NASA Snow Conference

March 29th – 31st 2016
University of Washington, Seattle, WA

Meeting summary report

Prepared by:

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Summary and attendees:

The meeting took place at the University of Washington between March 29th and 31st 2016. The program included a half day iSWGR meeting, 1.5 days dedicated to the planning of the SnowEx mission and half a day on JPL's Airborne Snow Observatory (ASO). The purpose of the iSWGR was to update the greater community on the transfer of leadership, to update the U.S. community about the Canadian Mission Concepts for snow remote sensing, to report on snow education initiatives and to identify emerging opportunities related to the Decadal Survey and the use of new technologies.

The SnowEx planning meeting continued discussions from summer 2015 about a ground and aerial field campaign to begin in Fall 2016 and Winter 2017. Discussions took place on the various decisions that need to be made regarding sites, sensors, sampling design and science questions. Finally, the ASO demonstration/workshop provided the greater snow community with hands-on experience using data obtained from airborne lidar from California, Colorado, and/or Washington.

This report will highlight the main discussion and action items discussed during the 2.5 day meeting. Over 60 people attended either in person or remotely. A detailed list of attendees and final program can be found in Appendix 1 and 2 respectively.

Feel free to contact either Jessica Lundquist or Alex Langlois for any comments, questions or concerns.

Jessica Lundquist and Alex Langlois
iSWGR Chairs

DAY 1

NASA International Snow Working Group remote sensing – iSWGR
8h30 – 12h00

General discussion occurred on the 'Got Snow? document, which is now available for download on the SnowEx and iSWGR website. This document is a great way to make decision-makers aware of snow-related issues. A list of industries/agencies who should receive the document was put together during the meeting.

There is a consensus on wanting to improve communication for iSWGR and the executive, and it was mentioned that the 'current' executive was unsure of the process involved on naming current chairs. A conclusion was reached that an iSWGR charter is needed and that a chain of communication should be established. Paul Racette agreed to put together a draft of the iSWGR charter, which will be circulated around for comments from the community. It is expected that a vote for the adoption of the charter will occur before the next meeting.

The 2016 ROSES call will identify 10-12 people to be on the science definition team for SnowEx and define a future snow satellite mission. Future ROSES calls will select science proposals associated with SnowEx. The current ROSES call is not a mechanism to get funding to be involved with the year 1 SnowEx field campaign. Jared Entin mentioned that he appointed Ed Kim and his team to put together SnowEx, and he plans for the process to be more open for years 2 to 5. A number of decisions needed to be made quickly given time constraints (i.e. Fall 2016 snow-free flights). Therefore, Jared will make the decisions for year 1.

It was mentioned that we could reach out to other groups (ex. GPM) and international agencies/groups (ex. Microsnow, CSA mission concept steering group) and that iSWGR could act as a mediator for all this. Simon Yueh will hold weekly teleconferences to keep track of existing and future efforts, as well as working on science definition. The Webex login information was shared by email.

Decadal survey reports are due April 30th. Matthew Sturm will take the lead for iSWGR.

A snow project office was created to facilitate communication, mentor younger scientists for snow remote sensing, and highlight significant research efforts. The project is led by Dorothy Hall, and any comments and questions can be directed to her.

An open discussion on snow schools suggested having a prerequisite for the remote sensing school. All agreed on the fact that 3 schools are necessary: measurements, remote sensing and modeling and that we need a long-term plan for this, but clarifications on funding are necessary. For the immediate future, H.P Marshall is in charge of remote sensing school, Kelly Elder will continue to run a field school, and Drew Slater will take charge of the modeling school. Alex Langlois will be the primary iSWGR liaison for schools in Canada and Europe. Jared suggested that he may add an amendment to the 2016 Terrestrial Hydrology ROSES call would be added to allow people to apply to host a snow school (or several snow schools) and still apply to be a member of the science steering group of 12.

NASA Airborne Snow Experiment – SnowEx
13h00 – 17h00

SnowEx General info and update:

- Year 1 field, Year 2 no field, Years 3-4-5 field
- Fall 2016: small deployment for snow free requirements;
- February 2017: larger deployment for the snow work, big ground crew

A round-robin type discussion worked on 4 questions. Comments on each question are summarized below:

1. What site characteristics should be a priority for SnowEx (year 1) considering the focus on forested environments?

- Range in forest variability from open, to dense and different vegetation types;
- Accessible;
- Dry snow during winter, with a period of wet snow during ablation;
- Variability in snow depth;
- Snow cover duration of 4-5 months;
- Variability in terrain with both flat and complex;
- Presence of historical records of meteorology and snow;

2. To answer the question of how much snow is there under and around trees, what should be measured? What sensors are most important to put on the plane? On the ground? If you're unfamiliar with specific sensors, what should they be able to do?

- Ground-based sensors needed, acknowledged difficulty of using aircrafts;
- Measurements:
    - Need infrastructure already on site
    - Land use/cover
    - Snow extent and SWE, depth
    - Characterize intercepted canopy snow
    - Typical geophysical variables (distributed meteorology measurements)

    - Snow and canopy structure (LAI, SV, types, etc)
- Lidar, PMW and radar to be used;
- Consider angular vs nadir measurements;
- Characterize the signal (for radar and microwave) due to forest alone without snow
- Consider adding cameras and spectrometer;
- Drones and UAVs be great, somewhat very limited in US compared to Canada;
- Do we need wall-to-wall coverage or a transect or swath?
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3. What should the measurement program for SnowEx look like? What is the sampling strategy? How should it be done?

- Lots of overlap with question 1;
- Need more visits over longer campaign;
- Coincide ground mission(s) with flights and with satellite overpasses if possible;
- 4 times per year, 2-3 during ablation period;
- Several visits, with different people;
- Over a dynamic range of snow and vegetation conditions;
- Evaluate the trade-off between scale-structure-instrumentation;
- Watershed scale, and coincident satellite passes;
- Create nested scales around existing instrumentation (watershed scale with hydrology as the integrating measurement; with smaller extent with higher frequency measurements)
- Study across gradients (range of veg types; flat to complex terrain; range of elevations; using a space for time substitution) may be sufficient without requiring wall to wall coverage or frequent repeat visits, although some wondered if it was practical to do gradients properly or if a footprint of more uniform structure would be better, focused on one small patch with multiple flights.

4. How should we use modeling and data assimilation in SnowEx?

- Areas modeling before and after the campaign;
- Use of ancillary data;
- Multiple models forced different ways;
- Make sure essential model parameters are measured (including snow microstructure, soil moisture, and forest characteristics)
- During the campaign, produce forward and backward modeling on site;
- Overall goals, spatially-coherent and time marching distributions of all the parameters we're interested in that merge observations, using knowledge of which observations work best when and were, to move from direct observations to useable products

The group working on question #4 also raised a question on data management for SnowEx. The SnowEx team acknowledged the information and will work on this aspect. Amanda Leon from NSIDC introduced herself as attending to take stock of data management needs.

DAY 2

NASA Airborne Snow Experiment – SnowEx
8h30 – 17h00

A panel on lidar discussed several theoretical and logistical aspects of ASO and LVIS. This panel was followed by another round-robin session working on the following 6 questions:

1) What are the current limitations and constraints using airborne lidar? What snow properties are crucial to lidar measurements?

- Clouds and dense vegetation can be a problem;
- Full waveform lidar is better than just point returns and is essential for distinguishing canopy characteristics from snow (both ASO and LVIS use this)
- IMU (inertial motion unit) error is angular and therefore worse the further off the ground you get
- Accuracy depends on slope and ground point density – higher slopes have more error
- 1064 wavelength is best for snow
- There are tradeoffs: higher altitude flights have wider swath (better covereage) but lower spatial resolution and accuracy; for example, LVIS flies at 10 km height and has a 5-10 m ground footprint
- Tom Painter expressed that while lidar is excellent from an aircraft, radar is our path to space for the upcoming decade.

2) What are the current limitations and constraints using airborne VIS-IR? What snow properties are crucial to VIS-IR measurements?

   - Clouds are a problem;
   - Vegetation and shaded are a problem, covering snow;
   - Interesting work to be done on fractional snow cover vs albedo;
   - Spectrometers to be used;
   - Proper Tsurface needed (radiometric);

3) What are the current limitations and constraints using airborne radar? What snow properties are crucial to radar measurements?

   - Need dry snow;
   - Snow free areas need to be characterized,
   - Bare soil in Fall needs to be characterized;
   - Signal is sensitive to snow grain size and shape;
   - Lower frequencies are less sensitive to this issue, but they are also less mature;

- Higher frequencies (X, Ku) won't penetrate forest canopies – L-band might work better but is a relatively new technology so performance is not well-known

4) What are the current limitations and constraints using airborne PMW? What snow properties are crucial to PMW measurements?

    - Need detailed grain size and stratigraphy;
    - Wetness is important in a dielectric context;
    - Soil roughness, freeze-thaw state;
    - SWE and bulk variability;
    - Typically get 250-500 m resolution from aircraft
    - Works better over flat terrain (complex terrain will be a problem)
    - Intercepted snow on trees will be a problem
    - Problems:
        - lower sensitivity to depth compared to grains;
        - saturation at 150 mm of SWE with typical 19-37GHz frequencies, can go lower but then run into RFI issues;
        - Spatial resolution is coarse;
        - Complex terrain is a problem;

5) What are the current modeling limitations and constraints from both snow and radiative transfer perspectives?

    - Need a vegetation model;
    - Need a snow model;
    - Fine scale required, aggregating often causes problems;
    - Do not underestimate the importance of proper forcing input data (precision, sensitivity of models to uncertainties in inputs);
    - Grain size and layering necessary for passive microwave modeling remains a challenge
    - Snow interception by trees remains a challenge
    - Scale issues with forest-snow interactions is a challenge

6) What are the current limitations and constraints measuring basic snow geophysical properties? What do we measure well, where do we lack?

    - Need to be accessible, and repeat over the winter;
    - Easy to use snowmobiles;
    - Safety vs measurements;
    - Wet snow conditions will be hard;
    - Frequent calibration will require infrastructure;
    - Consider data management
    - It's extremely difficult to quantify snow intercepted by trees

Break-out groups were then asked to each come up with their top 3 sites. Three sites were common across all six in-person groups at the meeting:

1. Western Colorado (Senator Beck, Uncompahgre, Grand Mesa)
2. Mammoth Mountain
3. Canadian Rockies

All of these sites are at relative high elevations, which will need to be considered with regards to aircraft and instrument availabilities and capabilities. Also, a seventh group of phone-in scientists expressed a strong desire for a field site in Alaska. (Note that many Alaskan scientists were prevented from attending the meeting due to volcanic eruptions stopping air flights out of the area and thus could only participate via phone.)

A panel of modeling experts described how snow fits in their modeling. The panel consisted of Leung Tsang (Open source microwave forward models, computer snow, snow correlation functions from grain sizes, solving Maxwell equations, SWE retrieval algorithm), Bart Njissen (continental scale snow and hydrology modeling), Sarah Kapnick (global climate models), and Glen Liston (high resolution modeling over intensive field study domain). In order to help in potentially developing requirements/preferences from potential "end use" cases on accuracy and spatiotemporal resolution, a suite of synthetic data assimilation experiments in a suite of basins to characterize land surface/hydrologic model sensitivity to retrieval errors and spatiotemporal resolution should be considered.

To make the hard decisions of what must be included in SnowEx, groups were then asked to create a Science Traceability Matrix for SnowEx as they envisioned it. The format for a Science Traceability Matrix is as follows:

Science Goal: Define a clear question related to understanding scientific processes (e.g., "Understand the physical controls on snow amounts and melt contributions worldwide.")

Science Requirements: Define what, specifically, you need to measure to answer the above question (e.g., "quantify SWE amounts worldwide")

Range and Precision: Define the range of values you need to measure and the precision with which you need that measurement to answer the science question (e.g., 0-3 m $\pm$ 0.1 m).

Frequency: Define how often you need that measurement to answer the science question (e.g., daily).

Spatial Domain: Over what domain do you need the measurement (e.g., everywhere on the globe with snow).

Spatial Resolution: Define at what resolution do you need the measurement (e.g, 500 m).

After a discussion on science questions that should drive SnowEx, a third round-robin working on the questions and requirements occurred. A total of 6 groups worked on defining a question with science requirements and measurement strategy to answer the question. The following 6 questions were established by the 6 groups, underlined and bold are words being repeated/synonyms:

Science questions:

Question 1: What is the **<u>spatial</u>** and temporal **<u>variability</u>** of snowpack characteristics?
Question 2: What is the **<u>spatial</u>** distribution of basin snow water storage?
Question 3: What are the **<u>spatial</u>**, inter-annual **<u>variability</u>** and secular trends of snow?
Question 4: How does snow depth **<u>change</u>** between small and larger scales, what are the **<u>effects</u>** of canopy and impacts on streamflow?
Question 5: Quantify the **<u>controls</u>** on snow maps, mass fluxes and energy fluxes.
Question 6: SWE?

Although the questions did not all follow the traditional traceability matrix format, they were all remarkably similar in wanting to understand the controls on spatial and temporal variability in snow amounts and properties. Specific requirements had more variability (see table below).

Review of requirements:

Variable	Precision	Resolution/Scale	Range	Synoptic
SWE	5-10%; 10cm; 10-20%	1m; 100m; 30m (monthly) 0.5-1km (daily); 1km;	0-2000mm; 0-4m; 0-5m;	10-20 days (winter) 2-6 days (ablation); Daily;
Snow depth	5% thin; 10% thick	1-3m;	0-10m;	Daily
Albedo	5%;	5-10cm;	-	Daily;
Density	30-50 kg·m^{-3};	5-10m;	0-1000 km·m^{-3};	-

DAY 3

NASA Airborne Snow Observatory – ASO
8h30 – 12h00

The Airborne Snow Observatory Team described their datasets, basin flown, methods of operation and processing, and data availability.

Sample ASO data are available here:
https://drive.google.com/open?id=0B7q3u1hfVsFKSzdpMHdrcGZ1dEk

All ASO presentation slides are available here :

https://drive.google.com/folderview?id=0B3abwEuUCDlQTGxMczJnaTlLQlU&usp=sharing

APPENDIX 1
List of attendees

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APPENDIX 2
Final program

Day 1: Tuesday 29 March 2016

8h00-8h30 Continental Breakfast Provided at Conference Location
8h30-8h45 Welcome and messages (M. Sturm, J. Lundquist)

NASA International Snow Working Group remote sensing - iSWGR

8h45-9h15 **Review of recent 2015-2016 iSWGR activities and leadership change**
9h15-10h30 **Decadal survey updates**

10h30-11h00 Break, Discussion

11h00-11h30 **Update on ROSES call, Snow Project Office**
11h30-12h00 **PAST and FUTURE Snow schools discussions**

12h00-13h00 Lunch on site

NASA Airborne Snow Experiment - SnowEx

13h00-13h15 **Opening Remarks**
13h15-13h30 **SnowEx background 1**
13h30-14h00 **Survey results and Round Robin Instructions**
14h00-15h00 **Round Robin #1 of 3**

15h00-15h15 Break

15h15-15h45 **Compilation of subgroup questions & results**
15h45-16h30 **Results overview / Reporting**
16h30-17h00 **SnowEx background 2 and Q&A**
(site criteria, site inventory)

17h00 **Adjourn, Happy hour 17h00-19h00 on site**

DAY 2: WEDNESDAY 30 MARCH 2016

8H00-8H30 CONTINENTAL BREAKFAST PROVIDED AT CONFERENCE LOCATION

NASA Airborne Snow Experiment - SnowEx

8H45-9H00 **CONSTRAINTS (PHYSICAL, FINANCIAL, TIMELINE)**
GROUND-BASED REMOTE SENSING INVENTORY CALL
9H00-9H30 **LIDAR PANEL**
9H50-10H20 **LIMITATIONS**

7) WHAT ARE THE CURRENT LIMITATIONS AND CONSTRAINTS USING AIRBORNE LIDAR? WHAT SNOW PROPERTIES ARE CRUCIAL TO LIDAR MEASUREMENTS?
8) WHAT ARE THE CURRENT LIMITATIONS AND CONSTRAINTS USING AIRBORNE VIS-IR? WHAT SNOW PROPERTIES ARE CRUCIAL TO VIS-IR MEASUREMENTS?
9) WHAT ARE THE CURRENT LIMITATIONS AND CONSTRAINTS USING AIRBORNE RADAR? WHAT SNOW PROPERTIES ARE CRUCIAL TO RADAR MEASUREMENTS?
10) WHAT ARE THE CURRENT LIMITATIONS AND CONSTRAINTS USING AIRBORNE PMW? WHAT SNOW PROPERTIES ARE CRUCIAL TO PMW MEASUREMENTS?
11) WHAT ARE THE CURRENT MODELING LIMITATIONS AND CONSTRAINTS FROM BOTH SNOW AND RADIATIVE TRANSFER PERSPECTIVES?
12) WHAT ARE THE CURRENT LIMITATIONS AND CONSTRAINTS MEASURING BASIC SNOW GEOPHYSICAL PROPERTIES? WHAT DO WE MEASURE WELL, WHERE DO WE LACK?

10H20-10H30 BREAK

10H30-11H00 **REPORT ON LIMITATIONS**
11H00-11H30 **PICK TOP 3 SITES**
11H30-12H00 **COMPILATION OF TOP SITES**

12H00-13H15 LUNCH

13H15-13H30 **OPEN PANEL FOR GROUP QUESTIONS ON MODELING**
13H30-14H00 **RESULTS SITE SELECTION AND RATIONALE**
14H00-15H00 **ROUND ROBIN #3 OF 3**

- SCIENCE TRACEABILITY MATRIX
- SKETCH YOUR IDEAL CAMPAIGN

15H00 COFFEE

15H00-15H30 **ROUND ROBIN #3 OF 3**
15H30-16H30 **REPORTING (2 SLIDES: 1 MATRIX – 2 CAMPAIGN)**
16H30-17H00 **CONCLUDING ON QUESTIONS, <u>DECISION</u>** (

17H30 HAPPY HOUR AT IVAR'S SALMON HOUSE
18H30 GROUP DINNER

Day 3: Thursday 31 March 2016

8h00-8h30 Continental Breakfast Provided at Conference Location
8h30-8h45 Welcome and messages (J. Lundquist)

NASA Airborne Snow Observatory - ASO

8h45-9h00 **ASO introduction** (
9h00-10h00 **Overview of ASO Capabilities**, Activities and Results

10h00-10h30 Break, Discussion

10h30-11h30 **ASO Data Demonstration**:
Bring Your Own Computer Hands On Activities
(Data Samples provided ahead of time for download)

11h30-12h00 **Integration with/Implications for SnowEx discussion**

12h00-13h00 Lunch on site

END