Emerging Themes

- Spatial variability in SWE and albedo among landscape types and corresponding snow types (boreal and tundra)
- Entire season (including melt timing)
- Super sites and Infrastructure (static/mobile)
- Land Cover shifts Arctic Boreal Future
- Pathway to Space and Impending Missions (NISAR)
- Planning for Problems
  - Weather constraints on work and equipment
  - Early planning, permitting, synergy
- Compatibility Prioritization
  - Modeling based or Technology proving ground?

Tundra/Taiga • Table 1

- **Science Questions**: How does spatial variability of snow properties change across a range of forest cover, permafrost, aspect, and lake substrate? What factors control or correlate with **spatial variability** of snow depth **spatial patterns** across this range of environments?
- **Measurement Questions**: How does **forest cover**, substrate (**permafrost**, **lake ice**) and snowpack characteristics (**grain size**, stratigraphy) affect L-band InSAR and X+Ku-band approaches for shallow snow? How much does **merging** with models help?
- **Essentials**: **Three(?) sites** with varying land cover characteristics (forest cover, permafrost, lake ice). Snow off observations, and then 8-10 snow on flights of all three sites. **Lidar, X+Ku, and L-band**, ideally albedo. Met towers, and forcings downscaled from RCMs.
- **Outcomes**: 10 days of 4 hour flights. Split into two-four periods. We expect to learn how substrate and forest cover dictate **spatial patterns,** how forest cover and substrate affect X+Ku and L-band, and the value of models in decoding complex signals.

What is the measurement variability in SWE/albedo? How spatially correlated it it? Does it differ from tundra to taiga to boreal? Does it vary in time? What about interannual variability? These are scale depend questions. Do we need to have the same requirements of SWE/snow depth accuracy over differing snow type regions? This would require some kind of hierarchy of measurements of measurements each tuned to a different scale. If we want a sense of temporal variability we need the campaign to be spread out over the entire snow season.

What can be done to measure SWE/albedo in vegetated/forested regions? E.g. Are there measurements we can make in open regions with sensors that we can scale to determine SWE/SD/albedo in forest? Does this ratio seasonally evolve? e.g. for LIDAR forest density is important. For drone optical imagery has problems with young new growth forests more than dense forests. It's unclear whether uncertainty in modelled density but good snow depth from LIDAR or optical drone would outweight uncertainty of active/passive SWE retrievals in forest). Prioritize active/passive probably for SWE.

Snow melt occurs quickly in tundra. Can we characterize differences in melting over each of these three snow types? Are there differences in snow melt timing that depend on underlying permafrost type? For melt/water measurements we prioritize L-band SAR for soil conditions.

1 campaign say based in Fairbanks, AK that has the ability to fly to surrounding sub sites and examine aspects of all 3 questions

Possible subsites: Trail Valley Creek, Alaska north slope (tundra), Bonanza Creek LTER (long term eco site).

Sensors: optical, thermal IR, active and passive microwave, LIDAR (for depth), drone optical structure for motion (for depth – can see in forest if there isn't low lying vegetation, but needs sunlight.

Boreal 3 Summary

- What questions should field campaign answer?
  - Better understand performance of various sensor types for sensing SWE / Snow depth including emerging sensor types such as wideband autocorrelation radiometry
  - Better understanding of snow microstructure and impact on Albedo/BRDF
  - Better understanding of canopy intercept effects on snow property heterogeneity
  - Snow on glaciers
  - Group noted that there are a wide variety of potential SWE applications; a focus solely on water resource management for human consumption drives mission in direction of mountain case (i.e. very fine spatial resolution) whereas many other valuable products could be addressed at coarser resolution
- What are essential characteristics of site and campaign?
  - Strong preference for dividing 4 weeks of observations into 1 week periods throughout season at same site, i.e. importance of a full season time series
  - Also idea of designating certain “super sites” as sites that will be continuously revisited over multiple campaign years; also consider including Eastern US sites in future
  - Group noted relevance of upcoming NISAR and CIMR missions and potential activities to support prep for using these datasets
  - List of in-situ parameters was agreed with; add snow impurities to list and divide radiation into up and down-welling terms; add more information of Vegetation characteristics; consider UAV for localized BRDF measurements
  - Make sure distributed in-situ measurements over area, e.g. ground-based lidar, GPR, snow pits, snow depth probes may be redundant w.r.t GPR data
  - Recommend including hyperspectral sensing for determination of albedo/BRDF/impurities info along with in-situ BRDF info, also L-band InSAR+SweSARR+ Lidar seem to be relevant sensors
  - Consider “downscaling/sub-grid scale heterogeneity” or “full season time series” as possible themes to organize around
- Constraints: See above

Tundra / Taiga / Boreal-Prairie

What questions must your field campaign answer?

- Arctic greening and disturbance in the context emerging technologies and models
- What are the temporal and spatial aspects to push retrieval boundaries

Model as a base for a campaign or technology proving ground?

Technology Options:

- Multi-sensor approach (Centric on snow depth)
    - Airborne LiDAR (Snow depth, veg influence on snow properties)
    - L-Band In-SAR (Snow depth, SWE)
    - Multi-frequency SAR (Sub-band FMCW Off-Nadir, SWESARR)
    - SfM (Testing tolerance to lighting conditions)

- Prioritize path to space or existing space measurements

Site Selections

- Tech application is subject to environmental condition requirements
- Flight hours must build in buffer
- Time-series capturing peak SWE
- Persistent presence: Melt happens rapidly and is very different between these domains, towers need frequently maintained

Circulate plan to other communities early on to find synergies

- Small changes might be possible to answer questions in ecology or permafrost