NASA SnowEx 2020

H.P. Marshall, Carrie Vuyovich, Chris Hiemstra, Kelly Elder, Ludo Brucker, Airborne Teams, Time Series Site Leads, and many, many others from 20+ universities and government labs

Photo Credit, Andrew Hedrick

hpmarshall@boisestate.edu

SnowEx 2020

The SnowEx 2020 Campaign consists of coordinated airborne and field-based experiments in the Western U.S.

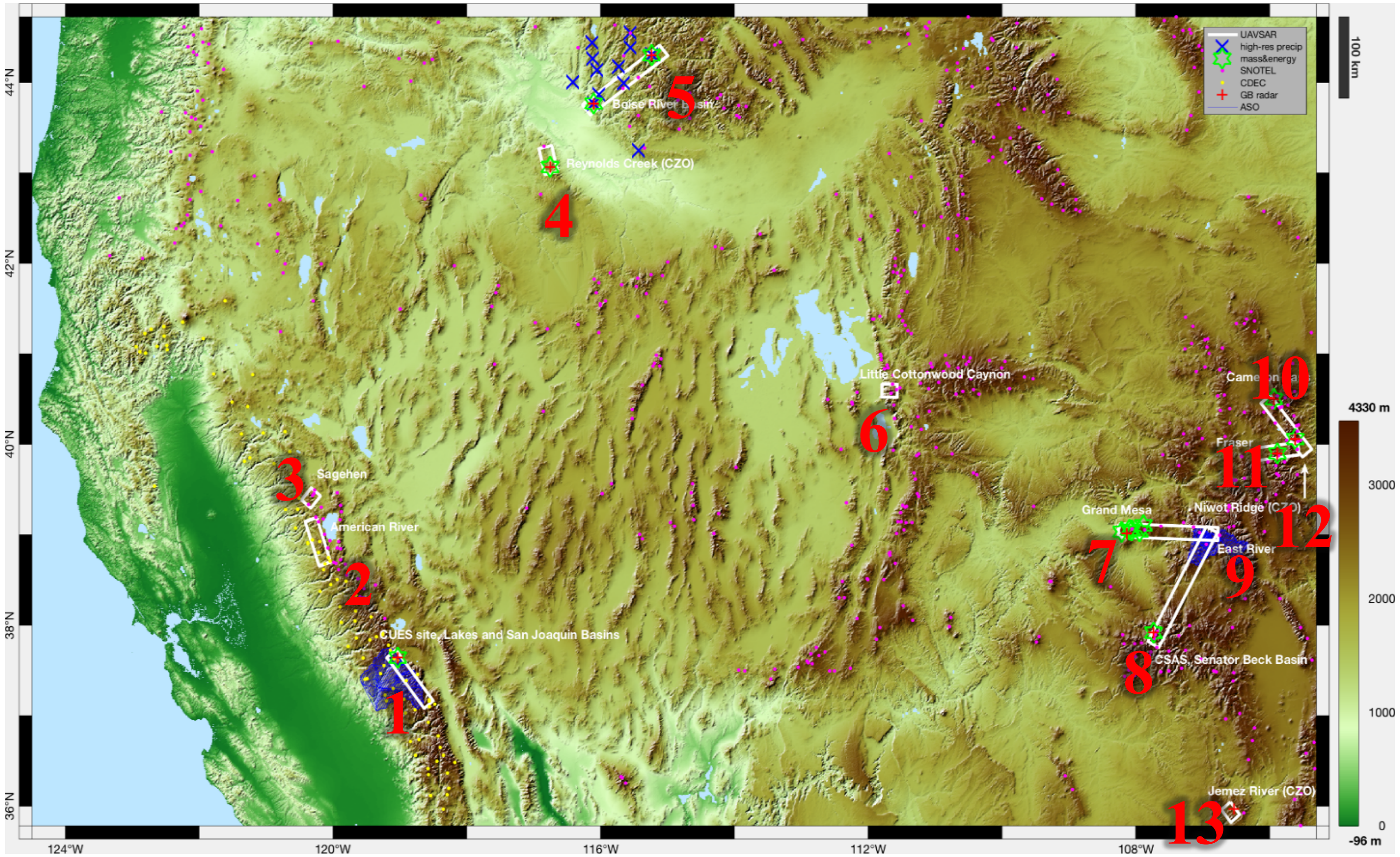
1. **A time series experiment with UAVSAR**
   - L-band Interferometric Synthetic Aperture Radar
   - Test in range of snow climates and during accumulation & melt
   - 13 sites, spanning 5 states
   - December 20, 2019 to March 12, 2020, with weekly to bi-weekly aircraft overflights and field campaigns
2. **A detailed experiment on Grand Mesa, Colorado**
   - SWE retrieval from active and passive microwave sensors
   - Surface temperature observations from Thermal IR
   - 5-day snow-off campaign November 4-8, 2019
   - 19-day snow-on campaign January 27 –February 14, 2020

Alignment with THP16 Science Plan

SnowEx 2020: Responds to 6 out of 7 Science Plan Gaps
- Snow climates (Forest, mountain, prairie, maritime)
- Wet snow, accumulation and melt (time series)
- Surface energetics (surface temperature)

SnowEx 2020: Responds to all Science Plan *Mission Critical, Crucial, Important* priorities
- L-band InSAR (UAVSAR)
- X-, K-, Ka-band Passive microwave (SWESARR)
- X-band, dual Ku-band SAR (SWESARR)
- Ka-band InSAR (GLISTIN-A)
- LiDAR (ASO, Quantum Spatial, CRREL HeliPod)
- Thermal IR (UW)
- Hyperspectral imaging (ASO, Quantum Spatial, SaraniaSat)
- Modeling / Data Assimilation (SEUP, NOHRSC)
- Photogrammetry / Structure from Motion (airborne and satellite based)
- FMCW radar (similar to IceBridge SnowRadar; University of Alabama)
- C-band SAR! (Science Plan team is adding this)

SnowEx 2020 – Time Series



Site	Site Name	Site Lead
1	Lakes Basin, CA	Ned Bair
2	American River Basin, CA	Roger Bales
3	Sagehen Creek, CA	Anne Nolin
4	Reynolds Creek, ID	Ernesto Trujillo
5	Boise River Basin, ID	Jim McNamara
6	Little Cottonwood Canyon, UT	McKenzie Skiles
7	Grand Mesa, CO	Hiemstra, Brucker
8	Senator Beck Basin, CO	Andy Gleason
9	East River, CO	Jeff Deems
10	Cameron Pass, CO	Dan McGrath
11	Fraser Experimental Forest, CO	Kelly Elder
12	Niwot Ridge, CO	Noah Molotch
13	Jemez River, NM	Ryan Webb

Time Series Summary

- 6 successful UAVSAR flights, between December 20 and March 12
- UAVSAR flight had conflicts with ISRO-ASAR, aircraft and instrument issues
- LiDAR acquisitions over Idaho, Colorado
- WV, ICESat2 collections
- Coordinated modeling
- Field teams deployed 9 times across 13 sites, providing unique time series of coordinated snowpit observations
- 100+ students, researchers from 20+ organizations
- 200+ pits during 9 week time series
- Liquid water content observations
- Temperature, density, SWE, depth, stratigraphy, microstructure, hardness

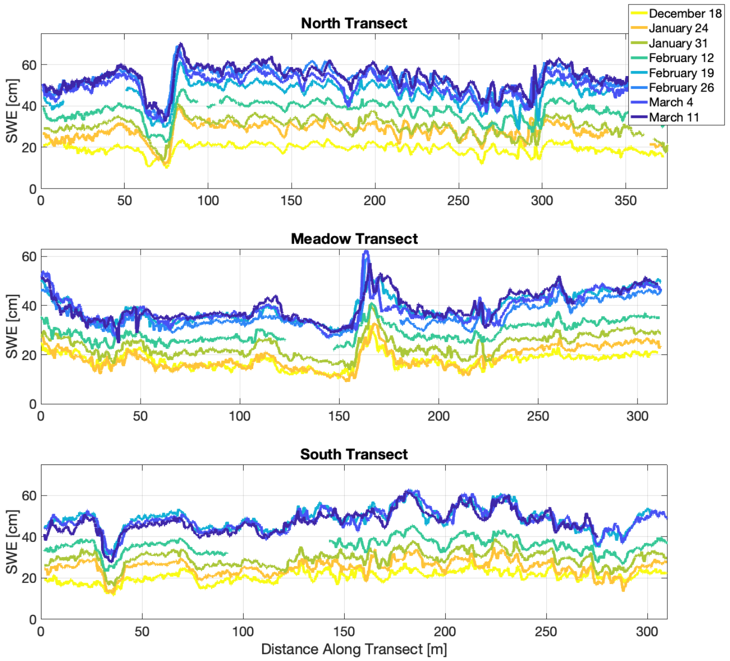
Snow microstructure observations, long-range L-band InSAR

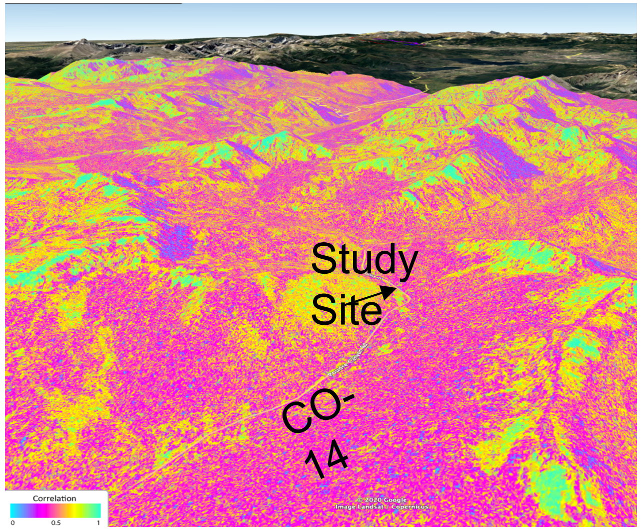
Time Series Summary

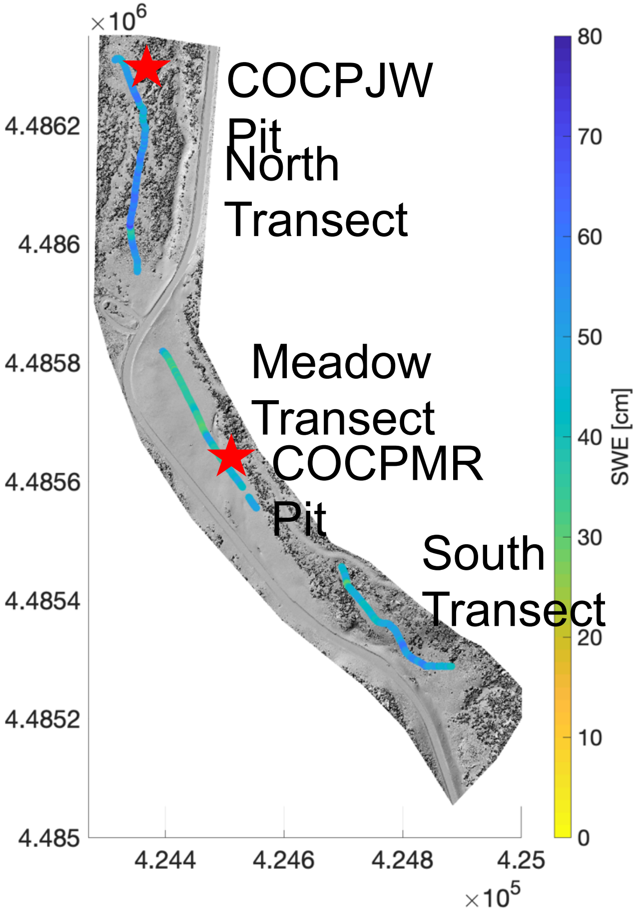
- Ground based radar
- Terrestrial LiDAR scanning
- Drone flights (Thermal IR, SfM) (coordinated activity)
- Coordinated with LiDAR surveys by U.S. Army Cold Regions Research and Engineering Laboratory
- Coordinated with USDA NRCS Snow Surveys
- Wide range of snow climates
- Winter Wildland Alliance SnowSchool partnership: K-12 students collected snow observations and submitted to SnowEx via CommunitySnowObs.org
- Time series cancelled early due to COVID-19 pandemic
- UAVSAR flight hours will be rolled over to 2021

Exec Director of national WWA SnowSchool program demonstrates snow density observations with K-12 students in Idaho

Time series example: Cameron Pass





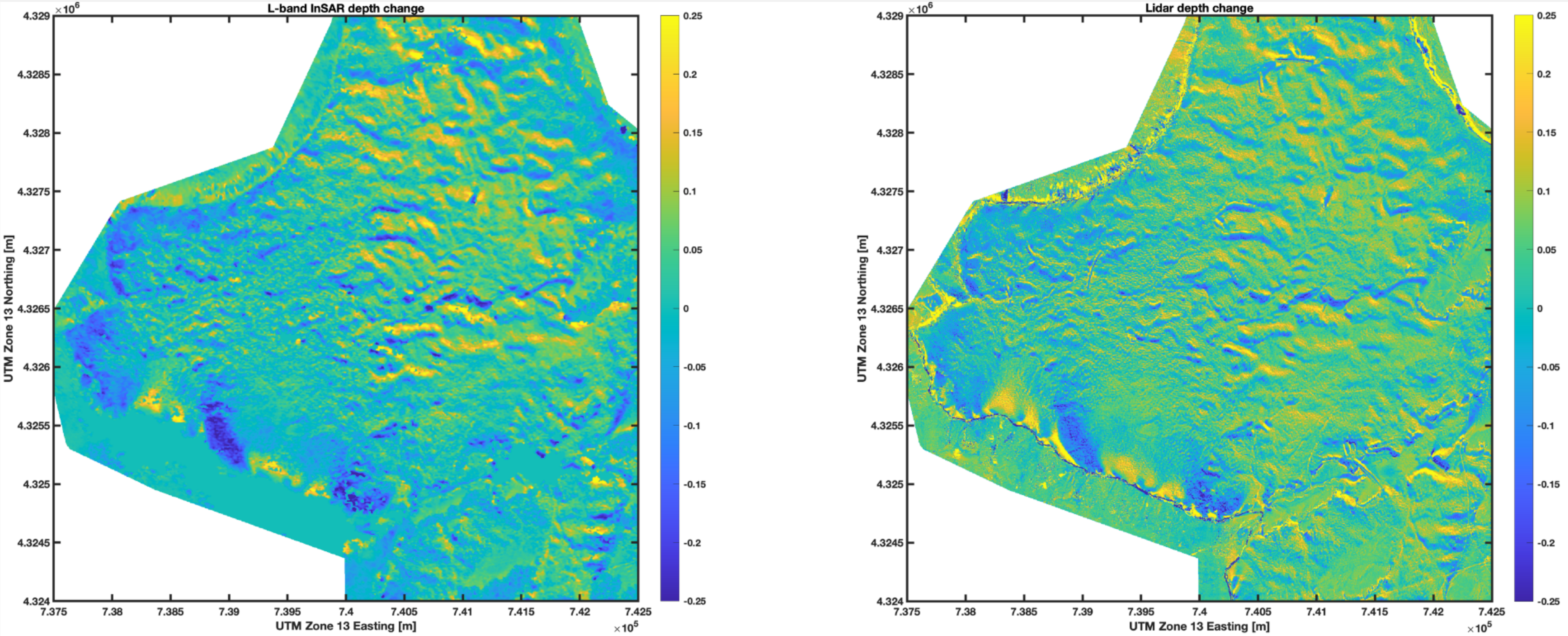


Repeat GPR surveys, SfM, TLS, UAV GPR

See Dan McGrath's poster.

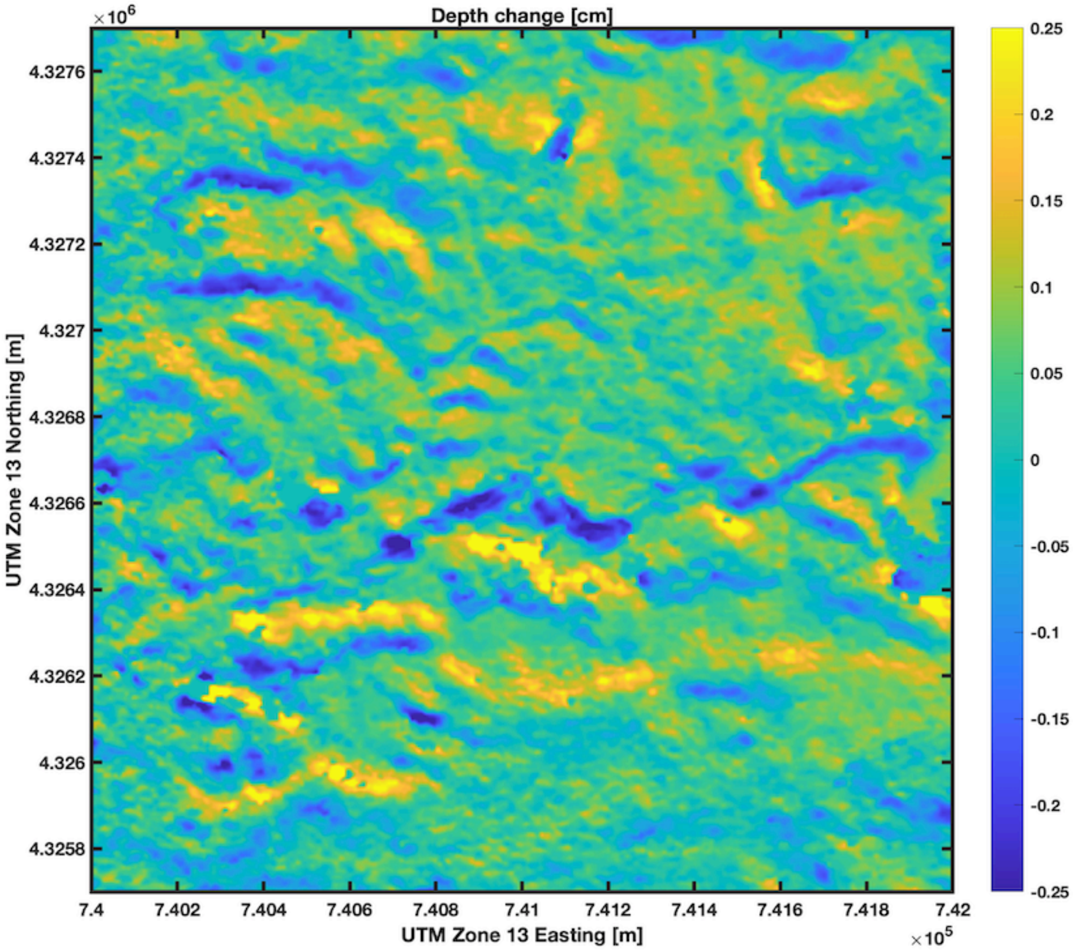
See also other GPR-related posters by Webb, Meehan, Bonnell

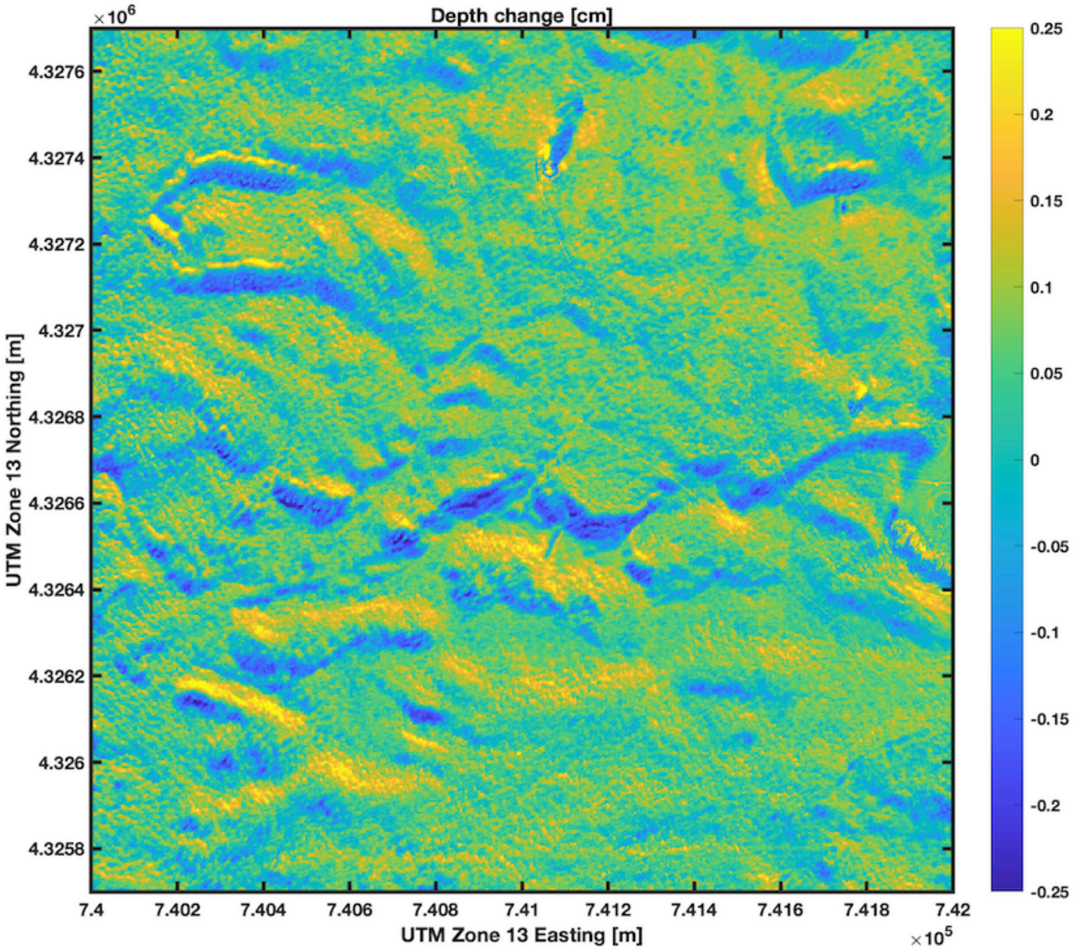
RECENT L-BAND INSAR RESULTS FROM SNOWEX 2020



- UAVSAR pair from Grand Mesa, Feb 13 - Feb 1, 2020
- Quantum Spatial Inc (QSI) lidar flights for depth change, Feb 12-Feb 1, 2020
- Lidar accuracy ~3-5cm per flight, expected ~6-10cm accuracy for depth/depth change products
- UAVSAR depth inversion uses phase change and incidence angle, with measured surface density (200 kg/m^3). No tunable parameters!

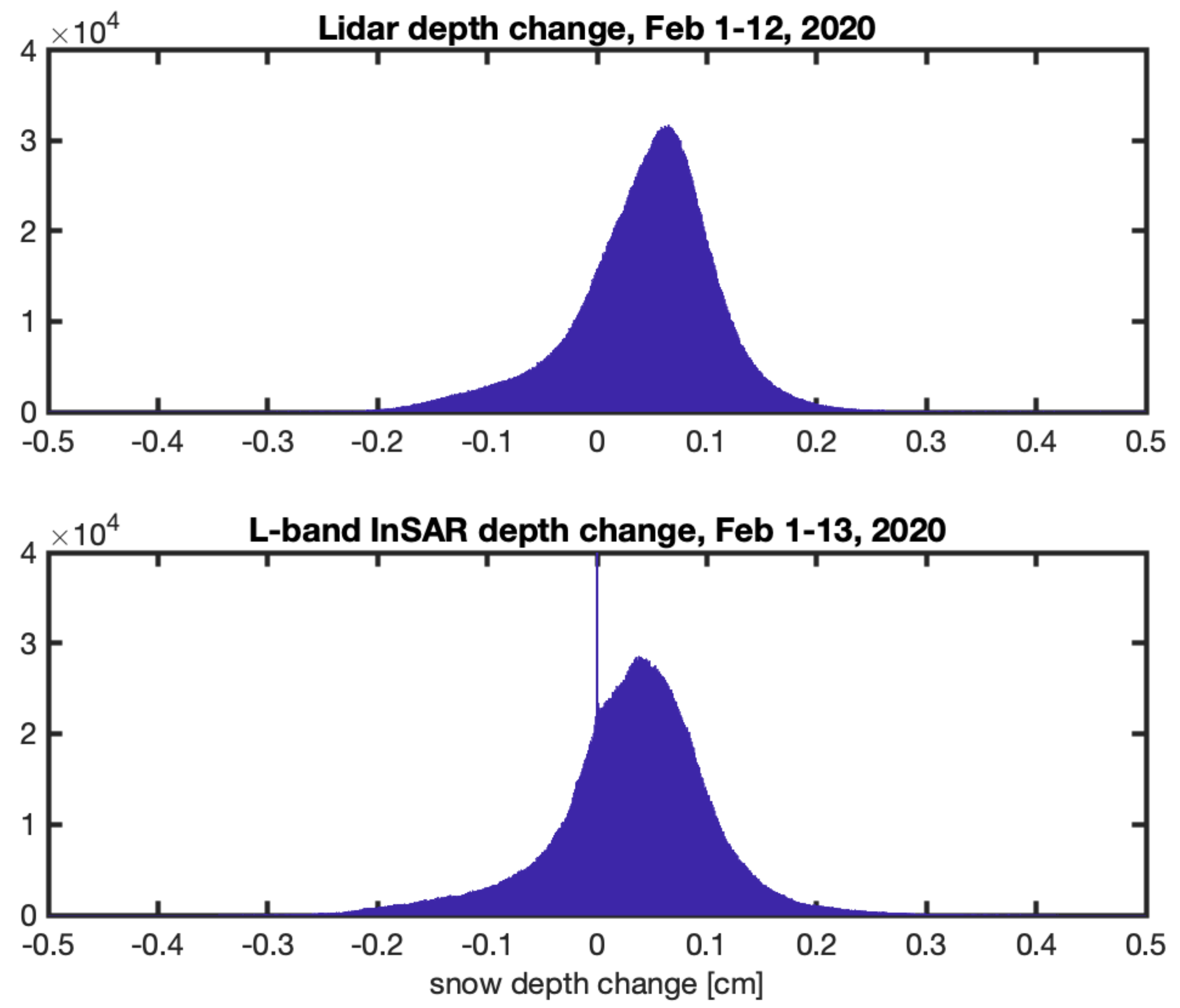
RECENT L-BAND INSAR RESULTS FROM SNOWEX 2020





- Zoom in on 2km x 2km region with dynamic range in depth
- R-value = 0.76, RMSD=4.7cm depth, 0.9cm SWE
- Independent high-resolution spatial snow information is critical for evaluation of radar approaches

RECENT L-BAND INSAR RESULTS FROM SNOWEX 2020



- Independent field observations of depth change show a mean depth change of 9cm over this period
- In these conditions (surface density ~200 kg/m^3), 360 deg phase change can capture 46cm depth change. Reference location and surface density estimate required.
- Correlation loss after 3-12 weeks depending on conditions, much shorter in vegetation
- SnowEx2021 focused on capturing larger SWE/depth changes, and exploring transition between dry and wet snow
- Technique shows promise for defining snow accumulation patterns
- More work needed to define limitations in vegetation and steep topography

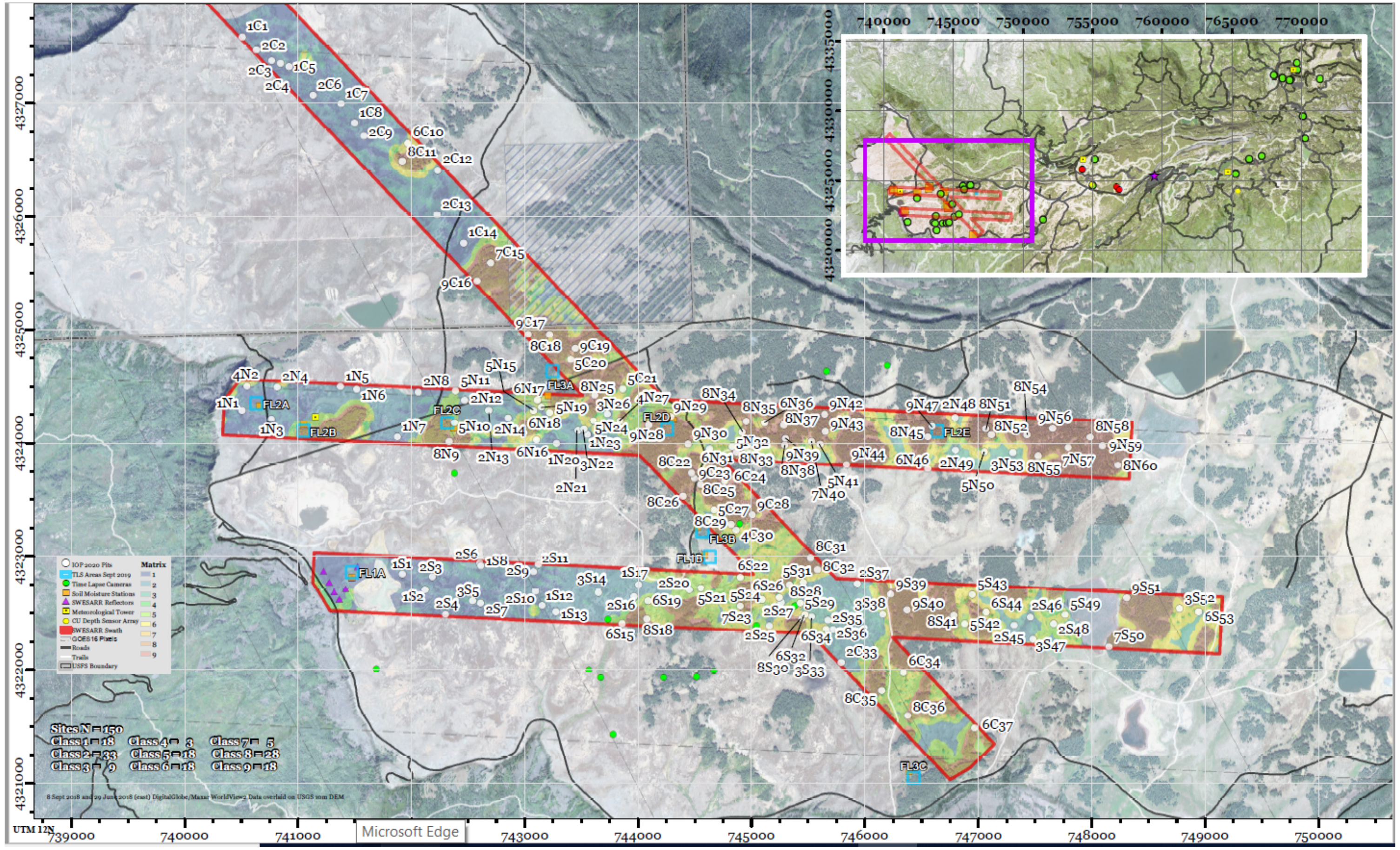
SnowEx 2020 – Grand Mesa

Primary Objectives:

1. Collect data needed test and validate SWE retrieval from active and passive microwave sensors
2. Collect thermal IR data to assess the value of kilometer-scale satellite IR observations (e.g., GOES-16/17) for snow energy balance modeling

- Focus on flat, open shrubland and meadows and transitioning into forests
- Ground observations of:
  - Snow depth and surface temperature spatial variability
  - Vertical profiles of snow stratigraphy and microstructure

SnowEx 2020 – Grand Mesa



Planned Ground Observations:

- Snow pits (150)
- Snow Depth Transects
- Terrestrial Laser Scanner (TLS)
- Passive microwave radiometer
- Ground penetrating radar
- Snow microstructure (grain size, SSA)
- Snow surface temperature

Planned Airborne Instruments:

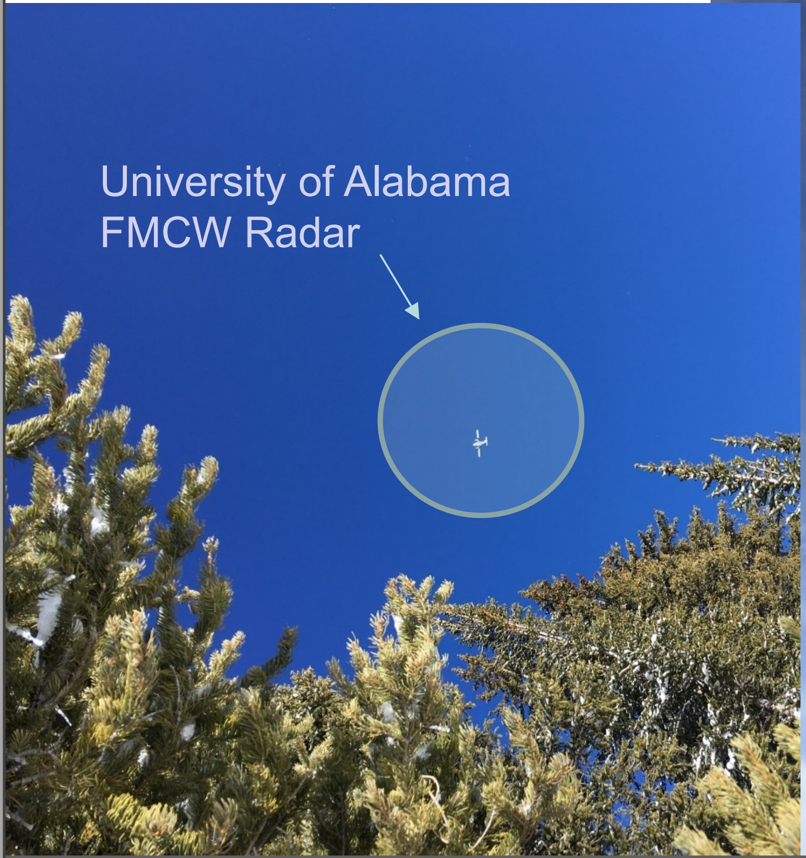
- Active/Passive microwave (SWESARR)
- Thermal IR (UW)
- L-band InSAR (UAVSAR)
- LiDAR (Quantum Spatial)
- Hyperspectral imaging (Quantum Spatial)
- Gamma (NOAA NOHRSC)
- FMCW radar (University of Alabama)

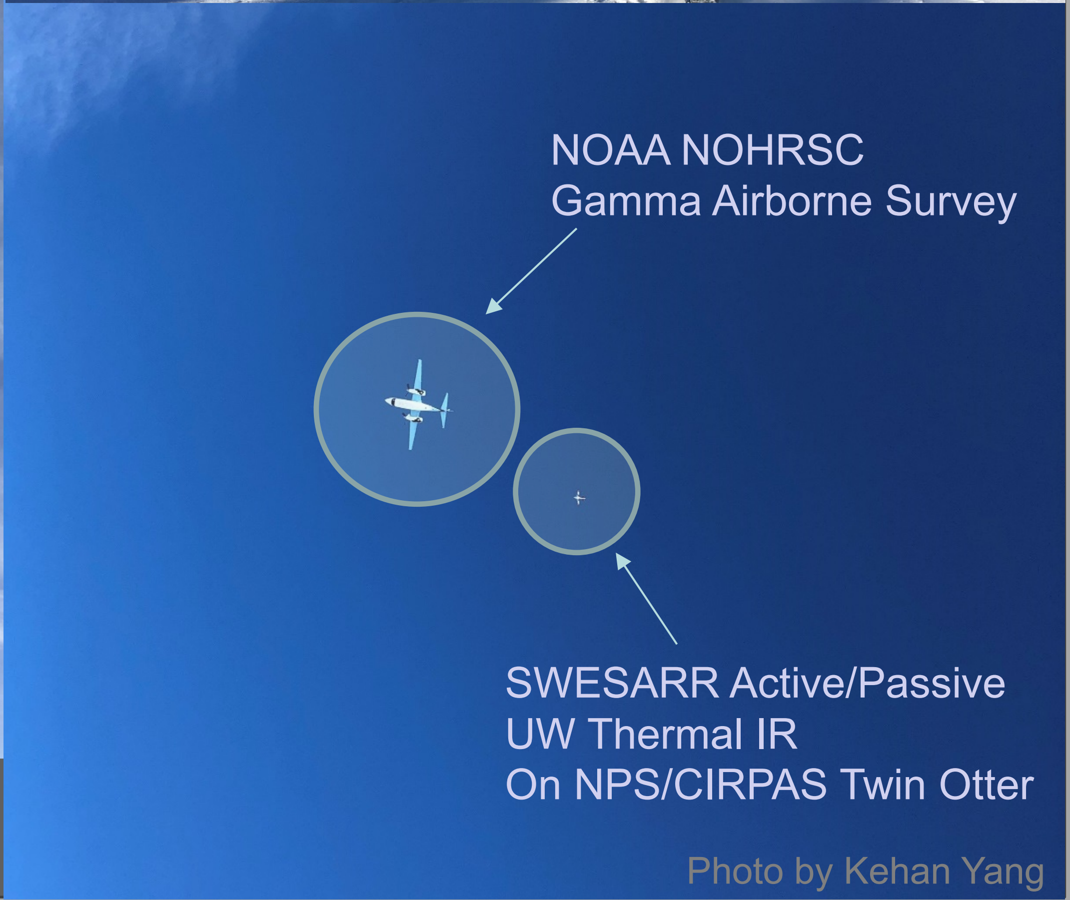
Grand Mesa Ground Campaign

- 153 Snow Pits
- Over 30,000 snow depth measurements
- SSA profiles at 99 pits
- 976 SMP profiles at 48 pits
- 73 snow casts at 12 pits
- PM radiometer measurements at 20 pits + grid
- IR radiometers & temperature profiles installed at 2 locations for 2-week period
- 4 radars covered over 500 km
- ASD measurements during both Quantum hyperspectral flights
- 9 TLS sites scanned
- 8 storm boards & 12 snow stakes installed and measured three times (2, 8, 13 Feb)
- SUS-V mobility measurements (coordinated activity)
- Drone flights (Thermal IR, SfM) (coordinated activity)

Snow pit with Celine Vargel, Jewell Lund and Trey Stafford (Photo by Megan Mason)

Airborne Campaign





The airborne SWESARR observations

SWESARR
Snow Water Equivalent Synthetic Aperture Radar and Radiometer

Team members

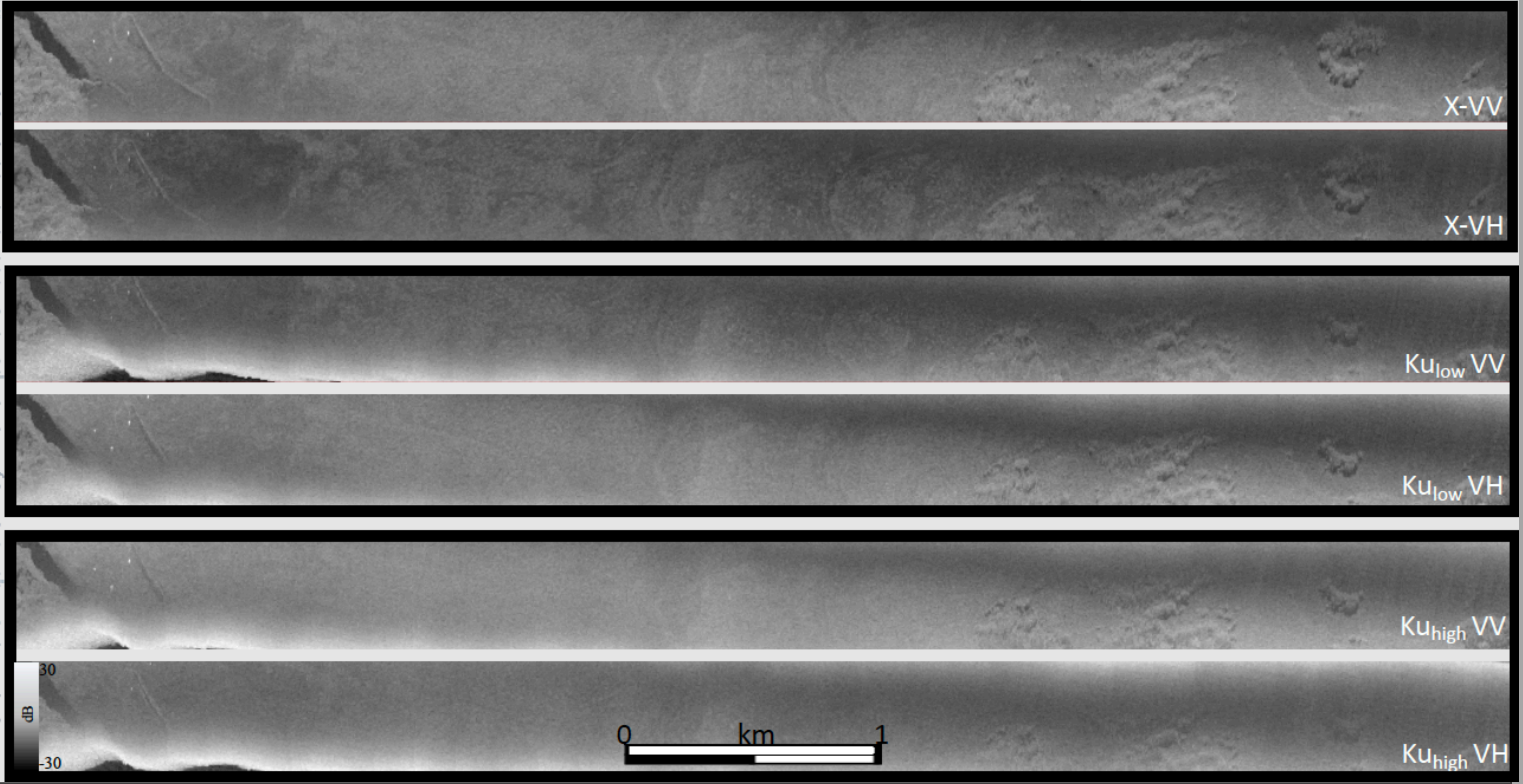
Batu Osmanoglu – Instrument Lead
Rafael Rincon – Radar Lead
Derek Hudson – Radiometer Lead
Ludovic Brucker – Radiometer Scientist
Martin Perrine – Radar Engineer
Chase Kielbasa – RF Engineer
Gabe Maymon – Antenna positioner / Mech. Eng.
Paul Racette – ex-Radiometer Lead/Antenna Design
Steve Seufert – Mechanical Engineer

1 antenna for observations at:
- 3 passive bands (X, Ku, Ka)
- 6 active bands (X, Ku-low, Ku-high)

Radar's altitude range: 1.5 – 3 km agl

Grand Mesa Lands End backscatter (11 Feb.)

	X VV	Ku-L VV	Ku-H VV
Abs. σ^0 stdev (dB)	0.9	1.3	2.9
Geocoding Error		<100 m	

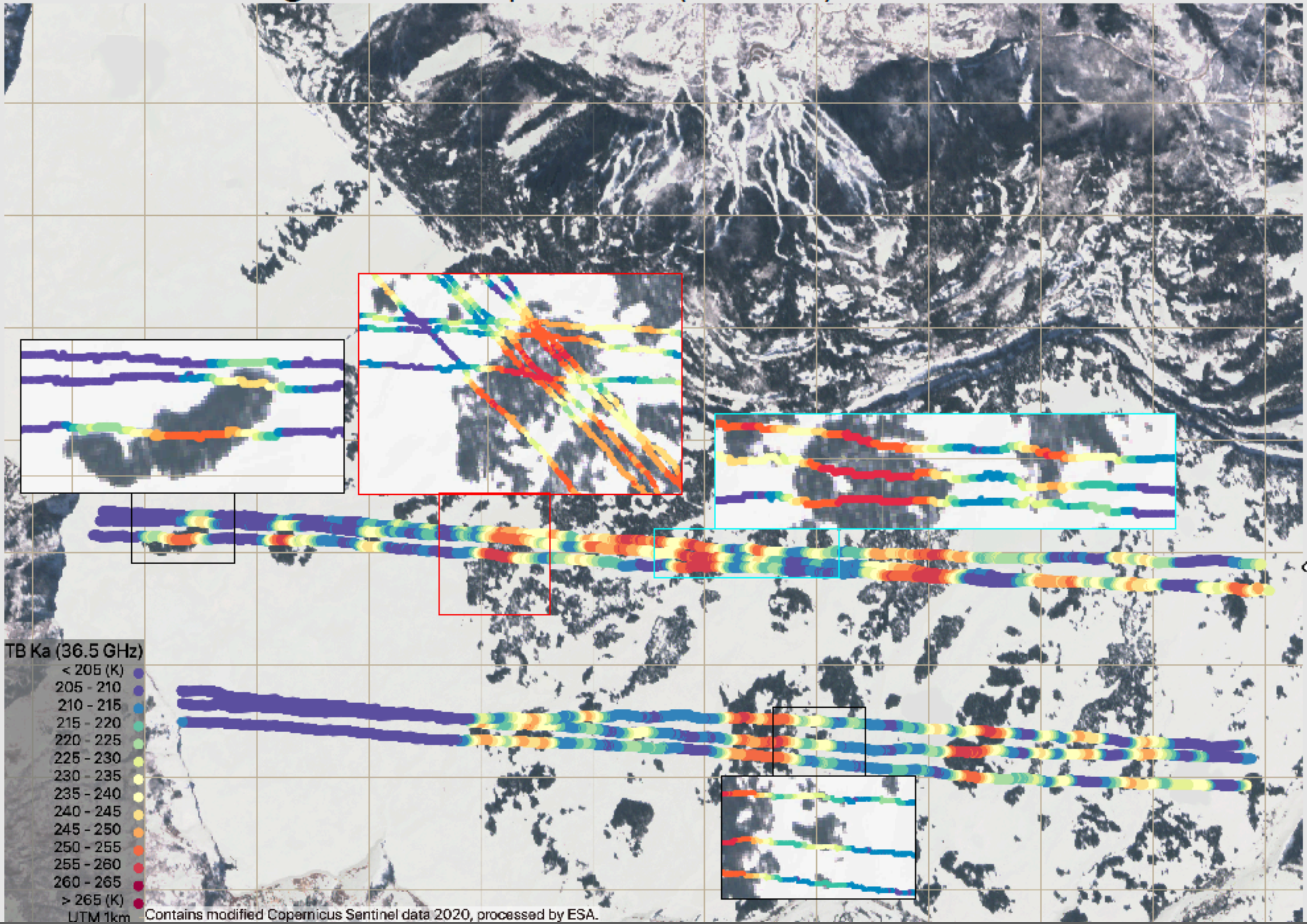


SWESARR
Snow Water Equivalent Synthetic Aperture Radar and Radiometer

SWESARR

Snow Water Equivalent Synthetic Aperture Radar and Radiometer

Grand Mesa brightness temperature (11 Feb.)



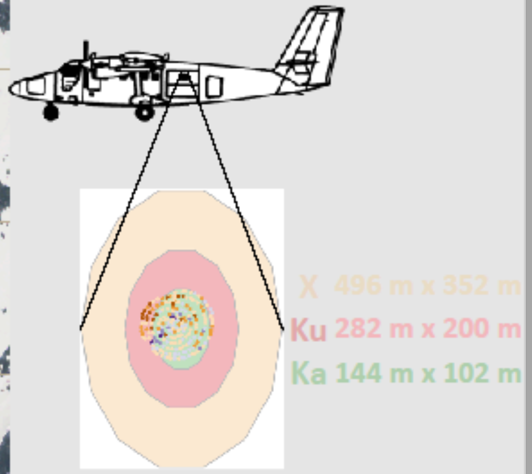
Simultaneous observations at:

. 10.65, 18.7, and 36.5 GHz

. 45° incidence angle

. horizontal polarization

Adjusted along-track



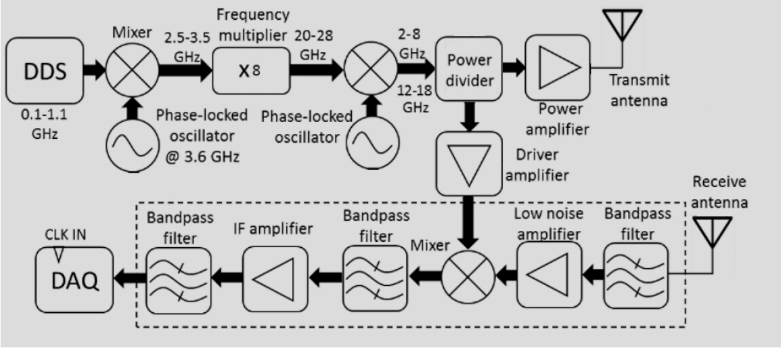
radiometer footprints & snow depth measurements

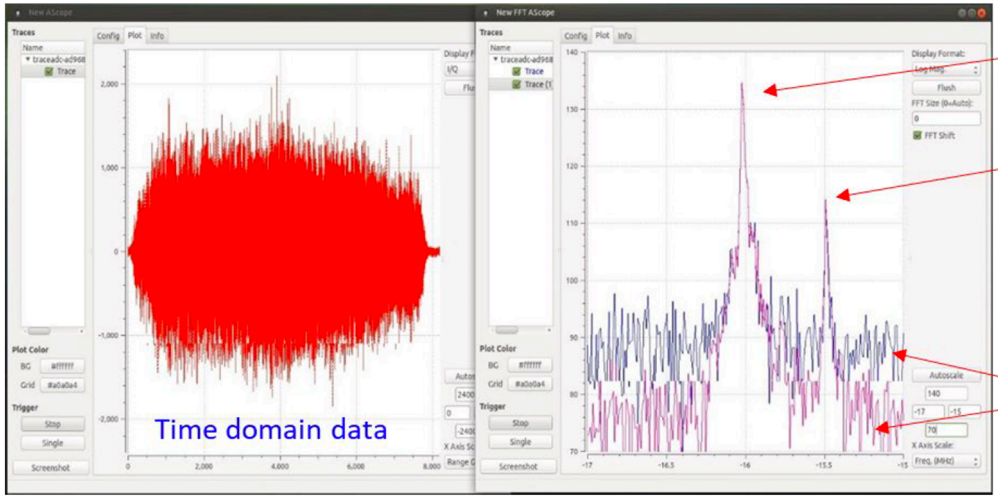
University of Alabama, Remote Sensing Center

Drew Taylor, Stephen Yan, Prasad Gogenini, and others

Airborne UWB FM-CW Radar

- 2.7-10.7 GHz/10.7-18.7 GHz
- 1 W peak transmit power
- 4 kHz PRF / 180 us pulse
- 1.52 cm vertical resolution in snow
- ~50 m x 300 m horizontal resolution





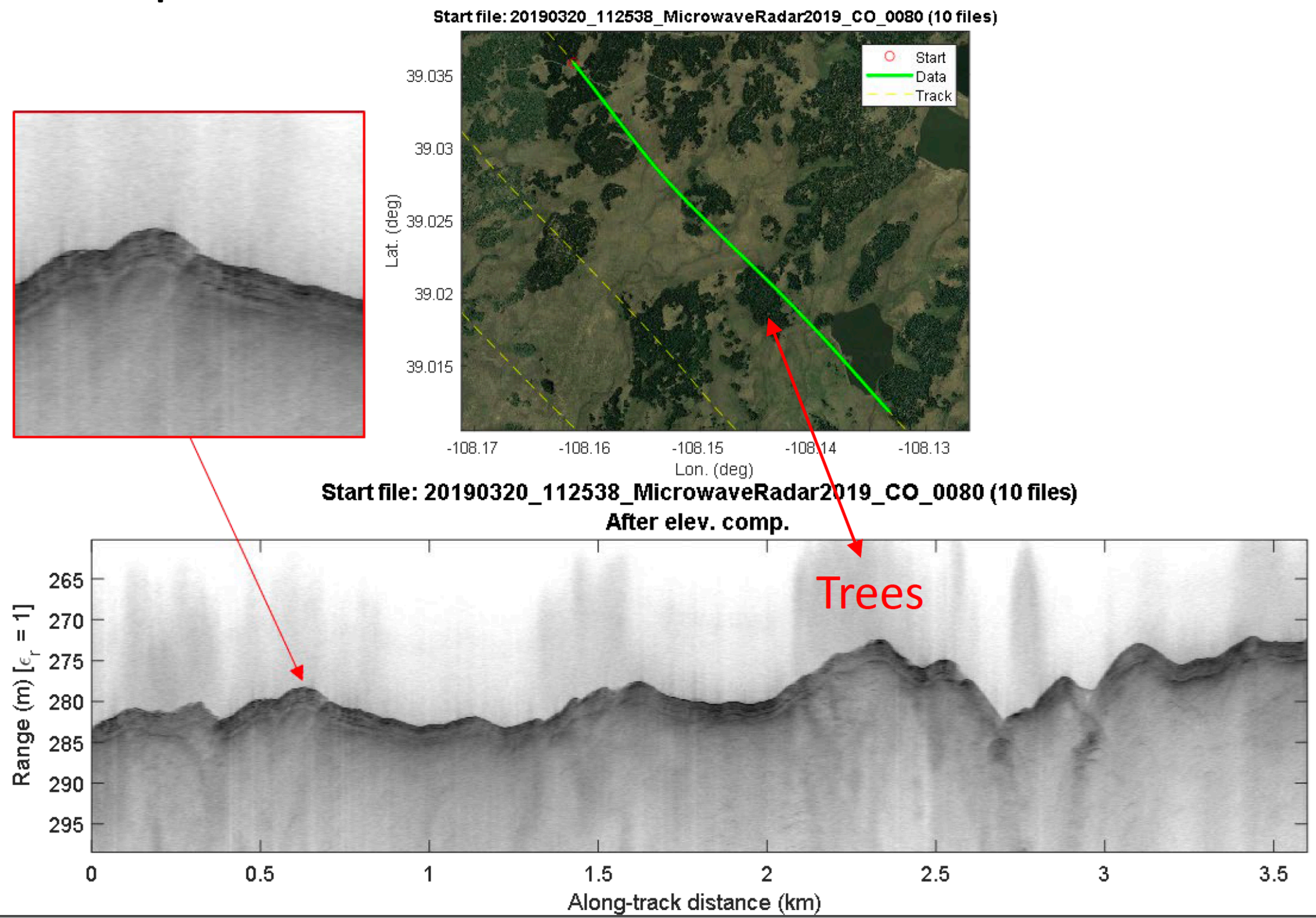
Simulated return from snow-air interface

Simulated return from snow-land interface

~50 dB SNR
~175 dB loop sensitivity

SNR gain due to real-time hardware averaging

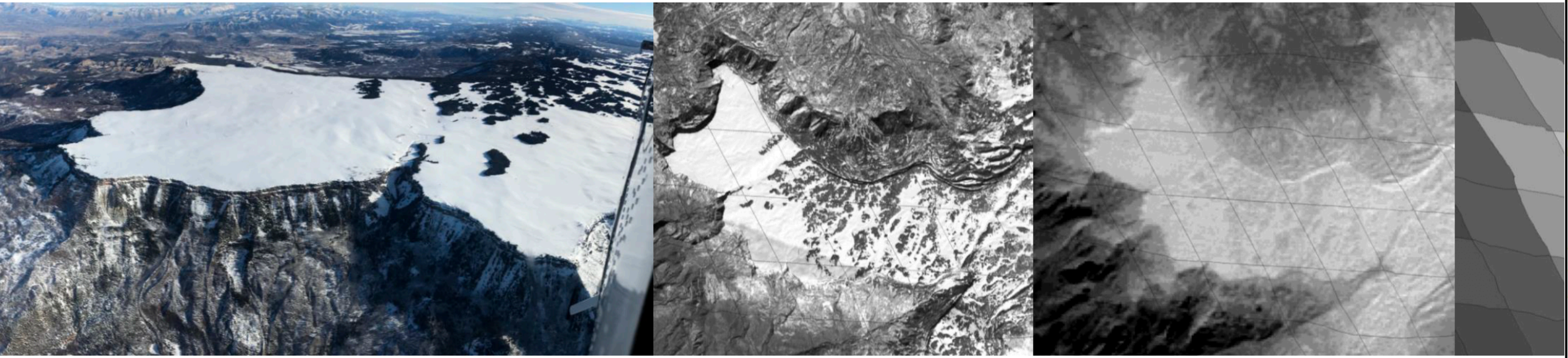
S. Yan, S. Gogineni, D. Braaten, J. Brozena, F. Rodriguez-Morales and E. Arnold, "Ultra-wideband radars operating over the frequency range of 2-18 GHZ for measurements on terrestrial snow and ice," *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, 2016, pp. 7078-7081.



- Snow depth appears resolvable under forest canopy
- Nadir observations worked well
- SAR approach still in progress
- Drone-based capability
- Future plans for installation on G-5, greatly enhancing possible range (currently on Twin Otter)

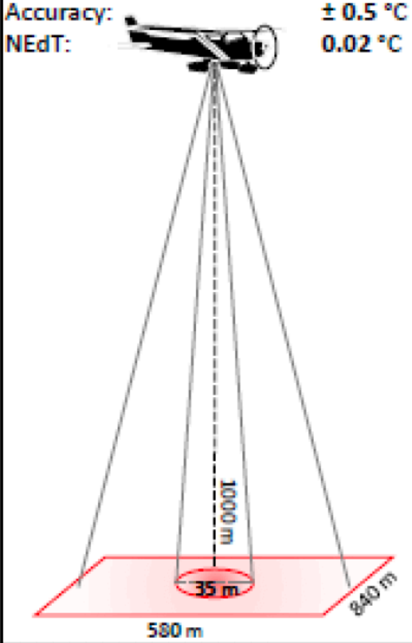
Snow Surface Temperature & Thermal Infrared Remote Sensing

Grand Mesa IOP - SnowEx 2020



TIR Camera:	DRS UC640-17
Detector Size:	640 x 480 px
Spectral Response:	8 – 14 μm
Accuracy:	± 1 °C
NEdT:	0.07 °C
(Noise Equivalent Differential Temperature)	

IR Radiometer:	KT15.85D
Field of View:	1.9° FOV
Approx. Spot Size:	35 m
Spectral Response:	9.6 – 11.5 μm
Accuracy:	± 0.5 °C
NEdT:	0.02 °C

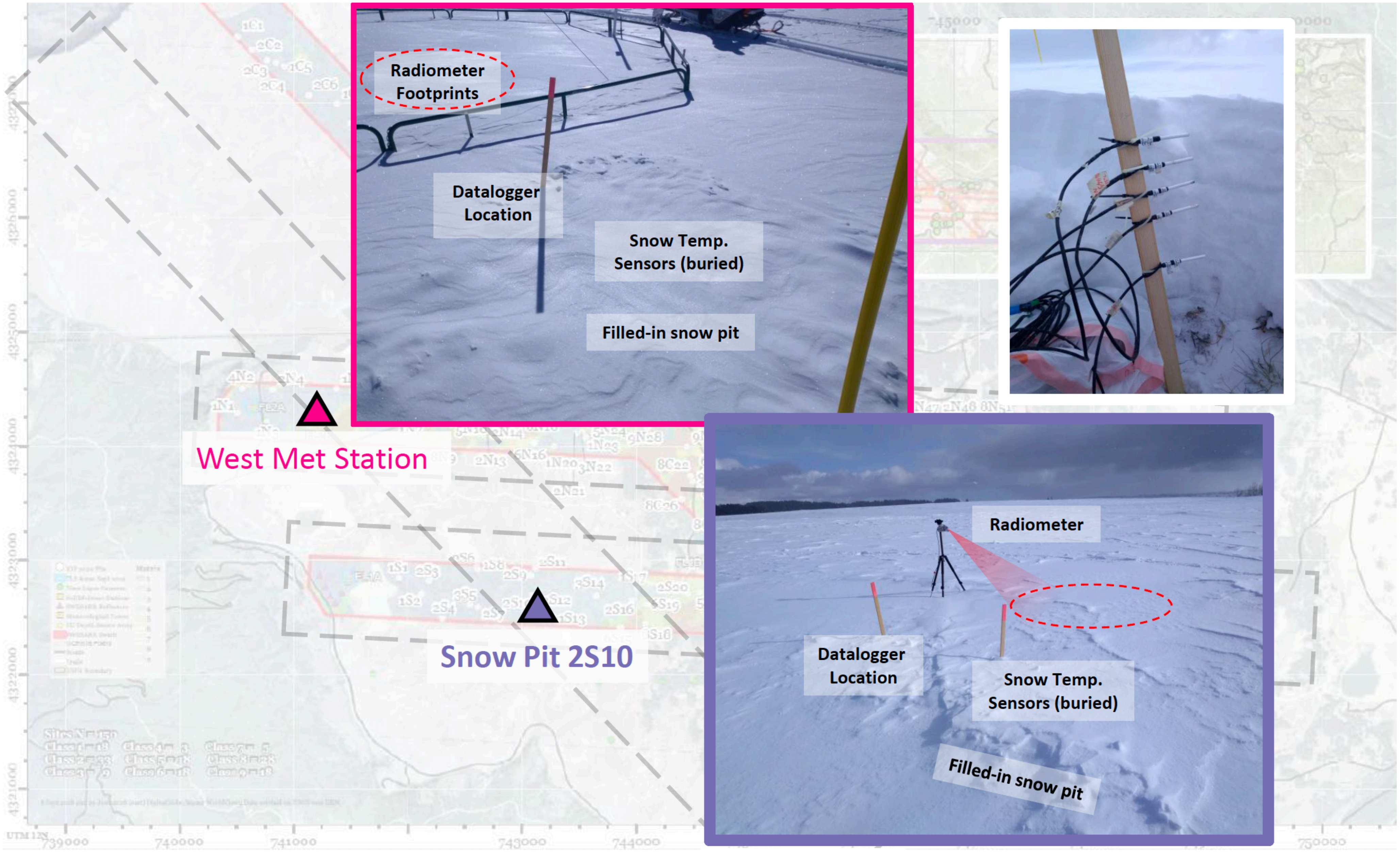


Steven Pestana[1]
Jessica Lundquist[1]
Chris Chickadel[1,2]

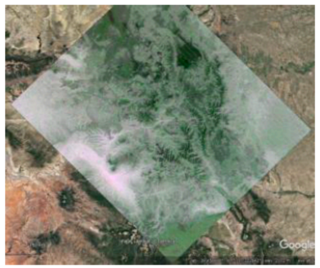
[1] Civil and Environmental Engineering, UW; [2] Applied Physics Lab, UW

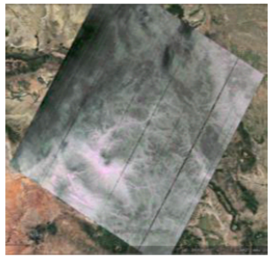
Photo credit: Chris Chickadel

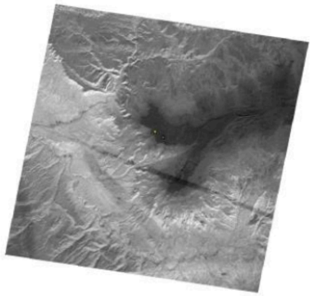
Fieldwork and ground-based data collection



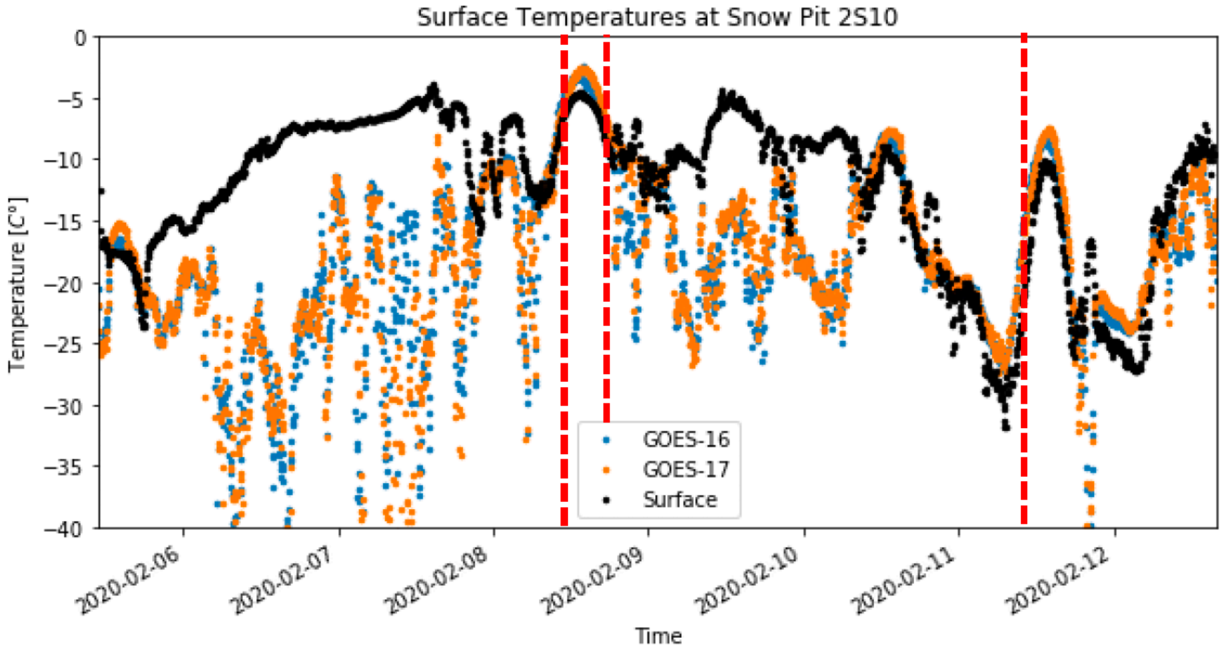
Grand Mesa map image and GIS files: Chris Hiemstra







Snow Pit 2S10



Preliminary snow-surface and depth profile temperature data:
https://github.com/spestana/snowex2020-snow-temp

SNOWEX 2021 OBJECTIVES

UAVSAR

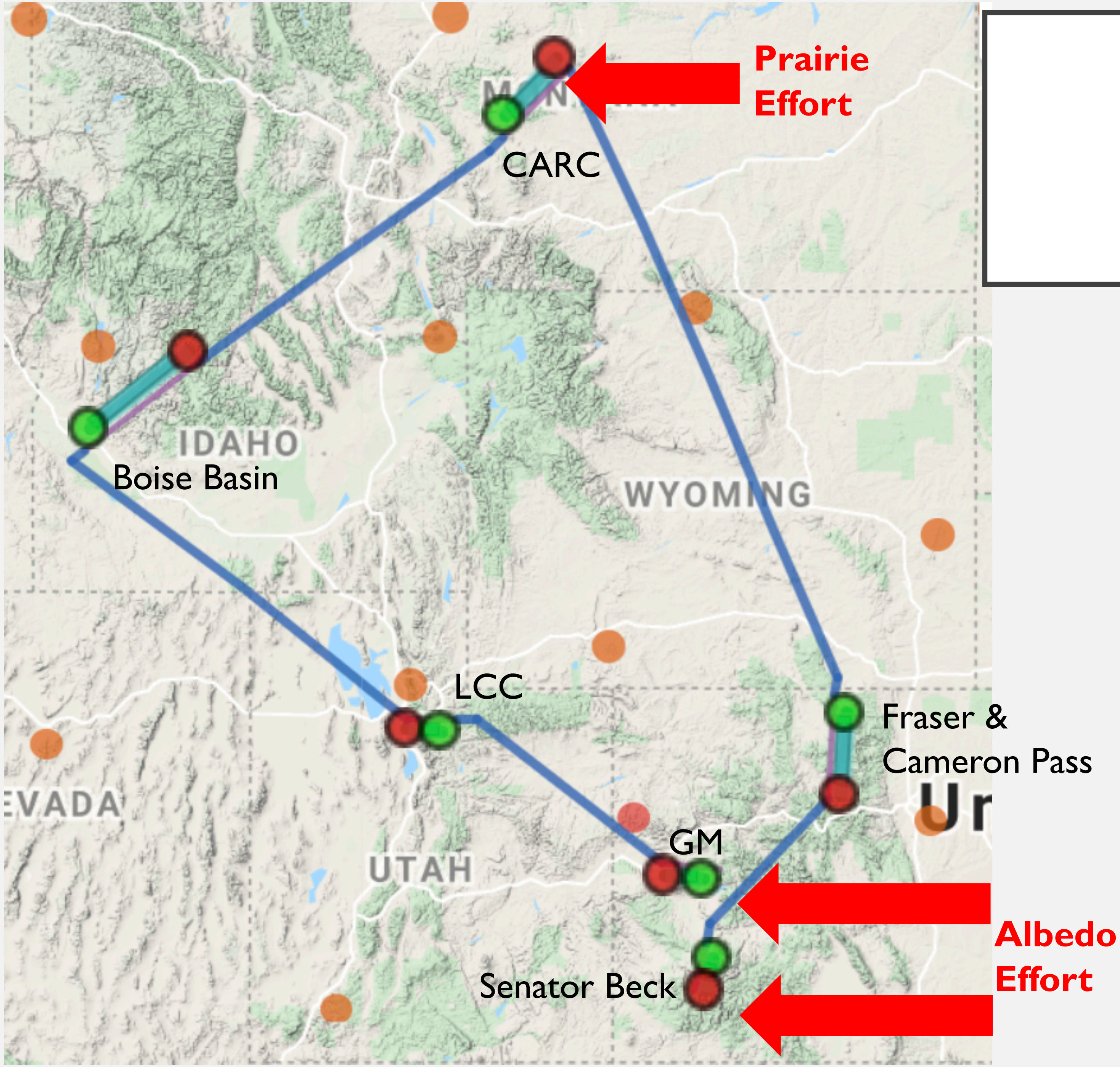
1. Define the snow conditions where L-band InSAR is likely to work (maintain coherence)
2. Quantify the accuracy of L-band InSAR retrievals of snow depth, density, SWE, and wetness

Albedo

1. To evaluate the spatiotemporal variability in snow albedo, the controls on this variability, and the uncertainty of remote sensing measurements relative to mountains, forests, and as snow albedo declines over time.

Prairie

1. Quantify the accuracy and uncertainty in SWE retrievals L-band InSAR in a Prairie environment, specifically assessing the impact of shallow, drifted snow, terrain with variability soil temperature and moisture conditions, and wet snow
2. Characterize the spatial heterogeneity of snow characteristics due to wind redistribution, landscape, and sublimation, and assess the scales at which different processes dominate, as well as the ability of remote sensing techniques to characterize spatial distribution.



POSSIBLE SNOWEX 2021 TARGETS

- Combines highest priority targets from L-band InSAR, Albedo, Prairie groups
- UAVSAR/AVIRIS-NG will be based out of Houston – proximity of sites is important for conserving flight hours
- Leverages ongoing field efforts, as little field budget is available
- Targets sites with planned UAV efforts
- Targets sites with ground-based L-band radar (InSAR and GPR)
- Plan will be flexible; UAVSAR flights depending on conditions

SNOWEX 2021 RECOMMENDATION

Site	Timeline	UAVSAR Flights	AVIRIS-NG flights	UAV flights	Continuous Obs	Ground Activities	Ongoing/Partner Activities
Senator Beck, CO	Dec 2020 – May 2021	12	3		broadband albedo, met station	Field spectrometer, snowpits/depth during flights	SaraniaSat hyperspec/ thermal IR
Cameron Pass/ Fraser, CO	Dec 2020 – May 2021	12	0	Optical SfM, UAV GPR	broadband albedo, met station	Snowpits/depth during flights	Ground-based GPR / SoOp towers, tower radar
Grand Mesa, CO	March – May 2021	3	3	Multispectral, thermal IR	broadband albedo, met station	Field spectrometer, snowpits/depth during flights	SaraniaSat hyperspec/ thermal IR, NOHRSC Gamma, UA FMCW
CARC, MT	Dec 2020 – Mar 2021	4	0	Lidar, broadband, hyperspectral, thermal IR	Met/snow/soil	Field spectrometer, snowpits/depth during flights	NSF agricultural initiative, NOHRSC Gamma
Little Cottonwood Canyon, UT	Dec 2020 – May 2021	12	0	Optical SfM	broadband albedo, met station	Snowpits/depth during flights	Ground-based L-band InSAR, infrasound avalanche detection
Boise Basin, ID	Dec 2020 – May 2021	12	0	Optical SfM, thermal IR	broadband albedo, met station	snowpits/depth during flights	CRREL helipod, ground-based L-band InSAR, tower radar

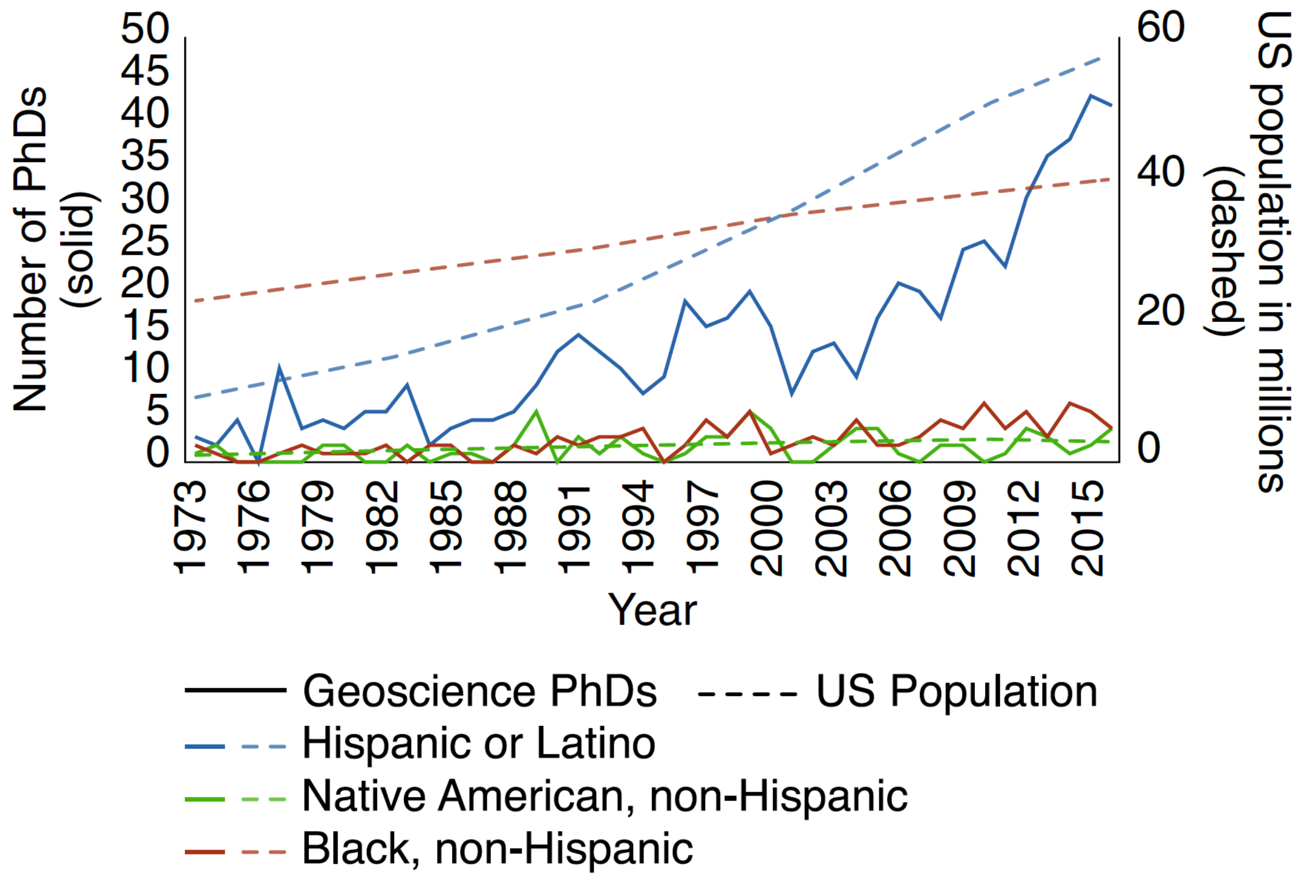
Promoting a snow community culture of data and code sharing, equal access, collaboration, inclusion.

SnowEx Hackweek, Summer 2021, eScience @ UW

We need tutorial leads!

Contact hpmarshall@boisestate.edu if you are interested in helping to develop/deliver tutorials

Diversity and equity in Geosciences



- *Bernard and Cooperdock, 2018, Nature Geoscience, 11, 292-296*
- No progress in increasing diversity over last 40 years
- SnowEx welcomes and strongly encourages participation from people of all backgrounds, races, religions, gender
- Ideas about how to improve? Contact hpmarshall@boisestate.edu

Thanks!