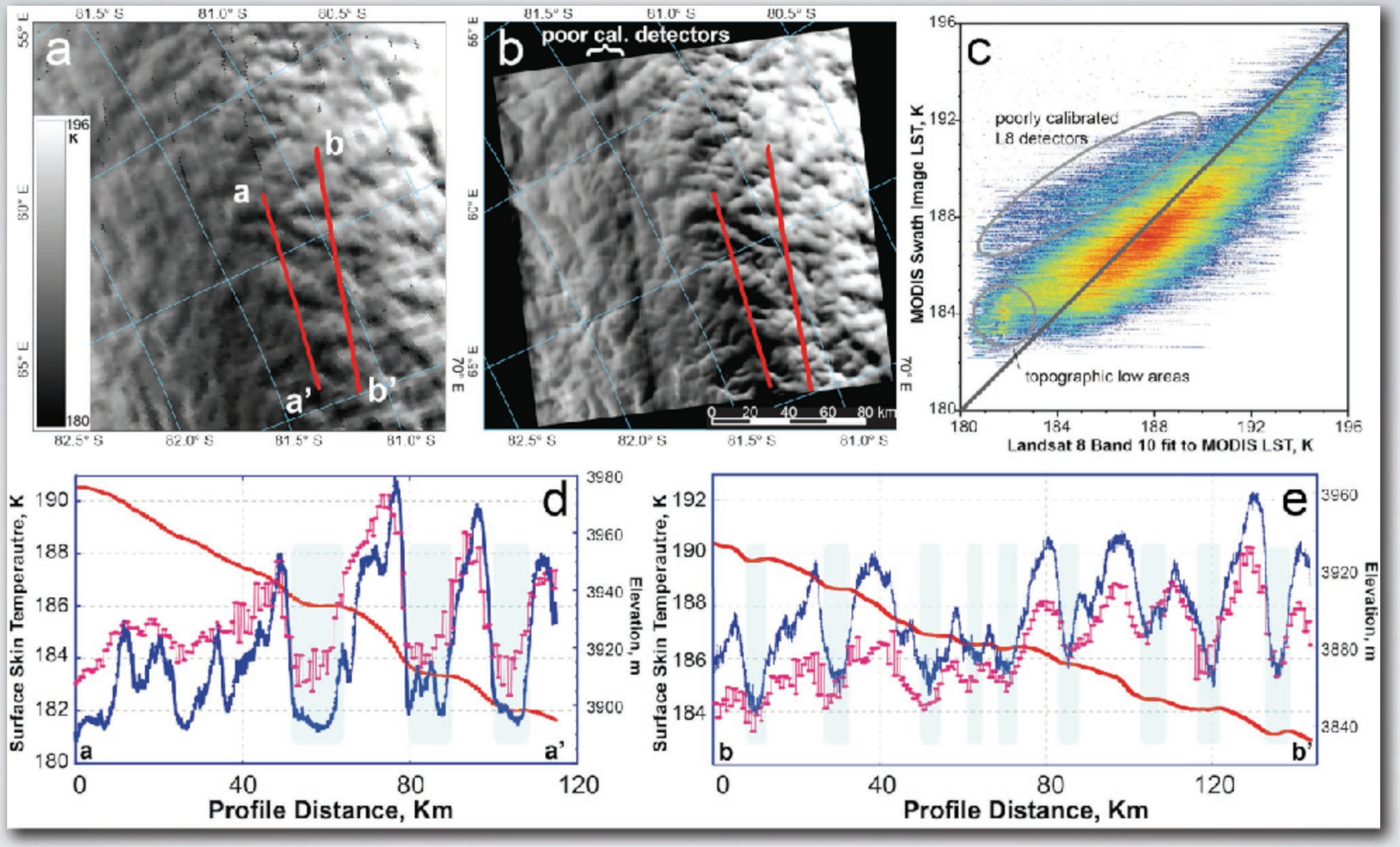
Photo: Ian Willis



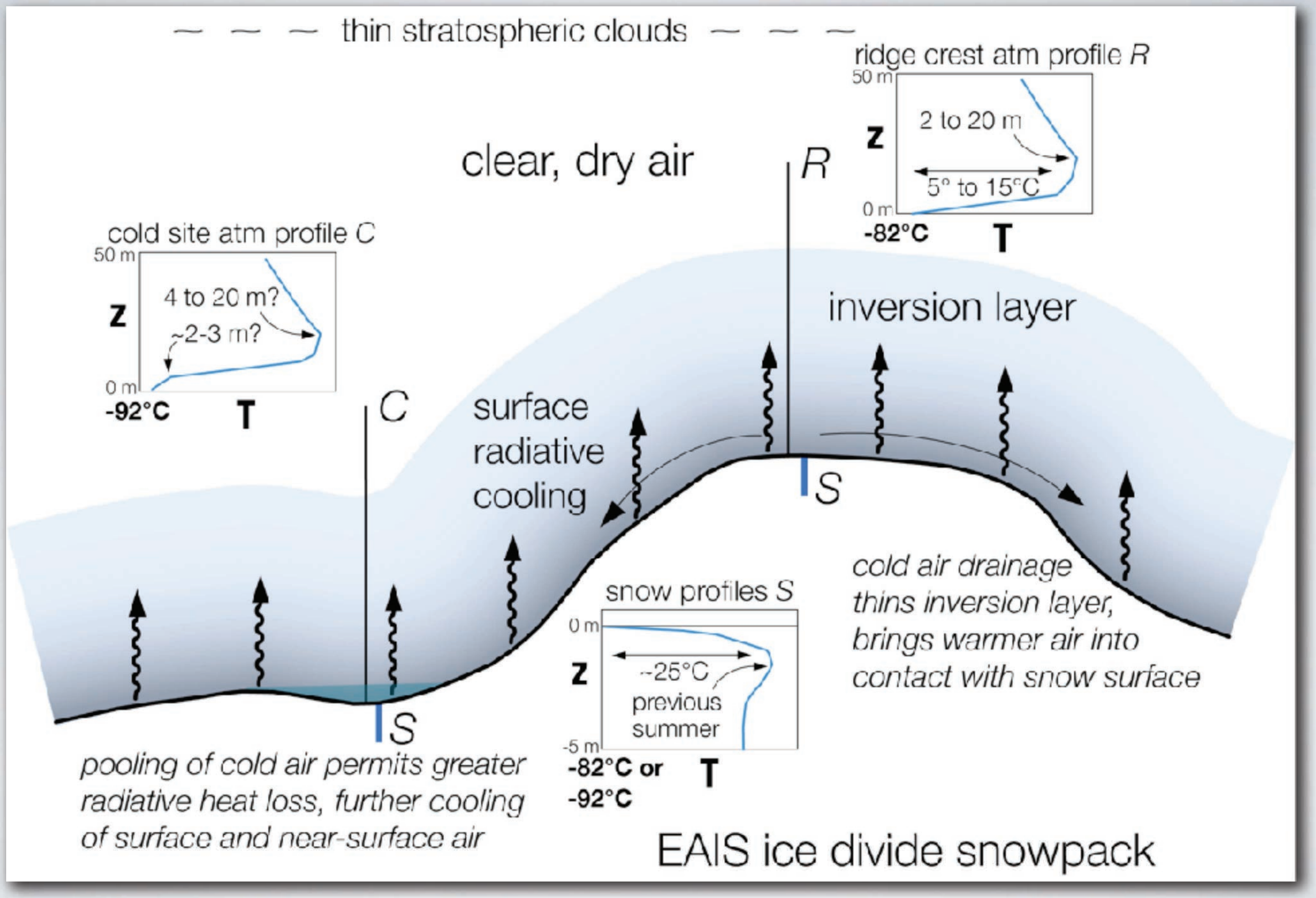
"The Coldest Place on



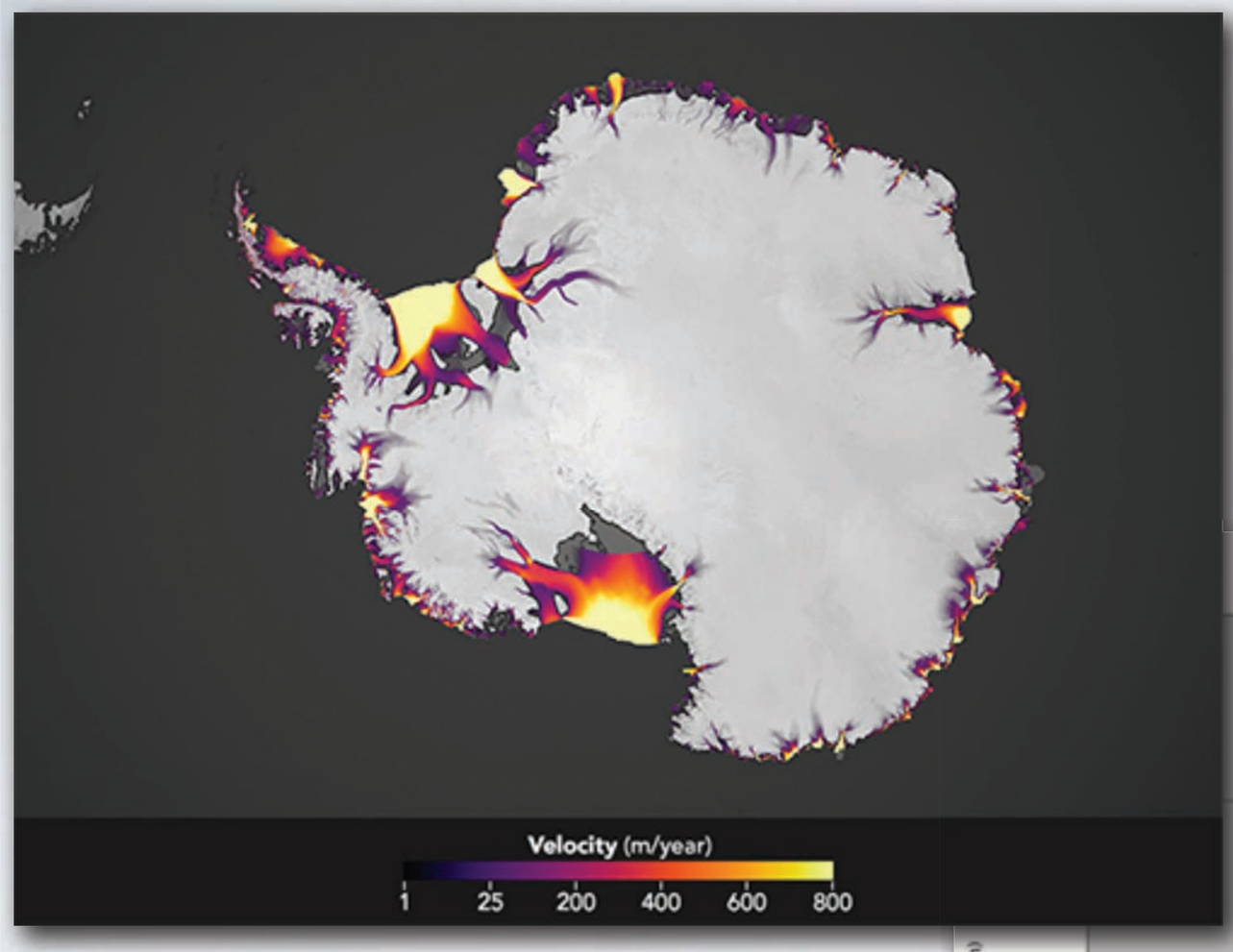
Ted Scambos

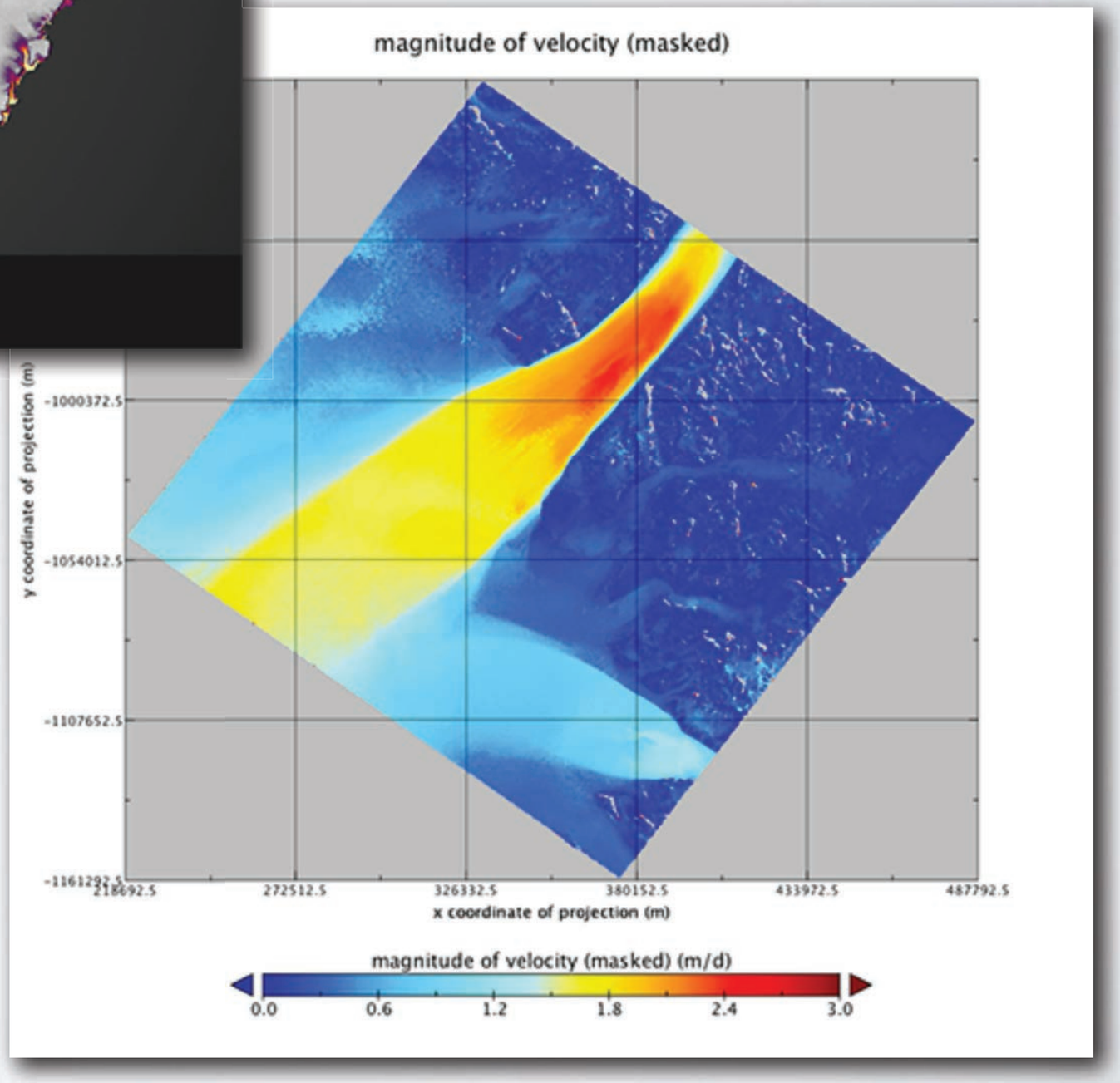

a
b
poor cal. detectors
C
196
K
180
a
a'
b
b'
81.5° S
81.0° S
80.5° S
55° E
60° E
65° E
70° E
82.5° S
82.0° S
81.5° S
81.0° S
0 20 40 60 80 km
poorly calibrated
L8 detectors
topographic low areas
MODIS Swath Image LST, K
Landsat 8 Band 10 fit to MODIS LST, K
d
e
Surface Skin Temperautre, K
Elevation, m
Profile Distance, Km

Ted Scambos

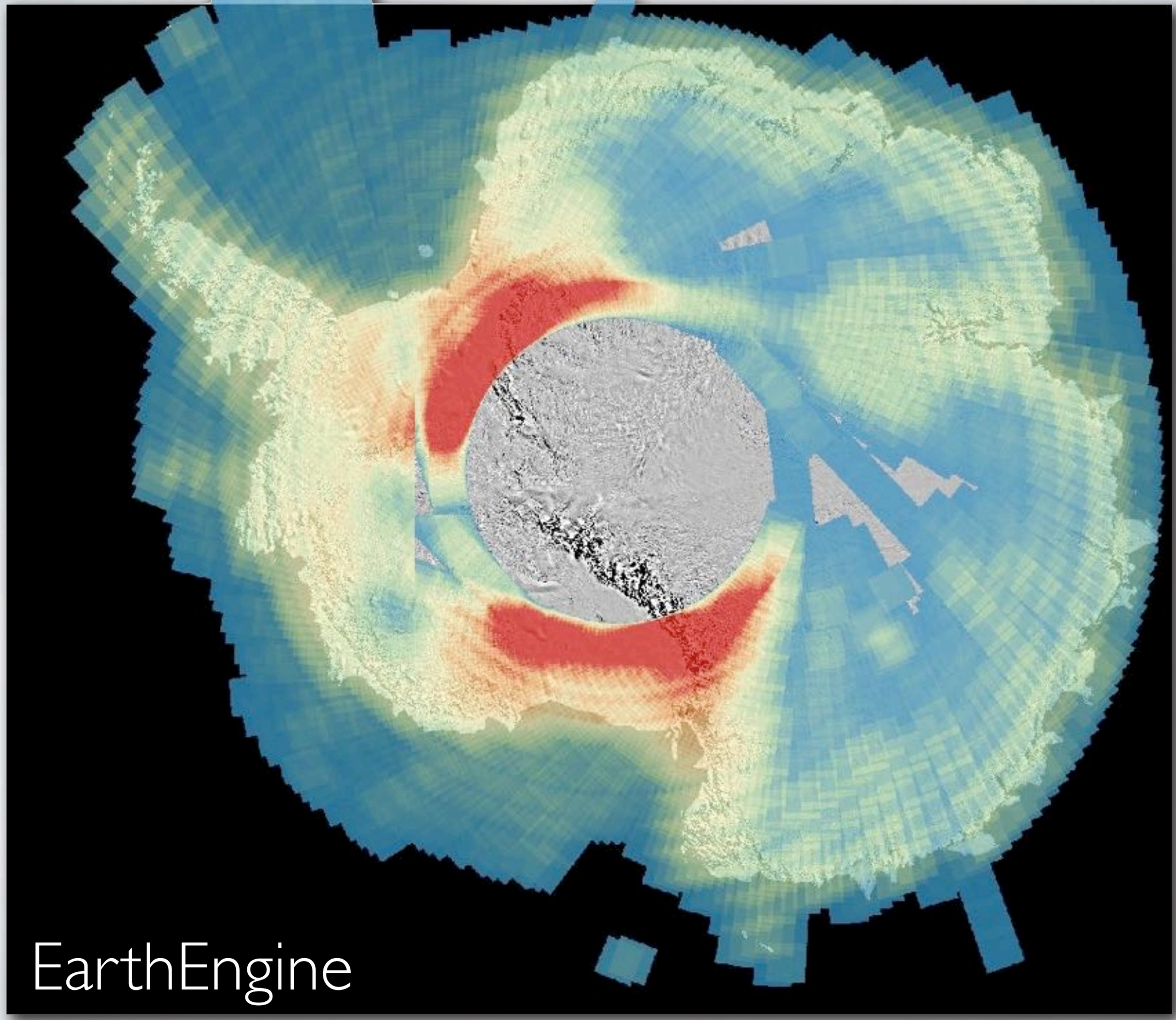

thin stratospheric clouds
ridge crest atm profile R
50 m
2 to 20 m
Z
5° to 15°C
0 m
-82°C
T
clear, dry air
R
cold site atm profile C
50 m
4 to 20 m?
Z
~2-3 m?
0 m
-92°C
T
inversion layer
C
surface
radiative
cooling
S
cold air drainage
thins inversion layer,
brings warmer air into
contact with snow surface
snow profiles S
0 m
Z
~25°C
previous
summer
-5 m
-82°C or
-92°C
T
pooling of cold air permits greater
radiative heat loss, further cooling
of surface and near-surface air
S
EAIS ice divide snowpack

Ted Scambos





NSIDC / NASA GoLIVE


EarthEngine

Open Data?
Open Code?

The ongoing melting of Alaska's Columbia glacier is shown in these Landsat images fro

EARTH OBSERVATIONS

US government reviews data fees

Images from Landsat satellites and agricultural-survey programme are freely available to scientists — for now.

AGU PUBLICATIONS

Earth and Space Science

TECHNICAL REPORTS: METHODS

10.1002/2015EA000125

Special Section: Geoscience Papers of the Future

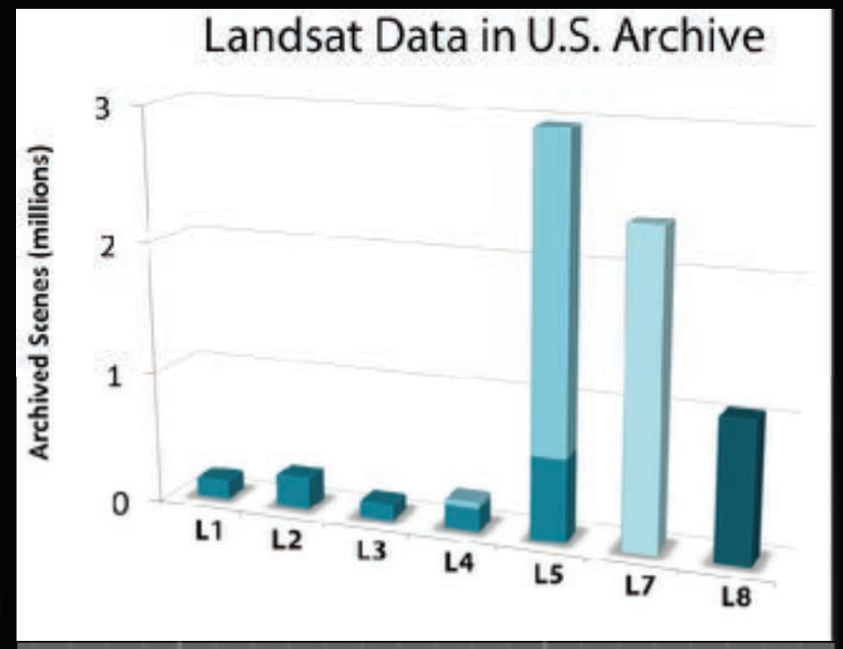
Reproducibly estimating and evaluating supraglacial lake depth with Landsat 8 and other multispectral sensors

Allen Pope[1]

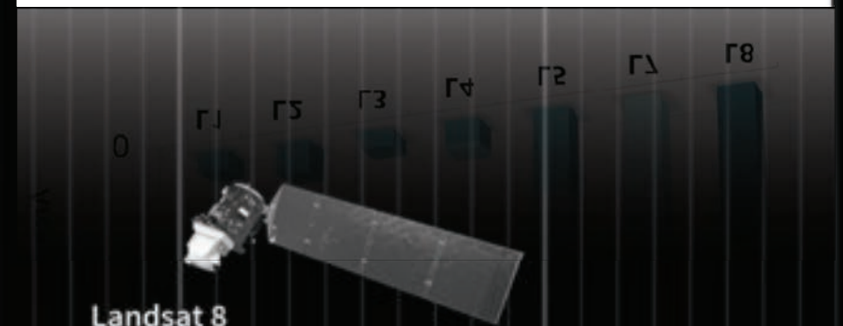
[1]National Snow and Ice Data Center, University of Colorado Boulder, Boulder, Colorado, USA

Abstract Lakes which form on the surface of ice sheets (supraglacial lakes) play an important role in the ice sheet hydrological system, serving as temporary reservoirs for meltwater that can lead to ice fracture

BUILDING ON THE LANDSAT LEGACY



As of Sept 2017



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1972-1978

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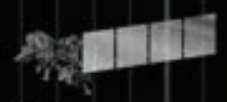


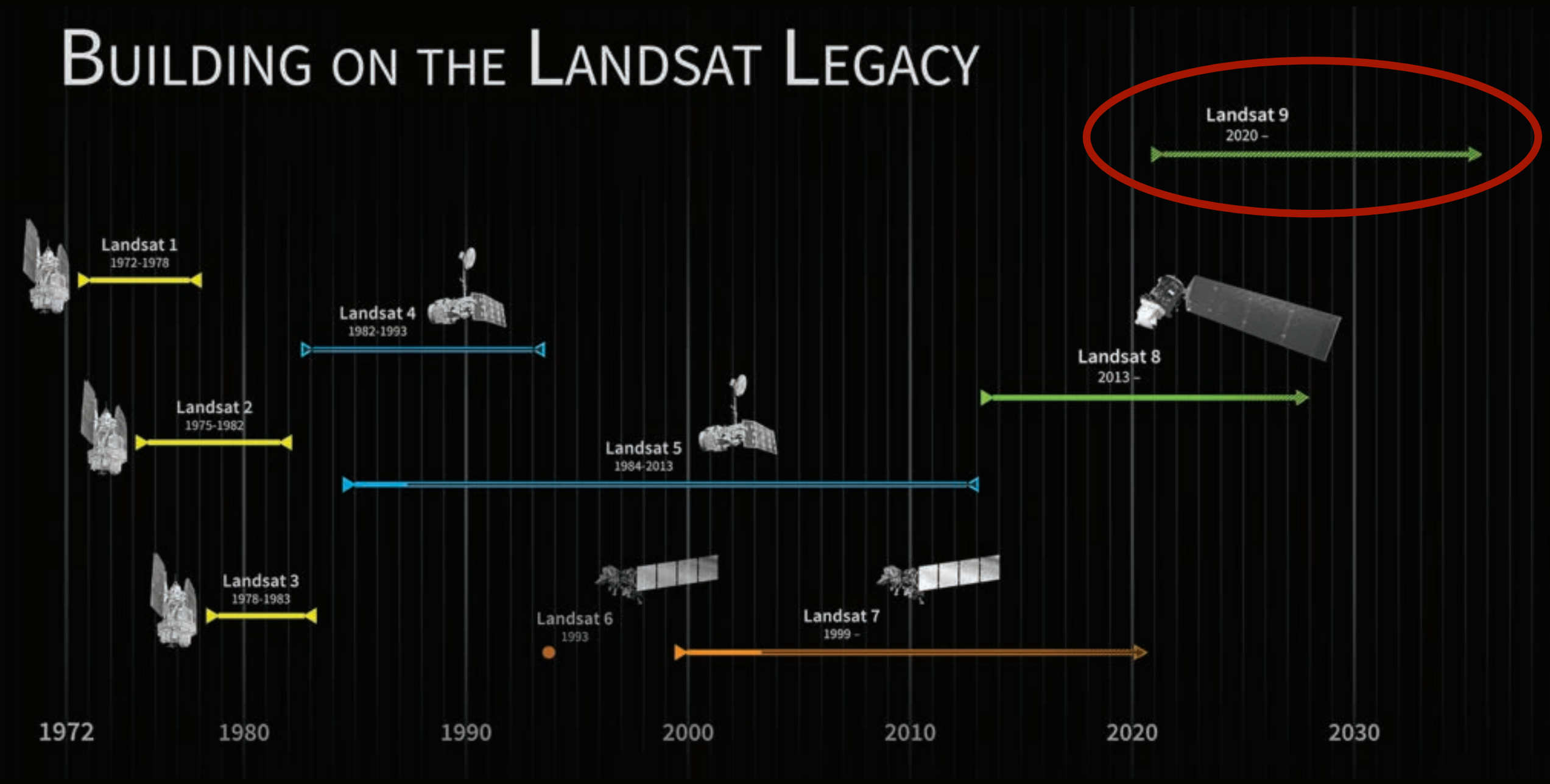
Landsat 6
1993

Landsat 7
1999 –

1972 1980 1990 2000 2010 2020 2030

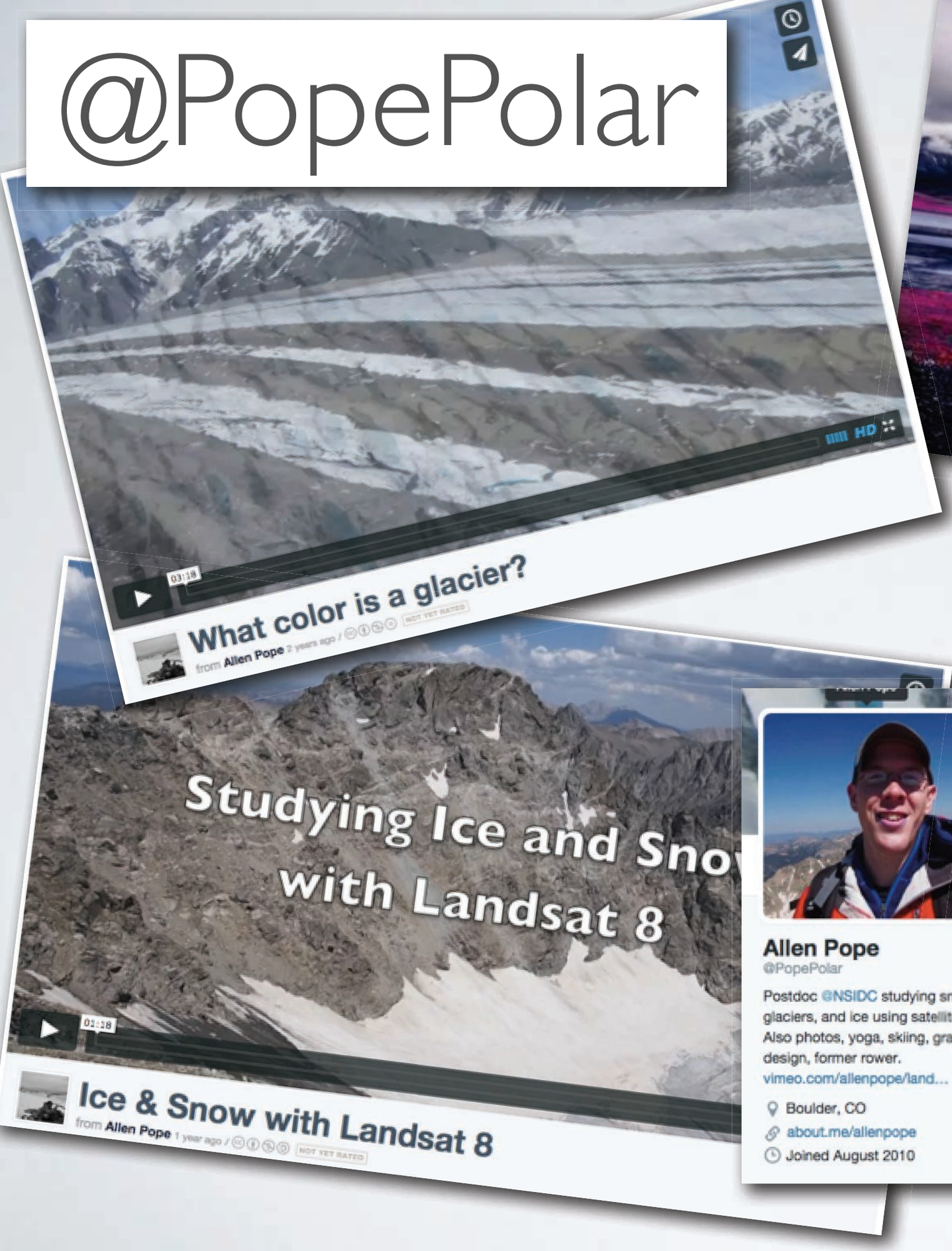
USGS / NASA

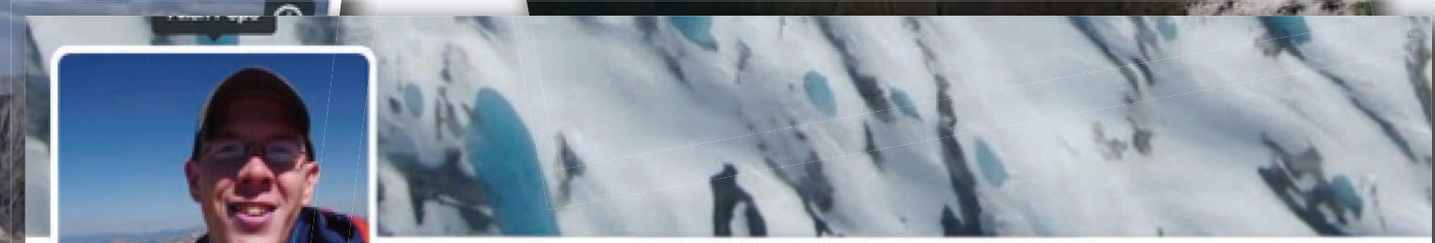
- Landsat 9 has been fast-tracked for a December 2020 launch.
- Very similar to L8, but with a few tweaks
- How is it funded? Demonstrating societal benefit!!



USGS / NASA

@PopePolar


What color is a glacier?
from Allen Pope 2 years ago
Studying Ice and Snow with Landsat 8
Ice & Snow with Landsat 8
from Allen Pope 1 year ago



Allen Pope
@PopePolar
Postdoc @NSIDC studying snow, glaciers, and ice using satellite imagery. Also photos, yoga, skiing, graphic design, former rower.
vimeo.com/allenpope/land...
Boulder, CO
about.me/allenpope
Joined August 2010
TWEETS 6,868
FOLLOWING 1,298
FOLLOWERS 2,235
FAVORITES 7
LISTS 2
Tweets
Tweets & replies
Photos & videos
Pinned Tweet
Allen Pope @PopePolar · Feb 16
This is 4:24 of pure awesome by @NASA_EO. @NASA_Landsat/@USGSLandsat does a #solstice long pass over the Arctic - earthobservatory.nasa.gov/Features/Arcti…

Progress on a Landsat 8 Image Mosaic of Antarctica

Allen Pope & Ted Scambos
e: allen.pope@nsidc.org
t: @PopePolar

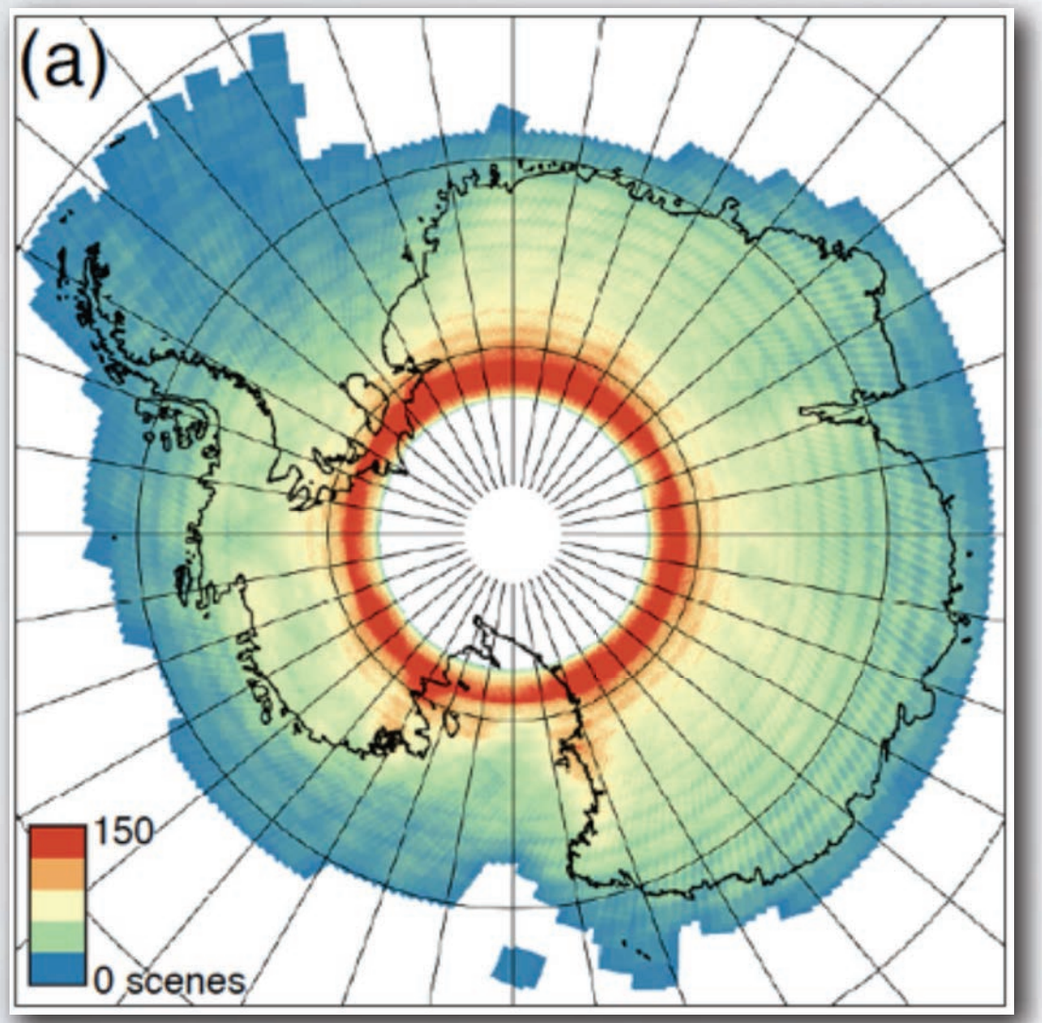
Why Mosaics?

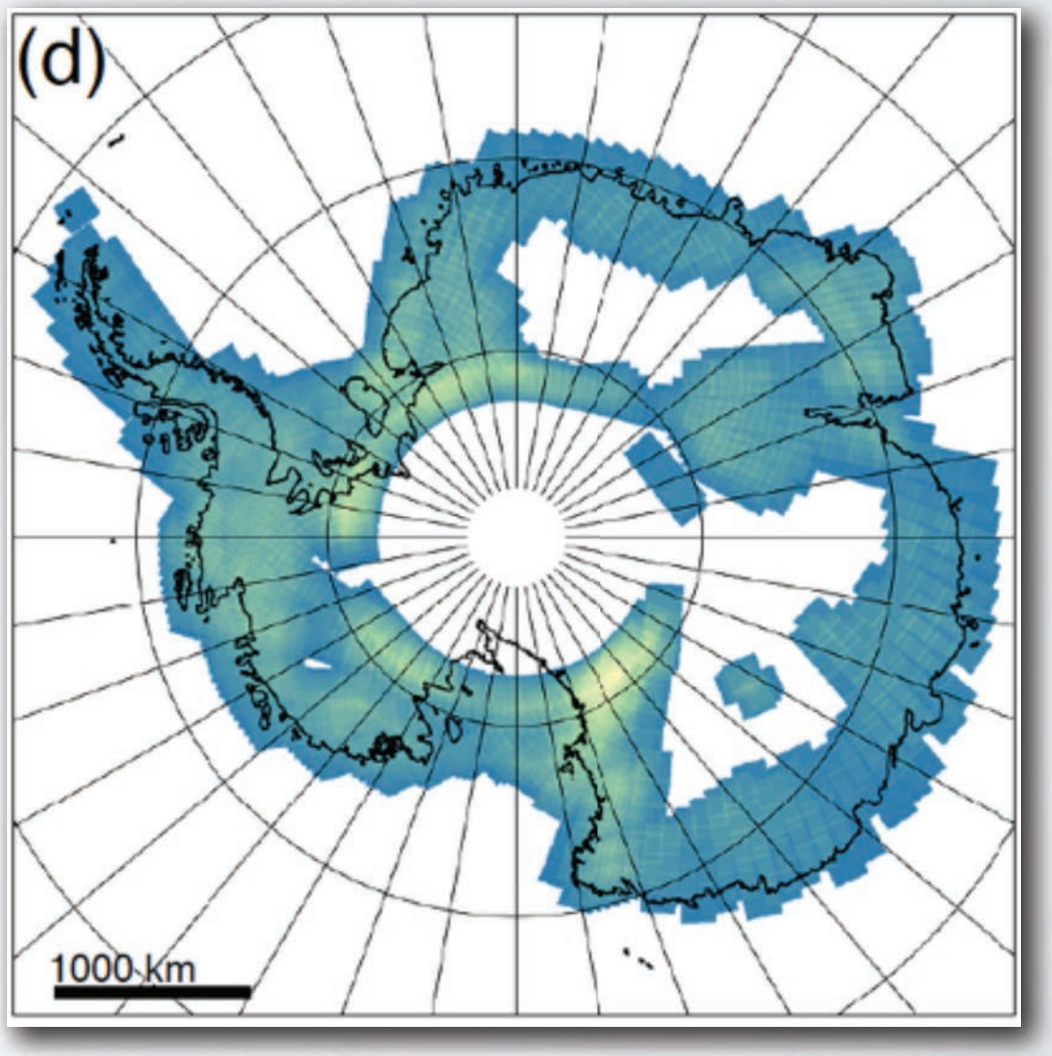
- Reference visualization / basemap
- Selecting the "best" imagery
- Synoptic view & analysis

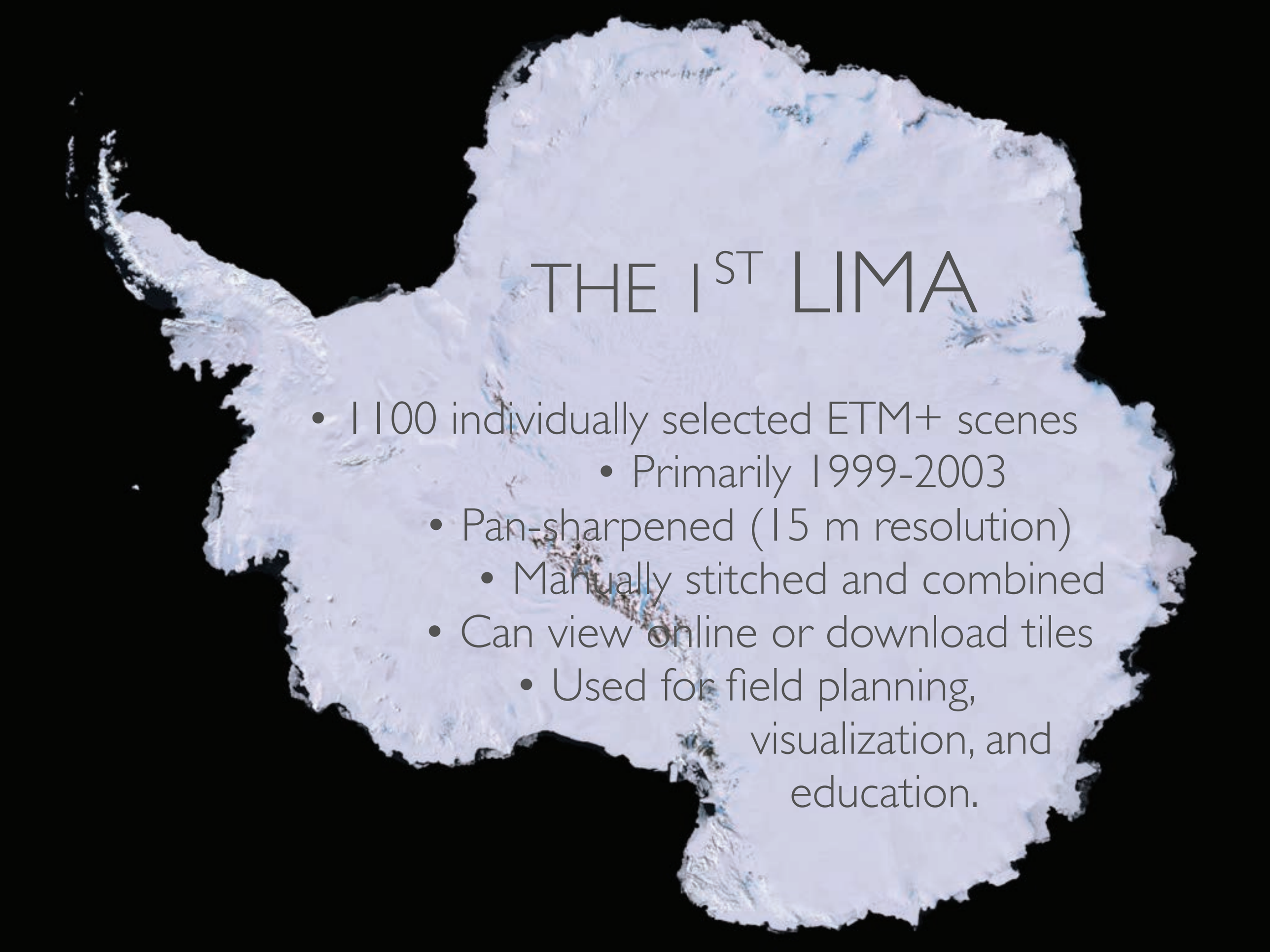
For example:
LIMA(+)
MOA (x3)
RAMP
PGC Viewer

Why Landsat 8?

- 12-bit radiometry means no saturation
- High geolocation accuracy (despite only L1GT)
- **High image acquisition rates**

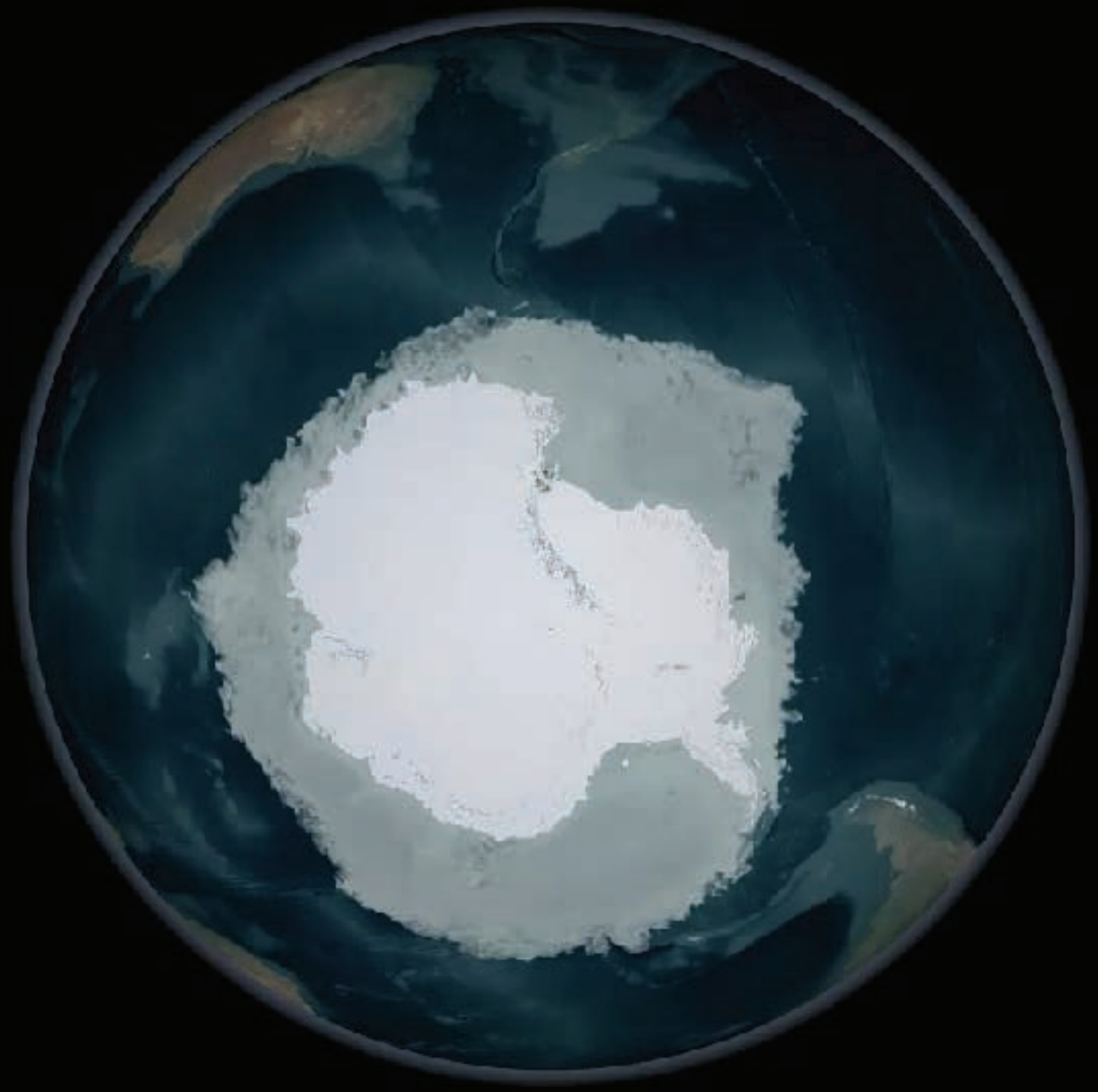






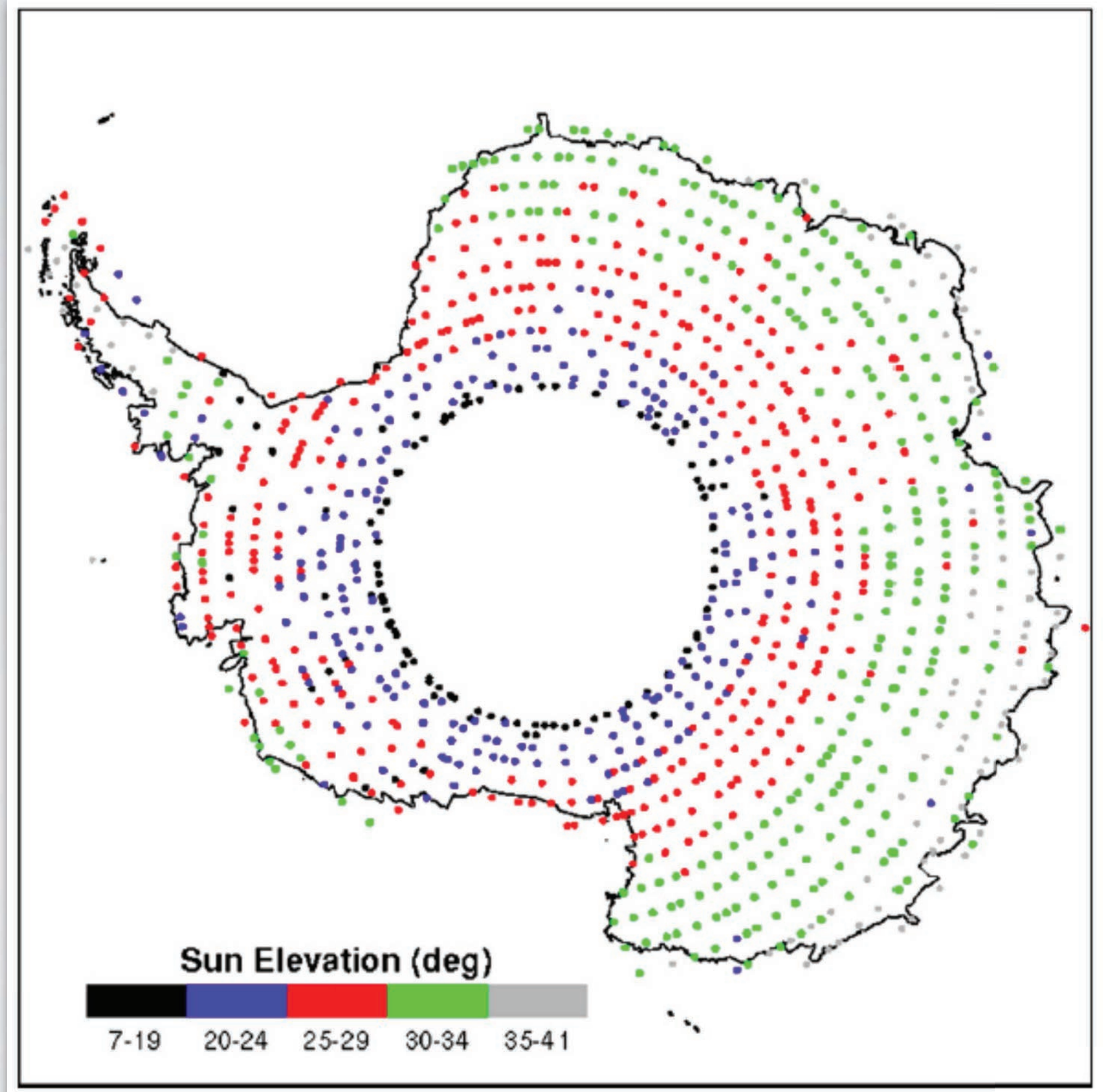
THE 1ST LIMA

- 1100 individually selected ETM+ scenes
- Primarily 1999-2003
- Pan-sharpened (15 m resolution)
- Manually stitched and combined
- Can view online or download tiles
- Used for field planning, visualization, and education.



BUILDING ON THE 1ST LIMA

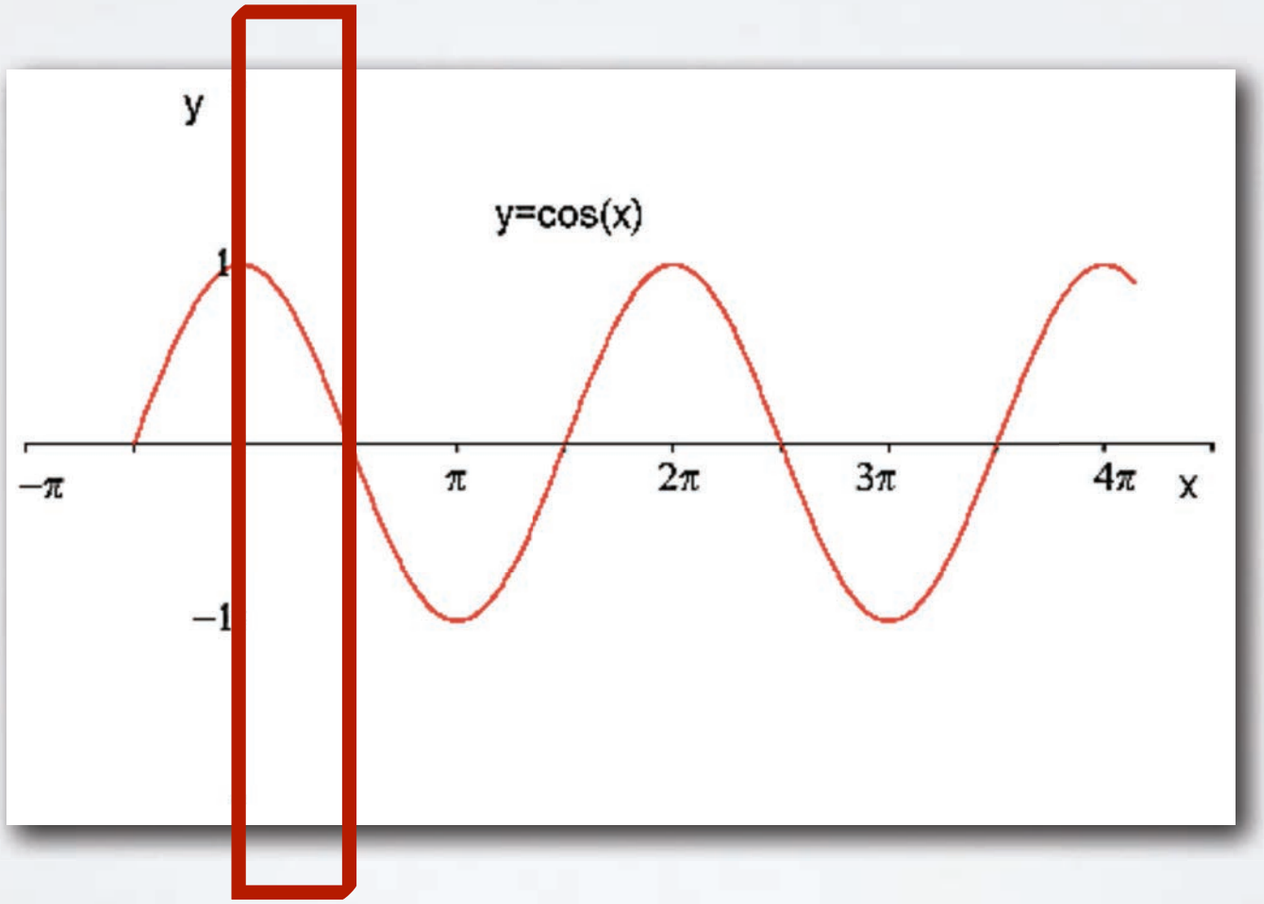
- Calculate top-of-atmosphere reflectance
- No atmospheric correction
- Cosine correction for sun angle
  (center, not corners or per-pixel)
- Not yet: empirical snow correction
  & "normalization"



Bindschadler et al. 2008

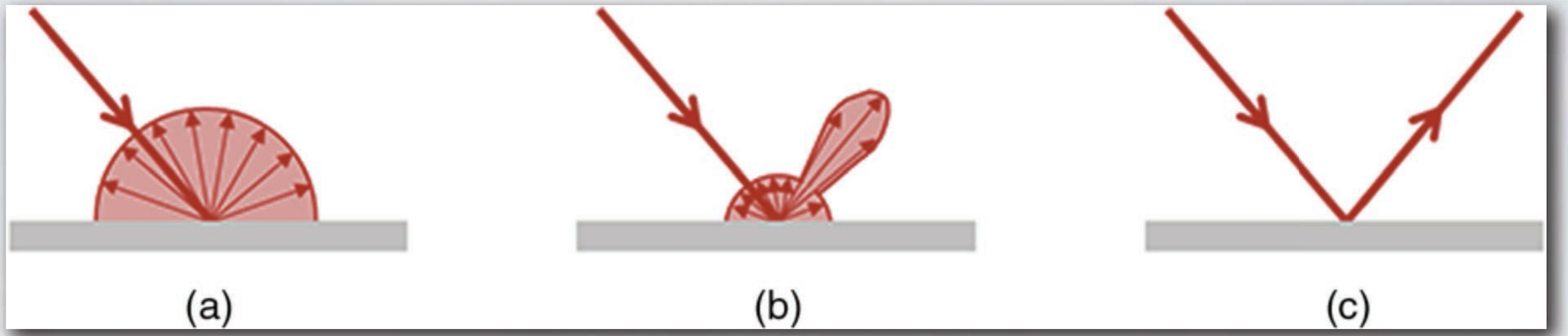
Cosine Correction

$$\text{Corrected reflectance} = \frac{\text{Raw reflectance}}{\cos(\text{solar zenith angle})}$$



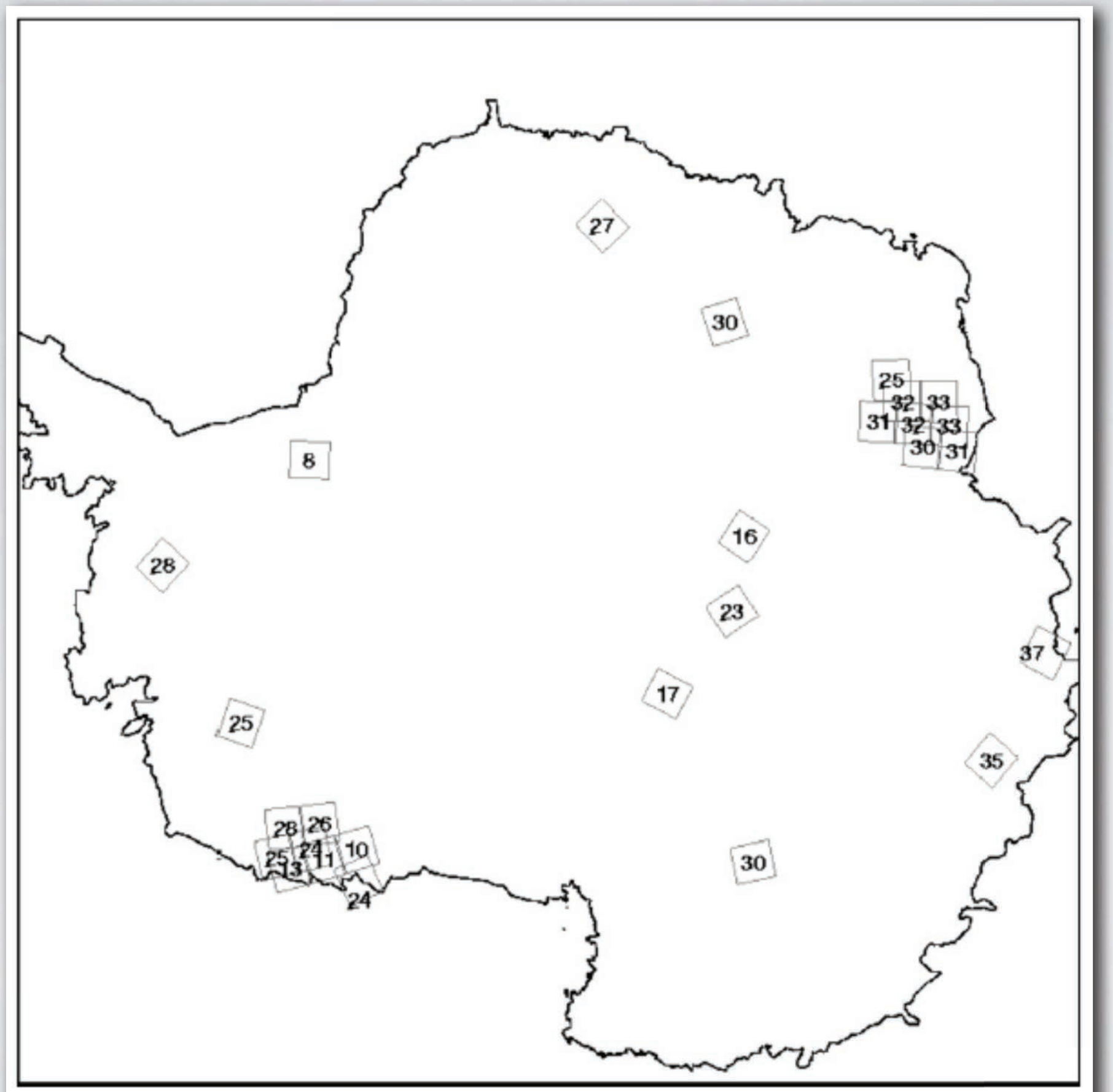
Surface Reflectance

Surface Reflectance



Lambertian (diffuse) ------- glossy -------- Specular (mirror)

Image: Wikipedia



Bindschadler et al. 2008

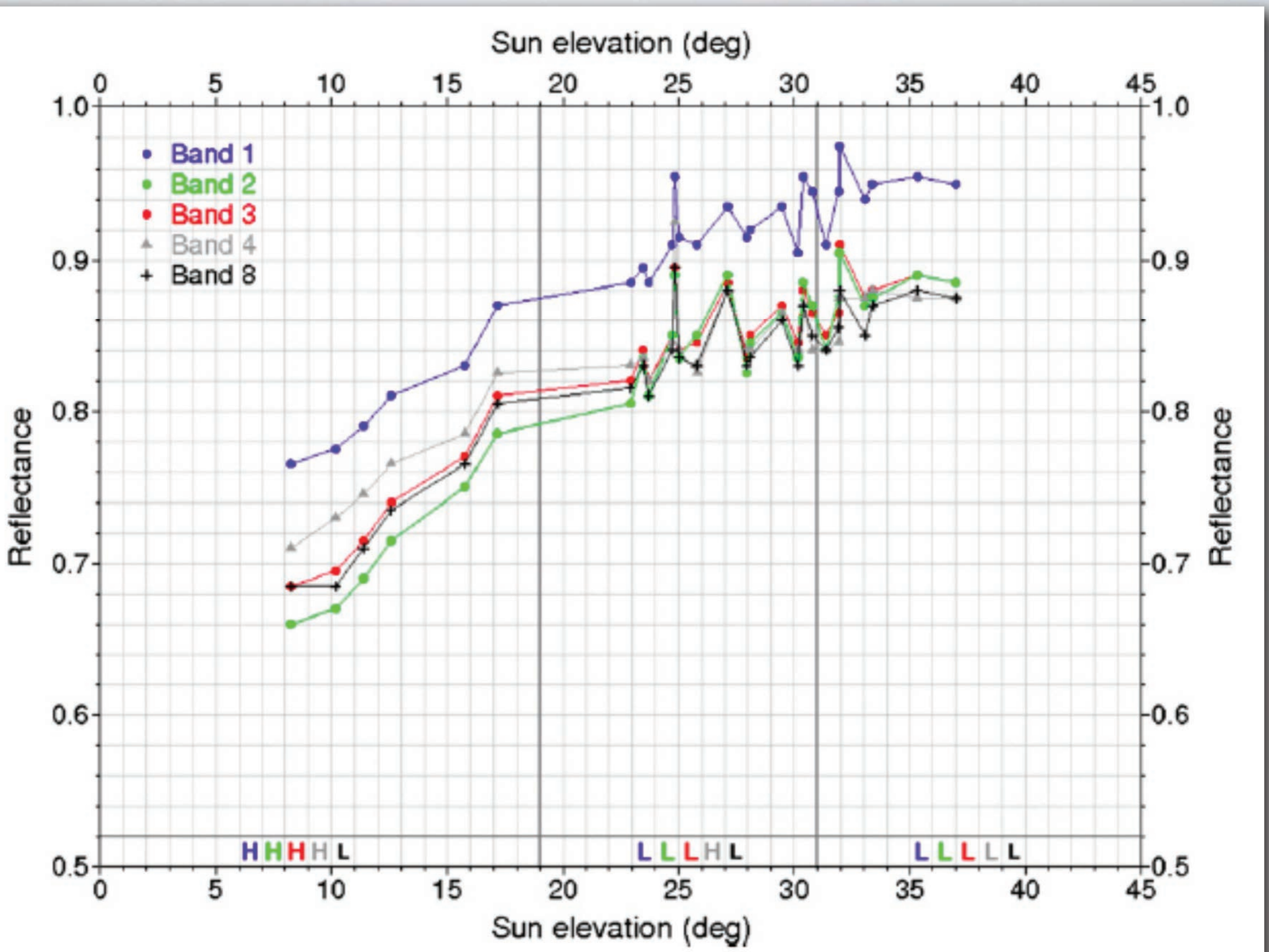
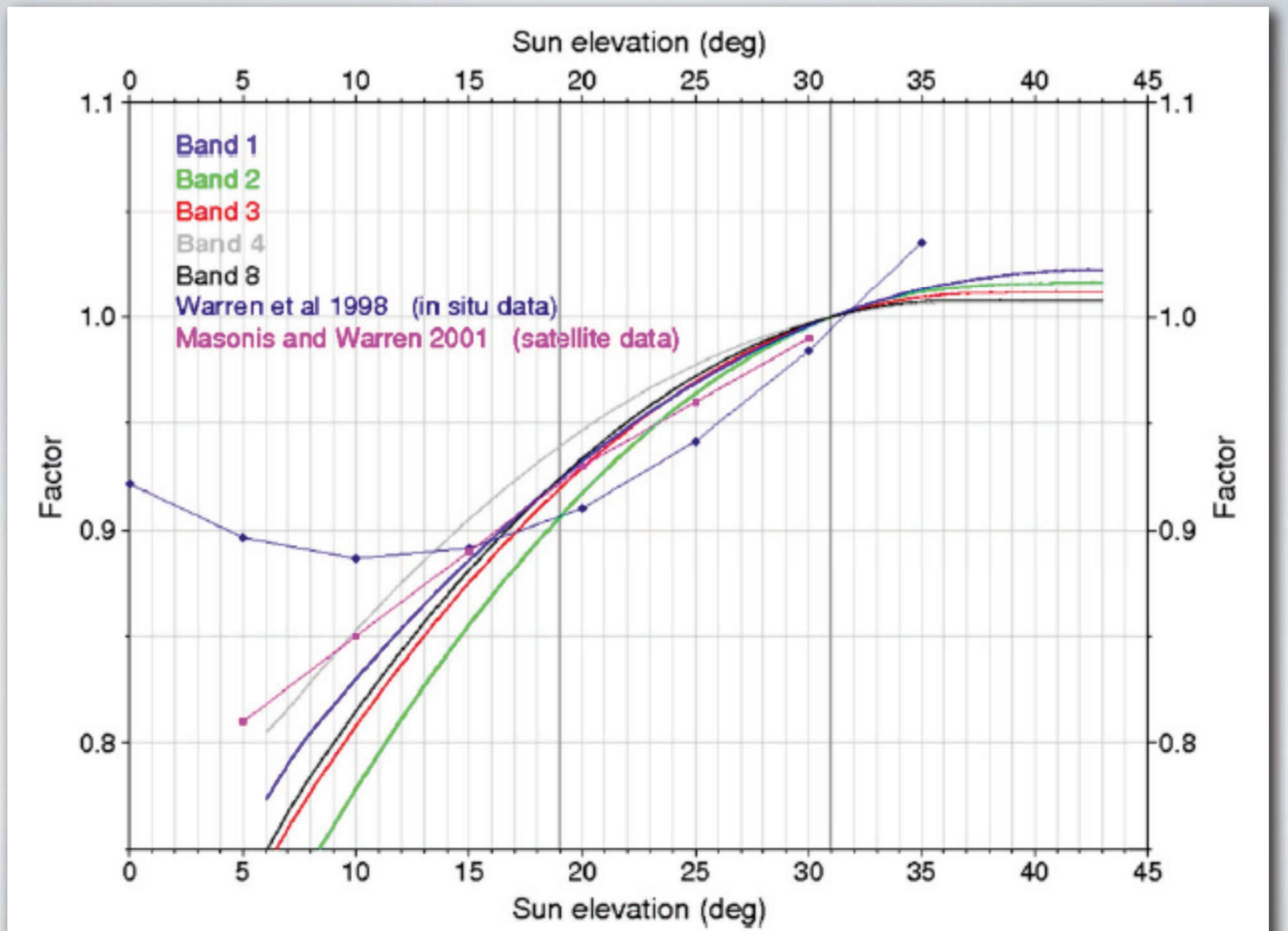
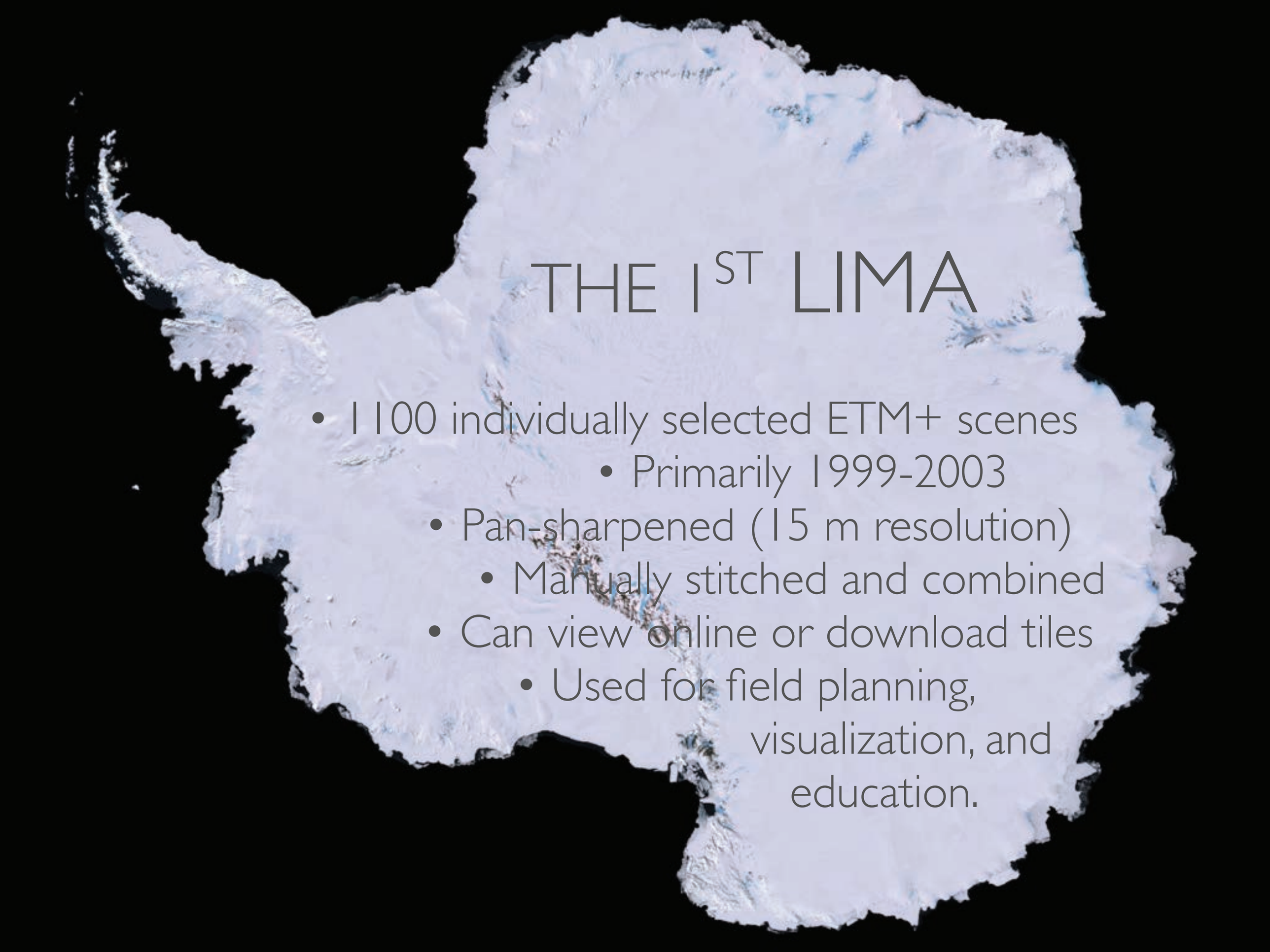


Fig. 6. Surface reflectance versus sun elevation (see Fig. 5) after saturation adjustment.

Bindschadler et al. 2008



Bindschadler et al. 2008



THE 1ST LIMA

- 1100 individually selected ETM+ scenes
- Primarily 1999-2003
- Pan-sharpened (15 m resolution)
- Manually stitched and combined
- Can view online or download tiles
- Used for field planning, visualization, and education.

THE PLATFORM: EARTHENGINE

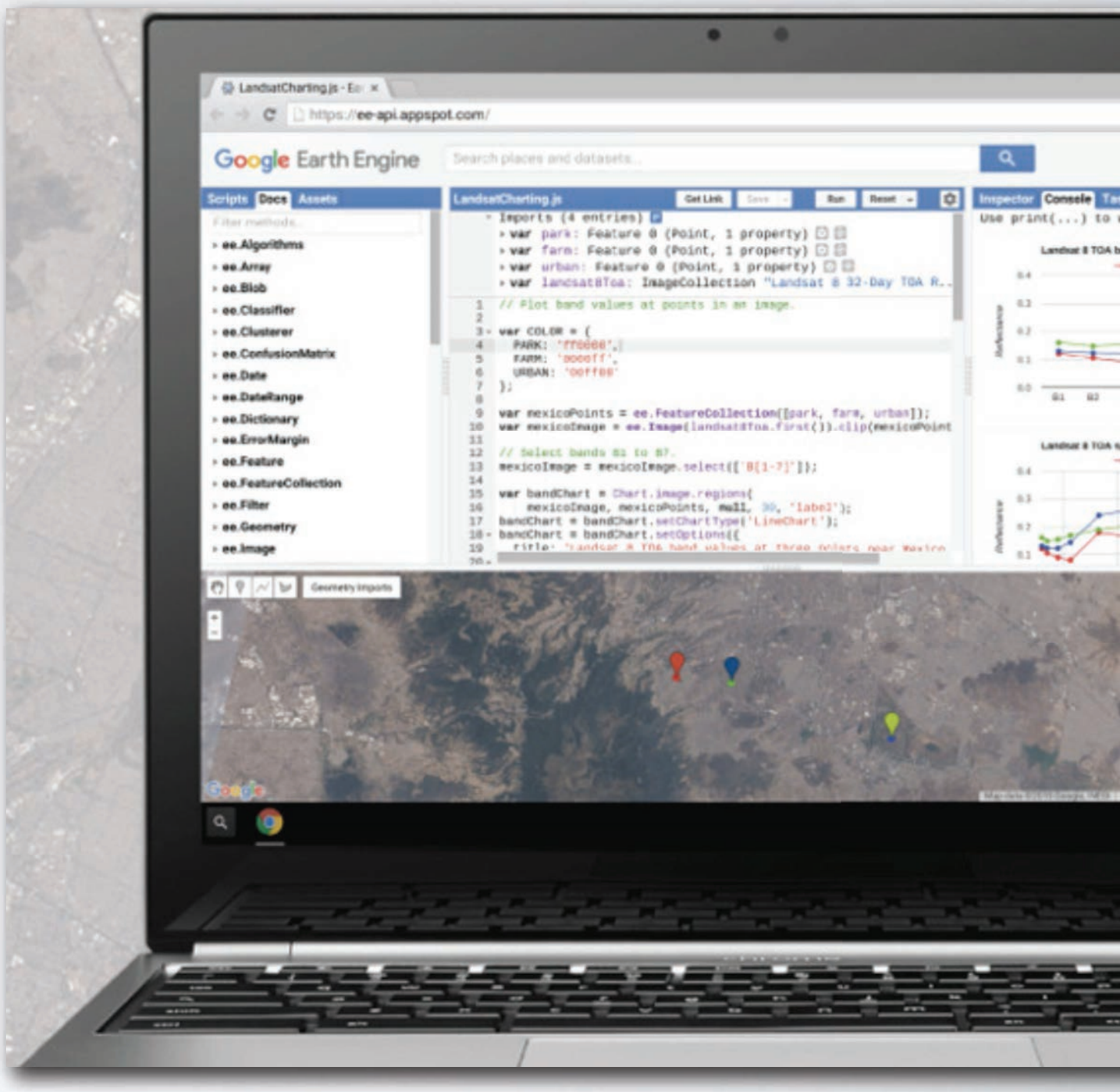
https://earthengine.google.com/

- (Web) platform for cloud-based remote sensing & GIS processing

- Java & Python APIs

- Petabytes of data (can upload own, too)

- High parallelized tools



The Problem: Clouds

Traditional Solutions

NDSI Threshold

BUT

Rocks get excluded.
Doesn't get cirrus clouds.

Band ratios
(Coastal, Red, SWIR, etc.)

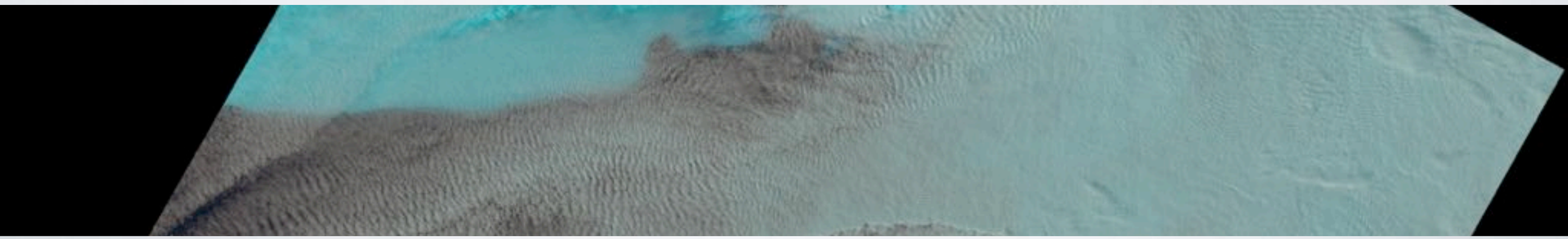
BUT

Reintroduces other errors.
Variable lithology problematic.

Cirrus Band Threshold

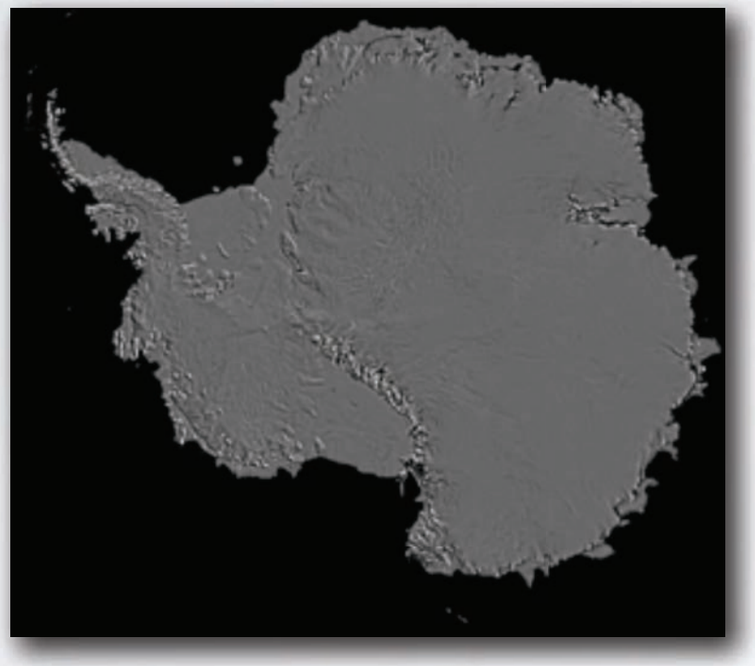
BUT

Sun-facing slopes are too bright.



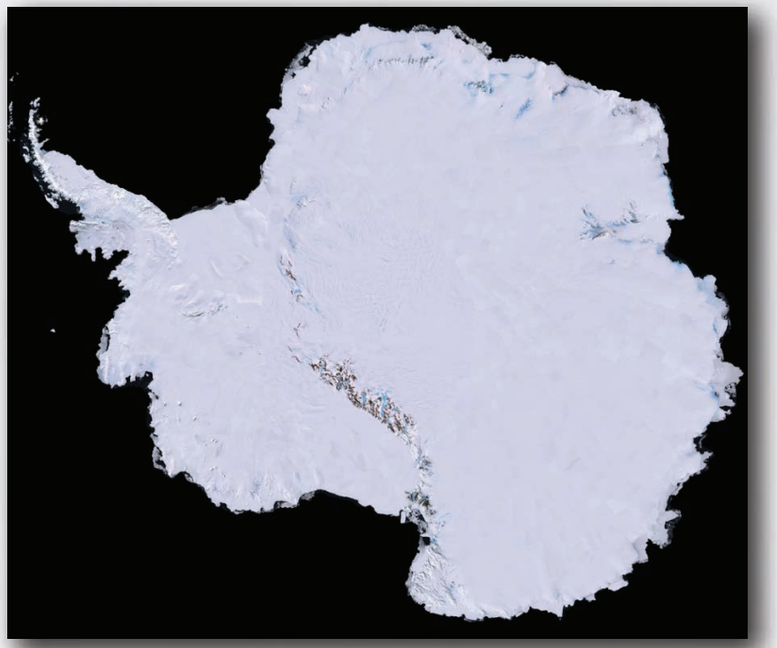
Comparing With a Mosaic?

- Both reflectance & high-pass filter
- Sum of error and correlation coefficient



MOA

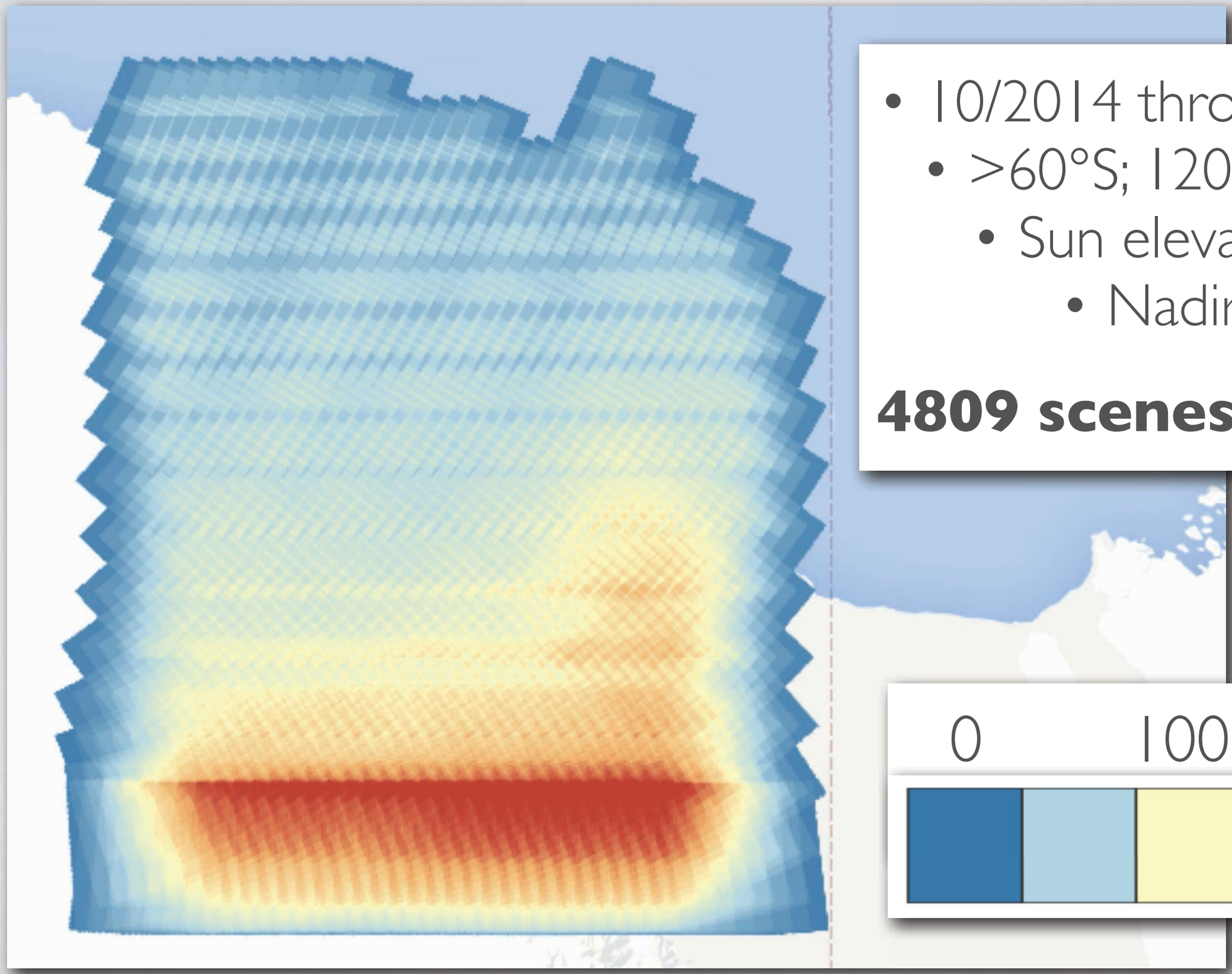
High quality mosaic,
but sun angle is wrong.



LIMA

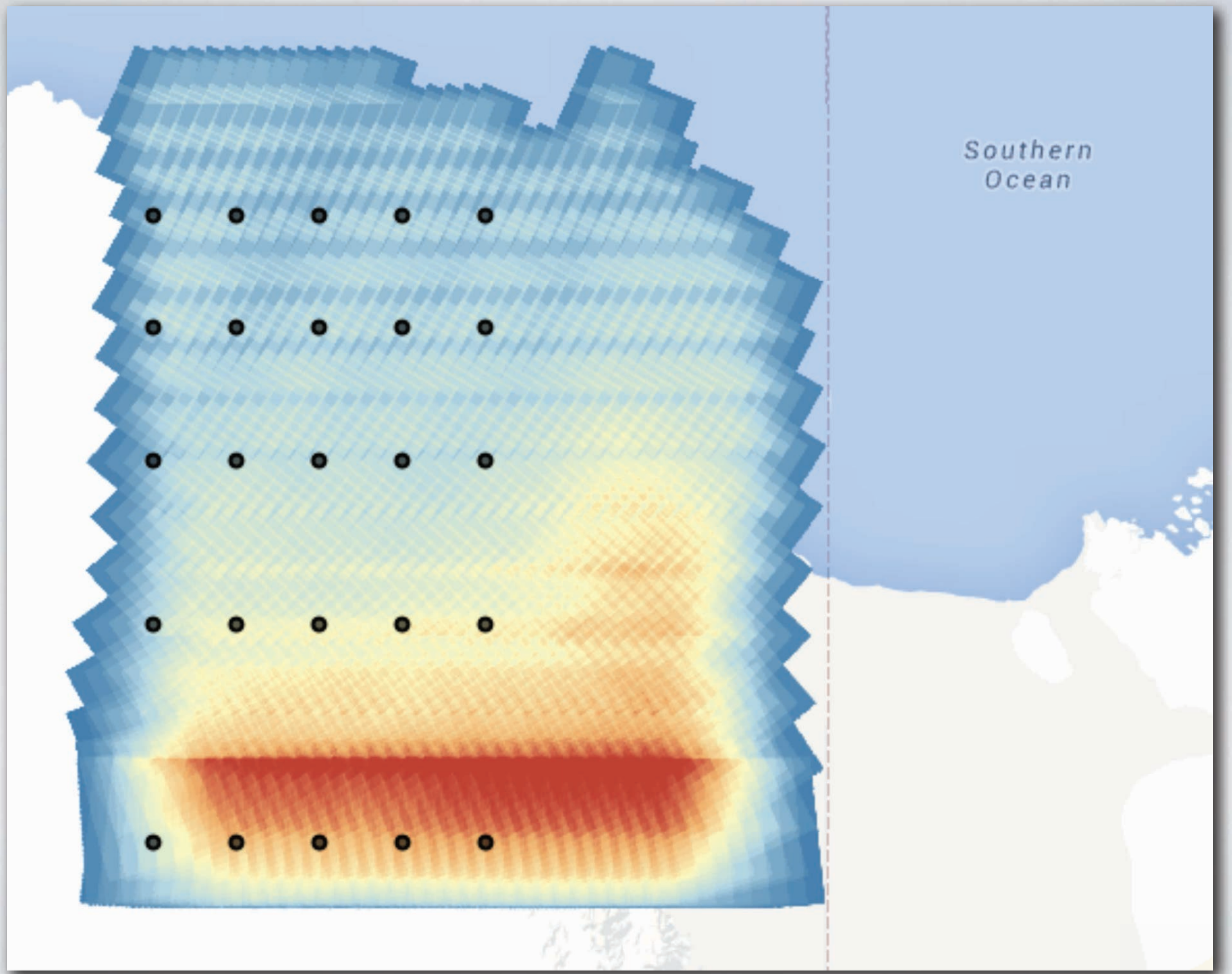
Too prescriptive.
Saturation issues?

High Image Density

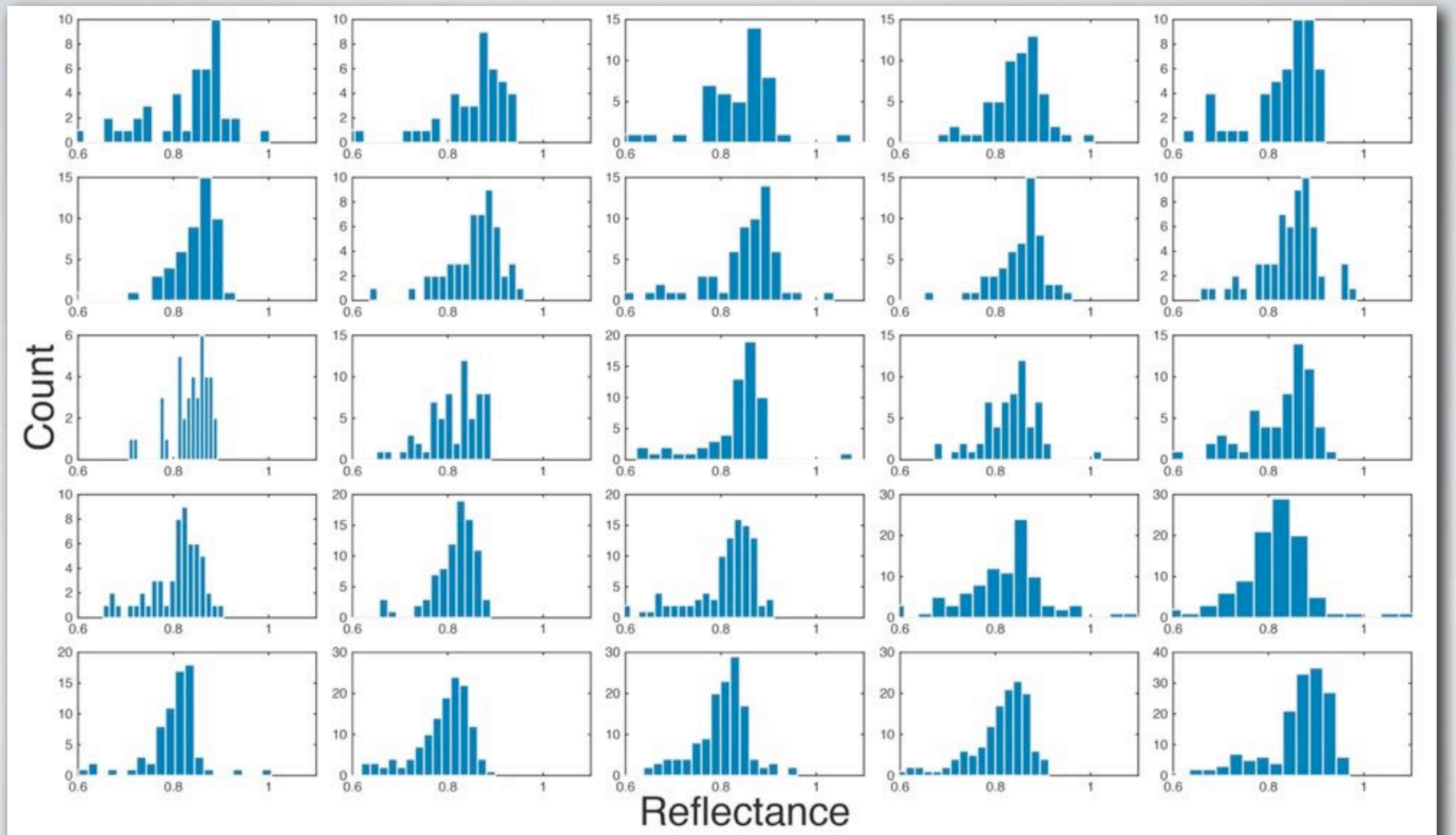


- 10/2014 through 03/2015
  - >60°S; 120° to 180°E.
    - Sun elevation >8°
      - Nadir only

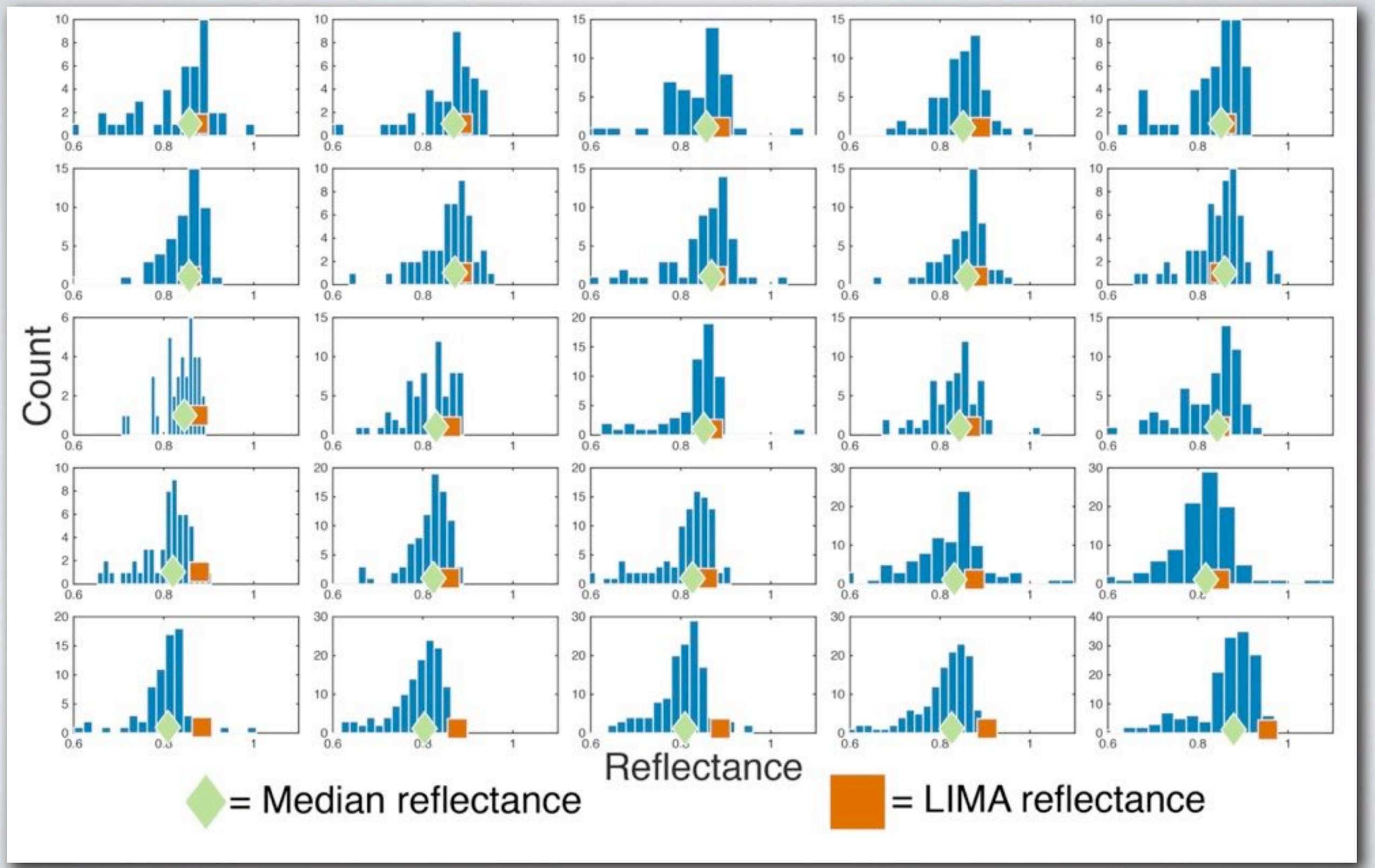
4809 scenes in <1 min


Southern
Ocean

Histograms of Reflectance



Histograms of Reflectance



Empirical Non-Lambertian Adjustment

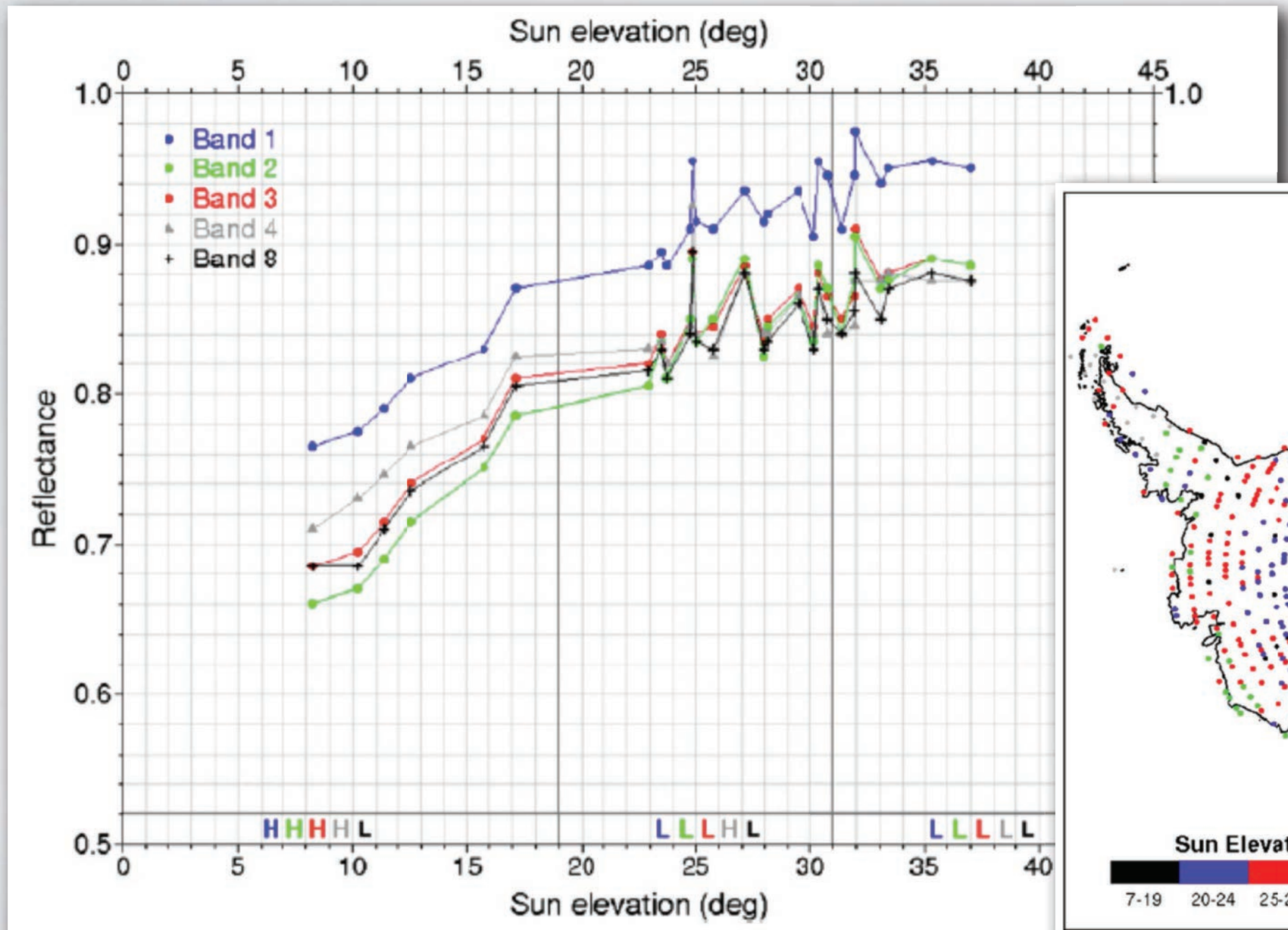
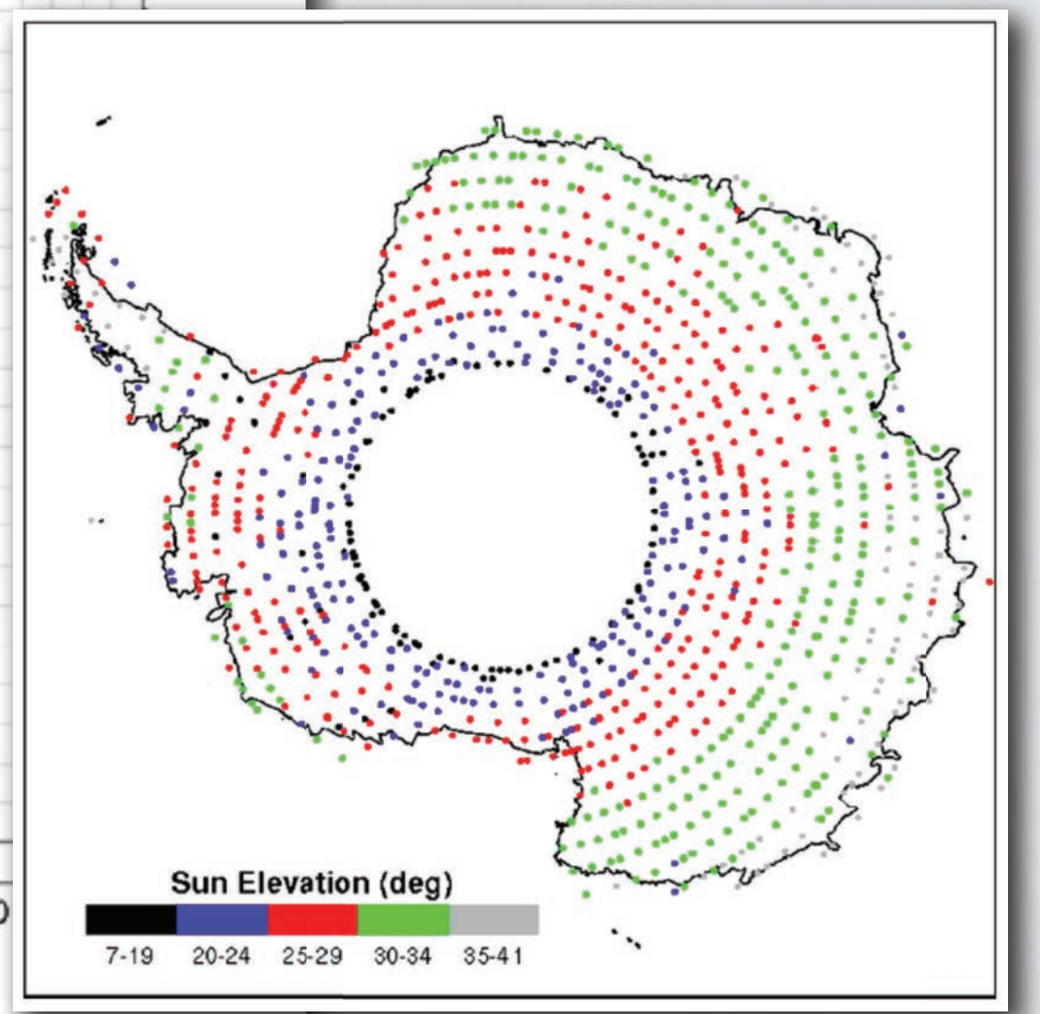
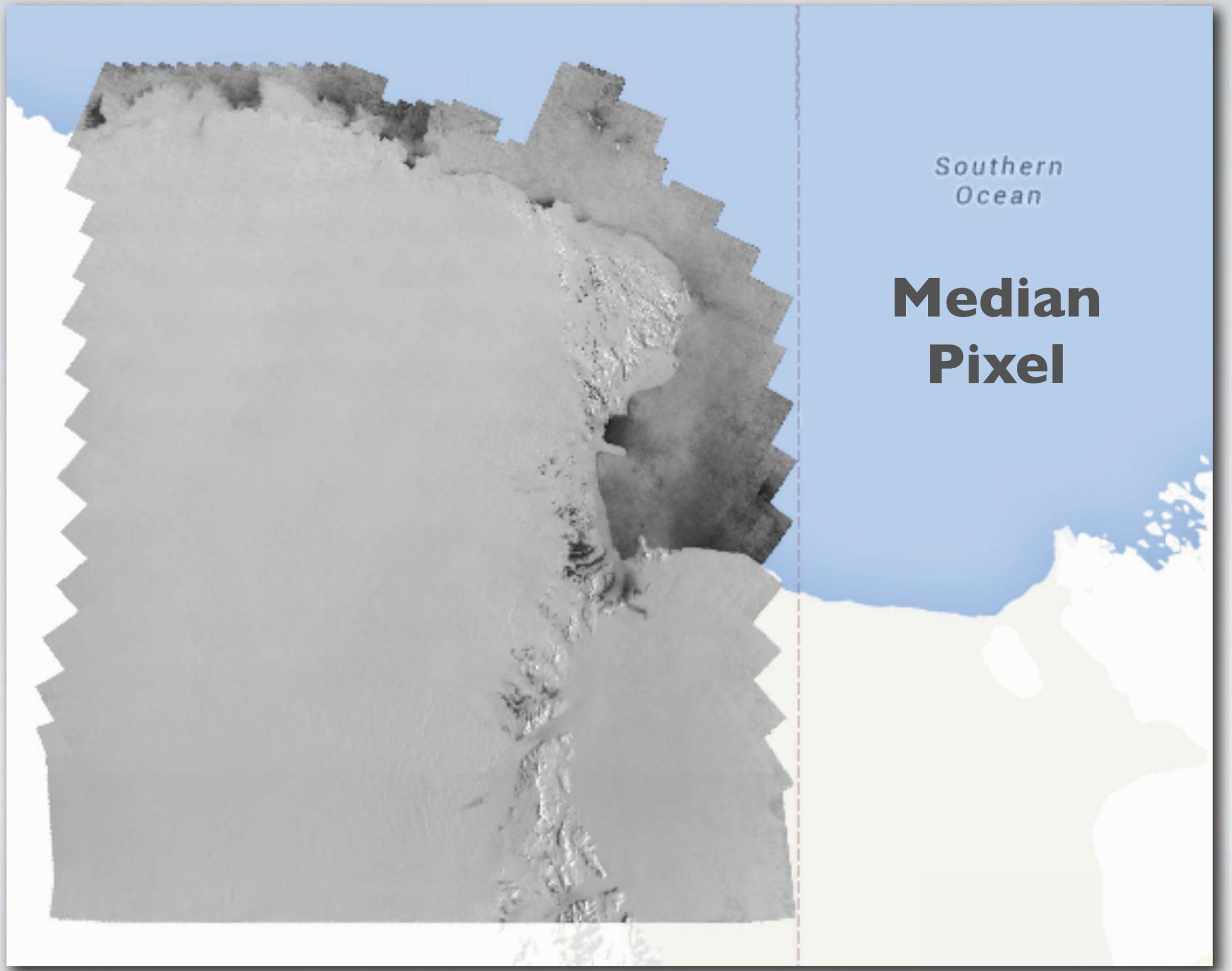


Fig. 6. Surface reflectance versus sun elevation (see Fig. 5) after saturation adjustment.

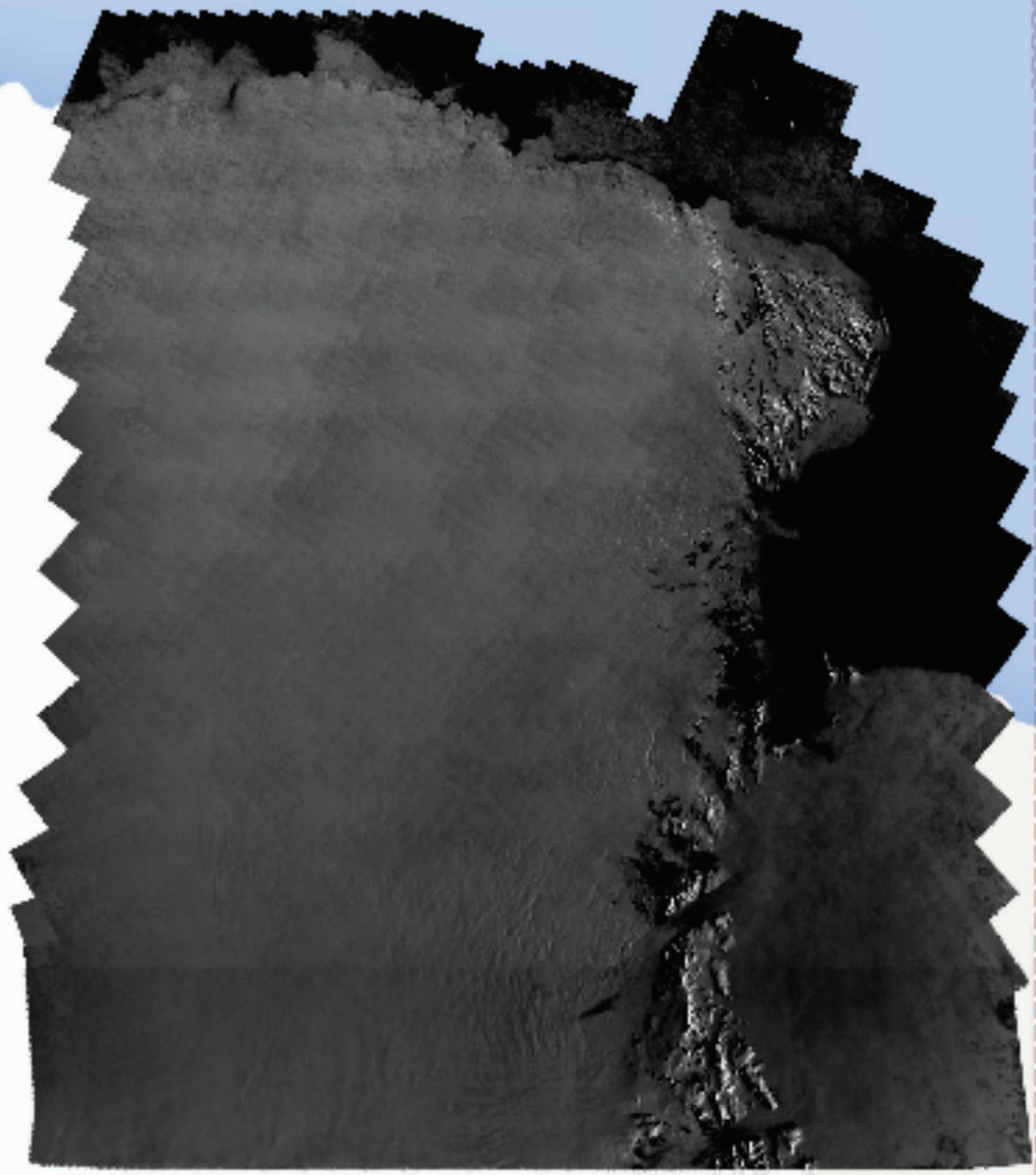
Bindschadler et al. 2008
Rem. Sens. Envi.





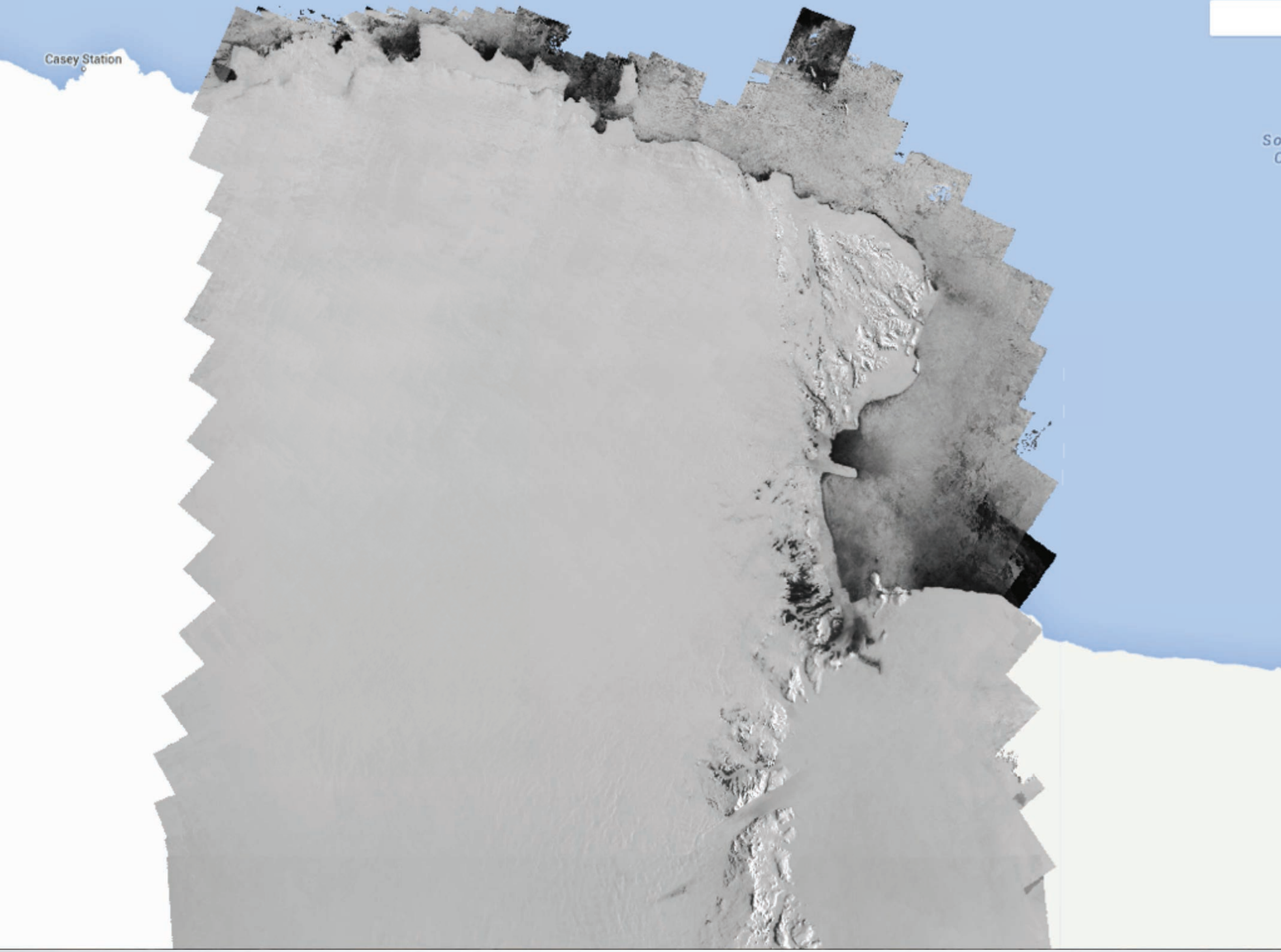
Southern
Ocean

Median Pixel

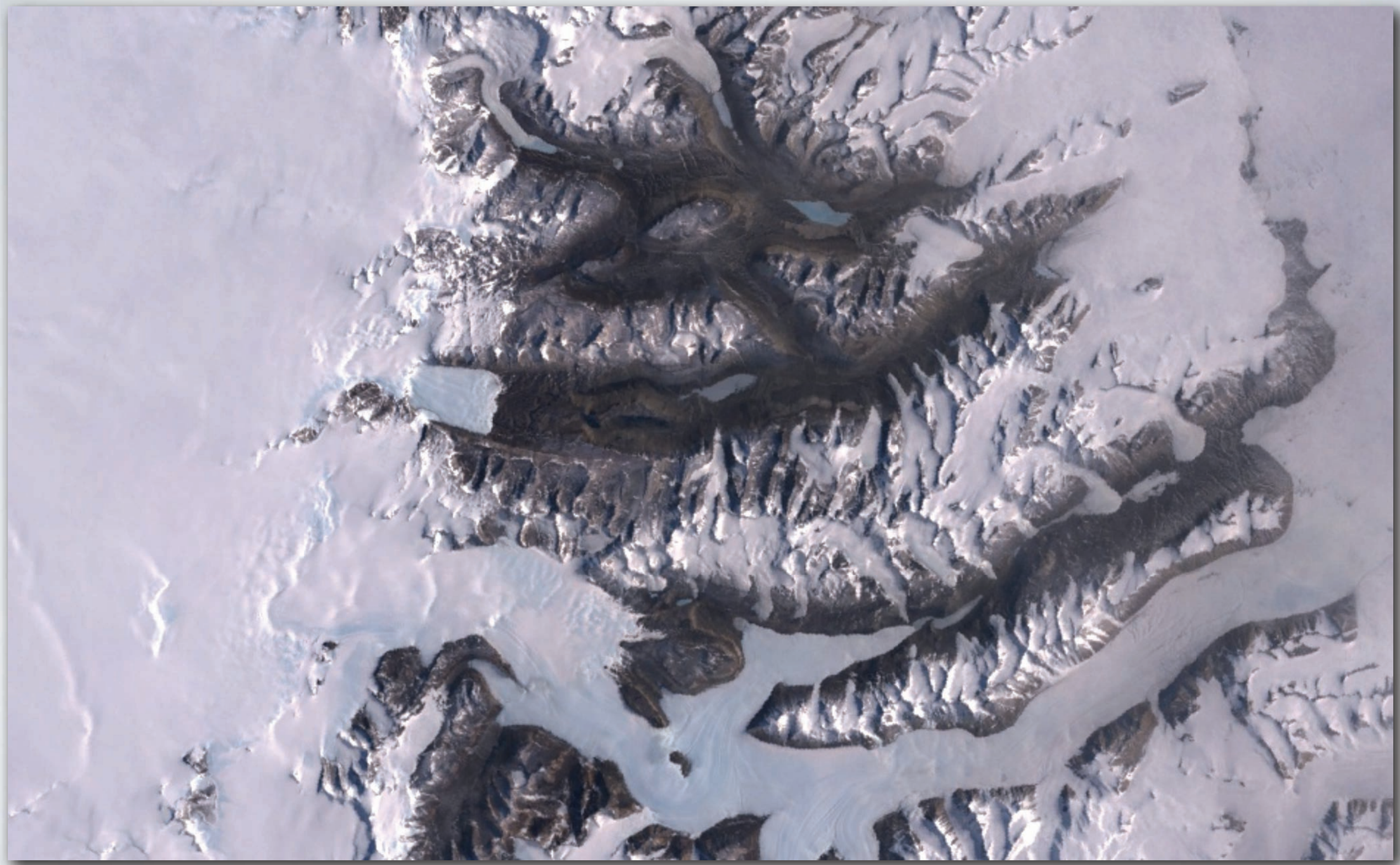


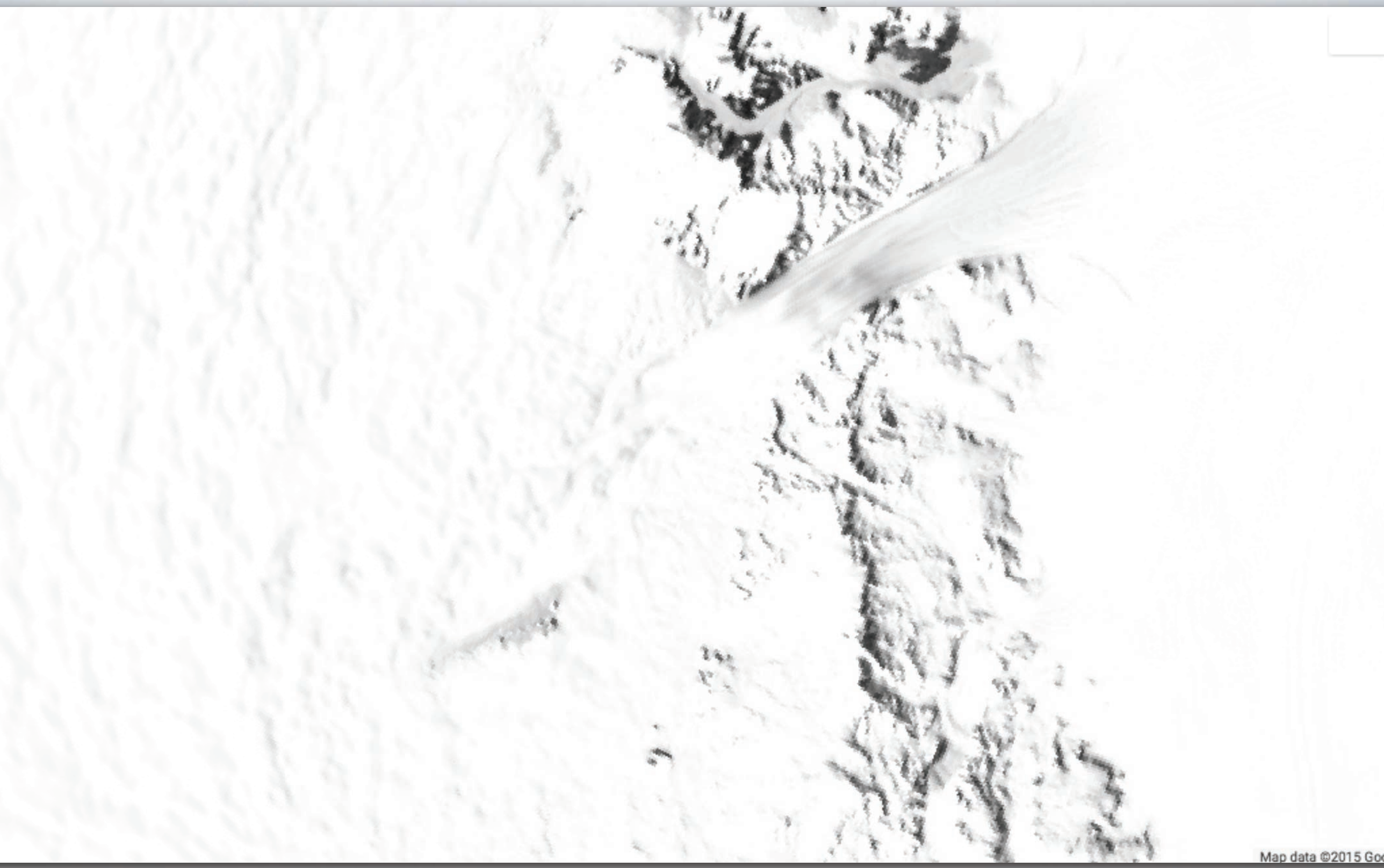
Southern Ocean

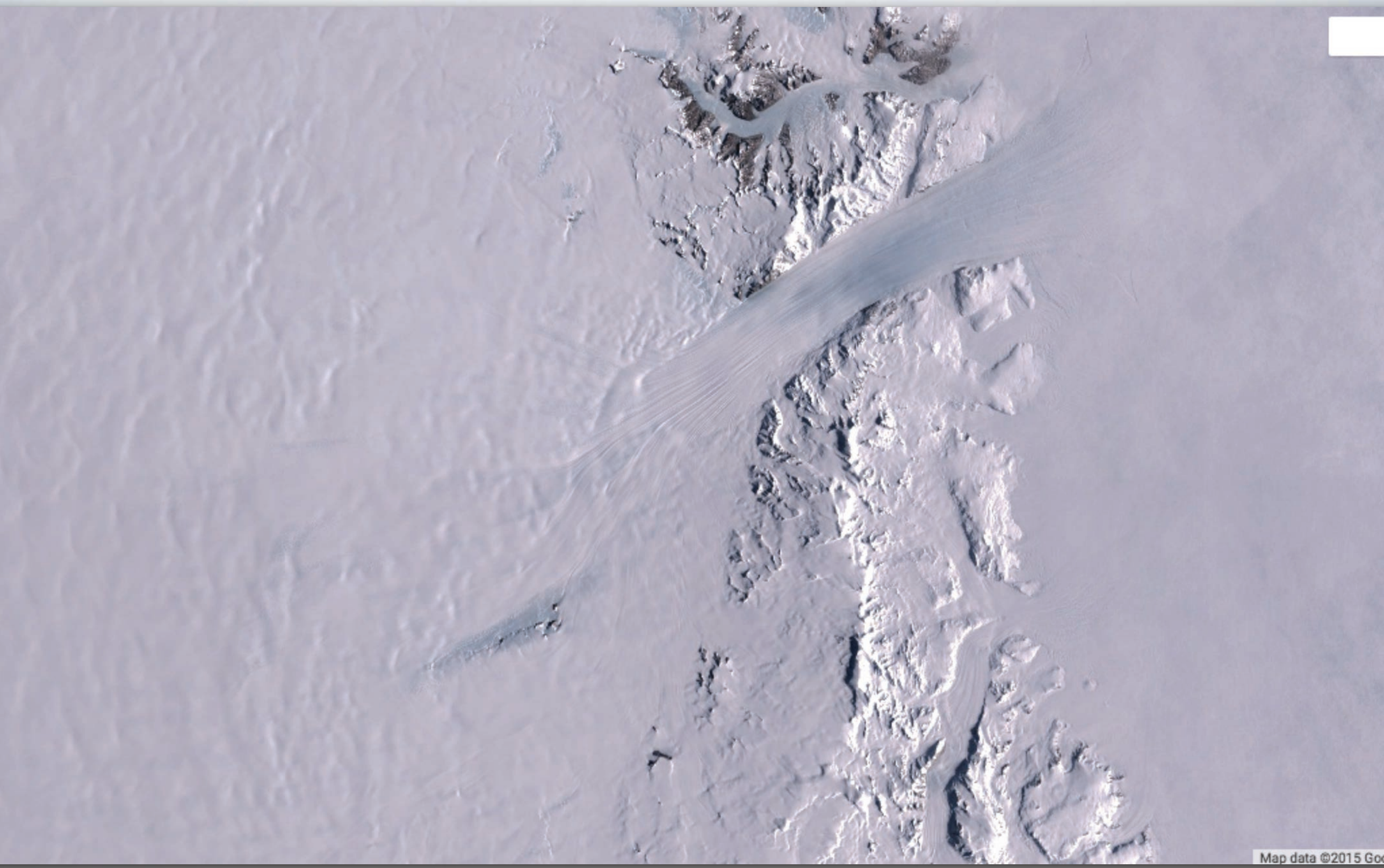
Median Pixel


Casey Station

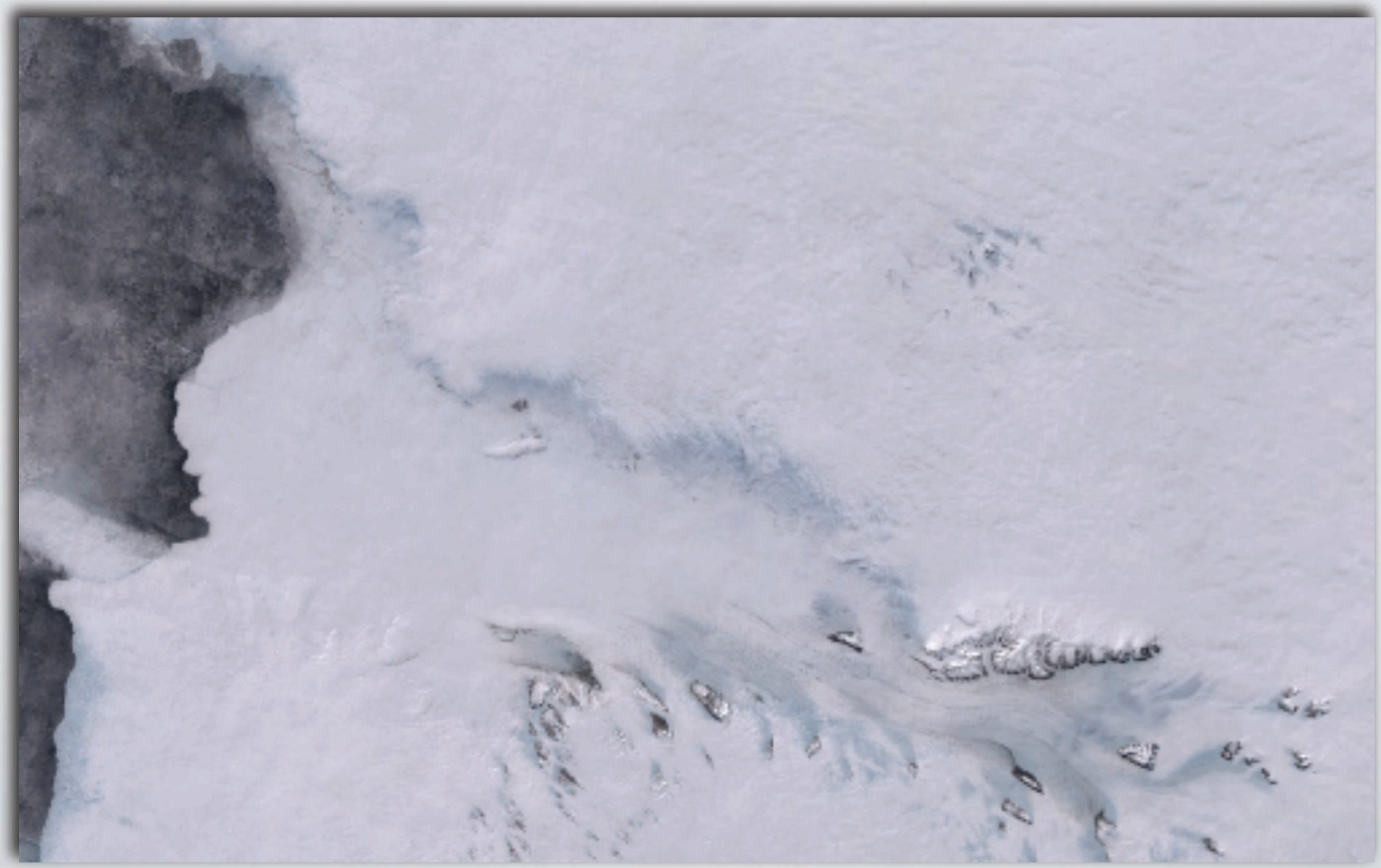
Casey Station

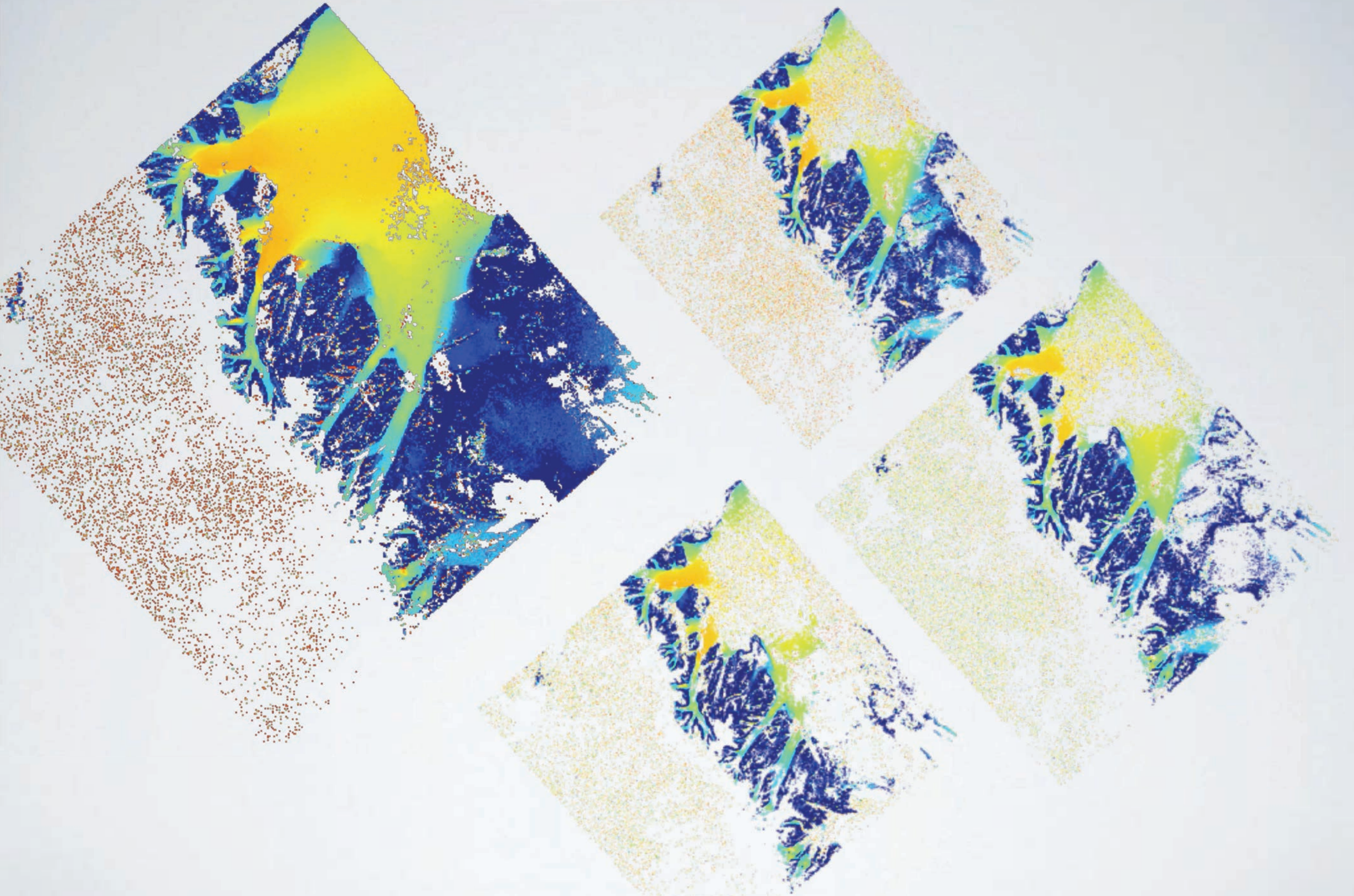



Map data ©2015 Goo


Map data ©2015 Go

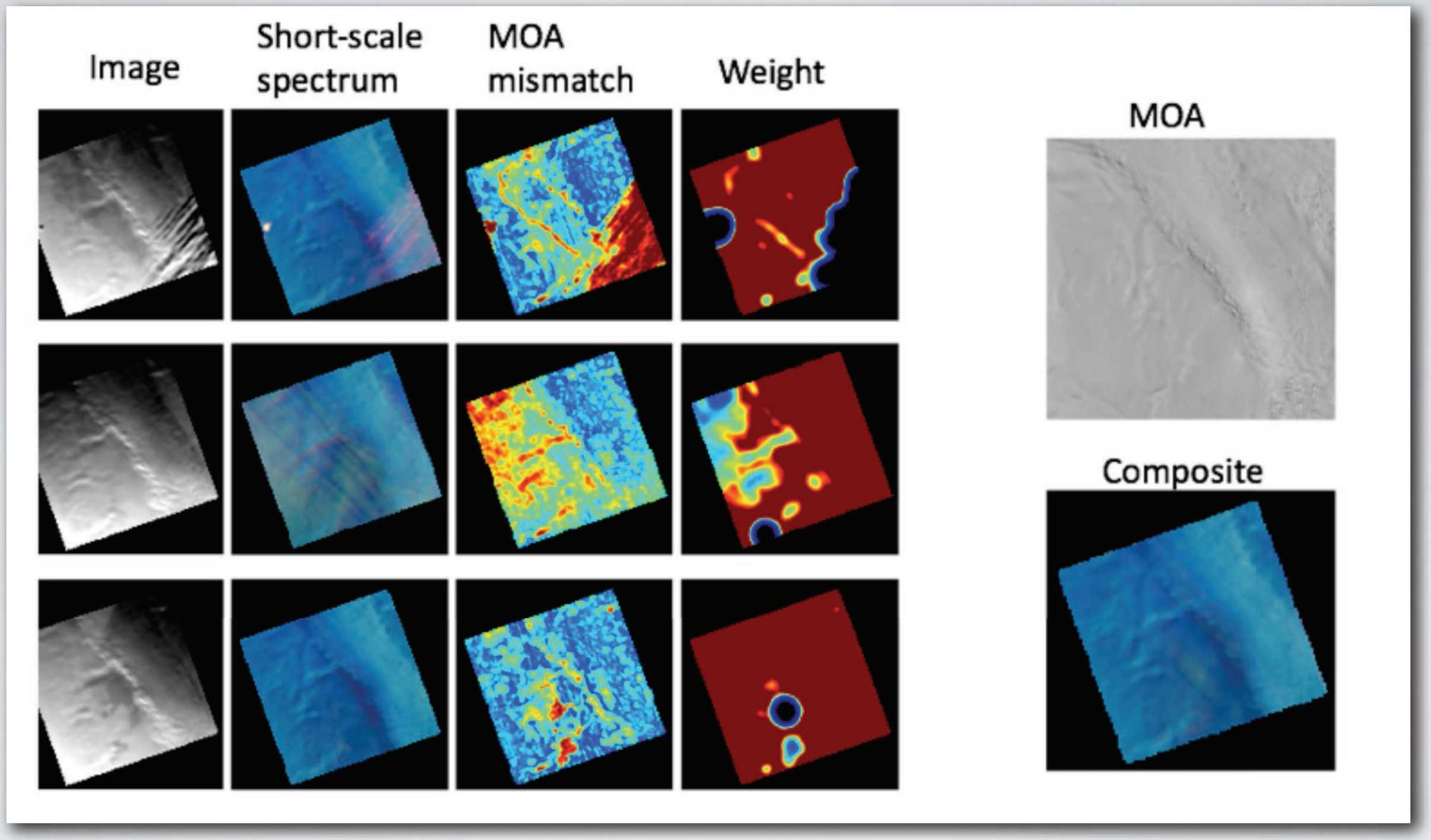

Davis



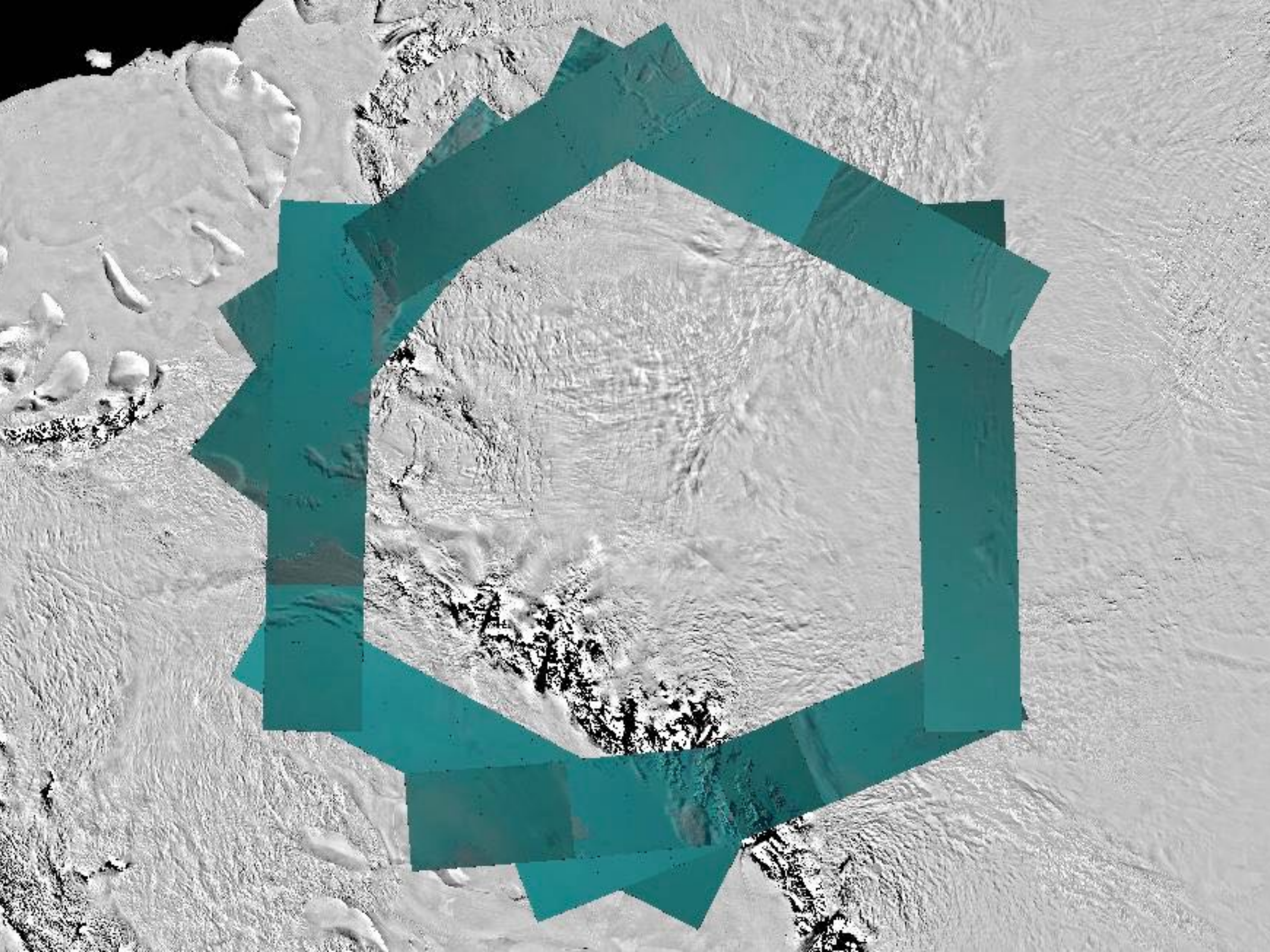


Cross-Correlation as Cloud Mask

Spectral Roughness as Cloud Mask



Courtesy: Ben Smith



TAKEAWAYS:

- Good progress on L8MA by choosing pixels, rather than scenes, using statistics.
- Google EarthEngine allows for fast processing & customization, but limits certain functions.
- Up Next: Implementing empirical BRDF correction, improved sun angle cosine correction, cloud masks, and inspection.

Questions?

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t: @PopePolar

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National Snow and Ice Data Center

CIRES

University of Colorado Boulder

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