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Interactive comment on "Snowpack and firn densification in the Energy Exascale Earth System Model (E3SM) (version 1.2)" *by* Adam M. Schneider et al.

Anonymous Referee #2

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This paper addresses a specific, pressing need to improve the simulation of firn in dry-snow zones of ice sheets in the E3SM. The authors present a compelling study of firn-density model improvements, ultimately achieving the first step toward implementing improved firn simulations in the ELM. Their work highlights the need for two models of firn densification, above and below the characteristic-density depth, to achieve simulated density-depth profiles as observations made in the field, and suggests the required next steps for using these models to generate better predictions of sea level rise. Below is a list of general and specific comments for the authors to consider in revising this manuscript.

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General Comments: - This is a very well written manuscript that is motivated and articulated clearly. I am not an expert in ESMs or their various component models, and therefore cannot comment on the authors' specific implementation of firn compaction models into the E3SM Land Model.

- The stated goal of this work is to more accurately simulate snowpack evolution in the ELM, including over the Greenland and Antarctic ice sheets. With this goal, why do the authors increase the snowpack from 1m (in the previous version) to up to 60 m in this version? In the dry snow zone, it's common for firn column to vary in depth from 50 to 120m (Cuffey & Paterson, 2010), depending on site conditions. Many sites have firn columns deeper than 60 m (and even the 80 m depth that Figure 1 indicates is possible), and therefore this estimate of snowpack evolution won't be valid for large swaths of the Greenland and Antarctic ice sheets. If instead the authors are referring to depths in m SWE, this should be made explicit within the text and in the figure axes.

- In various places the authors describe "improvements" or "slight improvements" between models, especially in Seciton 4.1. How do the authors determine these improvements? Are they quantifiable?

Specific Comments:

Section 3.1 – The abstract states that the authors improve the depth of snowpack in the ELM from 1 m to up to 60 m, while the Figure 1 caption states that the new model layers can extend to 80 m. Why is there a discrepancy between these two extended depths?

Section 3.3.2 – a brief description of the Greenland sites used from the Mosley-Thompson et al. (2001) study would be helpful here. There were quite a few cores in that thorough study. How did the authors decide which cores to average into a composite GrIS density profile? The accumulation rate varies quite a bit across Greenland, especially north to south. Were northern and southern sites averaged together?

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Additionally, only sites near Siple Dome were used in Antarctica. Since sites in East Antarctica has much lower mean annual temperatures and accumulation rates that Siple Dome, it may be more appropriate to claim that this applies to West Antarctica than both Antarctic ice sheets.

Section 4.1 – Lines 237-239: It would be helpful to the reader if the authors indicate which model they're referring here when they say "...this dynamic implementation of eq. (8)..." and "...the original compaction parameterization, from eq. (3)." Are these referring to models vK'17+ and A'76, respectively?

Lines 225-227: What is the justification for using the 1901-1920 reanalysis data to generate the steady-state density profiles? Is this considered an average period of time? If so, what metric was used to determine that it was best to use the data from 1901-1920?

Lines 225-227: The spin-up of the model simulated 260 years of snow accumulation is adequate for creating a typical dry snow-zone firn column in Greenland but would not reach back far enough to erase the natural firn density profiles in East Antarctica. Why was a spin-up of 260 years chosen?

Lines 227-229: are the authors referring to two of the examples given (-27C and -20C) here? Describing results for scenarios with mean annual temperature "within a couple degrees of -25C" is imprecise and leaves the reader wondering if they're missing a panel in Figure 2 for the -25C scenario (and other scenarios in between).

Lines 229-230: It'd be helpful to indicate here that the results from the Herron & Langway model are the colored bars in Figure 2.

Lines 237-239: In the discussion of Figure 3 here, the authors describe that the dynamic implementation of eq. (8) in the ELM (Again, is this the vK'17?) results in characteristics depth (550 kg/m3) more consistent with Herron & Langway for T > -32C, but the authors do no present any of the results for the T=-32C scenario. How was this

cutoff determined? Additionally, the panel for the T = -20C scenario shows that neither A'10 nor vK'17+ do a good job predicting the characteristic depth. Therefore, how do the authors conclude that the results are more consistent with H&L for T > -32C?

Figures 2 & 4: which lines are the authors referring to in these captions when they say "Line graphs show 100-year means from ELM simulations. . ."? All of the lines (except dashed & dotted?)? This vague statement is confusing due to the number of lines plotted.

Figure 2 – how are the range of surface densities used in the empirical modeling shown in the figure?

Figure 3 – comparing the steady-state density profiles generated for the 3 mean annual temperatures to sites with similar conditions (Table 2.2, Cuffey & Paterson, 2010), it appears that the ELM and empirical modeling results reach pore close-off density at too shallow of a depth for -20C, empirical modeling results.

Figure 4 – The stated goal for this figure is to better understand what drives rapid densification near the surface. Therefore, it would help the reader to have a second x-axis displaying the depth. Since we don't have a depth-age scale, it's hard to interpret where the near-surface is in this figure. What causes the jump in vertical strain rate in the empirical modeling results (colored lines)? Additionally, the error bars make it very hard to see the black and grey line trends. Consider altering the error bars in some way to allow the lines to become more visible. In the lower panel, why do the ELM simulation lines begin near 40 years instead of 0?

Technical Corrections: L10: remove 'when' from '. . .compared to when using. . .' L25: 'coupled' twice in this sentence, sounds awkward L34: need 'it' after 'implemented' here L225: the authors start what "with a baseline configuration. . ."? L260: don't need comma after "ELM" Figure 1: describe variable 'z' in the caption Figures 2 & 3: the bottom row of figures overlaps the y-axis units, space these out slightly so that each axis is legible. Figure 4: the top row of figures overlaps the y-axis units, space these

out slightly so that the axis is legible. Figure 6: add description of density measurements are shown in blue, as well as that the dotted and dashed lines represent the characteristic density and pore close-off density, respectively, to the caption.

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