Ground-Based Remote Sensing (GBRS) activities: formulation, implementation, and accomplishments

University of Michigan · University of Washington · Colorado State University · The Ohio State University · Oregon State University · Texas A&M University · Dartmouth · Columbia University · UVU · Utah State University · USDA · UCAR · UCSB · Center for Snow & Avalanche Studies · GESTAR · Forest Service

Université de Sherbrooke · Environment Canada · University of Waterloo · Northumbria University Newcastle · UiO : Universitetet i Oslo · Norwegian Polar Institute · National Weather Service · University of Colorado Boulder · NSIDC · JPL · US Army Corps of Engineers · CRREL · ATA Applied Technology Associates · USRA · Boise State University

Ground-Based Remote Sensing (GBRS) activities: formulation, implementation, and accomplishments

GBRS key players

Christopher Hiemstra, Hans-Peter Marshall, Roger De Roo, Mohammad Mousavi, Francis Bliven, Walt Peterson, Jeffrey S. Deems, Peter Gadomski, Arthur Gelvin, Lucas Spaete, Theodore Barnhart, Tyler Brandt, John Burkhart, Christopher Crawford, Tri Datta, Havard Erikstrod, Nancy Glenn, Katherine Hale, Brent Holben, Paul Houser, Keith Jennings, Richard Kelly, Jason Kraft, Alexandre Langlois, Jewell Lund, Daniel McGrath, Chelsea Merriman, Noah Molotch, Anne Nolin, Chris Polashenski, Mark Raleigh, Karl Rittger, Chago Rodriguez, Alexandre Roy, McKenzie Skiles, Eric Small, Marco Tedesco, Chris Tennant, Aaron Thompson, Liuxi Tian, Zach Uhlmann, Ryan Webb, Matt Wingo

… and even more contributors who helped pulling radars, carrying gear to the field,
and all the **transect, snowpit, and snow microstructure (SSA, SMP, snow cast) teams**
who collected the necessary in situ data to support the ground-based remote sensing activities

Time line

1 July 2016 – 28 February 2017

July – mid Aug.:

Solicited the community/Gather information on sensors & people availability

Selected Local Scale Observations Sites (LSOS)

mid. Aug. – Sept.:

Designed the campaign

late Sept./early Oct.:

Fall campaign (terrestrial lidar), installed LSOS and time-lapse cameras

Oct. – Jan.:

Developed the Experiment Plan, and addressed all the logistics

Feb.:

Executed the winter campaign

April 18-19

Lessons learned meeting with HQ and project office

May 17-20

Disassembled LSOS

July 20-24

GPS survey of the transect poles (survey grade acquisition)`

Ground Based Remote Sensing objectives

Solicit the community

Be in line with the Science Traceability Matrix

Define the Experiment Plan

Implement & Execute

snow.nasa.gov/snowex

SnowEx Overarching Question: How much water is stored in Earth's terrestrial snow-covered regions?				
SnowEx Year 1 Fundamental Questions	**Q1 –** What is the distribution of snow-water equivalent (SWE), and the snow energy balance, in different canopy types and densities, and terrain?			
	Q2 – What is the sensitivity and accuracy of different SWE sensing techniques in different canopy types, canopy density, and terrain?			
Mission Objective and Associated Ancillary Questions	**Measurement Requirements**	**Instrument Functional Requirements**	**Investigation Functional Requirements**	**Data Deliverables**
1) Quantify SWE in open and forested areas for different canopy densities and terrain (Response to Q1,2) A. What is the spatial variability of SWE in open and forested areas? B. What factors control snow variability in open and forested areas in different terrain? C. What is the sensitivity & accuracy of different sensors to SWE at different scales and under different canopy densities? **2) Quantify snow albedo in open and forested areas for different canopy densities & snow conditions (Response to Q1,2)** A. What is the spatial variability of snow albedo in open and forested areas? B. How does the average albedo of an area scale as we move from point to plot to hectare to stand and domain? C. What is the sensitivity & accuracy of different sensors to snow albedo at different scales?	Site with a range of forest densities & snow conditions, reliable & dry snow, and a wide range of SWE values. Selected sites: - Grand Mesa, Colorado is the primary site. - Nearby Senator Beck basin added as secondary site to investigate Q1 & Q2 in complex terrain. Multi-sensor airborne measurements at a spatial scale <200 m to measure: *Snow water equivalent* - Microwave emission - Radar backscatter time series - Interferometric phase change *Snow depth* - Waveform LiDAR *Spectral BRDF, Albedo* Hyperspectral VIS/SWIR reflected radiance *Snow areal extent* - VIS/NIR imagery (multi- or hyperspectral) - High-res digital photography Concurrent *in situ* ground truth measurements of micro- and macro-snow & forest properties - Depth, density, SWE - Grain size & morphology, - Snow surface roughness - Snow stratigraphy - Snow temperature profile - Forest litter content in the snow surface layer	<u>LiDAR</u> Full-waveform LiDAR system with <1.0 m horizontal resolution and <0.10 m vertical accuracy. <u>Active microwave</u> Dual-pol radar (10 &17 GHz) with spatial resolution of <10 m and a swath width of >100 m, Backscatter sigma 0 to -20 dB <u>Passive microwave</u> Dual-polarized microwave radiometer (minimum bands: 10, 18, & 37 GHz); spatial resolution <200 m, T_B accuracy of ±2K <u>Vis/IR</u> Multi-spectral/multi-angular high resolution radiometer (iFOV: <5°, spectral range: UV--NIR μm: absolute accuracy: <5%). VIS/NIR imaging spectrometer (FOV ≤40°, spectral range 400-1050 nm, iFOV < 1mrad) Imaging IR sensor and remote thermometer (sensor accuracy ±1K) High res digital nadir camera <u>L-band InSAR</u> L-Band frequency (~ 1.25 GHz) Dual-polarized or quad polarized <10° phase sensitivity <5 m horizontal resolution <u>Ground Truth</u> SWE accuracy: 2cm (SWE <20cm), 10% (SWE >20cm) Snow density accuracy: 20 kg/m^3 or 2% Snow depth accuracy: 3 cm Snow temperature: 1°C. Snow grain size: 0.2 mm (<1 mm), 1 mm (1-15 mm)	Field location representing gradients of forest density on relatively flat terrain and location with complex terrain to test all RS techniques. Airborne platform(s) with flexible range and altitude capabilities matching optimum sensing altitudes (e.g.,1000-6000 ft AGL), with capacity for multiple instruments and flight profiles Fully coordinated airborne and in-situ snow surveys at nested scales during the field season Temporal resolution — daily ground observations during airborne observations (at least 2 8hr-flights per week) at least two weeks in winter. Physical, empirical, and/or statistical snow distribution models to scale ground measurements to airborne and satellite remote sensing scales <u>Models</u> Spatial scaling models Radiative transfer and scattering models Snowpack physical models including snow redistribution and interception components Snow physical models (secondary) Hydrology / climate models SWE retrieval algorithms	<u>Ground Obs. Data</u> Ground observation logs and data records Instrument metadata Raw observations, and catalogued and corrected observations, measurement, and calibrations Filtered forest litter snow samples Local meteorological and radiation observations <u>Airborne Data</u> Level 0 raw instrument and engineering data stream for each flight Level 1 radiometric and geometric corrected data (i.e., brightness temperature, TB, backscatter), InSAR phase and coherence Level 2 geophysical parameter data (SWE, albedo, BRDF, HCRF …) Level 3 gridded data integrating airborne and ground measurements for select locations (e.g. SWE values and evolution over the season, albedo vs SWE relationships) Level 4 results from models incorporating L3 data Ancillary satellite data collected during field campaigns <u>Ground-based RS</u> Level 0 raw instrument and engineering data stream

Experiment Plan

SnowEx Experiment Plan
for TLS activities during SnowEx 2016 - 2017

This document explains and justifies why the following measurements are relevant to the SnowEx mission, and it summarizes all the work that will be done at both Grand Mesa and Senator Beck with TLS units. It refers directly to the Science Traceability Matrix.

Background on TLS activities

A brief section with some generalities and recent references to highlight work achieved in the field. Schematics/pictures showing the instrument and/or measuring techniques are encouraged.

Scientific goals

A prioritized, detailed section with everything that will be addressed using radar measurements and why it is relevant to SnowEx.

Measurement characteristics

Detailed explanations of the measurement characteristics (number, locations, etc.) for each scientific goal stated in the experiment plan. These measurements will be grouped by tiers to ease prioritizations in the field in the event of delays (e.g. due to weather).

Instrument descriptions

1. Instrument 1

1. Main characteristics
    1. Sensor characteristics
    2. Experimental design

e.g. acquisition frequency, etc.

3. Risks

e.g. May produce RFI, or is sensitive to RFI at frequency X, etc.

4. Operating in cold
5. Personnel needed
6. Other equipment needed

4. Instrument's point of contact

5. Protocol(s)

Few words about calibrations for example.

4. Deliverables

Few words about the lowest and highest data level that will be delivered to NSIDC.

5. Data format

→ 40 pages of crucial information on GBRS

Ground Based Remote Sensing objectives

. Obtain continuous observations throughout the winter

The February measurements (airborne, GBRS, or in situ) offer a snapshot, without the context/history of winter

. Guarantee that in situ snow properties are measured where GBRS data are collected

Remote sensing data without in situ measurements of snow properties is (still) insufficient

. Ensure that airborne sensors have a *GBRS equivalent*

For validation of airborne observations and retrievals, and also to address vertical scaling questions

. Enable observations from multiple sensors over the same sites and from different heights

To identify which combination of sensors have the best performance for SWE monitoring

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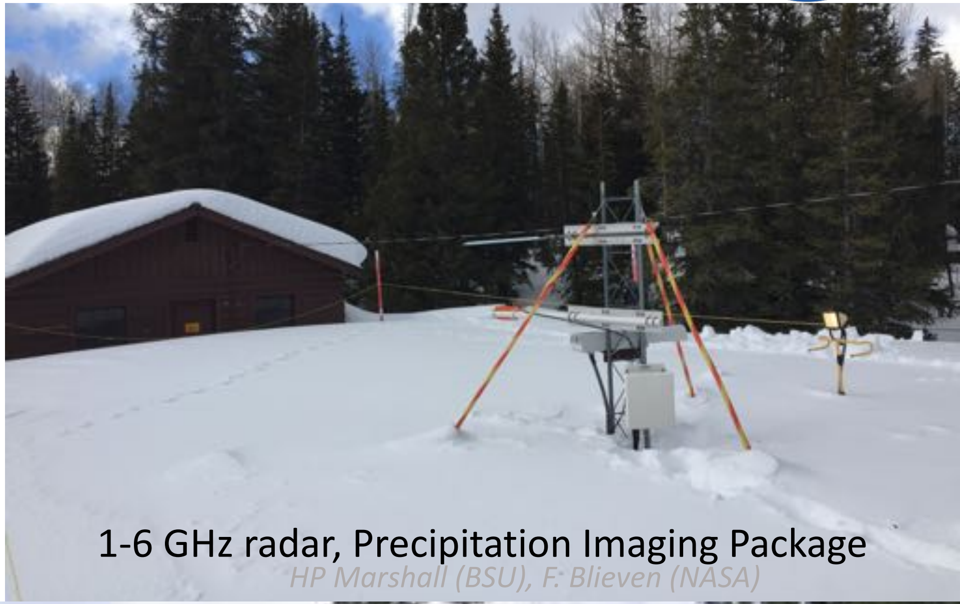
Provide continuous observations throughout the winter

Local Scale Observation Sites (LSOS)

Continuous monitoring by 12 instruments + 5 weather stations

Grand Mesa

- Microwave radiometers (Uni. of Michigan)
- Radars (Boise State Uni.)
  1-6 GHz impulse, 24-26 GHz FMCW
- Sun photometer (NASA GSFC, AERONET)
- GPS (Uni. of Colorado)
- Tree accelerometers (Uni. of Colorado)
- Precipitation instruments (NASA WFF)
- Snow depth sensors (Uni. of Colorado)
- Time lapse camera (Uni. of Washington)



1-6 GHz radar, Precipitation Imaging Package

HP Marshall (BSU), F. Blieven (NASA)

Microwave radiometer – M. Mousavis, R. De Roo (U. Michigan)

Provide continuous observations throughout the winter
Local Scale Observation Sites (LSOS)

Continuous monitoring by 6 instruments + 2 weather stations

Senator Beck

Senator Beck Basin is managed by the Center for Snow and Avalanche Studies
www.snowstudies.org

- Radars (Boise State Uni.)
  1-6 GHz impulse, 24-26 GHz FMCW
- Sun photometer (NASA GSFC , AERONET)
- GPS (Uni. of Colorado)
- Tree accelerometers (Uni. of Colorado)
- Time lapse camera (Uni. of Washington)
- Stream gauge (CSAS)

Precipitation radar, HP Marshall (BSU)

Provide continuous observations throughout the winter

Snow depth monitoring

CRREL:
C. Hiemstra
U. Colorado:
T. Barnhart,
K. Jennings,
N. Molotch
M. Raleigh
George Mason U.:
P. Houser
U. Washington:
J. Lundquist

Wed. 2:30 – P. Houser "Ground-based Automatic Weather and Snowpack Observations at SnowEx 2017"

Wed. 3:00– N. Molotch "Observations from snow depth sensor arrays representing diverse forest conditions during NASA's SnowEX 2017 campaign"

39 time-lapse cameras

Acoustic probes:
. 5 met stations
. 2 parks


Photos: Nick Wright

Provide continuous observations throughout the winter
Snow depth monitoring

2 GPS ground stations

Grand Mesa - LSOS Ranger Station

Swamp Angel Study Plot

Recording settings were adapted to support ASO

U. Colorado:
M. Raleigh,
E. Small

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What kind of in situ snow measurements to collect?

Tutorials - during lunch

C. Derksen: “An Overview of the Snow MicroPenetrometer Dataset: Raw Measurements to Microstructure Properties”

J. Pan & M. Durand: “The SNOWEX Snow Specific Surface Area Measurements and its Potential Application”

Location:	UTMN:	Surveyors:	Comments/Notes:
Site:	UTME:		
Pit: Total Depth (cm)	UTM Zone: Slope:	Date: Time:	

Density				Temperature		Stratigraphy							
Height above ground		Density profile A	Density profile B	Height above ground	Temp	Height above ground		Grain size (mm)			Grain type	Grain photo	Snow Wetness
top (cm)	bottom (cm)	kg/m³	kg/m³	(cm)	°C	top (cm)	btm (cm)	min	max	mean			

Location:	Surveyors:	Weather:	
Site:	Time:		
Pit:	Date:		

Check List

Metadata in Headers	Temperature Profile
NIR Photo of Pit Wall	Density Profile
VIS Photos of Pit Wall and Site	Snow Wetness Profile
Surface Roughness Photo	Soil Moisture Sample
Grain Photos - All Layers	Weather Observations
Grain Size Measurements	Ground Observations
Grain Type Measurements	Vegetation Observations
	Check Both Sheets

Precipitation (circle one)	None	Light Snowfall	Moderate Snowfall	Heavy Snowfall	Rain
Sky (circle one)	Clear	PC 25%	PC 50%	MC 75%	Overcast
Wind (circle one)	Calm	Breeze	Light	Moderate	Strong
Wind (circle one)	Intermittent	Gusty	Steady		
Ground Condition (circle one)		Frozen	Thawed	Uncertain	
Soil Moisture (circle one)		Dry	Moist	Wet	Saturated
Ground Roughness (circle one)		Smooth	Rough	Rugged	
Ground Vegetation (circle one or more)		Bare	Grass	Shrub	Deadfall
Height of Ground Vegetation (if present)			cm	cm	cm
Tree Canopy (circle one)		No Trees	Sparse (5-20%)	Open (20-70%)	Closed (>70%)

1. Approach pit on single trail - leave on same trail when finished
2. Fill out data sheet header and take photo of header with all cameras
3. Carefully excavate shaded face - leave area as undisturbed as possible
4. Take surface roughness photo with surface roughness board
5. Place ruler or depth probe on pit wall
6. Take NIR & visible pit wall photos, site photos N, E, S, W in order, and overhead canopy
7. Collect and label soil sample - label is pit number and date
8. Simultaneously: take temperature profile, stratigraphy, grain size, snow wetness
9. Take grain photos. Photograph layer info on data sheet before each new layer.
10. Measure density in dual profile top to bottom.
11. Fill in all data and check list on second page - Leave no blanks!
12. Backfill pit with snow - leave red pole marker on edge of disturbed snow

Grain Size			
Observed Grain Size	0.1-1.0 mm	1.0-5.0 mm	>5.0 mm
Resolution to Record	0.1 mm	0.5 mm	1 mm

Grain Type		Snow Wetness		
New Snow	N	Dry	Will not pack	D
Rounds	R	Moist	Sticks together	M
Facets	F	Wet	Perfect snowballs	W
Mixed Forms	M	Very Wet	Water can be squeezed out	V
Melt-Freeze	MF	Slush	Water drains freely	S
Crust	C	New snow last 24 hrs? Use SWE tube		
Ice Lens	L	Depth: cm	SWE: mm	

Properties at play in active & passive microwave RS were measured

And also profiles of:

. snow Specific Surface Areas (SSA)
. Snow Micro Penetrometer (SMP)
. Snow casts for micro Computed Tomography

Exhaustive set of measurements

ftp.nsidc.org/pub/projects/SnowEx/

Snowpits, Transects, and Trenches

Warm weather

+

Cold weather

=

Percolation features, ice lenses …

Snowpits, Transects, and Trenches

30-50 m Trenches

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To identify which combination of sensors have the best performance for SWE monitoring

Core GBRS Instruments

Airborne

UAVSAR, SnowSAR, WISM, GLISTIN-A

WISM, AESMIR

CAR,

Ground-Based

Terrestrial Lidar Systems (TLS)

Radars & Scatterometers

Microwave radiometers

Spectroradiometers, Goniometer

. Terrestrial Lidar System (x3)
. Radars (x5, of different kinds: FMCW, Impulse)
. Scatterometers (X & Ku bands)
. Microwave radiometers
(x2, truck-mounted & mobile systems)
. Spectroradiometers (x7)
. Acoustic snow depth sensors (2 parks, 7 stations)
. Time-lapse cameras (x29)
. GPS SWE retrieval systems (x2)
. Tree accelerometers, canopy loading (x5)
. AERONET Sun photometers (x2)
. Precipitation instruments

Collection of observations at different heights

Vertical scales

. 0-2 m	Surface based
. 2-10 m	Truck mounted
. 5-15 m	Scissor lift
. 0.3–10 km	Aircraft
. 700+ km	Satellite

Scissor lift platform

Scatterometer, R. Kelly, A. Thompson (U. Waterloo)

Truck-mounted microwave radiometer

MW Radiometer, M. Mousavis, R. De Roo (U. Michigan)

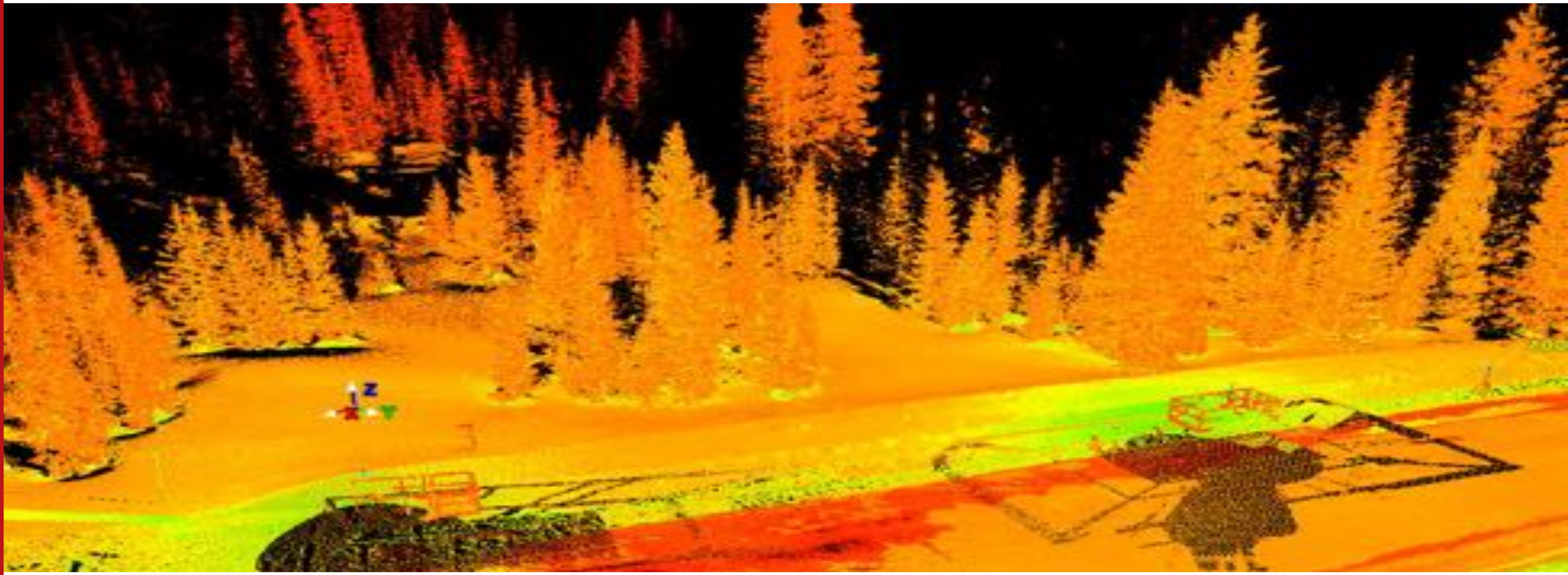
Collection of observations at different heights

CRREL:
A. Gelvin

U. Sherbrooke:
A. Langlois,
A. Roy

U. Waterloo:
A. Thompson
R. Kelly

<u>Scissor lift's area of operation as seen by a Terrestrial Lidar</u>



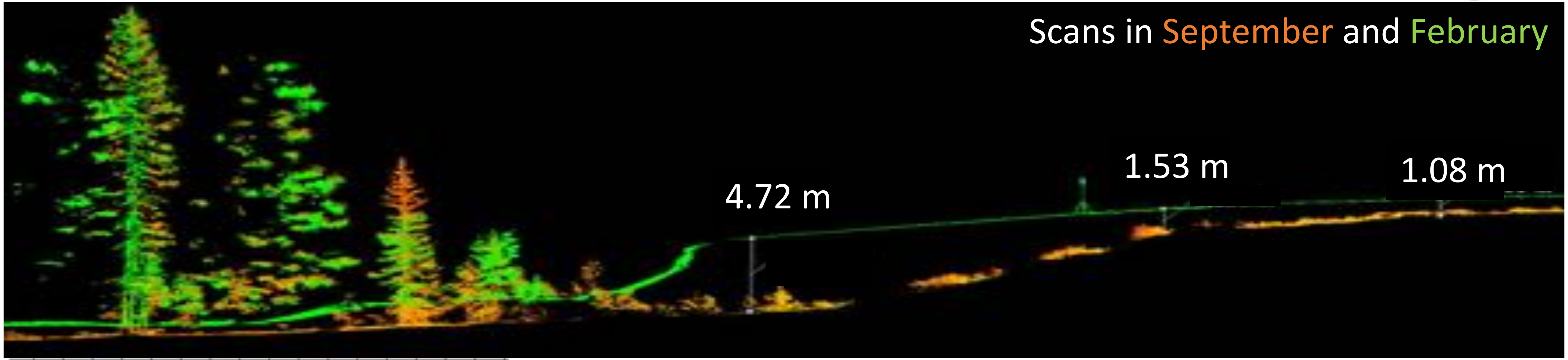
Observations at several locations and heights made with
lidar, radiometer, and scatterometer,
and one snowpit with microstructure measurements in the field of view

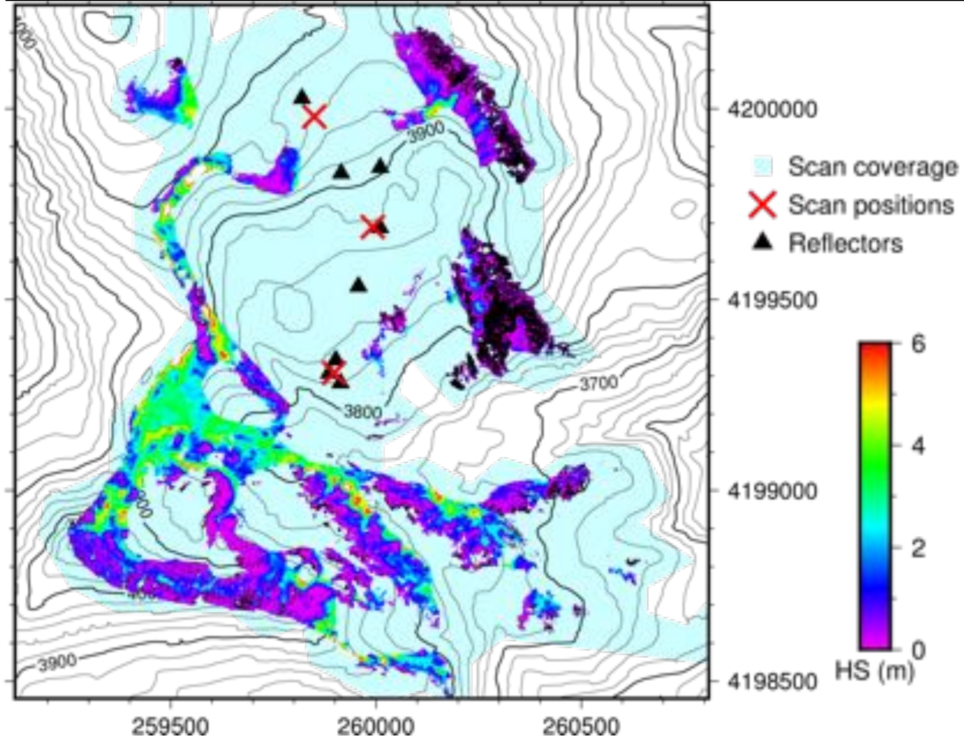
Terrestrial Lidar Systems

Berkeley:
C. Tennant
Boise State U.:
N. Glenn,
L. Spaete,
C. Merriman,
Z. Uhlmann
CRREL:
P. Gadomski,
A. Gelvin,
C. Hiemtra
NSIDC:
J. Deems
UCSB:
T. Brandt

Tues. 02:15 – J. Deems "SnowEx TLS Survey Overview and Results from Senator Beck Basin"

Poster – Z. Uhlmann "Investigating the effect of forest canopy on small-scale snow depth distribution using terrestrial laser scanning"





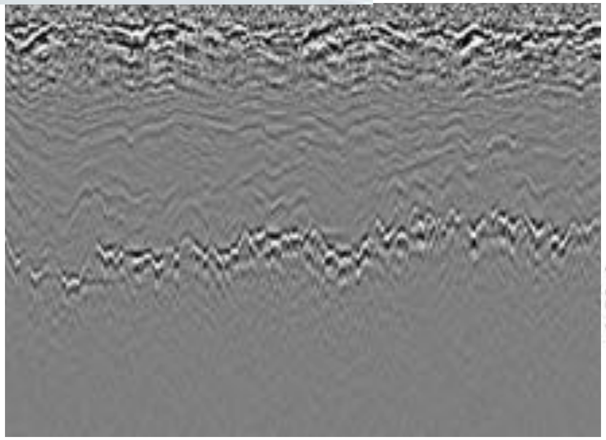
Boise State U.:
HP Marshall,
C. Rodriguez
Colorado State:
D. McGrath
U. Colorado:
K. Hale,
N. Molotch,
R. Webb
U. Oslo
J. Burkhart,
H. Erikstrod

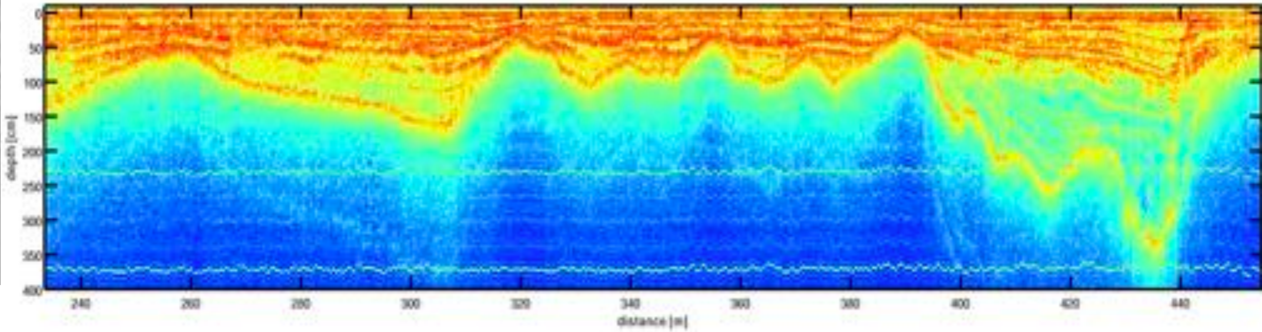
Wed. 1:45 – D. McGrath “Resolving spatial variability in snow water equivalent using a ground based GPR system”

Wed. 04:30 – R. Webb “Mobile Radar Results on Grand Mesa"

Radars

Mala ProEx unit with 1.6 GHz & 800 MHz antennas





<u>Mala GPR</u>

81 transects
5 independent grids
4 grids co-located with trenches
3 grids within terrestrial lidar sites

Mobile ultra-broadband FMCW

- Frequency range: 6-18 GHz, downward looking
- Estimates of SWE, depth, stratigraphy, 100 Hz
- Integrated survey-grade (cm) GPS
- 10 total days at Senator Beck, 3 total days at Grand Mesa

Scatterometers

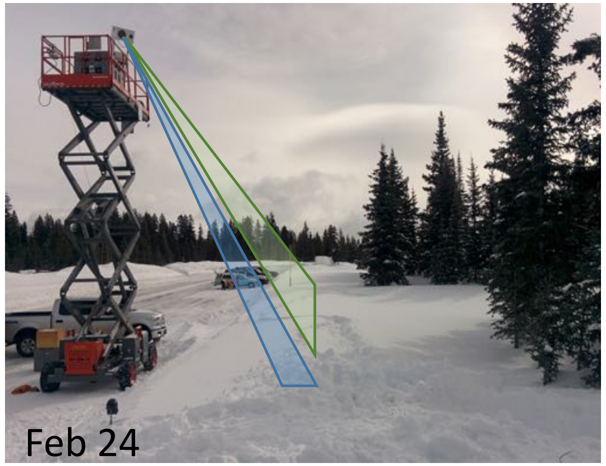
U. Waterloo:
A. Thompson,
R. Kelly

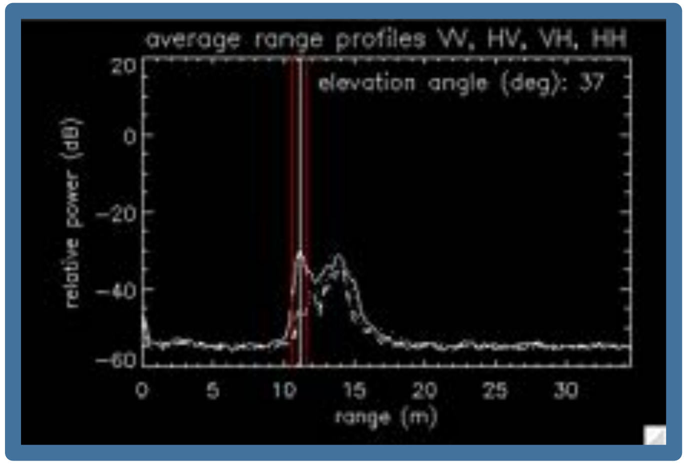
Tutorial on Wed.
A. Thompson:
"UWScat Data Products - Use and Interpretation"

Poster – A. Thompson
"Comparison of snow covered vegetation and ground on Grand Mesa with UWScat"

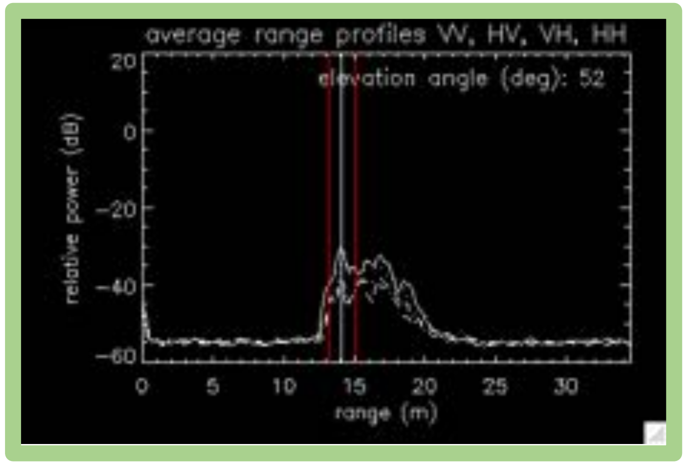
- Ku & X-band ground-based Scatterometer
- UWScat Scans:
  . 60° degree azimuth sweep (variable), 25° to 65° in elevation
  . Dual frequency, VV, HH, VH, HV
  . Open snow, forest snow and buried corner reflector experiment
- Adjacent snowpit with microstructure data (SSA and SMP)

Preliminary results from tree scan at Ku band (17.3 GHz)





Open snow impulse response (tight)

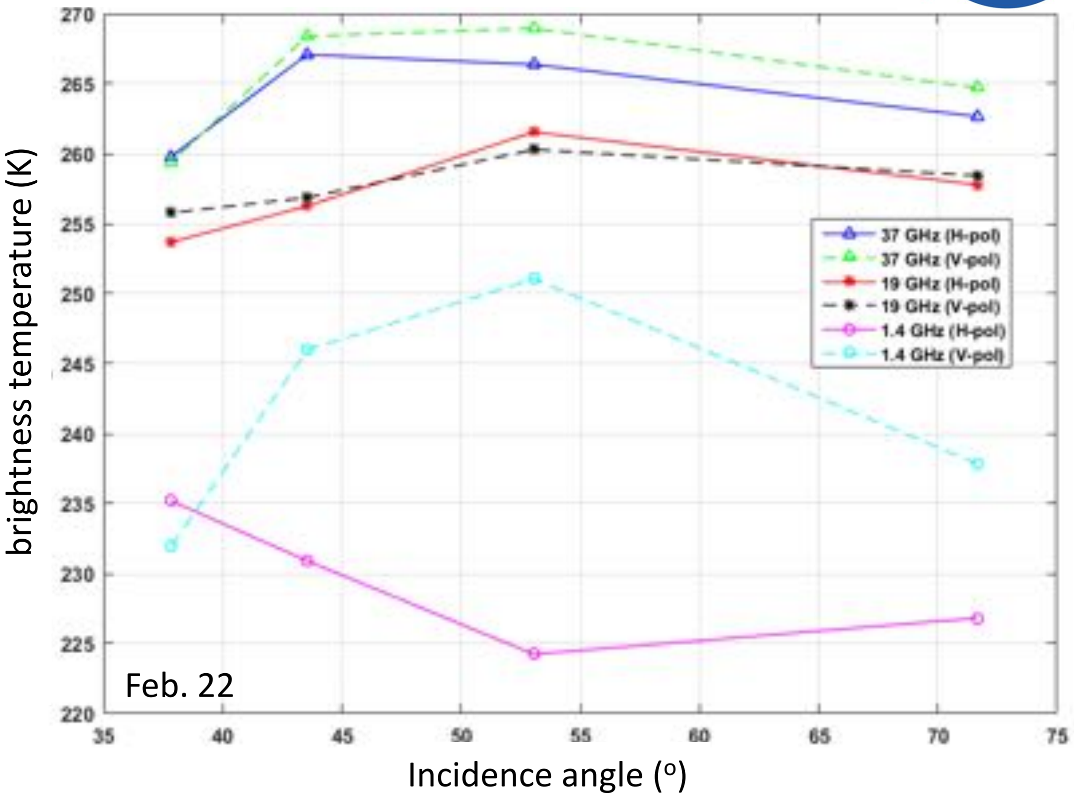


Tree canopy impulse response (spread)

Microwave radiometers – truck mounted system

U. Michigan:
M. Mousavis,
R. De Roo

Poster – M. Mousavis ”1.4, 19 and 37GHz radiometric observations from the Michigan boom truck ”



Measured brightness temperatures at **1.4, 19, and 37 GHz** at both H- and V-polarizations of evergreen trees close together for different incident angles.

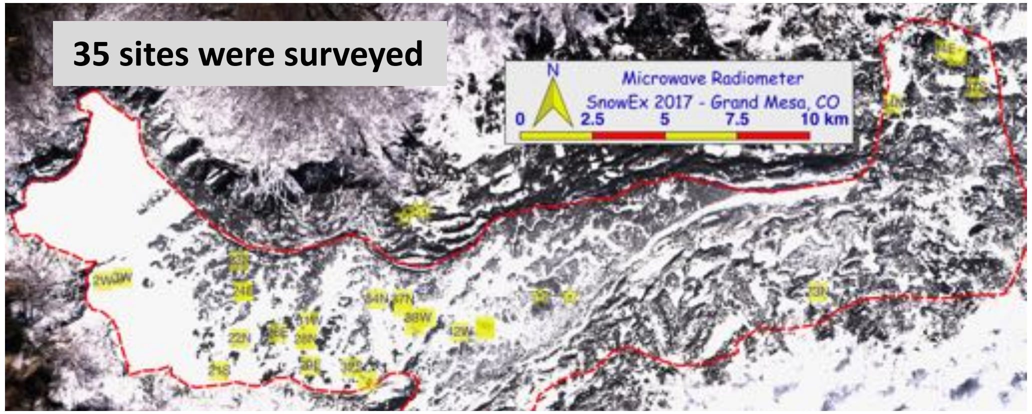
- Different field of views: gravel pad, rocky area, evergreen trees, and aspen trees
- Each target was measured at 3-4 different incident angles
- Six clear sky calibrations as well as 4 microwave absorber calibrations were made

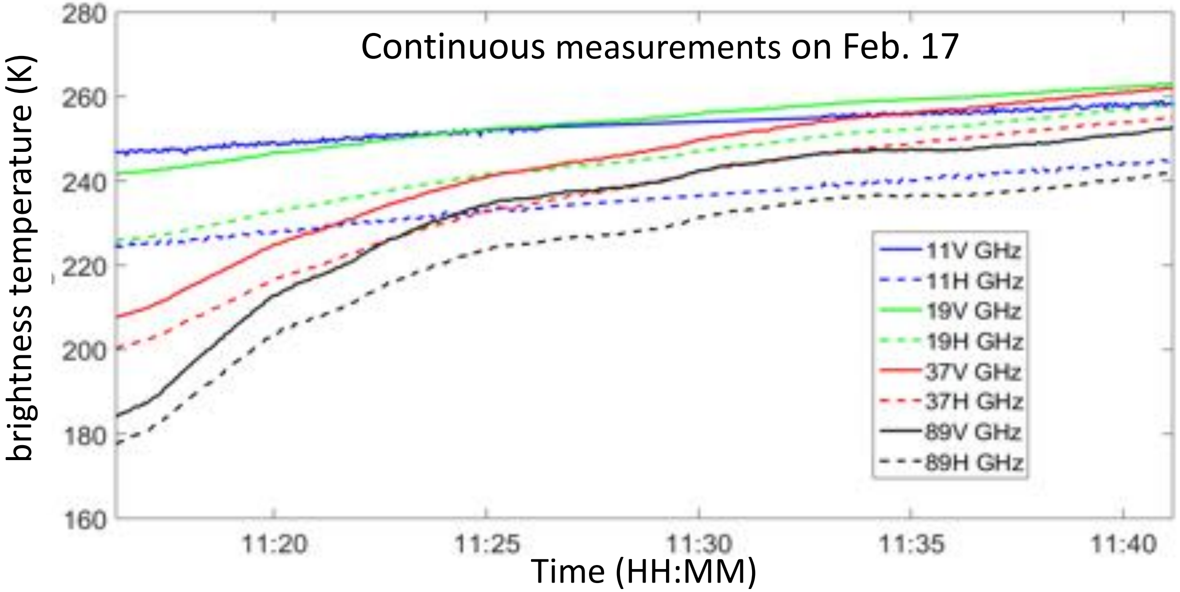
Microwave radiometers – mobile system

U. Sherbrooke:
A. Langlois ,
A. Roy

Poster – A. Langlois
“Overview of SnowEx 2017 in-situ passive microwaves measurements: a context for SWE assimilation”

. Calibration checks with ambient black body
. Liquid nitrogen calibration
. Mean absolute error of 1 K





- Significant TB increase due to melting snow
- Strong response of higher frequencies to the presence of liquid water
- Signal seems to saturate quickly (20 minutes)

→ Airborne observations may be impacted on warm days

C. Crawford,
T. Datta ,
B. Holben,
K. Jennings,
J. Kraft,
J. Lund,
A. Nolin,
C. Polashenski,
K. Rittger,
M. Skiles,
M. Tedesco,
L. Tian
H. Xie

Poster – J. Lund "Ground validation of spectral and broadband snow albedo from the Airborne Snow Observatory during SnowEx Year 1, Senator Beck Basin Study Area, CO"

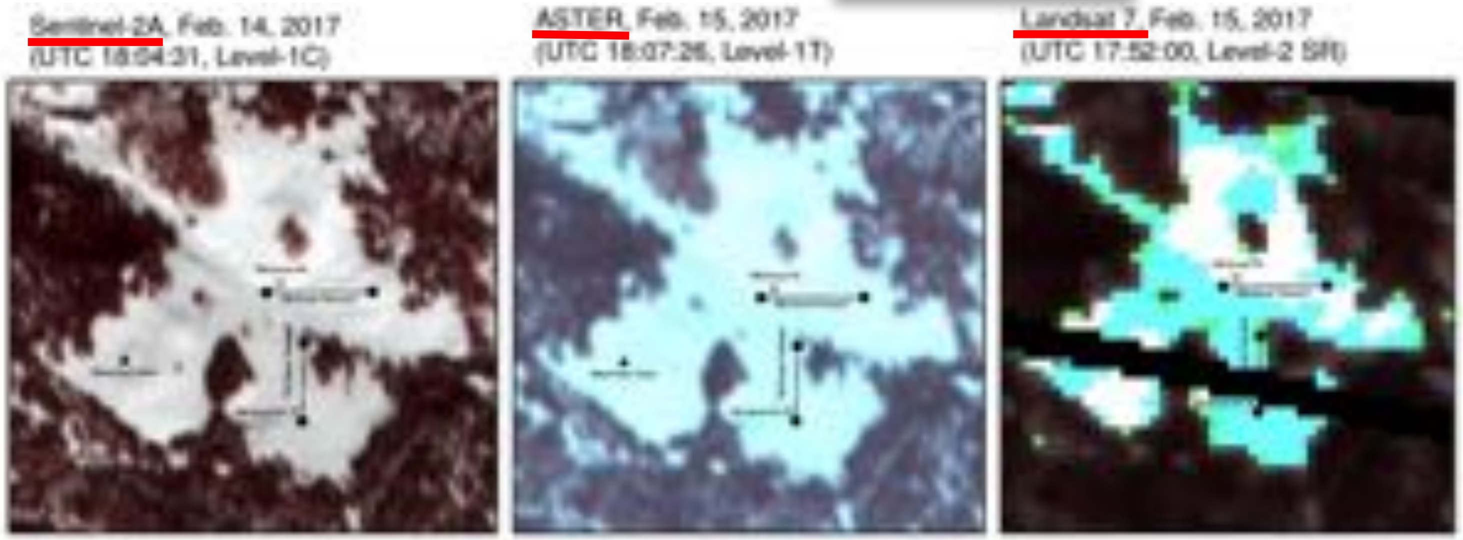
Spectroscopy

Measurements types along transects and in front of snowpit:

- . Irradiance
- . Radiance
- . Albedo
- . Reflectance

Opportunity for cross calibration

Comparisons possible with:



Thermal infra-red skin temperature measurements

USGS:
C. Crawford

Tues. 1:45 – C. Crawford "An overview of thermal infrared and visible-to-shortwave infrared instrument calibration activities for SnowEx Grand Mesa"

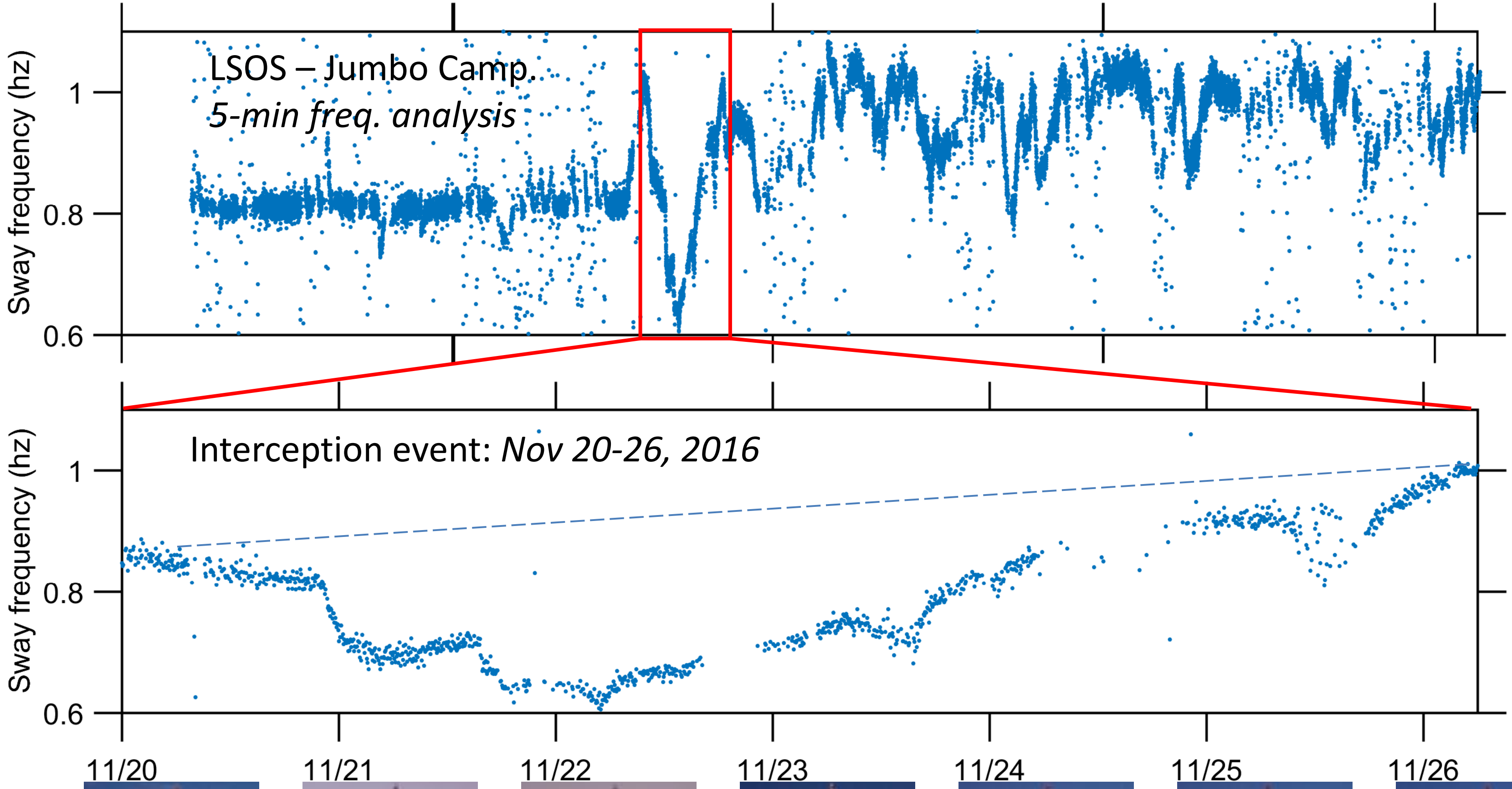
SnowEx meteorological tower TIR sensors were cross-calibrated on Feb. 15th

LSOS (10am),
Mesa West (12pm),
Mesa East (2pm),
and Mesa Middle (4pm)

TIR Field Measurements:

. Skin surface temperature / blackbody temperature.
. TIR sensor body temperature
. Blackbody incoming/outgoing longwave radiation (8-14µm)

Snow interception by canopy – tree sway frequency



U. Colorado:
M. Raleigh

Grand Mesa: 3 trees
Senator Beck: 2 trees

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To identify which combination of sensors have the best performance for SWE monitoring

An overview of SNOWEX Ground-Based Remote Sensing accomplishments

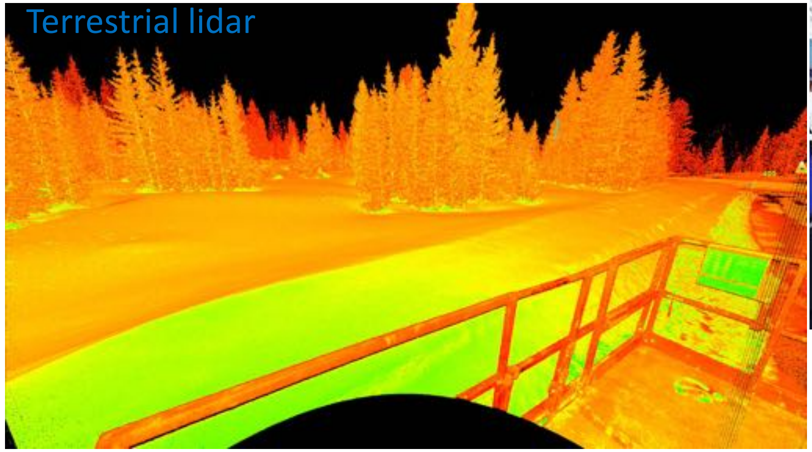
Coordinated observations of:
. Scatterometer (X & Ku bands)
. Radiometer (1.4, 19, 37 GHz)
. Snowpits
. Snow microstructure data (SSA)
. Snow MicroPenetrometer (SMP)

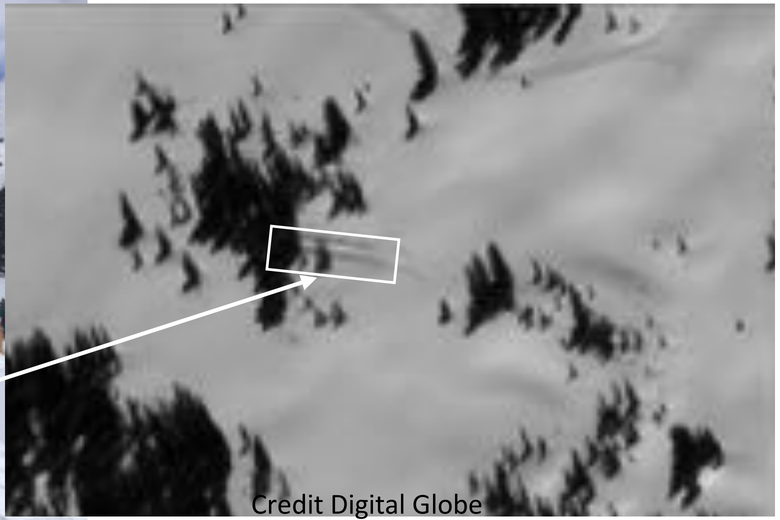
Coordinated PMW observations at different heights/scales, with:
. Surface based systems
. Truck-mounted systems

http://nsidc.org/data/snowex

Coordinated observations of:
. Radar (1-6 GHz)
. Radiometer (11, 19, 37, 89 GHz)
. Wallops's Precipitation Imaging Package
. Snowpits, SSA, SMP
. Snow casts for μ–computed tomography

An overview of SNOWEX Ground-Based Remote Sensing accomplishments





http://nsidc.org/data/snowex