**A1. Distribution of Landsat scenes used to map supraglacial lakes and channels over** Jakobshavn Isbræ **and** Zachariæ Isstrøm **study regions**

The use of visible imagery to delineate supraglacial hydrologic features is susceptible to reduced temporal sampling resulting from cloud-cover. For each year, the number of Landsat visible, cloud-free images used in this analysis is displayed for both the Jakobshavn Isbræ and Zachariæ Isstrøm study regions (Figure A1). Over the Jakobshavn Isbræ study area a total number of 536 lakes were mapped within the study area boundary from 2009 to 2012 from which a composite lake extent was derived . Only 67 composited lake features intersected OIB flight tracks and were used to assess the presence and properties of sub-surface water over the analysis period. A comprehensive list of Landsat-8 OLI scenes used to map lakes over the Jakobshavn Isbræ study area are listed in Table A1.1. Supraglacial channels used in this analysis were from an inventory of 1188 features mapped from Landsat-7 ETM+ over the 2007 melt season on June 6, 22, July 8, and August 9 (VanderBerg and Lampkin, 2013). Lake features within the ZIS study area that only intersected OIB flight tracks acquired from 2009 to 2012 were mapped. A composite of lake area was derived from a total of 141 lake features. Landsat-8 scene dates used to map ZIS lake features are listed in Table A1.2. The image count is displayed per month and cumulatively for each season. Maximum image count occurs near the peak of the ablation season (June, July, August) when melt rates are highest and lakes tend to be at their maximum extent.

Scenes used in the retrieval of lake depth through application of the Pope et al. (2016) algorithm on Landsat-8 OLI data from the summer of 2014 are listed in table A1.3.

Table A1.1: Scenes used to derive a composite supraglacial lake inventory over the Jakobshavn Isbræ study area from 2009 to 2012 using Landsat-8 OLI. Table displays Day of Year (Gregorian Date).

|  | |  |  |
| --- | --- | --- | --- |
| 2009 | 2010 | 2011 | 2012 |
| 203 (July 22 ) | 149 (May 29) | 168 (June 17) | 155 (June 3) |
| 210 (July 29) | 158 (June 7) | 177 (June 26) | 162 (June 10) |
| 217 (Aug 5) | 165 (June 14) | 223 (Aug 11) | 164 (June 12) |
| 219 (Aug 7) | 188 (July 7) |  | 171 (June 19) |
| 226 (Aug 14) | 190 (July 9) |  | 178 (June 26) |
| 235 (Aug 23) | 229 (Aug 17) |  | 196 (July 14) |

Table A1.2: Scenes used to derive a composite supraglacial lake inventory over the Zachariæ Isstrøm study area from 2009 to 2012 using Landsat-8 OLI. Table displays Day of Year (Gregorian Date).

|  | |  |  |
| --- | --- | --- | --- |
| 2009 | 2010 | 2011 | 2012 |
| 190 (July 09 ) | 179 (June 28) | 172 (June 12) | 173 (June 21) |
| 198 (July 17) | 190 (July 9) | 177 (June 26) | 176 (June 24) |
| 199 (July 18) | 192 (July 11) | 196 (July 15) | 189 (July 7) |
| 206 (July 25) | 197 (July 16) | 198 (July 17) | 191 (July 9) |
| 208 (July 27) | 206 (July 25) | 200 (July 19) | 192 (July 10) |
|  | 208 (July 27) | 204 (July 23) | 205 (July 23) |
|  | 209 (July 28) | 211 (July 30) |  |
|  | 211 (July 30) |  |  |

Table A1.3: Scenes used to estimate supraglacial lake depths using Landsat-8 OLI over the 2014 melt season. Table displays Day of Year (Gregorian Date).

| **Scene Dates** |
| --- |
| Day of Year |
| 159 (June 8) |
| 161 (June 10) |
| 184 (July 3) |
| 193 (July 12) |
| 195 (July 14) |
| 207 (July 26) |
| 216 (Aug 4) |
| 218 (Aug 6) |
| 223 (Aug 11) |
| 239 (Aug 27) |

**A2. Description of Numerical Model**

My*ICE*Lake uses the heat conservation equation to estimate the temperature distribution within each vertical zone assuming a horizontally homogenous, vertically stratified lake within the model domain, given as

(A2.1)

where *T* is water temperature (ºC), *K* the turbulent vertical (or eddy) diffusion coefficient (m2 day-1), local heating rate *Q\** (J m-3 day-1), specific heat capacity *Cp* (J kg-1 ºC-1), and water density *ρw* over vertical layers with area *A* (m2). The first-term on the right hand side (r.h.s) is diffusive mixing and the second accounts for local heating as a function of vertical water column depth *z* (m) and time *t* (Saloranta & Andersen, 2007). *K* is parameterized based on the Brunt-Väisälä frequency. Convective mixing is driven by an unstable density profile, where unstable layers are mixed with the vertically adjacent stable layer. This process continues until the entire water column becomes stable (Saloranta & Andersen, 2007).

therefore the volume of layer *i* is

(A2.2)

And the heat content of a given zone can be written as

(A2.3)

where is the volume-averaged temperature of layer *i*. Assuming zones have constant volume than the rate of change of is given by integrating equation A2.1

(A2.4)

where is the zone-averaged heating rate (Saloranta & Andersen, 2007). The zone balance equations for heat are solved as a system of linear, finite difference approximations for the temporal and spatial derivatives with ∆t = 24 hrs while ∆z is user-defined.

The initiation of an ice layer occurs when the water layer temperatures fall below the water freezing point such that the sensible heat deficit in the layer is converted into latent heat. Initially, the temperature of the super-cooled layers is set to the water freezing point (*Tf*). When the air temperature (*Ta*) is below *Tf* ice is accreted and the new thickness is estimated from Stefan’s Law given by

(A2.5)

where *k*ice is the thermal conductivity of ice, *ρice* is the density of ice, and *L* is the latent heat of freezing (Saloranta & Andersen, 2007). In conditions where snow is present over an ice layer, the model can account for the insulating effects of the overlying snow. When the weight of the overlying snow column exceeds the buoyancy of the ice, water can flood the snow layer resulting in the formation of slush. In the model, the saturated snow layer is assumed to be compacted into a snow-ice layer. New snow can accumulate on the surface based on measured precipitation data. The model accounts for snow compaction such that at the end of each time step, the bulk layer density is updated through calculating a new bulk weighted mean density based on newly added snow (with default snow density set to 250 kg m-3) (Yen, 1981). The thickness of the snow layer is (in water equivalents, *h*Sweq) given by

(A2.6)

where ρs is the estimated bulk snow density.

When the air temperature exceeds T*f*, T*ice* is set to T*f* and melting occurs. Snow is melted before ice driven by the estimated total surface heat flux. Albedo values are parameterized for melting snow and ice at 0.77 and 0.3 respectively (Perovich, 1998; Saloranta, 2000). If ice is present overlying water, the water surface temperature is set to T*f* and heat is allowed to diffuse through the ice to the underlying water surface, resulting in bottom melting of the overlying ice (Saloranta & Andersen, 2007).

Model configuration parameters, forcing variables and constants are detailed in Tables A2.1 and A2.2 below.

Table A2.1: Description of configuration and forcing data for My*ICE*Lake model experiments

|  |  |  |  |
| --- | --- | --- | --- |
| **Surface Forcing Data**  **[**spatial resolution: 10km]  [temporal resolution: daily] | **units** | **Model Configuration** | |
| number of layers:  time-step (∆t):  layer thickness (∆z):  max depth (z):  area of top layer (A) (z=0,surface):  area of bottom layer (A) (z=10,bottom):  initial water column temperature ():  initial snow/ice thickness:  analysis period: | 10  24 hrs.  1 meter  10 meters  24 m2  8 m2  0.5 ºC   1. meters   2009-2012 |
| Radiation | MJ m-2 |
| Cloud Cover | ----- |
| Air Temperature (2 m height) | ºC |
| Relative Humidity | % |
| Air Pressure | hPa |
| Wind Speed | m s-1 |
| Precipitation | mm d-1 |

**s**y.**h**

Table A2.2: My*ICE*Lake Model constants

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value** | **units** |
| water, ice and snow density (ρw, ρice, ρsnow) | 1000, 910, 250 | kg m-3 |
| thermal conductivity ice/snow (*k*ice, *k*snow) | 2.1, 0.2 | W K-1 m-1 |
| latent heat of fusion (L) (water/ice) | 333500 | J kg-1 |
| specific heat capacity (Cpsnow, Cpice) | 1960, 2108 | J kg-1 K-1 |
| gravitational constant | 9.81 | m s-2 |
| water freezing point (T*f*) | 273.15 | K |
| Volumetric heat capacity (water) | 4.18e+6 | J K-1 m-3 |

**A3. Comparison of measured and modeled lake surface snow and ice thickness**

As an assessment of the performance of the My*ICE*Lake model to estimate accumulated lake surface snow and ice thickness was implemented. Though not comprehensive, this comparison provides a quantitative measure of model performance. For each season, the distribution in the combined snow and ice thickness retrieved from OIB shallow radar samples along flight lines within the delineated lake boundaries over both the Jakobshavn Isbræ and Zachariæ Isstrøm study areas is shown in Figure A2. For each lake with intersecting flight lines, there are several radar returns providing an estimate of snow and ice thickness. Within each of these lakes, we display histograms of the spatial mean, minimum and maximum combined thickness and compare to the combined modeled ice thickness at each lake location where OIB data was acquired.

**B: Derivation of Solar Induced Mixed Layer Deepening**

Assuming an accumulated ice layer overlying a water column, the deepening of the mixed surface layer driven by solar insolation can be estimated following Bengtsson (1996). *I* is the intensity of solar irradiance that has transmitted through the ice layer, *h* the depth of mixing, and *T* water temperature such that the increase in temperature of the near surface water layer due to penetration of radiation through the ice is given by:

(B1)

Given a temperature gradient () below the mixed layer, the rate of mixed layer deepening can be determined using:

(B2)