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Direct Observations and Model Calculations of Air trapping in Polar Ice

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Air is enclosed during the firn-ice transition and stored in polar ice, forming a reliable archive for ancient atmospheric air. The complex enclosure mechanism determines the age difference between ice and enclosed air, but also the air content. The firn-ice transitions at two sites in Antarctica (EDC and EDML) and one in North Greenland (B26) have been investigated by using X-ray micro-computer-tomography (μCT) on a series of samples from the transition zone. The study focuses on the small-scale density/porosity variations across the firn-ice transition, the three dimensional structure of the pore space and especially the partition between open and closed pores. The observations are compared with results from a percolation model based on a regular bcc lattice. The agreement between model results and observations for the relatively small sample sizes are surprisingly good and allow to extend important results to a larger spatial extent. This allows especially to quantitatively estimate the connectivity through thin layers with larger densities. Small permeability is still possible through layers of ice with a density of up to 850 kg m^{-3} if the layer thickness is only a few millimeters. Model calculations show that the extend of the zone of air trapping and especially the final air content of the ice depend not only on the amplitude of porosity, respectively density variations with depth but also on the frequency of such fluctuations. We conclude that the mean porosity at the firn-ice transition (lock-in zone where vertical molecular diffusion stops) depends primarily on stratigraphic features and not or not so much on parameters at the surface as temperature or grain size as previously assumed. The strong influence of stratigraphy is supported by model results of the percolation approach. The air content and the extent of the lock-in zone for the three drilling sites are calculated based on such simulations.