Dynamic response of glaciers on the Tibetan Plateau to climate change
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First approaches in numerical modelling

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1 Introduction

The central goal of the project is improving our understanding of atmosphere-cryosphere inter-actions on the Tibetean Plateau (TiP) by adding new data and improved methods combining field studies (Fig. 1), remote sensing and numerical modelling. The development of a numerical model framework for computing surface energy and mass balance components on selected glaciers on the TiP is conducted collectively by the TU Berlin and the RWTH Aachen.

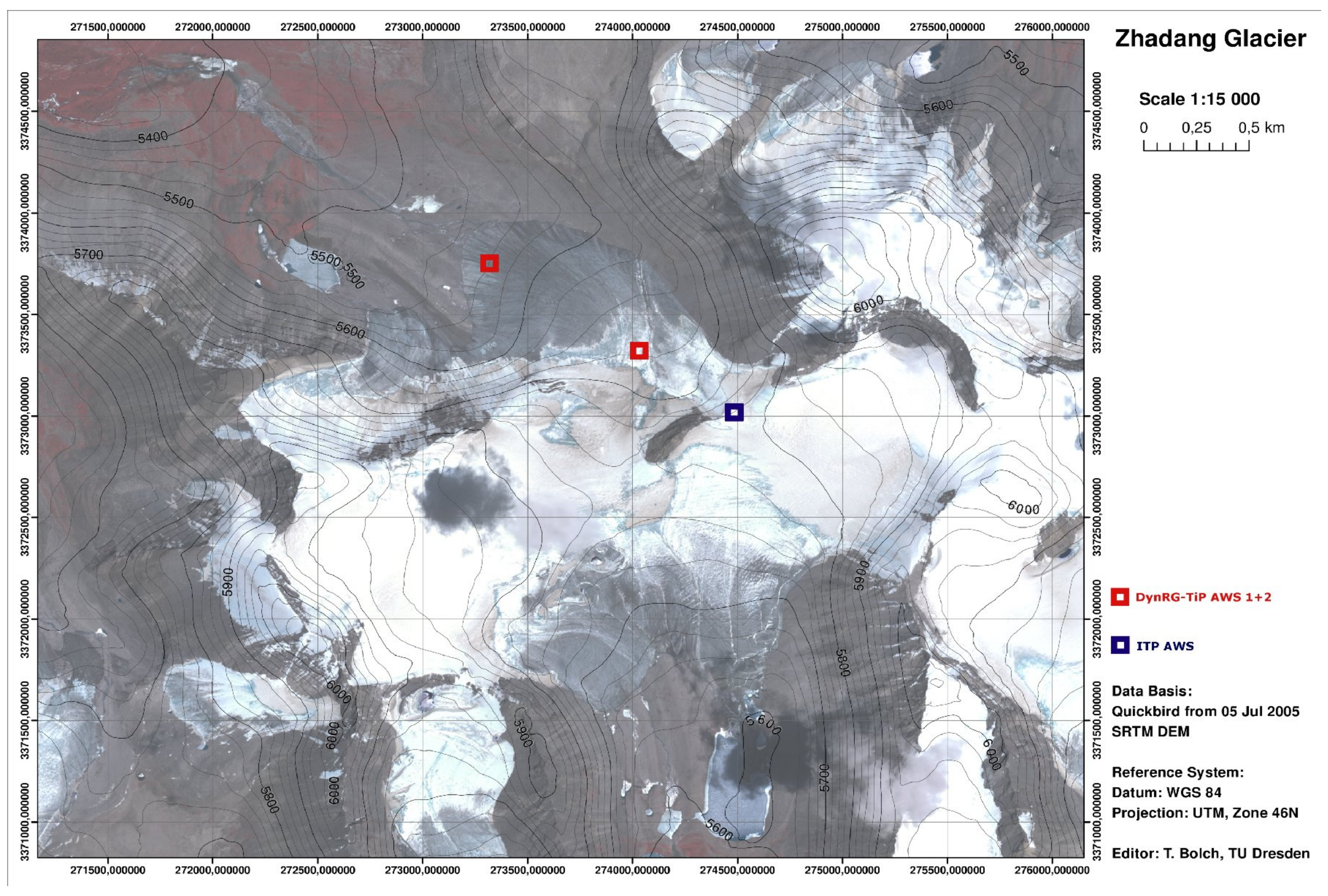

Fig 1: Quickbird scene of the Zhadang glacier (Nyangentangla range, Tibet, China) with appr. positions of the automatic weather stations (AWS)

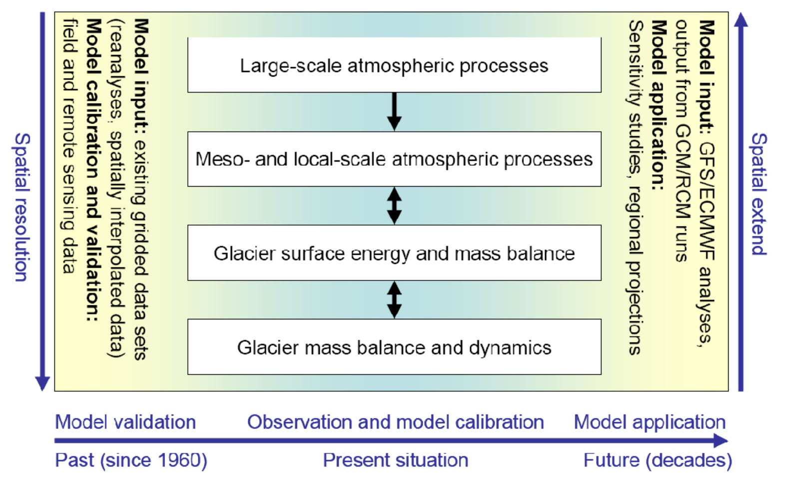

Fig 2: General research concept followed by DynRG-TiP

Phase one of the project focuses on the definition of a consistent and effective set-up for each component before their integration in the model architecture (Fig. 2).

2 Atmospheric modelling – WRF-ARW model

Weather Research and Forecasting model experimental set-up:

- WRF–ARW dynamical core V3.1.1
- 3 two-way nested domains centered on Nam Co
- 30Km → 10Km → 2Km grid resolution
- 28 vertical layers (eta-levels)
- 150 x 150 grid points
- 36 hours simulation periods with 12H spin-up time

The model is driven by the

- NCEP FNL (Final) Operational Global Analysis dataset (http://dss.ucar.edu/datasets/ds083.2)

with additional daily sea surface temperature input from the

- NCEP *RTG_SST_HR* dataset (http://polar.ncep.noaa.gov/sst/ophi)

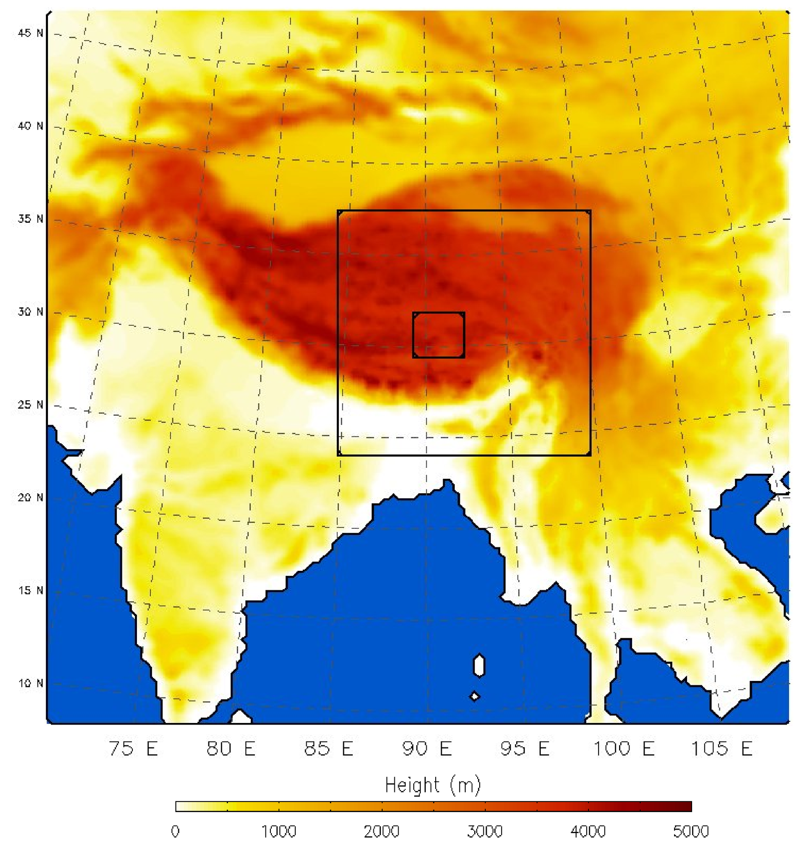

Fig 3: WRF domains definition and topography

Validation and sensivity study:

- Simulation of a precipitation event : Tropical Cyclone Rashmi (24.–28. October 2008)
- Validation by meteorological station from the NCDC network and TRMM remote sensing data (Tropical Rainfall Measuring Mission: 3-hourly, 0.25 deg. grid precipitation rates (http://trmm.gsfc.nasa.gov/3b42.html)

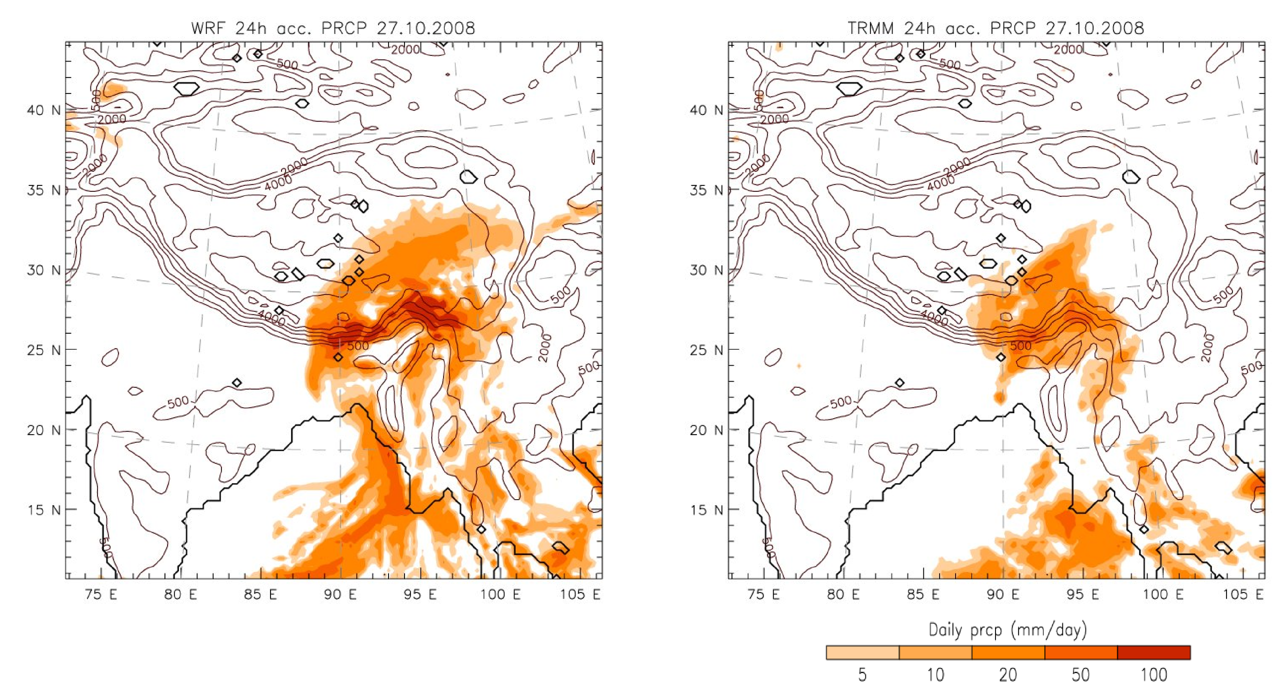

Fig 4: Daily precipitation patterns from the day 27/10/2008. Left : WRF 30Km domain output. Right: TRMM 3B42 product

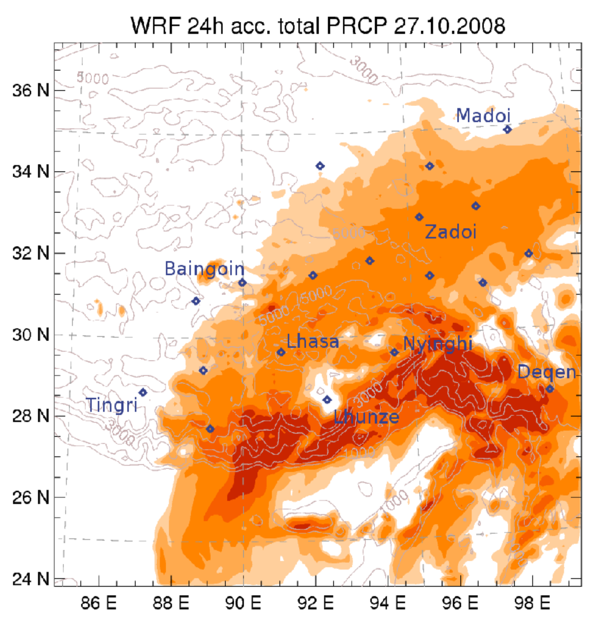

Fig 5: WRF domain 2 daily precipitation output and positions of the NCDC Meteorological stations

3 Numerical modelling – degree-day model (DDM)

- Temperature-radiation-index melt model after *Hock* (1999) with a radiation module after *Kumar et al* (1997)
- Degree-day approach:

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

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 (-)

- Calibration for the area of Zhadang Glacier based on mean annual measured mass balance values 2005-2008 (Kang et al 2009) (minimum-square-method)
- Daily temperature and precipitation values from Baingoin station (31°22' N, 90°01' E, 4.701 m a.s.l), approx. 120 km northwest of the glacier (Fig. 6)
- Due to large gaps in the precipitation data this time series was scaled after *Schuler et al* (2007) such that its monthly sums equal the measured values published by *Kang et al* (2009)
- For the values presented in tab. 1 measured and modelled mass balances are in good agreement ($rmse$ = 35 mm w.e.) (Fig. 7)

Tab.1 model parameters

parameter	value
Precipitation gradient*	0
Temperature lapse rate*	-0,7 (K / 100 m)
Degree-day factor for ice (DDF_{ice})	3,3 (mm w.e. K^{-1} d^{-1})
Degree-day factor for snow (DDF_{snow})*	1,65 (mm w.e. K^{-1} d^{-1})
Radiation factor a	4,7 (-)
Radiation factor b	5,8 (-)

* model assumption (not calibrated)

- The calibrated DDM is run for the area of Zhadang and Tangse River No.2 Glacier, assuming constant parameter values (Fig. 8)
- The influence of radiation decreases surface mass balances especially in the shaded regions in the north- and southwest and increases mass balances on the northern and southern glacier tongues

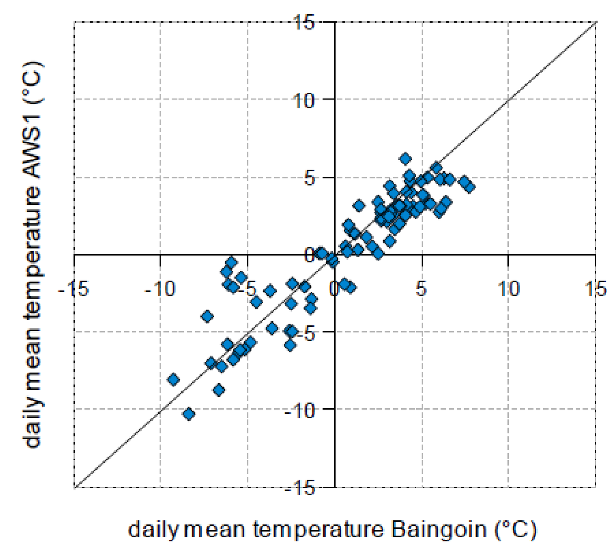

Fig 6: Daily mean temperatures from Baingoin Station vs. AWS1 (see Fig. 1),27.04.-24.07.2009 (r²=0,91)

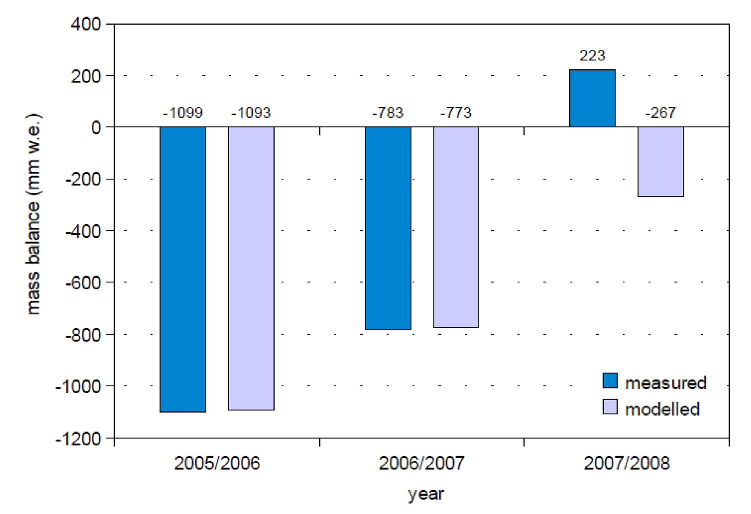

Fig 7: Measured vs. modelled mass balances of Zhadang Glacier, 2005-2008

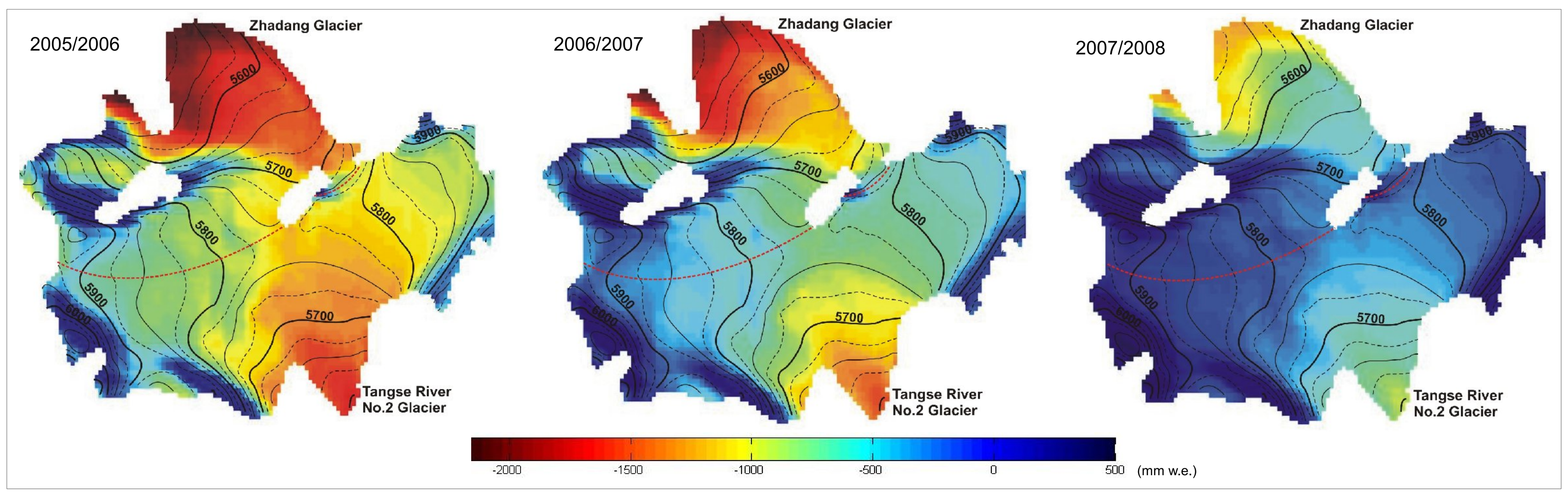

Fig 8: Modelled surface mass balances of Zhadang and Tangse River No.2 Glacier for the balance years 2005-2008

4 Conclusions and perspectives

- Two successful field campaigns in May and October 2009 and a good cooperation with our Chinese partners from the ITP-CAS (Institute of Tibetan Plateau Research, Chinese Academy of Science) made the Zhadang glacier one of the most extensively equipped and best observed "laboratory glacier" in Central Asia
- The WRF model shows good capacities in retrieving precipitation over this sparsely observed region. However, simulated precipitation amounts tend to be higher than those measured by TRMM (~72% for the day 27, WRF domain 1 output cropped on the domain 2) or by the NCDC stations (~42% for the day 27, WRF domain 2 output): this well documented effect can be attributed to an over-estimation by the model as well as to an under-estimation by the measurements
- The temperature-radiation-index melt model allows a spatially distributed estimation of surface mass balances
- Longterm datasets of daily values of regional temperature and precipitation rates are needed as input to calculate reliable mean annual mass balances
- The WRF model, running on the small domain can provide these longterm datasets; a first two-year long simulation period is scheduled for 2010

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