

NASA Community Snow Meeting
Day 2 Breakout Session II
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. This 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 II Questions:

1. What efforts are needed in the near term to mature technologies?
 - a. Field campaign, airborne campaigns, instrument development, etc?
 - b. Model advances, OSSEs,
 - c. Data merging, cloud computing, etc
 - d. What questions did SnowEx not address? What forward-thinking ways should we approach the next major campaign?
2. How can we better engage the applications & operational communities in future missions or campaigns?
3. How do we foster a community that is welcoming of new members?
4. Who are the partner user communities? Can we leverage advances or lessons learned in other communities for snow?
5. What white papers should go toward the next Decadal Survey?



Summary Slide (1) Kehan Yang, Eric Sproles

1. The following efforts are needed in the near term to mature technologies:
 1. We can better engage the applications & operational communities in future missions or campaigns in the following ways:
 1. We can foster a community that is welcoming of new members in the following ways:
 1. We can leverage advances or lessons learned in other communities for snow in the following ways
1. The following white papers should go toward the next Decadal Survey:

Summary Slide (2) Bert Davis, Rashmi Shah

1. The following efforts are needed in the near term to mature technologies:
 - Documentation of lessons learned from the SnowEx campaign should be done to inform the next major campaign. Have we exercised all the available data from all the previous campaigns e.g. CLPX?
 - Field campaigns in the future should include Maritime Snow especially since we will see more and more wet snow in the future.
 - Partner with the Canadians for Prairie Snow.
 - Planning of how the data from any campaign will be used in models and OSSEs from the beginning.
1. We can better engage the applications & operational communities in future missions or campaigns in the following ways:
 - Engage with the end-users early to plan the data needs and keep them engaged strategically throughout the process.
 - Understand the agencies with applications & operational communities are risk oriented and really care about uncertainties.
1. We can foster a community that is welcoming of new members in the following ways:

Make the data easily accessible. Highlight the linkage of the snow community to other communities like ecology, fisheries, wildfire, etc. Reach out to wider community for workshop like this. Indicate on the website what kind of people would be participating in workshop like this.
1. We can leverage advances or lessons learned in other communities for snow in the following ways
Groups doing the water supply and streamflow forecasting.
Globally get involved in organizations like WMO.
Build a community of interest outside the snow community.
1. The following white papers should go toward the next Decadal Survey:
 - Need to publish a community position peer-reviewed paper before the white paper e.g. something from this meeting
 - For white papers: need two of snow depth, snow density or snow water equivalent to address wet snow, maritime, prairie and mountain snow.

Summary Slide (3) Mahsa Moradi, JT Reager

1. The following efforts are needed in the near term to mature technologies:
 - Are the science goals that were shown sufficient? They need to be specific and clearly defined, need hypotheses, possible uncertainties, constraints on the questions, define the limitation for each target snow classes, better quantification of errors for different snow classes in the plan capabilities chart (No one mission can answer challenges related all snow classes)
 - Think more than technical aspects: Need communication with the end-users community (tribal needs, ecosystems, ...) to have a better understanding on how to prioritize the efforts, could be done through workshops
1. We can better engage the applications & operational communities in future missions or campaigns in the following ways:
 - Two-way communication with end-users/ More comprehensive approach
 - Continuous communication between western and eastern snow community outside of the conferences
1. We can foster a community that is welcoming of new members in the following ways:
 - Need to have “best practices” for models and available data, providing the workflow to use and process data
 - Small budget dedicated to support new members to
 - “gear library”: People are interested in getting involved in field campaigns, but logistics could cause limitations.
 - Better sharing culture to share the unused equipment to help new/early career members with limited funding
 - Mentor programs
 - Make data more accessible/ searchable
 - More outreach /education activities
1. We can leverage advances or lessons learned in other communities for snow in the following ways
 - End users assessment/ surveys
 - Application workshops
 - How to collaborate with other missions to make a better use of data outside of winter time (when such discussion should start?)
 - How to define requirements when proposing a new mission
 - Reach out to project scientists from other missions
 - How other communities include citizen science (ground observations could be valuable resources)
1. The following white papers should go toward the next Decadal Survey:
 - what methods are appropriate for global/regional applications?
 - More efforts to educate/include the community white papers

Summary Slide (4) Julien Meloche, Leung Tsang

1. The following efforts are needed in the near term to mature technologies:

Field campaign, airborne campaigns, instrument development, etc?

Need a comprehensive Review the SnowEx data, to identify the gaps

Liquid water content is a high priority in SnowEx data

Airborne campaign, strips data, downscale spaceborne data

Model advances:

combine machine learning with physical models

How do we best identify synergies between machine learning and physical models in the retrieval of SWE.

Data merging, cloud computing, etc

Inter-comparison of data

Reanalysis products. May not be accurate

ASO are flown on demand

Push data merging for users.

What snowex did not do?

SnowEx can have time series covering both dry and wet snow. The time series can extend to wet snow.

1. We can better engage the applications & operational communities in future missions or campaigns in the following ways:

Eastern and Western Snow Conference to attract operational communities.

CIRRH funded by NOAA for operational communities

Write more mission proposal so you are obligated to seek application and operational support

Engage Water management community for their support

1. We can foster a community that is welcoming of new members in the following ways:

Include the community in the white papers and other effort

1. We can leverage advances or lessons learned in other communities for snow in the following ways

Climate Engine (similar to google earth engine)

Soil moisture space borne experience

1. The following white papers should go toward the next Decadal Survey:

What need to be put in the white papers to elevate "SWE" to "designated variable?"

The total cost of SnowGlobe and Snowwatch is less than NISAR. We can have both missions as they are complementary.

Summary Slide (5) James Garrison, Anna Grunes

1. **The following efforts are needed in the near term to mature technologies:**
 - a. UAV P-Band - demonstrate this can fill gaps for forested areas & wet snow
 - b. Multi-instrument campaigns that are flown simultaneously - need time to organize well the first time...

1. **We can better engage the applications & operational communities in future missions or campaigns in the following ways:**
 - a. Latency - How can we make the data applicable on the timeline of operational feedbacks?

1. **We can foster a community that is welcoming of new members in the following ways:**
 - a. Spread the word! Snow schools, online modeling school, hackweeks, ect.

1. **We can leverage advances or lessons learned in other communities for snow in the following ways:**
 - a. Data needs to be accessible and reliable
 - b. Application workshops?
 - c. NASA Water Applications Postdoc Liaison or Fellowship Program

1. **The following white papers should go toward the next Decadal Survey:**
 - a. Which instruments to you want on the same platform at the same time? How are all the sensors working synergistically?
 - b. InSAR Constellation Approach: How much information do you gain from multiple satellites?
 - c. EarthVenture Airborne proposal

Summary Slide (6) Swati Tak, Ross Palomaki

1. The following efforts are needed in the near term to mature technologies:

- SnowEx did not address: wet snow, canopy interception, complex terrain; P band radar not part of measurement plan; issues with Ku and X band data
- Model developments: canopy sublimation
- Field campaigns: full watershed scale, from ridgeline to streamflow

1. We can better engage the applications & operational communities in future missions or campaigns in the following ways:

- Work with communities to develop a set of guidelines; understand different end user needs in different areas.
- 3 year missions might be too short to develop a fully operational product, but can maybe reduce uncertainty in smaller key areas for overall improvement. Talk with end users to identify these areas.
- Can/should we broaden our focus beyond new sensing techniques to include models, operations, etc?

1. We can foster a community that is welcoming of new members in the following ways:

- Collaboration with Chinese colleagues?
- Consider diverse backgrounds with respect to snow - NASA Snow School is a good example
- Use existing NASA resources to get the message out about what we're doing in this room! Engaging with public -> new community members
- Citizen science and public outreach, especially to younger students

1. We can leverage advances or lessons learned in other communities for snow in the following ways

- Science communities: soils community (model to develop consensus); economists; social scientists
- Partner user communities: ESA and other national space agencies, RFCs

1. The following white papers should go toward the next Decadal Survey:

- Living documents instead of static white papers? Follows Open Science Guidelines
- Check with end users before finalizing white paper topics.
- Is a concise list of talking points more effective than more white papers?

Summary Slide (7) Xiaolan Xu, Justin Pflug

1. The following efforts are needed in the near term to mature technologies:
 - a) More analysis for previous data (forest need to be classified into more detail)
 - b) Instrument measurement: 1) volume scattering (SWESAR??, TSMC cal/val) 2) inSAR (L-band not sufficient temporal revisit) Cal/Val campaign for NISAR using UAVSAR 3) SoOP (wet snow capability demonstration over 1 tower)
 - c) Snow model development (precip) Co-located sensors combined with airborne (UAVSAR flight)/combined with soil moisture. Co-located with model simulations! Model advances/OSSE need data; Quality control/open access/OSSEs: key error from the models. More focus on the atmos side (x or c-band atmospheric radar); Interaction between the snow and soil moisture/bedrock boundary layer
 - a) Future multi-year campaign: Forest(type)/wet snow(mixed)/maritime/prairie snow (spatially inhomogeneous); Melt season: precip - > model good enough/need observation; Elevation gradient (for wet snow application, slope/aspect); Uncertainties in snow sublimation

1. We can better engage the applications & operational communities in future missions or campaigns in the following ways:
 - Integrated hydrology. Connecting snow and soil moisture
 - Connecting those in operations with those collecting data and performing the snow science (integration and outreach)
 - State-level engagement. Soliciting what end-users need
 - Early-adopter programs
 - Leveraging connecting programs (like GEWEX)

1. We can foster a community that is welcoming of new members in the following ways:

Hackweek model → intro to the community/data and development of new tools
Across agency/university workshop

1. We can leverage advances or lessons learned in other communities for snow in the following ways
Inter-comparison/Early adaptor user group

1. The following white papers should go toward the next Decadal Survey:

Summary Slide (8) Mark Robertson, Rajeev Ranjan

- 1. The following efforts are needed in the near term to mature technologies:**
 - snow product bake-off (independent evaluation), uncertainty (could use existing SnowEx data), collaboration on approach/mission sooner rather than later, NASA SBIR for new sensor development, ground/airborne timeseries campaigns were more valuable
 - Gaps: uncertainty
- 1. We can better engage the applications & operational communities in future missions or campaigns in the following ways:**
 - Invite more stakeholders to these meetings (hear needs) and vice versa, connecting with Applied Sciences, focus on ways to make data complementary to existing ops
 - It's a challenge to address Research-to-Ops timeline - but there are examples (NRCS, USGS)
- 1. We can foster a community that is welcoming of new members in the following ways:**
 - Open science, snow schools and hack weeks are a powerful tool, more active efforts to engage new communities, mindset has to be learning as much teaching/dissemination
- 1. We can leverage advances or lessons learned in other communities for snow in the following ways:**
 - CAMELS basins (an agreed subset of 'representative' basins), tune v. test basins, LTER, NEON, 'supersites' - NRCS
- 1. The following white papers should go toward the next Decadal Survey:**
 - Long term snow validation sites (allow for bake-off for existing products, groundwork for future campaigns)

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

1. The following efforts are needed in the near term to mature technologies:

- Nested-scale autonomous observing platforms, standardized suite of observations and data formats
- Need to understand snow physics
- Best measuring protocols in a published formats for a variety of snow climates and conditions
- Publish SnowEx datasets to make it available to others!
- **'Gaps' in SnowEx:**
 - Coincident measurements (airborne, space and ground)
 - coastal, maritime, midwest prairie region
 - Extreme events (rain-on-snow, flooding)
 - Capturing spatial variability driven by atmospheric conditions
 - Societal impacts influencing the science

1. We can better engage the applications & operational communities in future missions or campaigns in the following ways:

- Build trust with operational water managers, LISTEN
- Low-latency Data synthesis transfer to operations
- Science attendance at operational events and vice versa, extended those invites

1. We can foster a community that is welcoming of new members in the following ways:

- Provide a space for participants of campaigns/meeting to provide feedback and reflect on experience (post-campaign surveys, offer external support)
- Providing gear and training

1. We can leverage advances or lessons learned in other communities for snow in the following ways

- Soil moisture
- Connect with indigenous communities (continue MAIANSE efforts)
- Engagement opportunities: Eastern/Western Snow Conference, ASO workshop, International Snow Science Workshop, Avalanche/Ski Patrol
- Practitioners offer lots of knowledge to research

Summary Slide (10) Adrienne Marshall, Uriel Aviles Ruiz. Actually: Arielle Koshkin, Mike Durand

- Promoting and advertising working groups to help folks loop into a smaller community. Working groups in application and operational are currently lacking, limiting the ability for parts of the community to be entrained.
- Continue Snow schools, and hack week but add a snow model school or developers conference to help new members learn models and be brought into the fold.
- Near term we need to learn from SnowEx data we have and SWESARR backscatter data must be published in the near term to enable retrieval studies
- Structured systematic review of SWE products and categorizing uncertainty in different products.
- Write a high level motivating paper explaining the need for a global snow mission and snow remote sensing.
- Community effort of white papers of snow (only 4 last decade).

Summary Slide (11) Cenlin He, Ethan Gutmann

1. The following efforts are needed in the near term to mature technologies:

Focus a new “field campaign” on What is a better dataset for model development and RS integration with Models

1. We can better engage the applications & operational communities in future missions or campaigns in the following ways:

Huge value of getting Snow Ops people “in the field” with feedback both ways, it is a great hook to engage.

Annual Meetings like this with focus on bringing ops community. Stakeholder + Science community (NOAA does this)
Leverage e.g. NASA Western Water Office and Earth Science to Action to find connections.

1. We can foster a community that is welcoming of new members in the following ways:

Snow School, Hackweeks, Workshops, field campaigns are very valuable semi-structured ways to connect people.

Connect more with other groups e.g. CUASHI sees the value of snow schools.

Also need support for, e.g. early career faculty to run snow school.

More travel support and extend invitation to broader community.

Consistency of financial support is more important than magnitude.

1. We can leverage advances or lessons learned in other communities for snow in the following ways

Private industry partners, NASA has to be willing to work more with private engineers.

NASA cryosphere, terrestrial ecology, and soil moisture communities should be connected all need snow

1. The following white papers should go toward the next Decadal Survey:

Update whitepaper on economic value of snow mission (Don Cline’s group wrote one a while back can we update it or start over)

More interest in whitepapers focused on property (SWE, SD, albedo) than technique, but include Models, Obs, RS in each

Emphasize Value of diversity in community.

Summary Slide (12) Hannah Besso, David Clemens-Sewall

1. The following efforts are needed in the near term to mature technologies:

Satellite-focussed field campaigns. Coordinating existing campaigns with satellite acquisitions, consistent protocols and guidelines, geolocation, contact person. Could data centers provide more curation? More time-series campaigns and distributed locations. Using models to guide measurement campaigns, incl. variables measured. Think through what happens after the campaign.

SnowEx did not address: maritime, wet snow, melt transition, precipitation, fall transition, seasonal lifecycle.

1. We can better engage the applications & operational communities in future missions or campaigns in the following ways:

Can we leverage operational knowledge and engage operational folks in the planning and execution of field campaigns. Snow stakeholder meeting? Opportunity to use ASO as a foothold. Making near-real time data publicly-accessible.

1. We can foster a community that is welcoming of new members in the following ways:

Geosciences as a whole can be insular. Snowex has been very good at engaging new members but it can be harder coming from the data and satellite community. Also, ski culture challenges. Lack of diversity in the community. Partnering with MSI's. Wintertime SAR (undergrad field program)

1. We can leverage advances or lessons learned in other communities for snow in the following ways
2. The following white papers should go toward the next Decadal Survey:

Review paper on current modeling+DA methods.

Have Early Career Researchers write a whitepaper on their perspectives (and maybe not just mission-focussed).

Synergies between different satellites.

How to promote beneficial unanticipated uses of satellite data.

Methods that did not work, could use SnowEx to analyze what datasets and methods have been more or less used.

Summary Slide (1)

1. The following efforts are needed in the near term to mature technologies:
 - A- Field campaign, airborne campaigns, instrument development, etc?
 - Challenge with the measurement of liquid water content in the snowpack : need to develop improved instruments to measure LWC ;
 - Develop measurement strategies to sample the variability of snowpack vertical properties (density, SSA, ...) at the scale of satellite footprints / model grid cells.
 - Develop consistency in measurement in-between campaigns and in-between winters.
 - B- Model advances, OSSEs,
 - Need to improve performances of detailed snowpack scheme applied across different snow climates
 - Challenges of selecting forcing data as a function of the domain of interest and of the resolution of interest.
 - Develop consistent approaches to generate met. ensemble to drive snow models (in the context of DA).
 - Some of the challenges associated with the snow models lie outside the snow modeling community: met. forcing at the appropriate resolution,
 - C- Data merging, cloud computing, etc
 - Major challenges associated with the variety of data formats to combine complex datasets.
 - Resources are required to support cloud computing, work on HPC, ...
 - Improve access to snow data through cloud computing: APIs, process/analyse the data where it is instead of downloading unnecessarily huge data volumes
 - D- What questions did SnowEx not address? What forward-thinking ways should we approach the next major campaign?
 - Improve the connection with the international snow communities for the next SnowEx campaign.
 - Temporal coverage, adapted to different environments (different requirements in the Arctic where the early snow season matters)
 - Focus also on areas outside the Western US and also Arctic environments, where many model components/processes are challenging - and Arctic areas are crucial for global climate/environment research
1. We can better engage the applications & operational communities in future missions or campaigns in the following ways:
 - Improve the engagement of communities outside the science community at workshops, ...
 - Develop fundings that are specifically targeted for applications of research projects (before we move to the next research project ...).
1. We can foster a community that is welcoming of new members in the following ways:
 - Improve collaborations between the different snow communities across continents (though dedicated meetings, ...) to benefit from various experiences (for example, in conducting measurement campaigns, ...)

Summary Slide (2)

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Summary Slide (3)

1. The following efforts are needed in the near term to mature technologies:
 - We need to narrow our scope and focus on a few sensors.
 - Include the water operation community and narrow down the focus on the operational needs
 - Data processing pipeline. Leverage cloud computing to minimize latency.

1. We can better engage the applications & operational communities in future missions or campaigns in the following ways:
 - Think about the longevity of the mission. Missions are short but operational needs are long term.
 - Find different uses for the sensors for different applications when planning a mission.

1. We can foster a community that is welcoming of new members in the following ways:
 - Clearer objectives can help different communities feel more welcomed

1. We can leverage advances or lessons learned in other communities for snow in the following ways
 - Explain the economical/environmental benefits of the mission to society.
 - Knowledge from the Airborne Snow Observatory

1. The following white papers should go toward the next Decadal Survey:
 - The combination of sensors we would want to put on the next satellite
 - How do we fill gaps (spatial and temporal gaps)?
 - What do we do beyond the lifespan of the mission

Summary Slide (4)

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Summary Slide (9)

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