Toward Global Snow from Space: Coverage of Snow Observation Constellation Configurations

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Outline

- Global snow mission background
- Which sensing technique?
- How to leverage existing/planned sensors
- Spatial/Temporal coverage results
- Role of SnowEx
- Next steps
- Upcoming activities

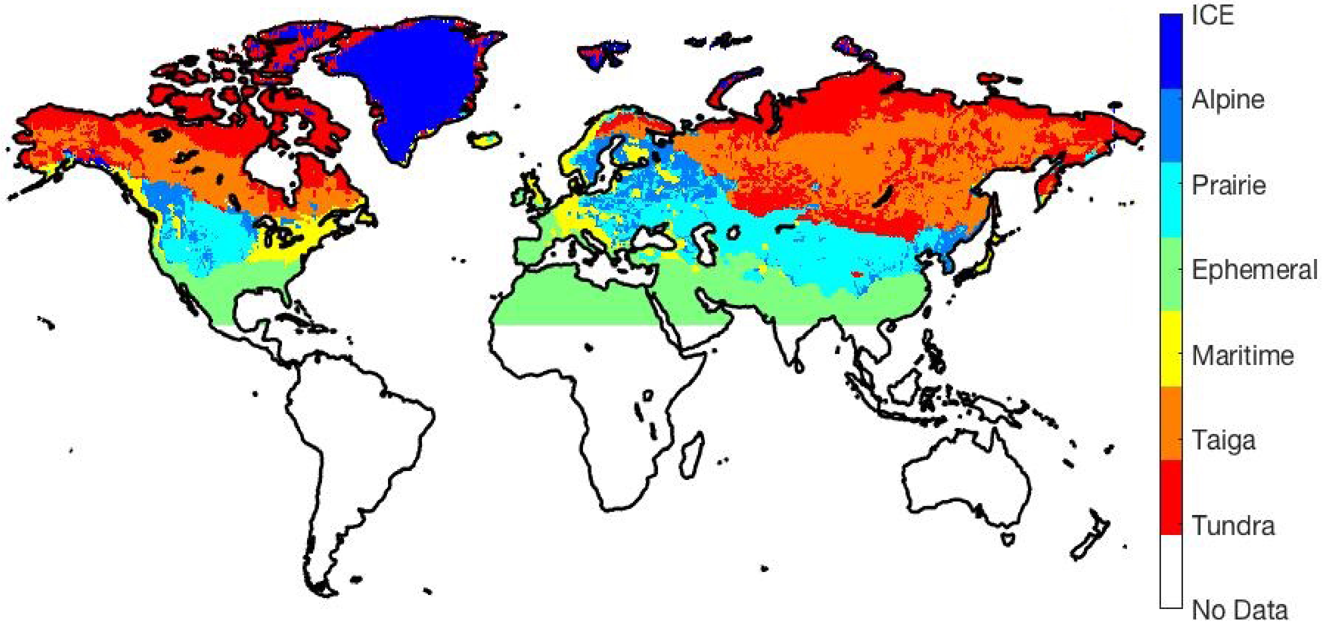
A Satellite Mission for Global Snow

- Recognition that seasonal snow water equivalent (SWE) is a key piece of the global terrestrial water cycle that is poorly quantified
- Recognition of societal impacts (water resources, natural hazards, etc)
- But what should a snow satellite mission look like?
- Many proposed answers over the years
  - A snow satellite mission appears in NASA Earth observing system studies at least as far back as 2002→ CLPP & 1st Decadal Survey
  - CoReH2O, EE10, CSA, WCOM, 2nd Decadal Survey
  - Plus operational/model-based snow products: GlobSnow, IMS, AMSR-E/2, NWP, reanalyses

So why aren't we already "done"?

- All the concepts, models, & products have significant limitations with respect to producing global SWE
- We need more accurate global observations to achieve global SWE
- None of the satellite concepts has been launched, and only one has been "selected"
- Snow remote sensing and modeling are *challenging*
- Snow itself presents significant challenges--metamorphism, dry vs. wet, wide dynamic range, strong space/time variability, etc
- A long list of sensing techniques are sensitive to SWE, but all have significant limitations

SWE Retrieval Success Depends on Snow Type…



Snow classes from Sturm et al, 1995

	Tundra	Taiga	Maritime	Ephemeral	Prairie	Alpine	Ice
$\frac{Area_{class}}{Area_{land}}$	8.45%	8.89%	3.95%	18.18%	10.03%	3.43%	1.60%

…and Snow Sensing Technique

- **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

- **Each has strengths and issues when faced with the challenges of snow sensing**
  - Forests & vegetation
  - Wet snow, deep snow, shallow snow
  - Complex terrain
  - Layering inside snowpacks. Metamorphism; Needing density to convert depth to SWE
  - Clouds, atmospheric propagation
  - Retrievals that need ancillary data on snow grain size, soil moisture, soil roughness, etc

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

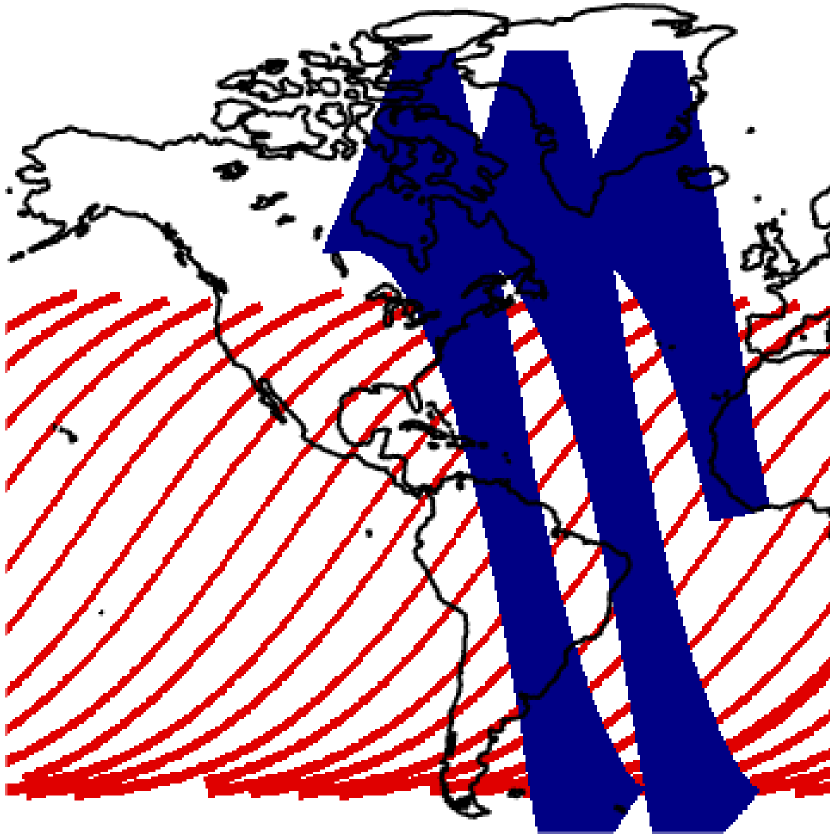
2 Types of Mission Concept Studies Needed

- Field data+ multi-sensor obs needed to construct algorithms → SnowEx
- Satellite orbit/coverage/repeat scenario trade studies → this study
  - Specifically, constellation scenarios involving different combinations of planned & existing sensors (leveraged sensors)
  - Will provide guidance on impact of potential sensors to add to the constellation→ if we add sensor X, what is the impact on global coverage, on coverage per snow class, for specific confounding factors, as a function of algorithm maturity, as a function of error bar size, etc?

What could a multi-sensor constellation do?

- For this preliminary study, focus on just 5 representative sensors
  - Passive microwave/AMSR-2/1450km .... ”PMW”
  - Ku-band SAR/TSMM/550km .... ”Ku-SAR”
  - C-band SAR/Sentinel-1A/250km .... ”C-SAR”
  - Narrow-swath lidar/ICESat2/0.06km .... ”n-LIDAR”
  - Wide-swath-lidar/hypothetical sensor/20km .... ”w-LIDAR”
- Use TAT-C tool to simulate orbits & swaths
- Simplifying assumptions (more fidelity to come later as study evolves)
  - Use Sturm (1995) snow classes
  - Nominal orbits & swath widths
  - Sensor footprints span full swath width
  - Use IMS average snow cover for February

Trade-space Analysis Tool for Constellations (TAT-C)



examples

4-hour Radiometer Viewing in Polar Orbit (Ascending Overpasses Only, e.g.)

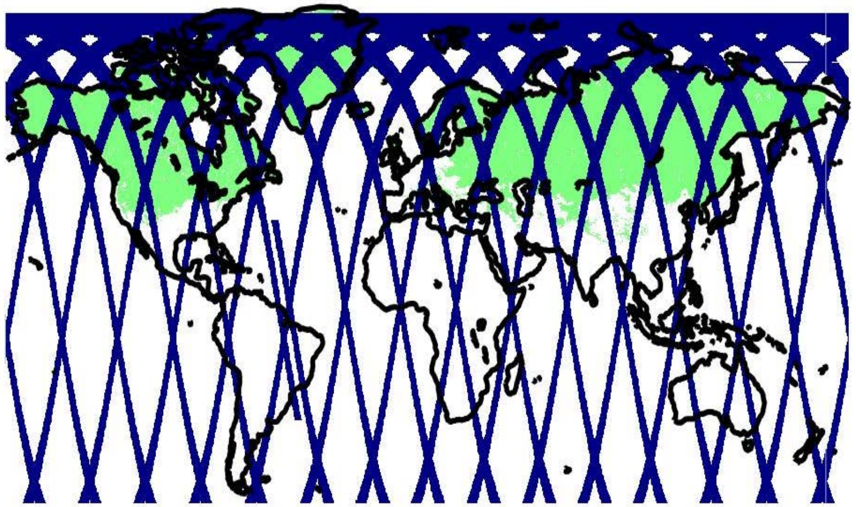
4-hour RADAR Viewing in Inclined Orbit (Descending Overpasses Only, e.g.)

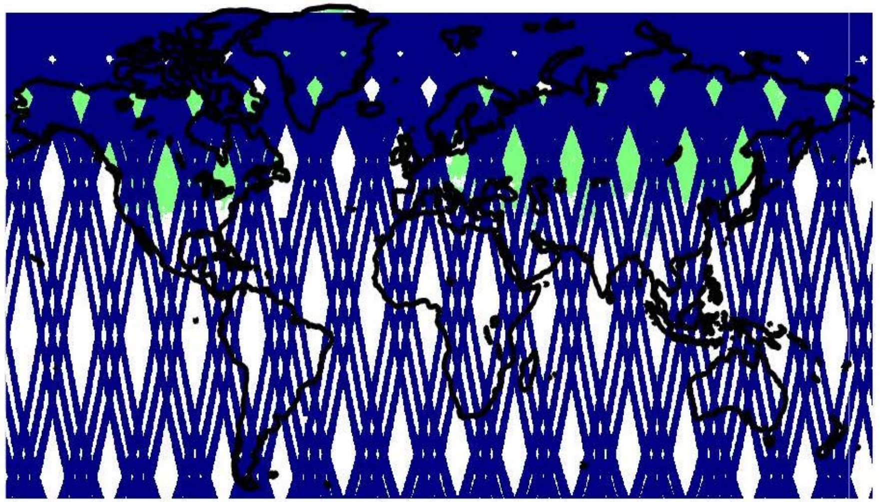
- Explore **trade-off** between engineering and science
  - Field-of-View (FOV)?
  - Platform altitude?
  - Repeat cycle?
  - Orbital configuration(s)?
  - Single platform vs. constellation?
- How do we get the most **scientific bang** for our buck?

[TAT-C will be available on the AMCDE cloud by the end of this year]

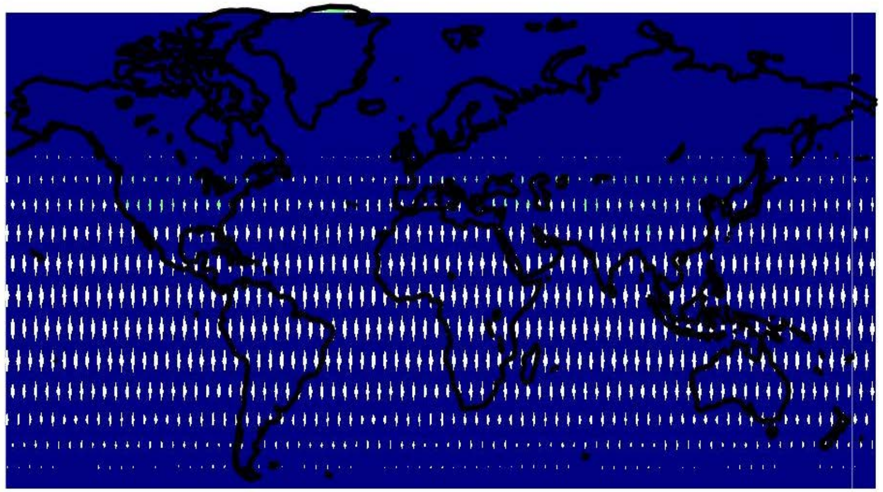
Figures courtesy of Lizhao Wang

Example of TAT-C + analysis: Sentinel 1-A

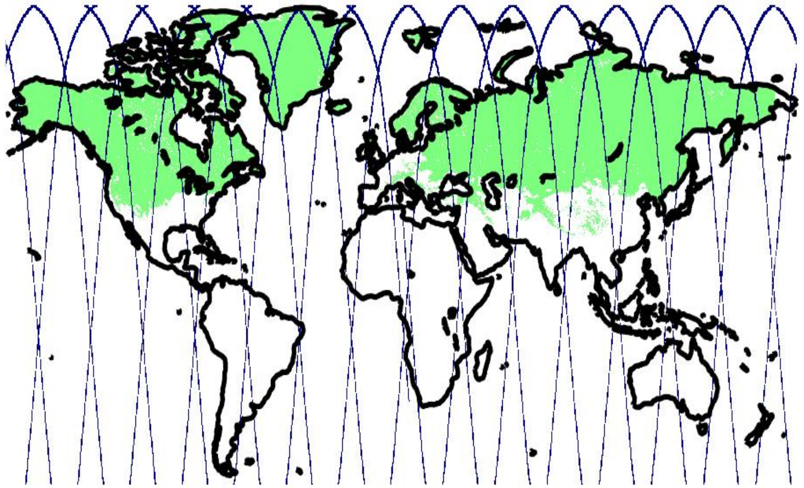


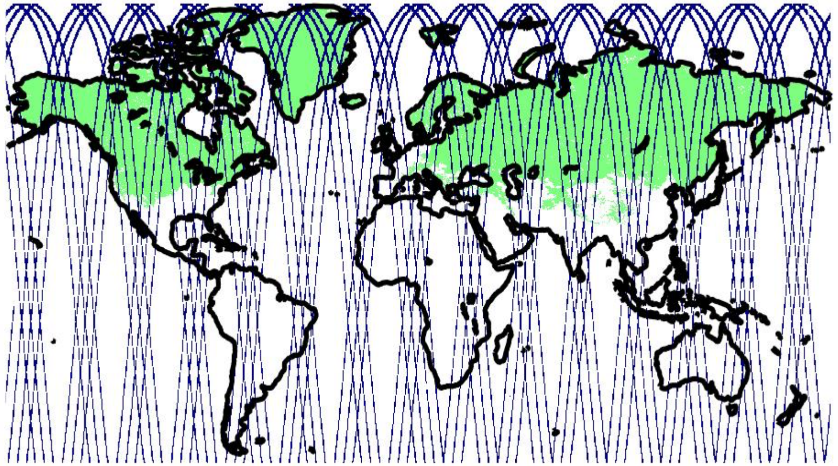


Sentinel 1-A ("C-SAR")
1, 3, 30 days' coverage

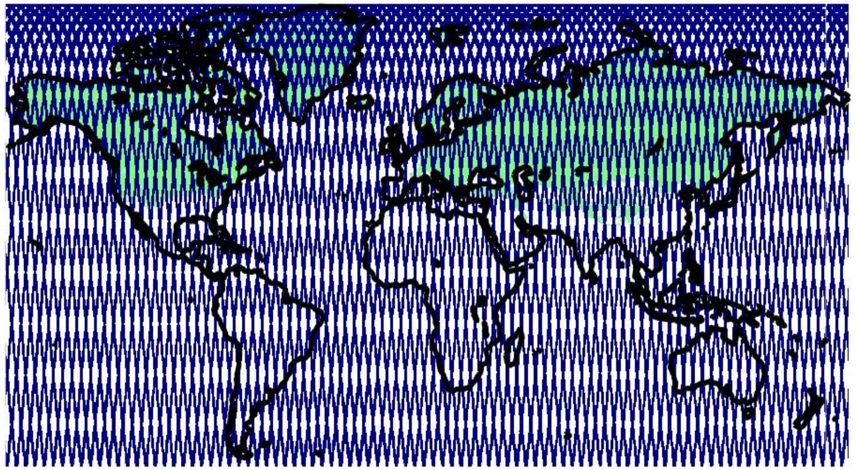


Example TAT-C + analysis: wide-swath lidar





Wide-swath lidar ("w-LIDAR")
1, 3, 30 days' coverage



Metric 1:
Average percentage of sensor-observed snow coverage

	1 day	3 day	30 day
PMW (AMSR-2)	98.3	99.8	99.8
Ku-SAR (TSMM)	68.0	97.2	98.5
C-SAR (Sentinel-1)	39.6	79.2	95.8
n-LIDAR (ICESat2*)	0 / 1.1	0 / 3.2	1.4 / 20.4
w-LIDAR (wide swath LIDAR)	5.7	15.8	49.2

*For ICESat2, the first value is calculated from its total swath width, the second value is calculated from its total footprint width.

Forest and cloud assumptions

1) Assume Passive Microwave (PMW) sensors do not work for forest (Taiga), deep snow (Maritime) and complex terrain (Alpine).
2) Assume RADAR sensors do not work for forest(Taiga).
3) Assume LIDAR sensors being affected by clouds, so only 50% of obs work.
4) Use weights below as a mask when calculating metrics.
5) Actual situation is more complex; this is just a first-order approximation.

	Tundra	Taiga	Maritime	Ephemeral	Prairie	Alpine
PMW	1	0	0	1	1	0
RADAR	1	0	1	1	1	1
LIDAR	0.5	0.5	0.5	0.5	0.5	0.5

Single Sensor Performance

Single sensor observation percentage within 3 days, weights applied.

$$*Percentage = \frac{A_{observed\_snow}}{A_{snow}} \times 100$$

	Tundra	Taiga	Maritime	Ephemeral	Prairie	Alpine
PMW Sensor (AMSR2)	100	0	0	100	100	0
Ku-Band SAR (TSMM)	99	99	0	77	90	98
C-Band SAR (Sentinel 1A)	82	83	0	64	65	76
Wide LIDAR	8	8	6	5	6	7
Narrow LIDAR (IceSAT-2)	2	1	2	0	1	2

Constellation Performance

Case 1: AMSR2 + narrow LIDAR; observation percentage

	Tundra	Taiga	Maritime	Ephemeral	Prairie	Alpine
1 Day	100	3	2	99	97	2
3 Days	100	8	6	100	100	7
30 Days	100	29	24	100	100	26

Constellation Performance

Case 2: AMSR2 + TSMM; observation percentage

	Tundra	Taiga	Maritime	Ephemeral	Prairie	Alpine
1 Day	100	0	60	100	99	59
3 Days	100	0	95	100	100	97
30 Days	100	0	98	100	100	98

Comments: Better observed over Alpine, but worse over Taiga

Constellation Performance

Case 3: AMSR2 + TSMM + Wide LIDAR; observation percentage

	Tundra	Taiga	Maritime	Ephemeral	Prairie	Alpine
1 Day	100	3	61	100	99	60
3 Days	100	8	96	100	100	97
30 Days	100	29	98	100	100	98

Comment: Improved over both Alpine and Taiga

Constellation Performance

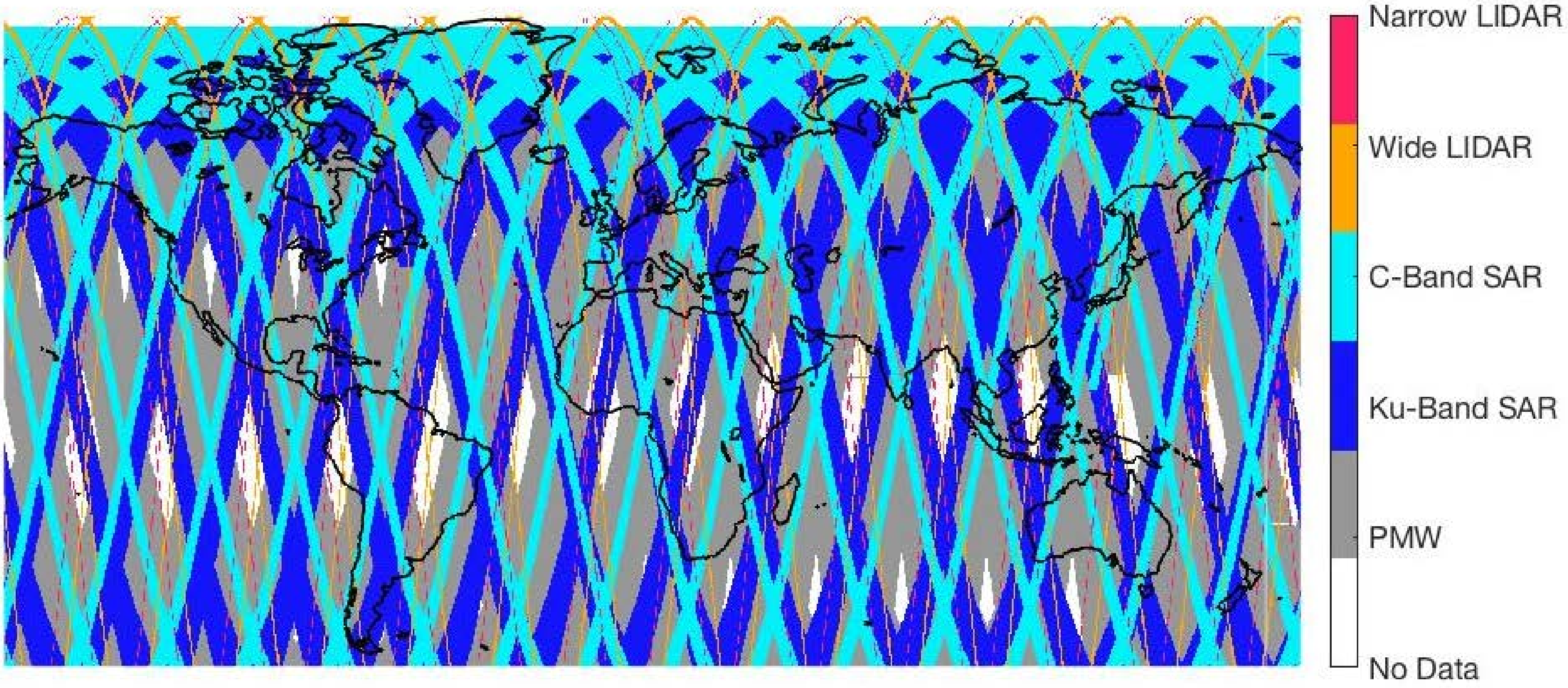
Case 4: AMSR2 + TSMM + Sentinel + Wide LIDAR + narrow LIDAR (All 5 Sensors)

observation percentage

	Tundra	Taiga	Maritime	Ephemeral	Prairie	Alpine
1 Day	100	3	73	100	99	72
3 Days	100	9	98	100	100	98
30 Days	100	41	99	100	100	99

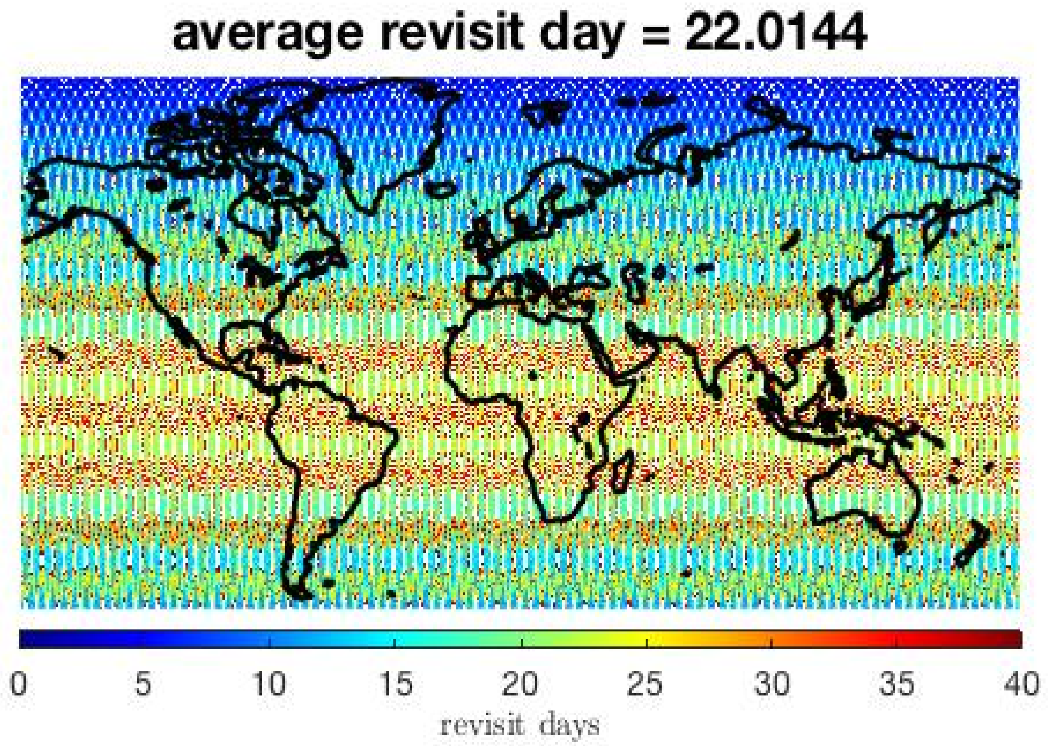
Examples of revisit interval scenarios

1 Day coverage map for different sensors

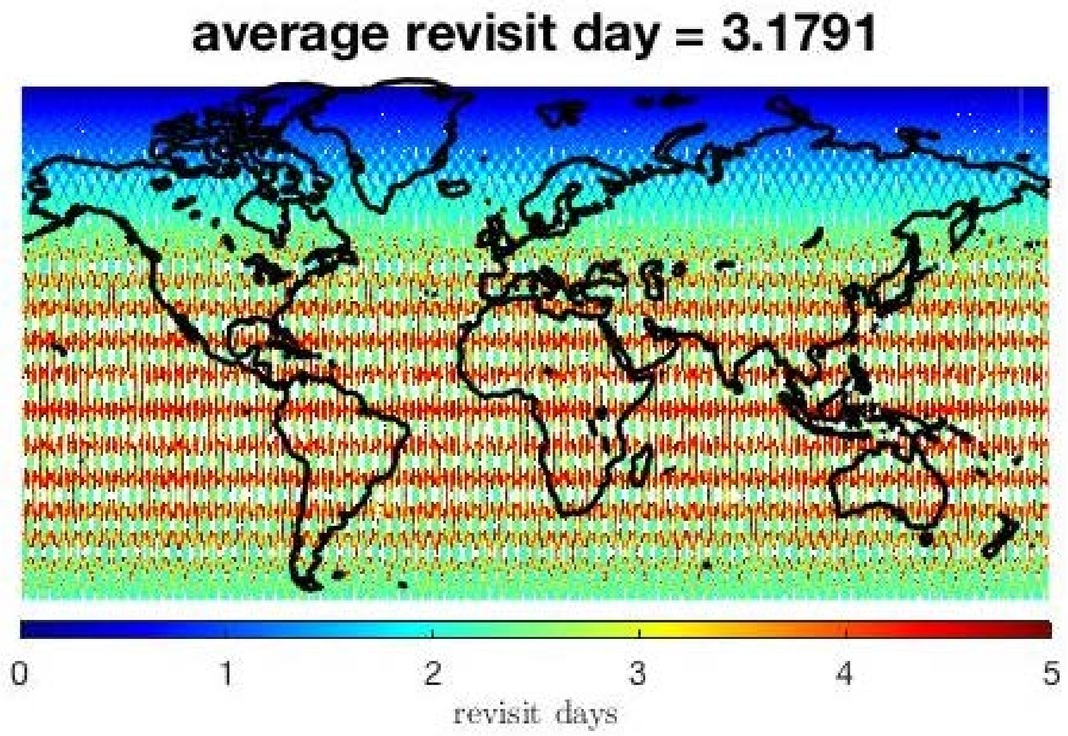


Examples of revisit interval scenarios

wide LIDAR +narrow LIDAR repeat intervals



sentinel1A + wide LIDAR repeat intervals



Metric 2: revisit intervals

Repeat intervals for single sensor (unit: days); smaller numbers --> more desirable

	Tundra	Taiga	Maritime	Ephemeral	Prairie	Alpine
AMSR2	1.2	-	-	1.6	1.5	-
TSMM	1.5	-	2.3	4.6	2.8	2.1
Sentinel 1A	2.7	-	4.3	6.2	5.4	4.0
Wide LIDAR	40	44	58	85	71	53
Narrow LIDAR	193	231	334	518	423	302

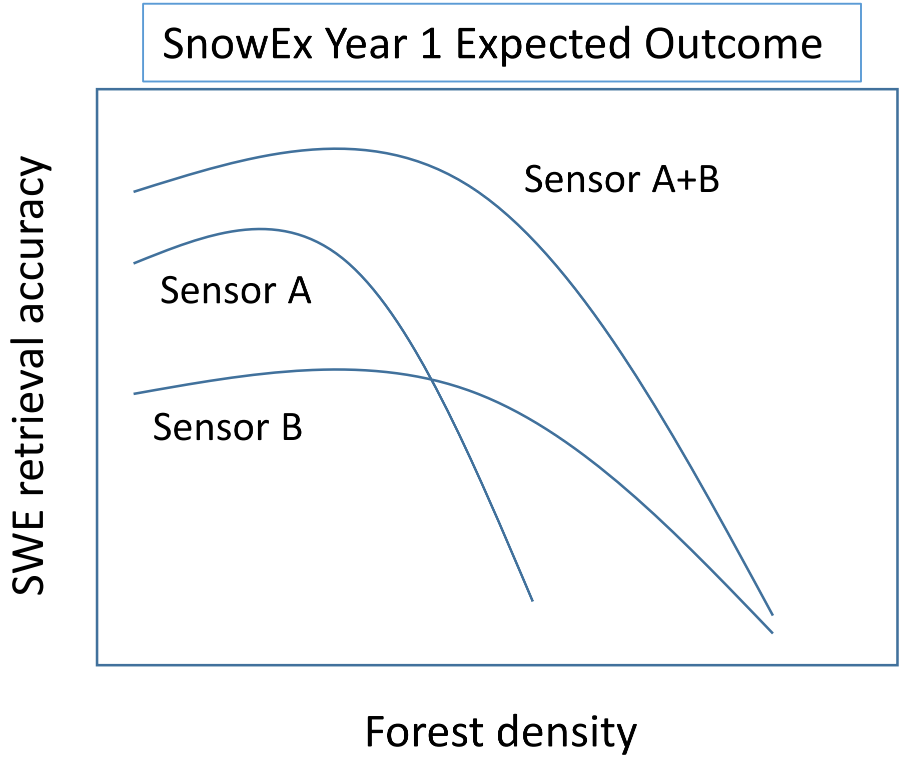
Metric 2: revisit intervals

Repeat intervals for Constellation cases (unit: days) ; smaller numbers --> more desirable

	Tundra	Taiga	Maritime	Ephemeral	Prairie	Alpine
Case1 (PMW+ n-LIDAR)	1.1	44	58	1.6	1.5	53
Case2 (PMW+ Ku-SAR)	0.7	-	2.3	1.2	1.0	2.1
Case3 (PMW+ Ku-SAR+ w-LIDAR)	0.6	44	2.2	1.2	1.0	2.0
Case4 (PMW+2SAR+2LIDAR)	0.5	37	1.5	1.0	0.8	1.3

Why SnowEx? and what we need from it

- A global snow mission should explore a multi-sensor approach
- Trade studies will be key to evaluate potential concepts
- The trade studies require multi-sensor field data (airborne + ground): SnowEx
- The trade space should span the sensors, snow types, & confounding factors



SnowEx will help provide input data for algorithms & mission concept trade studies

Next Steps

- More combinations of sensors, sensors + models
- Use higher-fidelity snow class map
- Higher-fidelity sensor observing geometries
- Repeat analyses considering additional tradespace parameters
    - spatial resolution
    - SWE retrieval accuracy
    - dry vs. wet snow
    - etc

Upcoming & Ongoing Snow Activities

- Special Issue of WRR (closed); 80+ papers
- Postponed SnowEx 2019 begins Nov 2019, ends spring 2020
- Future SnowEx (2020-21; 2021-22; 2022-23) brainstorming in progress; contact ed.kim@nasa.gov
- SnowEx workshop September 17-19, 2019; BWI airport (USA); contact Dorothy Hall; dkhall1@umd.edu (first workshop in 2017 had 90+ people)
- AGU town hall December, 2019; contact Dorothy K. Hall; dkhall1@umd.edu
- Snow field school Jan 6-9, 2020; apply by Sep 15, 2019; (USA); contact carrie.m.vuyovich@nasa.gov
- websites
  - depts.washington.edu/iswgr/
  - Snow.nasa.gov