A Mathematical Model for Melt Lake Formation on an Ice Shelf

August 9, 2017

The model is summarised in Figure 1. The steps that it takes are as follows:

1. The module setup takes place, requiring the functions 'ImportSnow' and 'ImportAWS'.
2. For each timestep, the surface boundary conditions are calculated using 'SfcBoundary'. The model then follows one of three paths, 'InitialSurfaceMelt' (no lake present, firn not completely saturated), 'LakeFormation' (no lake, firn fully saturated) or 'LakeDevelopment' (lake present, with or without a lid). For each of these paths, optional functions (connected with orange arrows) may be activated depending on the conditions.
3. Regardless of the path chosen the model will then run three or four functions at the end of each timestep. 'SnowDens', 'RefreezeInFirn' and 'Accumulation' are always run, and 'ResetCombine' is run only when the lake completely freezes over or a prescribed amount of melting occurs on the frozen lid surface.
4. For each timestep, points two and three are repeated.
5. The final output is delivered after the final timestep.

A brief description of the purpose of each function is included below.

Accumulation Adds fresh snow to the top of the firn profile.

Capillary Calculates the volume of water that will remain in each grid cell due to capillary forcing.

ImportAWS Imports the weather station data in a format suitable for the model to be forced with. Foehn winds are also added here.

ImportSnow Imports snowfall data which is used to determine when and how much snow is added to the firn profile.

InitialSurfaceMelt When a lake is not present this function determines if there is surface melt and calls the appropriate functions to determine the fate of this meltwater. This also calls the pde solver to calculate heat transfer through the firn.

LakeDevelopment Calculates the temperature profile of the lake and firn below it and determines the movement of the lake- firn boundary as the firn melts or the lake freezes.

LakeFormation Once the firn is fully saturated this function calculates the amount of surface melt that is taking place, until it is determined that a lake is present.

LidFormation Once a permanent frozen lid has formed on the lake this function calculates the expansion of this lid as the lake below it freezes.

Main The model is run from here.

NewLakeProfile Calculates the new lake temperature profile once it has melted some firn below it, before turbulent mixing occurs.

NewLakeProfile_Freeze Calculates the new lake temperature profile once some of its height has been lost due to the refreezing of the lid.

NewLakeProfile_LidMelt Calculates the new lake temperature profile once it has increased in depth due to melting of the lid from below.

Percolation Calculates the movement of meltwater down through the firn and subsequent refreezing and temperature changes.

Profile_After_Melt Calculates new density and water content profiles after melting has taken place at the surface.

RefreezeInFirn Checks for layers within the firn where the temperature has gone below the freezing temperature and freezes meltwater in this layer as well as calculating the new temperature and density of the layer a a result of this.

ResetCombine Once a lake has completely refrozen this combines the firn and frozen lake density, temperature and water content profiles to make one profile. The lake profile is also included in this if the function is called before the lake has completely refrozen due to a prescribed amount of melting occurring on the refrozen lid.

SfcBoundary Calculates surface fluxes from AWS data.

SnowDens Calculates dry snow densification.

TurbulentMixing This calculates the lake temperature profile once turbulent mixing has occurred.

VirtualLid Once the surface of the lake gets below freezing a 'virtual lid' of ice is formed and allowed to grow or shrink. If it reaches 10 cm in depth it is considered stable and therefore the model switches to a state of a permanent lid on top of the lake.

WaterRetention Once an ice lens has formed or meltwater reaches the pore closure depth further melting will accumulate on top of the ice and saturate the firn from the bottom upwards.

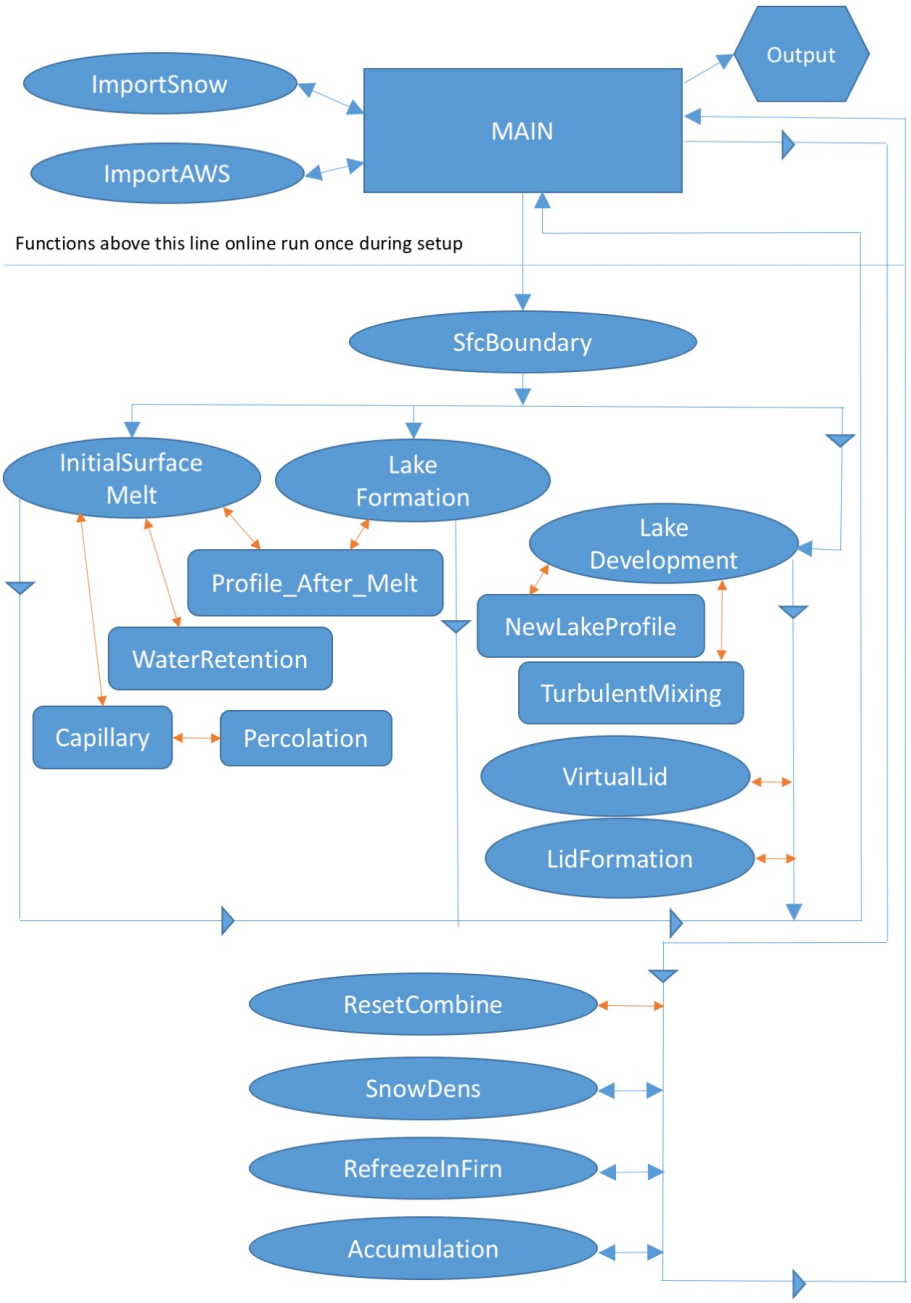

Figure 1: The functions that comprise the melt lake model and their interactions are summarised above. The model is run from the main module. Orange arrows represent optional paths that are only taken should certain conditions be satisfied (e.g the presence of meltwater).