Radar observations of seasonal snow in an agricultural field in S. Ontario during the 2013-2014 winter season

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I) Study Site

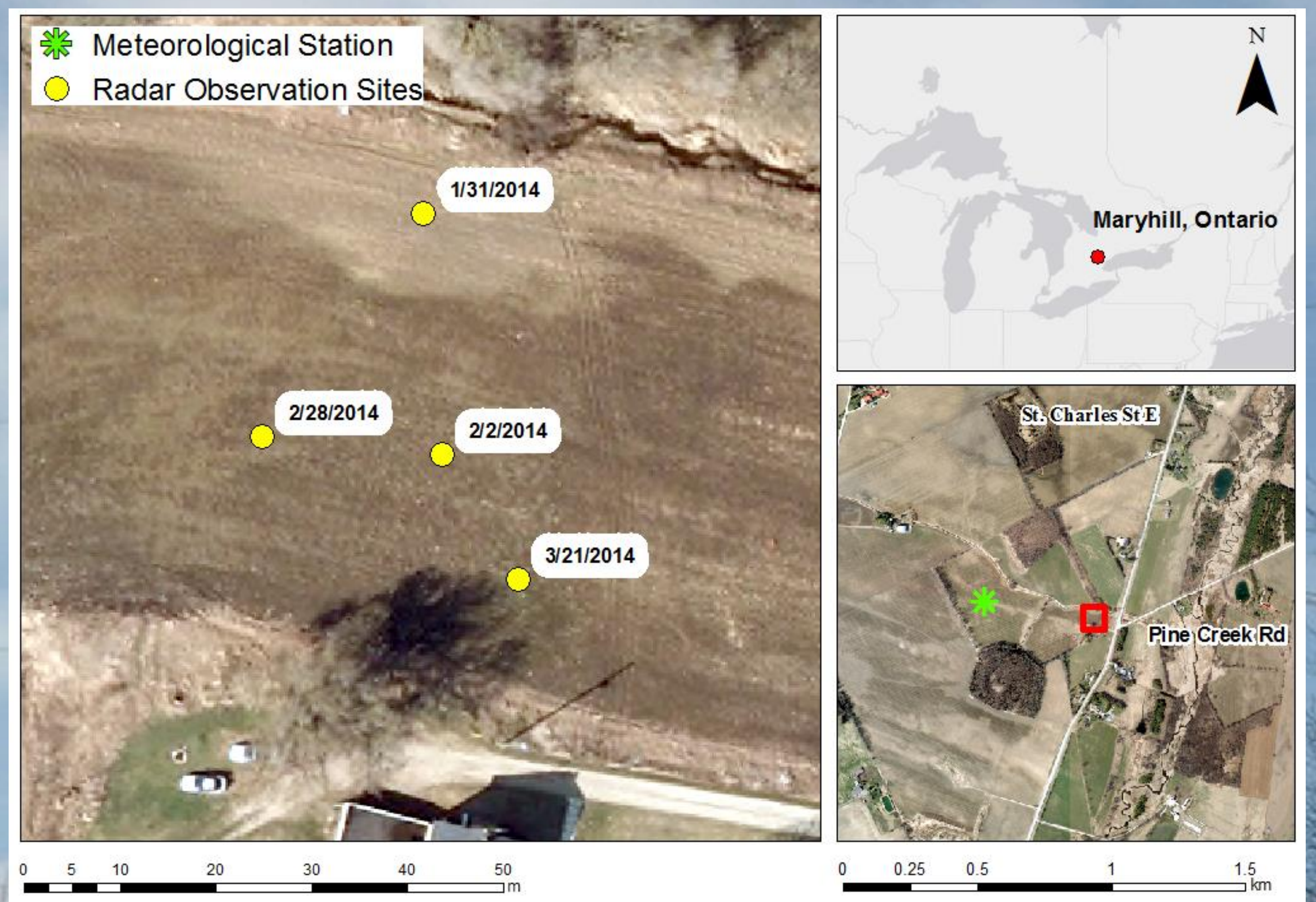

Figure 1. Study site near Maryhill, Ontario (Environmental Systems Research Institute, 2014; Ontario Ministry of Natural Resources, 2010)

The study site was located in a cut hay field, on Guelph loam and was visited 4 times between January and March; on each visit different levels of SWE were observed:

DATE	Snow Depth (cm)	Snow Density (kg/m^3)	SWE (mm)
January 31, 2014	40	344	138
February 2, 2014	28	287	80
February 28, 2014	55	280	154
March 21, 2014	23	420	97

Table 1. Summary of snow conditions at Maryhill for different dates.

The soil surface was characterized by 5 cm-deep furrows oriented in an E-W direction, with 55 cm spacing:

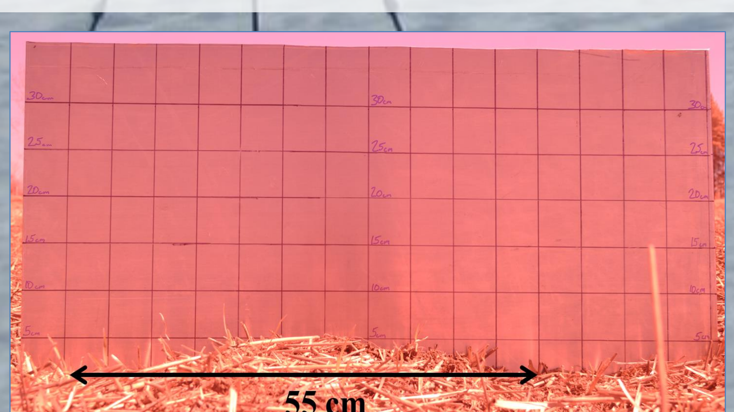

Figure 2. Typical roughness profile of field.

Air temperatures remained below 0°C for most of the observation period. During the first three observations the snowpack was cold and dry and the underlying soil was frozen. On March 21, the 2 m air temperature approached 0°C and melt was observed; the snowpack was wet and isothermal at 0°C. The soil surface thawed.

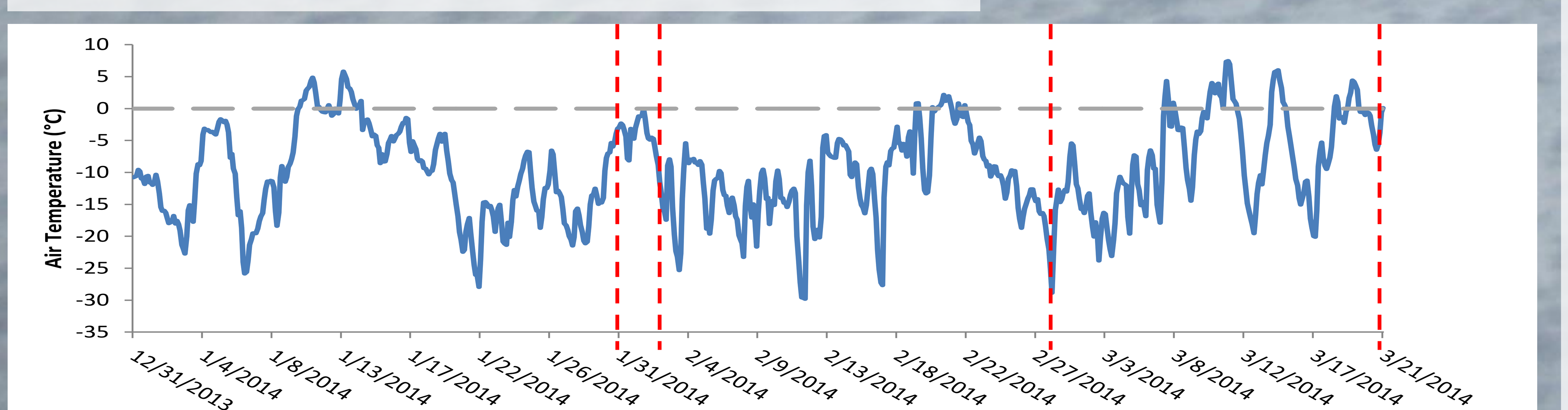

Figure 3. Air temperatures (2 m) for the study period. Red lines indicate observation dates.

RATIONALE: Studies in the European Alps, sub-Arctic Scandinavia and Canada have demonstrated a strong relationship between Ku- and X-band scatterometer observations and SWE. However, observations of SWE in mid-latitude continental snowpacks dominated by low pressure cyclones and lake-effect snow have not been tested using Ku- and X-band observations.

AIM

Explore Ku- and X-band response to moderate snow accumulation in an open field in S. Ontario

OBJECTIVES

- Understand backscatter from seasonal snow
- Understand polarimetric response
- Develop field data set to test microwave scattering models

II) Methods

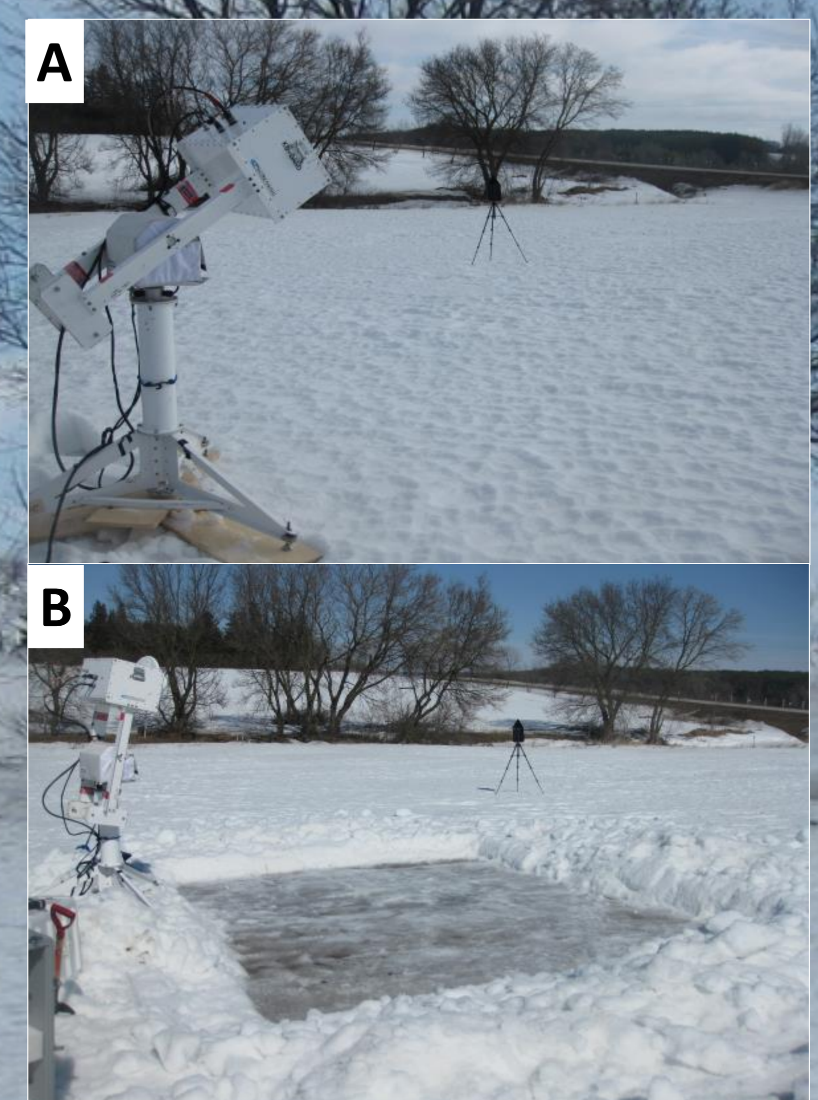

Figure 4. Scanning undisturbed snow (A) and excavated site (B) on March 21.

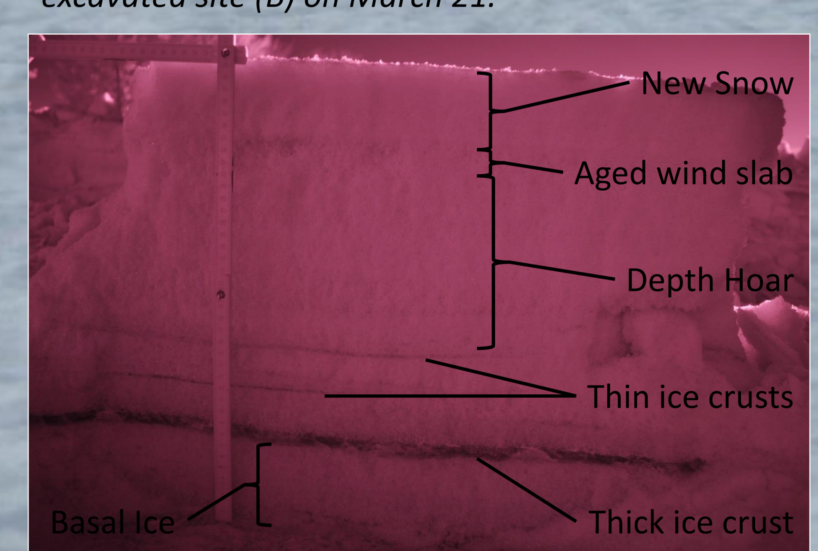

Figure 5. February 28th snow pit. Photo was taken with an infrared filter.

Radar observations were made at X- and Ku-band frequencies (9.6 GHz and 17.2 GHz respectively) using a fully polarimetric ground based scatterometer in a narrow-beam configuration.

The snow was first scanned in its natural state and then excavated to reveal the underlying soil. The bare soil was then scanned using the same parameters as the snow-on scans. In both cases, backscatter was observed.

In-situ measurements of snow were made at each observation site. Snow depth was measured using a Magnaprobe within a 10x10 m area in the radar field of view. A snow pit was excavated at each site and the stratigraphy was observed; snow samples were weighed for density and SWE calculations.

Backscatter was compared to elevation angle and SWE for snow-on and snow-off conditions.

III) Results

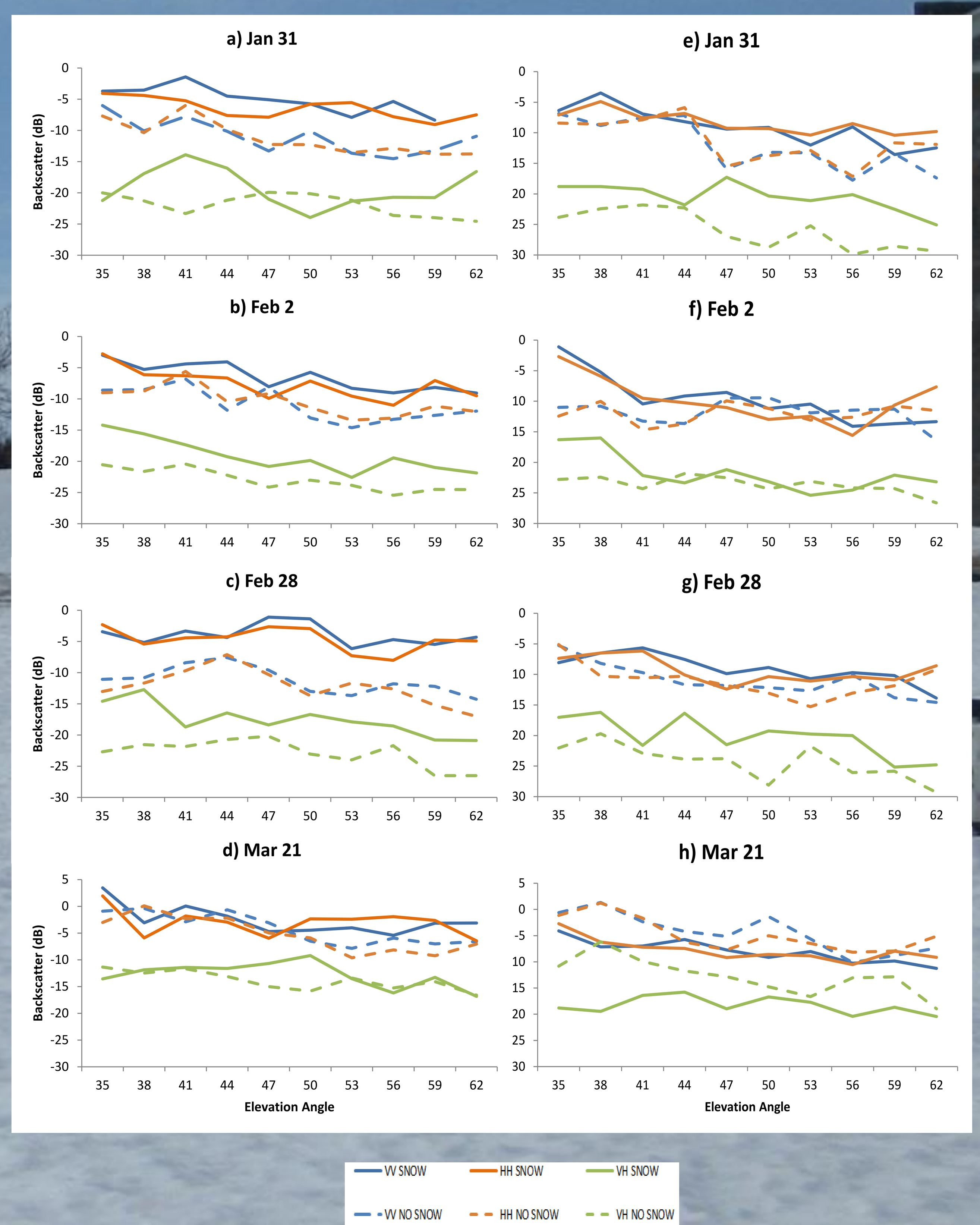

Figure 6. Angular response of backscatter by date for Ku-band (a-d) and X-band (e-h).

Good separation was visible between snow-on and snow-off, co-polarized responses at Ku-band, except for March 21. Similar separation was not apparent at X-band or for cross-polarized backscatter.

An increase in backscatter with SWE was apparent for the co-polarized response at Ku-band. No such increase was apparent at X-band.

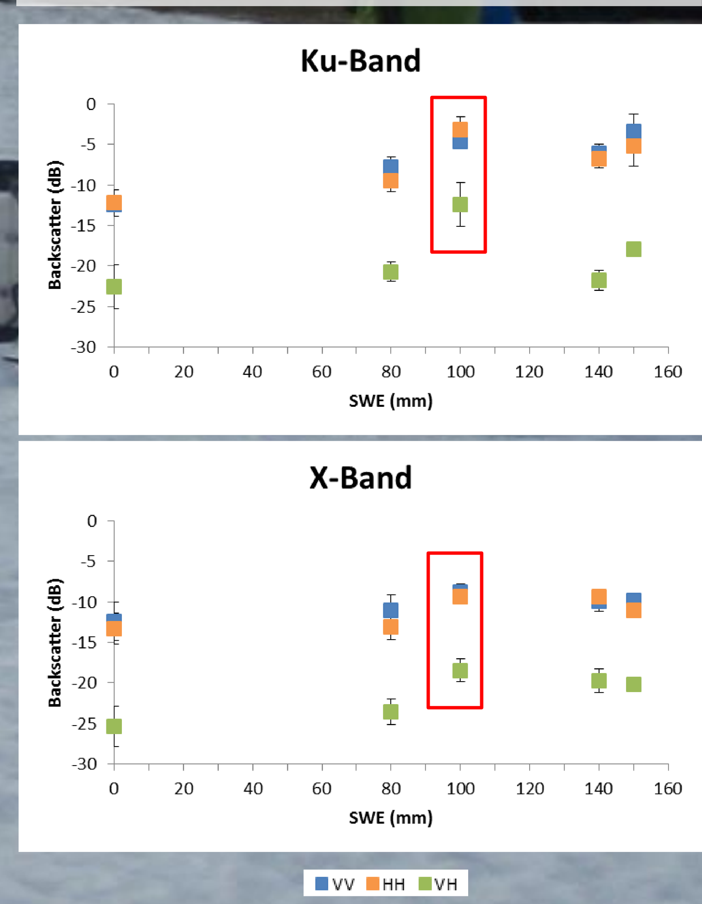

Figure 7. Comparison of backscatter and SWE. Error bars are 1 standard deviation. Red box indicates March 21, a special case.

IV) Conclusions

In cold, dry conditions, and 0 – 138 mm SWE:
- Ku-band interacted with the snowpack
- X-band signal originated from underlying soil
- Ku-band, co-polarized backscatter increased with SWE
- Ku-band, cross-polarized backscatter was similar for snow-on and snow-off conditions
- Enhanced Ku-band VV returns likely due to vertical orientation of depth hoar which comprised a substantial portion of the snowpack

Importance:
- Findings support the continued study of radar remote sensing of mid-latitude snow at X- and Ku-band frequencies

Special case: March 21
- Warm air temperatures & solar radiation caused snowmelt and isothermal snowpack at 0°C
- Backscatter increased for both frequencies
- Little difference in backscatter between snow-on and snow-off conditions
- Drainage of liquid water at surface was impeded by ice layers
- Presence of liquid water increased surface scattering

Importance:
- Implications for radar estimates of SWE in ripening snowpack

Future Work:
- Compare backscatter predictions from the sRT model with Maryhill observations