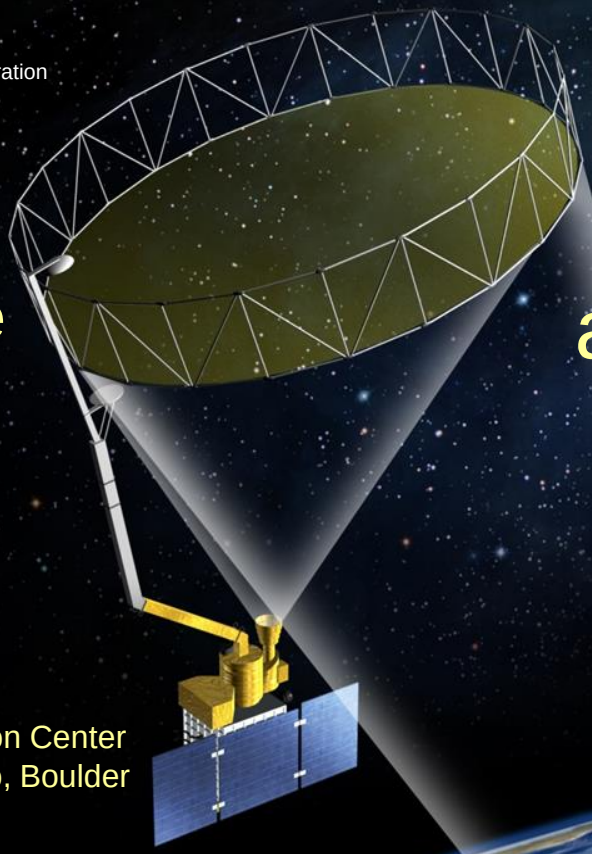
National Aeronautics and Space Administration

Soil Moisture Active Passive Mission

SMAP



Mapping Firn Aquifers and Ice Slabs within the Greenland Ice Sheet using Satellite L-band Microwave Radiometry

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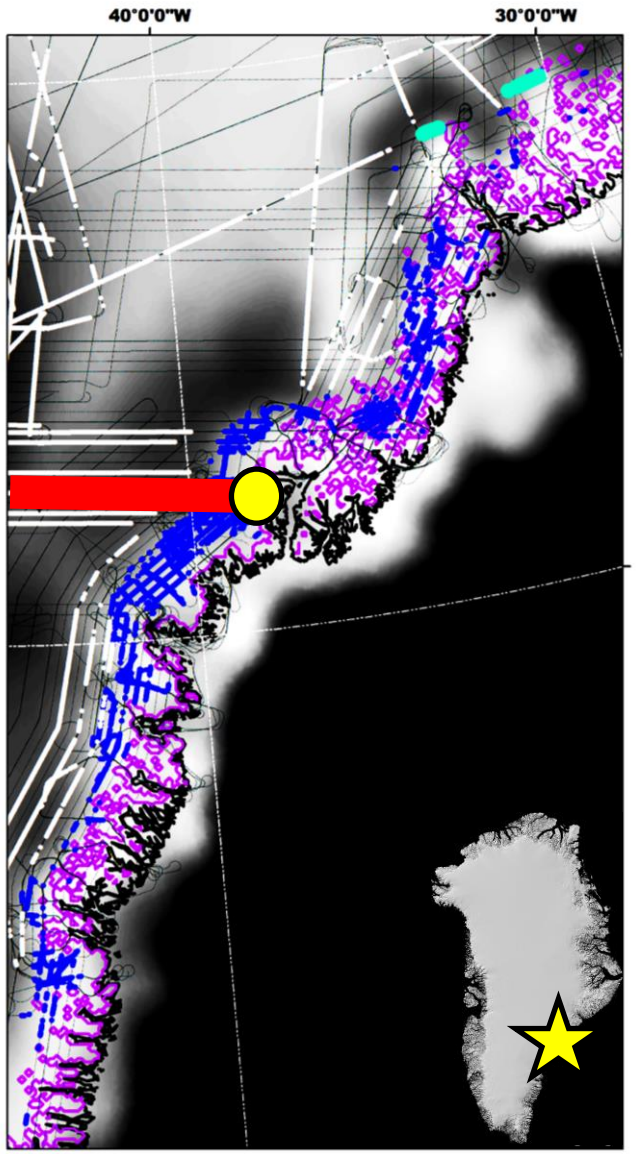
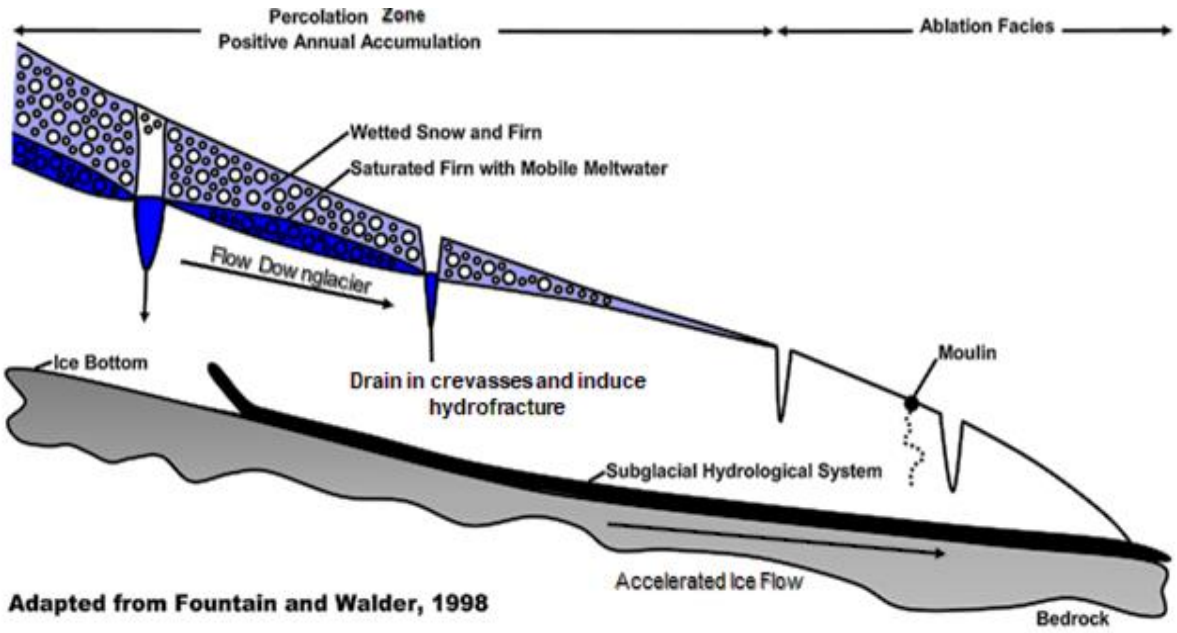
Firn Aquifers: Important Hydrological Component, Subsurface Meltwater Stored in Firn



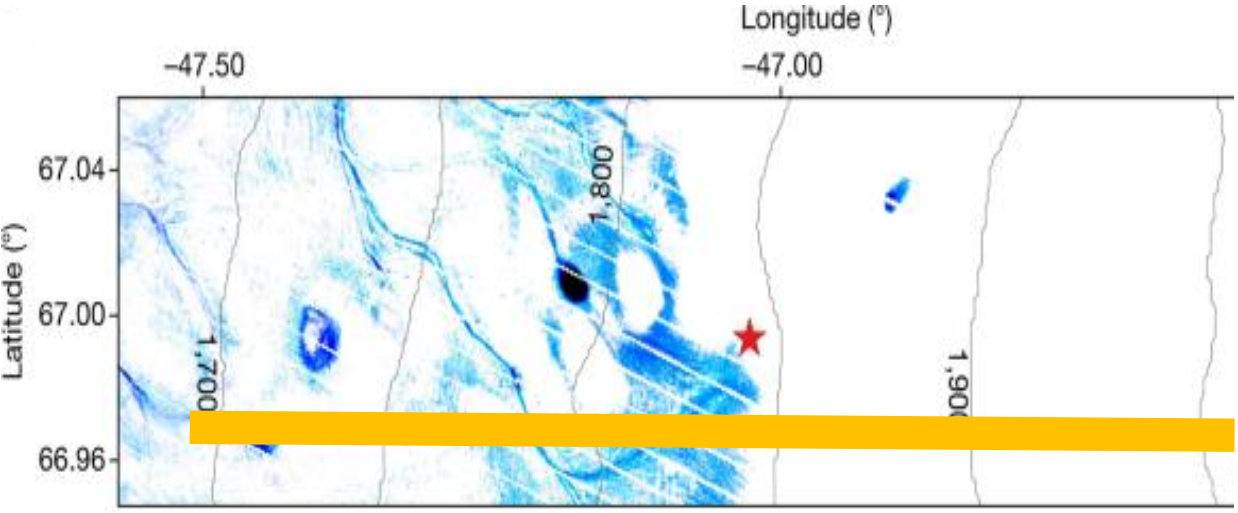


WHAT IS A FIRN AQUIFER?

Meltwater percolates downward through snow and firn to form a fully water-saturated layer on top of the nearly impermeable ice, and then flows from the water-saturated layer into shallow crevasses and moulins.

Fountain, A. G., and Walder, J. S.: Water flow through temperate glaciers. Review of Geophysics, 36, 299-328, https://doi.org/10.1029/97RG03579, 1998.

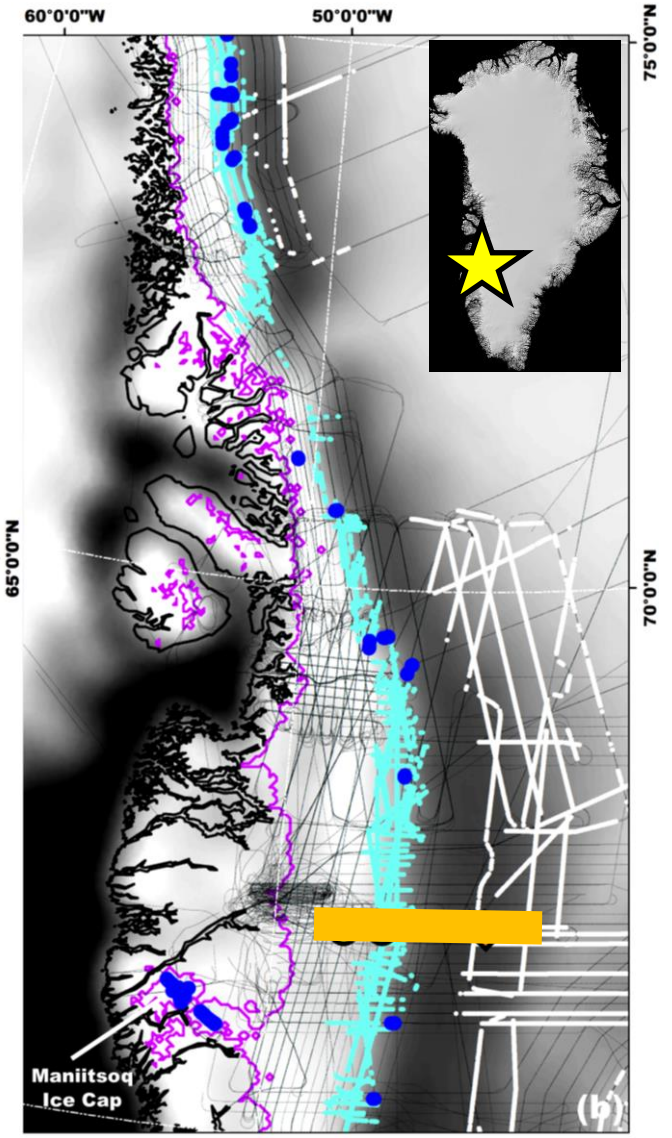
Ice Slabs: Subsurface Meltwater Refrozen in Firn, Impermeable Layers Enhance Runoff



WHAT IS AN ICE SLAB?

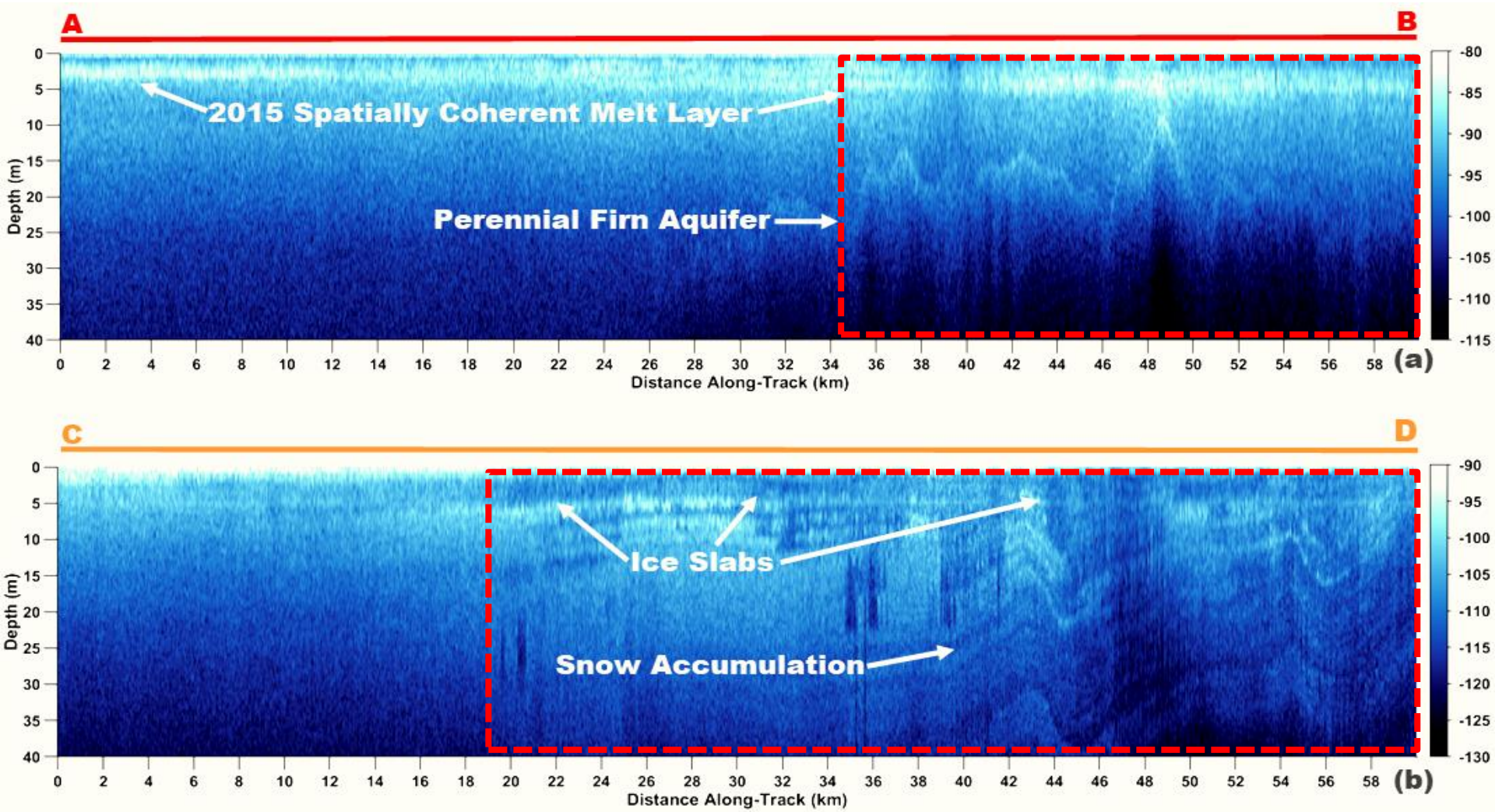
Meltwater runoff over ice slabs in SW Greenland

Field transect (orange line) overlaid on a Landsat 7 image from 16 July 2012 (contrast-enhanced to show surface water in blue). Graphic above shows 50 m contours from the Arctic Digital Elevation Model https://www.pgc.umn.edu/data/arcticdem/ .



McFerrin, M., Machguth, H., van As, D., Charalampidis, C., Stevens, C., Heilig, A., Vandecrux, B., Langen, P., Mottram, R., Fettweis, X., van den Broeke, M., Pfeffer, W., Moussavi, M., and Abdalati, W.: Rapid expansion of Greenland's low-permeability ice slabs, Nature, 573, 403-407, https://doi.org/10.1038/s41586-019-1550-3, 2019.

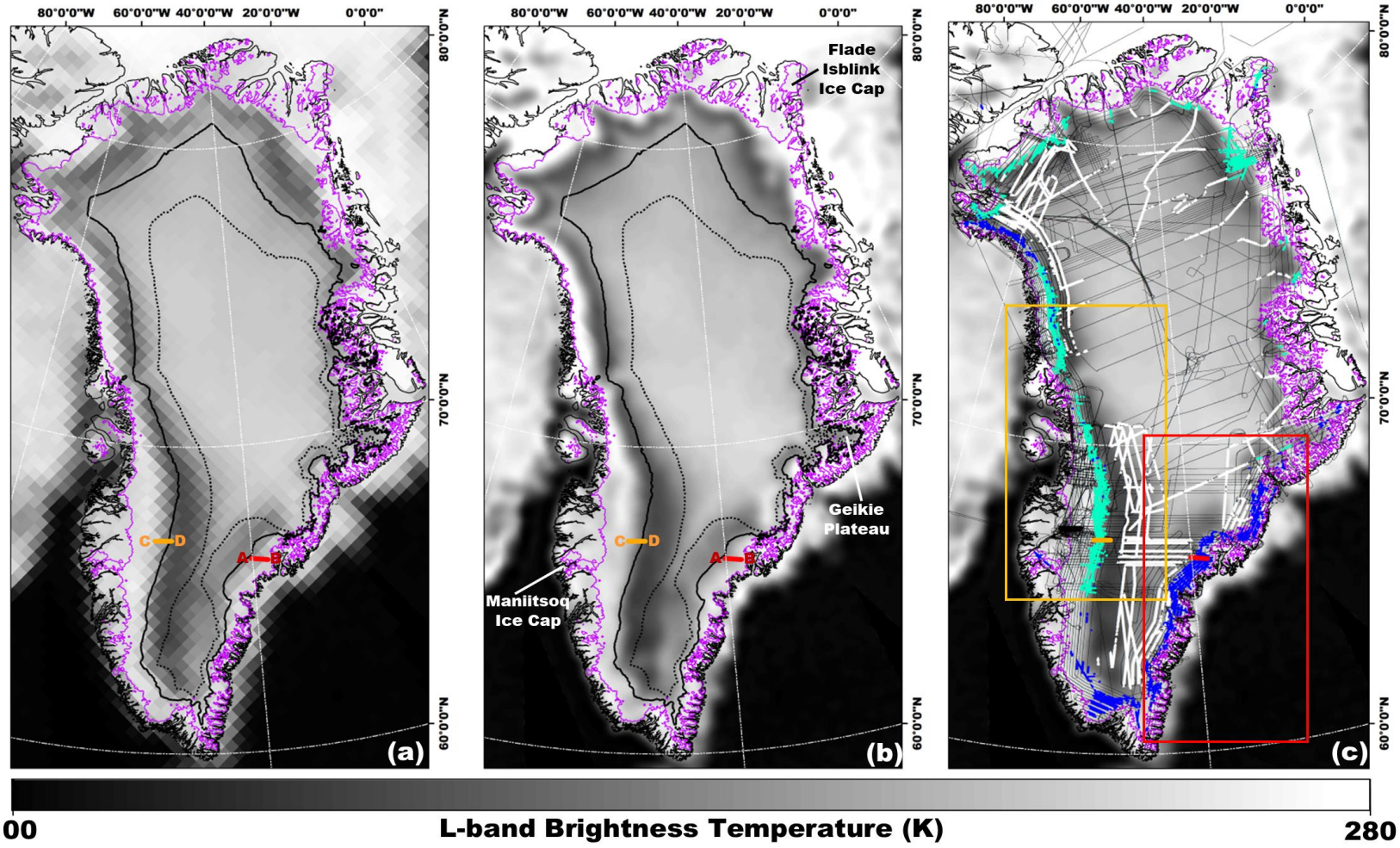
CReSIS Accumulation Radar Echograms: Detailing Subsurface Firn Hydrology



Center for Remote Sensing Ice Sheets (CReSIS*) Accumulation Radar Echograms

Accumulation Radar profile (a) along perennial firn aquifer transect A-B (red line, Slide 1 and 2) that was collected on 22 April 2017, and (b) ice slab transect C-D (orange line, Slide 1 and 3) that was collected on 5 May 2017. The Accumulation Radar operates at a center frequency of 750 MHz with a bandwidth of 300 MHz (*University of Kansas).

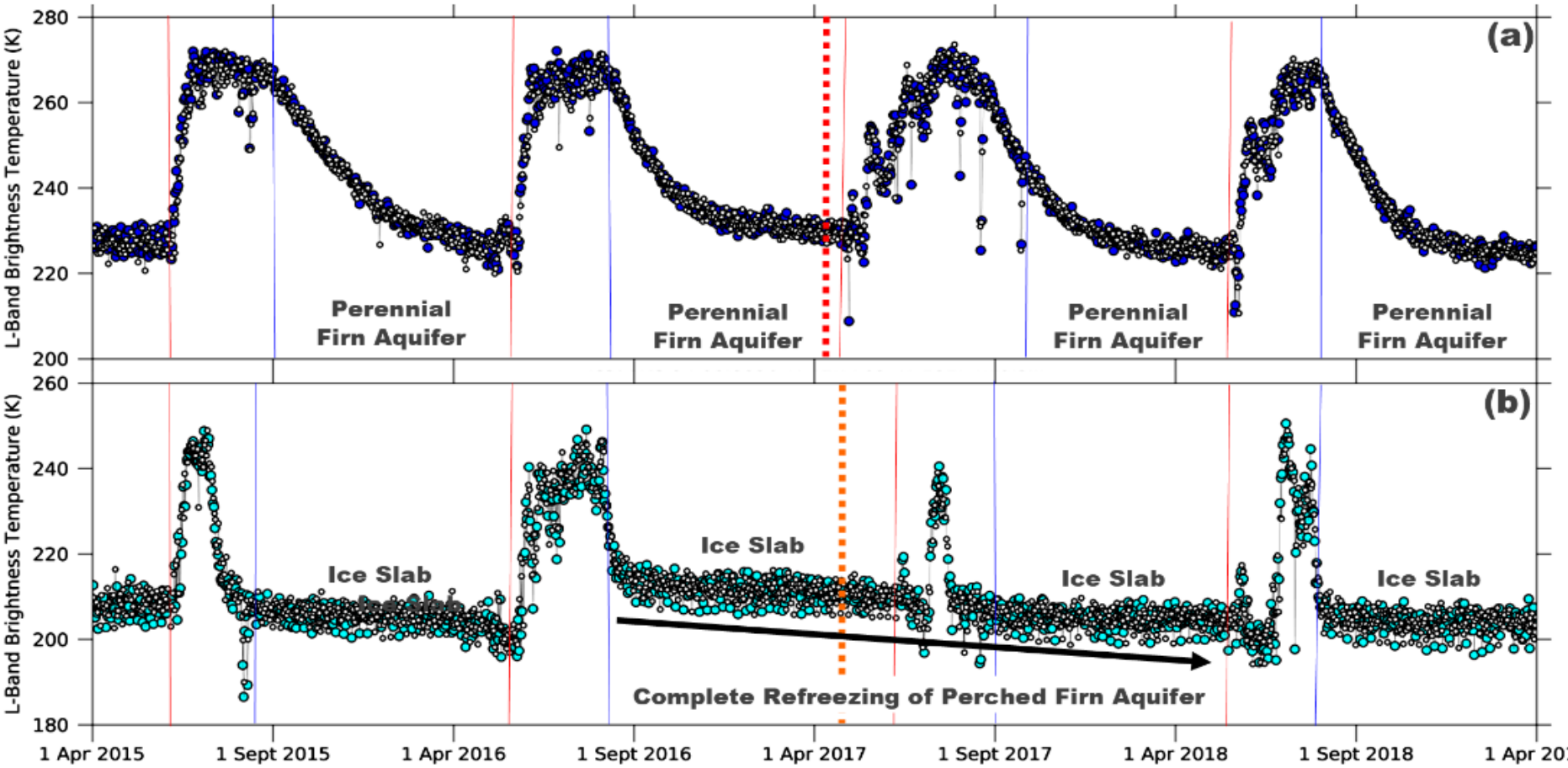
Enhanced-Resolution SMAP L-band T_V^B Imagery for Greenland Ice Sheet Facies Mapping



Enhanced-Resolution L-band T_V^B SMAP imagery https://nsidc.org/data/NSIDC-0738/versions/1

Gridded (25 km, a) and enhanced-resolution (3.125 km, b) imagery collected 15 April 2016. Imagery is overlaid with NASA Operation IceBridge 2010-2017 perennial firn aquifer (blue), 2010-2014 ice slab (cyan), and 2012 melt layer (white) detections along flight lines (black lines). The red and orange boxes in (c) are zoom areas over SE (Slide 2a), and SW (Slide 3b) Greenland.

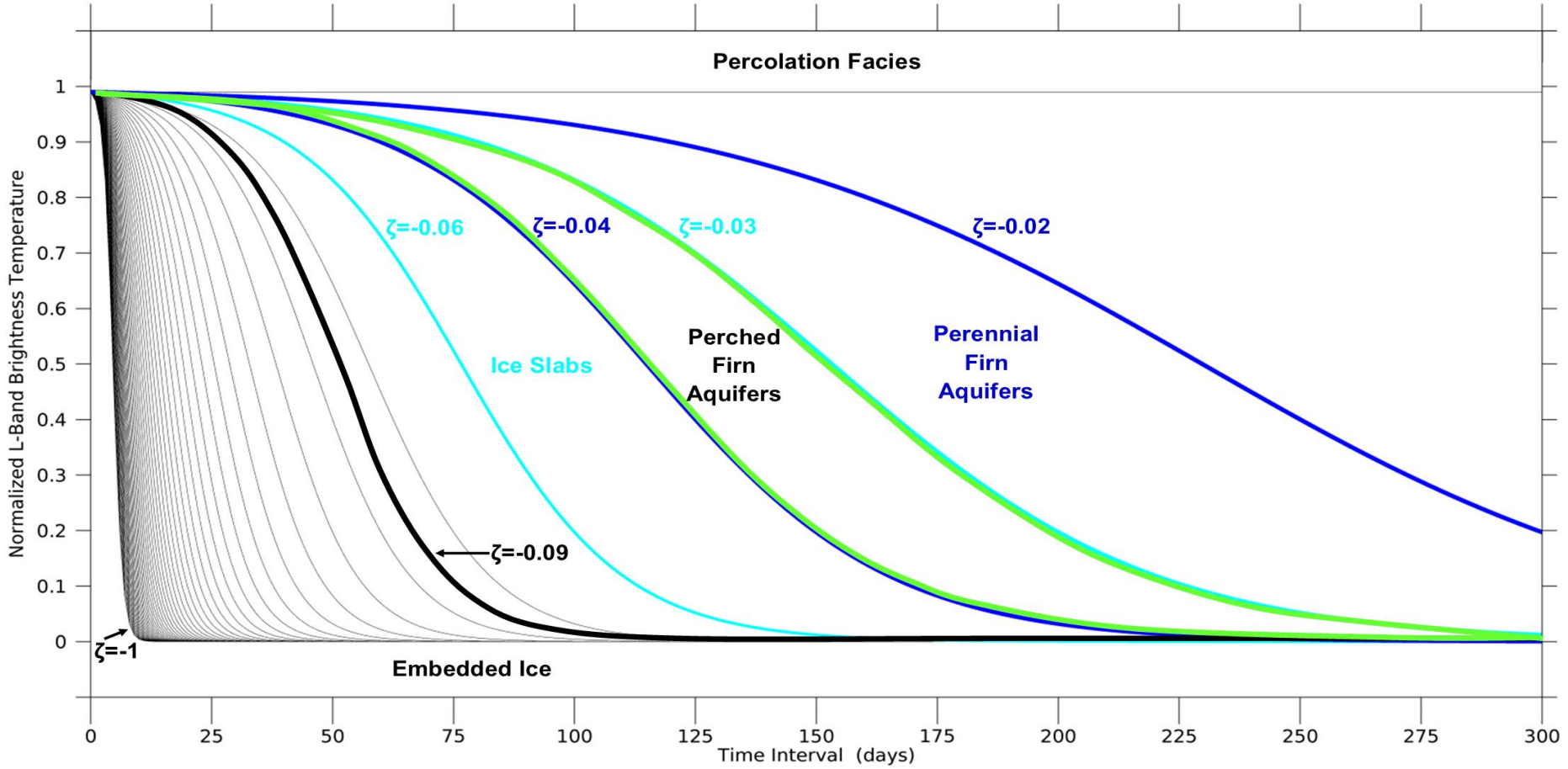
Enhanced-Resolution SMAP T_V^B Time Series Showing Annual Greenland Hydrological Cycle



L-band Perennial Firn Aquifer, Perched Firn Aquifer, and Ice Slab Signatures

Enhanced-resolution T_V^B time series collected over (a) perennial firn aquifer area (blue circle; Slide 3a), (b) perched firn aquifer area (Slide 3, 4b) Melt onset (red lines) and surface freeze-up (blue lines) dates are derived from thermal infrared T^B collected by MODIS on the Terra and Aqua satellites. Accumulation Radar echogram profile along perennial firn aquifer transect A-B (Slide 4a) and ice slab transect C-D (Slide 4b).

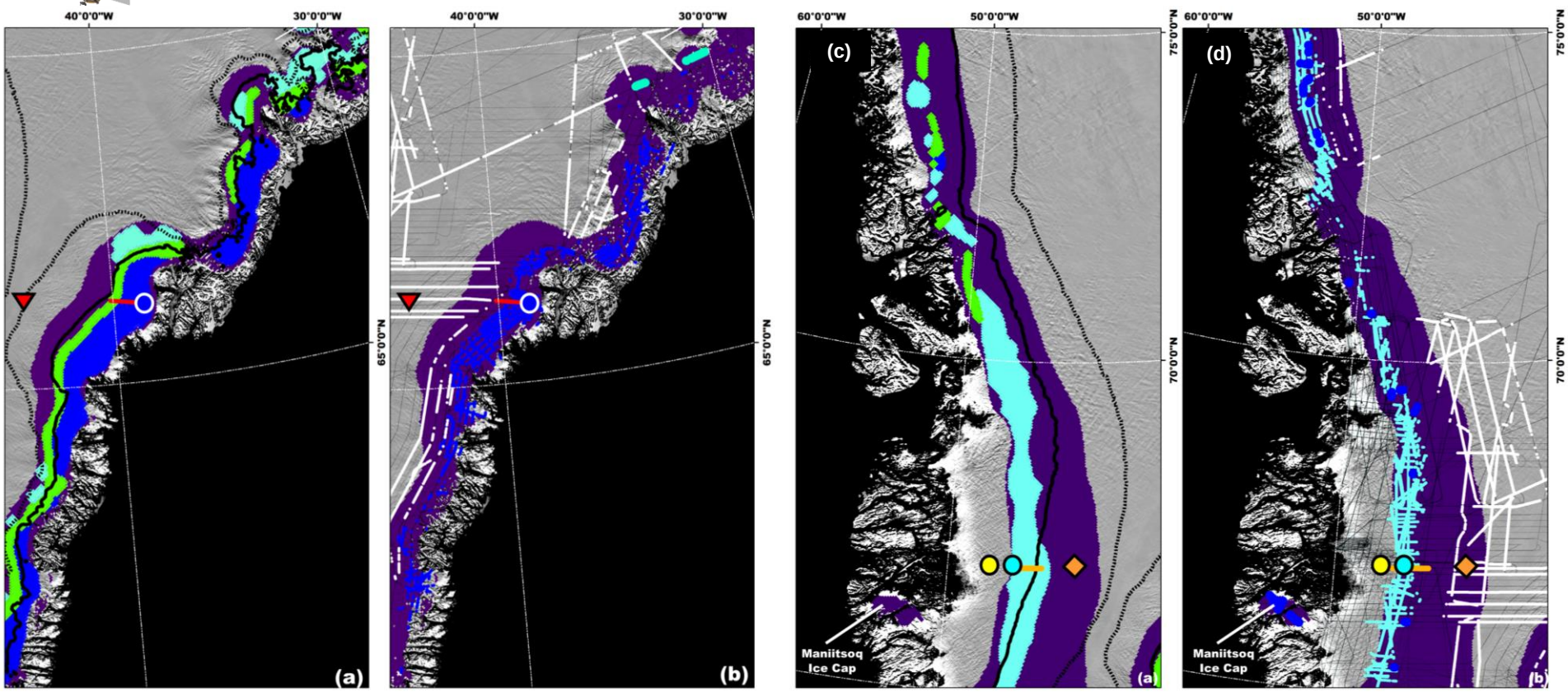
Empirical Algorithm for Mapping Subsurface Hydrological Ice Sheet Features



Continuous Logistic Model. *Example set of simulated sigmoidal curves that represent our model of the exponentially decreasing temporal L-band signatures predicted over the percolation facies. Modified from Miller et al, (2020).*

Miller, J. Z., Long, D. G., Jezek, K. C., Johnson, J. T., Brodzik, M. J., Shuman, C. A., Koenig, L. S., and Scambos, T. A.: Brief communication: Mapping Greenland's perennial firn aquifers using enhanced-resolution L-band brightness temperature image time series, The Cryosphere, 14, 2809–2817, https://doi.org/10.5194/tc-14-2809-2020, 2020.

Mapping Percolation Facies Hydrologic Features Southeastern and Southwestern Greenland



Empirical Algorithm Results *The SMAP-derived perennial firn aquifer (blue shading), ice slab (cyan shading), perched firn aquifer (green shading), and percolation facies (purple shading) extents (2015-2019) generated by the empirical algorithm overlaid on the 2015 MODIS Mosaic of Greenland image map over SE (a) , and SW (c) Greenland. The black line is the 2000 m.a.s.l. contour, and the black dotted line is the 2500 m.a.s.l. contour. The SMAP-derived extents are overlaid with NASA Operation IceBridge 2010-2017 perennial firn aquifer (blue), 2010-2014 ice slab (cyan), and 2012 melt layer (white) detections along flight lines (black lines) in (b) and (d).*

Mapping Firn Aquifers and Ice Slabs Within the Greenland Ice Sheet using SMAP

- We use enhanced-resolution SMAP L-band T_V^B imagery for mapping:
  - **Ice Slabs**: subsurface meltwater refrozen in firn, impermeable layers enhancing runoff
  - **Firn Aquifers**: important hydrological component, subsurface meltwater stored in pore space
  - **Perched Firn Aquifers:** transient, shallow firn aquifers that form on top of ice slabs
- Enhanced-resolution SMAP T_V^B time series show annual Greenland hydrological cycle of surface and subsurface snow and firn
- We adapt an empirical algorithm derived from the continuous logistic model calibrated with NASA Operation IceBridge airborne radar data to map subsurface firn aquifers, ice slabs and perched firn aquifers
- Mapping percolation facies hydrologic features over the Greenland Ice Sheet is important for understanding ice sheet-wide changes in surface and subsurface firn hydrology that impact surface mass balance, and for predicting the future instability of the Greenland Ice Sheet

Miller, J. Z., Culberg, R., Long, D. G., Shuman, C. A., Schroeder, D. M., and Brodzik, M. J.: An empirical algorithm to map perennial firn aquifers and ice slabs within the Greenland Ice Sheet using satellite L-band microwave radiometry, The Cryosphere, 16, 103–125, https://doi.org/10.5194/tc-16-103-2022, 2022.