SnowEx 2017 Summary

- Focused on forest “gap” (half the snow covered world)
- Short list of sensing techniques
  - Made & used inventory of sensors
  - Huge airborne effort
- Determined site requirements
  - Made & used site inventory (still available)
- Major field effort (ground truth)
- Major GBRS effort
- LSOS site
- Installed met station network
- Mature & experimental techniques

- 3-week IOP
- ~100 participants
- Major effort on community building in preparation for future SnowExs & snow mission
- Also to train next generation
- Major logistics & safety effort
- Engaged int’l collaborators
- Public outreach, press, local community
- Stood up snow.nasa.gov website

SnowEx 2017 Airborne Sensors & Aircraft

CORE SENSORS

- **SnowSAR: X & Ku-band radar (ESA)**
- **CAR: BRDF & multispectral imager (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)**
- **ASO suite (JPL)**
  - **Lidar**
  - **Hyperspectral imager**

EXPERIMENTAL ALGORITHMS

- **UAVSAR: L-band InSAR (JPL)**
- **GLISTIN-A: Ka-band InSAR (JPL)**

Prototype sensor

- WISM: active & passive microwave (Harris Corp IIP)

Aircraft (flight days)

NRL P-3 (6)

King Air (5)

Two NASA G-IIIs (4,3)

Twin Otter (3)

SnowEx 2017 Sites & Aircraft Bases

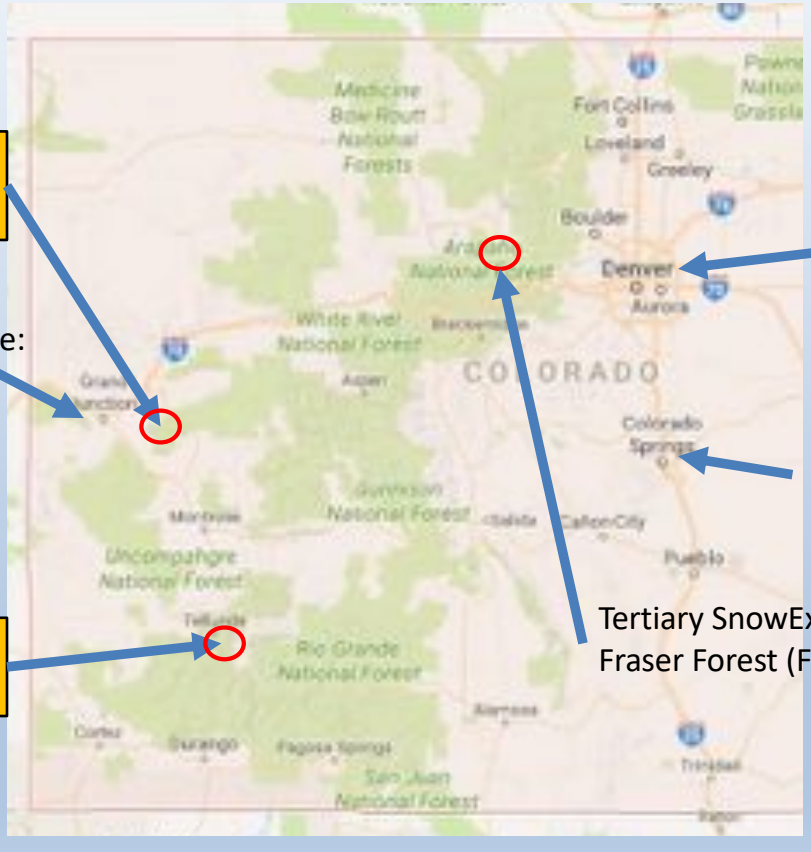
Selection based on Site requirements

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)



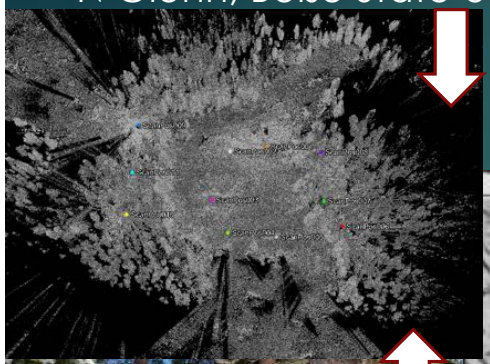
JSC G-III bases: Centennial (KAPA) & AFRC (KPMD)

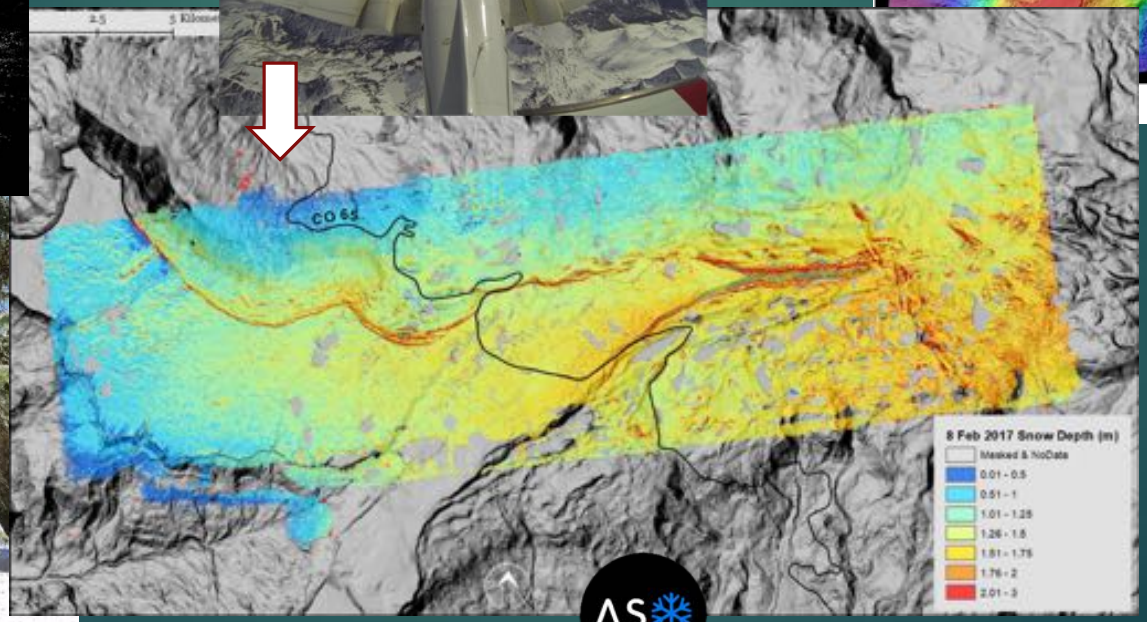
P-3 base: Peterson AFB (KCOS)

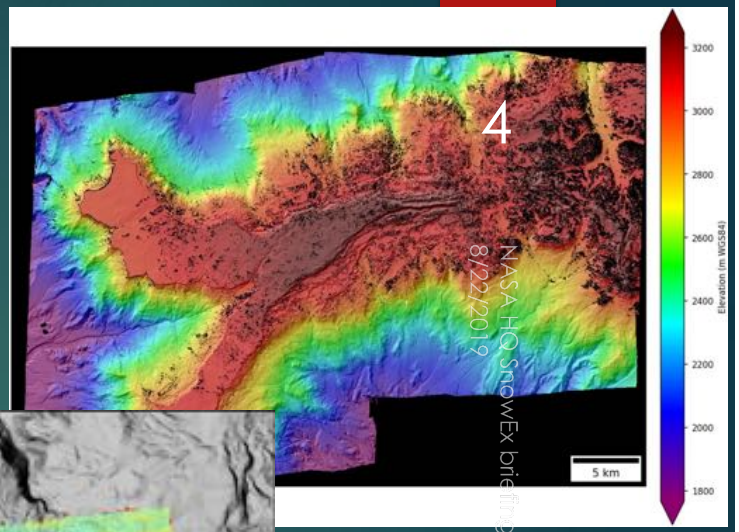
Tertiary SnowEx site: Fraser Forest (FF)

Ground, Aircraft and Satellite Remote Sensing

N Glenn, Boise State U



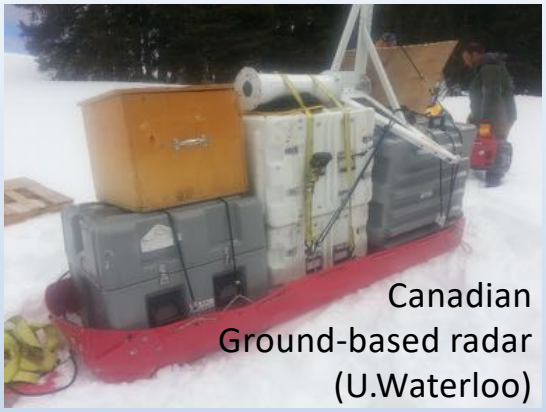




Stereo2SWE
D. Shean,
U Washington

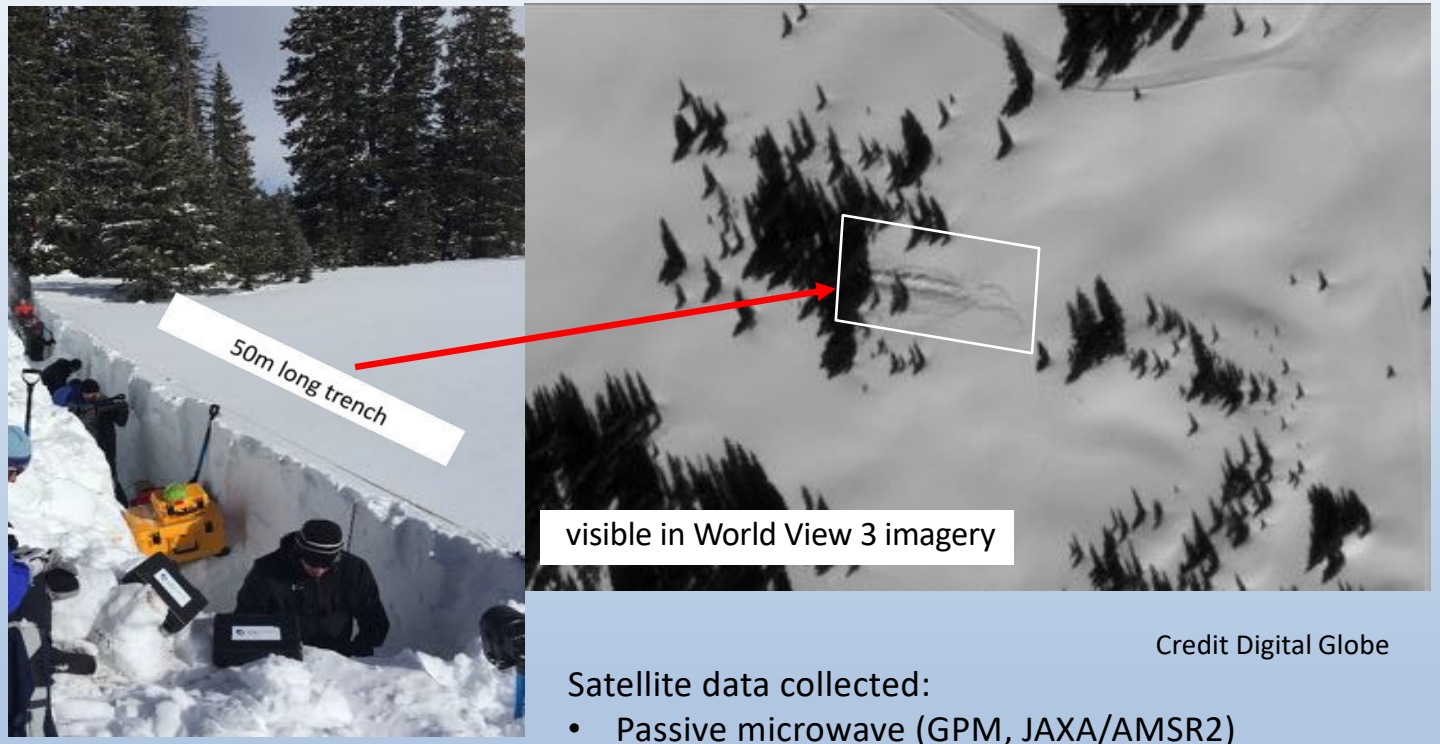
From Hiemstra, Brucker, Marshall, & Elder

Ground-base remote sensors on…



Sled towed by snowmobile (U. de Sherbrooke)

SnowEx 2017 was visible from space !



Credit Digital Globe

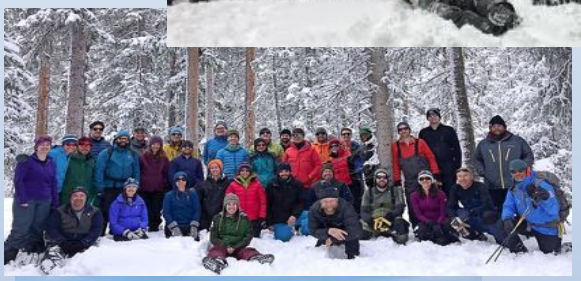
Satellite data collected:

- Passive microwave (GPM, JAXA/AMSR2)
- VIS/IR (MODIS, VIIRS, Landsat)
- SAR (Sentinel-1); radar (GPM)
- High-res optical (World View, etc)

Engaging the Snow Community

The offer:
folks who could commit a week of time were welcome to participate.

The response:
40-50 people
x 3 weeks; total
~100 participants
(13 international)



The previous
Snow Community
campaign had been
15 years back
(CLPX-1 in 2002-03)

So, community building
was a major component
of SnowEx 2017

SnowEx 2017 Results

New results keep coming in…

Very intriguing…already providing insight into snow mission options

See the 30+ posters!

Can’t wait to see what we’ll have after more SnowExs

SnowEx Motivation

- **A successful SWE satellite concept needs robust algorithms**
  - Past concepts' algorithms were judged to have insufficient maturity
  - In part, this resulted from a single-sensor approach to a complex target
- **Many sensing techniques are sensitive to snow variables**
  - SWE: passive microwave, SAR, InSAR, active-passive microwave
  - Snow depth: lidar, passive microwave, InSAR, Structure-from-Motion
  - SCA: VIS/IR, passive microwave, multispectral, hyperspectral
  - Albedo: VIS/IR, multispectral, hyperspectral

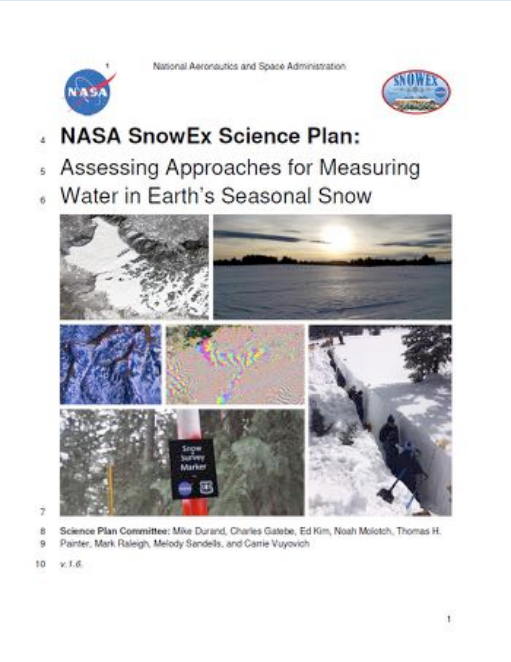
BUT: No single sensing technique works across all types of snow and confounding factors

- **The challenges of snow mass (SWE) retrieval include**
  - Forests (half the snow-covered world)
  - Wet snow, deep snow, shallow snow
  - Complex terrain
  - Layering inside snowpacks. Metamorphism; Needing density to convert depth to SWE
  - Clouds, atmospheric propagation
  - Retrievals that require ancillary data that is difficult to obtain

We need multi-sensor data to perform mission concept trade studies ⇨ SnowEx

Science & Implementation Plans

- THP16 group was charged with generating a Science Plan and Implementation Plans
- SnowEx Science Plan
  - Defines and articulates **gaps** in SWE retrieval capability
    1. Forest snow
    2. Mountain snow
    3. Tundra snow
    4. Prairie snow
    5. Maritime snow
    6. Snow surface energetics
    7. Wet snow
  - Lists sensing techniques, categories, & priorities


National Aeronautics and Space Administration

NASA SnowEx Science Plan:
Assessing Approaches for Measuring
Water in Earth's Seasonal Snow

Science Plan Committee: Mike Durand, Charles Gatebe, Ed Kim, Noah Molotch, Thomas H. Painter, Mark Raleigh, Melody Sandells, and Carrie Vuyovich

v.1.6

https://tinyurl.com/ybshd54d

Snow depth/SWE estimation capabilities

Current capabilities from SnowEx Science Plan

Rows =
- sensing techniques
- models

Columns =
- gaps,
- snow parameters,
- space potential

Check out newer version Poster!!

		Snow Characteristic			Gap Capabilities							Space Potential		
Type	**Snow sensing/ estimation Technique**	**Snow Depth**	**SWE**	**Melt**	**High-Res**	**Wet snow**	**Deep Snow**	**Forests**	**Complex Terrain**	**Shallow Snow**	**Clouds**	**Path to Space**	**Global coverage**	**Mature Algorithm**
SWE via snow depth	Lidar[1]													
	Ka-band InSAR													
	Dual band Ku/Ka altimetry													
	Stereo Photogrammetry													
	Wideband Radiometer													
Volume scattering	Ku-band SAR													
	Passive Microwave													
Signal interferom.	L-Band InSAR													
	Signals of Opportunity													
Airborne / ground only	FMCW Radar													
	Gamma													
Modeling	Physical Modeling													
	Radiative Transfer Modeling													
	Data-driven modeling													

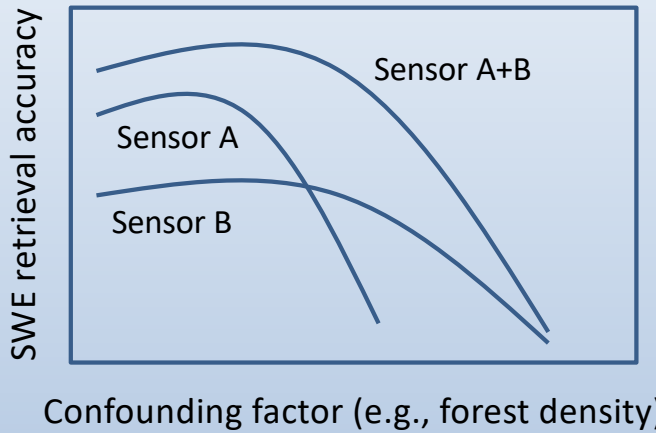
Green – Demonstrated capability. May not work in all areas, but uncertainty is understood. May still benefit from additional research and algorithm development. TRL > 5?
Yellow – Potential capability identified and validated in multiple studies. Research needed to better quantify uncertainty. TRL 3-5?
Orange – Potential capability identified, but uncertainty not quantified. High risk. TRL 1-2?
Red – No Capability

SnowEx at a Glance

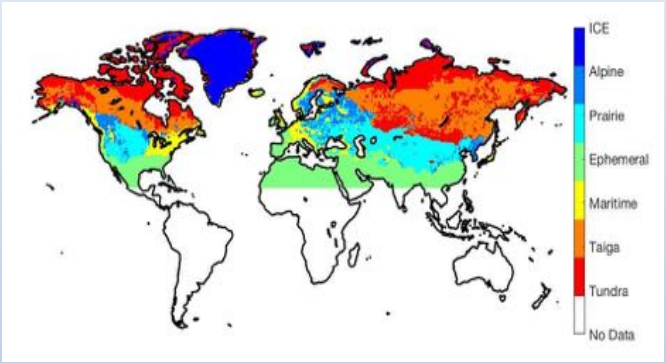
- SnowEx 2017
  - Feb 2017; Western Colorado;
  - Focused on forest gap
  - Community-building was a major goal
- SnowEx 2019 has become SnowEx 2020 (gov't shutdown)
  - Time series over the winter; western US
  - IOP on Grand Mesa
  - Addresses multiple gaps in Science Plan
- SnowEx 2021, 2022, 2023
  - Planning in progress by steering group (THP16 + THP17 selectees + Center reps)
  - Guided by SnowEx Science Plan ("gaps")

What we need from SnowEx

SnowEx Expected Outcomes:
Quantified SWE retrieval performance



SWE retrieval performance map
in snow mission proposal



(Snow classes from Sturm et al, 1995)

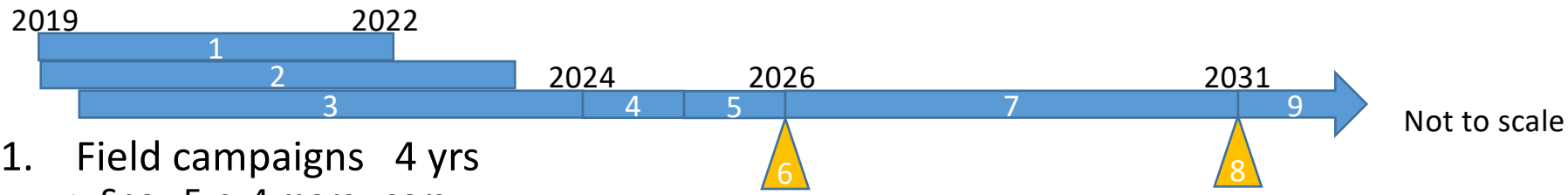
SnowEx is how we obtain input data for mission concept trade studies

- Which sensing techniques work how well for different snow types and under different confounding factors?
- The trade space should span the sensors, snow types, & confounding factors → SnowEx should span the same
- SnowEx 2017 focus: one confounding factor = forests (half of snow-covered land areas)

Ingredients for a winning satellite mission proposal

- Top notch science importance (why) — easy for snow
- Strong societal benefits (who cares) — easy for snow
- Mission concept (how, where, how often) — making progress
- Robust algorithms that convince reviewers (how) — needs (lots of) work
- Why now? (urgency, when) — easy for snow
- Unified community; strong team — making good progress
- Believable budget, schedule
- Mission proposals are major efforts—1 full year — clear your calendar
- Reviews are *really thorough* — as they should be for $100Ms
- Many successful examples: SMAP, Aquarius, GPM

Snow satellite mission timeline (notional)

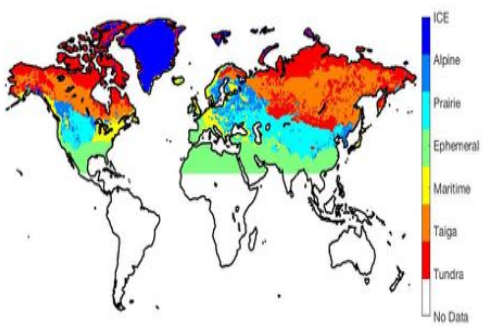


1. Field campaigns 4 yrs
   - SnowExs: 4 more years
   - Canadian campaigns?
   - Finnish campaigns: next 3 years
2. Analyze data/develop robust algorithms (coincident w/campaigns) 5-6 yrs
3. Design the mission concept (e.g., constellation components, models) ~6 yrs
4. Write the proposal 1 yr
5. Review panel/selection process 1 yr (note: timing of call not yet known)
6. Congratulations! Your mission proposal has been selected
7. Design, build, test your satellite ~5 yrs
8. Launch!
9. Groundbreaking science

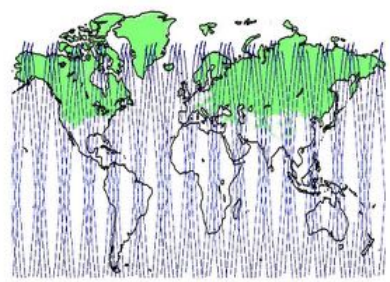
It is possible to accelerate this timeline

Ingredient: a mission concept

- No single SWE sensing technique works everywhere → combination
- Many sensors already in orbit or planned → leveraging
- No single space agency can afford the entire system → partnering
- Natural questions: what would we get from different mission configurations?
- Example: snow maps + orbit simulators



+



	1 day	3 day	30 day
AMSR-2	98.3%	99.8%	99.8%
Sentinel-1	24.7%	59.9%	92.2%
ICESat2*	0% / 1.1%	0% / 3.2%	1.4% / 20.4%
Wide swath LIDAR	5.7%	15.8%	49.2%

Average percentage of sensor-observed snow coverage

Snow Mission Context & Background

Previous/current attempts to get a snow satellite mission & opportunities

- US: Decadal Survey 1—"DS1" (2007)
  - Tier 1,2,3 missions; SWE ("CLPP") in Tier 3
- US: Decadal Survey 2—"DS2" (2017)
  - Mission categories (not a complete list)
    - Designated ≈Tier 1 = guaranteed missions; albedo (including snow) is in this category
    - Explorer ≈Tier 2 = 7 measurements vying for 3 mission slots; SWE is in this category
    - Our competition = the other 6 potential Explorer missions
- ESA: COREH2O, EE10
- Canada (TSMM), China (WCOM)
- Examples of what a global mission enables: Aquarius, SMAP, GPM
- Global snow products (cover, depth, SWE) already exist (IMS, GlobSnow, NWP, AMSRx), so a snow mission would be an *improvement* rather than a totally new product

"Surface Biology & Geology " Mission

"Snow Depth & SWE" Mission