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Impact of intercepted and sub-canopy snow microstructure on snowpack response to rain-on-snow events under a boreal canopy

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S1: Soil characterization at the MF and BRV sites

We performed detailed soil profile measurements at Montmorency Forest (13 July 2021) and Bernard River Valley (22 September 2020). In these measurements, we first characterized visually the different mineral soil layers up to 100 cm below the layer of organic material. We also measured the thermal conductivity of the soil at different depths using a TP02 heating needle probe from Hukseflux. Soil temperature was measured every 5 cm from the surface to 30 cm below and every 10 cm until a depth of 80 cm below the surface with a Greinsinger Pt-1000 (resolution: 0.1°C). We brough a 165 cm^3 sample of each layer back that we weighted and dried at 65 °C and 100 °C in the oven for organic and mineral soil, respectively. This allowed to estimate the volumetric water content and the bulk density of the soil at different depths. Other samples of each layer were taken and sent to a certified organic and inorganic chemistry laboratory for an analysis of soil component. The analysis revealed that the mineral soil could be classified as a sandy loam and as a silty loam at Montmorency Forest and Bernard River Valley, respectively. A summary of the soil characterization at Montmorency Forest and Bernard River Valley is presented on Figs. S1 and S2.

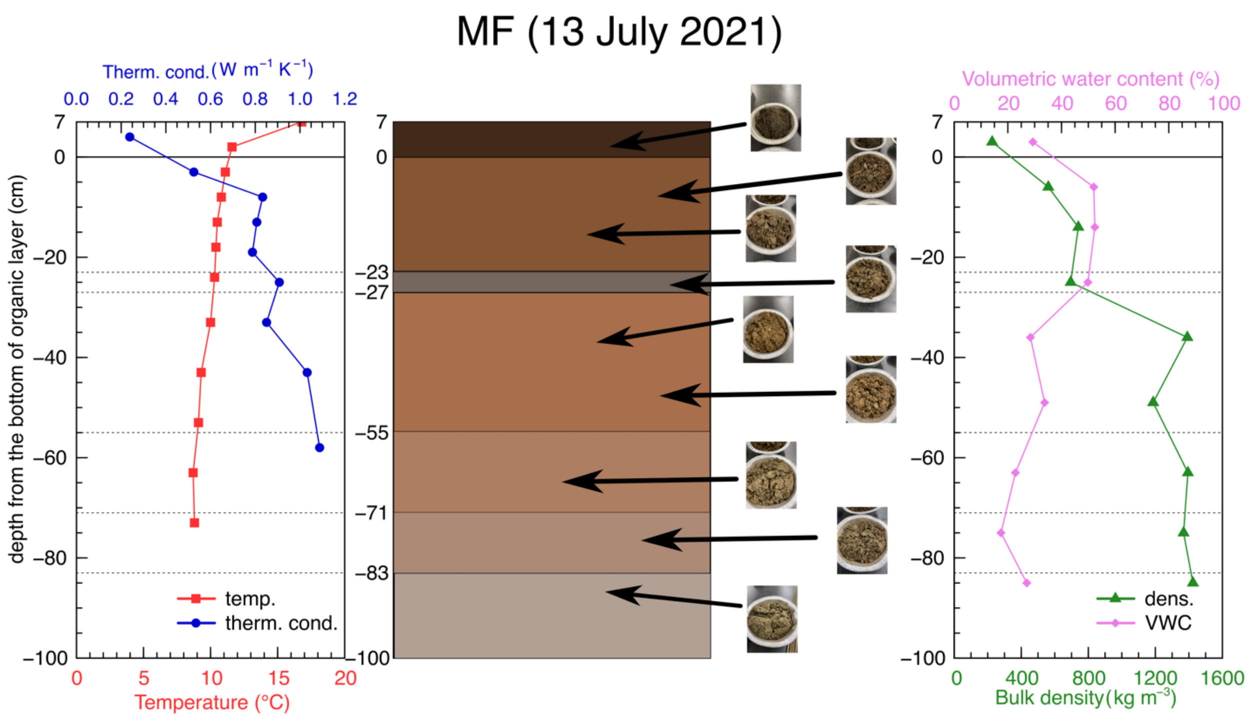

Figure S1: Summary of the soil characterization as observed at Montmorency Forest on 13 July 2021. The different soil layers are presented with a photo and a color representative of each sample in the center. The vertical profiles of thermal conductivity and temperature are displayed on the left panel. The vertical profiles of volumetric water content and bulk soil density are displayed on the right panel.

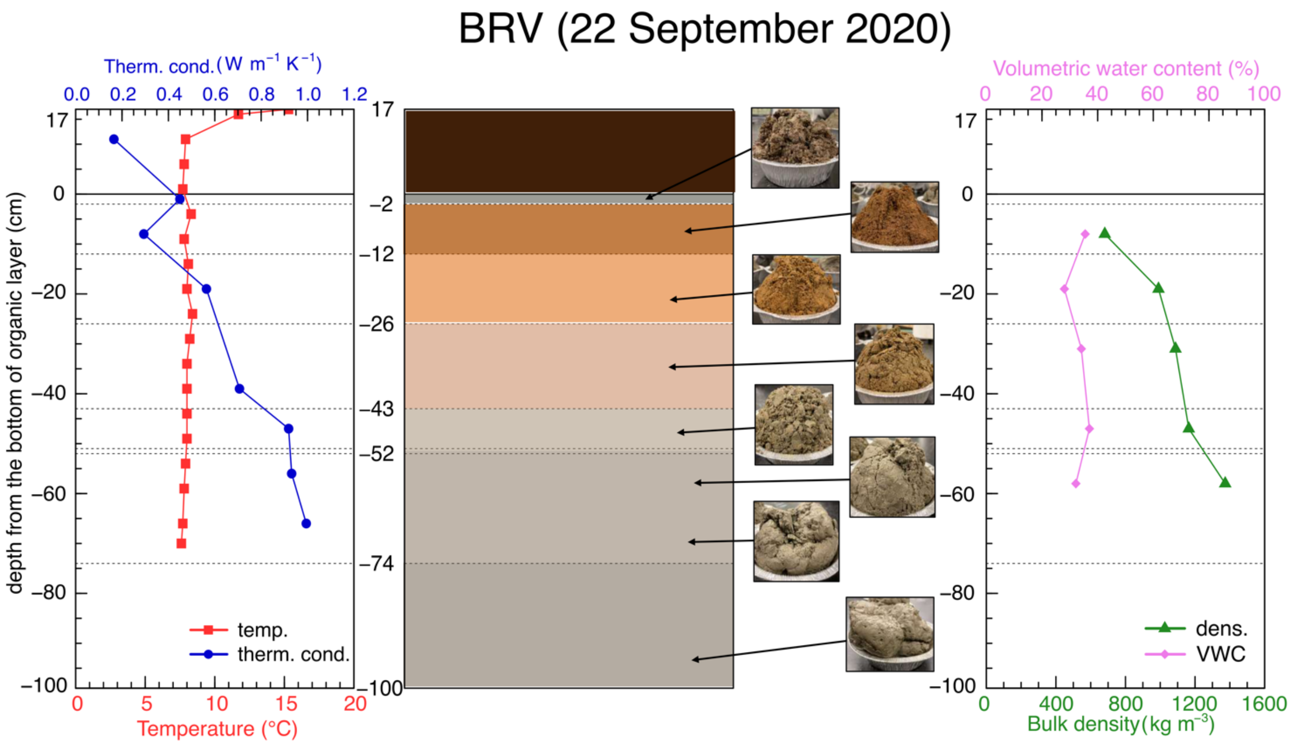

Figure S2: Summary of the soil characterization as observed at Bernard River Valley on 22 September 2020. The different soil layers are presented with a photo and a color representative of each sample in the center. The vertical profiles of thermal conductivity and temperature are displayed on the left panel. The vertical profiles of volumetric water content and bulk soil density are displayed on the right panel.

S2: Initial soil parameterization in SNOWPACK

The data collected in the soil sampling at both sites were used to define the partitioning of void, liquid water and solid material, the temperature, and the thermal conductivity in SNOWPACK before the 10 year (MF) and 12 year (BRV) spinup such as. Tables S1 and S2 show the parameters provided to SNOWPACK for simulations at both sites. We used 1265 and 2650 kg m^{-3} as density of solid material for organic and mineral soil at both sites, respectively, and an average heat capacity of 1000 J kg^{-1} K^{-1} for any soil layer. We used the ROSETTA Class Average Hydraulic Parameters for sandy loam (Montmorency Forest) and silty loam (Bernard River Valley) and hydraulic pedotransfer function parameters provided by Nemes et al. (2001) for water retention properties of the organic soil. The soil was initially set unfrozen with all water in the matrix flow domain.

Table S1: Initial soil properties provided to SNOWPACK based on field measurements at Montmorency Forest from 13 July 2021. Layers are presented from the bottom to the top.

Layer thickness (m)	Water vol. (0 – 1)	Void vol. (0 – 1)	Solid vol. (0 – 1)	Temp. (K)	Therm. Cond. W m^{-1} K^{-1}
1.1	0.271	0.192	0.537	281.95	1.826
0.12	0.174	0.309	0.517	281.95	1.826
0.16	0.228	0.246	0.526	281.95	1.826
0.14	0.337	0.215	0.448	282.35	1.883
0.14	0.284	0.191	0.525	283.15	1.317
0.04	0.499	0.239	0.262	283.45	2.398
0.12	0.524	0.196	0.280	283.55	1.799
0.11	0.520	0.268	0.212	284.05	1.83
0.07	0.271	0.532	0.197	286.13	0.44

Table S2: Initial soil properties provided to SNOWPACK based on field measurements at Bernard River Valley from 22 September 2020. Layers are presented from the bottom to the top.

Layer thickness (m)	Water vol. (0 – 1)	Void vol. (0 – 1)	Solid vol. (0 – 1)	Temp. (K)	Therm. Cond. W m^{-1} K^{-1}
1.13	0.322	0.160	0.518	280.9	1.511
0.09	0.370	0.190	0.440	281.15	1.617
0.17	0.341	0.248	0.411	281.22	1.254
0.14	0.280	0.346	0.374	281.32	1.089
0.11	0.355	0.388	0.257	281.20	0.370
0.18	0.180	0.620	0.200	283.23	0.321

S3: Evaluation of ERA5-Land precipitation

Figure S3 shows the cumulative precipitation from October 2019 to July 2020 estimated by ERA5-Land and compared with the observed precipitation from a nearby OTT Pluvio^2 gauge, operated by Hydro-Quebec. The reanalysis corresponds to a grid cell centered at the location of the weather tower and the snow station in the Bernard River Valley (BRV). ERA5-Land slightly underestimates the observed precipitation from October to March with a largest gap of 50 mm on 26 January 2020 which corresponds to an underestimation of 14%. ERA5-Land overestimates precipitation in March so this gap is compensated. At the end of June, ERA5-Land shows a positive bias of 20 mm (3%) for the cumulative precipitation. Overall, since the precipitation generated by ERA5-Land is close to the observed precipitation throughout the year, we are confident of using it as an input to SNOWPACK at BRV.

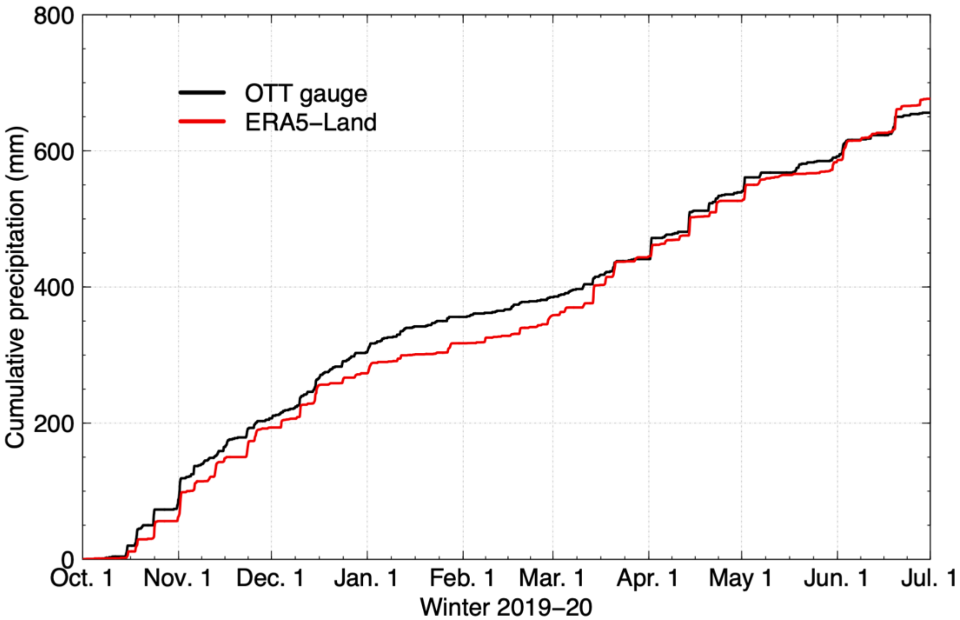

Figure S3: Cumulative precipitation generated by ERA5-Land over the Bernard River Valley from October 2019 to July 2020 compared with the cumulative precipitation measured by the OTT Pluvio^2 from Hydro-Quebec, located some 60 km away.

S4: Snow surface temperature

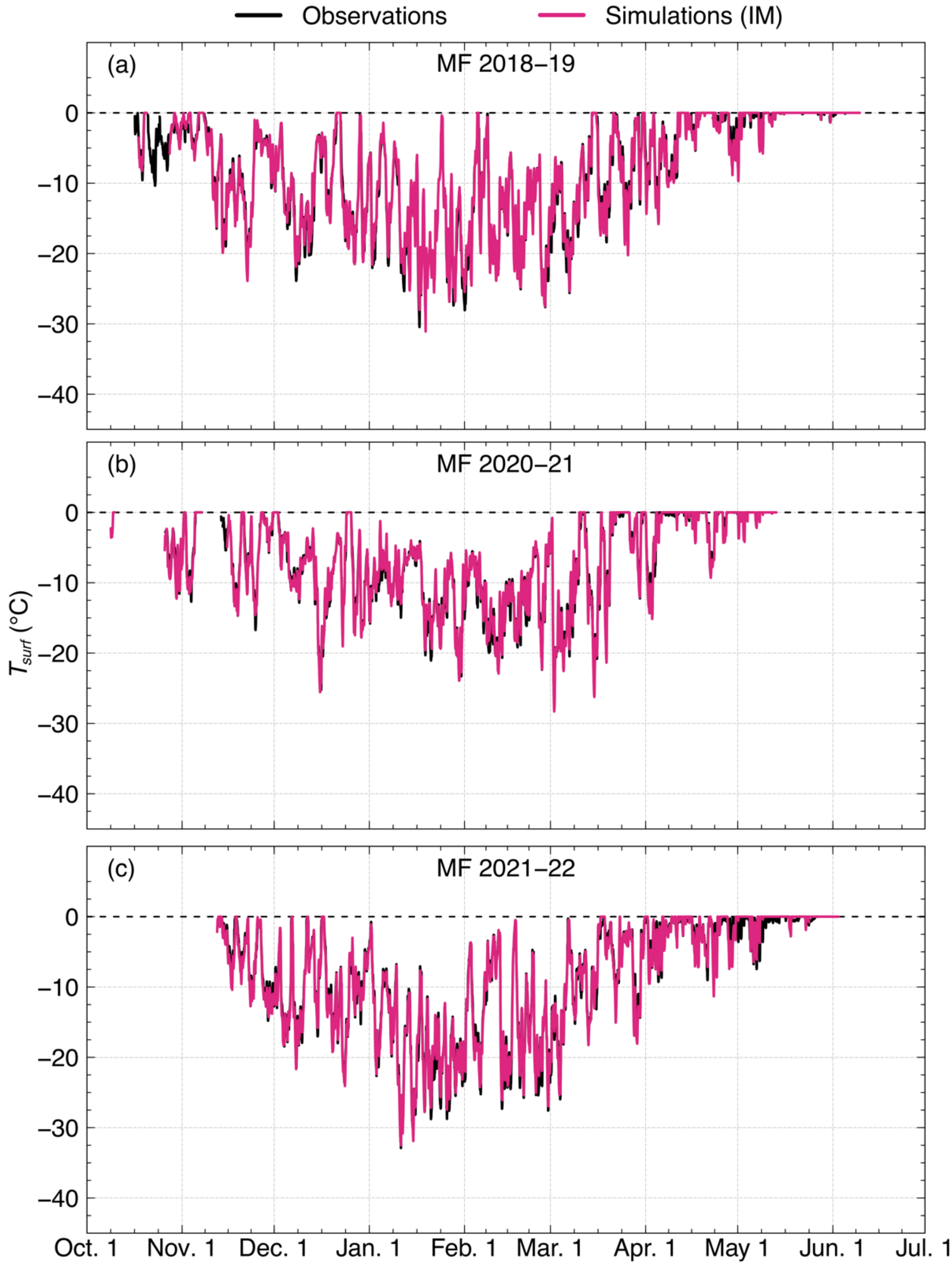

Figure S4: Comparison of observed (black) and simulated snow surface temperature with the Initial canopy Module (IM) at Montmorency Forest in 2018–19, 2020–21 and 2021–22.

S5: Side–by–side density profiles comparison

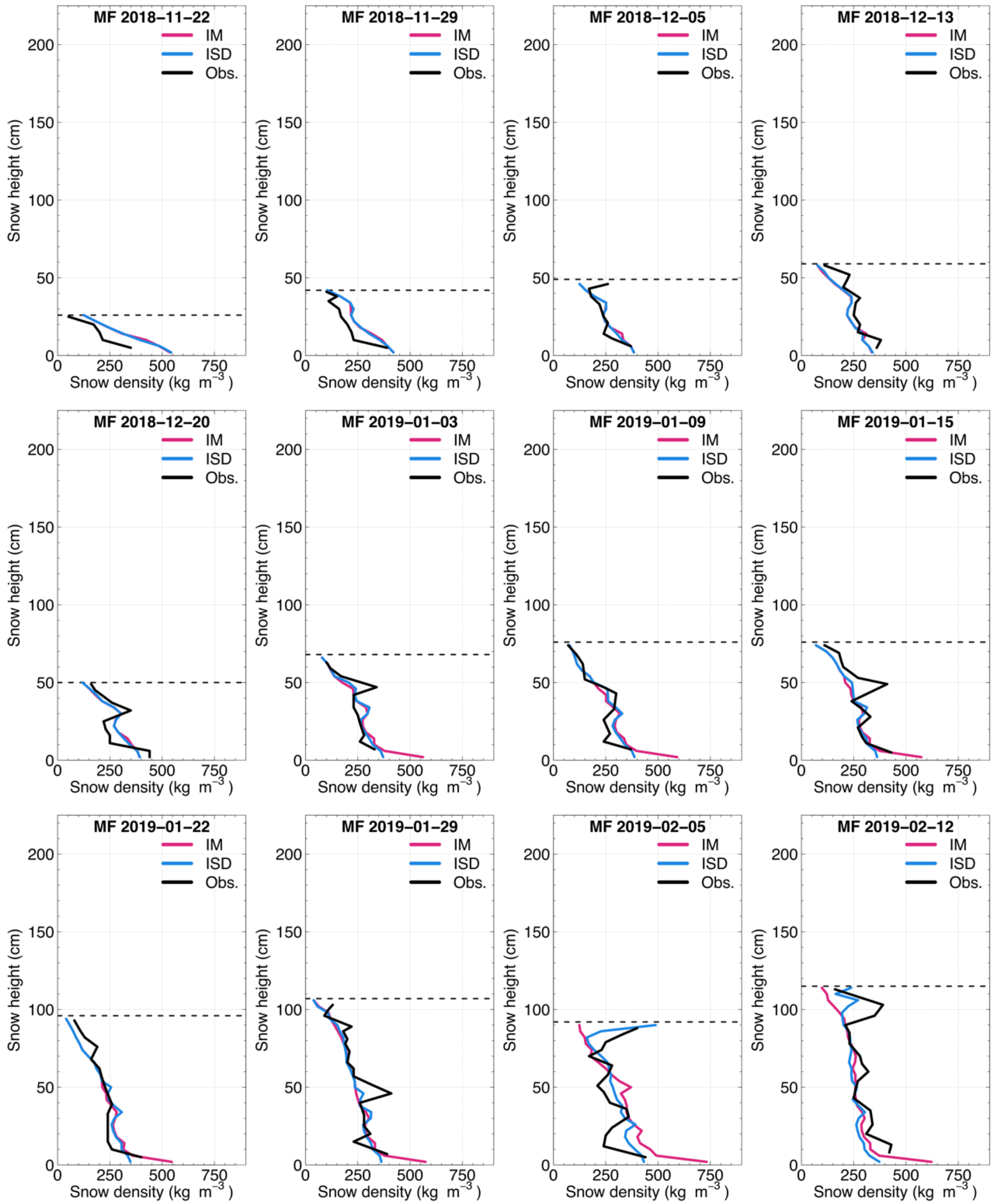

Figure S5: Comparison of observed and simulated density profiles from 22 November 2018 to 12 February 2019 at Montmorency Forest

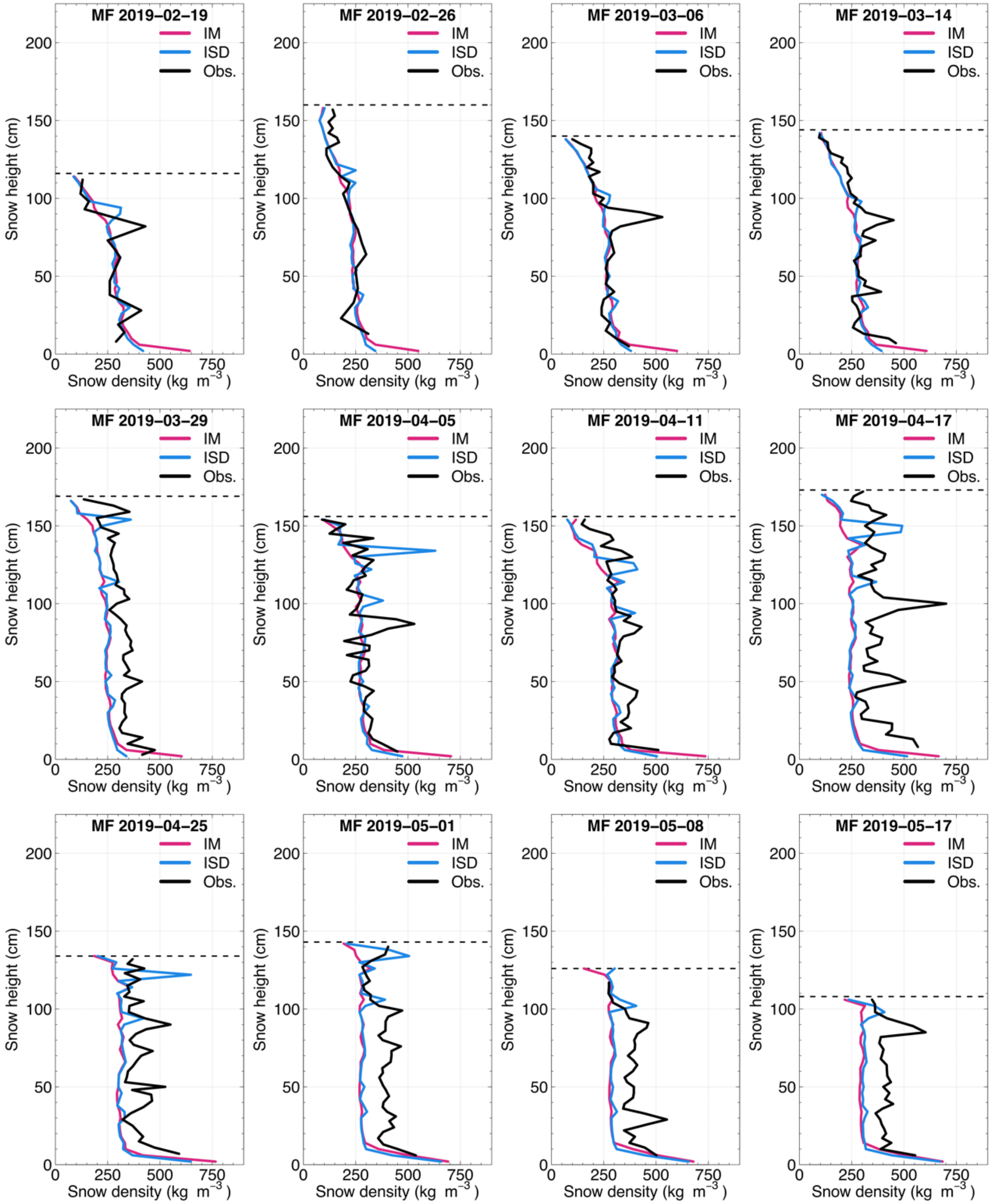

Figure S6: Comparison of observed and simulated density profiles from 19 February 2019 to 17 May 2019 at Montmorency Forest

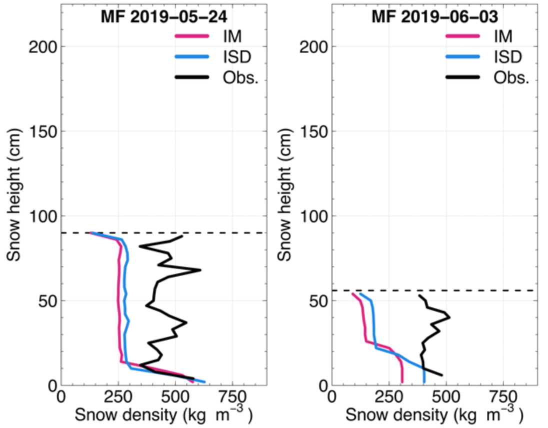

Figure S7: Comparison of observed and simulated density profiles on 24 May 2019 and 3 June 2019 at Montmorency Forest

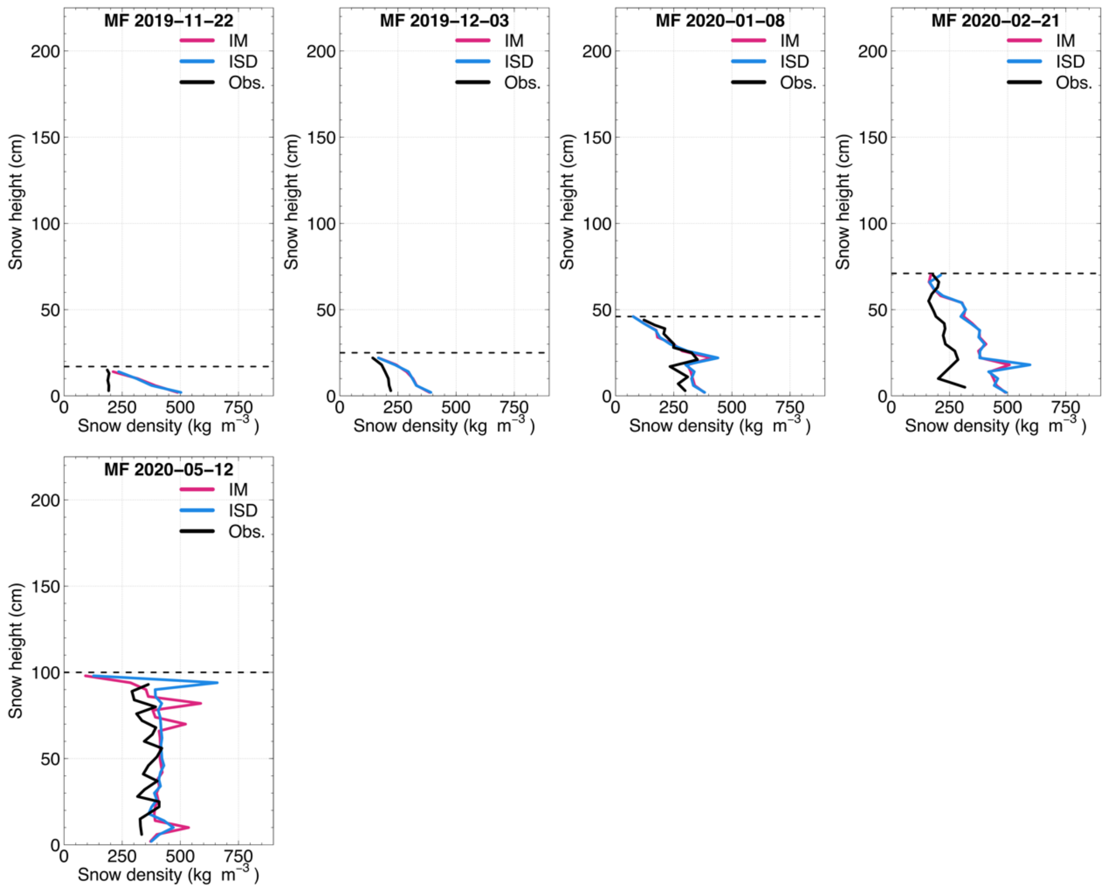

Figure S8: Comparison of observed and simulated density profiles from 22 November 2019 to 12 May 2020 at Montmorency Forest

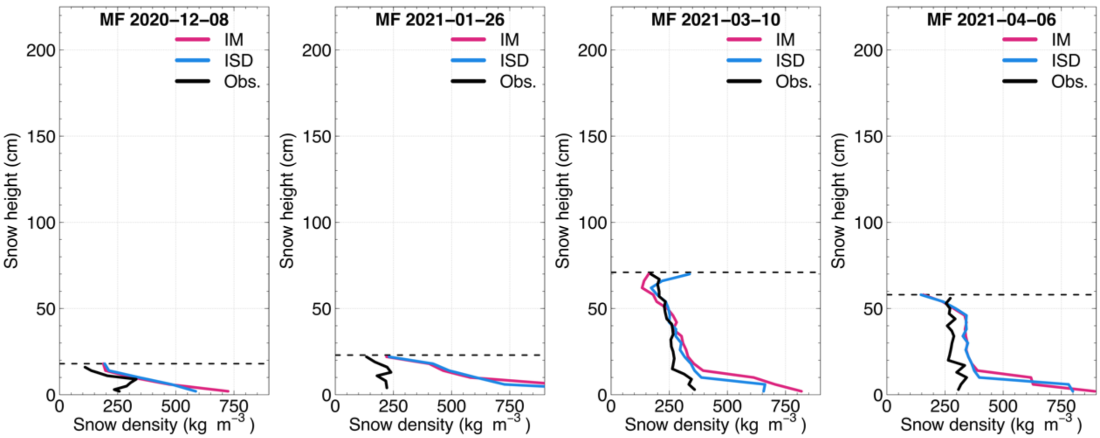

Figure S9: Comparison of observed and simulated density profiles from 8 December 2020 to 6 April 2021 at Montmorency Forest

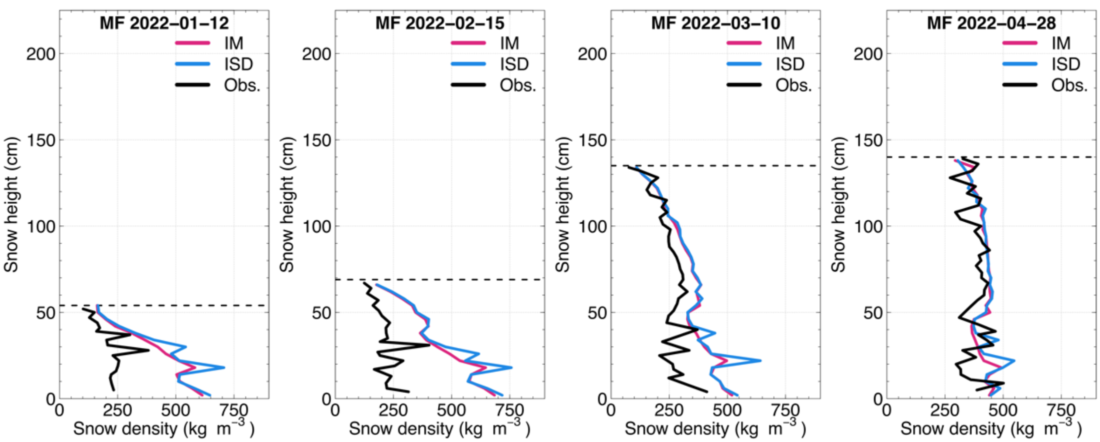

Figure S10: Comparison of observed and simulated density profiles from 12 January 2022 to 28 April 2022 at Montmorency Forest

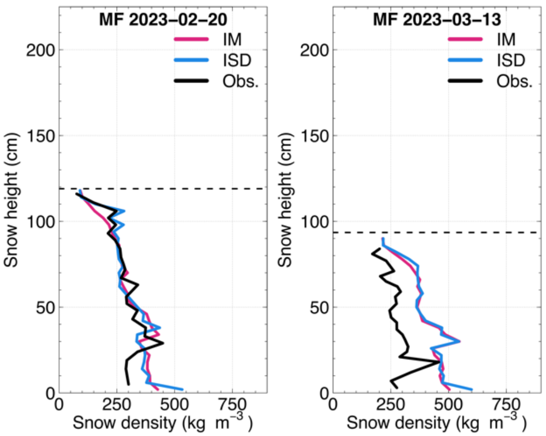

Figure S11: Comparison of observed and simulated density profiles on 20 February 2023 and 13 March 2023 at Montmorency Forest

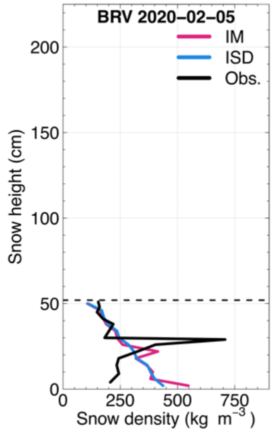

Figure S12: Comparison of observed and simulated density profiles on 5 February 2020 at Bernard River Valley

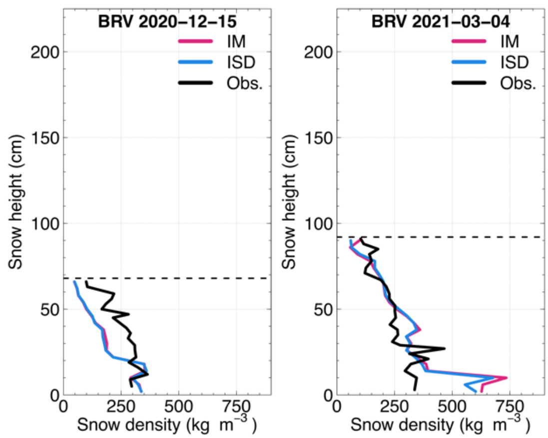

Figure S13: Comparison of observed and simulated density profiles on 15 December 2020 and 4 March 2021 at Bernard River Valley

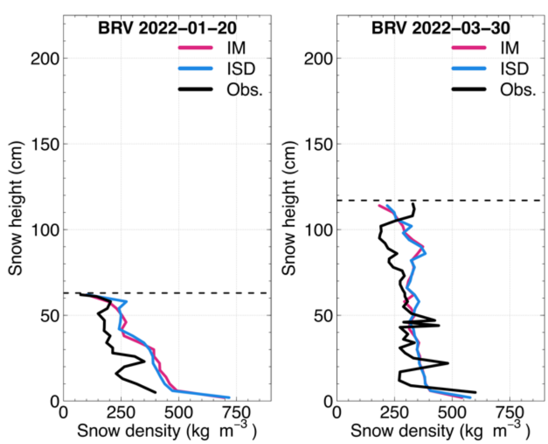

Figure S14: Comparison of observed and simulated density profiles on 20 January 2022 and 3 March 2022 at Bernard River Valley

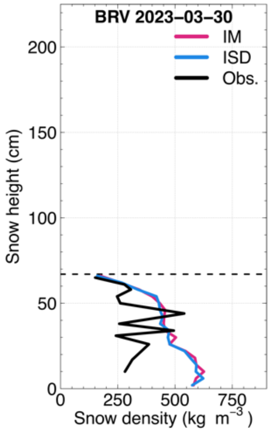

Figure S15: Comparison of observed and simulated density profiles on 30 March 2023 at Bernard River Valley

105 **S6: Grain type profiles comparison**

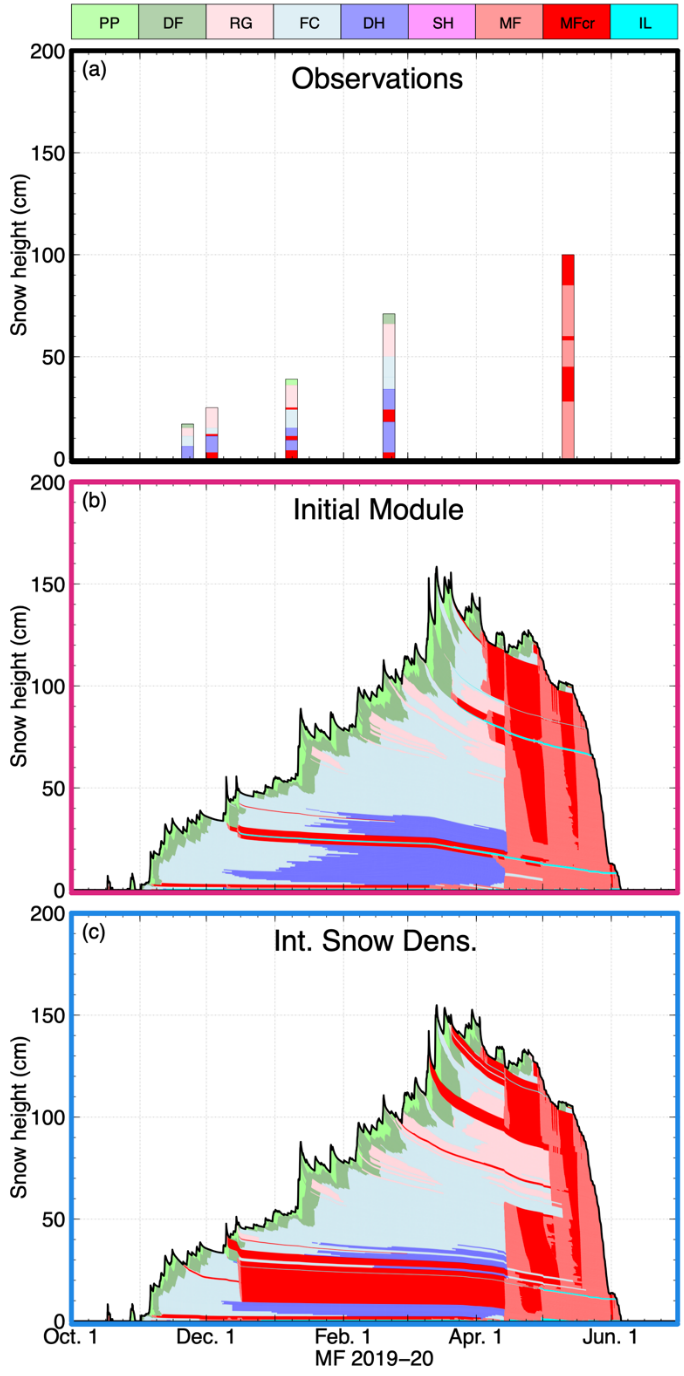

Figure S16: Comparison between the observed and the simulated grain type with both versions of the model during winter 2019–20 at Montmorency Forest

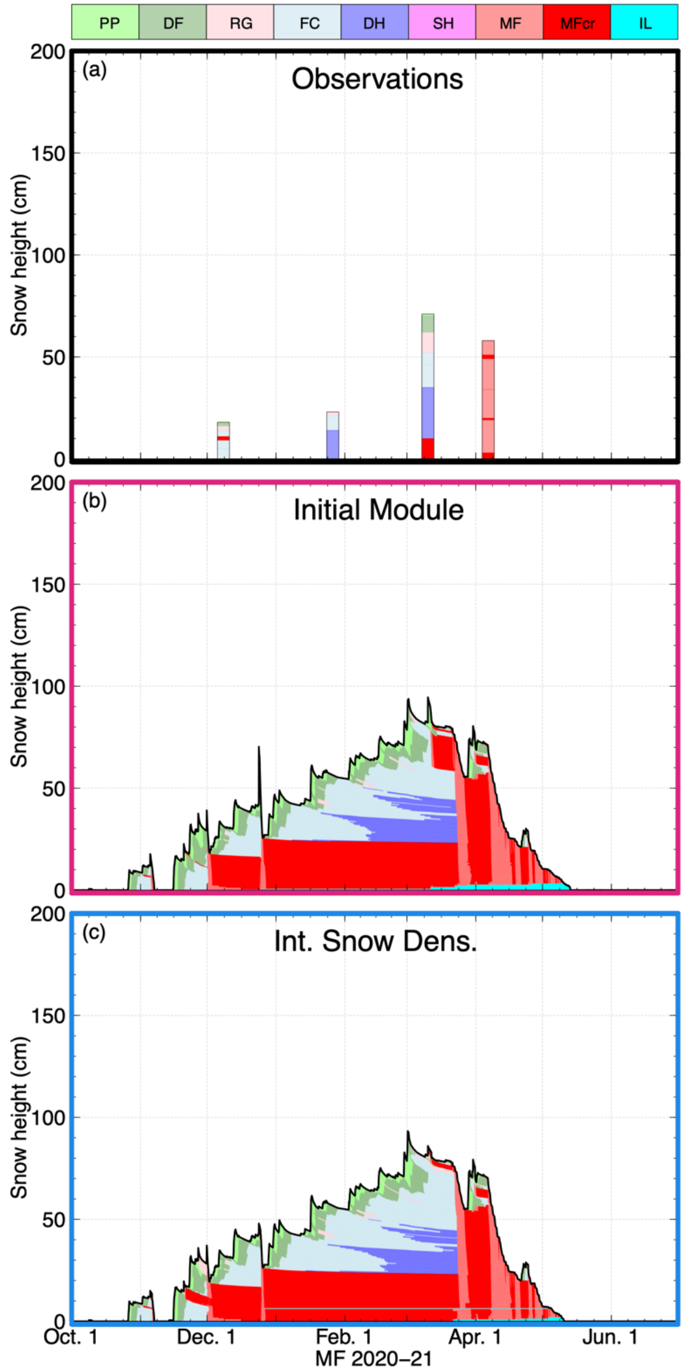

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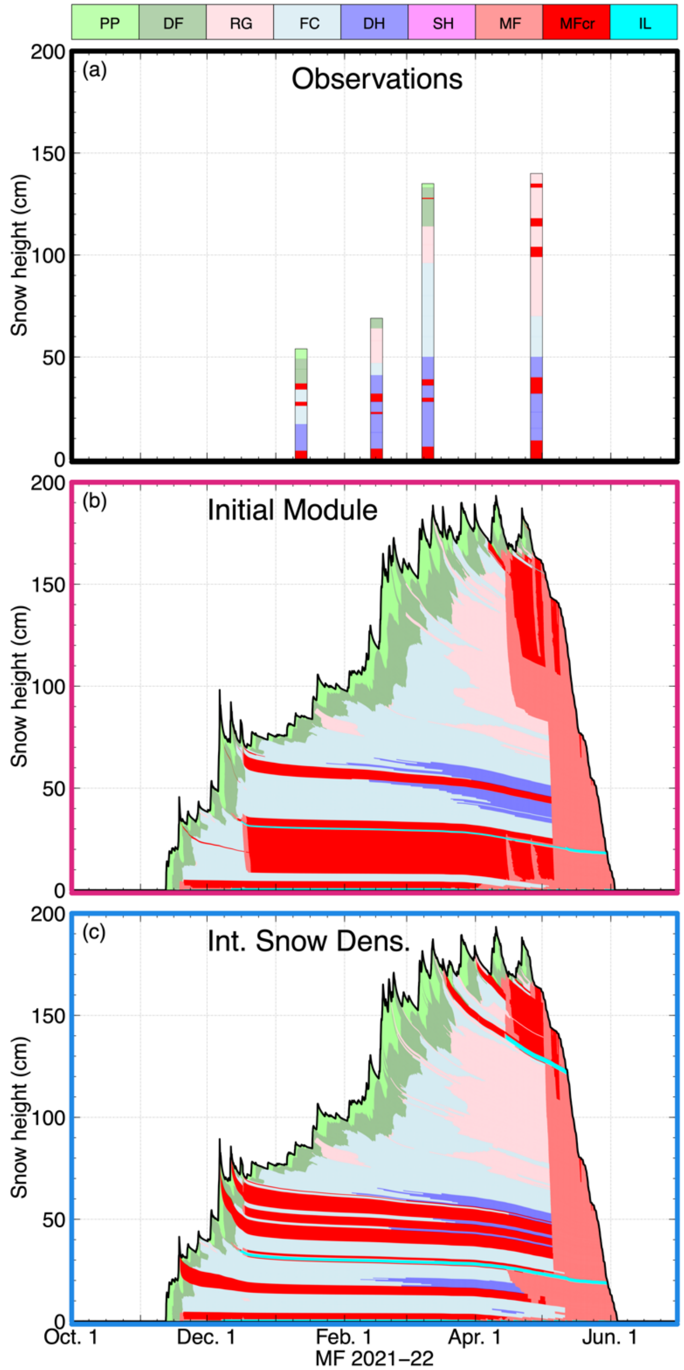
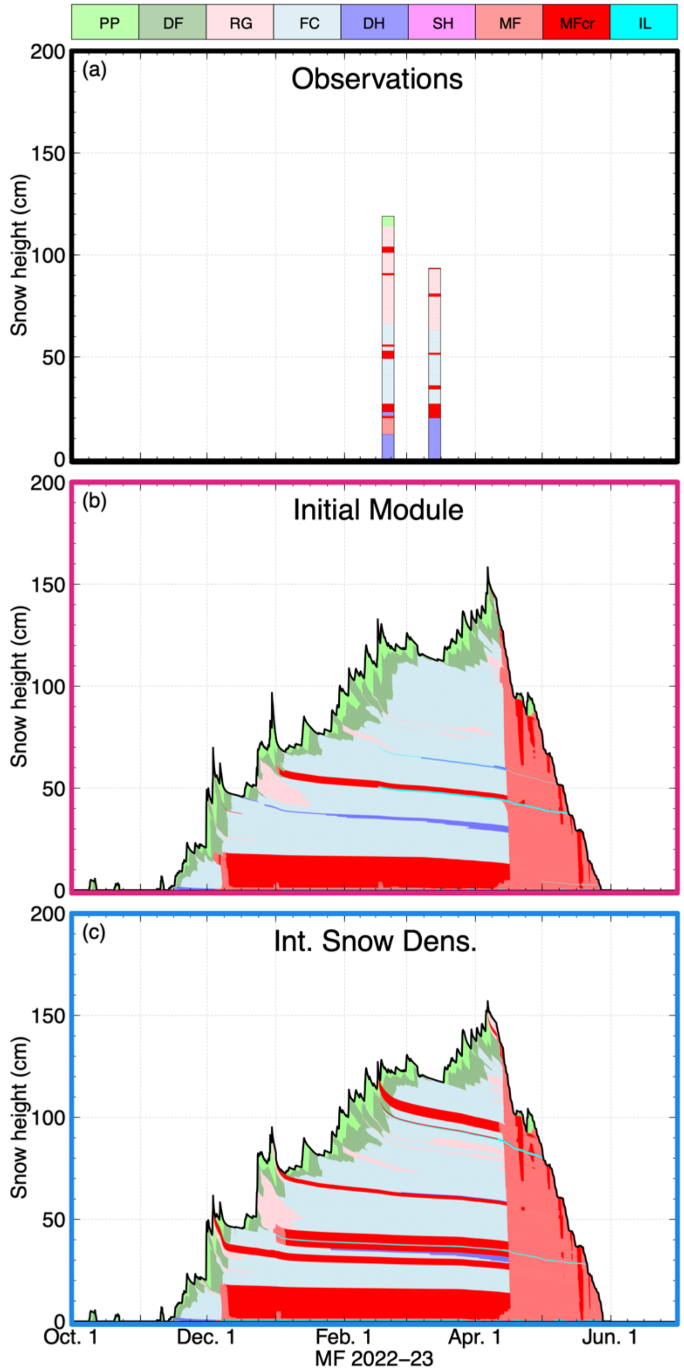
Figure S17: Comparison between the observed and the simulated grain type with both versions of the model during winter 2020–21 at Montmorency Forest



115 **Figure S18: Comparison between the observed and the simulated grain type with both versions of the model during winter 2021–22 at Montmorency Forest**



120 **Figure S19: Comparison between the observed and the simulated grain type with both versions of the model during winter 2022–23 at Montmorency Forest**

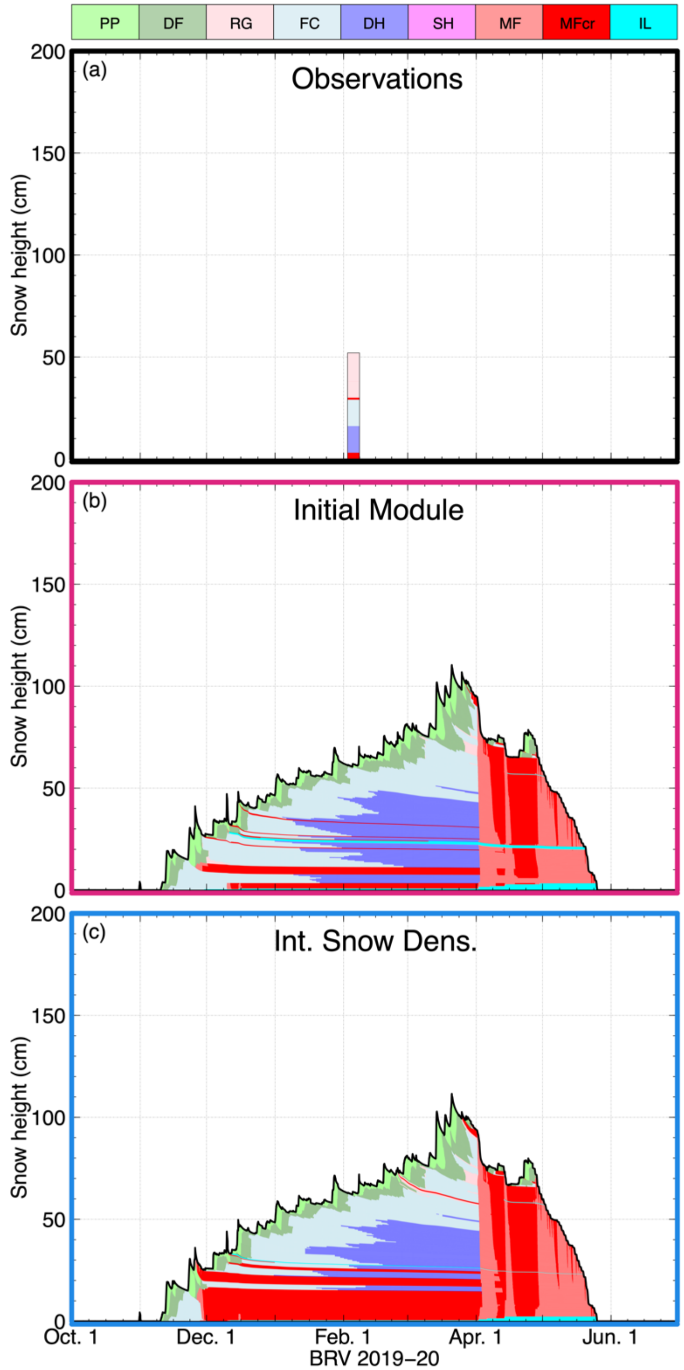


Figure S20: Comparison between the observed and the simulated grain type with both versions of the model during winter 2019–20 at Bernard River Valley

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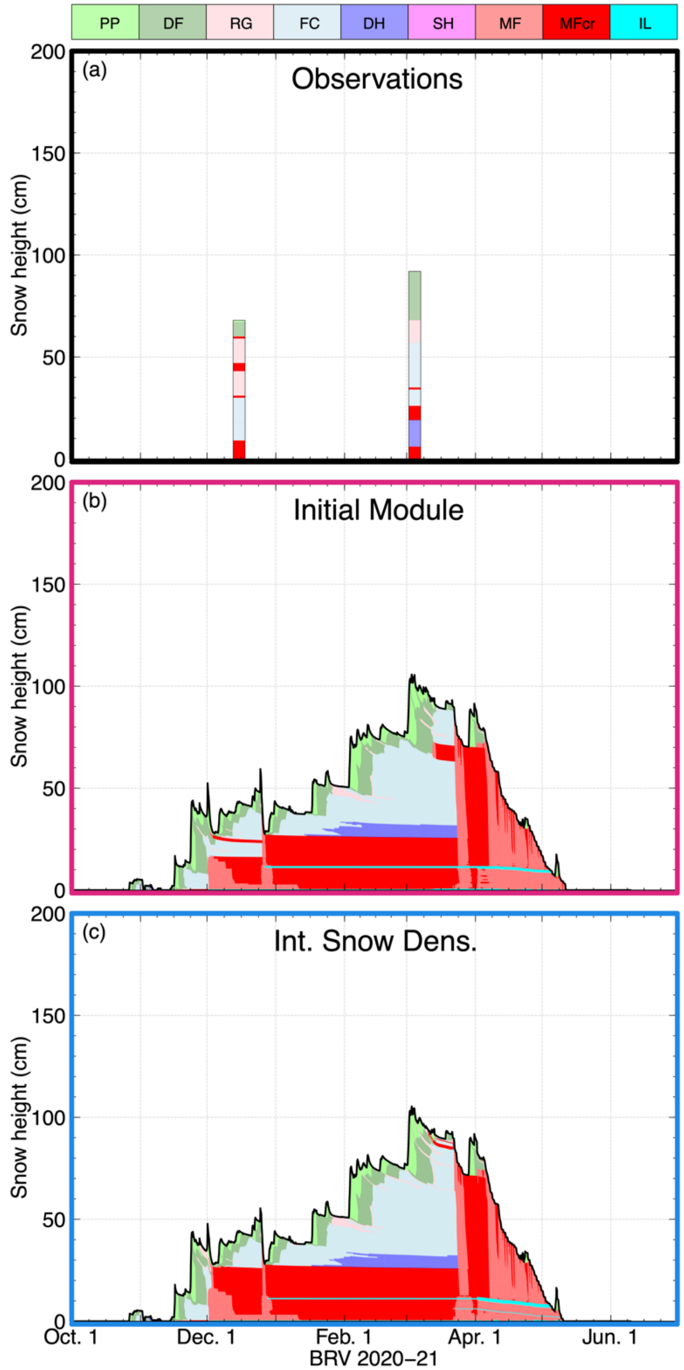


Figure S21: Comparison between the observed and the simulated grain type with both versions of the model during winter 2020–21 at Bernard River Valley

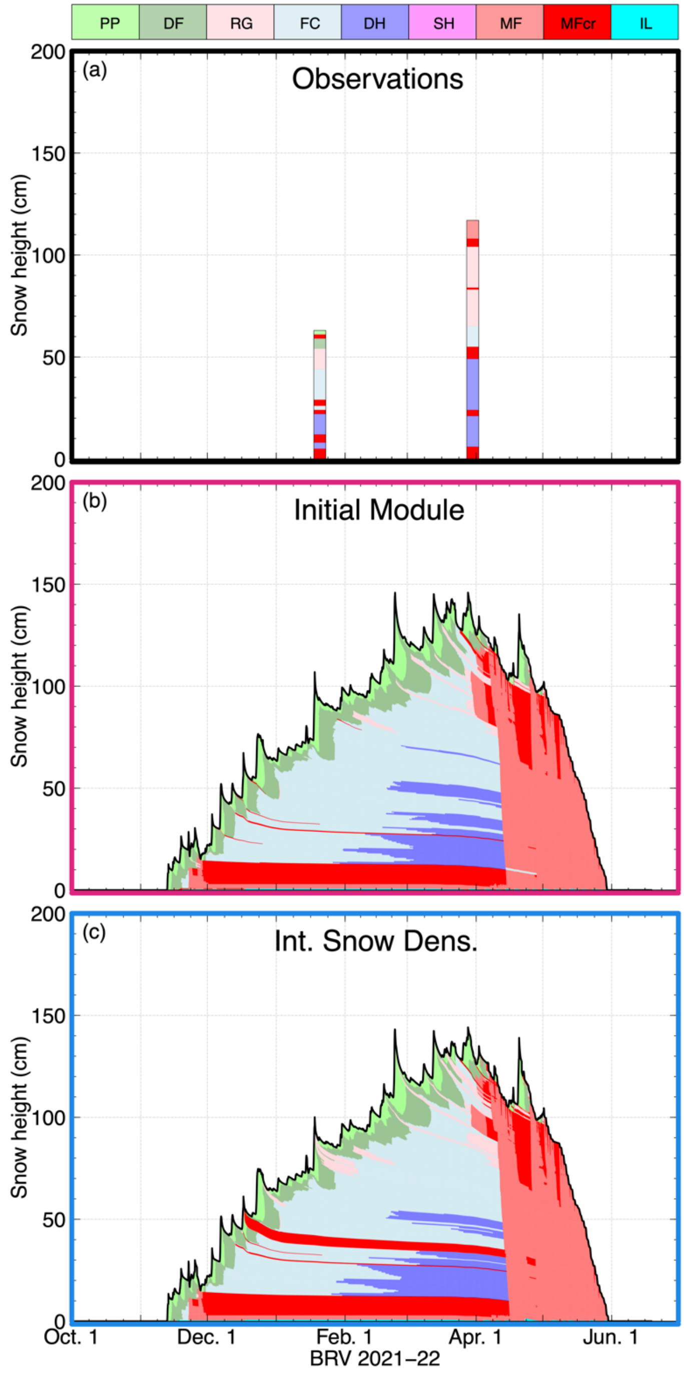
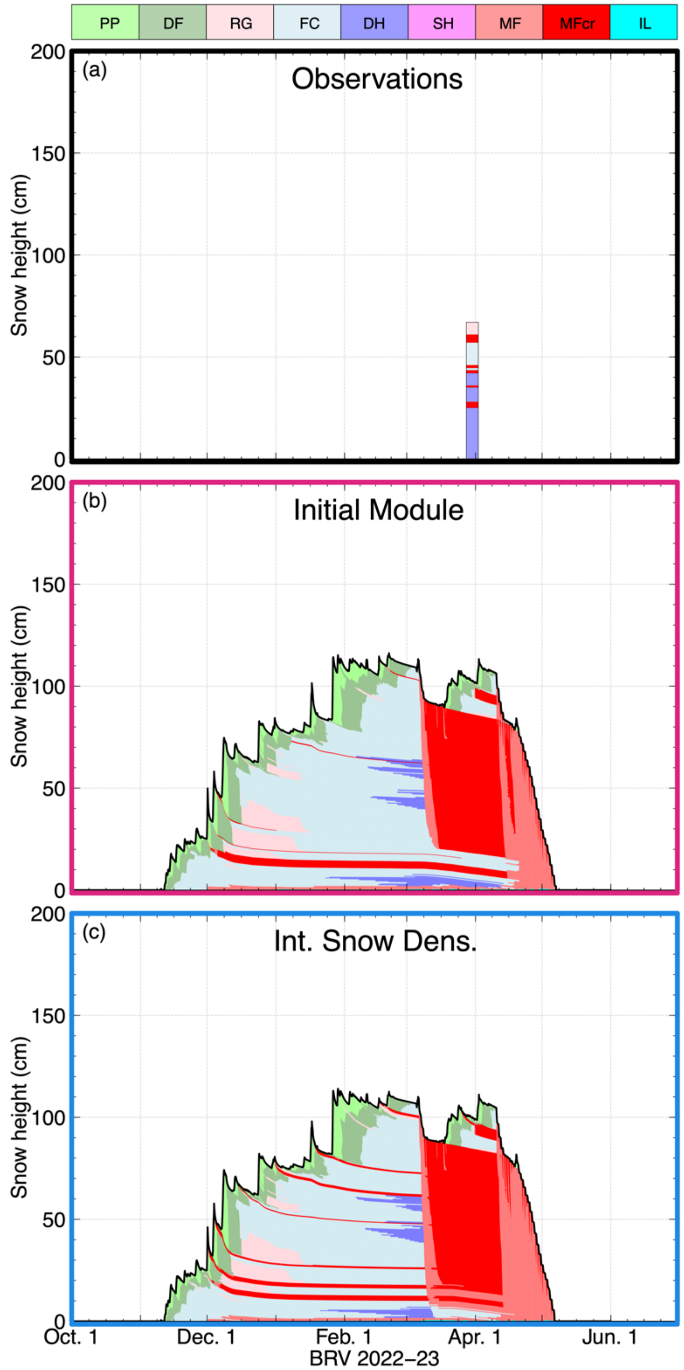


Figure S22: Comparison between the observed and the simulated grain type with both versions of the model during winter 2021–22 at Bernard River Valley



135 **Figure S23: Comparison between the observed and the simulated grain type with both versions of the model during winter 2022–23 at Bernard River Valley**

References

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