SUPPLEMENTARY MATERIAL

1-Temperature evolution for Simulation 2

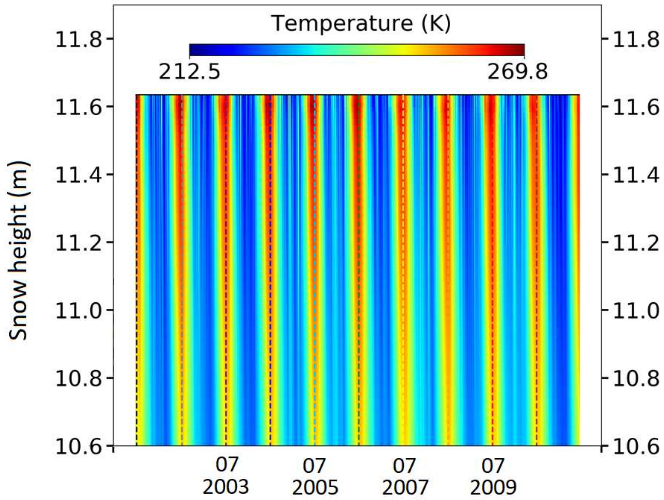

Figure S1. Simulation 2, evolution of temperature at GRIP, Greenland.

2-Density changes for Simulation 3 and 4, realized at Dome C, without precipitation.

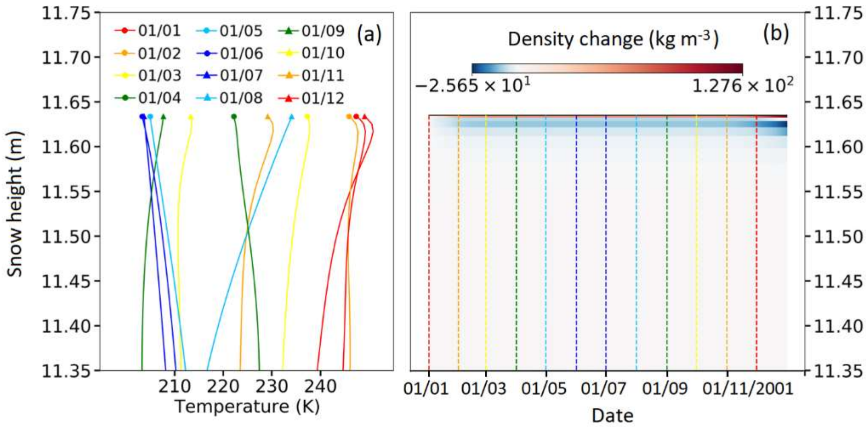

Figure S2. Simulation 3: (a) Temperature profile on the first day of each month, around 8 pm. The 1st of August corresponds to a short-term warm event within winter. (b) Change in snow density caused by vapor transfer over one year (cumulative). Here, 'density change' stands for the difference between density at t and at the beginning of the simulation for the selected layer.

For simulation 3 (Fig. S2), where vapor transport is active and compaction inactive, the density changes result only from vapor transport.

During summer, the first layer is gaining water whereas the layers immediately below (11.58 to 11.63 m) are losing water. Thus, the vapor departure region is not exactly at the top of the snowpack in this simulation. In detail, the density of the first layer increases by +127 kg m^{-3} over one year (Fig. S2). The underlying layers show a progressive decrease in density of -25 kg m^{-3} over one year. This upward flux of vapor in the top millimeters of snow reflects a slightly colder temperature at the top of the snowpack, and this even in summer, due to infrared radiation. Further down, layers are once again gaining water.

Density changes are very limited during winter. As long as the atmosphere remains cold, vapor moves upward, but in very small quantities, insufficient to make the summer density increase disappear. During short warm events in winter, and especially on the 1st of August, the first layer loses mass, but again the change remains small compared to the change observed in summer. As a conclusion, it seems that temperatures above about 240 K are required to observe significant changes in densities due to vapor transport at the seasonal cycle.

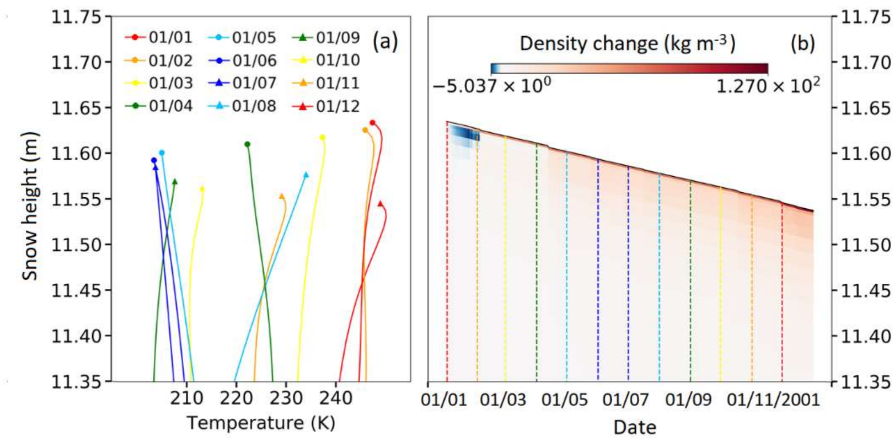

Figure S3. Simulation 4, evolution of the snow density over one year in a case with homogeneous compaction and wind drift, but without precipitation. The density change is taken as the difference relative to the first day for each layer (layer 1 is compared to layer 1, layer 5 to layer 5 etc…), even if they are not at the same height; thus density change may be overestimated compared to "horizontal" density change).

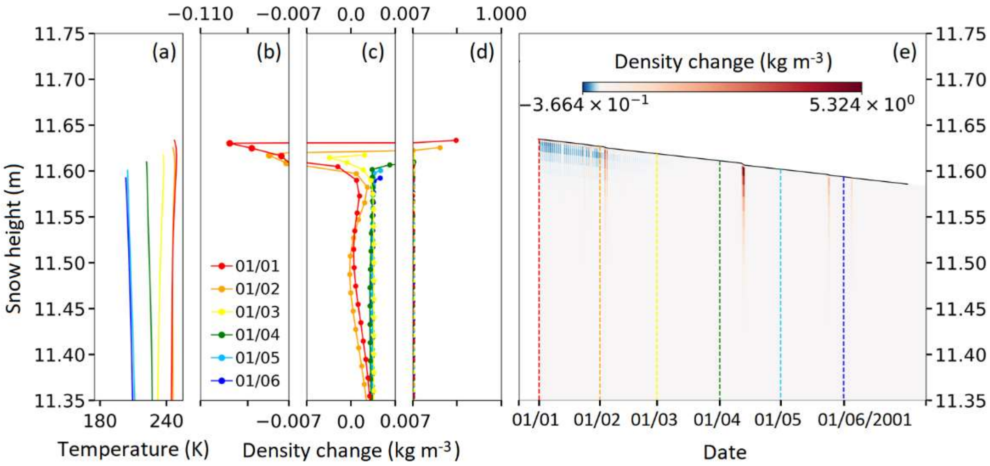

Figure S4: Simulation 4, density change per 12h (with vapor transport, with compaction and with wind drift).

In Simulation 4 (Fig. S3 and S4), there are three potential sources of density changes: homogeneous snow compaction, wind-induced snow compaction and vapor transport.

Figure S3 shows the total density change over one year. The total density change reaches +127 kg m^{-3} in the first layer. Several events of compaction by wind drift are visible, in particular on the 2^{nd}-3^{rd} of February, the 11^{th}-12^{th} of April, the 23^{rd}-24^{th} of May and on the 3^{rd}-4^{th} of June, on the 18^{th} of October and the 27^{th} of November (see also Fig. S4, density changes per 12 h period). Vapor transport effect on density change is visible only during the first summer.

Figure S4 shows density change per 12h period instead of the cumulative density change. Thus, the magnitude of the change is necessarily reduced (shorter period). But wind compaction events become more visible (Fig. S4e). They correspond to a strong increase in density associated to a decrease of snow height (for instance on the 2^{nd}-3^{rd} of February, the 11^{th}-12^{th} of April, the 23^{th}-24^{th} of May and on the 3^{rd}-4^{th} of June). In the first two months, when the temperatures are highest, vapor transport is visible, but it becomes insensitive later on. Wind drift events are rare but lead to strong density changes (up to +5 kg m^{-3} $(12\ h)^{-1}$). Vapor transport occurs every day in summer but never leads to changes larger than 650 g per 12 h (350 g per 12 h for negative density change). Figure S4b-d show the vertical profiles density changes at 6 dates. They show two interesting features not visible on Fig. S4e. First, positive density changes are observed in the first layer (region of water arrival) at the end of January and February, indicating the orientation of water transport. Second, the layers below 11.50 m all show a slight density increase (3.5 g m^{-3} $(12\ h)^{-1}$). This homogeneous increase, constant with time, is caused by homogeneous compaction.

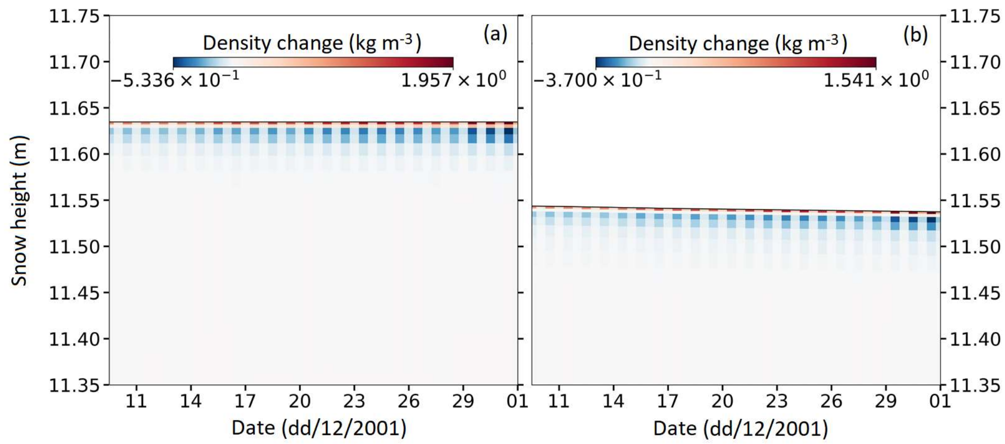

Figure S5: Simulation 3 and 4 compared. Density change per 12h period (caused by vapor transport only), in a case without compaction (a) and in a case with homogeneous and wind compaction (b), for the last days of December 2001.

Using the mass variation of each layer, it is possible to separate density changes caused by compaction or by vapor transport. Here we show the density changes caused by vapor transport only, per 12h period, for the case without any compaction (Simulation 3, Section 4.2.1.) and for the case with wind and homogeneous compaction (Simulation 4, Section 4.2.2.), in the last days of December (most active vapor transfer). The pattern is exactly the same, but the magnitude of the change is different. When the two compactions are active, the first layer receives less water and the layers below lose less water. This decrease in the intensity of vapor transport is expected because 1) the compaction leads to a smaller porosity, limiting vapor transport, and 2) because compaction increases the layer density and its thermal conductivity, thereby reducing temperature gradients in the snow, which force vapor diffusion.

3- **Density changes for Simulation 5, realized at Dome C, with precipitation.**

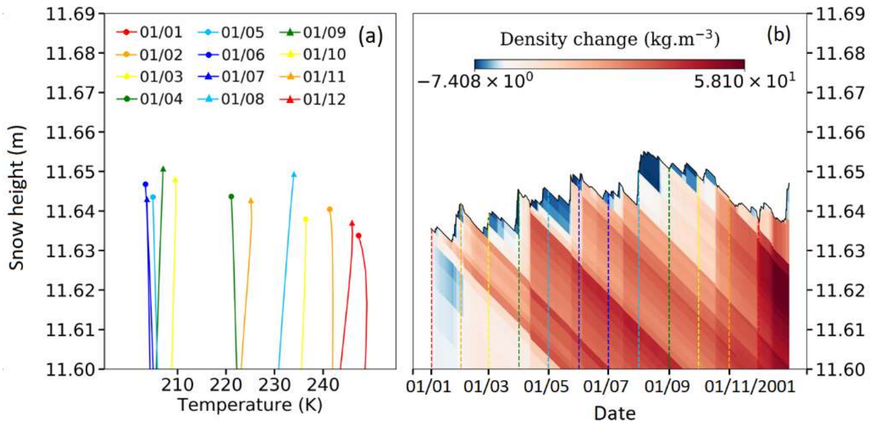

Figure S6. Simulation 5: Snow density change (relative to original density profile at t0) over one year: precipitation (snowfall) active, compaction (wind and weight) active, vapor transfer active.

Figure S6 presents the results of density change for the Simulation 5. Here, the density change is the difference between density at t and at t0 for layers having the same number (layer 1 to layer 1, layer 5 to layer 5). Note that these layers may not have the same height and were not deposited at the same date. Thus, we restrict our description to the first centimeters of the snowpack.

Snowfall events are characterized by an increase in the snow height, and also by a 'decrease' in the first layer(s) density. This decrease can reach 7.4 kg m^{-3}. Because in the original profile, the density of the first layer was 311 kg m^{-3}, and because the new snow from snowfall has a fixed density of 304 kg m^{-3}, it is logical to find a difference (or density change) of the order of 7 kg m^{-3}. The value might be lower if the deposition of new snow is associated with wind compaction. In between snowfall events, the density of the first layer increases again due to wind compaction and homogeneous compaction. As a result of these various processes the density in the first layer varies between 304 and 370 kg m^{-3}.

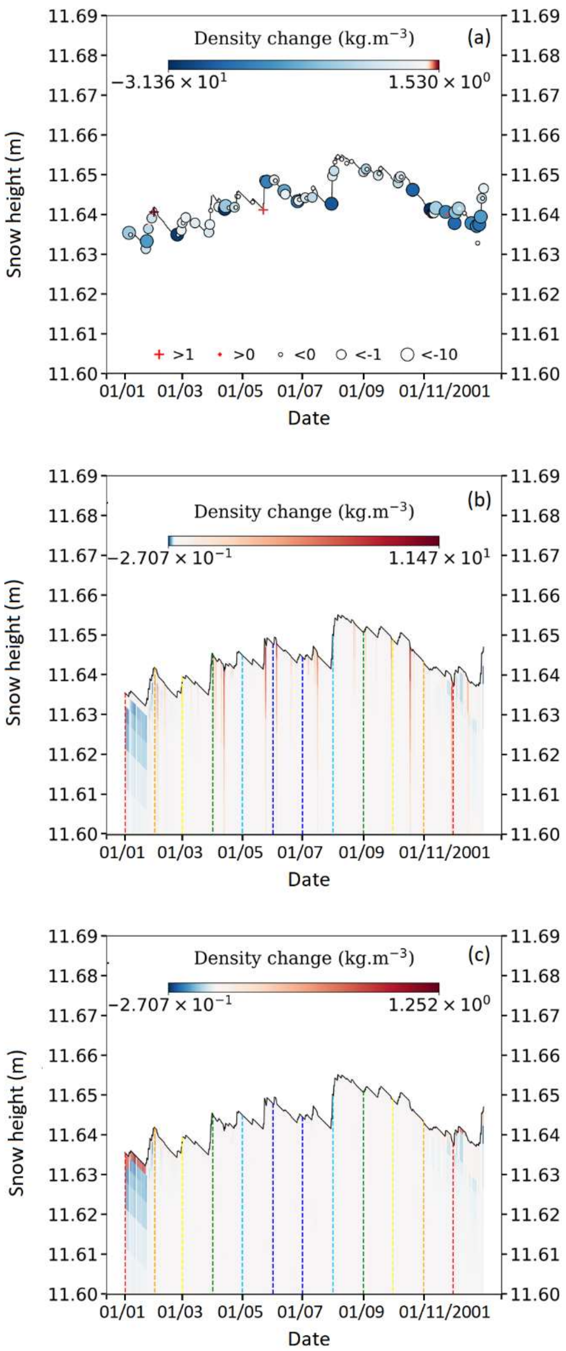

Figure S7: (a) Snow density change (12 h-period) for days with snowfall (snowpack height increases). (b) Snow density change (12 h-period): for days without snowfall (snowpack height decreases). (c) Change in snow density caused by vapor transport (days without snowfall only).

Figure S7 (a) shows the density change per 12 h period in the first layer, only for periods with snowfall (increase of the total snow height). The values range from -31.3 kg m^{-3} to +1.53 kg m^{-3} with a mean value of -6.5 kgm^{-3} (or -2 % of the total density). Because of the low density of the new snow (304 kg m^{-3}), we indeed expect density loss during these snow fall events. Since the highest density measured in the first layer is 347 kg m^{-3}, the maximum density change on the advent of snowfall should be -43 kg m^{-3} (which is not attained here). The lower maximum, as well as the rare positive values of density change, is probably due to other processes active at the same time (compaction and/or vapor transport).

In between snowfall events (Fig. S7b), the density changes per 12 h period are mainly caused by wind compaction (with a maximum increase of 11.5 kg m^{-3} per 12 h period). Vapor transfer has a much smaller impact, with a decrease of density limited to 0.270 kg m^{-3} in the departure layers and a density increase limited to 1.25 kg m^{-3} per 12 h in the first layer (Fig. S7c). Thus precipitation and wind compaction are the largest contributors to density change in the first layer, and vapor transport has a limited impact. On Figure S6, in the zone of vapor departure, the density change caused by vapor transport is visible only on the first half-summer (and overprinted by compaction in the second half-summer).

4-Comparison between $\delta^{18}O$ in precipitation and surface snow for Simulation 5

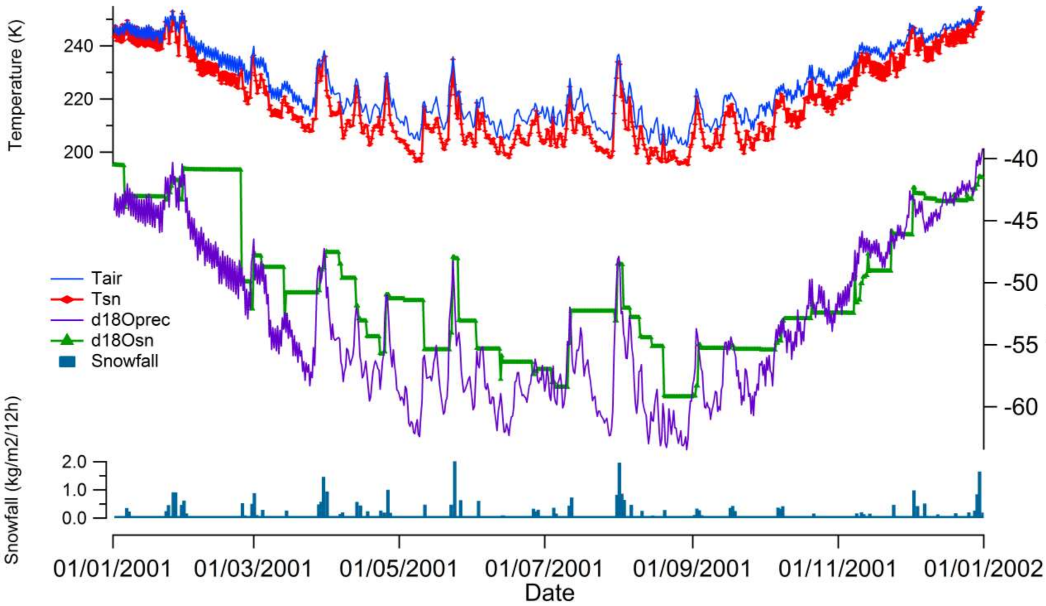

Figure S8: Seasonal evolution of $\delta^{18}O$ in the precipitation ($\delta^{18}O_{sn}$) as well as in the first layer of snow ($\delta^{18}O_{sn}$) as a result of variability in air temperature (T_{air}) for Simulation 5 (vapor transport, wind and weight compaction are active).

In this simulation, the same as for Fig. 7 in the main text, the temperature in the first layer (T_{sn}) closely follows the variations of the air temperature (T_{air}, 2 m) but is shifted toward lower values (~-6 °C in winter; ~-4.5 °C in summer). Snowfall events are associated with temperature increases, and therefore to peaks in the $\delta^{18}O_{prec}$ values predicted in the precipitation. The $\delta^{18}O_{sn}$ evolves mostly through brutal changes at each snowfall event, where it acquires the signature in the snowfall (new snow layer) or get closer to the composition in the snowfall (assimilation of the new snow in the preexisting first layer). The impact of vapor transport is not visible.