



Supplement of

Dry snow initialization and densification over the Greenland and Antarctic ice sheets in the ORCHIDEE land surface model

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S1 Snow thermal conductivity equation

In ORCHIDEE, the snow thermal conductivity is divided in two terms. The first term represents the snow thermal conductivity (Yen et al., 1981).

$$\Lambda_{snow\ cond} = \Lambda_{ice} \cdot \exp\left(1.88 \cdot \frac{\rho_{snow}}{\rho_{water}}\right) \quad (S1)$$

5 Where $\Lambda_{ice} = 2.2 \text{ W m}^{-1} \text{ K}^{-1}$.

The second term represents the thermal conductivity resulting from the vapor transfer in the snow (Sun et al., 1999):

$$\Lambda_{snow\ vap} = \max\left(0, a_{\Lambda} + \frac{b_{\Lambda}}{T_{snow} + c_{\Lambda}} \cdot \frac{P_0}{P_a}\right) \quad (S2)$$

Where $a_{\Lambda} = -0.06 \text{ W m}^{-1} \text{ K}^{-1}$, $b_{\Lambda} = -2.54 \text{ W m}^{-1} \text{ K}^{-1}$, $c_{\Lambda} = -289.99 \text{ W m}^{-1} \text{ K}^{-1}$, $P_0 = 1000 \text{ hPa}$ and P_a the atmospheric pressure in hPa.

10 The resulting snow thermal conductivity is expressed as follows:

$$\Lambda_{snow} = \Lambda_{snow\ cond} + \Lambda_{snow\ vap} \quad (S3)$$

S2 Snow heat capacity equation

Snow heat capacity is expressed in ORCHIDEE as follows:

$$\lambda_{snow} = a_{\lambda} \cdot \rho_{snow} \quad (S4)$$

15 Where $a_{\lambda} = 2.106 \cdot 10^3 \text{ J K}^{-1} \text{ kg}^{-1}$.

S3 Albedo scheme from Chalita and Le Treut (1994)

$$\alpha_{snow} = a_{aged} + b_{dec} \cdot \exp\left(-\frac{\tau_{snow}}{\tau_{dec}}\right) \quad (S5)$$

Where a_{aged} represents the albedo of old snow covered surface (after aging), b_{dec} is defined in order that the sum of a_{aged} and b_{dec} represents the fresh snow albedo, τ_{snow} is the snow age and τ_{dec} represents the snow age decay rate in days.

20 The parameterized snow age, τ_{snow} is expressed as following:

$$\tau_{snow}(t + dt) = \tau_{snow}(t) + f_{age} \quad (S6)$$

where t represent time and dt the model time step. The term, f_{age} , which represents the effect of low temperatures on metamorphism is shown:

$$f_{age} = \frac{(\tau_{snow} + (1 - \frac{\tau_{snow}}{\tau_{max}}) \cdot dt) \cdot \exp(-\frac{P_{snow}}{\delta_c}) - \tau_{snow}(t)}{1 + g_{temp}(T_{surf})} \quad (S7)$$

- 25 where T_{max} is the maximum snow age, P_{snow} is the snowfall amount during the model time step dt , δ_c is the critical snowfall depth required to reset the snow age and T_{surf} is the temperature on the surface of the snowpack.

$$g_{temp}(T_{surf}) = [\frac{\max(T_0 - T_{surf}, 0)}{\omega_1}]^{\omega_2} \quad (S8)$$

where ω_1 and ω_2 are tuning constants.

S4 Albedo parameters

Table S1. Albedo values used for the ORCHIDEE simulations

Parameter	Description	GrIS ASIM12L	GrIS OPT12L	AIS
A_{aged}	Old snow albedo	0.553	0.58	0.75
B_{dec}	Sum with A_{aged} for the fresh snow albedo	0.32	0.28	0.08
δ_c	Snowfall depth required to reset snow age [m]	0.783	1.0	1.0
τ_{dec}	Snow age decay rate [d]	6.911	2.0	6.9
ω_1	Tuning constant	3.037	3.0	3.0
ω_2	Tuning constant	3.974	6	6
τ_{max}	Maximum snow age (d)	56.183	54	54
α_{ice}	Ice albedo	0.476	0.420	0.420

30 S5 Surface snow density parameterizations

S5.1 MAR (Kittel et al., 2021)

$$\rho_s(ws_{10m}) = 200 + 32 \cdot ws_{10m} \quad (S9)$$

With ws_{10m} in m s^{-1} .

S5.2 IMAU ANT (Lenaerts et al., 2012; Veldhuijsen et al., 2023)

$$35 \quad \rho_s(T_s, ws_{10m}) = 83 + 0.77 \cdot T_s + 11.67 \cdot ws_{10m} \quad (S10)$$

With ws_{10m} in m s^{-1} and T_s in K.

S5.3 IMAU GR (Ligtenberg et al., 2018)

$$\rho_s(T_s) = 362.1 + 2.78 \cdot (T_s - 273.15) \quad (\text{S11})$$

With T_s in K.

40 S5.4 SNOWPACK (Groot Zwaaftink et al., 2013)

$$\rho_s(ws_{10m}) = 361 \cdot \log_{10}\left(\frac{ws_{10m}}{4}\right) + 250 \quad (\text{S12})$$

With ws_{10m} in m s^{-1} .

S6 Observational uncertainties

For each metric ρ_{5m} and ρ_{10m} , the observational uncertainty is estimated using the standard deviation, calculated over observations within a 2 m interval around the metric, divided by the square root of the number of observations. When fewer than 10 observations were available, the interval is expanded to include the ten closest observations to ensure a representative sample for computing the standard deviation.

For surface density, uncertainties are calculated for locations with at least five observations using the standard deviation divided by the square root of the number of observations. For locations with fewer than five observations, the uncertainty is set to the average value computed from locations with five or more observations. In Antarctica, where uncertainties are sometimes provided with surface density measurements, they are used to compute an average uncertainty. The resulting average uncertainties are 28.3 kg m^{-3} for Antarctica and 24.3 kg m^{-3} for Greenland, which are applied to locations with fewer than five observations in the upper 20 cm.

S7 Additional figures

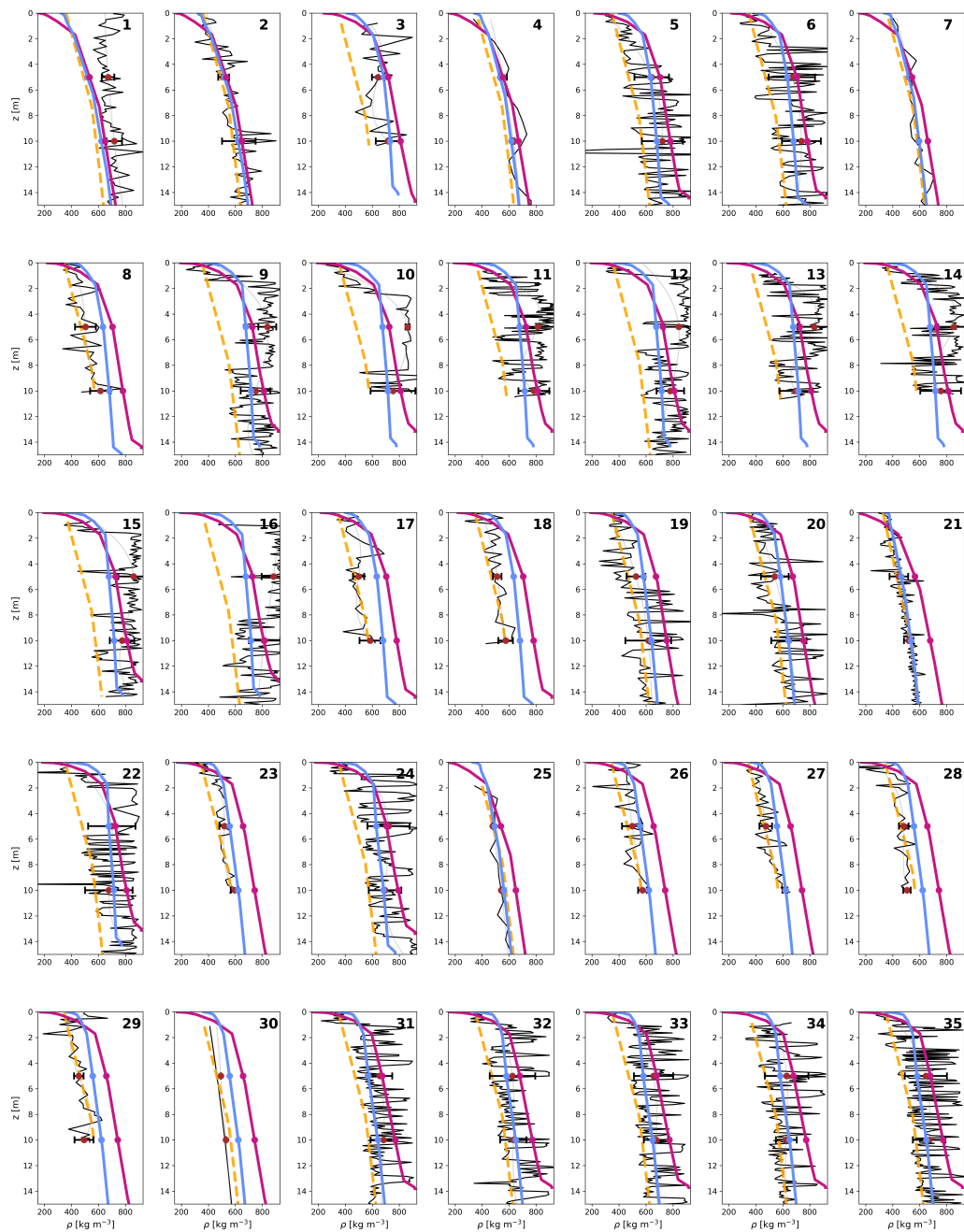


Figure S1. Density profiles in Greenland. Dark lines represent observed density profiles, orange dashed line the initialization profile, grey line represents the fitted profile, the purple curve the density profile before developments and calibration (OR OLD) and in blue the updated density profile (OR NEW). Error bars represent observational uncertainties.

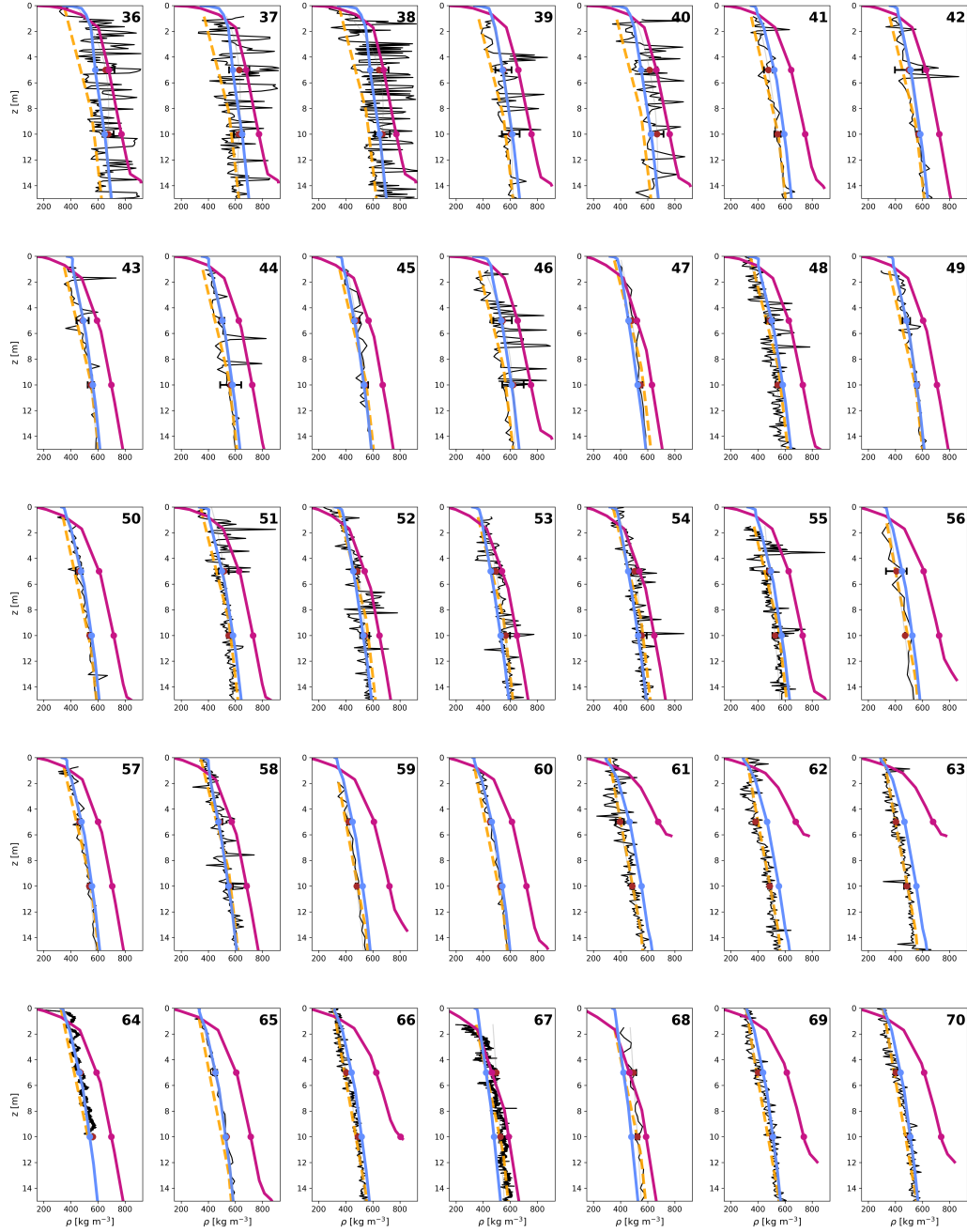


Figure S2. Density profiles in Greenland. Dark lines represent observed density profiles, orange dashed line the initialization profile, grey line represents the fitted profile, the purple curve the density profile before developments and calibration (OR OLD) and in blue the updated density profile (OR NEW). Error bars represent observational uncertainties.

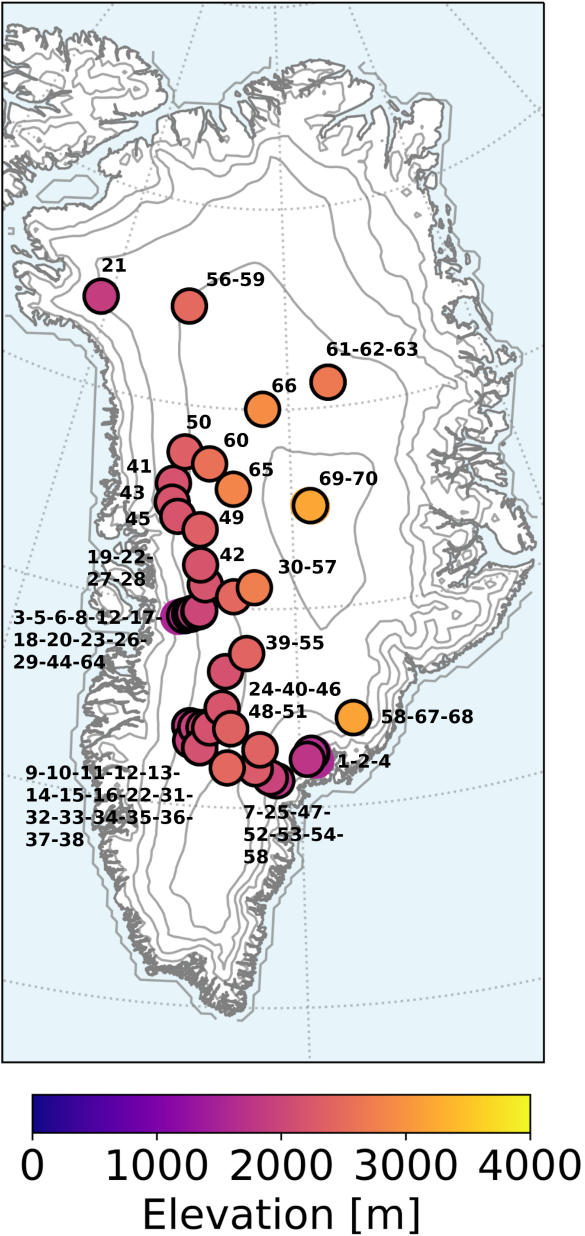


Figure S3. Locations of the enumerated density profiles in Greenland presented in Figures S1 and S2. The locations are represented as a function of their surface elevation.

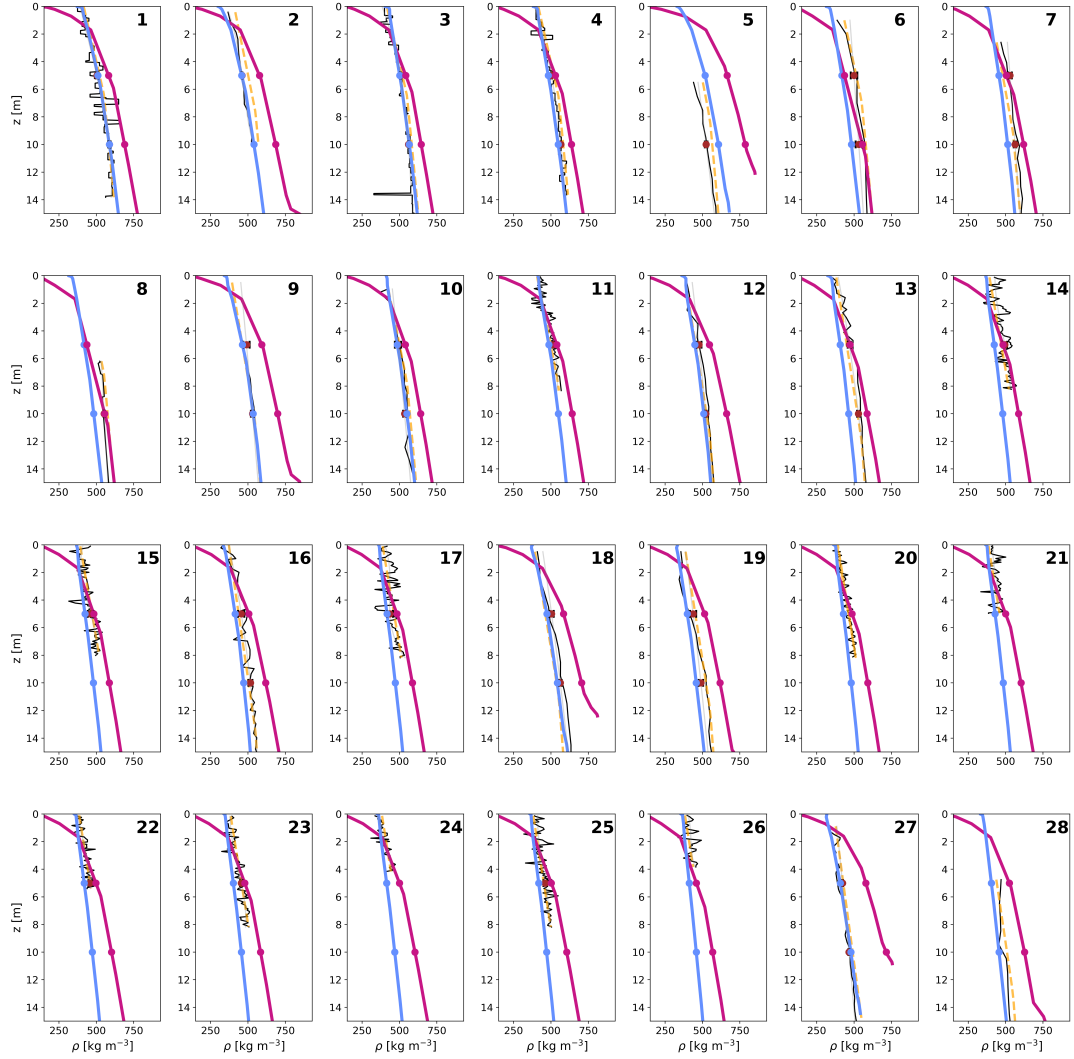


Figure S4. Density profiles in Antarctica. Dark lines represent observed density profiles, orange dashed line the initialization profile, grey line represents the fitted profile, the purple curve the density profile before developments and calibration (OR OLD) and in blue the updated density profile (OR NEW). Error bars represent observational uncertainties.

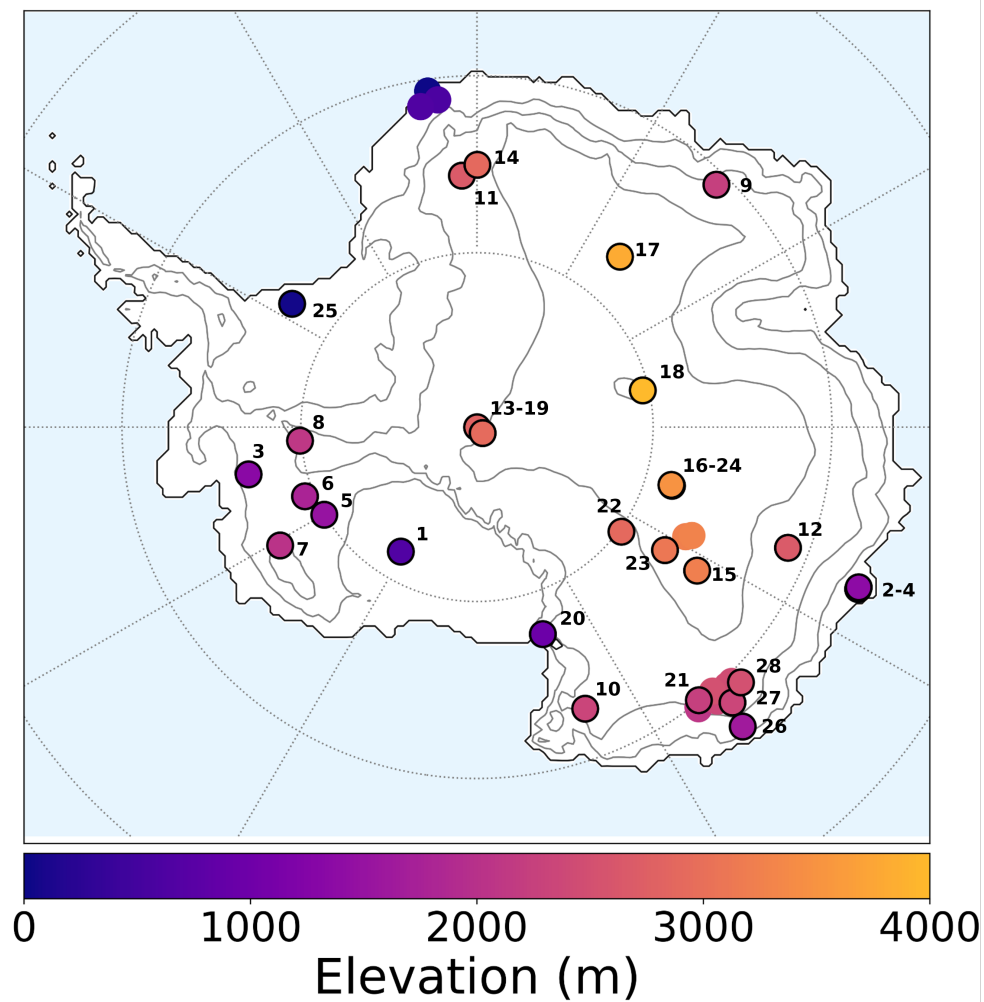


Figure S5. Locations of the enumerated density profiles in Antarctica presented in Figure S4. The locations are represented as a function of their surface elevation.

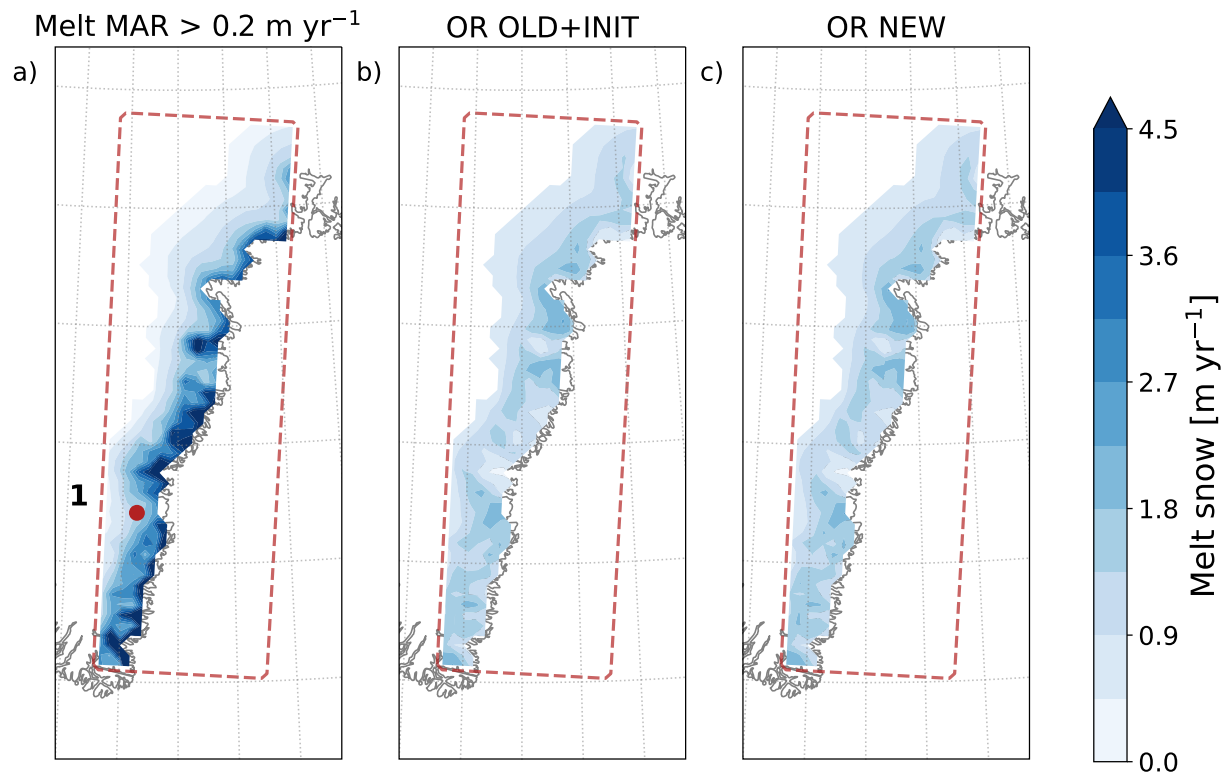


Figure S6. (a) Average melt from the MAR model over the southeast coast of the GrIS, where melt exceeds a threshold of 0.2 m yr^{-1} , between 2010 and 2019. (b, c) 10 years melt average from ORCHIDEE using the OPT12L albedo parameters over the same region for OR OLD INIT (b) and OR NEW (c).

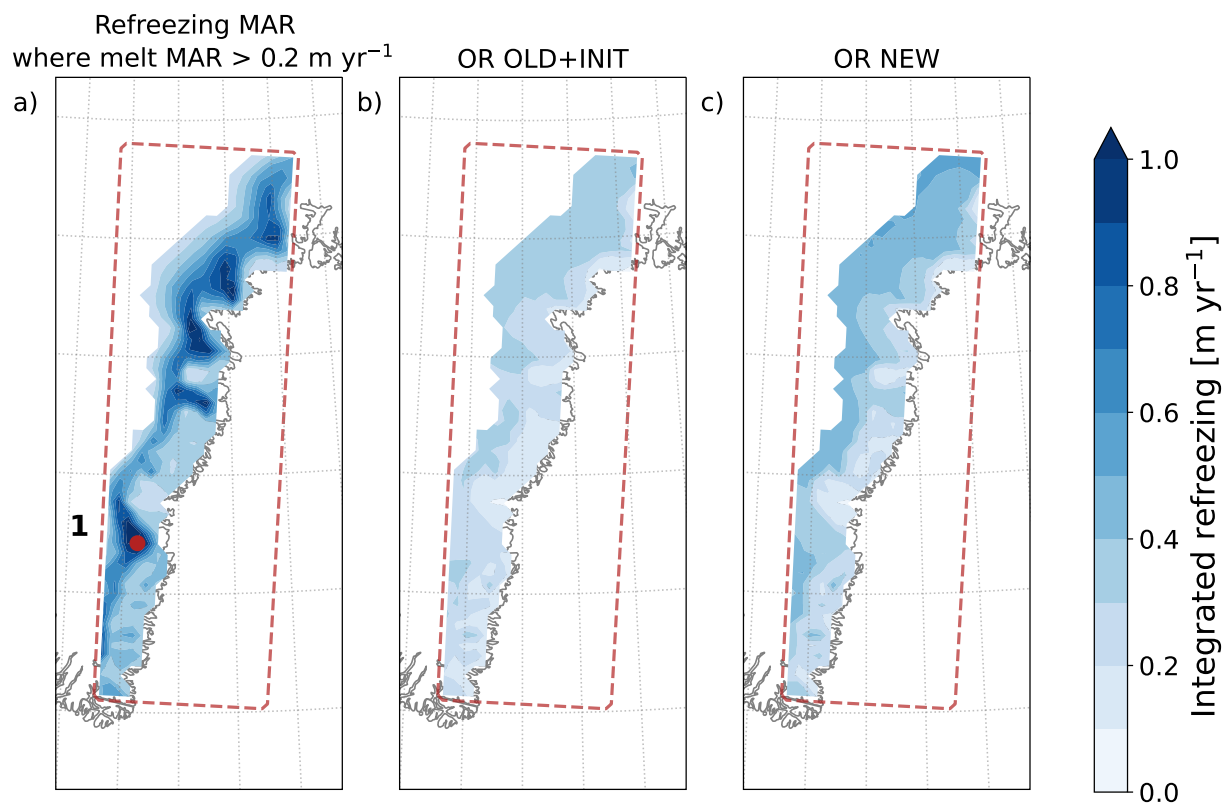


Figure S7. (a) Average refreeze from the MAR model over the southeast coast of the GrIS, where melt exceeds a threshold of 0.2 m yr^{-1} . (b, c) 10 years refreeze average from ORCHIDEE using the OPT12L albedo parameters over the same region for OR OLD INIT (b) and OR NEW (c).

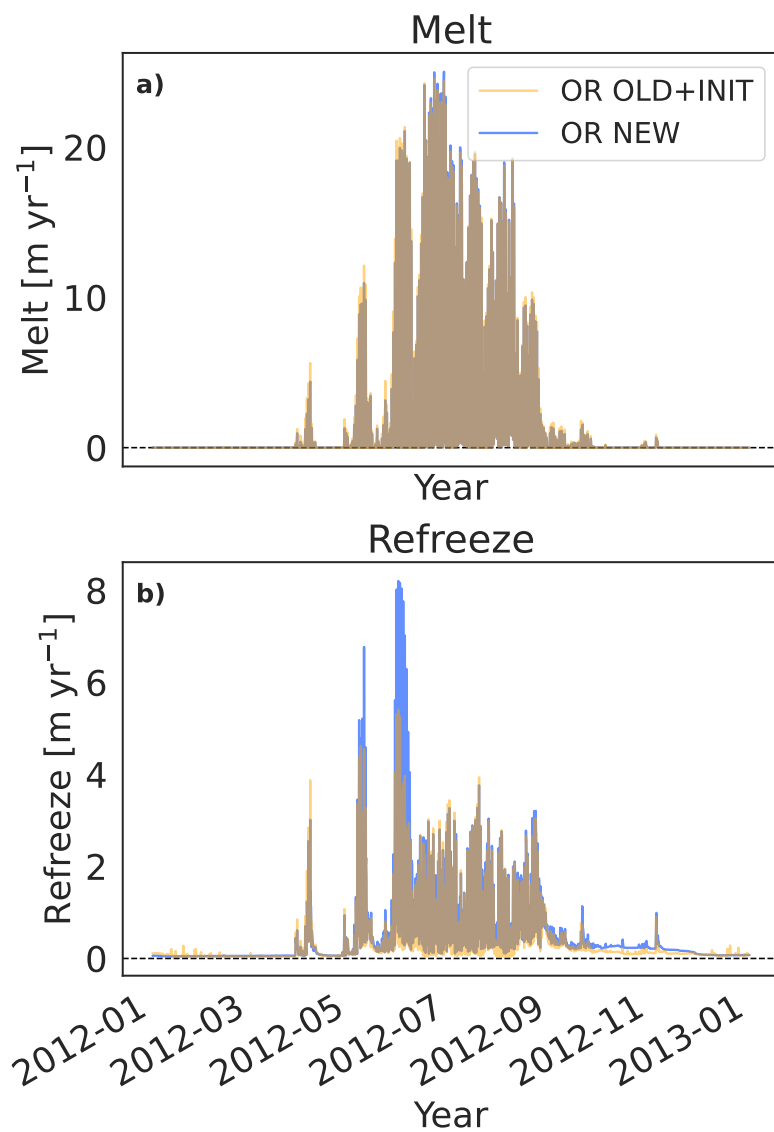


Figure S8. Seasonal three-hourly melt (a) and refreezing rates (b) during 2012 from OR OLD INIT and OR NEW using the OPT12L albedo parameters over the same region as presented in Figure S6 and S7.