WORLD METEOROLOGICAL ORGANIZATION

Polar Space Task Group

Summary of the Snow Radar Science Meeting

30-31 January 2018

World Meteorological Organization

7bis, avenue de la Paix, Geneva

1 Introduction

The snow radar science meeting held 30-31 January 2018 had its genesis in the World Meteorological Organization Polar Space Task Group, specifically the Synthetic Aperture Radar (SAR) Coordination Working Group which works closely with the polar science community to coordinate space agency and industry polar SAR data acquisitions to support research needs. Snow science represents a key theme within the Working Group.

In recognition of the need to better understand snow mass properties and the potential for satellite-based radar measurements to support this information requirement, the PSTG welcomed the opportunity to host a meeting of leading snow and radar science experts. Discussion was organized to focus on addressing current and future needs facing the international snow science community, understand the status of efforts to address these issues with satellite-based data collection, and discuss mechanisms for collaboration.

In her welcoming address to meeting participants Rodica Nitu, WMO Global Cryosphere Watch (GCW) program manager, noted the importance of snow science issues to WMO, particularly in polar and high mountain environments. GCW is a developing program under the WMO mandate that seeks to link cryosphere science to specific WMO policy and service decisions.

Within this context, WMO is interested in the synergy between the arctic observation network and satellite-based cryosphere data collection. Rodica noted that this network can be an important source of ground-based data for validation of satellite observations.

2 Meeting Objectives

The key meeting objective was to endorse a set of recommendations and actions to address the priority scientific, technical, and operational challenges which must be addressed to advance the scientific foundation of emerging spaceborne radar snow missions.

Following this consultation and based on the agreement and endorsement of the workshop attendees, it was intended to provide these recommendations and actions via WMO/EC-PHORS/PSTG to scientific bodies and heads of space agencies for further coordination.

Ultimately, there is a desire to develop an overall science plan, from which components can be selected and addressed within individual, national, or agency level proposals and activities.

Meeting Themes

The two-day meeting was structured around discussion on seven thematic areas. Each theme begin with a short presentation focused on relevant overarching science goals followed by a series of key issues facing the community with respect to that particular theme. A round-table discussion followed with the goal of producing a theme-related recommendation for endorsement.

The seven themes were:

1) Review ***gaps in current snow products***; reconfirm SWE observation requirements;
2) Identify priority ***driving scientific questions*** and required geophysical products;
3) Review ***mission requirement maturity as well as technical readiness levels*** of potential mission concepts to fulfill measurement requirements for snow;
4) Identify ***observational (field campaign) and modeling studies*** to support and advance SWE retrieval techniques relevant to mission concepts (science readiness level);
5) Identify the state of readiness for ***operational data assimilation;***
6) Identify ***secondary geophysical parameters*** for a snow radar mission in order to broaden the scientific and user base; and
7) Define potential avenues for near term (3-5 years) ***inter-agency collaboration*** on a satellite snow mission, including scientific, technical and programmatic partnerships.

A brief discussion document was circulated to participants in advance of the meeting. For each theme, current status statement and recommendations were proposed as a means of guiding discussion.

Each theme session had its own expert facilitator who began the session with a presentation on the current status and key issues to be addressed. This was followed by discussion among meeting participants.

Recent Context

Chris Derksen of Environment and Climate Change Canada introduced the meeting, pointing out the high degree of current global activity around snow science of relevance to the discussion of satellite-based cryosphere data collection. Several recently completed or ongoing initiatives were highlighted including:

- CoReH2O Phase 0 and Phase A work undertaken as part of ESA Earth Explorer-7;
- The ESA 'SnowConcepts' project initiated in 2017 and with planned completion in 2018;
- The Canadian Space Agency Terrestrial Snow Mass Mission concept study with planned completion in 2018;
- NASA's first NASA SnowEx campaign in February 2017;
- U.S. Decadal Survey released in early January 2018; and
- Submission of a snow radar mission proposal under the ESA Earth Explorer-10 initiative.

3 Discussion Overview

Each of the workshop themes are presented in this section, highlighting the initial status and recommendations followed by key priorities arising from the discussion.

Theme 1: Status of Snow Data Products

Facilitator: Helmut Rott

Status: Recent dataset inter-comparison studies such as the ESA Satellite Snow Product Intercomparison and Evaluation Exercise (SnowPEx) have significantly advanced understanding of the level of agreement and primary sources of uncertainty in current snow extent and SWE products. The spatial resolution and accuracy of these SWE products is insufficient to address requirements for operational environmental prediction and climate services.

Recommendation: Advance the development of new satellite mission concepts through coordinated engagement of technical, scientific, programmatic, and applications-focused elements.

Actions:

Review and revise the documentation on snow observation requirements (SWE and other parameters), accounting for the specific needs to address priority science questions and applications in operational forecasting.

Review and quantify the information content of current satellite microwave sensors for observing snow physical properties (including SWE) that to date have been only marginally exploited for these tasks (e.g. L-band SAR interferometry, Ku-band radar).

Elaborate a comprehensive strategy for snow observations that comprises current satellite missions, in situ measurements and snow process models, to optimize the exploitation of current observation systems and to support the definition of new satellite snow missions.

A great deal of effort has been made through past studies to define snow data product requirements. Tables on observation requirements (spatial resolution, repeat coverage, accuracy) have been compiled by various organizations and in the frame of international initiatives, addressing needs for science and operations. While comprehensively documented, the requirements in terms of spatial resolution and repeat coverage show a wide spread depending on the application.

Because of the diverse requirements, a given sensor type can serve only a subset of user needs. As a result, definition of priorities in terms of applications including clear definition

of accuracy requirements is needed for selection and development of suitable sensor(s) and satellite missions.

Ensuing discussion highlights included:

- Past efforts to define snow observation requirements remain valid but there is a need to update some aspects
- The importance of ground observations was highlighted as the community draws on a combination of remotely sensed data, modeling, and surface observations
- ongoing inter-comparison studies (i.e. SnowPEx) and snow/climate projects independent of new mission development efforts (CCI+; ESM-SnowMIP; etc.) are important
- Continuing coordination and expansion of the in-situ snow measurement network is important for supporting SWE retrievals from satellite data and for validation.
- The definition of requirements for SWE satellite products should also take into account the availability / need for complementary satellite snow products (i.e., snow cover extent, etc).

Theme 2: Identifying Priority Science Drivers

Facilitator: Chris Derksen

Status: Development of science drivers and product requirements is ongoing through a variety of loosely coordinated activities at various agencies (NASA, ESA, CSA etc.). A rigorous assessment of scientific readiness levels are required to support mission concept proposals.

Recommendation: Improve communication and linkages between snow mission development activities to strengthen proposal development for both mission concepts and supporting scientific activities.

Actions: Collate science drivers, science traceability matrices, geophysical product requirements (L1 to L4), and science readiness levels from ongoing and recently completed concept studies at CSA, ESA, and NASA.

Discussion around this theme focused on identifying the priority science questions/drivers to address terrestrial snow water equivalent. These questions can then drive the definition of spaceborne measurement requirement and the required modelling and retrieval algorithms.

A question was posed as the potential to define science readiness levels from previous missions and activities such as QuikScat.

An additional challenge may be the need to balance the science requirements for snow mass with other variables and the needs of other communities.

Discussion highlights included:

- Freshwater availability has emerged as a key driver for snow mass projects/missions
- Unique aspects to 'science' vs. 'application' drivers
- No single mission concept can address all snow science drivers, so clear user requirements linked to science need(s) are required to drive concepts
- Important to identify opportunities for added value to baseline missions through additional parameters

Theme 3: Mission Requirements Maturity and Technical Readiness

Facilitator: Michael Kern

Status: Reviews of multiple snow mission concepts were conducted within the ESA SnowConcepts project. NASA JPL has reviewed general snow radar mission configurations. Snow radar mission concept development is ongoing in Canada via a CSA contract to Airbus.

Recommendation: Endorsement of a wide-swath, moderate spatial resolution Ku-band radar concept as one approach to address snow, ice, and ocean winds applications. Continue to develop the potential viability of other options, including InSAR-based (single and repeat pass) approaches.

Actions: Define and implement science support activities and campaigns to address scale analysis (for example, extend synergistic active/passive microwave SWE retrievals from the plot scale to airborne and satellite measurements).

Investigate opportunities to advance understanding of snow (depth) on sea ice.

Pursue efforts to address end-to-end simulation capabilities (CoReH20 simulator provides a starting point).

Evaluate the potential impact of a snow mission on Numerical Weather Prediction activities.

The intent of this theme was to discuss snow science from the mission perspective. Examples were drawn from ESA processes and the Canadian Space Agency Terrestrial Snow Mass Mission concept study.

Clear linkages between user needs, science readiness levels, and mission technical concepts is essential for proper mission definition and system and payload requirements. This requires that scientific goals must be clearly defined and translated into mission objectives (see Theme 2), mission requirements and system requirements. As mission and engineering changes are made, it is important to be able to maintain a traceable link back to user needs.

Key discussion outcomes included:

- It is critical to establish traceable links from user needs to a measurement concept with a defined technical readiness level roadmap to a geophysical retrieval

methodology with a SRL and error through to an appropriate calibration/validation plan
- The use of measurements from other missions is important to fully address the snow science issues (for instance, low frequency radar for soil freeze/thaw etc.)
- The community needs to define a roadmap of relevant activities to increase TRL

Theme 4: Supporting Experimental Campaigns and Modelling Requirements

Facilitator: Juha Lemmetyinen

Status: The ESA SCADAS project has completed coordinated analysis of past SnowSAR campaigns. A CSA/ECCC/NASA/UMass Ku-band radar campaign is planned for Canada in March 2018/19. The NASA SnowEx program provides potential campaign opportunities.

Recommendation: Continue coordinated campaign planning and data sharing between ESA, CSA/ECCC, NASA, and other agencies.

Action:

Coordination of already planned campaign activities should focus on addressing gaps in the previously acquired NoSREx and SnowSAR datasets. Campaigns should ensure quantification of snow microstructure is performed comprehensively using a variety of instrumentation, to collect the relevant input information for the latest forward models. Lessons learned from CoReH2O campaigns should be a priority in campaign planning, including. the acquisition of snow-free backscatter scenes for reference (missed in almost all SnowSAR campaigns to date).

Expand the scope of campaign activities to address potential new concepts in terms of wavelength and sensor combinations (e.g. Ka-band radar; coincident active/passive observations). Dedicated campaigns should focus on new methodologies employing InSAR techniques. Campaigns addressing snow on sea ice using multiple radar frequencies should be initiated.

The session began with a summary of the SCADAS project which provided a review of past SnowSAR field campaigns. The review highlighted the importance of understanding radar backscatter relationships to microstructure and SWE. The datasets collected in CoReH2O phase A allow for comprehensive assessments of snow cover backscattering signatures over certain terrain types, and have revealed new information especially regarding spatial variations in snow microstructure. However, some gaps in the acquired datasets still prevent a full assessment of the CoReH2O retrieval approach for SWE. It was also noted that new approaches to SWE retrieval, InSAR evaluation, modeling capabilities, field observing techniques etc. have all advanced since CoReH2O (2009-2011).

Similarly, new instrument development opportunities exist (i.e. SnowLab; JPL snow radar) as do new field deployment opportunities (i.e. NASA SnowEx)

The discussion reiterated the need to define a roadmap of relevant activities to increase snow mass retrieval SRL.

Theme 5: Data Assimilation

Facilitator: Richard Essery/Patricia De Rosnay

Status: Snow physical models have advanced, and can provide snow microstructure variables when forced with temperature gradient and liquid water content inputs which could soon be available from operational prediction systems.

Further development and validation studies are required to ensure physical snow models can provide snow microstructure simulations of suitable quality for assimilation and retrieval applications. New radar modeling frameworks have recently been developed and are being implemented in data assimilation systems for experimentation.

Recommendation: Coordinate progress between operational centers on coupling physical snow models with forward radar models; identify priority research areas (i.e. OSSEs, required model development) to advance the capacity to assimilate radar measurements over snow covered areas.

Actions: Inter-comparison of forward radar modeling using state-of-the-art snowpack information from several operational Centers (comparing offline forward modeling is a first step before coupling). While requiring investment of resources, comparison between several centers will identify the spread due to the physical models which is also a useful indication of readiness. It would also clarify areas of improvements for each center involved.

Conduct Observing System Simulation Experiments (OSSE's) to determine potential impacts of backscatter assimilation.

It was noted that current operational snow models are relatively simple but various centres are moving towards the use of multi-layer snow models with prognostic temperature, density and liquid water content. While not all of these include representations of snow microstructure, as the evolve the ability to predict temperature gradients and liquid water in snow will be essential for extending models to include microstructure as a later step.

Influences of SWE and microstructure on microwave radiance and backscatter from snow are difficult to disentangle. Well-validated microstructure models could provide the

necessary background information for assimilation. Field studies combining snow structure and microwave measurements are important for this validation.

For operational NWP, direct assimilation of level-1 observations is the preferred approach based on comments from Patricia de Rosnay of the European Centre for Medium-Range Weather Forecasts. Binary snow / no-snow information provides most information at short lead times, but ability to constrain snow mass will be more important on medium range to seasonal scales (no in situ or remote snow mass is currently assimilated). Assimilation of SWE products would also be beneficial for hydrological forecasting. Assimilation of optical properties of snow could also be beneficial, both for large influence on surface energy balance and perhaps for constraint of near-surface microstructure.

Considerable progress has been made in microwave radiative transfer modelling for snow. Research codes are more sophisticated than those used in operational centres but there is a move to more sophisticated implementation.

Microwave forward modelling has mostly been implemented in advanced DA frameworks (EnKF, PF) for research. Operational land DA currently uses simple approaches (e.g. OI). Moves towards better integration of land and atmospheric DA is in the plans at ECMWF and at ECCC as it would also benefit from improved radiometric characterisation of snow-covered land surfaces (e.g. better exploitation of lower troposphere sounding channels). Sub-km resolution of radar satellite concepts is good for current and near-future NWP grid scales, but ideal latency < 4 hours is challenging.

Theme 6: Potential Secondary Parameters for Snow Radar Missions

Facilitator: Simon Yueh

Status: Measurements from previous Ku-band radar missions were successfully exploited for ocean winds, sea ice, land ice, and frozen ground applications.

Recommendation: Emphasize variables in addition to terrestrial snow in mission proposal documents; increase engagement of sea ice and ocean winds scientific and user communities.

Actions:

Understand information requirements for key application areas and demonstrate the advantages of Ku band applications.

Assess the impact of secondary parameter support on mission operational constraints (such duty cycle, data accessibility, etc.).

In the context of a potential Ku-band snow mission, there is considerable published reference to the utility of these data in the measurement of other geophysical parameters related to:

- ocean winds (detailed wind features, upwellings);
- sea ice (multi-year ice discrimination, onset of melt, ice motion);
- land ice;
- lake ice;
- landscape freeze/thaw state

While potential broader applications exist, it will be important that they be considered in a manner that does not compromise core snow measurement requirements, particularly on data access, duty cycle, etc.

Theme 7: Inter-Agency Programmatics and Collaboration

Facilitator: Yves Crevier

Status: Inter-agency partnerships on snow and radar mission development are presently informal.

Recommendation: Use existing programs and coordination frameworks (distributed globally) to ensure coherent and cohesive advancement of scientific and technological challenges related to the monitoring of snow cover - building on existing technology development and scientific advancement programs.

Actions: Regional and thematically focused coordination activities are currently ongoing under the authority of several space agencies. Some of those coordination activities are project and instrument/mission focused and time constrained. In order to ensure coordination continuity among the snow science community and to facilitate the dialogue with a broad set of space agencies, the creation of an ad hoc snow remote sensing science working group under the auspices of the Polar Space Task Group is recommended. This new working group would build-on the regional working groups currently supported, ensure alignment to the overarching GCW coordination objectives towards the consolidation of a global monitoring network for snow, and finally provide a neutral forum to address key science and technology related priorities to be presented to CEOS and CGMS agencies.

The session included presentations on several operational missions and programs as well as some future mission opportunities supporting snow science initiatives. A presentation of the recently published U.S. National Academies of Science, Engineering and Medicine Decadal Survey for Earth Observation from Space, highlighted recognition of the importance

of ongoing snow science observation in the areas of snow mass, snow amount and melt rates, ice sheet elevation and surface deformation.

Additional updates were provided by:

- NASA International Snow Working Group Remote Sensing;
- European Commission Copernicus Services and Plans;
- ESA Explorer 10 Overview; and
- WMO Global Cryosphere Watch.

4 Conclusions and Recommendations

The snow radar science meeting provided a venue for international representation by snow science experts and supporting organizations. In total eight countries and regional organizations participated in addition to several research/science institutions, operational centers, industry, and space agencies.

The discussion confirmed agreement that snow is a key observational gap and that among the distributed interest groups there was a converging interest in addressing this gap based on sound science drivers and policy anchors. These interests are leading to the development of snow earth observation mission concepts, numerous experimental measurement programs, technological development, and advancements in snow science.

It was generally agreed that given the numerous scientific and technological challenges still to be addressed, *ad hoc* coordination was not optimal. In order to ensure coordination continuity among the snow science community and to facilitate the dialogue with a broad set of space agencies, the creation of an ad hoc snow remote sensing science working group under the auspices of the Polar Space Task Group is recommended.

The benefit of a coordinated approach includes the following:

- By distributing the workload, existing and new resources can be leveraged to maximize complementary scientific advances and minimize duplication;
- The potential exists to distribute costs as opposed to pursuing single sources of funding; and
- Applying multiple resources increases the potential that the “best minds” will be at work to address the challenges.

Addendum I- Meeting Agenda

Polar Space Task Group Snow Radar Science Meeting
World Meteorological Organization
7bis, avenue de la Paix, Geneva
30-31 January 2018
Workshop Agenda (v9)
Meeting Room: C2 (basement)

Tuesday 30 January

9:00	Welcome and Introductions	Rodica
9:45	Meeting objectives and review of pre-workshop recommendations	Chris Derksen
Review gaps in current snow products; reconfirm priority SWE observation requirements Facilitator: Helmut Rott		
10:00	Overview presentation and seed questions	Helmut Rott
10:30	Discussion: review status, draft recommendations, and proposed actions	All
11:15	Break	

Identify priority driving scientific questions and required geophysical products Facilitator: Chris Derksen		
11:30	Overview presentation and seed questions	Chris Derksen
12:00	Discussion: review status, draft recommendations, and proposed actions	All
13:00	Lunch	

Review mission requirement maturity as well as technical readiness levels of potential mission concepts to fulfill measurement requirements for snow Facilitator: Michael Kern		
14:00	Overview presentation and seed questions TSMM mission concept	Michael Kern Geoff Burbidge
14:30	Discussion: review status, draft recommendations, and proposed actions	All
15:30	Break	

Identify observational (field campaign) and modeling studies to support and advance SWE retrieval techniques relevant to mission concepts (science readiness level) Facilitator: Juha Lemmetyinen

16:00	Overview presentation and seed questions	Juha Lemmetyinen
16:30	Discussion: review status, draft recommendations, and proposed actions	All
17:30	End of day	

Wednesday 31 January

9:00	Review of Day 1	Chris Derksen
Identify the state of readiness for operational data assimilation Facilitator: Richard Essery (via WebEx)		
9:15	Overview presentation and seed questions	Patricia de Rosnay
9:45	Discussion: review status, draft recommendations, and proposed actions	Richard Essery
10:45	Break	

Identify secondary geophysical parameters for a snow radar mission in order to broaden the scientific and user base Facilitator: Simon Yueh		
11:15	Overview presentation and seed questions	Simon Yueh
11:45	Discussion: review status, draft recommendations, and proposed actions	All
12:45	Lunch	

Define potential avenues for near term (3-5 years) inter-agency collaboration on a satellite snow mission, including scientific, technical and programmatic partnerships Facilitator: Yves Crevier		
14:00	Overview presentation and seed questions U.S. Decadal Survey and snow Earth Explorer 10 Overview Copernicus Program WMO Global Cryosphere Watch Program	Yves Crevier H-P Marshall Michael Kern Mark Dowell Rodica Nitu
15:00	Discussion: review status, draft recommendations, and proposed actions	All
16:00	Break	

Final endorsement of workshop recommendations		
16:30	Discussion	All
18:00	End of day	

Addendum II – Participant List

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