

# 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 & 1<sup>st</sup> Decadal Survey
  - CoReH2O, EE10, CSA, WCOM, 2<sup>nd</sup> Decadal Survey
  - Plus operational/model-based snow products: GlobSnow, IMS, AMSR-E/2, NWP, reanalyses



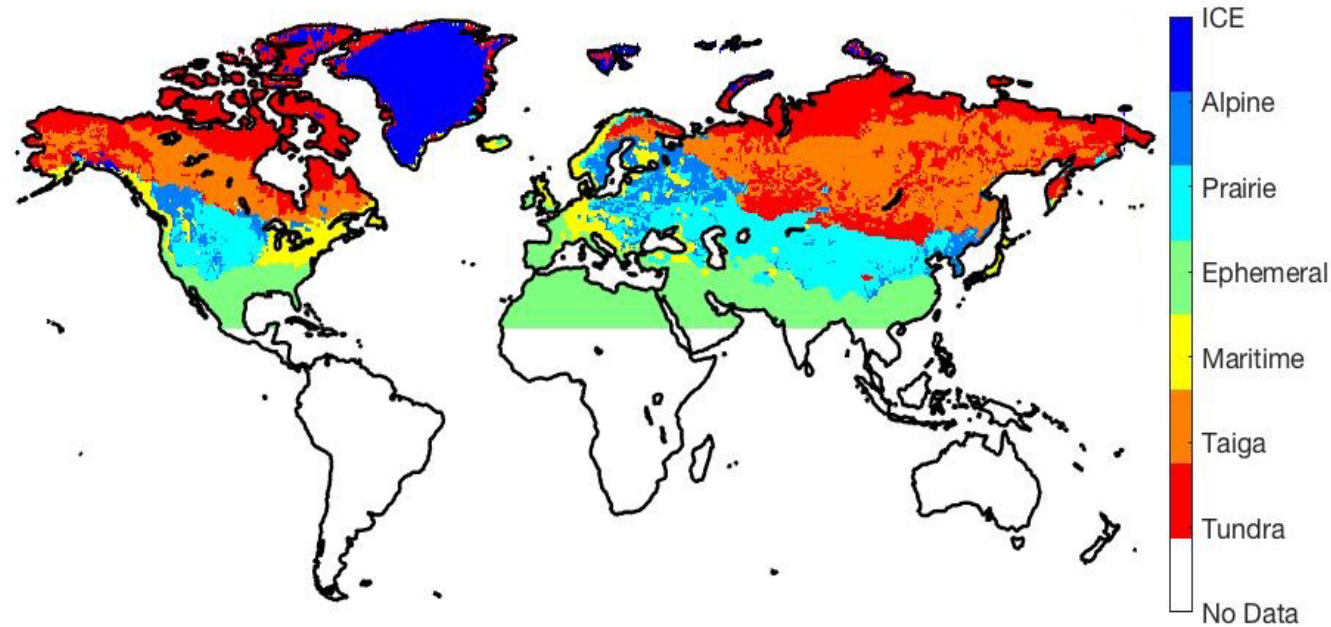
# So why aren't we already "done"?



- 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

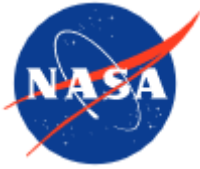


# SWE Retrieval Success Depends on Snow Type...



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?

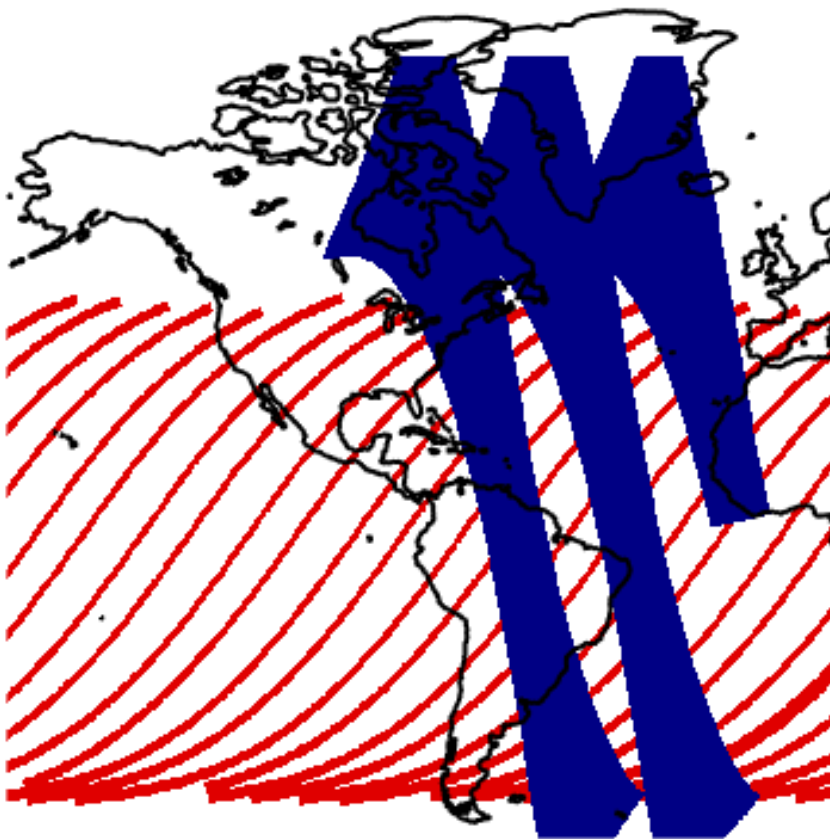


# What could a multi-sensor constellation do?



- For this preliminary study, focus on just 5 representative sensors
  - Passive microwave/AMSR-2/1450km ..... "PMW"
  - Ku-band SAR/TSM/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





examples

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

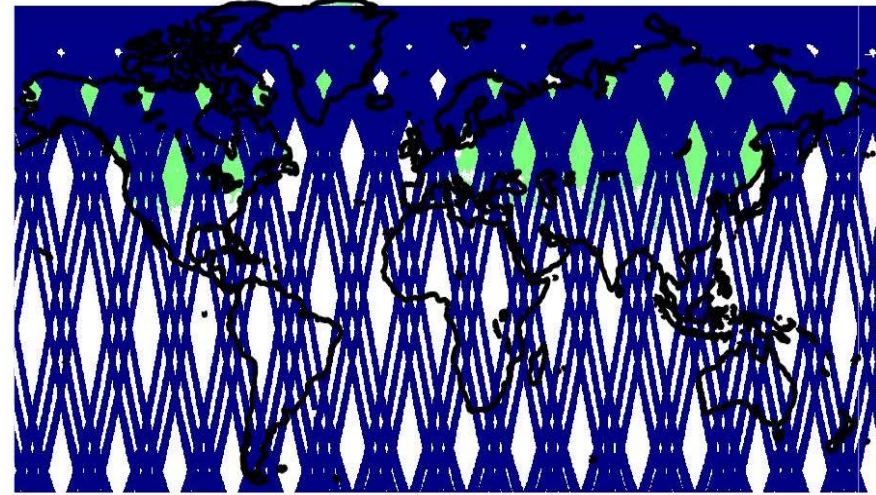
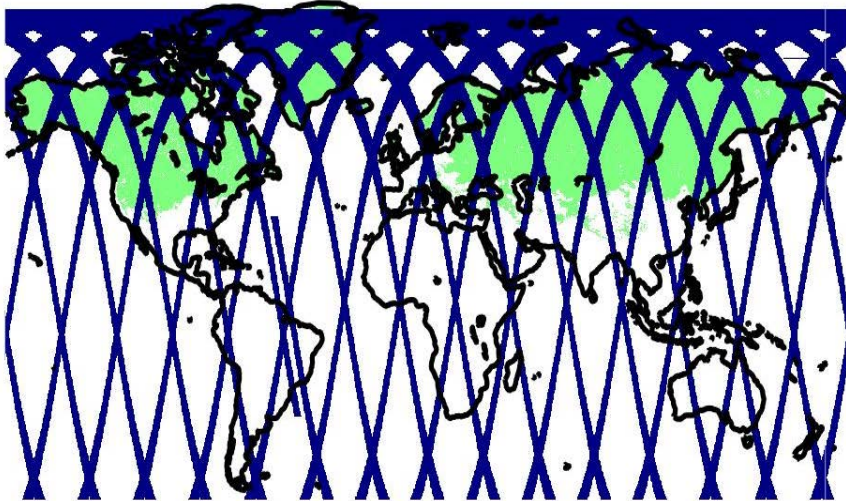
4-hour RADAR Viewing in Inclined Orbit (Descending Overpasses Only, e.g.)

- 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?

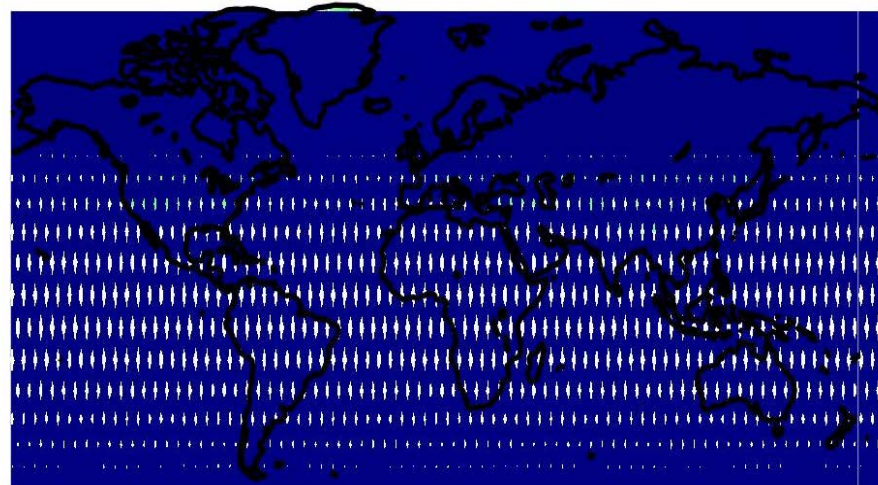
[TAT-C will be available on the AMCDE cloud by the end of this year]



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



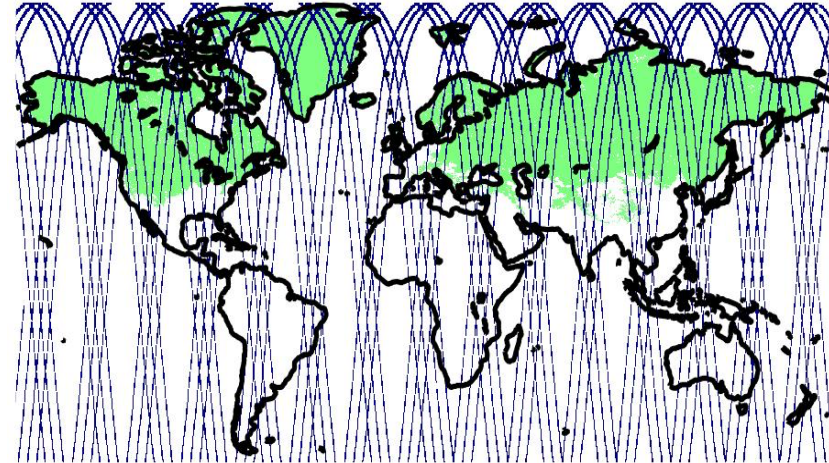
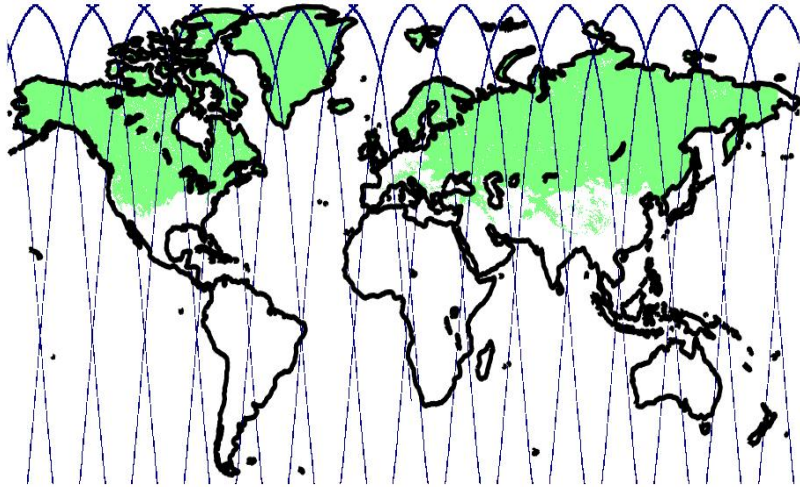
Sentinel 1-A ("C-SAR")  
1, 3, 30 days' coverage



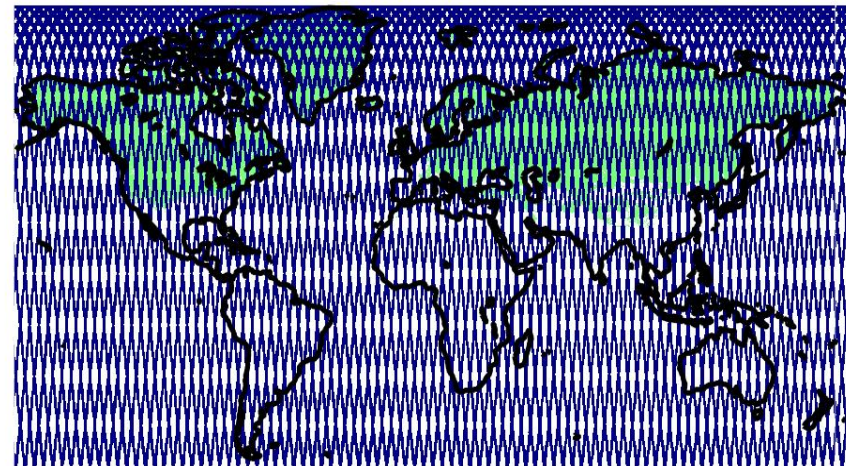




# Example TAT-C + analysis: wide-swath lidar



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 (TSM11)	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

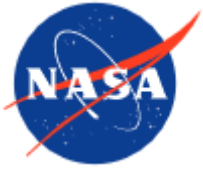


# Constellation Performance



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

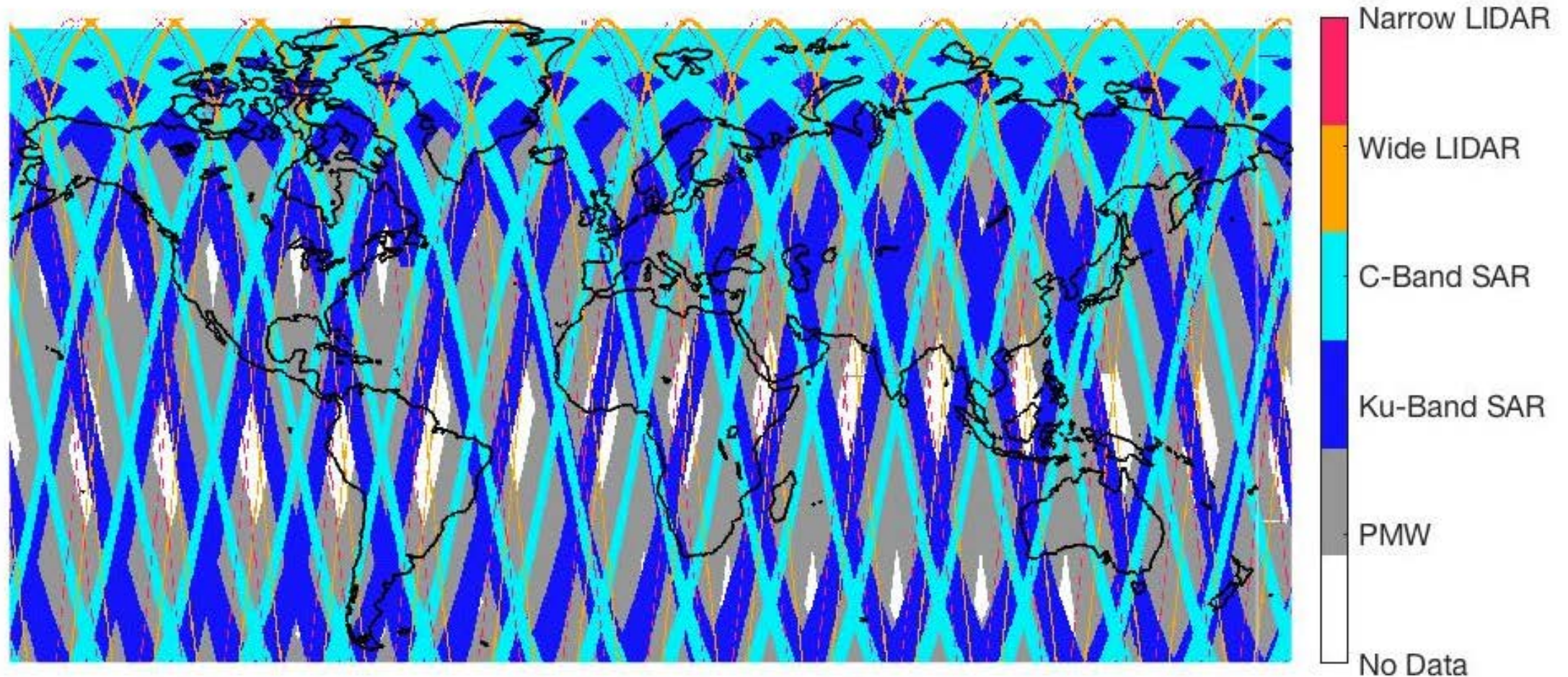
	Tundra	Taiga	Maritime	Ephemeral	Prairie	Alpine
1 Day	100	3	73	100	99	72
3 Days	100	9	98	100	100	98
30 Days	100	41	99	100	100	99



# Examples of revisit interval scenarios



1 Day coverage map for different sensors







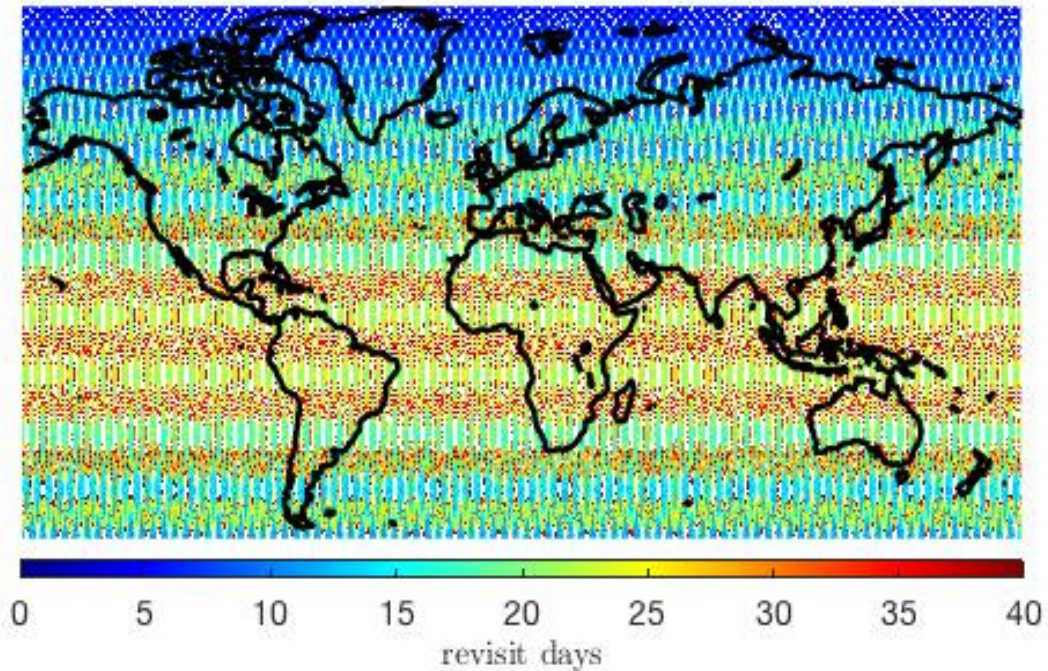
# Examples of revisit interval scenarios



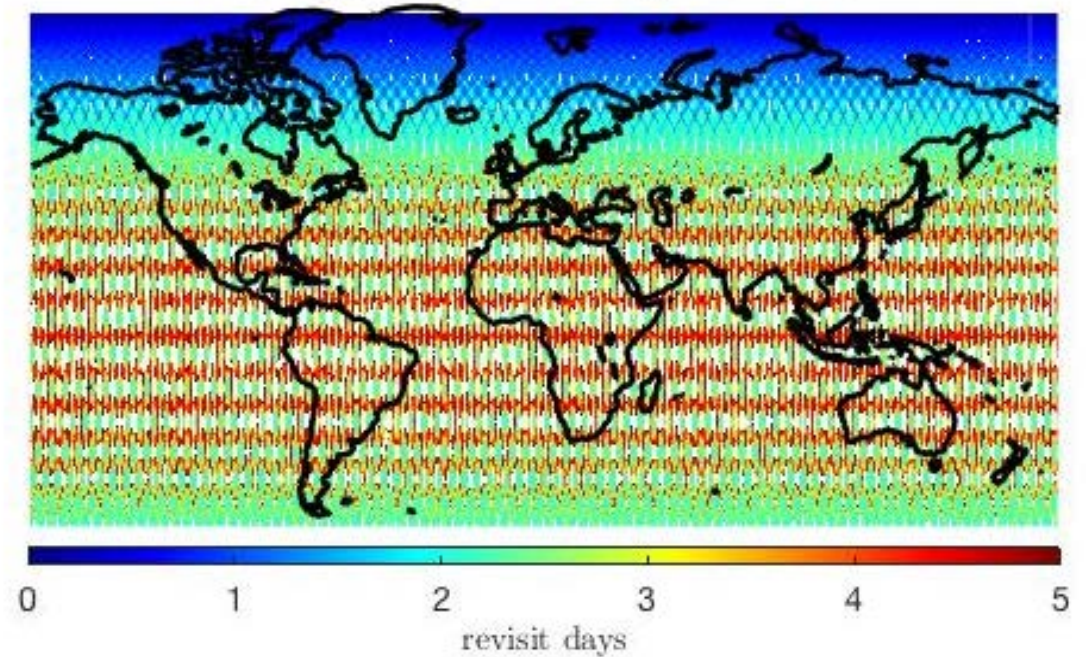
wide LIDAR + narrow LIDAR repeat intervals

sentinel1A + wide LIDAR repeat intervals

average revisit day = 22.0144



average revisit day = 3.1791





# 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

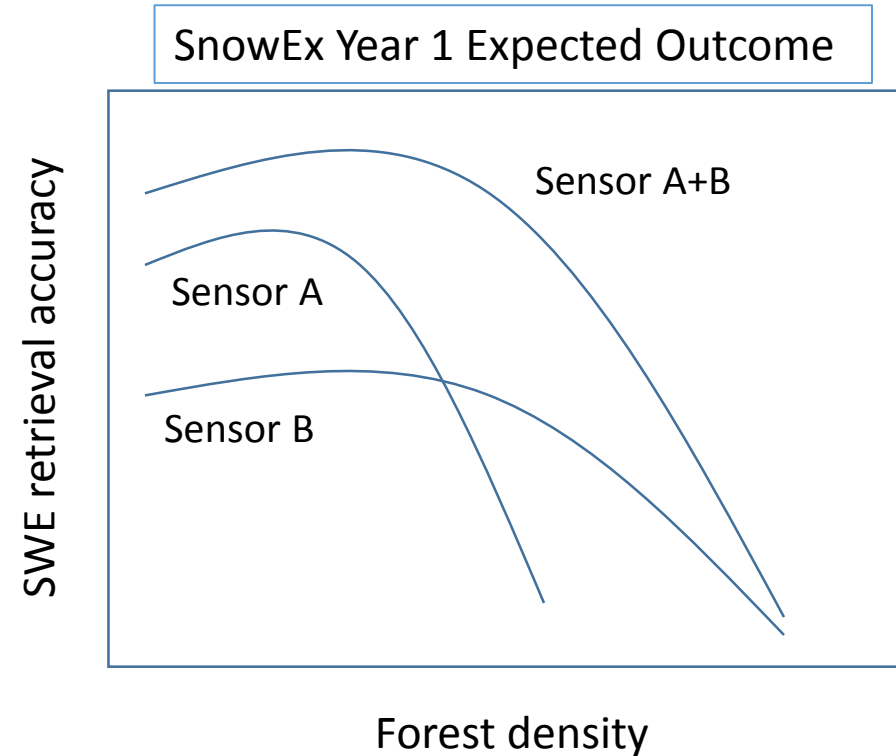
	Tundra	Taiga	Maritime	Ephemeral	Prairie	Alpine
Case1 (PMW+ n-LIDAR)	1.1	44	58	1.6	1.5	53
Case2 (PMW+ Ku-SAR)	0.7	-	2.3	1.2	1.0	2.1
Case3 (PMW+ Ku-SAR+ w-LIDAR)	0.6	44	2.2	1.2	1.0	2.0
Case4 (PMW+2SAR+2LIDAR)	0.5	37	1.5	1.0	0.8	1.3



# 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](mailto:ed.kim@nasa.gov)
- SnowEx workshop September 17-19, 2019; BWI airport (USA); contact Dorothy Hall; [dkhall1@umd.edu](mailto:dkhall1@umd.edu) (first workshop in 2017 had 90+ people)
- AGU town hall December, 2019; contact Dorothy K. Hall; [dkhall1@umd.edu](mailto:dkhall1@umd.edu)
- Snow field school Jan 6-9, 2020; apply by Sep 15, 2019; (USA); contact [carrie.m.vuyovich@nasa.gov](mailto:carrie.m.vuyovich@nasa.gov)
- websites
  - [depts.washington.edu/iswgr/](http://depts.washington.edu/iswgr/)
  - [Snow.nasa.gov](http://Snow.nasa.gov)

