Overview of SnowEx Year 1 Activities

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A giant ‘thank you’ to all who helped with SnowEx!

SnowEx at a Glance

What is SnowEx?

- Multi-year airborne snow campaign

Why?

- Address key issues for a global snow satellite mission
- Collect multi-sensor obs + ground truth for
  - Algorithm development
  - Mission trade studies
- Year 1 will challenge sensing techniques with forested conditions

Where?

- Made exhaustive site inventory (available on snow.nasa.gov/snowex)
- Western Colorado, 2 sites
  - Primary: Grand Mesa
  - Secondary: Senator Beck basin

When?

- Year 1 = 2016-17
- Year 2: no campaign
- Years 3,4,5: campaigns

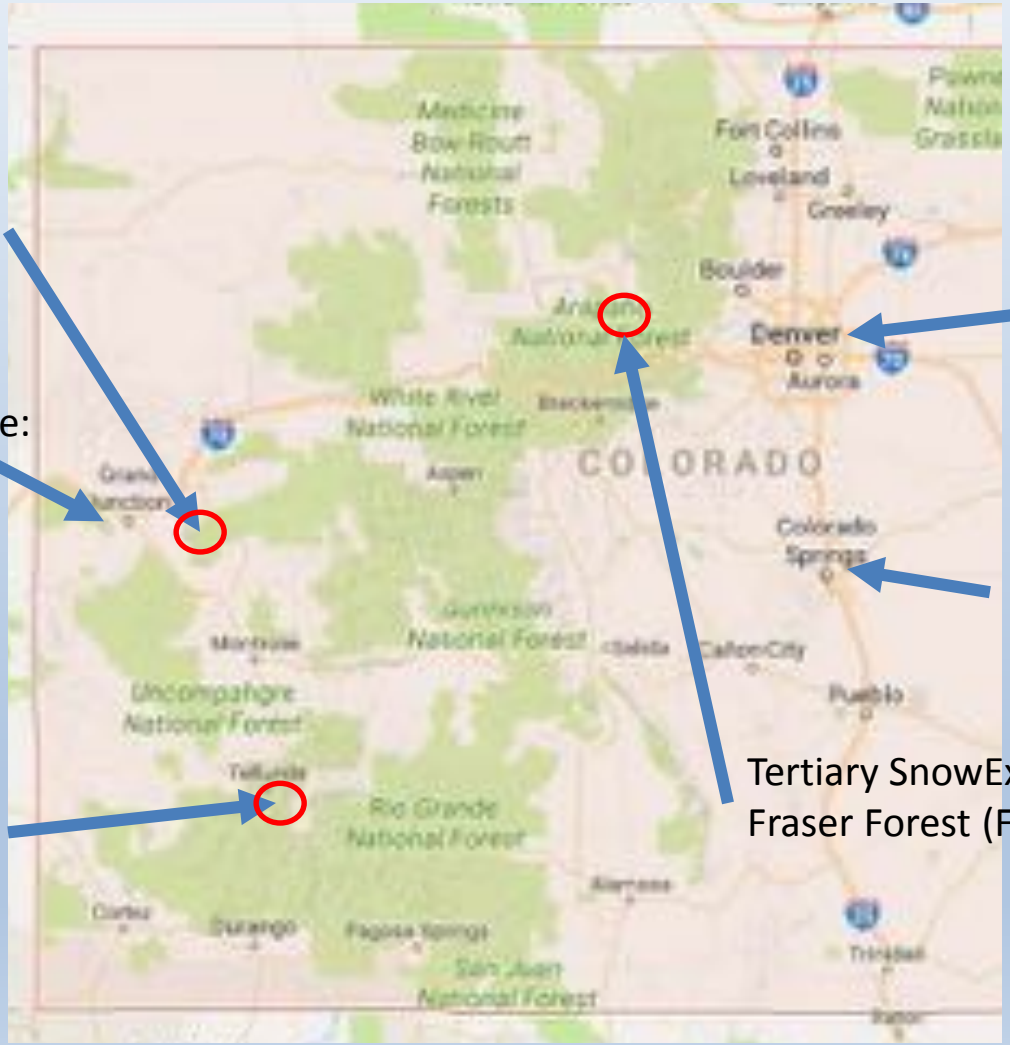
Who

- Lead: NASA Goddard Space Flight Center
- Partners
  - US Forest Service
  - Cold Regions Research Engineering Lab
  - Naval Research Lab
  - Jet Propulsion Lab
  - European Space Agency
  - Center for Snow & Avalanche Studies
  - National Snow & Ice Data Center
  - National Weather Service
  - NOAA
  - Universities, research centers

4 major components

- Airborne
- Ground based remote sensing (GBRS)
- Ground truth
- Modeling & analysis

SnowEx Target Locations & Aircraft Bases



Primary SnowEx site:
Grand Mesa (GM)

King Air & Twin Otter base:
Grand Junction (KGJT)

Secondary SnowEx site:
Senator Beck Basin (SB)

AFRC G-III base:
AFRC (KPMD)

JSC G-III bases:
Centennial (KAPA)
& AFRC (KPMD)

P-3 base:
Peterson AFB
(KCOS)

Tertiary SnowEx site:
Fraser Forest (FF)

Airborne

lead: Ed Kim

deputy leads: Charles Gatebe, Eugenia De Marco

Year 1 Airborne Sensors & Aircraft

aircraft	
CORE SENSORS	

• **SnowSAR: X & Ku-band radar (ESA)**
• **CAR (BRDF from GSFC)**
• **AESMIR (passive mw, from GSFC) 18 & 36 GHz (did not fly)**
• **Thermal IR/video suite**
  • **Imager (GSFC)**
  • **High-accuracy non-imaging (KT.15, from U.Washington)**
  • **Video camera (GSFC)**
	NRL P-3

• **ASO suite (JPL)**
  • **Lidar**
  • **Hyperspectral imager**
	King Air

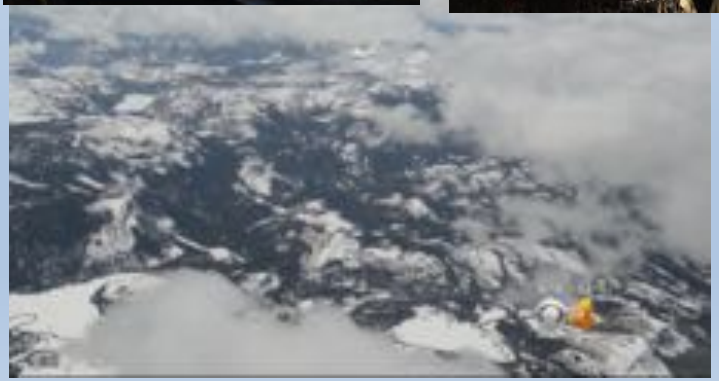
EXPERIMENTAL SENSORS	
• **UAVSAR: L-band radar (JPL)** • **GLISTIN-A: Ka-band radar (JPL)**	Two NASA G-IIIs
Prototype sensor	
• WISM: X, Ku, & Ku-band radar (GSFC)	Twin Otter

SnowEx Aircraft

P-3

G-III x2

King Air



Twin Otter

SnowEx Aircraft Sortie Summary

Aircraft	Instruments	# Sorties	FEBRUARY																											
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
P-3	SnowSAR, CAR, IR Suite (AESMIR)	6															1	1		1		1	1	1						
TOI	WISM	3								1	1	1																		
King Air	ASO	6								1								1				2	1				1			
G III (AFRC)	GLISTIN-A	4									1											1	1				1			
G III (JSC & AFRC)	UAVSAR	3						1																1			1			

Corrected to show only science flights over SnowEx sites.

Aircraft Summary: P-3

NRL P-3:

- support from the aircrew was exceptional.
- The aircraft had a few issues in the field, as is expected of older aircraft.
- Successfully accommodated flight changes while in the air multiple times

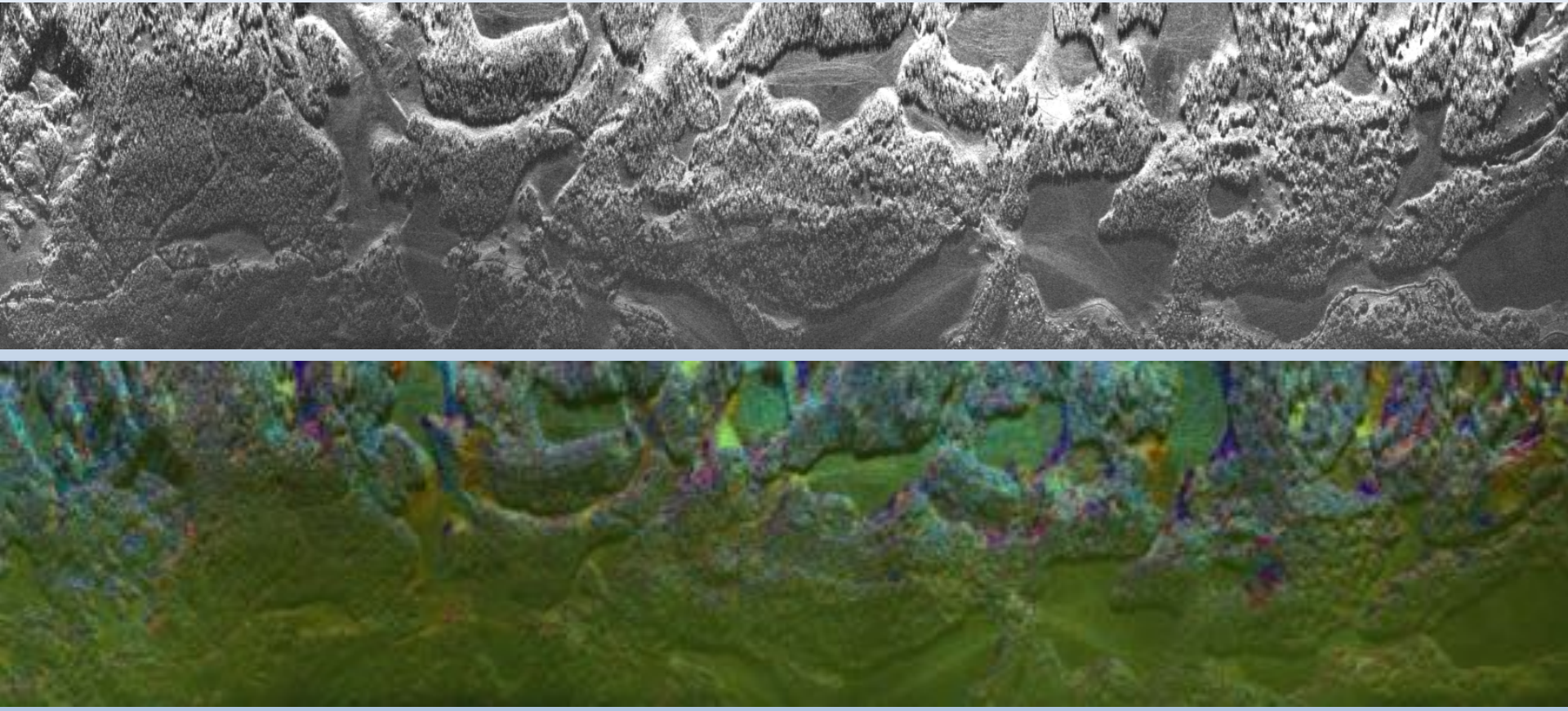
Summary of flights

- Feb 15: P-3 arrival in Peterson AFB, Colorado Springs
- Feb 16: First science flight complete (4.4 hours) over Fraser Forest (FF), Grand Mesa (GM), and Senator Beck (SB) sites
- Feb 18: 2nd science flight (3.7 hours) to FF and GM
- Feb 20: 3rd science flight (4.0 hours) to FF and GM. RTB early due to SnowSAR inop
- Feb 21: 4th science flight (5.8 hours) to FF, GM, SB. No CAR data over GM due to cloud coverage.
- Feb 22: 5th science flight (5.0 hours) RTB early SnowSAR inop
- Feb 25: Cracked windshield prevented further science flights
- Mar 4: P-3 returned to Pax River

SnowSAR - Summary

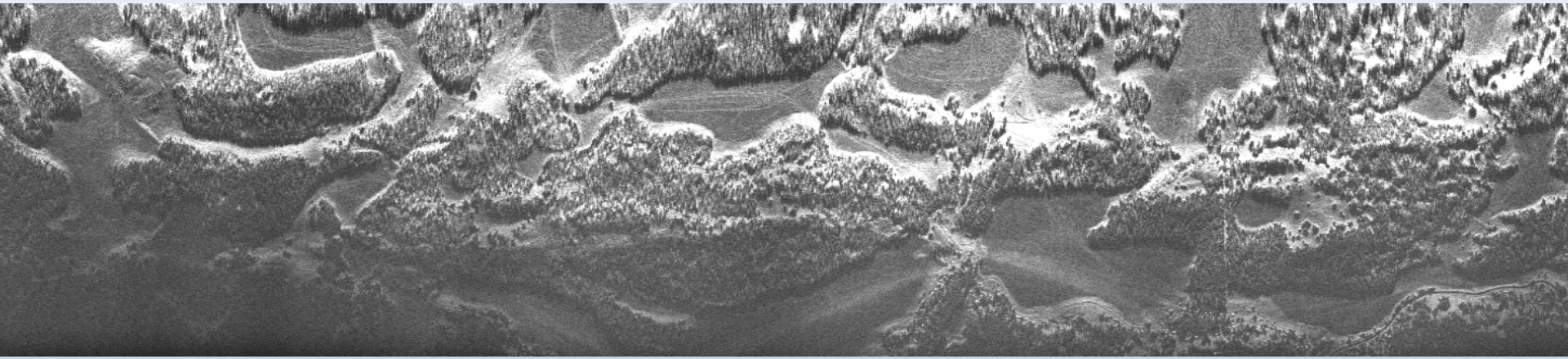
- SnowSAR dual freq SAR sensor (X & Ku)
- Developed for ESA's CoReH20 effort
  By MetaSensing
- Validated by repeated campaigns worldwide on different carriers between 2011-2014
- First time installation on P3; short testing time
- Schedule/bureaucracy/weather/aircraft not always cooperative
- SnowSAR deployed within SnowEx campaign in February 2017
- Best Data-set acquired on 21st Feb.
  - X band: 4 channels with good SNR (despite high noise in 2 channels)
  - Ku band: 2 channels (1 Co, 1 X pol) with acceptable SNR (low returns)

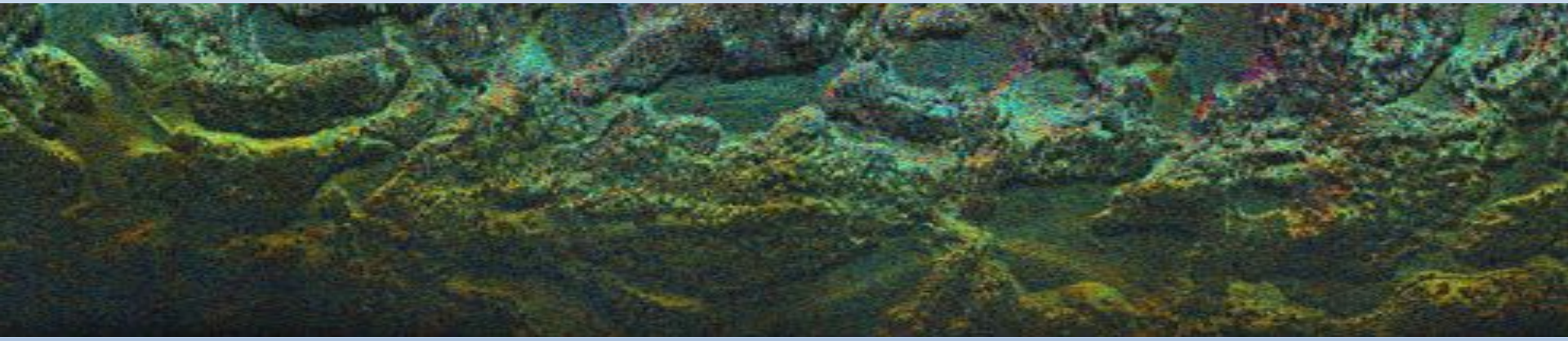
Preliminary results – X band INT



Imagery from MetaSensing

Preliminary results – Ku band INT





Imagery from MetaSensing

AESMIR Summary

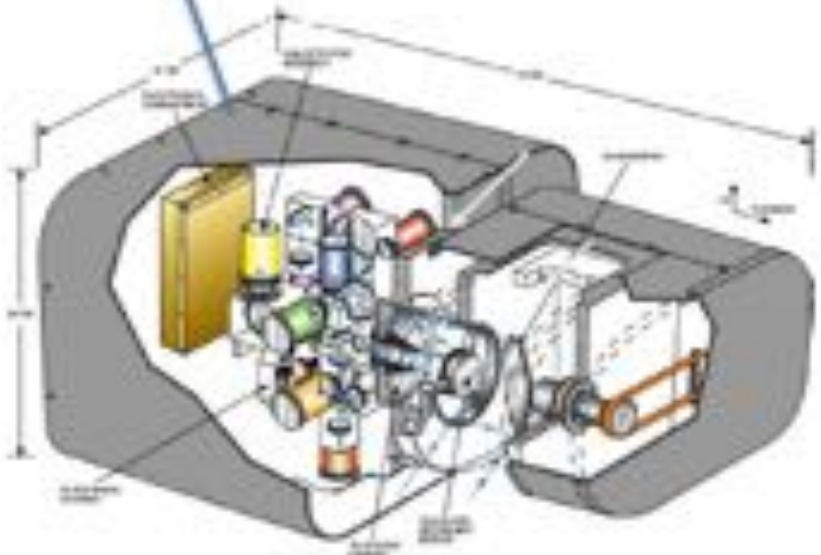
- Airborne Earth Science Microwave Imaging Radiometer
- Multi-band Passive microwave
- 18.7 & 36.5 GHz installed for SnowEx Year1
- The AESMIR instrument itself was cleared to fly and has flown before
  - Instrument was fit-checked on aircraft and successfully operated on the ground
  - All systems were fully functional
- The aerodynamic fairing for the instrument was not cleared to fly
- Removed from aircraft to allow other P-3 instruments to go make SnowEx observations
- Passive obs during deep warm snow conditions weeks 1-2 would have been saturated; primary multisensor objective of campaign would have been met in week 3, so P-3 flew to CO in week 2, and efforts focused on catching cold wx in week 3

Control Rack

Overview of the CAR Instrument

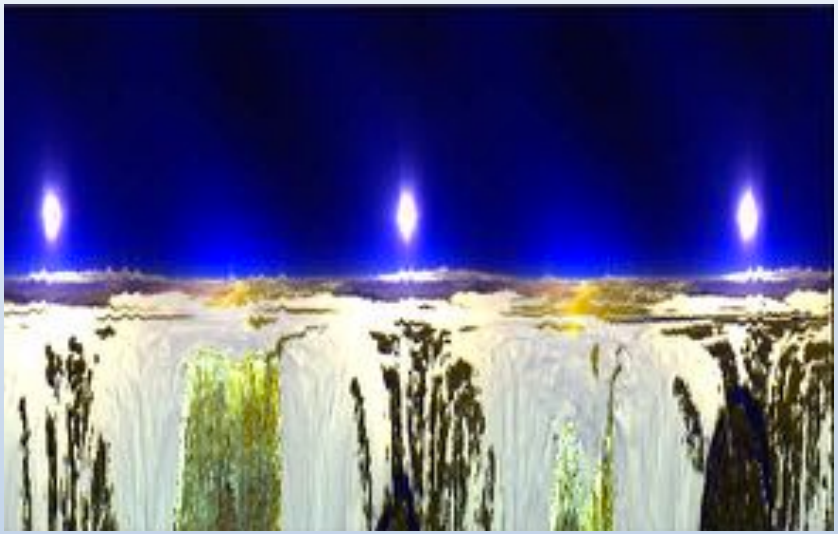
Sensor Characteristics:

- 14 spectral bands (0.34 to 2.29 μm)
- scan ±95° from horizon on right-hand side of aircraft or image 190° horizon-to-horizon
- field of view 17.5 mrad (1 deg.)
- scan rate 1.67 Hz (100 rpm)
- data system 9 channels @ 16 bit
- 395 pixels in scan line
- Platform: NRL P-3B



https://car.gsfc.nasa.gov/

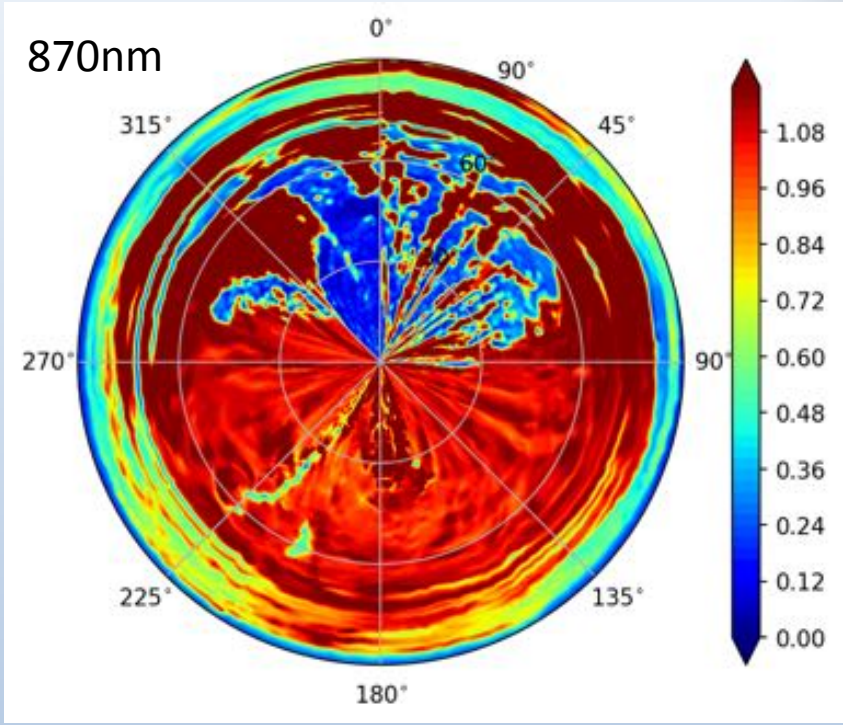
CAR/BRDF Grand Mesa



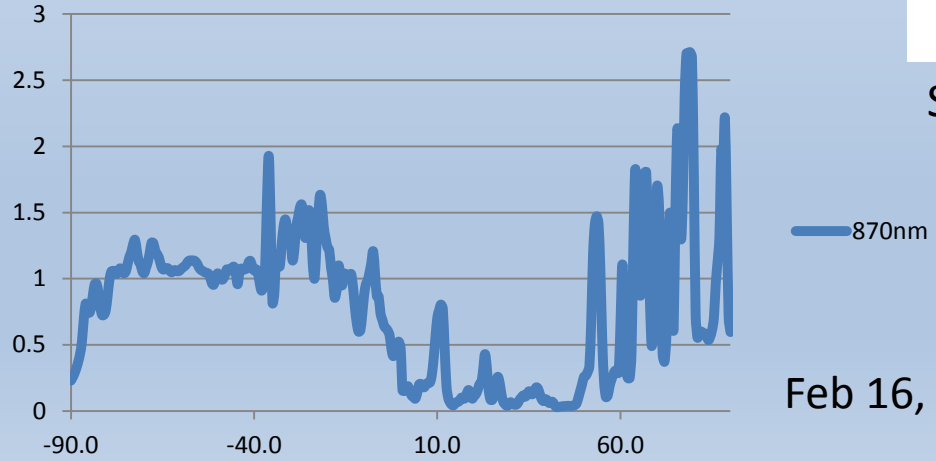
22:47:00UTC

870nm

22:53:00 UTC



SZA = 73.70

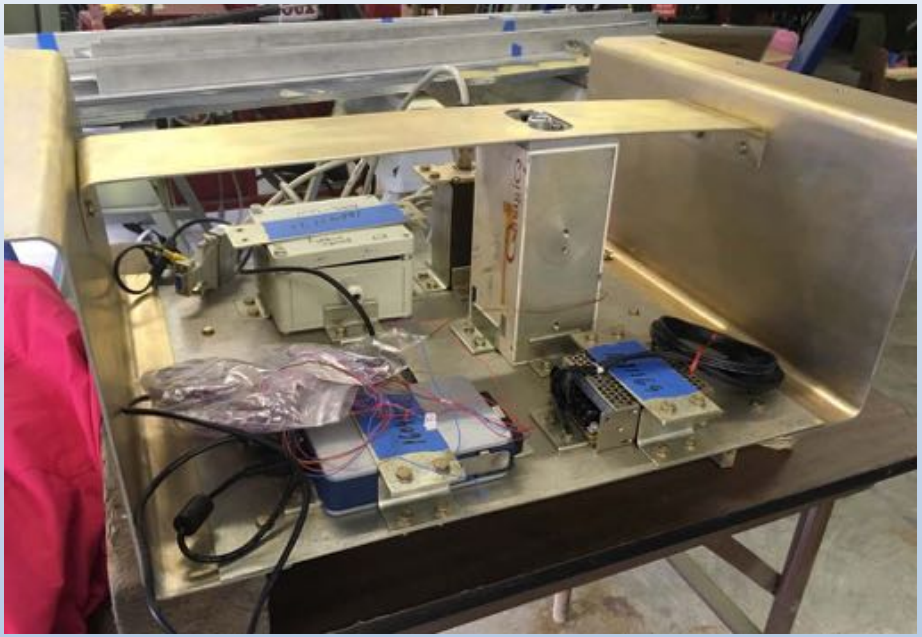


Feb 16, 2017

CAR = Cloud Absorption Radiometer
Multispectral BRDF sensor
& imager

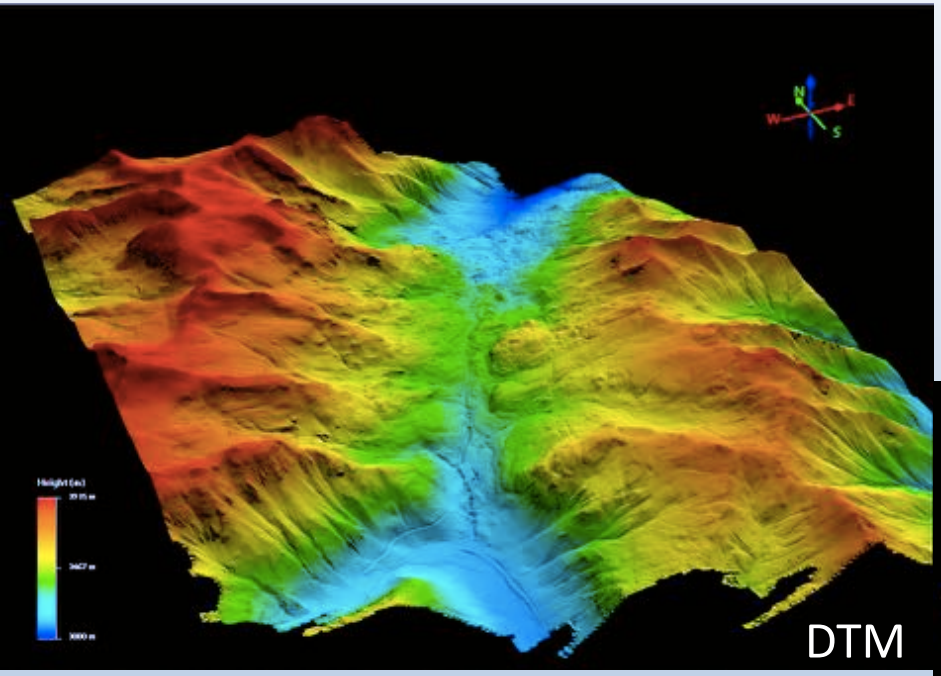
P-3 Thermal IR Sensor Suite

- IR Sensor Suite consists of two instruments and a camera
  - QWIP infrared imager
  - KT-15 infrared thermometer
  - HD visual video camera
- All instruments point nadir through germanium/glass windows
- Windows, ambient, and instrument temperatures logged with thermocouples
- IRSS Instruments were cross-calibrated with ground team field IR targets before deployment
- IRSS Instruments calibrated with handheld target before/after each flight

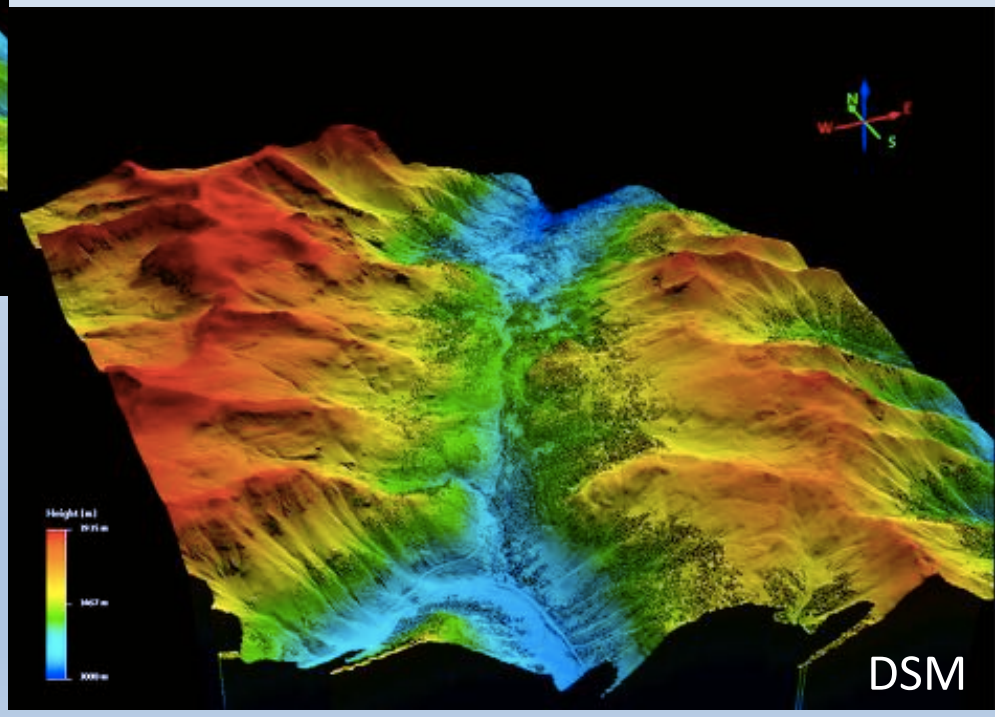


P-3 Nadir Camera View

ASO (Airborne Snow Observatory)



ASO
Senator Beck Feb 8, 2017

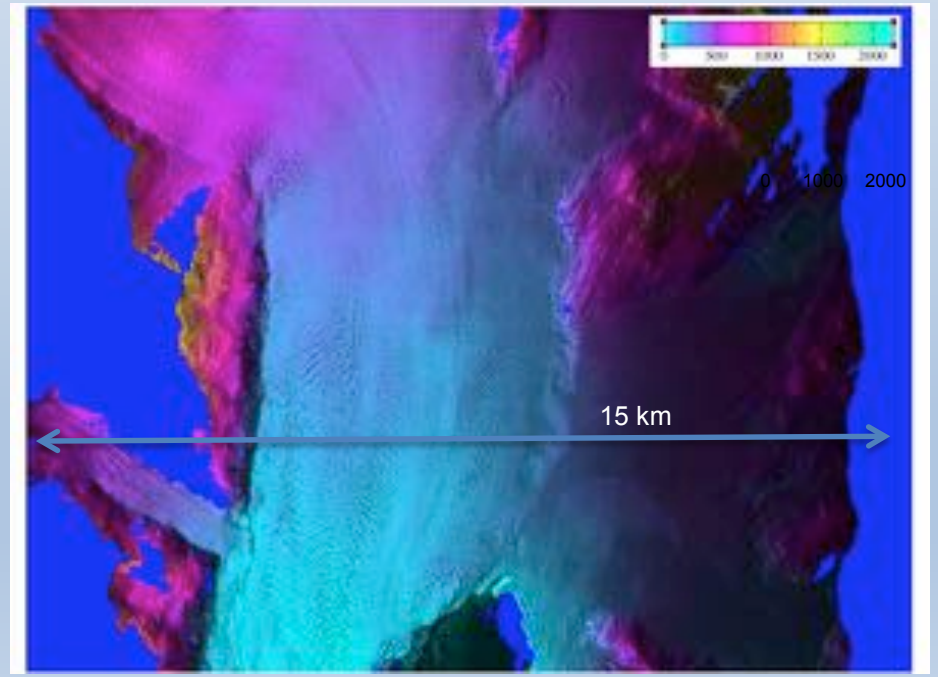


2 sensors:
Imaging lidar
Imaging hyperspectral

Airborne Glacier and Ice Surface Topography Interferometer (GLISTIN-A)

- Ka-band interferometric front-end interfaces to UAVSAR hardware and infrastructure in a plug-and-play way.
- Snow depth retrieval (Moller et al.,2017)
  - Leverage ASO legacy for unique distributed SWE mapping & integration
  - Geodetic snow depth mapping approach
  - Operates through cloud cover
  - Insensitive to liquid water (distinct to volume-scattering radar approaches)
  - Pathway to space mission

The GLISTIN-A hardware resides in the UAVSAR pod flush behind the two Ka-band interferometric antennas



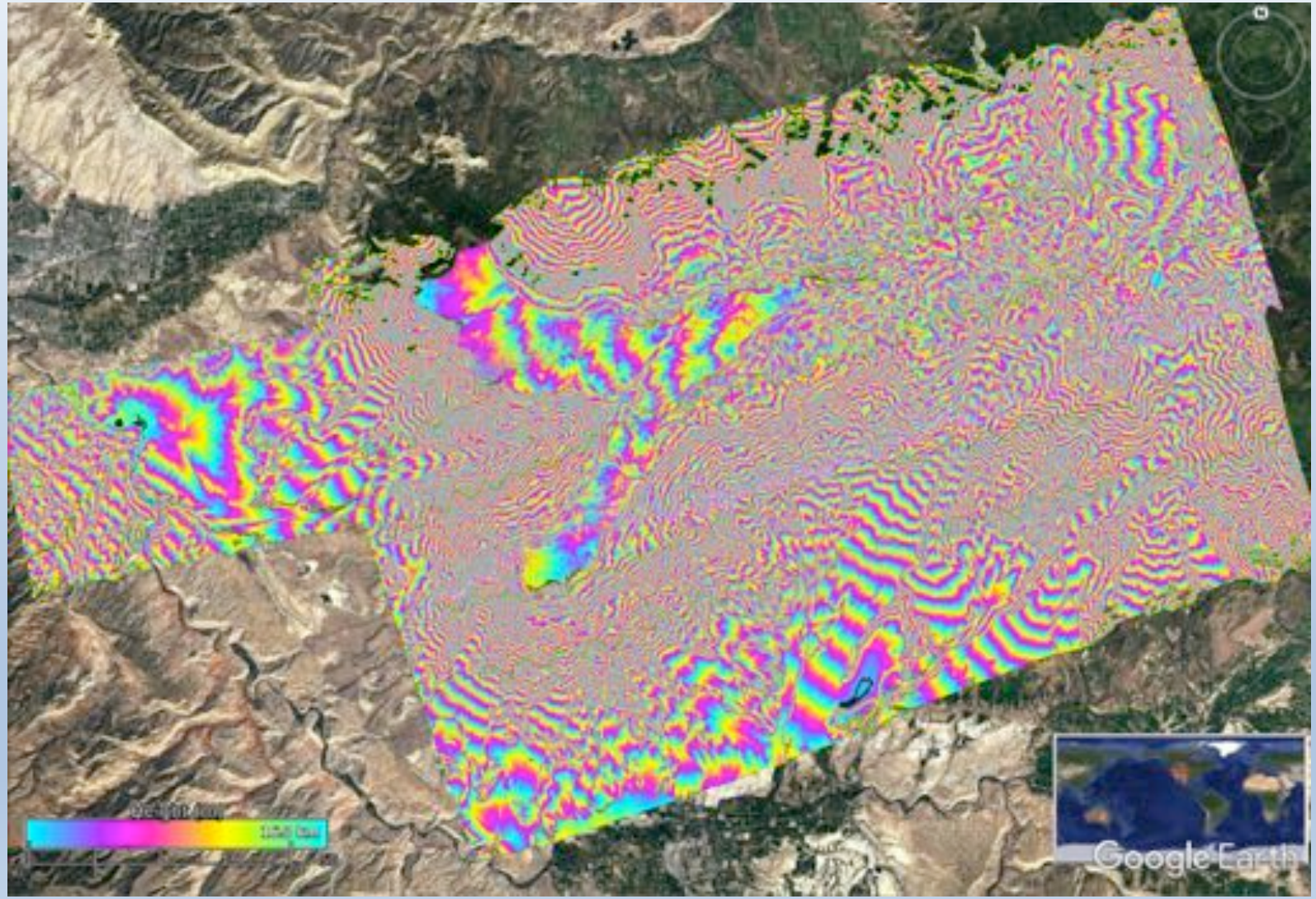
Left: Example height map over Columbia Glacier 4/27/12 for a single swath (data are posted at 3m x 3m resolution, color-bar is height in m).

GLISTIN/ASO SnowEx Flights

- Snow-off flown 9/27 & 9/28 2016
- Snow-on flown February 2017

Date	GLISTIN-A (Basin/hours)	ASO (Basin/hours)
9/27/2016	SB/2	
9/28/2016	GM/2	
2/8/2017		SB & GM/5:00
2/9/2017	SB & GM/6	
2/16/2017		SB & GM/4:24
2/20/2017	SB & GM/6	SB&GM/ 3:18
2/21/2017	SB & GM/6	SB&GM/2:45
2/25/2017	SB & GM/6	SB&GM/4:01

Grand Mesa – GLISTIN-A



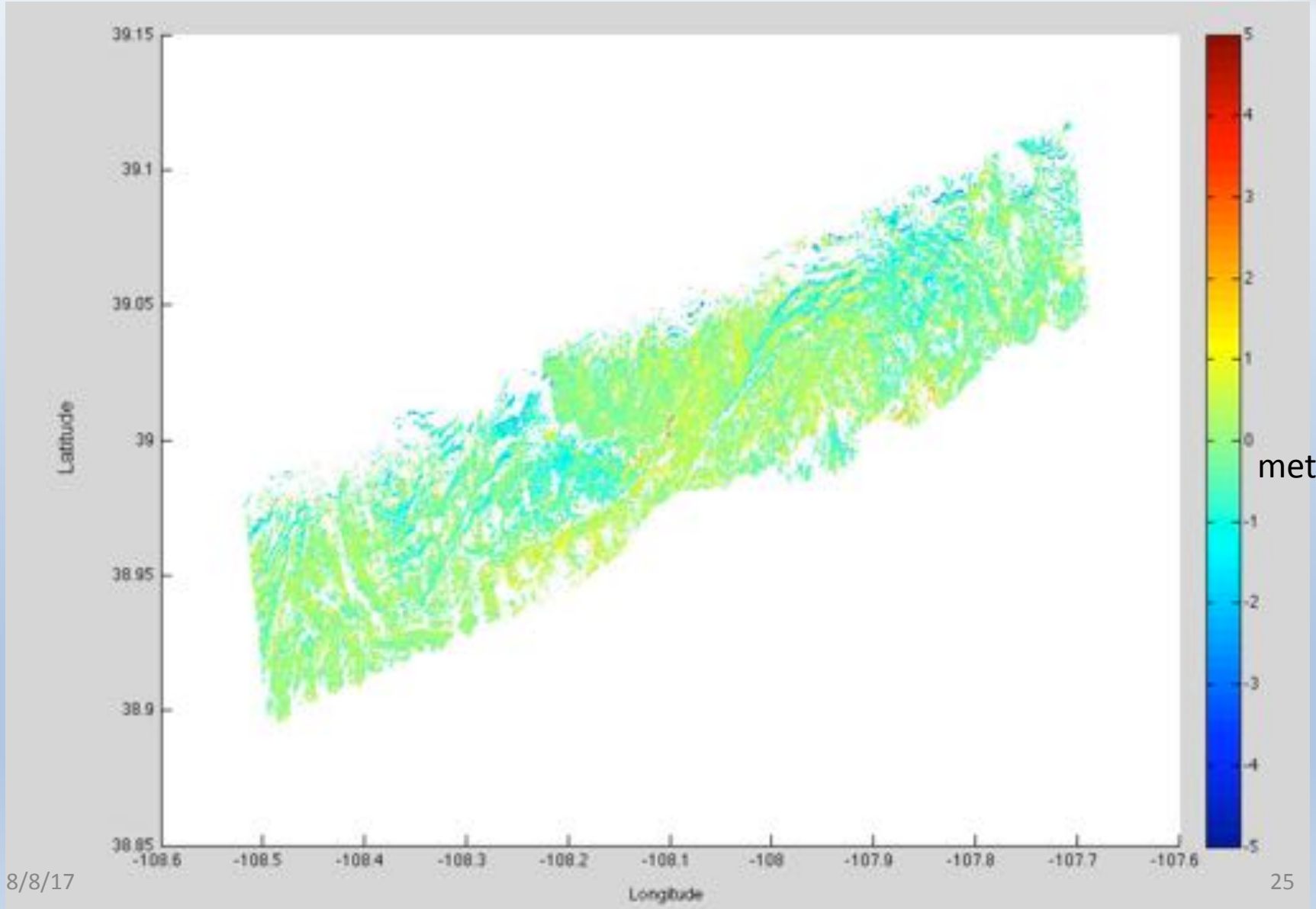
InSAR Snow-Depth Methodology

- Mask trees
- Geo registration (GLISTIN) and calibration
- Multi-look (average)
- Generate “depths” (snow-on – snow-off)

Analysis to Date

- Only data from the winter (snow-on) collection has been calibrated and delivered
- Initial analysis confined to Grand Mesa calibration-line time series
- Tree masking, initial data calibration and geolocation done
  - Heavy tree cover (50%)
- In lieu of snow-off data have generated preliminary snow-difference maps
- No ASO validation yet – next step when data is processed

Depth Differences (Feb 21-Feb 20)



UAVSAR support for SnowEx

Mission Details

- L-Band (~ 1 GHz / 24 cm)
- Interferometric radar acquisitions
- SnowEx funding for 3 flights with 6 flight lines per flight (Feb 2017)
- NISAR SDT funding to continue collections (~ 3) after SnowEx
- SnowEx collection dates: Feb. 6, 22, 25
- **Analysis:** change in phase between acquisitions is related to the integrated snow depth/density (SWE)

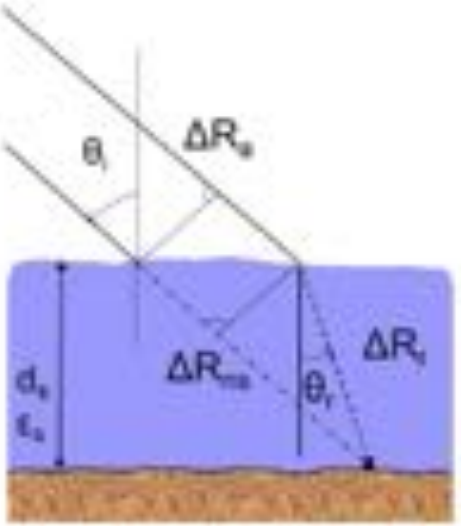
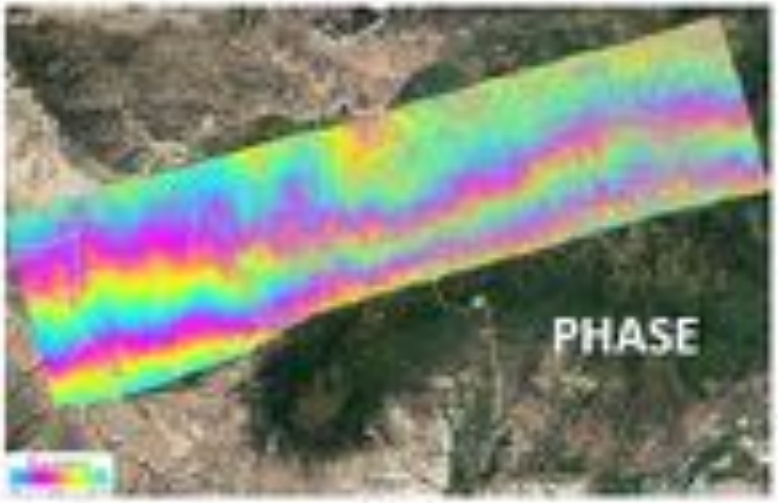


Figure 1. Idealized radar propagation: through atmosphere (ΔR_a) and through snow ($\Delta R_s + \Delta R_s$) (modified from Guneriussen et al., 2001).

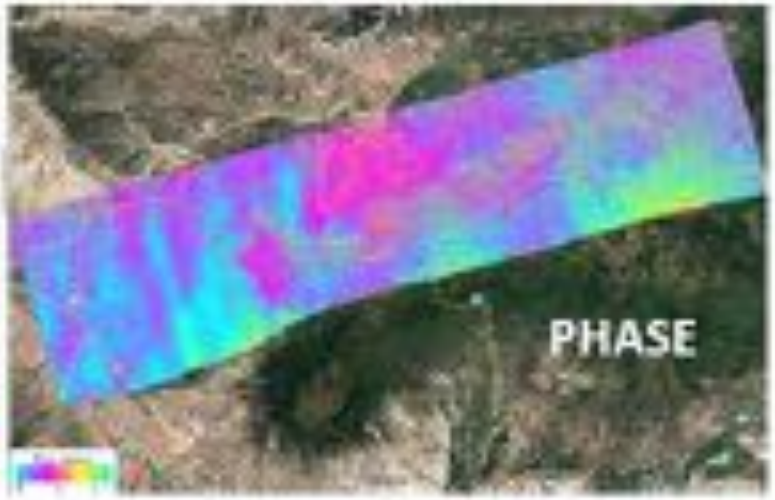
UAVSAR Grand Mesa Results

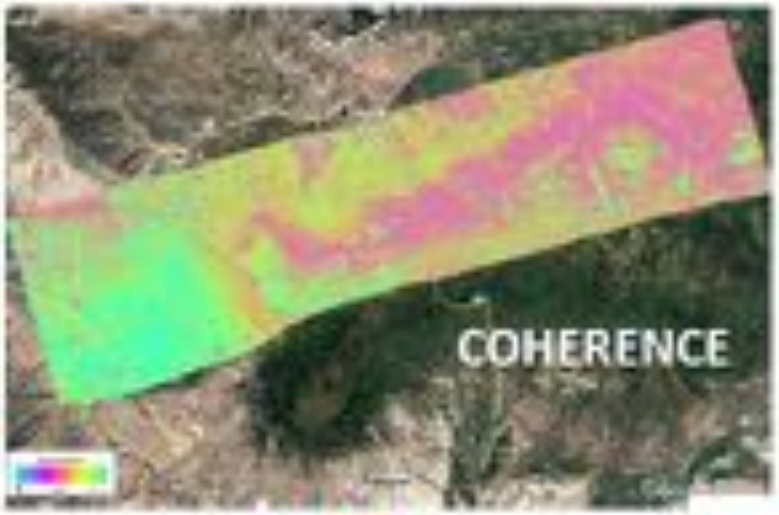
preliminary

InSAR results for Feb 6 – 22



InSAR results for Feb 22 - 25

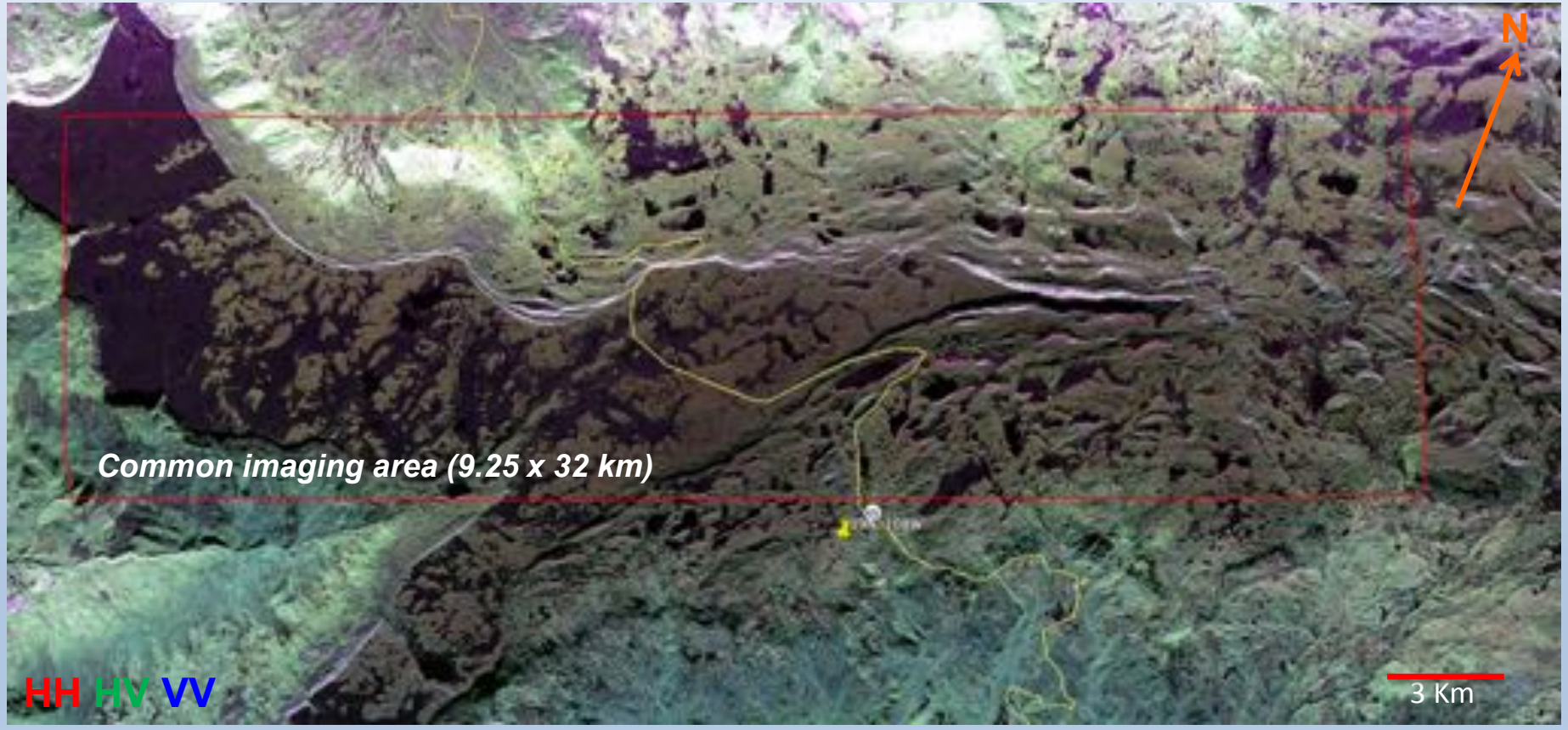




UAVSAR Polarimetric Image over Grand Mesa, Colorado

SnowEx Experiment in February 2017

- **UAVSAR flight aboard the JSC G-III on February 6, 2017 – successfully acquired 6 flight lines over Grand Mesa, Telluride (Senator Beck Basin), and Slumgullion respectively.**
- **Next UAVSAR flight is scheduled for February 20 aboard the AFRC C-20A jet, weather permitting.**



Preliminarily calibrated PolSAR image over Grand Mesa's common study area

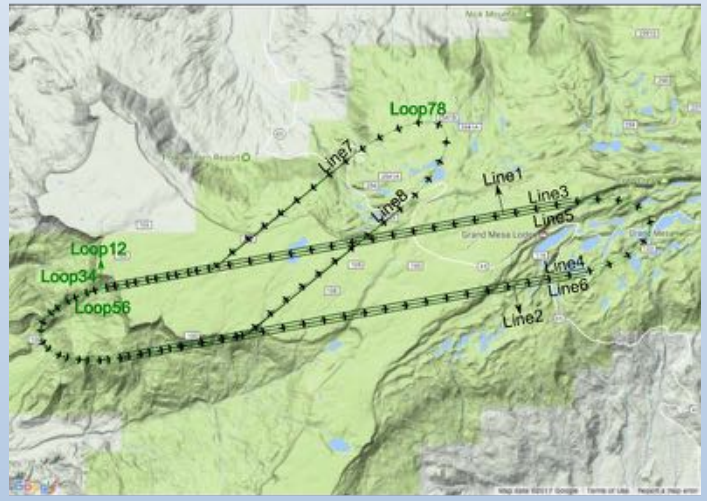
Wideband Instrument for Snow Measurements (WISM)

- Radar bands
  - 9.6, 13.6, 17.2 GHz (V-pol transmit/V&H receive)
  - Calibration via loop back and corner reflectors
- Radiometer bands
  - 10.6, 17.2, 36 GHz (H-pol)
  - Calibration via internal references, thru feed noise injection, pre- & post flight sky/box measurements
- Seven sorties flow (Feb 3 – 10)
  - 2 flights over Grand Mesa
- Preliminary data processing shows some radiometer data for 1-2 days. Accuracy not yet determined.
- Radar and radiometer data processing continuing

WISM installed on the Twin Otter

WISM Campaign #3 – Flight Summary

FL #	Date	Status	Hrs	Notes
1	02/03/17	Radar Only	0.8	Engineering Test Flight around **airport**/normal operation
2	02/05/17	Radar Only	0.8	Engineering Test Flight around **airport**/*no data collected*
3	02/05/17	Radar Only	0.7	Engineering Test Flight around **airport**/normal operation
4	02/06/17	Radar & Radiometer	0.8	Engineering Test Flight around **airport**/normal operation
5	02/08/17	Radar & Radiometer	0.5	Science flight over **Grand Mesa** *terminated due to radar problem*
6	02/09/17	Radar & Radiometer	1.9	Science Flight over **Grand Mesa**/ normal operation
7	02/10/17	Radar Only	1.7	Science Flight over **Grand Mesa**/ normal operation



Grand Mesa Flight Lines: Three loops staggered and dog leg run over auxiliary (boom truck) site

SnowEx Ground Measurements

Winter Campaign

Teams

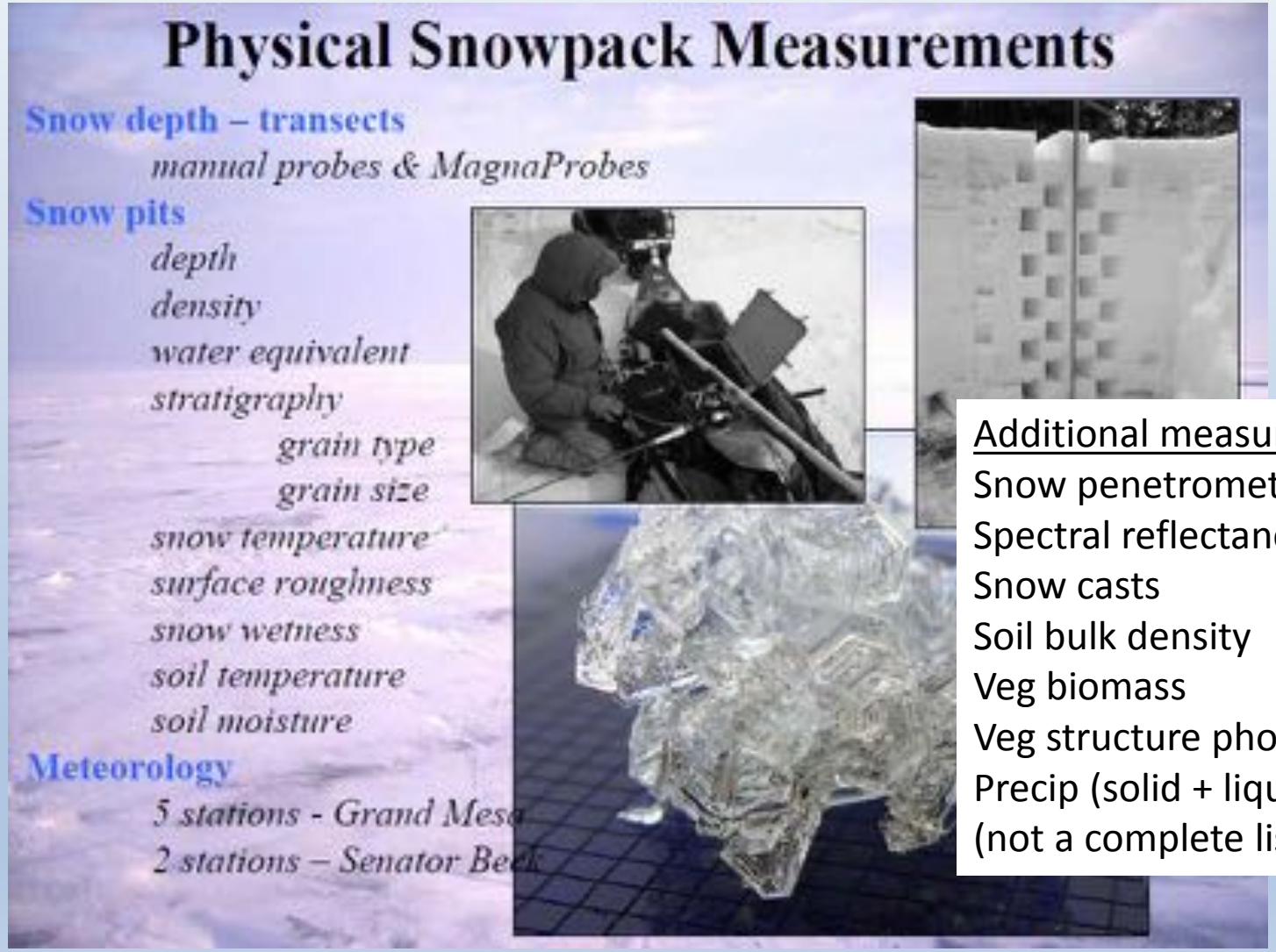
Science

Kelly Elder
Chris Hiemstra
Hans-Peter Marshall
Ludovic Brucker

Logistics

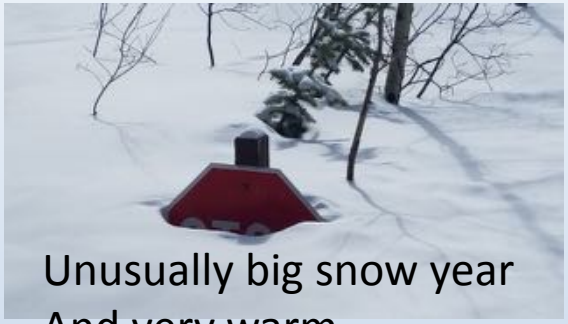
Jerry Newlin
Mark Thomas
Tim Niemeyer
Joann Collins
Amaya Odiaga

Ground Truth



Additional measurements:
Snow penetrometer
Spectral reflectance
Snow casts
Soil bulk density
Veg biomass
Veg structure photos
Precip (solid + liquid)
(not a complete list)

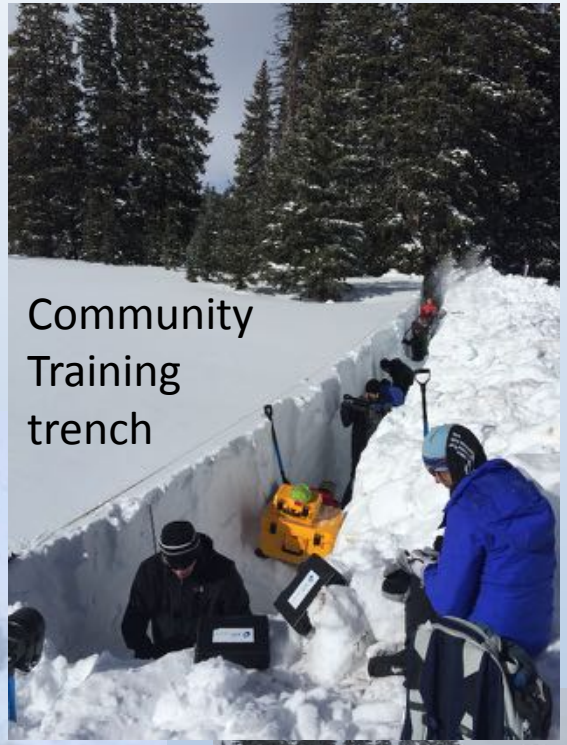
Ground Truth & Community Building



Unusually big snow year
And very warm

Snowpack
Internal
layers

Typical
snow pit



Community
Training
trench

Time lapse cameras

Mandatory training

Ground Truth

165
Transects
~ 16,500 depth measurements

154 snow pits
~4500 density measurements

Too many pits!

Safety first!
Too many pits → snow jail

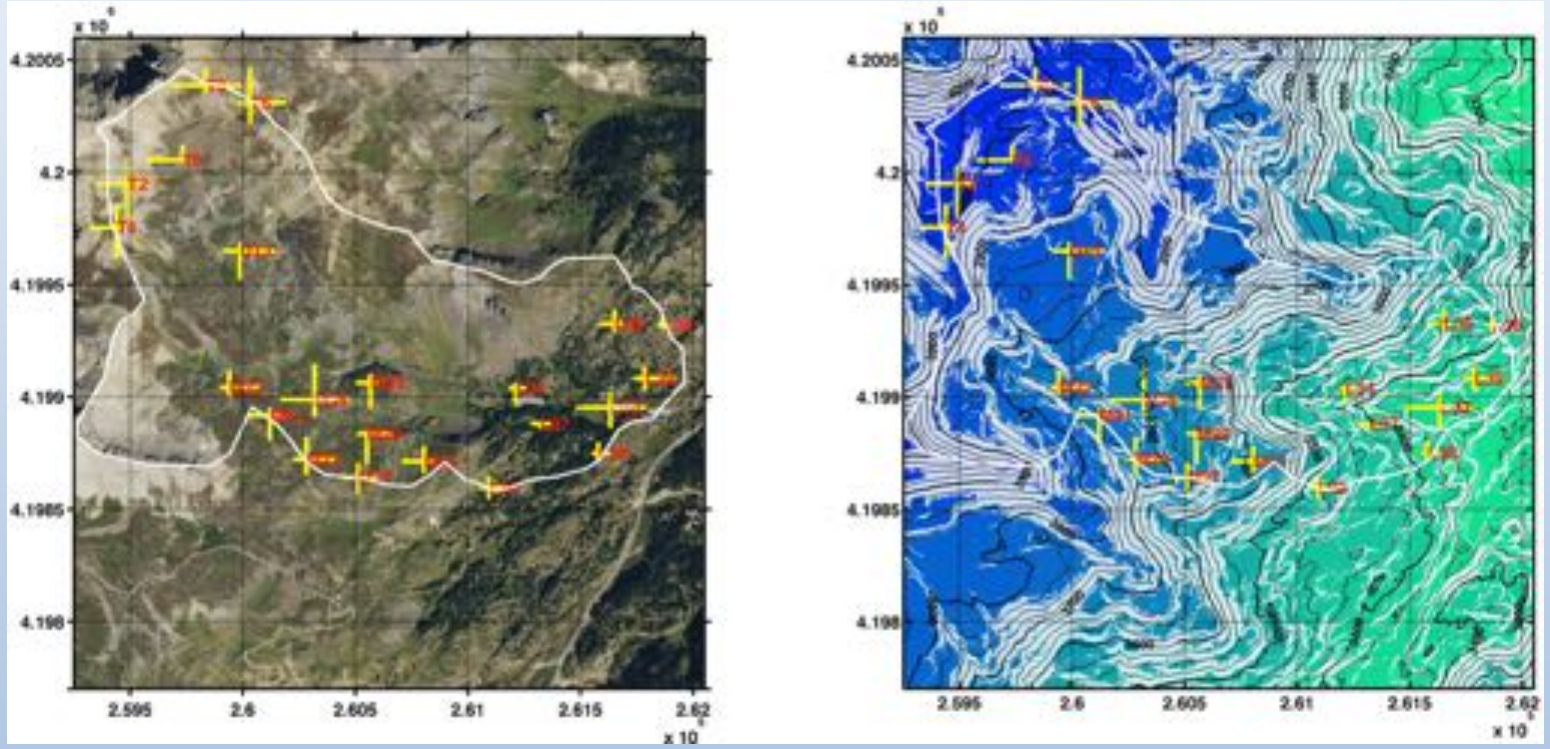
special thin wall pit

Senator Beck

Senator Beck Basin – *SnowEx Site #2*

- H.P. Marshall, *BSU and U.S. Army CRREL*
- Andy Gleason, *Ft. Lewis College and Trautner*
- Jeff Deems, *NSIDC and WWA*
- Pete Gadomski, *U.S. Army CRREL*
- Andrew Temple, *CSAS*
- Chago Rodriguez, *Boise State Univ.*
- Ned Bair, *U.S. Army CRREL and UCSB*
- Karl Rittger, *NSIDC*
- McKenzie Skiles, *Univ. Utah and NASA JPL*
- Jewel Lund, *Univ. Utah*
- Gus Goodbody, *NRCS*
- Pat Kormos, *USDA*
- Andrew Hedrick, *USDA*
- Ty Brant, *UCSB*
- Jeff Derry, *CSAS*
- Mark Raleigh, *CIRES and CU*

Senator Beck Basin – *SnowEx Site #2*



- Core measurements: same pit, transect protocol as Grand Mesa – Week 1 and Week 3
- Steep terrain, above and below treeline; avalanche hazard, visibility, exposure limited upper basin sampling
- GBRS - mobile: TLS, Spectrometer, FMCW radar
- GBRS – continuous: GPR, FMCW, GPS, timelapse cameras, tree accelerometers, sun photometer, 2 energy balance AWS
- Sampling performed throughout basin, covering range of elevation and vegetation, both weeks, with safety 1st!

Ground Based Remote Sensing (GBRS)

lead: Ludovic Brucker

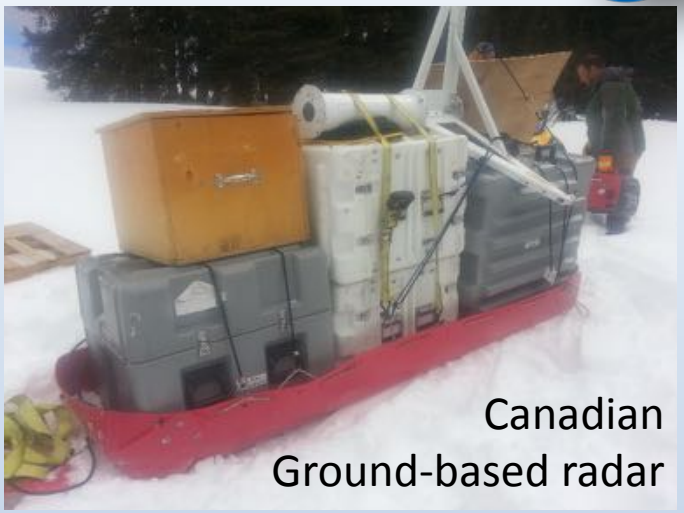
Overview of the SnowEx 2017 Ground Based Remote Sensing

Theo Barnhart, Uni. Colorado
Francis Bliven, NASA WFF
Ty Brandt, UCSB
John Burkhart, Uni. Oslo
Christopher Crawford, Uni. MD
Tri Datta, Columbia Uni.
Roger De Roo , Uni. Michigan
Jeffrey Deems, NSIDC
Havard Eriksrod, Uni. Oslo
Peter Gadomski, CRREL
Arthur Gelvin, CRREL
Nancy Glenn, Boise State Uni.
Katherine Hale, Uni. Colorado
Christopher Hiemstra, CRREL
Brent Holben, NASA GSFC
Keith Jennings, Uni. Colorado
Richard Kelly, Uni. Waterloo
Jason Kraft, NASA GSFC
Alexandre Langlois, Uni. Sherbrooke
Hans-Peter Marshall, Boise State Uni.
Daniel McGrath, Colorado State Uni.
Chelsea Merriman, Boise State Uni.
Noah Molotch, Uni. Colorado
Mohammad Mousavis, Uni. Michigan
Anne Nolin, Oregon State Uni.
Walt Peterson, NASA MSFC
Chris Polashenski, Dartmouth College
Mark Raleigh, Uni. Colorado
Karl Rittger, Uni. Colorado
Chago Rodriguez, Boise State Uni.
Alexandre Roy, Uni. Sherbrooke
McKenzie Skiles, Utah State Uni.
Eric Small, Uni. Colorado
Lucas Spaete, Boise State Uni.
Marco Tedesco, Columbia Uni.
Chris Tennant, Berckley
Aaron Thompson, Uni. Waterloo
Liuxi Tian, Uni. Texas
Zach Uhlmann, Boise State Uni.
Ryan Webb, Uni. Colorado
Matt Wingo, NASA MSFC

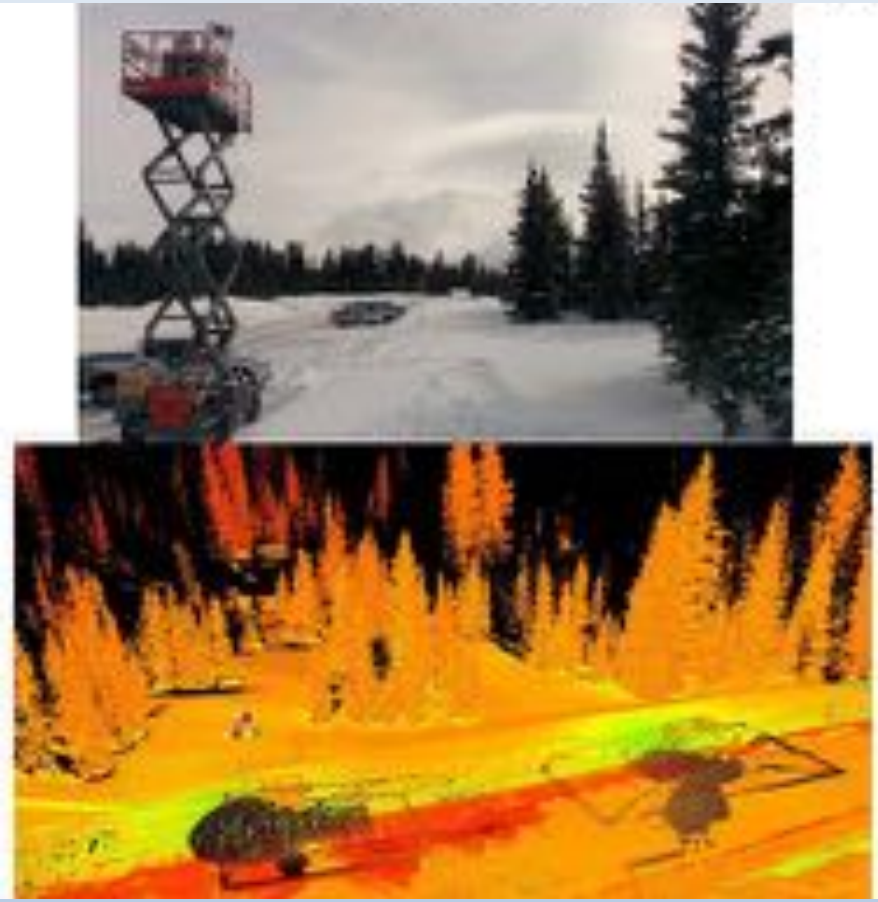
...and even more contributors who helped pulling radars, carrying gear to the field,

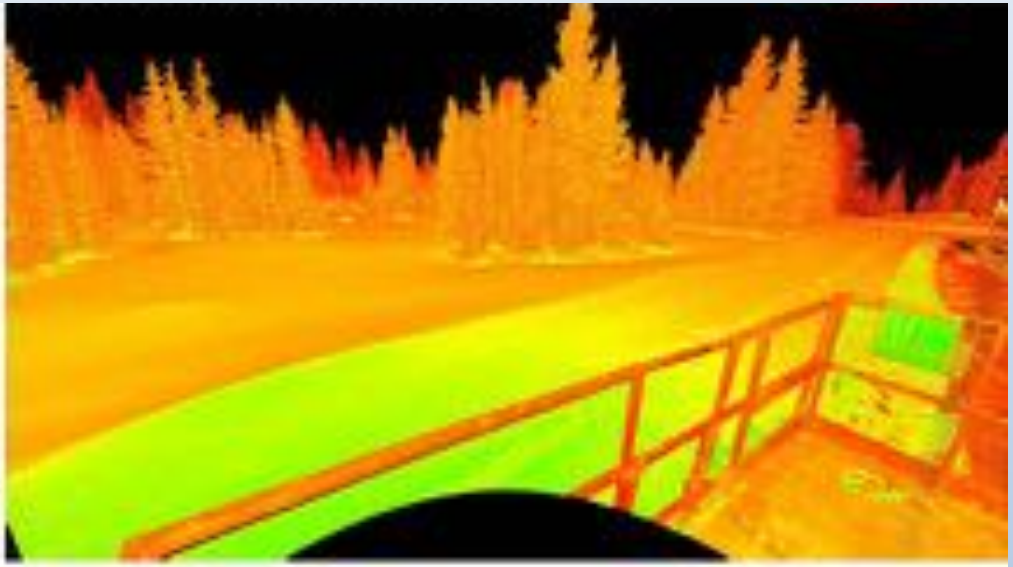
and all the **transect, snowpit, and snow microstructure (SSA, SMP, snow cast) teams** who collected the necessary in situ data to support the ground-based remote sensing activities

Ground-base remote sensors on…



Example GBRS observations

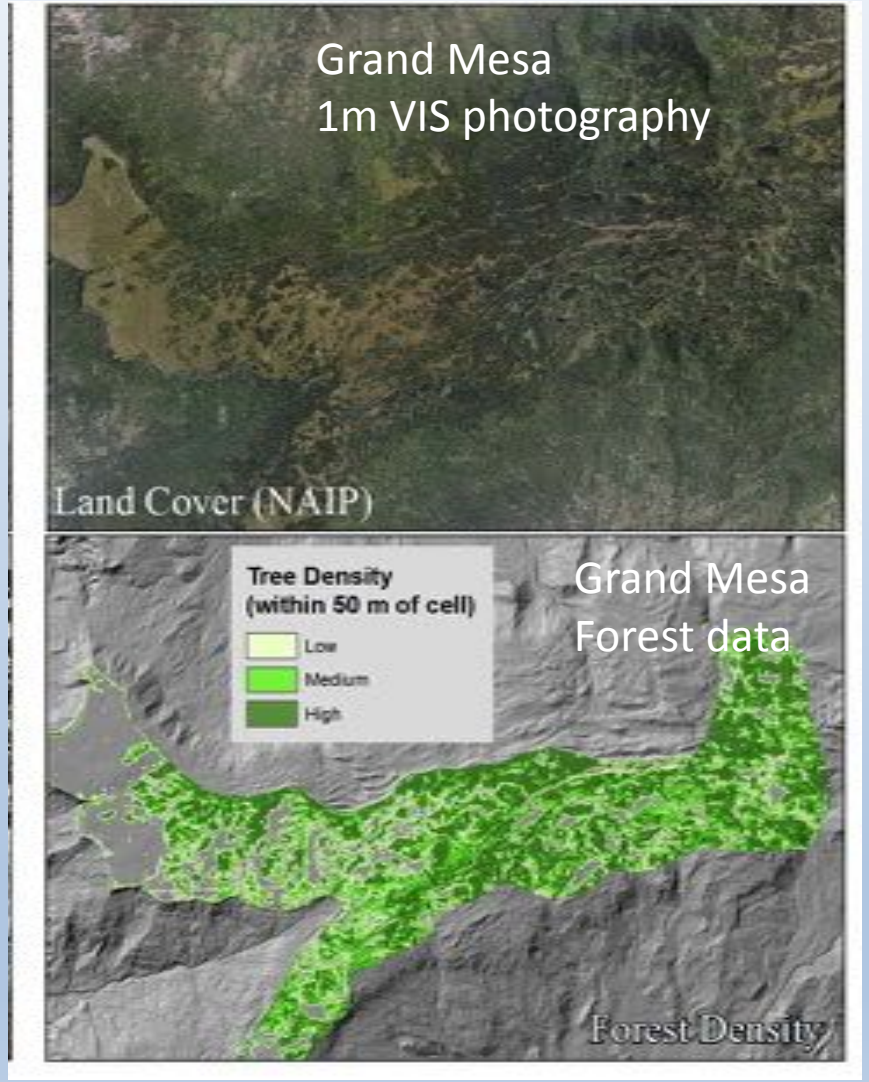


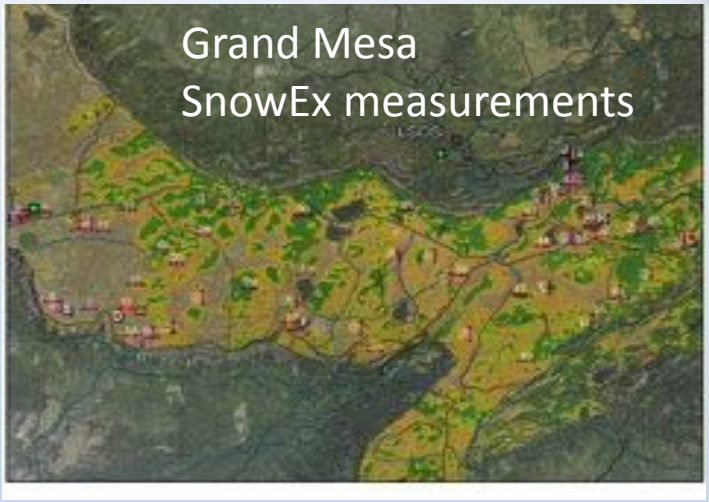


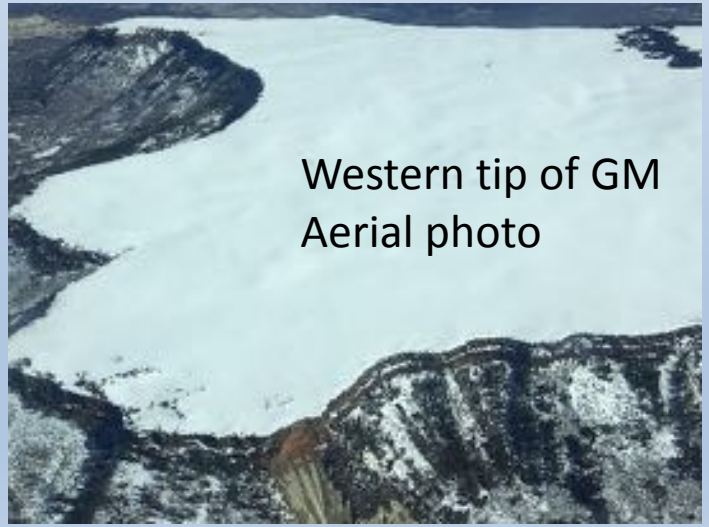
Lidar, radiometer, and scatterometer observations at several heights from a scissor lift, and one snowpit with microstructure measurements in week 3

Ancillary Data

Ancillary data of Sites-GM examples







Satellite Data Example

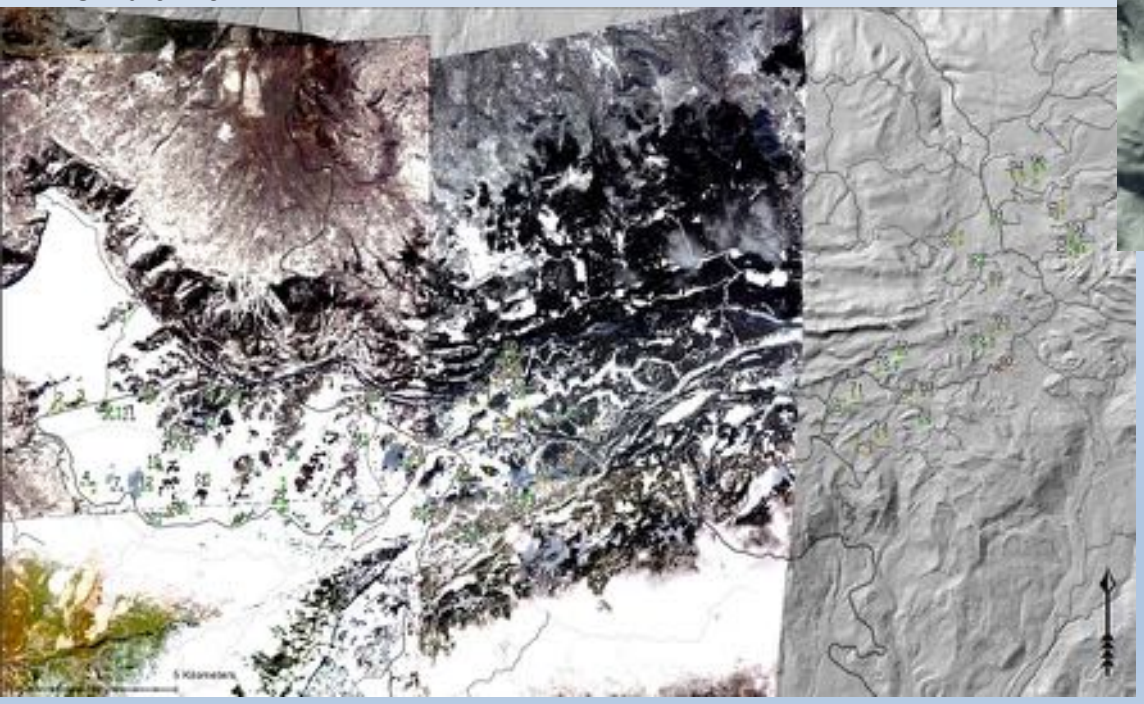
2017 Snow-On High Resolution Stereo Imagery (WorldView 3)

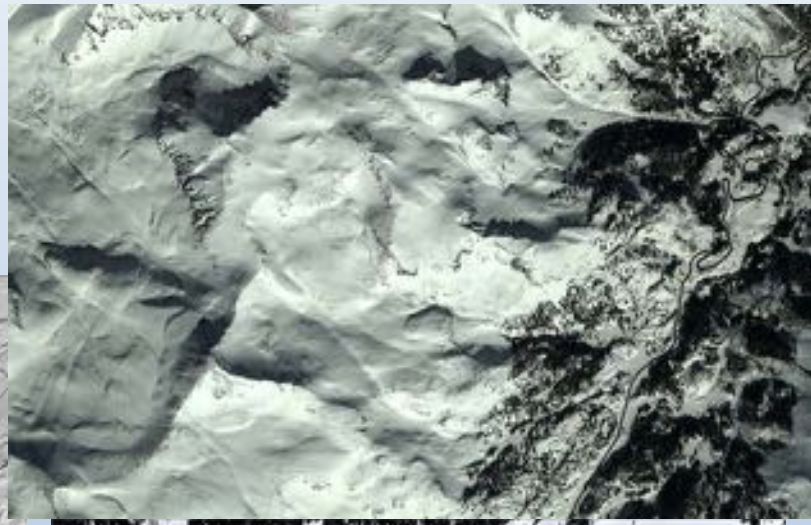
D. Shean, J. Lundquist, & C. Hiemstra

Grand Mesa
27 January 2017
1 February 2017
26 February 2017
18 March 2017

Senator Beck
8 February 2017
20 February 2017

Images Copyright Digital Globe



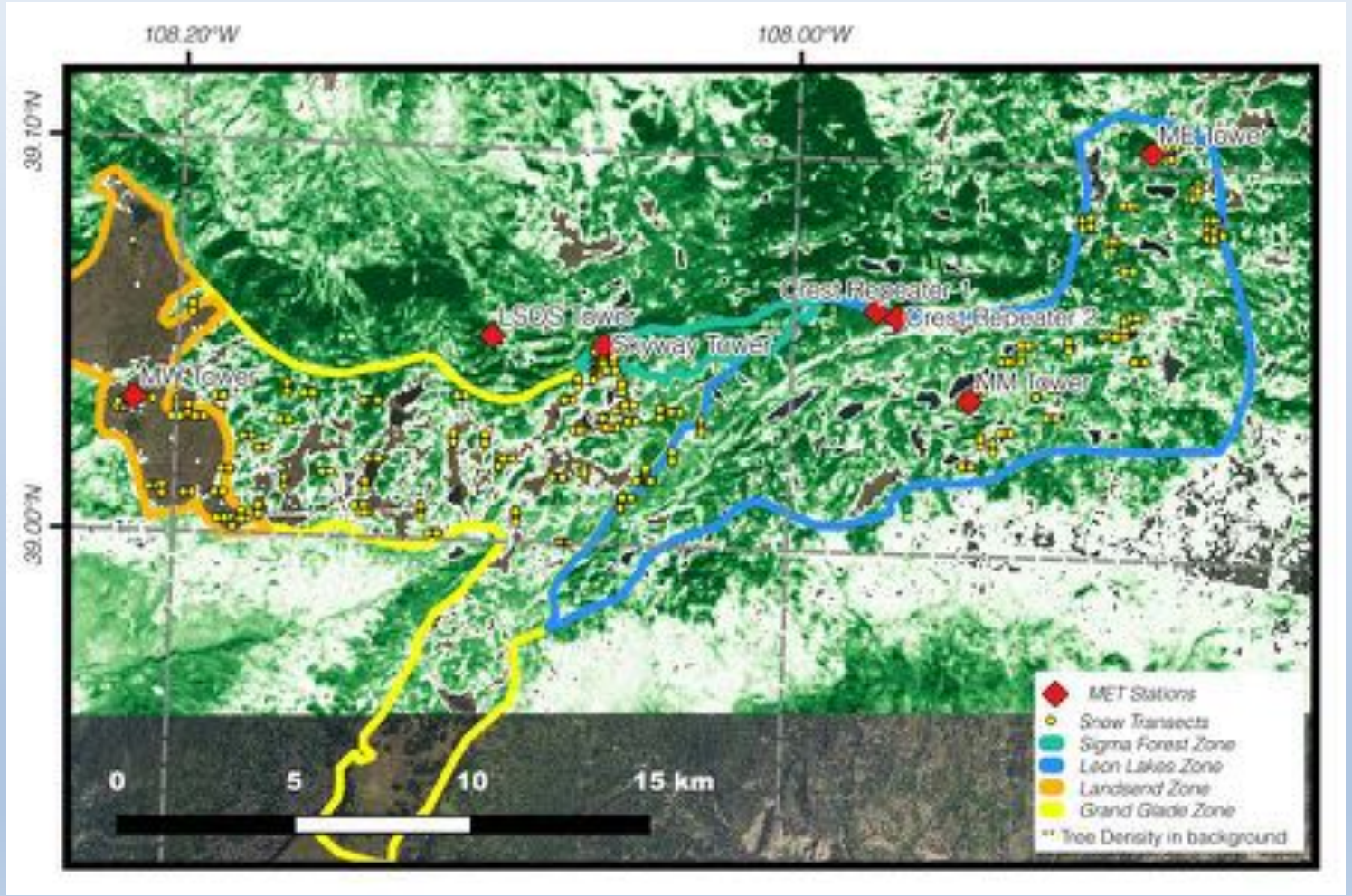


Met Stations

lead: Paul Houser

Grand Mesa Met Stations (5)

2 met stations in SBB were also augmented



Typical Met Instruments

ME Tower (20ft)

- Lat: 39.10374
- Lon: -107.88448
- Elev: 3078m
- 1X Campbell CR6, 10s sampling, 10min and hourly sample, average, max, min, standard deviation
- 3X Stevens HydraProbe II soil moisture sensors (-5cm, -20cm, -50cm)
- 4X Apogee IR radiometers (2X Nadir, 30deg N, 30deg S)
- 2X RM Young 05103 wind sensor (12ft, 20ft)
- 2X HC2S3 temperature/humidity sensor (12ft, 20ft)
- 1X SR50A sonic snow depth sensor
- 1X CNR4 4 component net radiometer
- 1X CS106 barometric pressure
- 25 node soil/snow thermocouple string (300,275,225,175,150,125,100,75,50,40,30,20,10,5,2.5,0,-2.5,-5,-10,-20,-30,-40,-50cm)
- 1X RF451 radio modem
- 1X time-lapse camera, 3hr

Data Delivery

lead: Steve Tanner

NSIDC overall lead: Amanda Leon

Official Data

- Official SnowEx must meet NASA data standards in order to be “delivered” to NSIDC
- This includes, for example, extensive metadata
- In addition to rigorous quality control
- Expected timeframe: months
- The first 1 or 2 data products are almost ready
- Snow.nasa.gov -> snowex -> data
- Inventory/status spreadsheet

See Amanda!
Update your info

UnOfficial Data

- To help proposal writers, etc, limited unofficial data are available in the short term
- NASA THP call due August 3
- Caveats: no real quality control, no real metadata, no support
- Ground truth (pits & transects) unofficial v1 (digital) data posted 2 weeks ago at NSIDC
- Airborne: CAR near final, ASO examples
- Watch for announcements on snowex email list (are you signed up?)
- ftp://ftp.nsidc.org/pub/projects/SnowEx/colorado_year1/
- Eratta sheet on google docs

What’s next?

SnowEx Outreach – 2017

•23 – 28 April – European Geophysical Union, SnowEx Community poster using contributions from this webex (edited to fit poster!)

•6 – 8 June – Eastern Snow Conference, SnowEx overview

•16 May – "Mini" session on GLAWEX at the International Association for Great Lakes Research (IAGLR), Detroit, MI

•24 – 28 July – Special Session on SnowEx at IGARSS, Ft. Worth, TX – multiple presenters

•8 – 10 August – SnowEx Workshop on Preliminary Results, Longmont, CO

•12 – 16 December – AGU Special Session has been accepted, New Orleans, LA

•Plus other articles, presentations, etc

Year 1 isn't over yet!

Still to come:

- Data delivery
- In progress: Site un-deployment (removal of equipment per agreement w/Forest Service)
- LSOS met station has been removed;
- Jumbo campground (LSOS) re-opened for campers end of May
- 3 dedicated met stations on Grand Mesa will remain in operation for at least next year; semi-live data link
- 2 pre-existing met stations at Senator Beck will remain, possibly with slight sensor changes

Opportunities

- Just-closed THP ROSES call focused on developing elements of snow mission algorithms
- Recently-selected 'snow roundtable group' will develop THP's snow science and implementation plans, including where SnowEx years 3,4,5 will go & the foci
- 2nd Decadal Survey will contain snow advice (of course, the basic science questions, societal impacts, and options for mission concepts are already well-known)
- THP Snow Program Office at GSFC, led by Dorothy Hall. Assists THP PM (Jared Entin) on snow. You are encouraged to contact Dorothy about any THP snow matters!

Year 1 Major Accomplishments (so far)

- Community building: ~100 participants from dozens of institutions trained & participated
- Strong international participation
- 5 of 5 aircraft flown
- 9 of 10 airborne sensors flown
- 165 transects measured
- 154 pits measured

800 pages of data

- 22 GBRS instruments
- 4 new met stations; 3 existing stations augmented
- No significant injuries
- Official data to be archived at NSIDC; unofficial data coming in
- Dozens of press reports, interviews, social media products, etc.
- Field site inventory, airborne lidar inventory
- Planned and executed in ~1 year (don't try this at home)

Concluding Remarks

- A giant “thank you” to all who helped make the Feb 2017 deployment safe & successful
- The snow community can do some truly amazing things working together
- A major step toward a global snow satellite mission
- If you’re a data provider, we’ll be in touch to work on data delivery—SEE AMANDA TODAY!!!
- Check snow.nasa.gov/snowex periodically for updates
- Call us, email us with your Year 1 questions and suggestions!

Looking Forward

- We can do incredible things working together as a community
- Much larger than a prof + a couple students
- The scales are larger; satellite missions are inherently global in scope; THINK BIG!
- It's been a decade since this many snow folks have gathered in one place with fresh data coming out—DON'T MISS THIS OPPORTUNITY TO BUILD NEW COLLABORATIONS IN ORDER TO DO SCIENCE ON A NEW SCALE
- You're going to hear a lot of great ideas—listen, get excited, but also be a scientist, and ask "show me the data"

NASA mission life cycle