Firn Layer Evolution at Summit, Greenland

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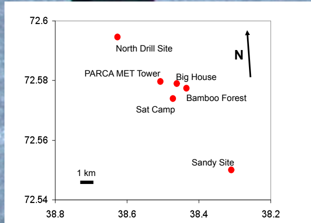
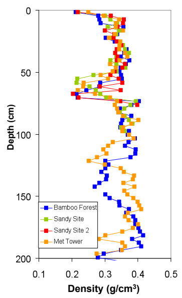
Abstract Physical properties of snow and firn layers in snow pits from Summit Station, Greenland, have been examined over the span of two season, summer and spring, and during subsequent years. Summit Station is a year-long research station located at the summit of the Greenland Ice Sheet, an area that experiences melt extremely rarely. In this region, snow layers persist year after year, are buried by subsequent storms, and undergo firn metamorphism, primarily driven by diurnal temperature gradients in the top two meters. Repeat pits at exact locations have been dug and analyzed for stratigraphy, density, and air permeability. The spatial variability of the snow from small to large scale has been examined, as well as the temporal variability of the near surface snow. We see that pits spaced several kilometers from one another have generally the same structure, with some localized differences in stratigraphy due to the presence or absence of such features as sastrugi and hoar layers. In general, we see an increase in permeability as a specific firn layer ages and is buried. These changes in physical properties are linked to changes in the firn microstructure due to temperature gradient metamorphism. More data are available, including grain size, gas diffusivity and thermal conductivity for select samples.



Site Map locating various pits. Distance from pits at the Bamboo Forest (2006-2008) to North Drill Site is 7 km, and to Sandy Site is 5 km.



Density profiles in the top 2m at various sites. In general, there is good agreement amongst the profiles of sites 5-7 km apart. Offsets in the high/low peaks of the density are due to local features such as sastrugi and drifts.

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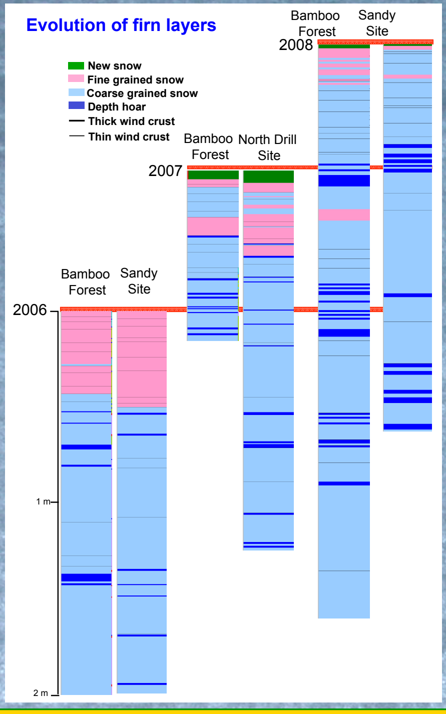
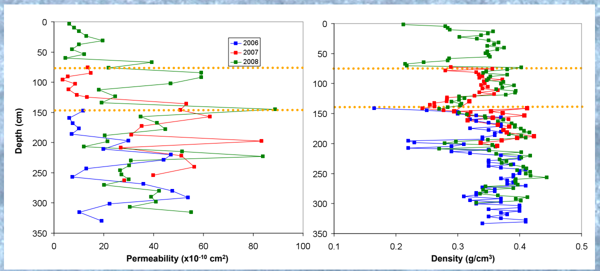
Evolution of firn layers

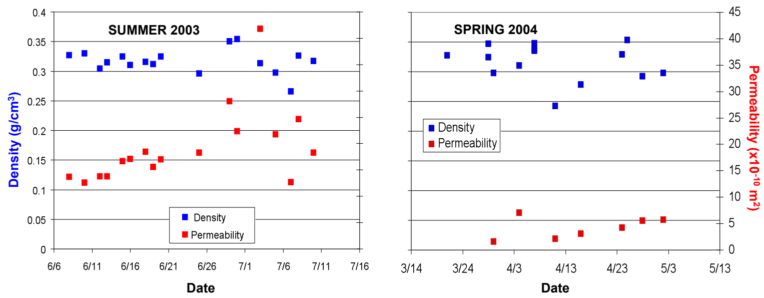


Stratigraphy from three years of pits. After excavating one pit near the Bamboo Forest at Summit in summer 2006, poles were used to mark the sample wall, and spaces for subsequent years were marked out. The surface was demarcated with string. In 2007 and 2008, pits adjacent to the original pit were dug in undisturbed snow. Also shown are the stratigraphic horizons from pits dug in the same year as the Bamboo Forest, but in different locations. In 2006, the second pit was dug at the Sandy Site. In 2007, pits were dug near the PARCA Met Tower and the North Drill Site. In 2008, pits were dug at Sandy's Site and the PARCA Met Tower.



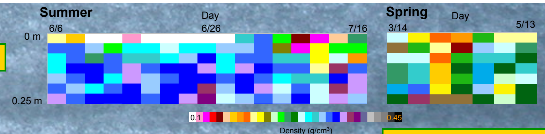
Permeability and density evolution over time. The permeability and density profiles from 2006 and 2007 have been shifted down to where their surfaces were located in the 2008 pit (at 71 and 140 cm, respectively). Surface snow, undergoes rapid changes in the first year, with permeability increasing dramatically. The firn becomes denser over time, but in a more uniform manner.

Seasonal Surface Evolution: Spring and Summer

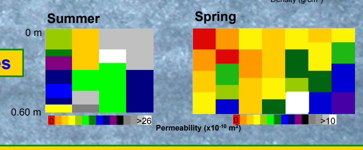


Shallow (25 cm) deep pits were dug over the course of one summer season, from June 12th to July 11th, 2003 and again in the spring, March 14th to May 13th 2004 near Summit Station's "Sat Camp" as part of a photochemistry experiment. A 100 cc (3-cm resolution) box cutter was used with a spring scale (1 g resolution) to determine density. The average density over the top 25 cm is reported here, with the density with depth is shown below. Permeability was determined by measuring flow rate and subsequent pressure drop using the custom-made CRREL permeameter (Albert et al., 2000). Here the average permeability values are reported for the top 60 cm, with the permeability profiles shown below. The density shows a slight upwards trend over the summer and spring, but stays relatively constant in the top surface layers, while the permeability shows a marked increase as both seasons progress. A year-round study shows similar results (Albert et al., in prep.) The average density in the top 25cm for spring is 0.29 g/cm^3 while for summer the average density is 0.32 g/cm^3. The permeability in the summer is much higher on average than in the spring, 19.2×10^{-10} cm^2 vs. 4.2×10^{-10} cm^2

Density Profiles



Permeability Profiles



Surface evolution. In summer months, the density in the top 25 cm stays relative constant, with the most notable changes occurring late in the season. The permeability changes dramatically from season to season and over time (note different scales between summer and spring).

Conclusions

- Spatial variability: overall trends of high and low density due to seasonal flucuations are apparent in two meter pits from sites ranging from 5 to 7 km away. Some deviations are seen in locations due to buried sastrugi and other localized features.
- Seasonal evolution and variability in near surface: Surface snow during summer and spring months undergoes rapid transformation in the summer, most noticeably an increase in permeability, while density stays relatively constant. Snow on the surface in summer months have much higher permeability and lower density than in spring months.
- Layer evolution: Surface snow, with low permeability, increases in permeability values from year to year at a faster rate than subsurface snow. The firn becomes denser over time, but in a more uniform manner.

References Albert, MA, E Shultz and F Perron, Snow and firn permeability studies at Siple Dome, Antarctica, Ann. Glaciol., 31, 353-356, 2000
Albert et al., Seasonal Variability at Summit, Greenland, JGR, in prep.

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