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Linking surface energy balance calculations and Temperature Index models of surface melt: Revision of the Positive Degree-Day (PDD) methodology for the Greenland Ice Sheet

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Positive Degree-Day (PDD) methodology (Braithwaite and Olesen, 1989; Reeh, 1991) is widely used in conjunction with observationally-derived Degree-Day Factors (DDFs) for snow and ice in order to simulate ice-sheet wide ablation rates using mean monthly temperature as the only input. Monthly PDD totals are calculated using the assumption that the monthly temperature distribution follows a Gaussian relationship with a spatially and temporally invariable standard deviation (σ_m), typically in the range of 4-5^{o}C. DDFs for snow and ice used in ice sheet modelling are usually fixed at $\sim$3 and 8 mm w.e. ^{o}C^{-1} day^{-1} respectively, but field observations show that these can vary by at least a factor of two depending on the albedo characteristics of the glacier surface (Hock, 2003).

At odds with the assumption of constant σ_m, it has been shown that temperature variability is reduced at temperatures close to or above the melting point, due to thermal (latent heat) buffering and the maximum temperature of 0^{o}C for a melting snow/ice surface (e.g., Marshall and Sharp, 2009). Analysis of hourly temperature data from 22 GC-Net stations (Steffen and Box, 2001) spanning the period 1995-2010 shows that observed σ_m follows a quadratic relationship with observed average monthly temperature. Comparisons of calculated and observed monthly PDD totals from GC-Net locations show that current assumptions of σ_m = 4-5^{o}C can overestimate monthly PDD totals by 25% on average, compared to $\sim$3% for the new methodology using a spatially varying σ_m.

In the absence of extensive field measurements, ‘theoretical’ daily melt rates are calculated at several GC-Net locations using available field data to estimate the components of the daily surface energy budget (Net radiation, sensible and latent heat and subsurface energy flux). Subsequently, ‘theoretical’ DDFs are evaluated as a function of surface albedo. Our results suggest that future studies should consider DDFs for snow and ice of 3-7 mm w.e. ^{o}C^{-1} day^{-1} and $>$ 9 mm w.e. ^{o}C^{-1} day^{-1} respectively, alongside the use of a spatially and temporally variable σ_m, which can be parameterized as a function of monthly mean temperature.

We demonstrate the impact of our new methodology and previous assumptions of fixed σ_m on millennial-scale changes in Greenland Ice Sheet volume and resulting global and local RSL predictions using a 3D thermomechanical ice model where a spatially and temporally variable σ_m acts to reduce the magnitude and variability associated with surface melt. These results demonstrate a need for additional empirical derivations of Degree-Day Factors in Greenland and their relationship with surface albedo in order to compliment the purely theoretical approach taken in this study.