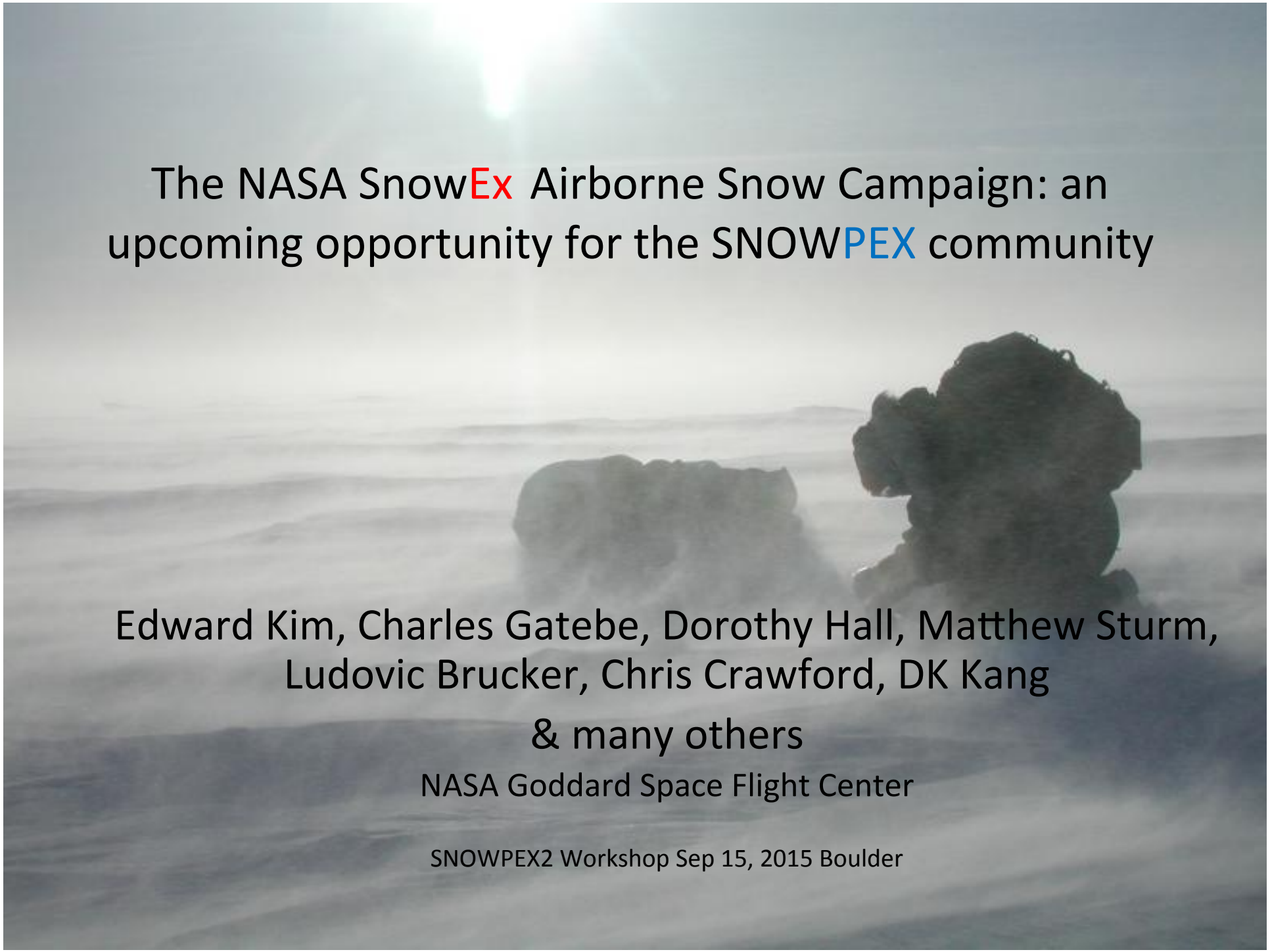


The NASA SnowEx Airborne Snow Campaign: an upcoming opportunity for the SNOWPEX community

Edward Kim, Charles Gatebe, Dorothy Hall, Matthew Sturm, Ludovic Brucker, Chris Crawford, DK Kang

& many others

NASA Goddard Space Flight Center

SNOWPEX2 Workshop Sep 15, 2015 Boulder

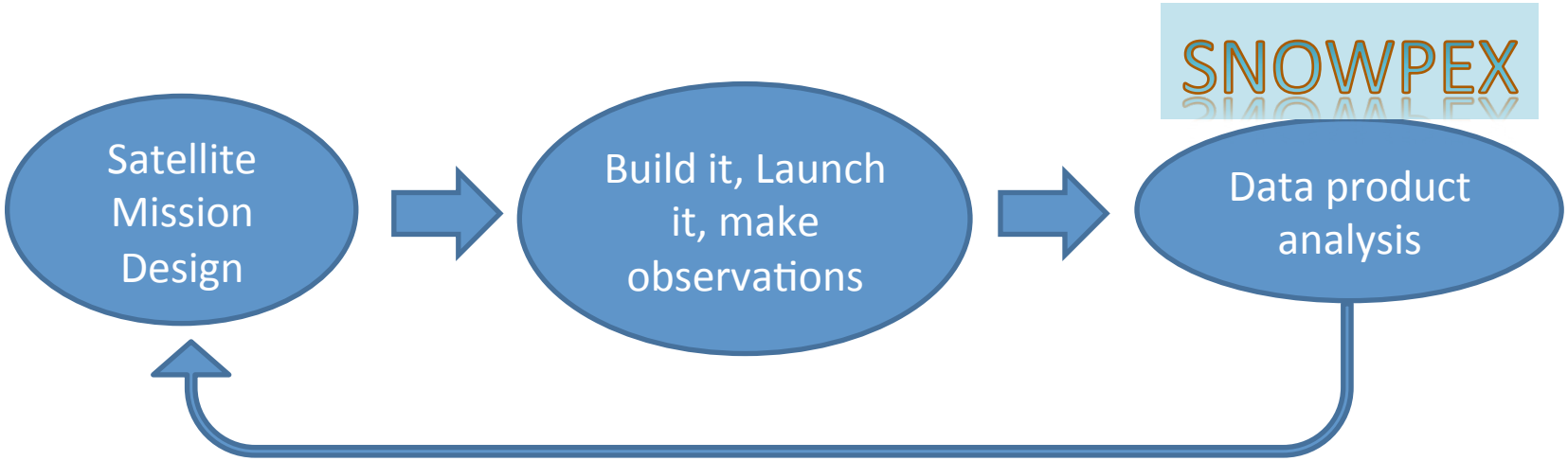
The snow RS community speaks

- Recent snow remote sensing community consensus has been reached 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 for mission design, so…
- …the NASA Terrestrial Hydrology Program has stepped up to provide us with an opportunity to address the lack of multi-sensor data (not fully, but a huge start)

Goal of SnowEx

- So a snow satellite mission would ideally include multiple sensors:
  - Passive & active optical
  - Passive & active microwave
  - Plus modeling
- That's expensive; the only way to make it practical is to be prepared to make trades
- Snow mission design trade studies will require multi-sensor obs w/ground truth…
- …which we do not currently have!
- SnowEx is being designed to collect multi-sensor obs to populate a mission concept tradespace

SNOWPEX-style analysis is not the end!



Background

Since 2002, there have been multiple attempts by the snow remote sensing community to get a snow mission

- Satellite missions
  - CoreH2O (ESA)
  - EX-7 -> CLPP -> SCLP (NASA)
- Airborne missions
  - Venture class round 1 (2009) 1 proposal (NASA)
  - Venture class round 2 (2014) 2 proposals (NASA)

Outcome: None were selected

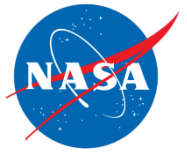
Motivation

- One definition of insanity is…to try the same thing again & again and expect a different result
- If we try again without addressing major weaknesses (perceived by reviewers), we should not expect a different outcome
- Something must change if we ever want to see a snow mission

We need a new approach

Instead of the old way of focusing on types of snow or a particular snow application (like water resources), what would happen if we asked "can we identify an issue X, that if progress were made on issue X, we would address a common/repeated weakness of recent mission proposals?"

Convergence?

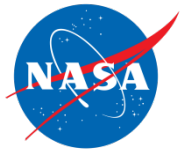


- Reviewers of 3 of the 4 unsuccessful mission proposals identified the lack of retrievals in forests as an issue
- Forested areas cover a large part of the snow covered world
- So far, we've avoided forests because all 'traditional' techniques have issues there
  - But new techniques (lidar) appear to offer significant progress to retrieve snow in forests
  - Other new techniques might also change the game to permit limited forest retrievals

What space agencies want

- ESA & NASA are in the satellite business, so a snow satellite mission is the goal (but NASA says an airborne *component* is not ruled out)
- A NASA snow satellite mission needs to be global—a mission that only addresses snow in a limited domain does not meet this requirement

Top level questions for SNOWPEX



- Has the SNOWPEX community identified gaps in the understanding of snow remote sensing techniques that would help reduce SNOWPEX uncertainties?
  - Sensing in complex pixels (forest, topography)
  - Spatial scaling (mixed pixels)
- Would specific studies/field measurements help resolve gaps in understanding?
- Can SnowEx be leveraged to address such issues?
- One obvious next step for SNOWPEX is multi-sensor blended analyses that would inform us where & when to use which combination of sensors to best retrieve snow

The SnowEx white paper

- A 3-page white paper was distributed prior to the July 16, 2015 SnowEx workshop (copies available)
- Following the "different approach" theme, the proposed focus: snow in forested areas
- "forest" doesn't mean 100% canopy fill or opaque forest; real forests have gaps, and sensors can see through the gaps
  - Clever new approaches might open up limited retrievals in "forests"
  - "forest" is actually a continuum from 0% trees to 100% filled
- A future snow mission doesn't need to retrieve snow everywhere in all conditions, but it should do better than today's sensors (e.g, those used by SNOWPEX)

Basic components

Like any well-designed remote sensing field campaign, there are 3 key components

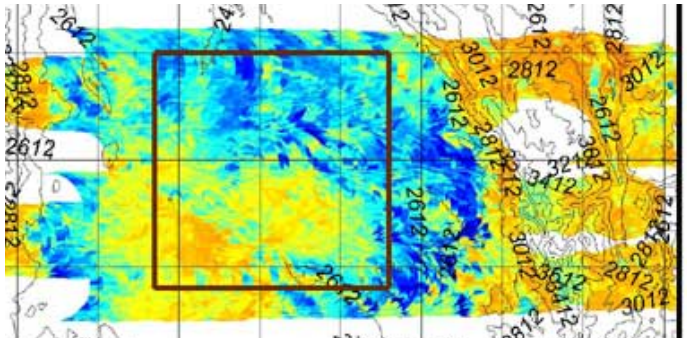
- Remote sensing obs
- Ground truth
- Modeling

Caveat statement:

- All information here is notional
- SnowEx is still being defined

Airborne campaigns

- Community consensus that multisensor snow campaigns with ground truth are needed to move forward
- Last highly multi-sensor snow campaign was 2002-2003 CLPX
  - Major step forward
  - Enabled a decade of snow remote sensing advances
- Dedicated snow campaigns are few
  - Partial 2013 support for ESA SnowSAR in Canada & Alaska
  - Partial ASO support, but addressing *global multisensor* snow requires new steps
  - Multisensor snow IIP campaigns 2015-16; radar, lidar, PM; but limited spatial scope



Airborne Multisensor Snow RS Activities

- Some examples of multisensor snow observations projects in North America.
- Not a complete list. Not all sensors flown simultaneously.
- Based on late 2014 info

	CLPX-1	CLPX-2	Envir. Canada	ASO	Snow Net	Snow IIP	Ice Bridge	Snow Ex
years	2002-2003	2007-2008	1990s?--now	2012--	2008-2014?	2015-2016	1990s-2017	2016-2019
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

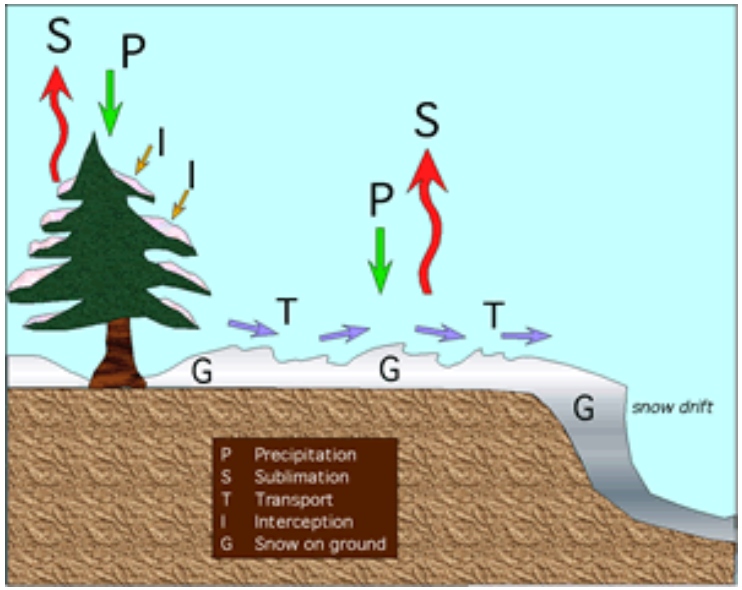
Field (ground truth) measurements

Field measurements are a key need

- At point/local scale to improve/validate remote sensing techniques under controlled conditions
- At watershed scale (multiple satellite footprints) for testing retrieval algorithms at useful scales
- In areas with confounding characteristics (forests, topography), field measurements at sub-footprint scale are the best way to address scaling-related uncertainty
- Large campaigns are of very limited use without good ground truth. Ground truth over large areas is rarely collected.

Land modeling, data assimilation

- DA is a way to integrate remote & in situ obs
- Strong interest from global modeling community for more accurate SWE info
- Both NWP & seasonal forecast communities recognize their weaknesses with respect to snow predictions
- Climate community also needs obs with as much space/time consistency as possible
- All the above need global snow observations
- Attempts to assimilate existing global SWE *products* like AMSR-E do not yield significant improvement
- Validation of model output is a key challenge; better validation data sources would be a significant improvement



when

- Year 0 = 2015/16 N.Hemisphere winter
- Year 1 = 2016/17
- Year 2 = 2017/18
- Year 3 = 2018/19

- Can be slipped later if really necessary

Where, when, what measurements?

- Discussions are in progress
- Are there "lessons learned" from SNOWPEX that should be incorporated into choices?
- This is *the* perfect time to provide input

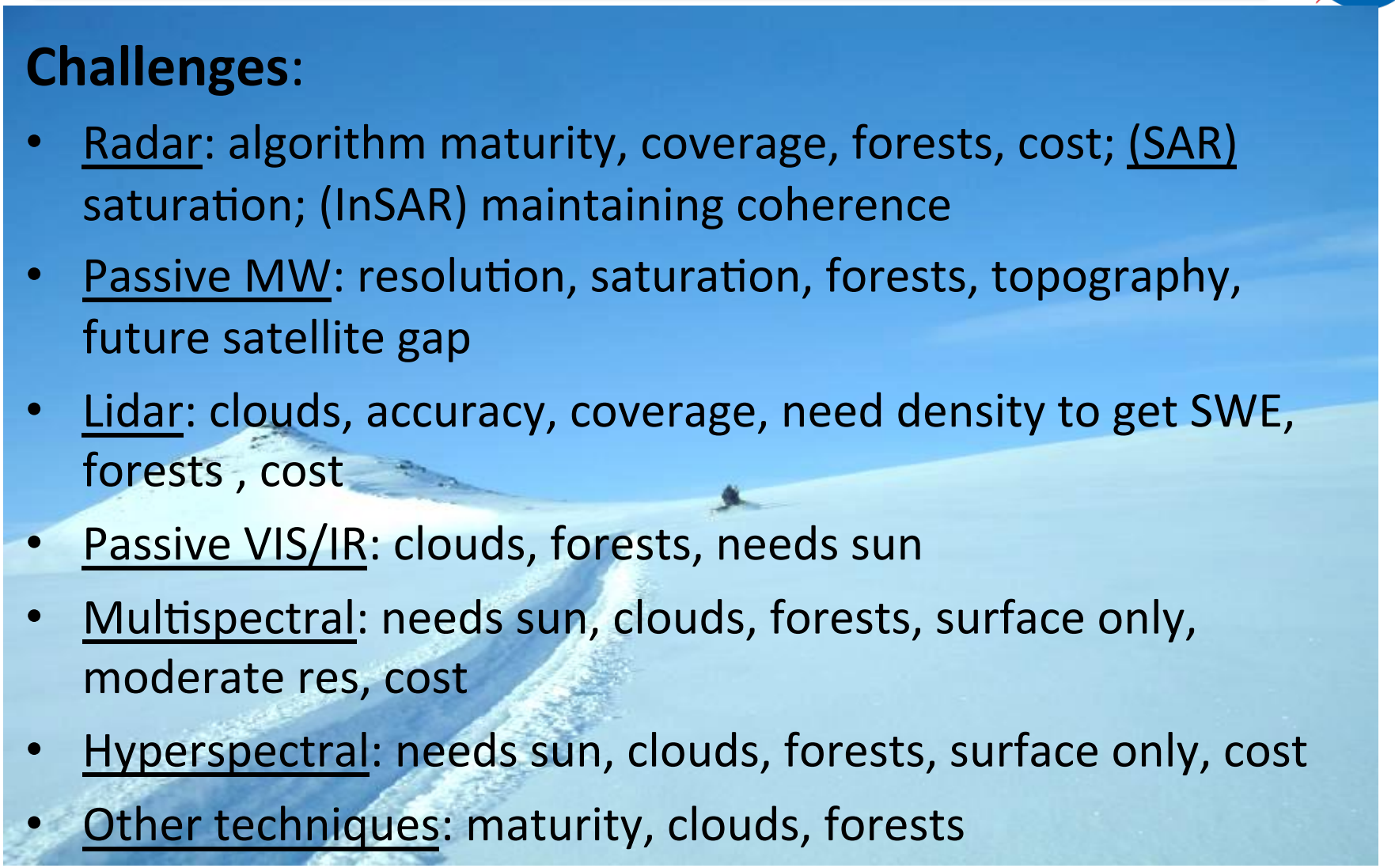
  - Depth, extent, SWE, SCF, wetness, microstructure?
  - Snow types, confounding factors
  - time of year, temporal extent, temporal resolution
  - location, spatial extent, spatial resolution
  - Accuracy, precision, uncertainty
  - What ancillary data?
  - What about ephemeral snow?

Rem. Sensing techniques for global snow

Advantages/Strengths:

- Radar: (SAR & InSAR) 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
- Passive VIS/IR: long record, global coverage exists, decent resolution, can provide albedo (even BRDF from aircraft)
- Multispectral: MODIS/VIIRS exist, fSCA, albedo, grain size, moderate spatial res
- Hyperspectral: fSCA, albedo, surf grain size, mod/high spatial res
- Other techniques: structure for motion & others

Rem. Sensing techniques for global snow



Challenges:

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

Future Snow Mission Opportunities

- US 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 International Space Station in 2018
  - Latitude limit ~57 degrees
- NASA IceSAT2 (lidar)
  - Launch 2018
- China WCOM water cycle mission
  - Launch 2020?
- NASA Venture Class airborne missions
  - Next opportunity 2020-2024 timeframe, proposals due i years
- ESA Earth Explorer 9
  - Call expected Nov 2015
  - Preliminary concepts being explored now
  - Launch ~2027?

Summary

- SnowEx is a multi-sensor multi-year snow campaign
- Primary focus on populating an algorithm/ mission design tradespace
- Timeframe is 3 years beginning late 2016/early 2017
- Candidate sensors include passive & active VIS/IR and microwave, plus some experimental techniques
- Detailed ground truth
- Modeling to help integrate RS obs & ground truth
- Straw man design around forest
- Help design SnowEx (contact Ed Kim)
- Look for Town Hall at AGU meeting
- Join Int'l Snow Remote Sensing Working Group ("iSWGR") http://nasasnowremotesensing.gi.alaska.edu/
- SNOWPEX can inform SnowEx design & analysis