EGU2013-3486 Prognostic experiments for fast flowing ice streams in the Academy of Science Ice Cap: overall ice flux changes modelled by 2D ice flow line thermo-coupled model

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1. Introduction

The prognostic experiments were carried out for fast flowing ice streams on the south side of the Academy of Sciences Ice Cap in the Komsomolets Island, Severnaya Zemlya archipelago. The prognostic experiments are based on the inversions for basal friction coefficients that were performed by 2D flow line thermo-coupled model (Pattyn, 2000, 2002) and by the Tikhonov's regularization method. Modelled ice temperature distributions in the cross-sections have been obtained using the ice surface temperature histories that were inverted previously from the bore hole temperature profiles derived at the Academy of Sciences Ice Cap (Nagornov et. al., 2006). The input data for the performance of both the forward and the inverse problems included InSAR ice surface velocities, ice surface elevations and ice thicknesses obtained from airborne measurements, all were taken from Dowdeswell et al. (2002) and the surface mass balance was taken from Bassford et. al. (2006). The prognostic experiments provide the data for the assessment and prediction of the overall sea ice flux changes in time (changes of the total ice flux from the glacier to the sea) for different climatic scenarios in the future. The prognostic experiments have been carried out on the assumption of unchanged friction coefficient distributions retrieved from the surface velocities for 2002 surface ice flow and ice thickness distribution data (Dowdeswell et al., 2002).

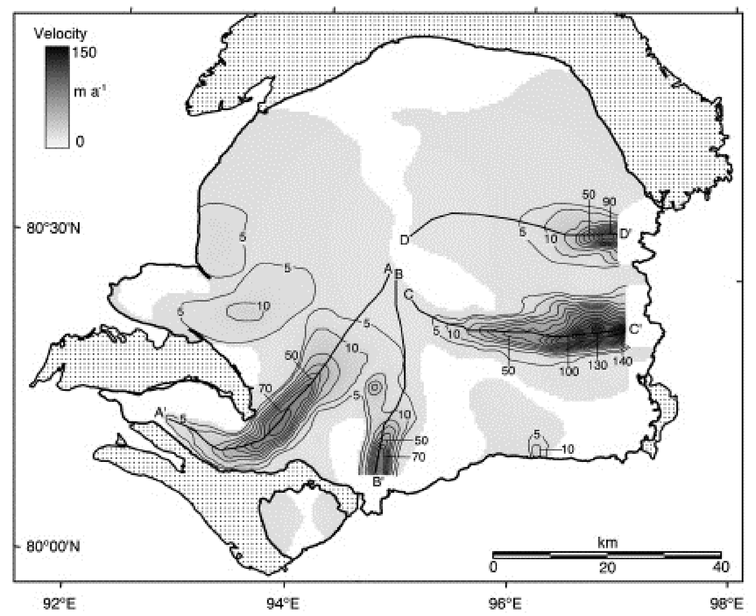

Fig.1. Interferometically derived ice surface velocities at the Academy of Sciences Ice Cap. The first two contours are at velocities of 5 and 10 m/yr, with subsequent contours at 10 m/yr intervals. Dotted areas are bare land (Dowdeswell et. al., 2002).

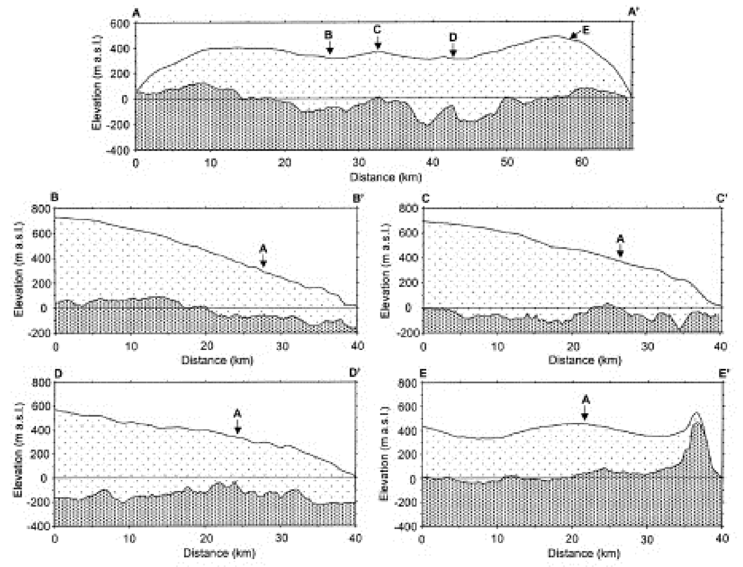

Fig.2. The cross-sections that cross down the fast flowing ice streams in the Academy of Sciences Ice Cap (Dowdeswell et. al., 2002).

2. Field equations

2.1. Forward problem (The diagnostic equations)

The 2D flowline model includes the continuity equation for incompressible substance, the mechanical equilibrium equation in terms of stress deviator components and the Glen law (Pattyn, 2000; 2002):

$$\begin{cases} \int\limits_{h_b}^{z} \frac{\partial u}{\partial x} dz' + \frac{1}{b}\frac{db}{dx}\int\limits_{h_b}^{z} u\, dz' + w - w_b = 0; \\ 2\frac{\partial \sigma'_{xx}}{\partial x} + \frac{\partial \sigma'_{yy}}{\partial x} + \frac{\partial^2}{\partial x^2}\int\limits_{z}^{h_s} \sigma'_{xz}\, dz + \frac{\partial \sigma'_{xz}}{\partial z} = \rho g \frac{\partial h_s}{\partial x}; \\ \sigma'_{ik} = 2\eta \dot{\varepsilon}_{ik}; \quad \eta = \frac{1}{2}\left(m A(T)\right)^{-\frac{1}{n}} \dot{\varepsilon}^{\frac{1-n}{n}}; \\ 0 < x < L; \; h_b(x) < z < h_s(x). \end{cases} \qquad (1)$$

The forms of the boundary conditions including the friction law that were applied in the model are described in (Konovalov, 2012).

2.2. Inverse problem for the friction coefficient

The friction coefficient retrieving was implemented by the gradient minimization procedure for the "smoothing" functional (Tikhonov and Arsenin, 1977):

$$F = \int\limits_0^L \left(u_{obs} - u_{\mathrm{mod}}\right)^2 dx + \beta \int\limits_0^L \left(K_{fr}^{\;2} + q(x)\left(\frac{dK_{fr}}{dx}\right)^2 \right) dx .$$

(2)

The details of the gradient minimization procedure are described in (Konovalov, 2012).

2.3. The prognostic equations

The 2D thermo-coupled prognostic experiments imply that the 2D flowline model includes the heat transfer equation (Pattyn, 2000, 2002)

$$\frac{\partial T}{\partial t} = \chi\left(\frac{\partial^2 T}{\partial x^2} + \frac{1}{b}\frac{db}{dx}\frac{\partial T}{\partial x} + \frac{\partial^2 T}{\partial z^2}\right) - \left(u\frac{\partial T}{\partial x} + w\frac{\partial T}{\partial z}\right) + \frac{2A^{-\frac{1}{n}}\dot{\varepsilon}^{\frac{1+n}{n}}}{\rho C} ,(3)$$

and the mass balance equation (Pattyn, 2000, 2002)

$$\frac{\partial H}{\partial t} = M_s - M_b - \frac{1}{b}\frac{\partial(\bar{u} H b)}{\partial x} .$$

(4)

3. Results

3.1. C-C' profile (Fig. 2): friction coefficient inversion and modelled histories

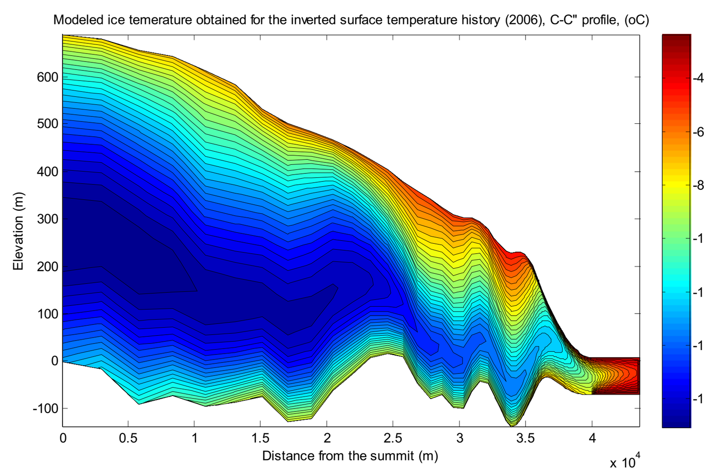

Fig. 3.1.1. Modelled ice temperature. Surface temperature history was inverted previously from the bore hole temperature profiles (Nagornov et. al., 2006). Surface temperature gradient (elevational gradient of temperature changes) was taken equal to 6.5 10^{-3} ^{0}K/m.

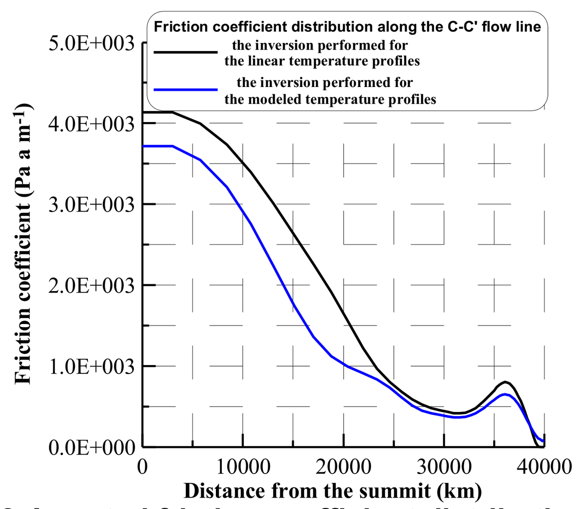

Fig. 3.1.2. Inverted friction coefficient distributions along the flow line in the cases of linear temperature profiles and the modelled temperature shown in Fig. 3.1.1.

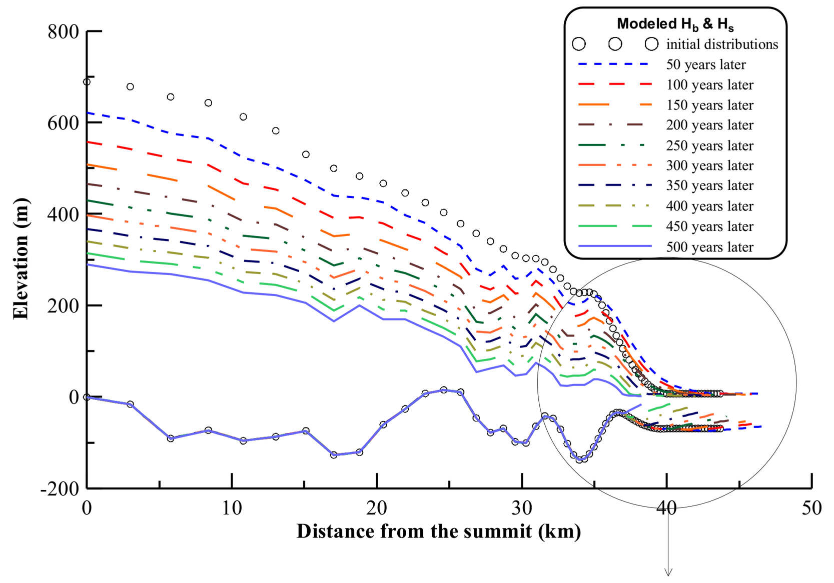

Fig. 3.1.3. The C-C' profile evolution as the ice stream response to environmental impact which corresponds to the surface mass balance retrieved in (Bassford et. al., 2006). In the experiment the mass balance is considered as time-independent.

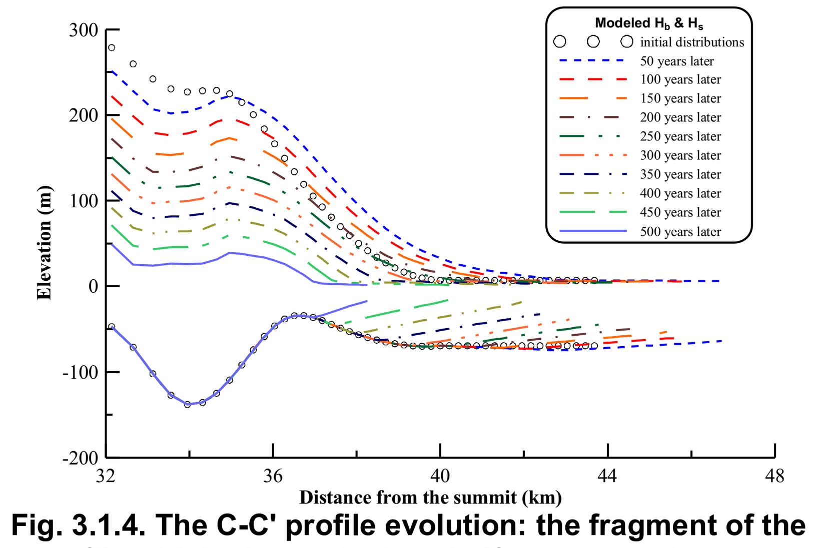

Fig. 3.1.4. The C-C' profile evolution: the fragment of the profile which shows the ice shelf geometry changes.

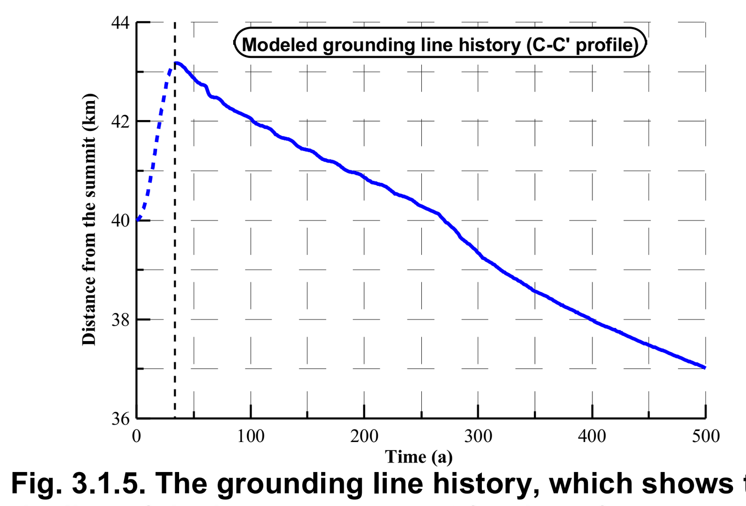

Fig. 3.1.5. The grounding line history, which shows the decline of the ice stream extent for the reference mass balance (Bassford et. al., 2006).

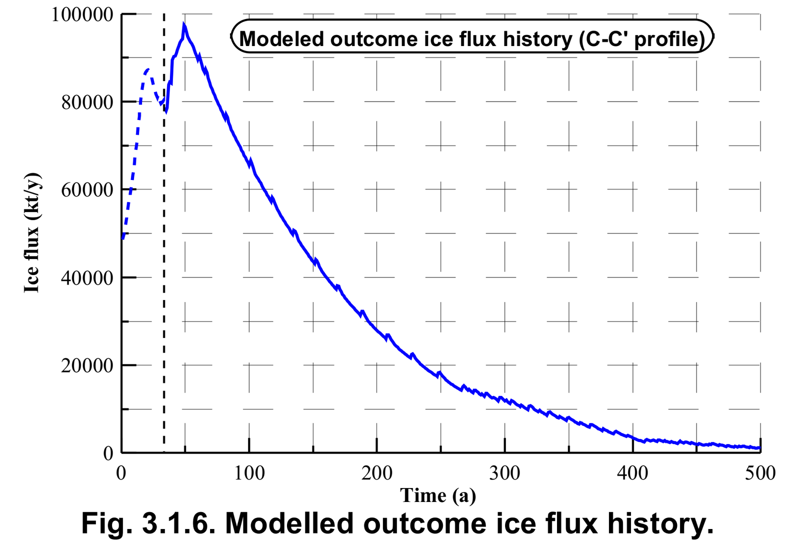

Fig. 3.1.6. Modelled outcome ice flux history.

3.2. B-B' profile (Fig. 2): modelled histories

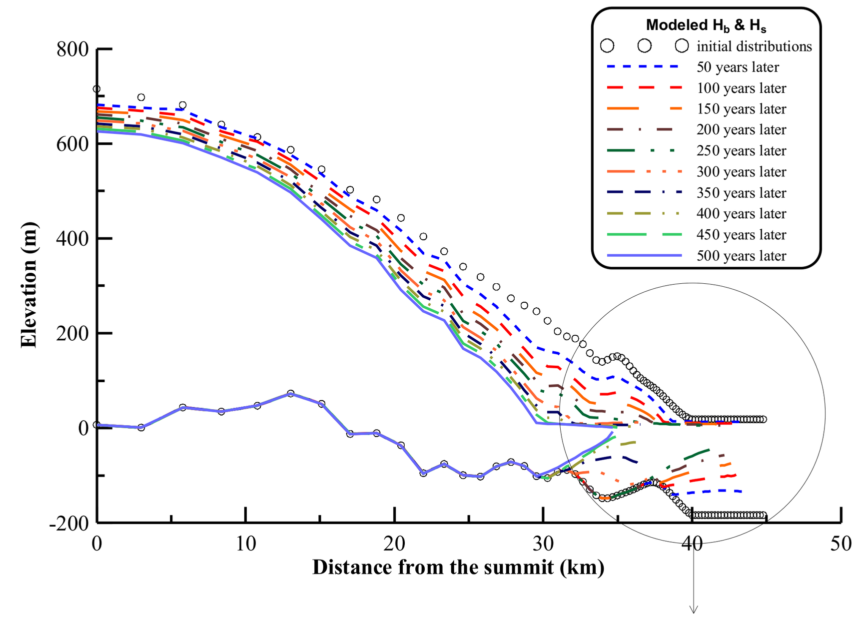

Fig. 3.2.3. The B-B' profile evolution as the ice stream response to environmental impact which corresponds to the surface mass balance retrieved in (Bassford et. al., 2006).

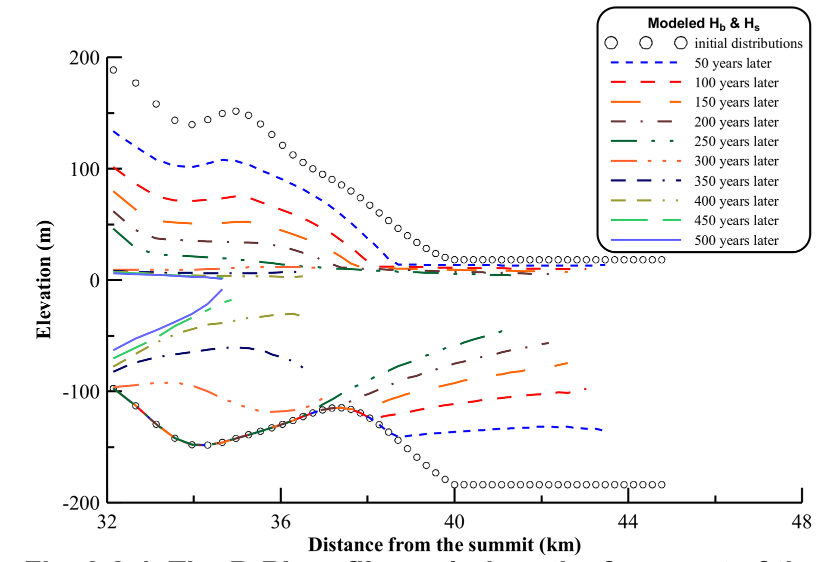

Fig. 3.2.4. The B-B' profile evolution: the fragment of the profile which shows the ice shelf geometry changes.

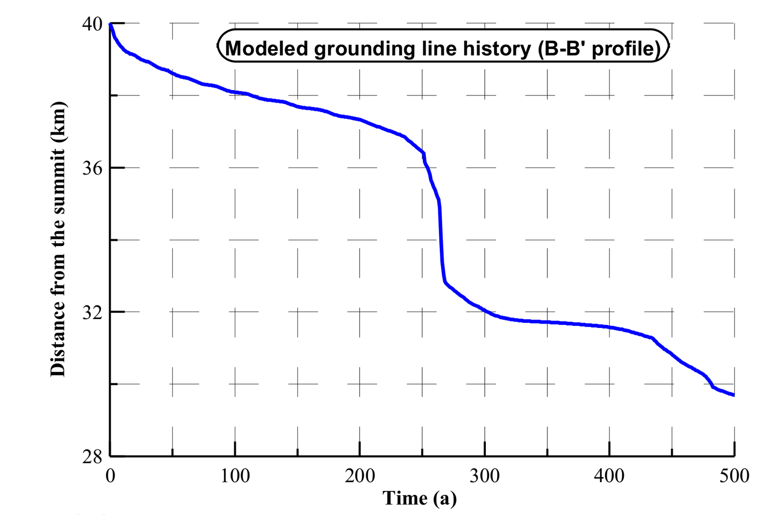

Fig. 3.2.5. The grounding line history, which shows the decline of the ice stream extent for the reference mass balance (Bassford et. al., 2006).

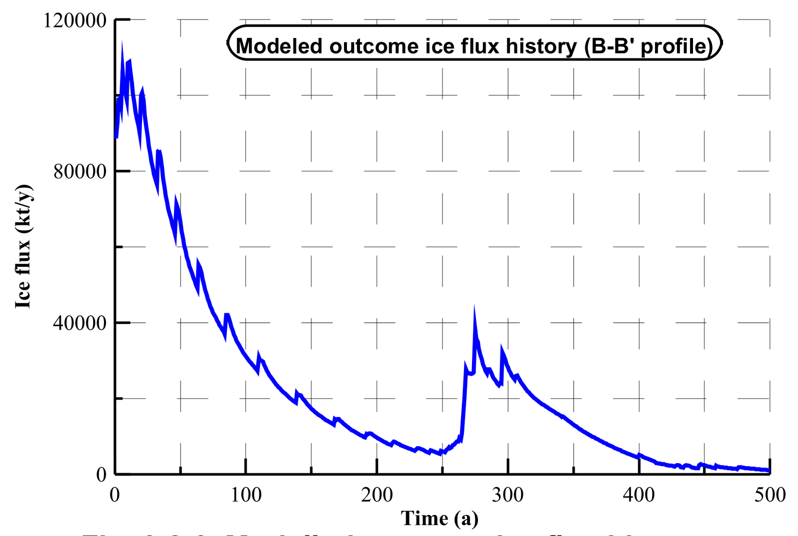

Fig. 3.2.6. Modelled outcome ice flux history.

3.3. D-D' profile (Fig. 2): modelled histories

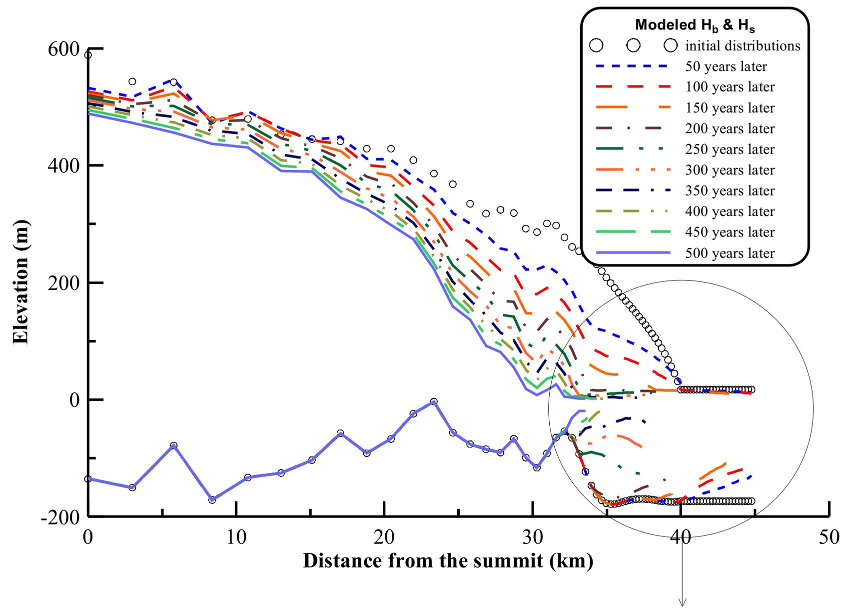

Fig. 3.3.3. The D-D' profile evolution as the ice stream response to environmental impact which corresponds to the surface mass balance retrieved in (Bassford et. al., 2006).

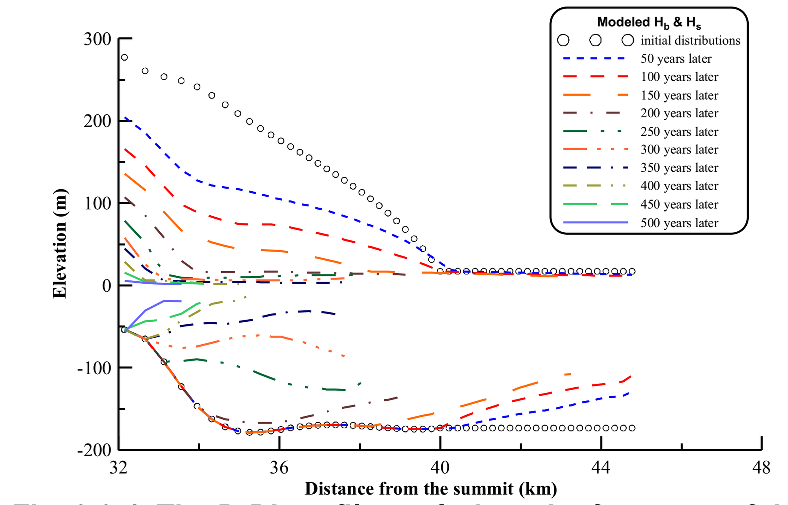

Fig. 3.3.4. The D-D' profile evolution: the fragment of the profile which shows the ice shelf geometry changes.

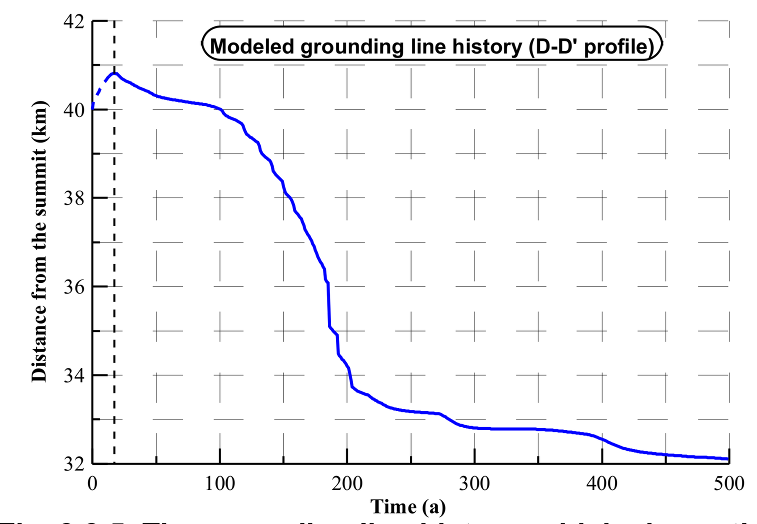

Fig. 3.3.5. The grounding line history, which shows the decline of the ice stream extent for the reference mass balance (Bassford et. al., 2006).

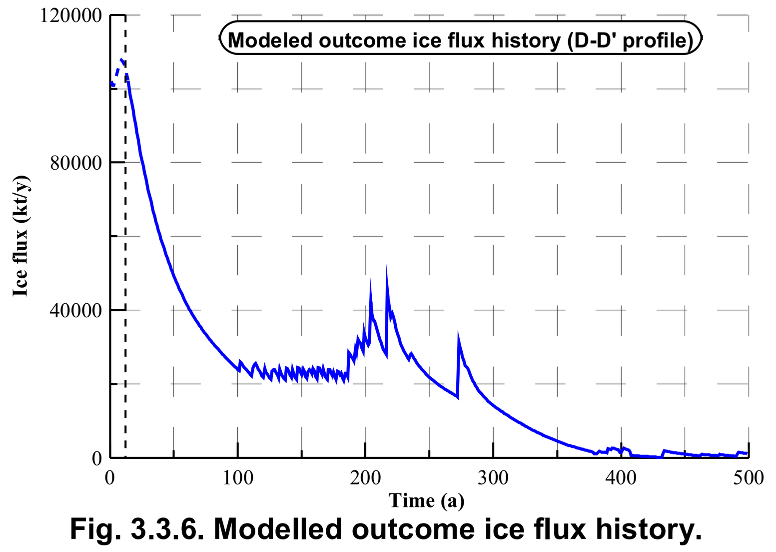

Fig. 3.3.6. Modelled outcome ice flux history.

3.4. D-D' profile (Fig. 2): friction coefficient inversion and modelled histories

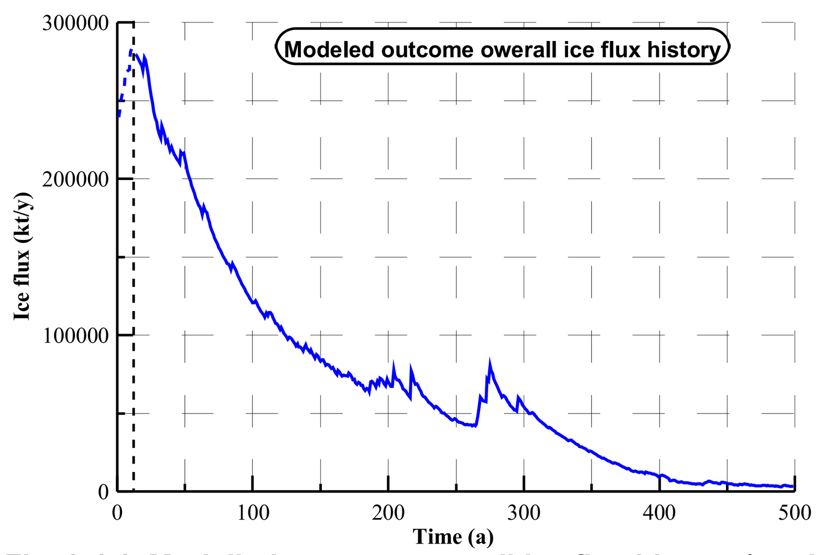

Fig. 3.4.1. Modelled outcome overall ice flux history (total sum of three ice fluxes from the three ice streams).

4. Summary

The prognostic experiments that were carried out with three of the four fast flowing ice streams in the Academy of Sciences Ice Cap, reveal both ice mass and ice stream extents decline. The decline is the ice streams response to the environmental incident, which defines the annual surface mass balance. Exactly, grounding line retreats (a) along C-C' flow line from about 43 km to about 37 km (the distance from the summit) (b) along B-B' flow line from about 40 km to about 30 km (c) along D-D' flow line from about 41 km to about 32 km - during considered time period of 500 years and in the assumption of time-independent mass balance. Moreover, the warming decreases the mass balance (Bassford et. al., 2006) and, evidently, the future warming will urge more intense ice decline than the ones are shown in Fig. 3.i.3. Ice flow velocity drops and this trend yield the diminish of outcome ice flux and, thus, holds up the arctic sea ice decline. The modelled histories are in agreement with the observations of sea ice extent and thickness showing a continual ice decline in the Arctic.

References

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