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Impact of horizontal strain on firn-air content

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Knowledge of changes in firn density is essential to infer the mass balance of the ice sheets from repeat satellite-altimetry observations. Models of firn densification remain the largest source of uncertainty within this method because the physical processes responsible for firn compaction are not fully captured within the models. For example, the impact of horizontal strain on firn depth-density profiles is neglected in most firn-densification models, yet is likely important in regions of dynamic flow. In order to investigate the impact of horizontal strain on dry firn depth-density profiles, we have added a two-step layer-thinning method to the Community Firn Model, which is an open-source modular firn-model framework. In each time step of our layer-thinning method, the firn first densifies through the equations of the user-selected 1-D firn-densification model; then, the firn is stretched as prescribed by a specified horizontal strain rate without further density changes. We test our layer-thinning method under idealized conditions common to the Amundsen Sea sector of Antarctica. Idealized tests show that incorporation of horizontal strain rates greater than 10^{-3} yr^{-1} reduces the firn-air content of the firn column by more than 0.9 m. We then test our method by following firn columns on two flowlines on Thwaites and Pine Island Glaciers using along-flow total horizontal strain rates, accumulation rates, and surface temperatures. These flowline tests indicate that incorporation of horizontal strain rates reduces the firn-air content by up to 13 m on Thwaites Glacier and 7 m on Pine Island Glacier, depending on the location along the flowline (i.e., which gives different climate forcing and thinning conditions), and the 1-D firn-densification model used. Further, we make an initial investigation into how evolving glacier dynamics (i.e., changing horizontal strain rates) may change the firn-air content. These initial results indicate that the firn-air content may change by up to several meters over two decades, a timescale that is relevant to altimetry surveys. Although the impact of horizontal strain has been shown to be essential to consider in modeling firn density in regions of dynamic flow, the response of microphysical firn-densification processes to horizontal strain may also be important, and should be evaluated in future work.