

I. Introduction

• Valley glaciers and small ice caps are expected to provide the bulk of the cryosphere's contribution to sea-level rise over the next century (> 0.2 m, IPCC 2001). A lack of quantitative data for the vast majority of glaciers worldwide (only 100 glaciers out of a total population of 160,000 have mass balance records for longer than 5 years) makes this estimation difficult.

• We have developed the following four stage procedure to calculate sea-level rise with an associated confidence:

1. Construct a generic valley glacier system model that predicts variations in width, depth, accumulation and ablation along the glacier.
2. Calibrate the model against the small number of glaciers for which we have sufficient data.
4. Sample the response function in accordance with estimates of the global distribution of glaciers in the climate-topography phase space to estimate the overall sea-level rise.

• To construct a response surface that captures glacier variability to topographic and climatic changes, one must understand the spatial variation and sensitivity of parameters within the model.

• This poster demonstrates the modelling technique used in the project and investigates the regionalisation of model parameters.

II. Model

• One-dimensional flow line model capable of dealing with tributary systems.

• The model may either be forced with ERA-40 or a meteorological station data.

• Ice flow in the model is described by the usual Glen Law.

• Three schemes are available to calculate the mass balance:
  a. A Positive Degree Day scheme
  b. A simple energy balance model
  c. An energy balance model

• Ice thickness and width are allowed to evolve over the length of the glacier.

• Snow pack evolution. The model accounts for the formation of superimposed ice within the snow pack. As the snow pack melts a fraction is allowed to refreeze as superimposed ice. Finally, once the snow pack and superimposed ice is removed, the glacier ice is ablated.

• Optimisation of parameters in this model run uses the Nelder-Mead method. Other optimisation routines are used with the model such as Genetic Algorithms and PEST.

The overall structure of the model is detailed in the flow diagram (Figure 1).

Figure 1. Flow diagram of the model structure. Currently the model is configured to use Meteorological Data from the meteorological station from the nearest station to the glacier of interest.

IV. Glaciers

The two glaciers, Midre Lovénbreen and Storglaciaren, used in this study were chosen as they have similar climatic regimes, with comparable average annual precipitation and annual mean temperature (Figure 2). The glaciers also have comparable maximum length (4 km), maximum width (1 km), average thickness (110 m) and have a comparable retreat history, with only small changes in length over the last 30 years. Both valley glaciers terminate on land (Figure 3).

These glaciers have good climate records and survey data on which to initialise the model. The initialisation of the free parameters in the model also allows an investigation of the remaining free parameters. Additional survey data is used to calculate the thickness along the lineae and the free is used in the cost function.

Figure 2. Mean monthly temperature and precipitation for Midre Lovénbreen (left) and Storglaciaren (right) for the period of study.

The glaciers differ in their classifications, Midre Lovénbreen is an Arctic glacier while Storglaciaren is a Subarctic glacier. They also occupy very different altitudinal ranges: Midre Lovénbreen ranges from 50 m a.s.l at the terminus to 550 m a.s.l, while Storglaciaren ranges from 1130 m a.s.l at its terminus to 1760 m a.s.l.

The similarities of these two glaciers provides an opportunity to investigate the impact of altitude range on parameters within the model.

Figure 3. The glacier profile along the central flow line for Midre Lovénbreen (left) and Storglaciaren (right), for the initial conditions and at one of the survey thicknesses used for optimisation.

V. Results

The model is able to find the global minimum for 4 parameters for Midre Lovénbreen (Figure 5). The optimised values are given in Table 1. With these optimised values it is possible to produce a good representation of glacier thickness over its length (Figure 7).

The model struggles to find a global minimum when optimising for 4 parameters for Storglaciaren (Figure 5). The values it optimises to are a local minima (Table 1). It is still capable of capturing the changes in ice thickness over the glacier length (Figure 7).

The phase space diagrams also show the model's sensitivity to the different parameters. Both glaciers are not sensitive to Wmax (fraction of precipitation that refreezes), and both are sensitive to the air and precipitation lapse rates.

As the four parameters operate in a compensatory manner, determining where the global minima is a complex iterative process.

VI. Summary and Future Work

• A numerical model capable of responding dynamically to imposed climate change has been tested for two glaciers, Midre Lovénbreen and Storglaciaren.

• Parameter calibration was performed using the Nelder-Mead method on both glaciers. A significant regionalisation of parameter values was found.

• Future work includes:
  - Selecting glaciers from a variety of climatic and topographic regimes to test the model further
  - Testing the model with the Energy Balance Model to investigate the impact of slope and aspect
  - Integration with ERA-40 reanalysis data with associated error estimates
  - Further investigation of the length scales at which parameters within the model vary (i.e., their geostatistics).

Table 1. The optimised values for both Storglaciaren and Midre Lovénbreen.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Storglaciaren</th>
<th>Midre Lovénbreen</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>-0.003789</td>
<td>0.000001070</td>
</tr>
<tr>
<td>plapse</td>
<td>0.7287</td>
<td>0.002876</td>
</tr>
<tr>
<td>wmax</td>
<td>0.0025</td>
<td>0.0035</td>
</tr>
<tr>
<td>pddf</td>
<td>-2e-5</td>
<td>-3e-5</td>
</tr>
</tbody>
</table>

Figure 4 and 5. Location maps for the glaciers used in this study. Midre Lovénbreen has a more northerly aspect than Storglaciaren.

Figure 6. Phase space diagrams for all combinations of the 4 free parameters in the model for Midre Lovénbreen.

Figure 7. Phase space diagrams for all combinations of the 4 free parameters in the model for Storglaciaren.