

Supplementary material to the manuscript *C and K band microwave penetration into snow on sea ice studied with off-the-shelf tank radars*

Arttu JUTILA^{1,*} and Christian HAAS^{1,2,3}

¹*Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany*

²*Institute of Environmental Physics, University of Bremen, Bremen, Germany*

³*Previously at Department of Earth and Space Science and Engineering, York University, Toronto,
Ontario, Canada*

** Currently at: Finnish Meteorological Institute, Helsinki, Finland.*

Correspondence: arttu.jutila@fmi.fi

This supplementary material lists the Figures S1–S6 of all detailed snow studies not shown in the manuscript itself.

References

Fierz C, Armstrong R, Durand Y, Etchevers P, Greene E, McClung DM, Nishimura K, Satyawali PK and Sokratov SA (2009) The International Classification for Seasonal Snow on the Ground. Technical report, UNESCO-IHP, Paris, IHP-VII Technical Documents in Hydrology N°83, IACS Contribution N°1

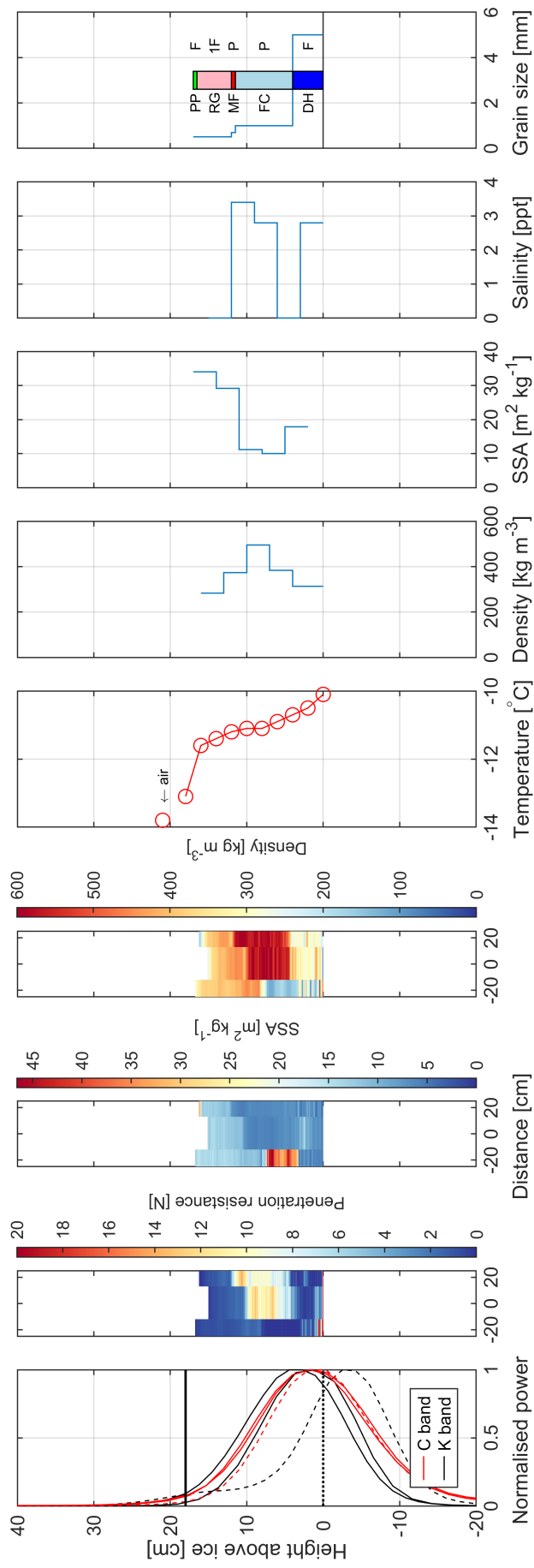


Figure S1: Snow pit #1 FYI buoy on 12 May 2018. The first panel shows the normalised radar returns for C (red) and K bands (black) and for the lower (solid) and higher (dashed) measurement height with the horizontal lines marking the snow (solid) and sea-ice (dotted) surfaces. The next three panels show the SnowMicroPen measurements across the radar footprint, where zero distance indicates directly under the radar at the middle of the instrument stand and positive distance is to the right. Remaining panels show the standard snow pit measurements. SSA stands for specific surface area. Letter and colour code for snow grain type: precipitation particles (PP), lime; decomposing and fragmented precipitation particles (DF), forest green; rounded grains (RG), light pink, faceted crystals (FC), light blue; depth hoar (DH), blue; melt forms (MF), red; ice formations (IF), cyan. Letter code for hand hardness: very soft, F (fist); soft, 4F (4 fingers); medium, IF (1 finger); hard, P (pencil); very hard, K (knife blade); ice, I (ice) (Fierz and others, 2009).

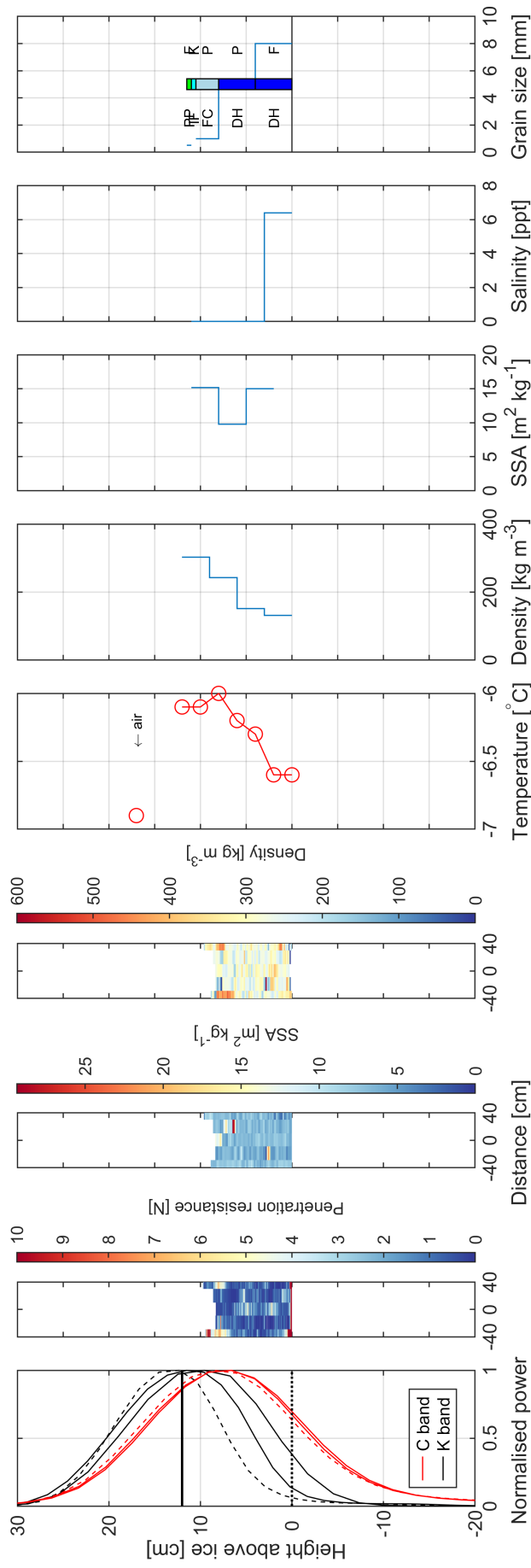


Figure S2: Snow pit #3 FYI OIB on 16 May 2018. The first panel shows the normalised radar returns for C (red) and K bands (black) and for the lower (solid) and higher (dashed) measurement height with the horizontal lines marking the snow (solid) and sea-ice (dotted) surfaces. The next three panels show the SnowMicroPen measurements across the radar footprint, where zero distance indicates directly under the radar at the middle of the instrument stand and positive distance is to the right. Remaining panels show the standard snow pit measurements. SSA stands for specific surface area. Letter and colour code for snow grain type: precipitation particles (PP), **lime**; decomposing and fragmented precipitation particles (DF), **forest green**; rounded grains (RG), **light pink**, faceted crystals (FC), **light blue**; depth hoar (DH), **blue**; melt forms (MF), **red**; ice formations (IF), **cyan**. Letter code for hand hardness: very soft, F (fist); soft, 4F (4 fingers); medium, IF (1 finger); hard, P (pencil); very hard, K (knife blade); ice, I (ice) (Fierz and others, 2009).

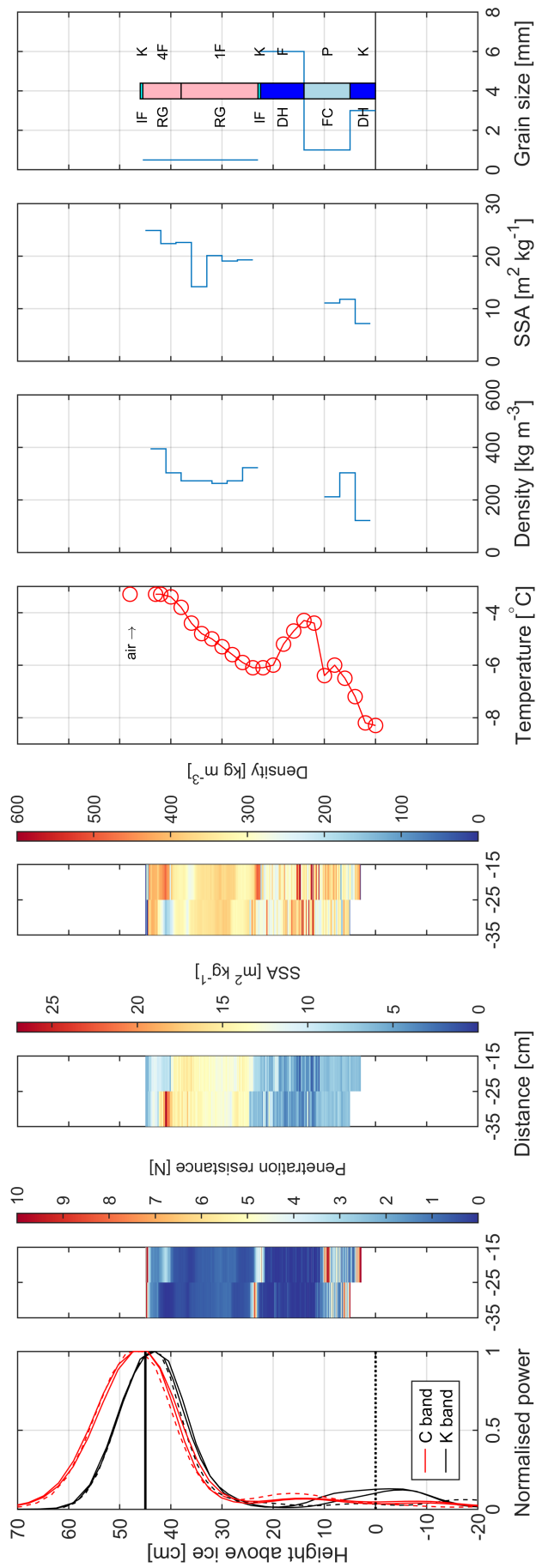


Figure S3: Snow pit #4 MYI OIB on 18 May 2018. The first panel shows the normalised radar returns for C (red) and K bands (black) and for the lower (solid) and higher (dashed) measurement height with the horizontal lines marking the snow (solid) and sea-ice (dotted) surfaces. The next three panels show the SnowMicroPen measurements across the radar footprint, where zero distance indicates directly under the radar at the middle of the instrument stand and positive distance is to the right. Due to a data saving failure, only the two leftmost SMP profiles were recorded. Remaining panels show the standard snow pit measurements. SSA stands for specific surface area. Letter and colour code for snow grain type: precipitation particles (PP), lime; decomposing and fragmented precipitation particles (DF), forest green; rounded grains (RG), light pink; faceted crystals (FC), light blue; depth hoar (DH), blue; melt forms (MF), red; ice formations (IF), cyan. Letter code for hand hardness: very soft, F (fist); soft, 4F (4 fingers); medium, IF (1 finger); hard, P (pencil); very hard, K (knife blade); ice, I (ice) (Fierz and others, 2009). The salinity profile is not shown, because all MYI snow pits had zero salinity.

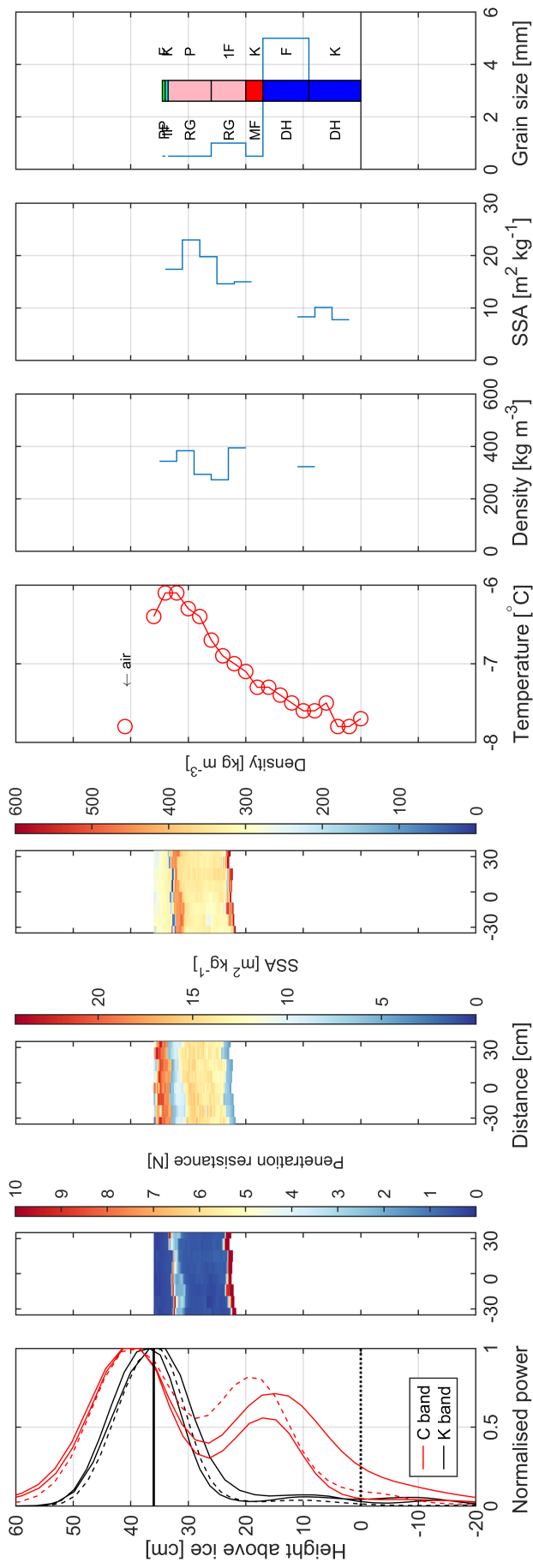


Figure S4: Snow pit #5 MYI OIB floe N on 21 May 2018. The first panel shows the normalised radar returns for C (red) and K bands (black) and for the lower (solid) and higher (dashed) measurement height with the horizontal lines marking the snow (solid) and sea-ice (dotted) surfaces. The next three panels show the SnowMicroPen (SMP) measurements across the radar footprint, where zero distance indicates directly under the radar at the middle of the instrument stand and positive distance is to the right. The SMP could not penetrate the melt-freeze layer at approximately 20 cm above the sea-ice surface (maximum power threshold). Remaining panels show the standard snow pit measurements. SSA stands for specific surface area. Letter and colour code for snow grain type: precipitation particles (PP), lime; decomposing and fragmented precipitation particles (DF), forest green; rounded grains (RG), light pink, faceted crystals (FC), light blue; depth hoar (DH), blue; melt forms (MF), red; ice formations (IF), cyan. Letter code for hand hardness: very soft, F (fist); soft, 4F (4 fingers); medium, IF (1 finger); hard, P (pencil); very hard, K (knife blade); ice, I (ice) (Fierz and others, 2009). The salinity profile is not shown, because all MYI snow pits had zero salinity.

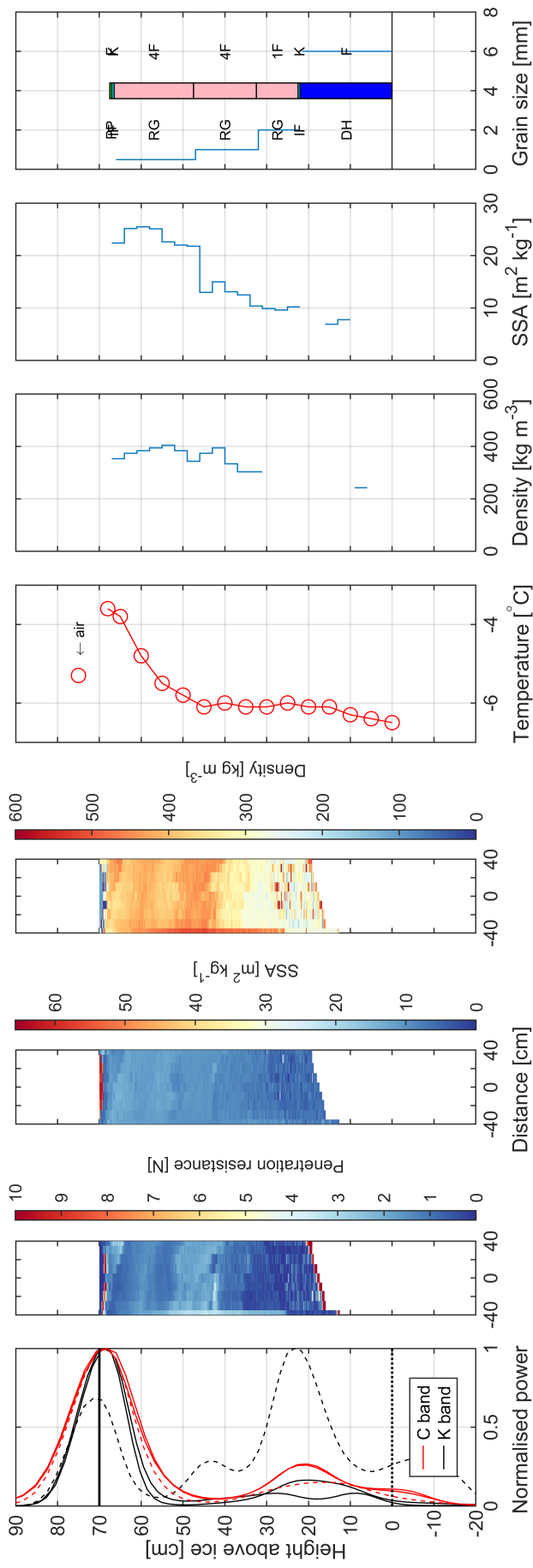


Figure S5: Snow pit #6 MYI OIB floe S on 21 May 2018. The first panel shows the normalised radar returns for C (red) and K bands (black) and for the lower (solid) and higher (dashed) measurement height with the horizontal lines marking the snow (solid) and sea-ice (dotted) surfaces. The next three panels show the SnowMicroPen (SMP) measurements across the radar footprint, where zero distance indicates directly under the radar at the middle of the instrument stand and positive distance is to the right. The SMP could not penetrate the ice lens at 15–20 cm above the sea-ice surface (maximum power threshold). Remaining panels show the standard snow pit measurements. SSA stands for specific surface area. Letter and colour code for snow grain type: precipitation particles (PP), lime; decomposing and fragmented precipitation particles (DF), forest green; rounded grains (RG), light pink, faceted crystals (FC), light blue; depth hoar (DH), blue; melt forms (MF), red; ice formations (IF), cyan. Letter code for hand hardness: very soft, F (fist); soft, 4F (4 fingers); medium, 1F (1 finger); hard, P (pencil); very hard, K (knife blade); ice, I (ice) (Fierz and others, 2009). The salinity profile is not shown, because all MYI snow pits had zero salinity.

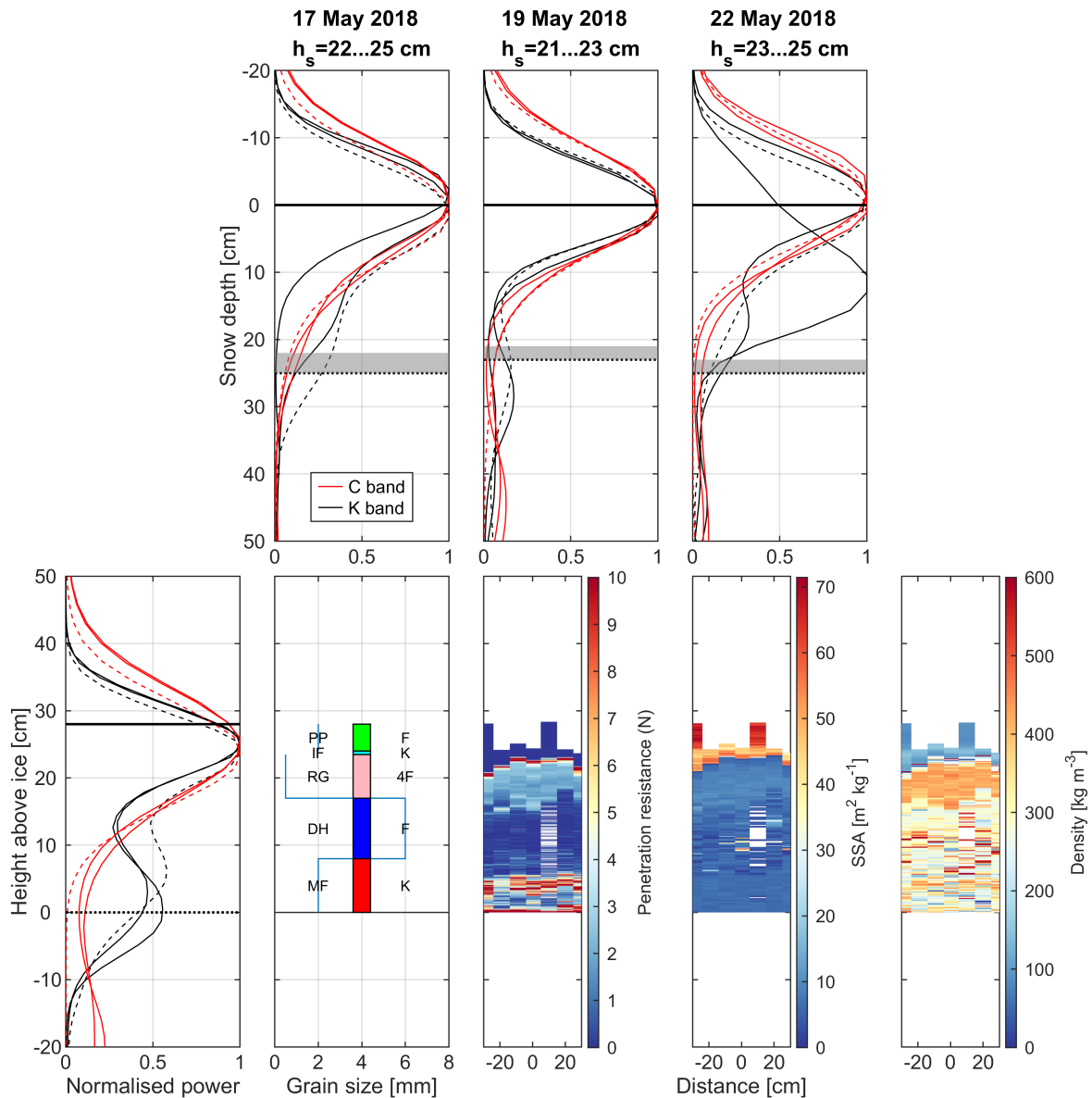


Figure S6: Measurements at the study location #9 MYI temporal. (Top) Repeated C (red) and K band (black) radar measurements for the lower (solid) and higher (dashed) measurement height between 17 and 22 May 2018 without detailed snow pit measurements. Note that the vertical axis is normalised to the snow surface and converted into snow depth. Range of snow depth values probed under the radar are indicated above each panel and as grey transparent boxes. (Bottom) Radar measurements on 24 May 2018 followed by stratigraphy and penetrometer measurements. Note that the vertical axis is now normalised to the ice surface. Letter and colour code for snow grain type: precipitation particles (PP), **lime**; decomposing and fragmented precipitation particles (DF), **forest green**; rounded grains (RG), **light pink**; faceted crystals (FC), **light blue**; depth hoar (DH), **blue**; melt forms (MF), **red**; ice formations (IF), **cyan**. Letter code for hand hardness: very soft, F (fist); soft, 4F (4 fingers); medium, 1F (1 finger); hard, P (pencil); very hard, K (knife blade); ice, I (ice) (Fierz and others, 2009).