NASA Community Snow Meeting

Day 2 Breakout Session I

Snow Remote Sensing & Measurement Approaches

August 15, 2024

Session Objectives, Format, and Intended Outcome

- **Objective:** Map out future directions for snow science, modeling and remote sensing. Identify areas that the snow community should focus on in the next decade to make major advances in the future, both in snow and in the broader earth science communities.
- **Format:** Breakout session by random assignment (8-10 individuals per group). In person, an early career leader is paired with senior leadership to facilitate each breakout group discussion. Remotely, one identified leader will facilitate each breakout group discussion. Each group will have access to a Google Drive folder with the breakout session guidelines, formatted summary slides (this file), and a blank Google document where group leaders can take notes.
- **Outcome:** By the end of the hour, the two group leaders will compile 1 presentation slide summarizing the state of the art for each technique. Theis slide will be presented immediately afterward to the larger group.

Group Numbers and Session Leaders:

In-person	Virtual
1. Kehan Yang, Eric Sproles	1. Niklas Bohn
1. Bert Davis, Rashmi Shah	2. Dhanendra Singh
2. Mahsa Moradi, JT Reager	3. Vincent Vionnet
3. Julien Meloche, Leung Tsang	
4. James Garrison, Anna Grunes	
5. Swati Tak, Ross Palomaki	
6. Xiaolan Xu, Justin Pflug	
7. Mark Robertson, Rajeev Ranjan	
8. Shad O’Neel, Ally Fitts	
9. Adrienne Marshall, Uriel Aviles Ruiz	**10.**
10. Cenlin He, Ethan Gutmann	
10. Hannah Besso, Sam Tuttle	

Day 2 Breakout Session I Questions:

1. What are the target snow-community science questions to observe snow globally?
    a. What are the most important remaining science questions (measurement, snow science, data science)?
    b. What is needed to address and answer these questions?
2. What are the target science and operational applications?
3. How are past, current and future satellite missions poised to address snow-related science questions?
    a. What are the shortcomings?
4. What should a future snow mission provide?
    a. Temporal repeat?
    b. Spatial resolution?
    c. Accuracy across landscapes/canopy?
    d. Snowpack depth?
    e. Soil moisture co-measurements?
    f. Auxiliary snow density information?
    g. Coverage?
    h. Other considerations?

Summary Slide **(1) Kehan Yang, Eric Sproles**

1. Target snow-community science questions to observe snow globally:

1. Target science and operational applications:

1. Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:

1. A future snow mission should provide:

Summary Slide **(2) Bert Davis, Rashmi Shah**

1. Target snow-community science questions to observe snow globally:

Two of the three observable: SWE, snow density and snow depth. Wet snow, mountain snow, vegetation, and above the tree line measurement are the big gaps.

1. Target science and operational applications:

Basin scale - hydrological/water resources/ecological application (Food and water security). There needs to be top-down approach, what does the user community need and then bring it down to what is needed. We need to understand where the biggest value from the applications point of view.

1. Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:

Need to look seriously on multi-modal aspect, what is all the satellites currently providing and understand where the remaining gap is. Also a needs assessment that used to be done so things can be more top down.
Should be a nail looking for a hammer and not a hammer looking at nail.

1. A future snow mission should provide:

- Spatial-temporal agility in the data collection
- Algorithm agility: regionally tuned-algorithm
- Maximize ground observation data from a minimum number of ground observations. Cost-benefit analysis on additional ground observations.

Summary Slide **(3) Mahsa Moradi, JT Reager**

1. Target snow-community science questions to observe snow globally:
   - Snowpack evolution with better temporal resolution
   - Wet snow
     - from operational forecasting point-of-view: Continues values needed for daily forecasting, only one peak SWE is not enough
     - Peak SWE also is not enough for Ephemeral regions due to their transient nature.
     - Rain-on-snow and future changes
     - Even the in-situ equipment not suitable for wet snow to be used for validation
   - Some satellite like GRACE do not work on the steep regions like mountainous area with high SWE (important for regional applications but can we justify the use of satellite for this purpose?)
1. Target science and operational applications:
   - Integrate snow science with Wildfire forecast models and post fire hydrology
   - Mobility at snow covered areas
1. Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:
   - Successful in snow depth estimation
   - Issues with snow density estimation
1. A future snow mission should provide:

Summary Slide **(4) Julien Meloche, Leung Tsang**

1. Target snow-community science questions to observe snow globally: Understanding accuracy and uncertainty of various lengths of various kinds of snow. How do snow change over space. Complex topography, mountainous area, the data they need the most, most uncertainties of the Evolution of sow in complex terrain Snow wetness. When the snow is wet, how do we still get SWE

1. Target science and operational applications:
Water resources in mountainous areas. Water management. Wild life management . Climate feedback snow on the ground. Interactions of snow with ground water. Snow data set to relate to sea surface temperature   Correlations of swe with El NIno.

1. Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:
Unproven technology stability of satellites. All satellite remain functional, commercial partner. Design robustness
Passive current mission and the future CMIR mission

1. A future snow mission should provide:
Temporal repeat: 6 days, sentinel , 6 days is super helpful, 12 days, up and down. Meteorological 3 to 4 days
Airborne data are important to supplement satellite data.
Spatial resolution: 250m is fine. Airborne data are important to supplement satellite data.
Spatial is more important than temporal…
Accuracy across landscapes/canopy: Knowing snow in forested areas . are important.
Snowpack depth: 4m?
Coverage: Global

Summary Slide **(5) James Garrison, Anna Grunes**

1. **Target snow-community science questions to observe snow globally:**
    a. How are other disciplines impacted by changing snow? (hazards, flooding, ecology ect.)
    b. How can we improve snow sensing for shallow, low-elevation, wet snowpacks? - at risk areas, urban environments
    c. How can we leverage data from different types of snow from different locations (think Mars) to improve our understanding of gaps?

1. **Target science and operational applications:**
    a. What are the user needs/end products? - work backwards
    b. Review Paper - what are the leading products? Can we form some sort of general consensus?
        i. Western US?

1. **Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:**
    a. Wet snow! - primarily occurs in high risk areas
    b. How can these missions inform hazards and flood management beyond just water resources?

1. **A future snow mission should provide:**
    a. Addressing temporal and spatial resolution useful for both event analysis (flood/av) and seasonal water use predicitions
    b. Cross-discipline collaboration (atmospheric science community)

Summary Slide **(6) Swati Tak, Ross Palomaki**

1. Target snow-community science questions to observe snow globally:

We want everything, everywhere, all the time. We need a framework for the multi-directional communication for the “three legged stool”. How do we do this globally?

1. Target science and operational applications:

Predictions for operational/disaster and real time data.

1. Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:

1. A future snow mission should provide:

Summary Slide **(7) Xiaolan Xu, Justin Pflug**

1. Target snow-community science questions to observe snow globally:

- A lot of focus on data access and utility. Need for a central location (cloud-based) for increasing data access and understanding. Needs change as users change → "Definable roadmap" and action items driven by science and end-user needs.
- Snow to get a "foot in the door". E.g., NISAR core project doesn't have a snow-focused project tasked. Snow needs to be on the satellite needs working group
- Agreement on specific observable (global snow vs. mid-latitude snow)
- Snow is a forecast variable (think water towers). Connecting that with decisions at later dates
- Better need to determine specs (like resolution)
- Limitation of the satellite. Sub-orbital platform to supplement.

1. Target science and operational applications:

    Application specific. Does soliciting feedback needs from an RFC address needs globally? What is equitable?

1. Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:
    a) need to snow representative for satellite need group
    b) different users: nominal operation vs. emergency response (daily vs. hourly)
    c) bridge the technology capability with user need

1. A future snow mission should provide:

- Not just a snow mission. A lot more goes into this (e.g., DA, data access/storage/organization). Specifics driven by end-user needs (especially the "middlemen" like RFCs, BRec, etc.).
- Response time flexible for emergency responses (e.g., rain on snow)

Summary Slide **(8) Mark Robertson, Rajeev Ranjan**

1. **Target snow-community science questions to observe snow globally:**
   - We may need to reevaluate if global SWE if possible, think about partial SWE in area/times that are most important (cost/benefit analysis). But also: wet snow, sublimation/evaporation, canopy interception, wind redistribution, ecosystem, global snow density has not gotten much attention
   - Continue with cross-sensor approaches, and continue on existing path, which has been successful

1. **Target science and operational applications:**
   - Streamflow forecasting and water resources, climate and ecology, avalanche, snow/ski recreation

1. **Past, current and future satellite missions are/are not poised to address snow-related science questions:**
   - ARE: will learn a lot from NISAR, Icesat-2 SCA, albedo, shortcomings of spaceborne lidar, GNSS, SOO, fusions of approaches and partial datasets can be explored further
   - ARE NOT: dedicated SWE, sublimation/evaporation, density

1. **A future snow mission should provide:**
   - Yes. But in lieu of that, further outreach with end-result stakeholders, continued cross-disciplinary approach, wet snow, prairie, cost/benefit analysis

Summary Slide **(9) Shad O'Neel, Ally Fitts**

1. **Target snow-community science questions to observe snow globally:**

- Address precipitation variability (observations and modeled)
- Studies of poorly behaved snow! E.g. Wet, wind blown, complex terrain
- Align needs & capabilities between observation-modeling communities; research -operations - industry
- Model intercomparisons
- Analysis of high/low use data from big efforts like SNOWEX. → Use the data we already have!

1. **Target science and operational applications:**

- Coupled earth system components (Snow, hydro, soil, water management)
- Automated weather stations targeted at certain parameters to standardize measurements while decreasing variability
- Short-turn around.

1. **Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:**

- Wet snow conditions (any high maintenance snow)

1. **A future snow mission should provide:**

- Incorporate lessons learned from the past (pre-conceived data management plan, re-evaluate high level products)
- Nested Test-bed basins / Super-sites **consistent and continuous observations** to plug into the episodic, remotely sensed, and modeled efforts. Observations across space and time scales (look at soil moisture community)

Summary Slide **(10) Adrienne Marshall, Uriel Aviles Ruiz**

- The impact of snow on climate should remain the driving science question, and water resources should remain the driving application questions
- Can we combine the missions as a designated observable constellation (SnowCon)? There is a need for both high res in mountainous areas and capturing global spatial domain.
- Important to make the data retrievals easily accessible for water managers to use quickly.
- Models and assimilation will continue to play a role in "filling in the gaps", e.g. estimating SWE in forested areas and during ablation.
  - Albedo, snow depth, LWC, and energy forcing information is important

Spencer Shawn, Arielle Koshkin, Patrick Naple, Dennis Lettenmaier, Dave Kanzer, Kyla Christopher-Moody, Lindsay Bearup, Jack Tarricone, Mark Raleigh, Mike Durand, Adrienne Marshall

Summary Slide **(11) Cenlin He, Ethan Gutmann**

1. **Target snow-community science questions to observe snow globally:**
   - **Global Spatiotemporally continuous/complete snow data product**s (e.g., SWE, snow cover, snow albedo) with high spatial and temporal resolution (relevant for local water resource management)
   - **Comprehensive unified QC'ed synthesized snow measurements data products** (for various snow quantities) from previous field measurements and **open-access unified platforms/databases**
   - Need **more representative measurements** (beyond SNOTEL) for key snow quantities under under-studied areas, e.g., complex terrain, forests.
   - Coordinated snow measurements (e.g., tower, ground, UAV, satellite, etc.) with different/diverse groups to build a complete/comprehensive snow dataset (requires reliable significant funding)
   - **Disconnection between modeling groups and measurement groups, need more communication**
   - **Need innovative ideas to leverage the new tech, big data, powerful computers,** Go beyond model DA through using obs (need more innovative model-obs integration methods)
   - Need accurate satellite measurements of SWE and other measurements of snow quantities to advance fundamental understanding of some key snow processes

1. **Target science and operational applications:**

Water resource prediction (high-res is important) and reservoir; **Extreme events and hazards** (flooding, drought, avalanche); **Snow drifting and transportation safety**; **Ecosystem evolution** and habitat (e.g. animal migration); **Food-water security**; Snow melting coupled with river ice and lake processes; **Climate change** (global snow picture becomes important); model-obs integration; **More applications beyond North America and Europ**e (e.g,. Asia, South America); Reducing model uncertainty (Precipitation, phase changes, rain-on-snow, etc).

1. **Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:**
   - Data products' discontinuity spatially and temporally, out-dated algorithms
   - Lack of "real" truth remote sensing data (the current forward model may not be as good as we thought it would be)
   - Need collocated multi-instrumentation measurements for cross-checking
   - Data product uncertainties that are too large for some high-res local applications

1. **A future snow mission should provide:**
   - Spatially and temporally continuous and high-res data with high accuracy and sufficient vertical resolution of snowpack column profile
   - Data ready to be used for operational weather and water predictions, and allow us to know precisely where and when there is snow and accurately characterize snowpack water and energy balance
   - SWE is one of the key things for water resources and energy balance (land-atmos feedback), Snow depth, Snow albedo

Summary Slide **(12) Hannah Besso, Sam Tuttle**

1. Target snow-community science questions to observe snow globally:

SWE is the big observable we need. We also need to measure wet snow using satellites (especially in maritime climates), constrain melt rates (especially in the Rockies), and collaborate more across disciplines to utilize all tools available to us since we don't have yet one single measurement/method that gives us everything we need. We need a review paper or some sort of summary of different approaches with errors

1. Target science and operational applications:

Need to make science easily accessible for water managers, build long-term relationships with managers (maybe through third party consultants or orgs like the Bureau of Rec to maintain long-term projects.

1. Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:

We need a 'gold standard' or even 'silver standard' ground-based measurements: robust observations that we can use to evaluate satellite and model data. Maybe like another SnowEx but targeted for satellites? One of the big questions with that is the issue of scale.
Nisar doesn't have snow as a science goal, so the data isn't targeted to benefit us. We're mostly using data that was not designed for snow, and trying to fit it to our needs.

1. A future snow mission should provide:

Customized processing tools are helping, but ideally we need a satellite that has high return interval with resolution of at least 500m. There's a tradeoff between whether we want global data or focus on North America. We want longevity from a satellite, so a long record and we can feel confident investing time and effort into incorporating the data into our models/operations. So maybe we need to say, we'll take 3 years of really intensive satellite data that will allow us to learn a ton, improve our models a lot that we can then continue to use that knowledge past the lifespan of the satellite. Also if we can focus on the commercial aspect, we can get lots of satellites in orbit really fast. We also need short latency. We also discussed how it would be great for commercial data to be available after a certain time period when it's no longer valuable to them.

Summary Slide **(1) Niklas Bohn**

1. Target snow-community science questions to observe snow globally:

   Snow melt… How quickly do water managers need information about the snow pack conditions? In the absence of SWE measurements, how can we characterize them? What is the best type of measurements for snow? How could we optimally combine different types of measurements?

   i. We need a lot of experiments… Synthetic experiments, real experiments.
   ii. Data fusion! Combine different latencies, new technologies, e.g., machine learning.
   iii. Bring the community/experts together to harness the power of all of them.
   iv. We need a mission dedicated to combine all the different missions, in order to learn different techniques.
   v. Provide specific funding for missions to target community outreach and connections to applications and actions, and other missions/fields of research. Connecting scientists to applications/actions/stakeholders => Funding needed!

1. Target science and operational applications:
   a. Supply forecast for watersheds, freshwater availability, flood risk.
   b. Distinguishing arctic snow science (permafrost, vegetation, ice caps, glaciers) from mid-latitude mountains.
   c. Think about global snow products and applications

1. Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:
   a. Shortcomings: interest of missions only in specific areas, technical/funding limitations, limited to particular science topics

1. A future snow mission should provide:
   a. Ideal world: daily observations
   b. Spatial vs. temporal resolution: applications would rather pick spatial (preferably less than 200m GSD)
   c. Measurements and models should optimally line up on the same day
   d. Way forward: combine many smaller missions with just a few essential requirements to get to comprehensive data products

Summary Slide **(2)** Remote group 1 (**Nicolas Leroux)**

1. Target snow-community science questions to observe snow globally:
- Higher spatial resolution of SWE product on the ground as it would improve forecasting: we do not have the forcing data to model at fine scale + problems of validation
- Improving dynamic land surface changes in the models: forest fires, urban growth, forest annual evolution
- Similarly, account (better) for dynamic land surface changes in retrievals

1. Target science and operational applications:
- Forecasting point of view: Excited by future snow satellite missions estimates of SWE with a certain degree of uncertainty + advances in data assimilation that help SWE estimates/ensembles

1. Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:

- We have many satellites measuring at different frequencies. How can we combine the different frequencies to benefit from the strenghts of the different sensors to improve SWE?

1. A future snow mission should provide:

Summary Slide **(3) Vincent Vionnet**

1. Target snow-community science questions to observe snow globally:
- Challenge in estimating snow density either from remote sensing and from models (especially across large domains)
- Uncertainties in interactions between signal in different bands and snow conditions on the ground (dry snow, wet snow)
- Better understanding of the state of the snow surface (refrozen snow, impact of the strong diurnal cycle in mid latitude areas).
- Challenge with the impact of high-vegetation of various density on the remotely-sensed signal, better quantify the performances across different environments.
- High vegetation also creates a large variability in the snow cover and properties which impact the remotely-sensed signal. This variability is often neglected when processing the data.
- Snow is a rapidly changing process. We have some great techniques, but some difficulty to measure and model accumulation over time. Which is where we have room for space measurements for correction.

1. Target science and operational applications:
- Current and historical SWE estimate for water resources management (especially in western US and Canada) and flood forecasting.
- Application for recreations (ski resorts, rafting, …).

1. Past, current and future satellite missions are/are not poised to address snow-related science questions in the following ways:
- Cf points discussed below

1. A future snow mission should provide:
- SWE is the key variable.
- Key importance of the spatial resolution (ideally go below 10 m) and of the accuracy across landscapes and canopy.
- Temporal resolution is a key for mid-latitude regions (ideally below 4 to 5-day return)
- Ancillary snow density information are important but require improvements compared to current estimates; cf earlier point)
- Additional consideration: latency of the data is a large issue for operational use (requires consistent format and storage requirements)

Summary Slide **(4) Name**

1. Target snow-community science questions to observe snow globally:

1. Target science and operational applications:

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1. A future snow mission should provide:

Summary Slide **(5) Name**

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Summary Slide **(6) Name**

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Summary Slide **(7) Name**

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1. Target science and operational applications:

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Summary Slide **(8) Name**

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1. A future snow mission should provide: