Modeling future volume changes of glaciers using ERA40-reanalysis and climate models – A sensitivity study at Storglaciären, Sweden

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PURPOSE

to model the mass balance and volume evolution of Storglaciären, a 3 km² glacier in Sweden, and to investigate the sensitivity of the results to variations in the model approach and to the choice of the climate model

Storglaciären, Sweden, 3 km²

DATA

- Winter & summer mass balance of Storglaciären (1945-)
- ERA-40 reanalysis data: daily air temp and precip
- Output from climate models (grid point closest to Storglaciären):
  - Regional climate model, RCA3 (Rossby Centre, SMHI)
  - 6 GCMs (IPCC 2001, B2 emission scenario, 1961-2100)

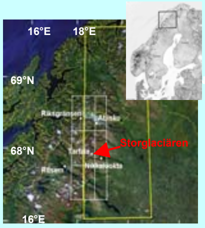


Fig. 1. *Study area. Nine grid cells with the resolution of 0.5°x0.5° (~50 km²) correspond to ERA-40 gridded data, while the large grid cell shows the grid cell used from the GCM with highest resolution (ECHAM/OPYC3, 2.8°x2.8°).*

METHODS

- ***Mass balance model:***

$$b_s = \alpha_s \sum_{i=t_1}^{t_2} a_i T_i + \beta_s \qquad \begin{cases} a_i = 1, T_i > 0 \\ a_i = 0, T_i \le 0 \end{cases}$$

summer mass balance

$$b_w = \alpha_w \sum_{i=t_1}^{t_2} a_i P_i + \beta_w \qquad \begin{cases} a_i = 1, T_i < 0 \\ a_i = 0, T_i \ge 0 \end{cases}$$

winter mass balance

function of air temperature (T) and precipitation (P) from ERA-40, 8 different model variants differing in the temporal resolution of the input (seasonal, monthly, daily) and in the method by which ERA-40 temperatures are adjusted prior to model input to represent local conditions

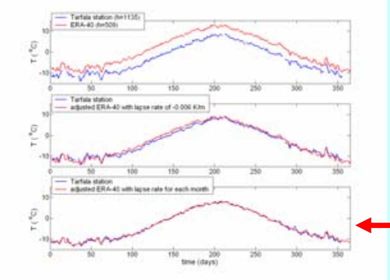


Fig. 2. *Daily air temperatures averaged over the period 1965-2001.*

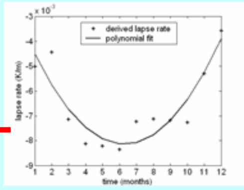


Fig. 3. *Monthly lapse rates derived from ERA-40 and Tarfala station temperatures averaged over the period 1965-2001.*

- ***Dynamics:*** area-volume scaling (Bahr et al., 1997); volume is proportional to area to the power of γ=1.375, the former changing as a function of mass balance
- ***Statistical downscaling:*** 'local scaling' using differences over baseline period between ERA-40 and climate model data (Figs. 4, 5)

Downscaling of temperature

done on monthly basis (Fig. 5a) due to large differences in seasonal cycles (Fig. 4)

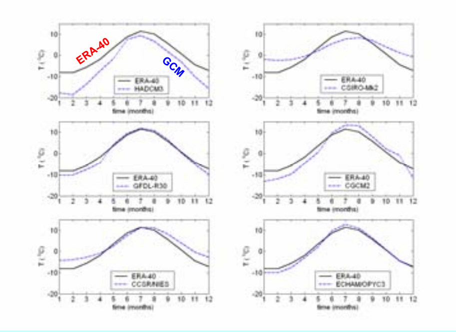


Fig. 4. *Temperature seasonal cycles averaged over 1961-2001 from ERA-40 and six GCMs*

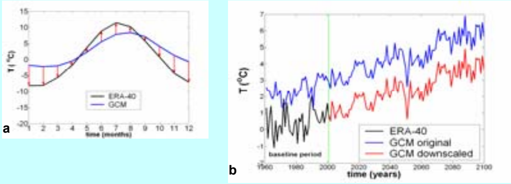


Fig. 5. *Illustration of the downscaling using mean monthly differences (a): averaged seasonal cycles of temperatures from ERA-40 and GCM; red arrows show correction i.e. downscaling (b): original and downscaled annual temperatures from GCM.*

Downscaling of precipitation

Future series of P(t) are generated by:

$$P_i(t) = P_{i,c}(t)\frac{\overline{P_{ERA}}}{\overline{P_c}}, \qquad i=1,\ldots,12$$

$P_{i,c}$ - monthly precipitation sum from climate model (t=2001-2100)
P_c, P_{ERA} - averaged precipitation over the baseline period

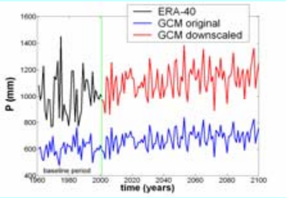
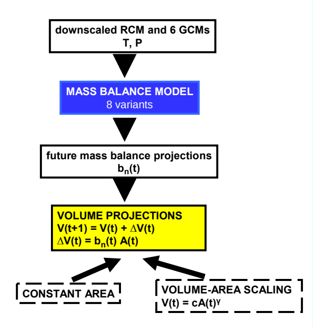


Fig. 6. *Future GCM and downscaled GCM series of annual precipitation sums.*

SCHEME for deriving future volume changes



downscaled RCM and 6 GCMs
T, P

MASS BALANCE MODEL
8 variants

future mass balance projections
$b_n(t)$

VOLUME PROJECTIONS
$V(t+1) = V(t) + \Delta V(t)$
$\Delta V(t) = b_n(t)\,A(t)$

CONSTANT AREA

VOLUME-AREA SCALING
$V(t) = cA(t)^{\gamma}$

RESULTS

- ***Mass balance model:***

explains ~70% of variance of measured mass balance (Fig. 7) when input temperatures from ERA-40 are reduced by lapse rate that maximizes model performance

the model perform equally well with ERA-40 as with the observations

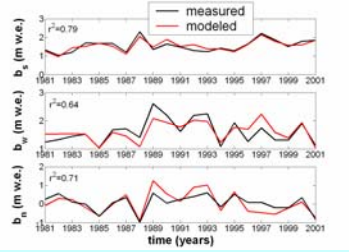


Fig. 7. *Summer, winter and net mass balance series: measured and modeled with the variant VII from the mass blalance model (monthly input of T and P, ERA-40 temperatures lowered by the optimized lapse rate).*

- ***Volume projections until 2100***

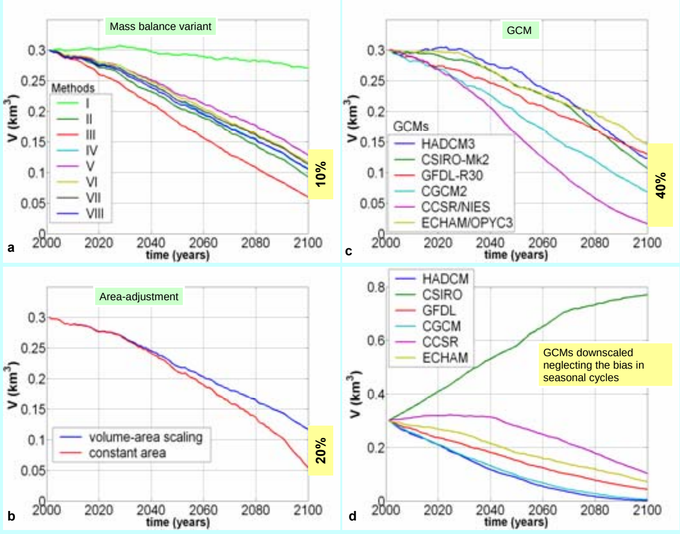


Fig. 8. *Volume projections for Storglaciären derived from: (a) 8 methods (I-VIII) of the mass balance model and RCA3 output downscaled with ERA-40, (b) method VII applied on the RCA3 data, and with volume-area scaling and constant area, (c) method VII applied on the six GCMs, (d) as (c) but downscaling on annual basis and not monthly basis. Projections vary by the amount in % (yellow labels) of the initial volume until 2100.*

CONCLUSIONS

- ERA-40 data can be used for mass balance modeling independently of observations; encouraging for the areas where meteorological observations are not available
- Loss of 50-90% of the initial glacier volume by 2100 (when excluding explainable outliers)
- Differences are mainly due to different GCM input to mass balance model (Fig. 8c)
- The correction of biases in the seasonal temperature cycle of the GCMs with respect to the ERA-40 data (Fig. 5) is crucial; neglect can lead to unrealistic volume predictions (Fig. 8d, CSIRO)

Radic, V. and R. Hock. 2006. Modeling mass balance and future evolution of glaciers using ERA-40 and climate models – A sensitivity study at Storglaciären, Sweden. *Journal of Geophysical Research, in press.*