

Extensive liquid meltwater storage in firn within the Greenland ice sheet

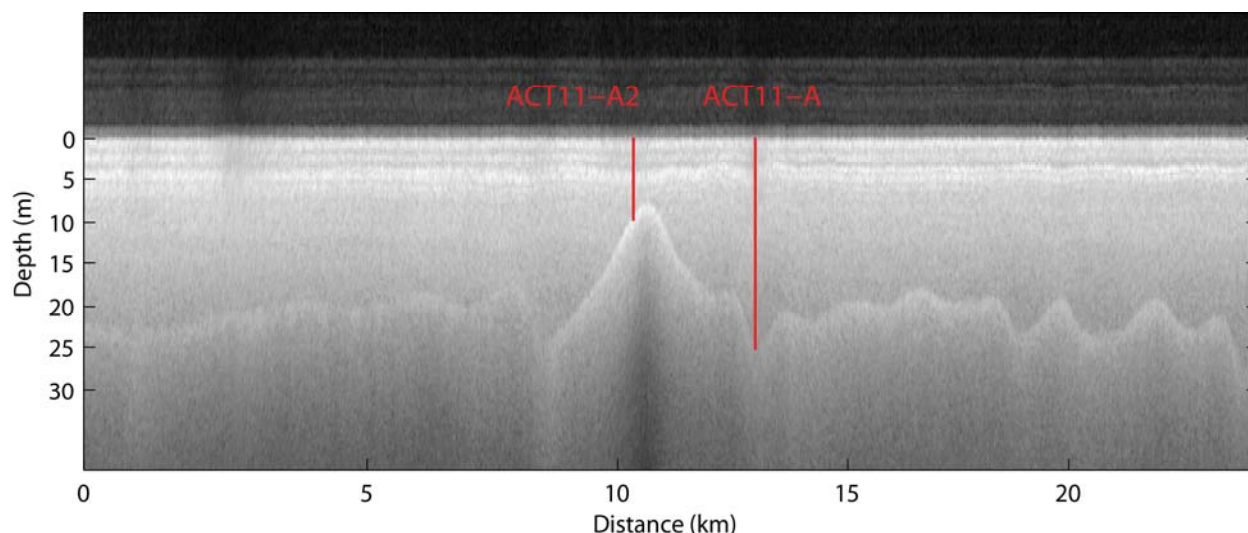


Fig. S1. OIB Accumulation Radar echogram collected on the ACT-11 traverse. Top boundary is ice sheet surface and internal bright horizon is top of PFA. Note vertical exaggeration and water firn cores in red. For location see Figure 1. The faint reflections above the surface are sidelobes associated with stepped-chirped architecture of the AR system occurring as a result of the pulse compression and Fourier transform used in post processing.

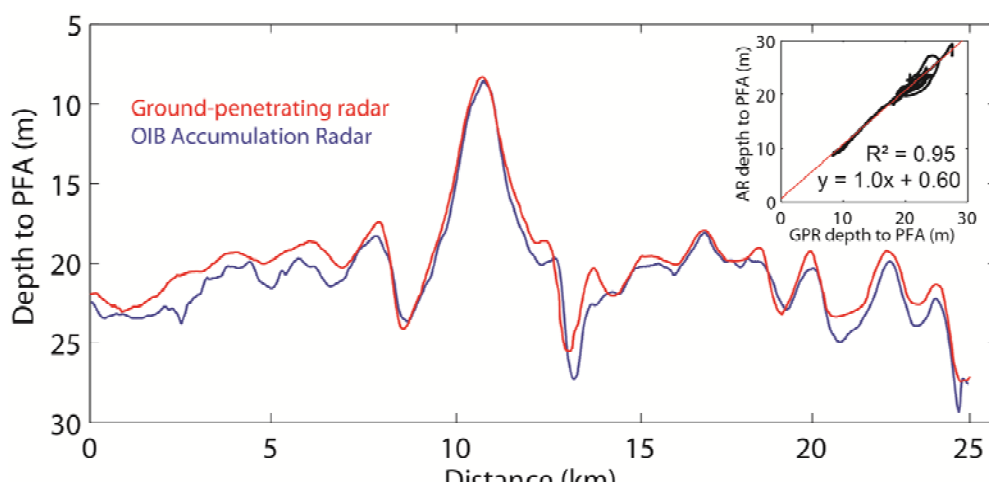


Fig. S2. Depths to top of PFA along ACT11 traverse including water core locations from GPR and OIB Accumulation Radar. For location see Figure 1. Inset, scatter plot and linear regression.

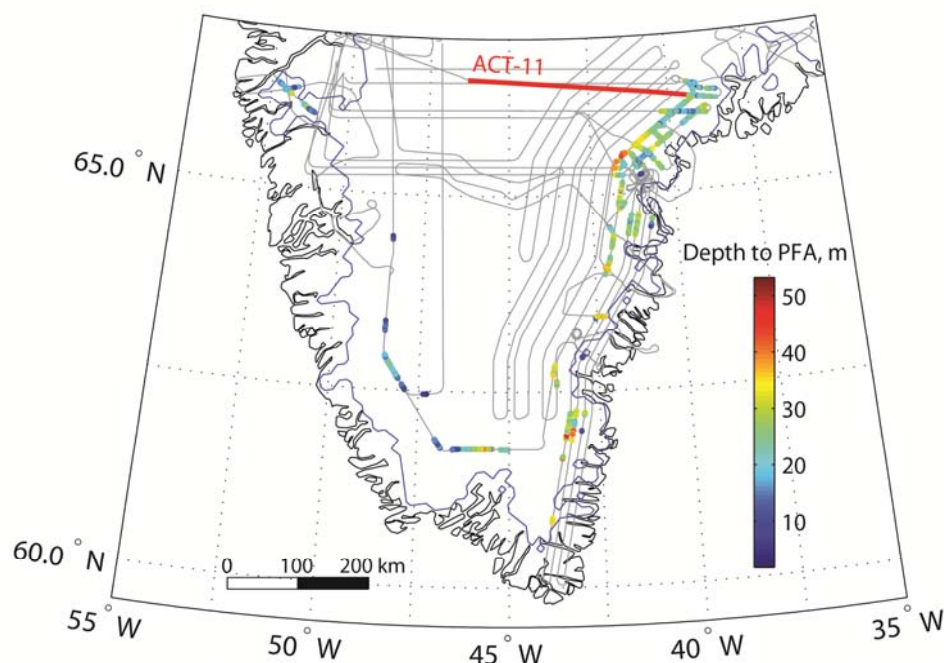


Fig.S3. Depth to top of the PFA, in color, retrieved from the OIB Accumulation Radar. The April 2011 flight lines are gray and ACT-11 traverse path is red.

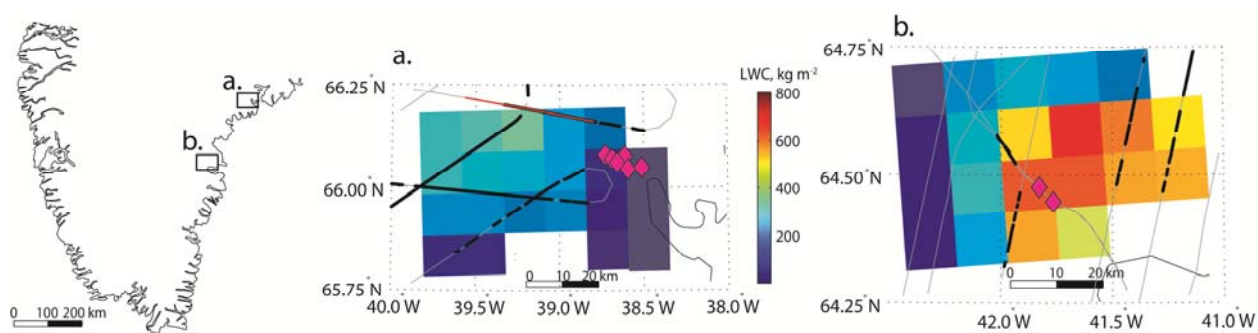


Fig. S4. Evidence of crevasses (magenta diamonds) using visual observations (a) and IceBridge CAMBOT L1B Geolocated Images of 2011²⁵ (b). Colored pixels represent RACMO2/GR liquid water content (LWC) estimates and the black dots show the evidence of water from the AR on board of IceBridge.

1. Snow accumulation grids

The RACMO2 snow accumulation grids (fig. S5) have a similar spatial pattern to (10) (Fig. 3). There are differences in the magnitude and the local maxima in the south and southwest are nearer the coast than in the Burgess et al. grids¹⁰. The differences in the magnitudes at the locations of the PFA are also illustrated in the histograms (fig. S6). The two data sets cover different time periods, Calibrated Polar MM5 1958-2008 and RACMO2 1990-2011. The Burgess et al. (10) grids are based on Polar MM5 solid precipitation output, implicitly accounting for combined surface and blowing snow–water vapor fluxes, while in RACMO2 these components are computed and explicitly accounted for in their accumulation grids. Neither the accumulation nor the melt fields can be rigorously evaluated in these data-sparse, high-accumulation regions. However, the association of high accumulation and PFA is strengthened by the fact that these two accumulation data sets, which are derived from independent models, both show high accumulation in areas of PFA.

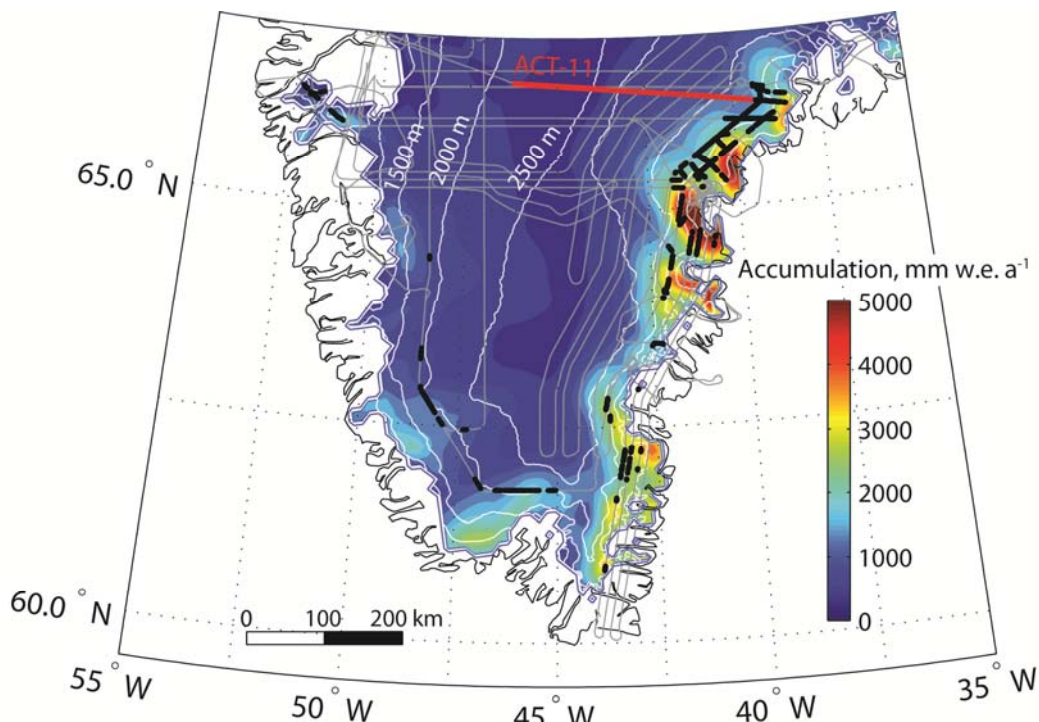


Fig. S5. Yearly snow accumulation modeled by RACMO2/GR averaged for the 1990-2011 time period (color). Elevation contours²³ (white), OIB flight lines (gray) and locations of PFA from OIB Accumulation Radar (black) complete the map.

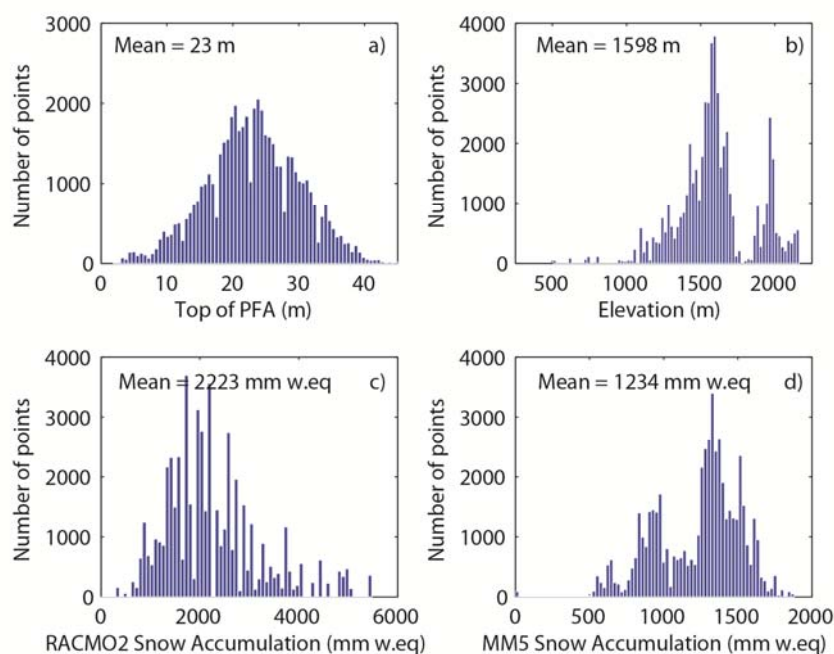


Fig. S6. Histograms of the PFA locations from OIB AR for: a) depth to top of the PFA, b) elevation DEM²¹, c) yearly-averaged accumulation rate of RACMO2/GR for 1990-2011 and d) yearly-averaged accumulation rate of Calibrated Polar MM5¹⁰ for 1958-2008 time period.

2. Mechanisms of PFA formation

Movie S1 shows an animation of daily average 2010 (date at bottom) snow temperature (red) and liquid water content (blue) for four individual RACMO2 grid cells situated in the southeast GrIS along the 66 N latitude circle. The top left represents a grid cell in the ablation area at 500 m altitude. Below a snow layer, which forms in winter, solid ice is present at this location. In spring the snow layer becomes saturated with liquid water and is completely melted at the end of summer. The top right represents a location situated within the PFA. In winter, the thick snow layer isolates the PFA from the cold atmosphere. In summer, surface meltwater makes the connection with the PFA and the complete upper firn layer becomes isothermal at the melting point, until fresh snowfall isolates the PFA again in September. The bottom left represents a location higher up the ice sheet, for which 2010 is the first year in which liquid water persists until December, between 3 and 10 m depth. This shows how the PFA migrates up the ice sheet in a high-melt year. The bottom right represents a location higher up the ice sheet. At this location all the summer melt water is refrozen in the snowpack, and the temperature of the snow remains below the melting point. For each of the pixels the maximum liquid water content was 40 kg/m³, in the model, linked to the water holding capacity of the firn.

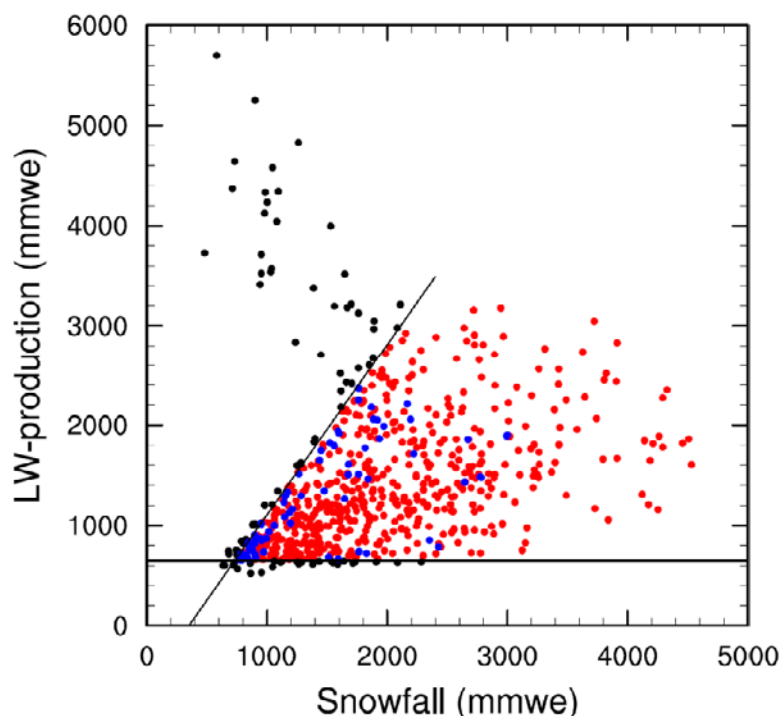


Fig. S7. Scatter plot of RACMO2/GR SMB components for grid cells which had at least one year with liquid water in the snow pack in April during the period 2001-2010. Snow fall is total solid precipitation during the year and liquid water production represents melt water plus rain. The results of this two component parameterization, with the bounds shown, to predict the location of modeled PFA are shown as: red, correctly predicts, blue: predicts but not modeled, and black: does not predict but is modeled.

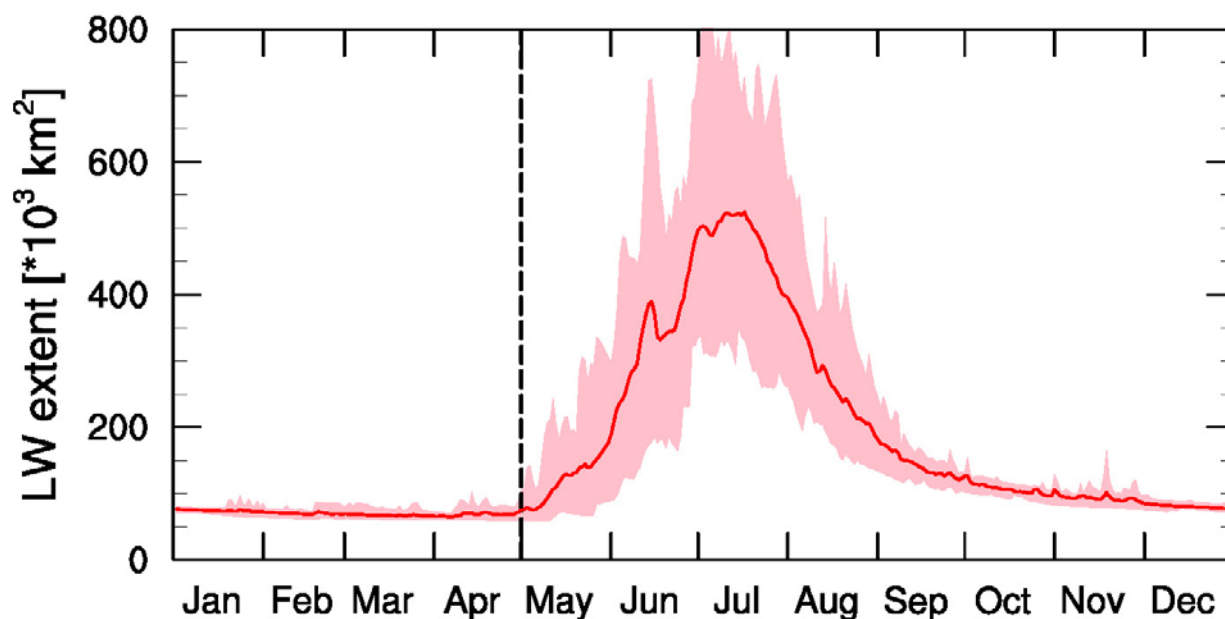


Fig. S8. Seasonal cycle of liquid water extent averaged over 1992-2011 from RACMO2. Uncertainty in extent represents the 5-95% band for the 20 years. The dashed line represents the date the bore holes were drilled in 2011.

Supplementary Information References

24. Kovacs A., Gow A.J. & Morey R.M. The in-situ dielectric constant of polar firn revisited. *Cold Regions Science and Technology* **23**, 245–256
25. Krabill, William B.. 2010. *IceBridge CAMBOT LIB Geolocated Images* [April 2011]. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center.