Dynamic response of glaciers on the Tibetan Plateau to climate change - Mass balance modelling of Zhadang Glacier, Tibetan Plateau

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1 Introduction

- A simple surface mass balance (SMB) model including potential incoming shortwave radiation is set up and calibrated for Zhadang Glacier in order to assess spatially distributed mass balance values over decadal time scales both into the past and the future.
- Two different surface energy balance (SEB) approaches are set up to be able to reveal the interactions between energy balance components and their influence on glacier mass balance.
- The driving forces for glacier melt as well as the reaction of the glacier itself are very complex as the glacier is supposed to be polythermal and the region is both influenced by Indian monsoon in summer and westerlies in winter.
- The SMB/SEB models are calibrated using data from glaciological field studies (poster Huintjes et al. "Glaciological field studies") and will be tested over timescales of several years by applying WRF model output (poster Maussion et al. "Regional atmospheric reanalysis").
- From the output of the ultrasonic anemometer (Gill Windmaster) at AWS 1 the sensible heat flux is directly calculated and compared to a standard SEB approach.

2 Temperature-index surface mass balance model (TI-SMB)

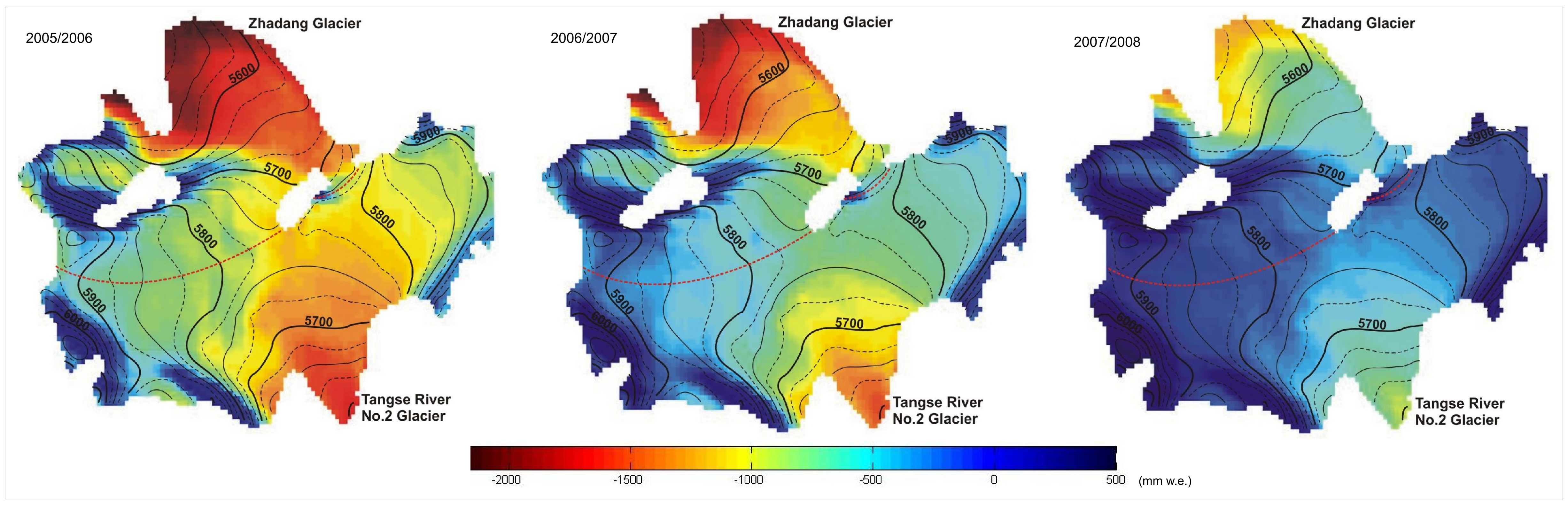


Fig 1: Modelled surface mass balance of Zhadang and Tangse River No.2 Glacier for the balance years 2005-2008

- A distributed temperature-index surface mass balance (TI-SMB) model after *Hock* (1999) with an additional radiation module after *Kumar et al.* (1997) has been calibrated for annual mean SMB of Zhadang Glacier (Fig. 2).
- SMB is calculated using the following equation:

$$M = \begin{cases} \frac{1}{n} DDF_{snow/ice} T + \left(a + b\left(\frac{r}{\bar{r}}\right)\right) & T > T_T \\ 0 & T \leqslant T_T \end{cases}$$

M: meltrate (mm w.e. per time unit)
DDF: degree-day factor for snow and ice surfaces (mm w.e. K^{-1} d^{-1})
T: mean air temperature per time unit (°C)
T_T: threshold temperature above which melting is assumed (°C)
n: number of time units per day
r: mean modelled radiation at one grid cell of the glacier area (W/m²)
$\bar{r}$: mean modelled radiation on the whole glacier area (W/m²)
a: radiation factor (-)
b: radiation factor (-)

- Daily mean air temperature and shortwave incoming radiation measured at AWS 1 (Fig. 5) are taken as input data for calibration.
- The calibrated model is run for the area of Zhadang and Tangse River No.2 Glacier (Fig. 1).
- Influence of radiation introduces a spatial pattern due to slope exposition and shading.

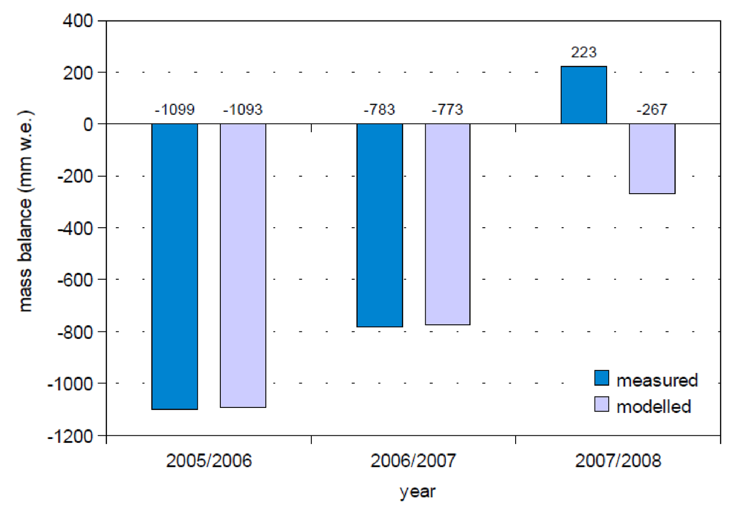


Fig 2: Measured and modelled mass balance at Zhadang Glacier, 2005-2008 (measured values from Kang et al. 2009)

3 Surface energy balance models (SEB)

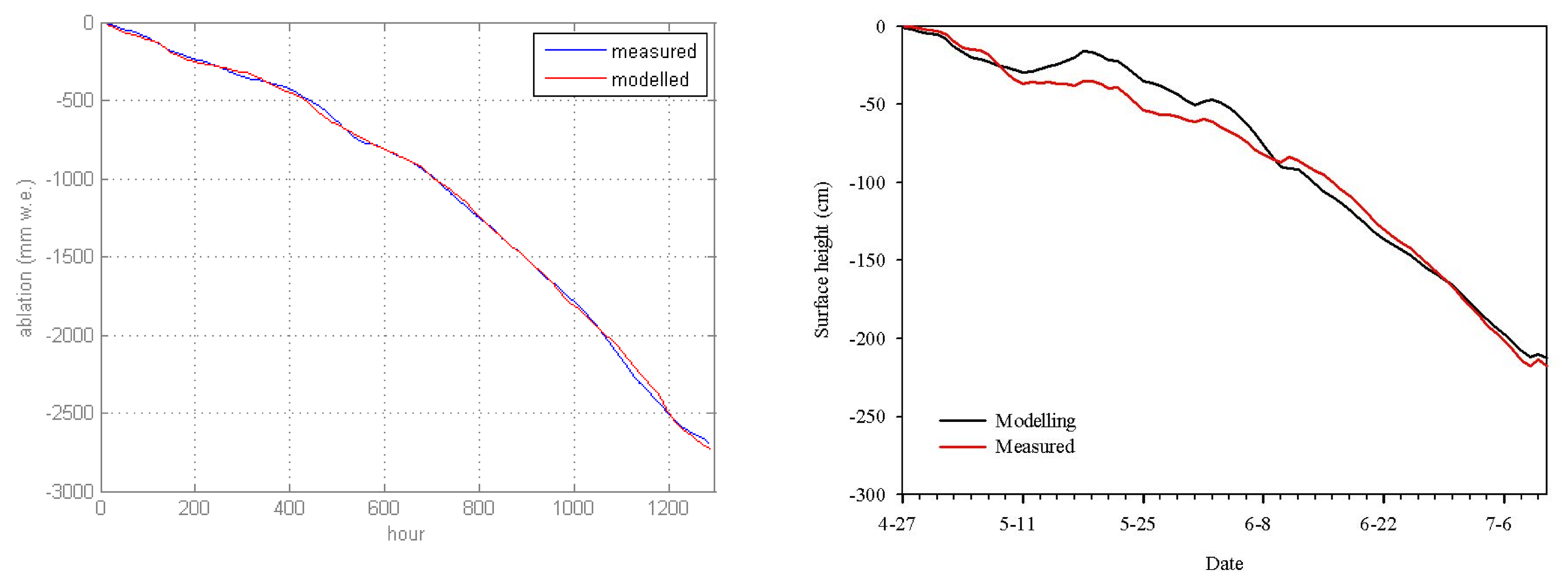


Fig 3: Measured and modelled mass balance at AWS 1; left: simplified SEB model 13.5.-11.7.2009; right: sophisticated SEB model 27.4.-11.7.2009 (measured values from ultra-sonic depth sensor (SR 50))

Fig 5: AWS 1 with Gill Windmaster and SR50 (right) in May 2010 on Zhadang Glacier

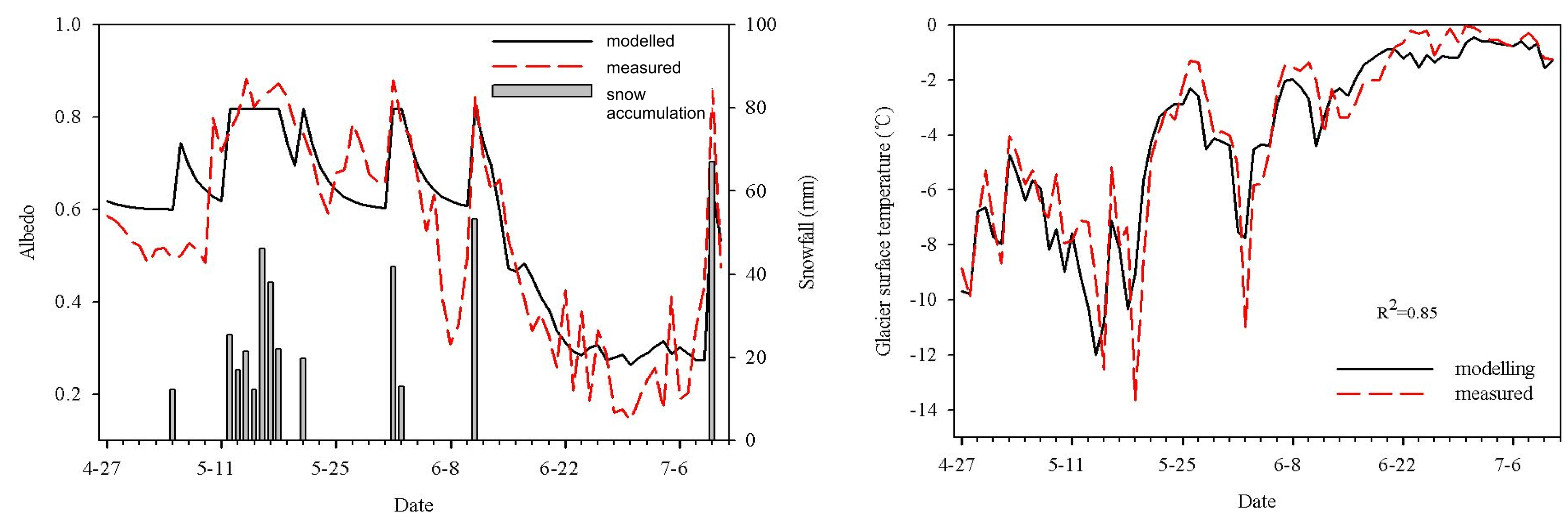


Fig 4: Measured and modelled values for the sophisticated SEB model 27.4.-11.6.2009 at Zhadang Glacier; left: daily albedo optimised to measurements; right: daily surface temperatures

- Two SEB approaches have been set up during Phase I and II using hourly data from AWS 1 (Fig. 5)
- Both models were run for a two months period in summer 2009 (Fig. 3) using the following equations:

$$\Psi = Q(1-\alpha) + L_{in} + L_{out} + Q_H + Q_L + G \qquad MB = -\frac{\Psi}{L_m} + \frac{S}{L_S} + P_{solid} + f$$

Ψ: melt energy (W/m²)
Q: shortwave incoming radiation (W/m²)
α: albedo (-)
L_{in}: incoming longwave radiation (W/m²)
L_{out}: outgoing longwave radiation (W/m²)
Q_H: sensible heat flux (W/m²)
Q_L: latent heat flux (W/m²)
G: subsurface heat flux (W/m²)

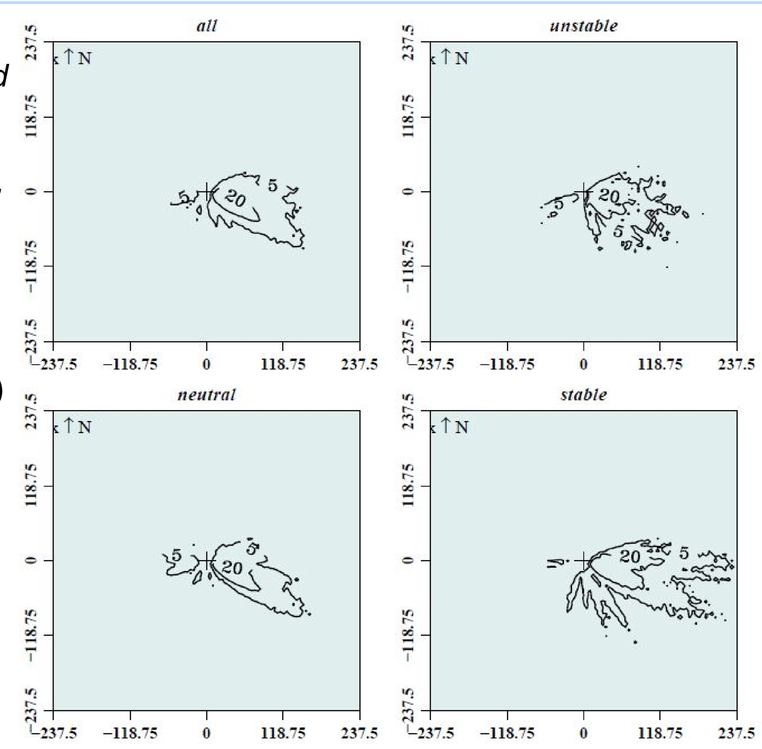
MB: surface mass balance (w.e.)
L_m: latent heat for melting (J/kg)
S: mass exchange due to sublimation (J/kg)
L_s: latent heat for sublimation (J/kg)
f: refreezing of meltwater (w.e.)

- The simplified SEB model based on the gradient method neglects ground heat flux (G), sublimation (S), accumulation (P_{solid}) and refreezing (f) (marked with red circles in the equations above)
- The sophisticated SEB model based on the bulk approach considers these parameters (Fig. 4)
- Both models show good results compared to measurements (Fig. 3,4) and will be further improved

4 Turbulent fluxes

- For the period 24.-30.6.2009 data from the ultrasonic anemometer (USA) at AWS 1 (Fig. 5) was used to directly calculate the sensible heat flux (Q_H).
- Data is processed in the software package TK2 developed by the Department of Micrometeorology at the University of Bayreuth (*Mauder & Foken 2004*).
- Results are compared with respective calculations of the bulk approach (Fig. 7)
- Mean Q_H calculated with TK2 (ECS in Fig. 7) is approx. twice of that calculated with the bulk approach. Diurnal cycle with positive Q_H in the early morning and negative Q_H in the afternoon, depending on air temperature, is captured by both approaches (Fig. 7).
- Analyses of the footprint climatology with a routine from *Göckede et al. 2008* determine the source areas contributing to the flux measurements of the USA, depending on dominating wind direction and stratification (Fig. 6).
- The footprint is largest for stable stratification with laminar flux dominated by katabatic wind from southeastern direction.
- For further footprint analyses see poster Maussion et al. „Atmospheric data retrieval"

Fig 6: Footprint climatology displayed on the landuse matrix (snow) for stable, unstable, neutral and all stratification conditions, 24.6.-30.6.2009 (length of matrix is given in m; effect levels specify the rel. flux contribution for the measurement site, the number indicates rel. contribution from outside the area)



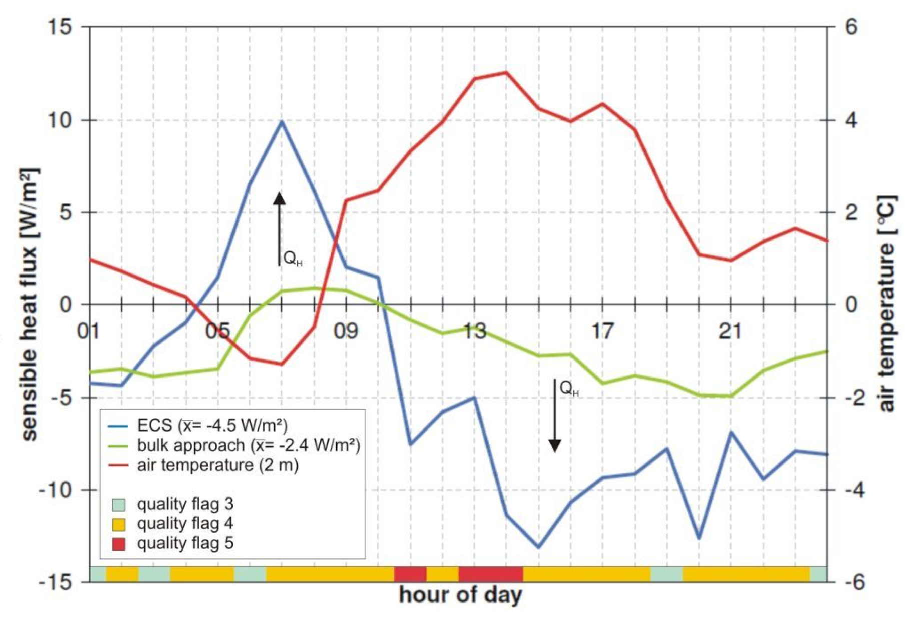


Fig 7: Mean diurnal cycle of sensible heat flux and air temperature at AWS 1, 24.6.-30.6.2009 (flagging system for ECS after Rebmann, 1= high data quality, 5=low data quality)

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