SnowEx: a new NASA airborne campaign and snow satellite mission directions

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(with contributions by many others)

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Webex Agenda

- Background
- Instruments & Aircraft
- Sites
- Ground truth
- Snow Satellite
- Summary

- For more information, see snow.nasa.gov

Background

- Recent snow community consensus about the need for a multi-sensor approach…and
- …the realization that we don't have a good multi-sensor dataset to use for algorithm development or to perform trade studies to design a mission concept
- NASA Terrestrial Hydrology Program has stepped up to provide us with an opportunity to address the lack of multi-sensor data via a multi-sensor airborne campaign ->SnowEx

What is SnowEx?

- SnowEx is a multi-year airborne snow campaign. Its goal is to collect multi-sensor observations plus ground truth to enable trade studies for snow satellite mission designs.
- **SnowEx is all about *challenging* the sensing techniques and algorithms….until they break**. Only then will we learn when & where each technique works or doesn't work—and why.

NASA-SnowEx Context

- NASA is a space agency
- A NASA snow satellite mission needs to be global
  - a mission that addresses snow only in a limited domain does not meet this requirement
  - Conversely, a mission that cannot sense snow over a large domain is less desirable than one which can
  - It's perfectly fine for a mission to exclude areas where a retrieval is not practical (example: SMAP)
- SnowEx is about measurement of global types of snow

SnowEx Driving Questions

- Primary driving question: What is the optimum combination of sensing techniques to measure global SWE? (where, when, how much)
- Secondary driving question: What is the optimum combination of sensing techniques to measure global snow melt/energy balance-related info? (where, when, how fast)

- SnowEx must keep in mind that the answers need to be applicable to a spaceborne measurement system, so we must repeatedly ask ourselves if the experiment design as well as the answers will translate to space.

When is SnowEx?

- Year 1 = 2016/17 Winter: campaign
- Year 2 = 2017/18 Winter: no campaign
- Year 3 = 2018/19 Winter : campaign
- Year 4 = 2019/20 Winter : campaign
- Year 5 = 2020/21 Winter : campaign

- Please Note: 'Year 1' is the beginning. Things that are beyond Year 1 resources can be addressed in following years. We don't need to do everything in Year 1.

"Campaign" includes

- fall no-snow background obs w/lidar & radar
- Spring dry snow obs w/full sensor suite

Where will SnowEx be?

- Site selection will be primarily based on the site characteristics needed to achieve SnowEx objectives.
- A detailed list of characteristics came from the 2015 Columbia, MD community workshop and have been refined.
- See snow.nasa.gov for a comparison of potential sites.

Instrument types & aircraft

- From the 2015 Columbia SnowEx workshop, the core sensor types were
  - Lidar
  - Radar (SAR, volume scattering approach)
  - Passive microwave
  - Passive VIS/IR
- Also discussed in other community fora
  - Multispectral, hyperspectral, photography
- We can consider adding other sensors, but Year 1 is strongly resource limited
- An exhaustive aircraft evaluation is in progress

Why challenge with forests?

- Reviewers of 3 of the unsuccessful recent snow mission proposals identified the lack of retrievals in forests as an issue
- Forested areas cover a large part of the snow covered world
- So far, we've avoided forests because all 'traditional' techniques have issues there
  - But new techniques (lidar) appear to offer significant progress to retrieve snow in forests
  - Other new techniques might also change the game to permit limited forest retrievals

Don't take "forest" literally!

- "forest" doesn't mean 100% canopy fill, opaque forest; real forests have gaps
  - Clever new approaches are opening up retrievals in "forests"
  - For SnowEx, "forest" means the continuum from 0% trees to 100% filled, because that will allow us to determine when a sensing technique stops working
- A future snow mission doesn't need to retrieve snow everywhere in all conditions

These are all examples of “forest”

Instrument Requirements

- Starting point = recent spaceborne snow concepts
- Modified for airborne situation
- Not totally final, but the longer it takes to finalize, the greater the risk

- Other considerations
  - Maturity
  - Availability
  - Accuracy
  - Cost
  - (not a complete list)

- Instrument & aircraft choices are closely linked
- Baseline instruments need to be known in order to select aircraft
- Aircraft need to be nailed down by end of Seattle meeting-at the latest
- Therefore, instruments need to be nailed down at the Seattle meeting to reduce risk
- The candidates are limited in most cases

Instrument Candidates-overview

- Radar (SAR)—SnowSAR (ESA/MetaSensing)
- Passive MW—AESMIR (NASA GSFC)
- Passive VIS/IR—CAR (NASA GSFC)
- Multi-spectral--included w/CAR
- Hyper-spectral--lidar candidates co-fly w/this
- Photography-- lidar candidates co-fly w/this
- Lidar

- Instrument selection involves many considerations

Radar Requirements & Candidates

Volume scattering-based approach

- Prefer 2 frequencies and (VV,HH,cross) polarizations from among 10, 14, & 17 GHz (similar to CoReH2O & SCLP which were 10 & 17) but with 14 GHz added based on recent work. 17 GHz is most sensitive, then 14, then 10. Other freqs have been mentioned over the years, but these are the current main candidates.
- Prefer a SAR to get small footprints, but a scatterometer flying at low altitude might work.
- AirSWOT, GLISTIN-A, IcePod. wrong frequency.
- GPM airborne radars: has 14 GHz, not SAR.
- POLSCAT: 14 GHz scatterometer.
- SnowSAR: 10,17 GHz SAR. Previously flown but concerns about data delivery/accuracy. Concerns are being addressed; agreement w/MetaSensing would insist on healthy reserve to address this risk.
- WISM: has 10,14,17 GHz SAR, but might not be ready for SnowEx winter 1.

Phase-change based approach (e.g.,Deeb et al)

- UAVSAR: L-band of interest to explore this approach
- PLIS, dbSAR: not as mature

- Flying more than one radar may move us closer to "ideal," but with increased cost, complexity, and risk. If we can only afford one freq, the most sensitive is 17 GHz. Of the options, SnowSAR is the most mature with 17 GHz capability.
- Conclusion: use SnowSAR & keep options open if WISM becomes ready; discuss other scenarios. Explore adding L-band SAR for phase-change approach.

Passive Microwave Candidates

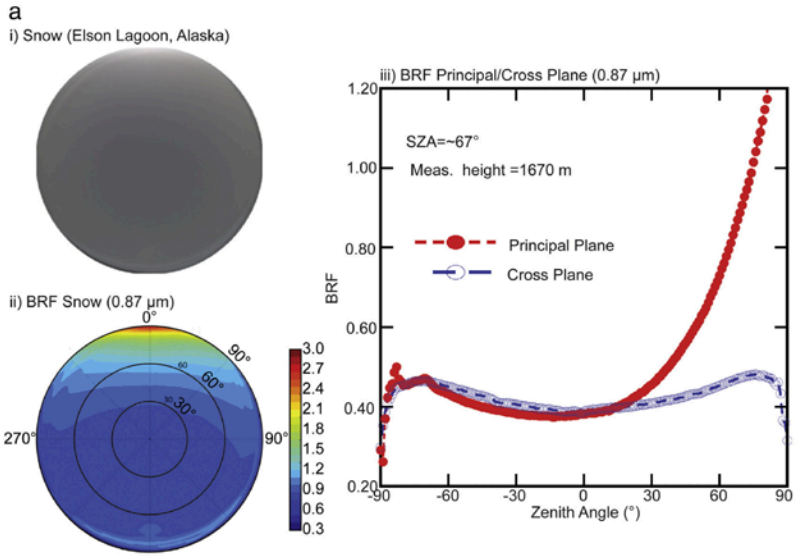
- Minimum 18 & 36 GHz, V &H pols
- Want imagery to match w/other sensors
- 10 & 89 GHz of secondary interest

- candidates
  - AESMIR
  - PSR
  - APMIR (no 89 GHz)

- All require heavy-lift aircraft

Passive VIS/IR Candidates

- Cloud Absorption Radiometer (CAR)
  - BRDF capability
  - Multi-spectral: 14 bands (0.34 to 2.29 µm)
  - Mature



- More info at

  http://car.gsfc.nasa.gov/

  Publication:
  http://car.gsfc.nasa.gov/publications/pdf/Gatebe_and_King_2016.pdf

Lidar Candidates

- LVIS (GSFC)
- ASO (JPL)

- Many lidars were initially considered
  - SIMPL, MABEL, ATM, mini-ATM, IcePod, G-LiHT
- Both candidates can do what SnowEx needs
- Both are mature
- Both are reasonably available schedule-wise
- Both co-fly w/hyperspectral sensors & photography (cameras)
- LVIS is a simulator for GEDI on ISS

Multispectral/Hyperspectral Candidates

- If we fly either lidar candidate on the previous slide, they co-fly with hyperspectral sensors
- These are also mature

Airborne Multisensor Snow RS Activities

- Some examples of multisensor snow observations projects in North America.
- Not a complete list. Not all sensors flown simultaneously.
- "SnowBridge" is a notional activity modeled on IceBridge.

	CLPX-1	CLPX-2	Envir. Canada	ASO	Snow Net	Snow IIP	Ice Bridge	Snow Bridge
years	2002-2003	2007-2008	1990s? --now	2012 --	2008-2014?	2015-2016	1990s-2017	???
Radar	X	X	X		X	X	X	X
Passive MW	X		X			X		X
Lidar	X	X	X	X	X	X	X	X
Hyper spectral	X			X				X
VIS/IR					X	X	X	X
other	X						X	X

Int'l snow remote sensing working group

- **What**: a group to foster snow community knowledge & activities related to snow RS; advocacy group for snow RS opportunities
- **Who**: anyone interested in snow remote sensing; international
- **How to join**: email chair,

  Matthew.Sturm@gi.alaska.edu
- **When**: reincarnated 2013
- **URL:** http://nasasnowremotesensing.gi.alaska.edu/

Int'l Snow Remote Sensing Working Group

Recent activities

- Town hall meeting: AGU 2012
- Open workshops: Aug 2013, Jan 2014
- Strong international participation
- Field measurement school: Jan 2014 (Colorado USA)
- Modeling school: summer 2014
- Website

Upcoming activities

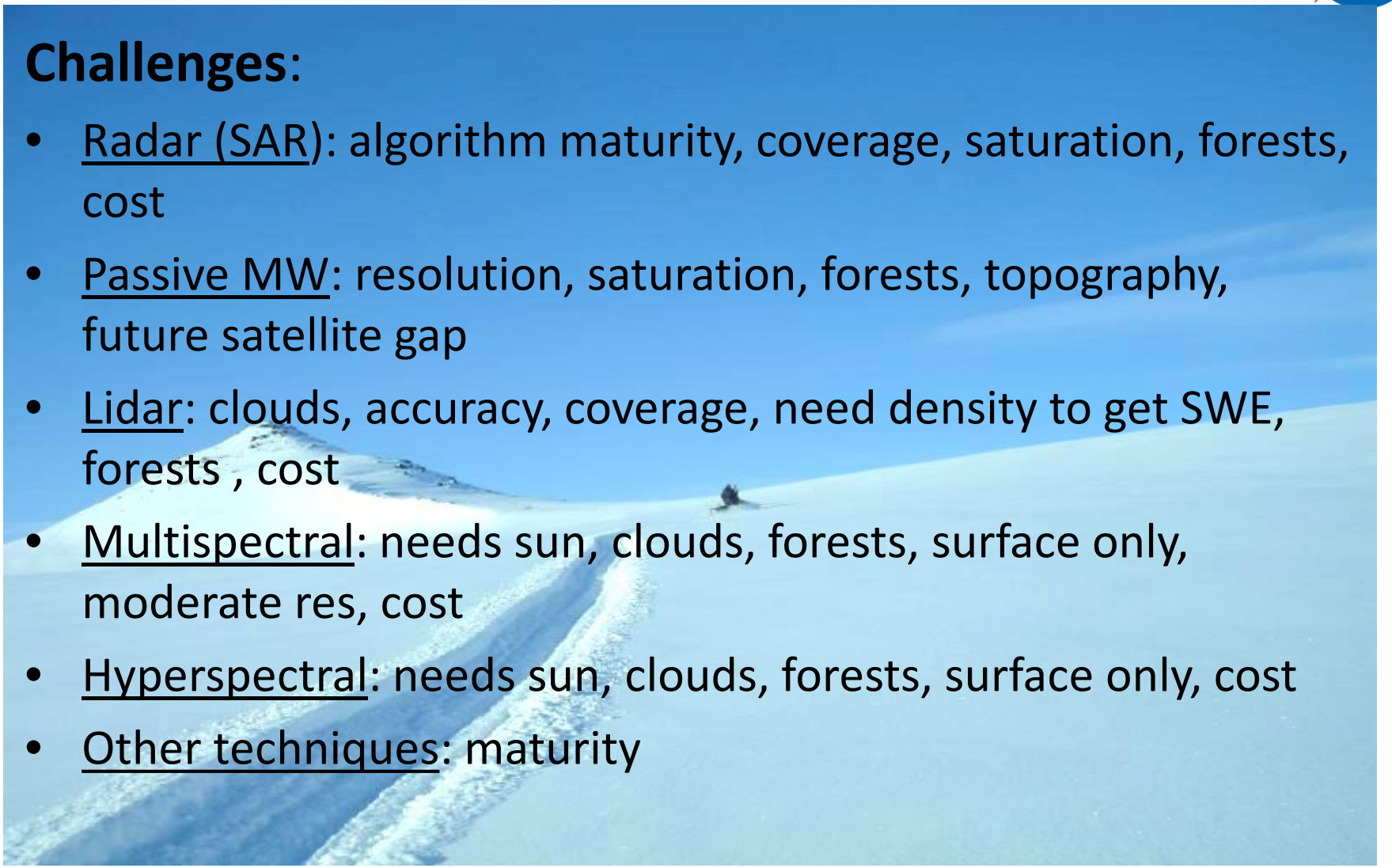
- Town hall meeting: AGU 2014
- Field measurement school: early 2015
  - Sherbrooke, Canada
  - Sodankylä, Finland
- Decadal survey 2: white paper in progress
- Repeat modeling school?
- Add remote sensing school?

Rem. Sensing techniques for global snow

Advantages/Strengths:

- Radar (SAR): senses SWE & melt, high res, topography OK, clouds OK, no sun needed
- Passive MW: senses SWE & melt, global daily coverage exists, clouds OK, no sun needed, very long record
- Lidar: snow depth, accuracy OK for deeper snow, SWE (need density), very high res, forests ~OK, topography OK
- Multispectral: MODIS/VIIRS exist, fSCA, albedo, grain size, moderate spatial res
- Hyperspectral: fSCA, albedo, surf grain size, mod/high spatial res
- Other techniques: a few in development

Rem. Sensing techniques for global snow



Challenges:

- Radar (SAR): algorithm maturity, coverage, saturation, forests, cost
- Passive MW: resolution, saturation, forests, topography, future satellite gap
- Lidar: clouds, accuracy, coverage, need density to get SWE, forests , cost
- Multispectral: needs sun, clouds, forests, surface only, moderate res, cost
- Hyperspectral: needs sun, clouds, forests, surface only, cost
- Other techniques: maturity

Future NASA Snow Mission Opportunities

- Decadal Survey 2
  - Exercise is starting; complete in a few years
  - Snow is getting attention lately
  - Tempered by DS1 ratio of 2:17 funded
- Global Ecosystem Dynamics Investigation (GEDI)
  - Lidar to fly on Int'l Space Station
  - Latitude limit

- Venture Class suborbital missions
  - EVS-2 selections expected by end of 2014
  - 2 known snow proposals

Thoughts on snow mission concepts

(My own view, not necessarily NASA's or working group's)

- Must address *Global* snow (this one is also a NASA view)
- Therefore must include multi sensors (community consensus)
  - Active & passive mw, lidar, multi-spectral VIS/IR
- Need mature technology & algorithms
  - SCLP & CoReH2O both suffered on radar algorithms
- Satellite mission must avoid high cost
  - Leverage existing assets (satellite PM & multispectral)
  - But some satellite assets might go away (PM?)
- International partnering is the key to
  - Leveraging technology & algorithm development investments
  - Spreading costs
- Some sensors can/should be suborbital
  - E.g., Lidar on aircraft and other sensors on satellites
- Societal benefits & science return already strong

Summary

- Already many existing ESA-NASA cryo collaborations: complementary; yield enhanced science; position us well for the future
- NASA Cryospheric Sciences Program very open to continue & to enhance these plus develop new future collaborations
- NASA THP very open to collaborative efforts, particularly to mature snow sensing techniques
- Int'l Snow RS Working Group seeks to strengthen collaborations among its int'l membership, to mature multisensor snow sensing, and be ready for snow mission opportunities
- Airborne multisensor snow studies are strongly needed over all snow types, forests, etc.
- NASA wants global snow observing (frequently, too!) and is eager to work with others toward this goal