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CR4.3: Debris-covered glaciers

Investigating ice cliff evolution and contribution to glacier mass-balance using a physically-based dynamic model

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1. Introduction

Debris cover reduces glacier melt through insulation (Østrem, 1959). Supraglacial cliffs are typical of debris-covered glaciers (e.g. in High Mountain Asia) and may account for high mass losses by providing a direct ice-atmosphere interface. Their role has been investigated re either in point scale studies of single cliffs (Sakai et al., 1998; Han et al., 2010, Reid & Brock, 2014, Steiner et al., 2015) or at the large-scale from satellite imagery, so that a gap in scale is evident.

Buri et al. (2016) suggested the first grid-based energy balance and ablation model for single cliffs, and demonstrated high variability in melt rates at the cliff scale. Building on that, we develop a dynamic 3D-backwasting model accounting for recovering/exposure of ice based on surrounding topography. Using this model approach we assess the importance of ice cliffs in terms of melt at the glacier and catchment scale.

2. Study site

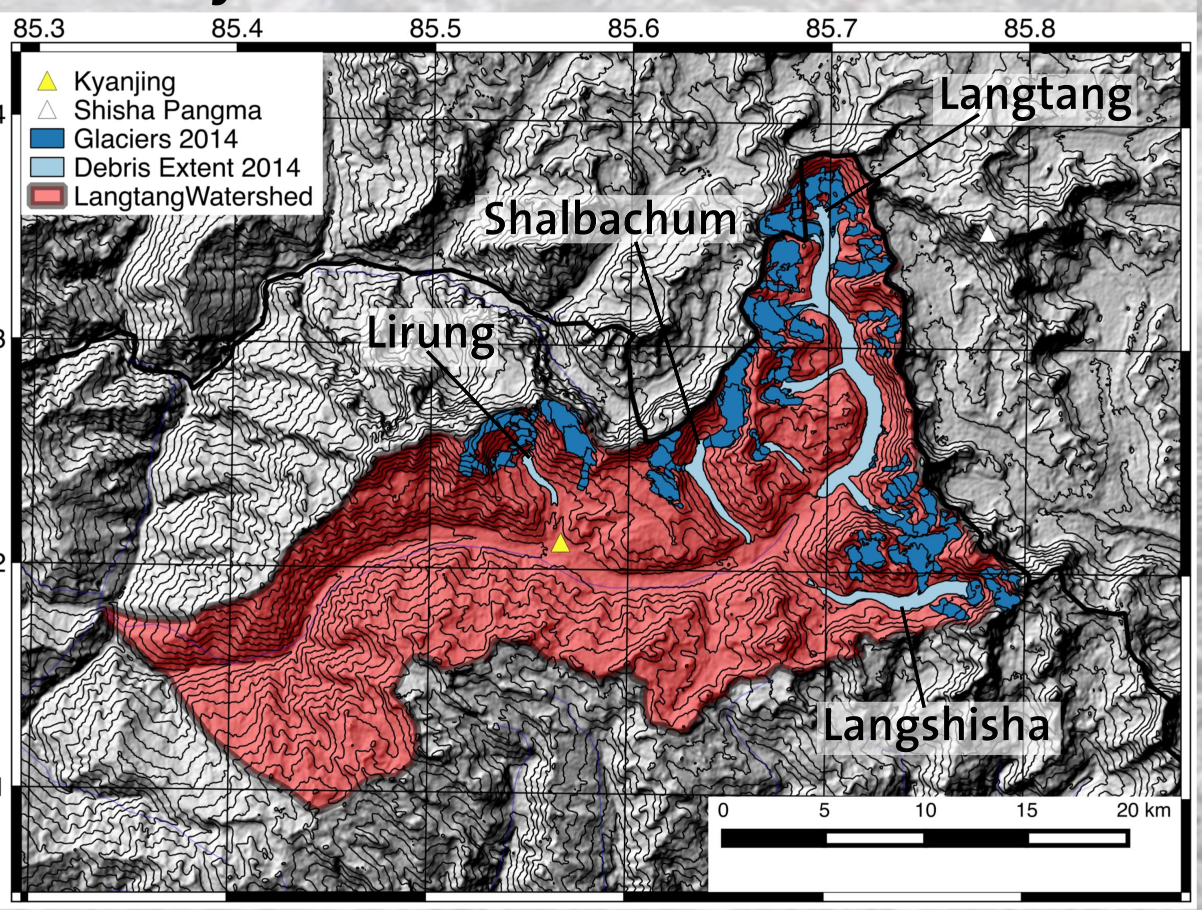


Figure 1: Langtang Valley, central Nepalese Himalayas.

Table 1: Glaciers studied (from Ragettli et al., 2016, under review).

Glacier	Glacier area [km²]	Debris cover [%]	Elevation range [m a.s.l.]
Langtang	46.5	33.3	4479 - 6615
Langshisha	16.3	27.6	4415 - 6771
Shalbachum	10.2	25.5	4231 - 6458
Lirung	6.5	16.9	4044 - 7120

3. Methods

– Models –

Static: distributed physically-based energy-balance model (Buri et al., 2016)
- considers shading/fluxes from surrounding topography

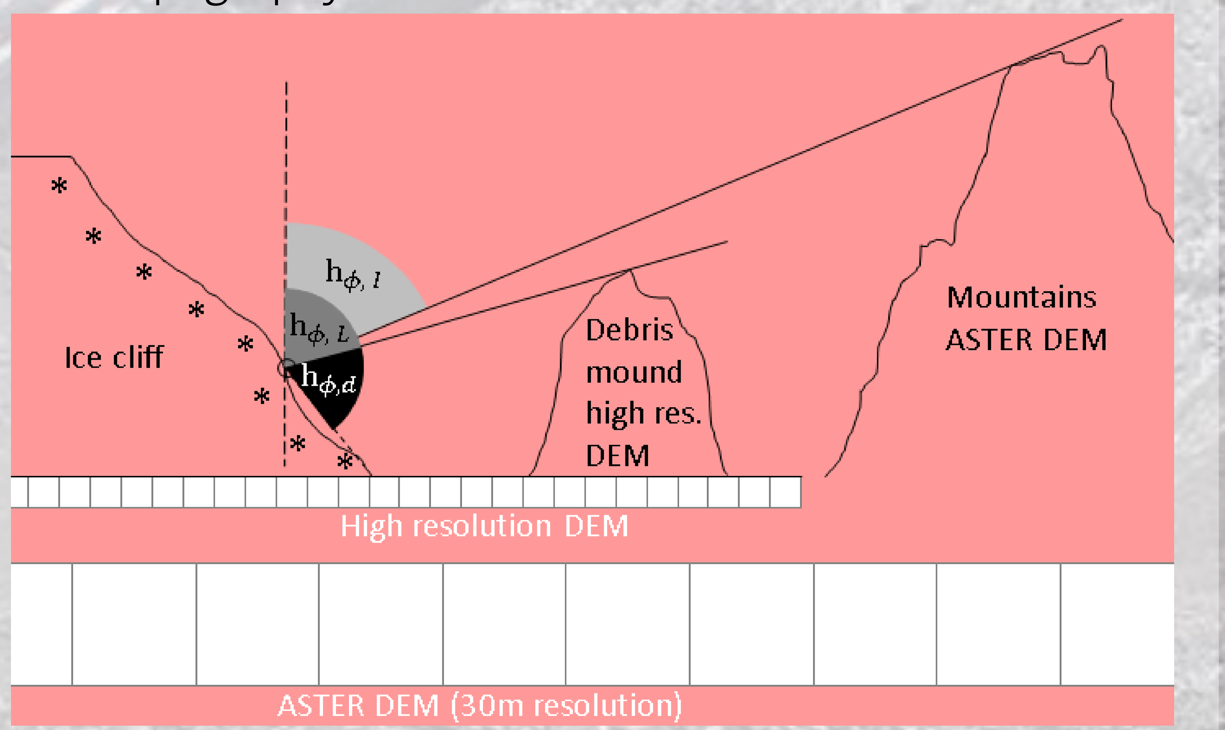


Figure 2: Modelled interplay between topography and ice cliff (static and dynamic model).

Dynamic: 3D-backwasting model (based on static model)
-monthly cliff geometry corrections based on melt
-considers recovering by debris and exposure of ice

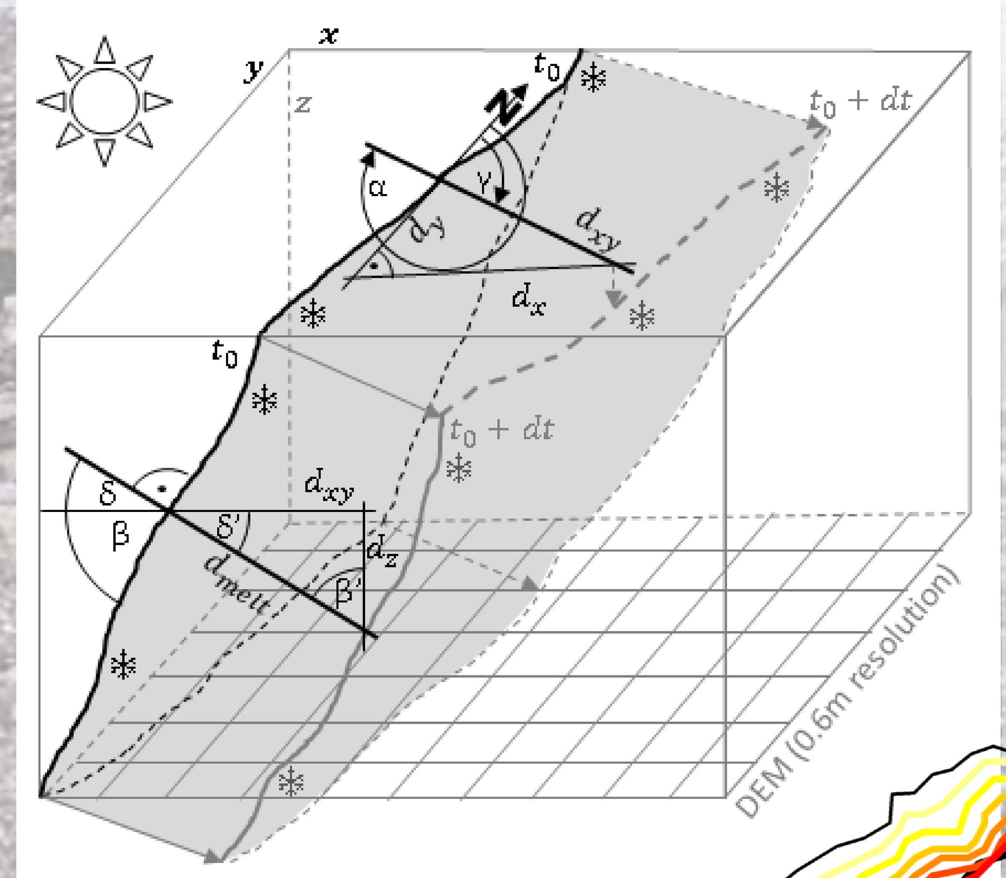


Figure 3: Geometric correction (dynamic model).

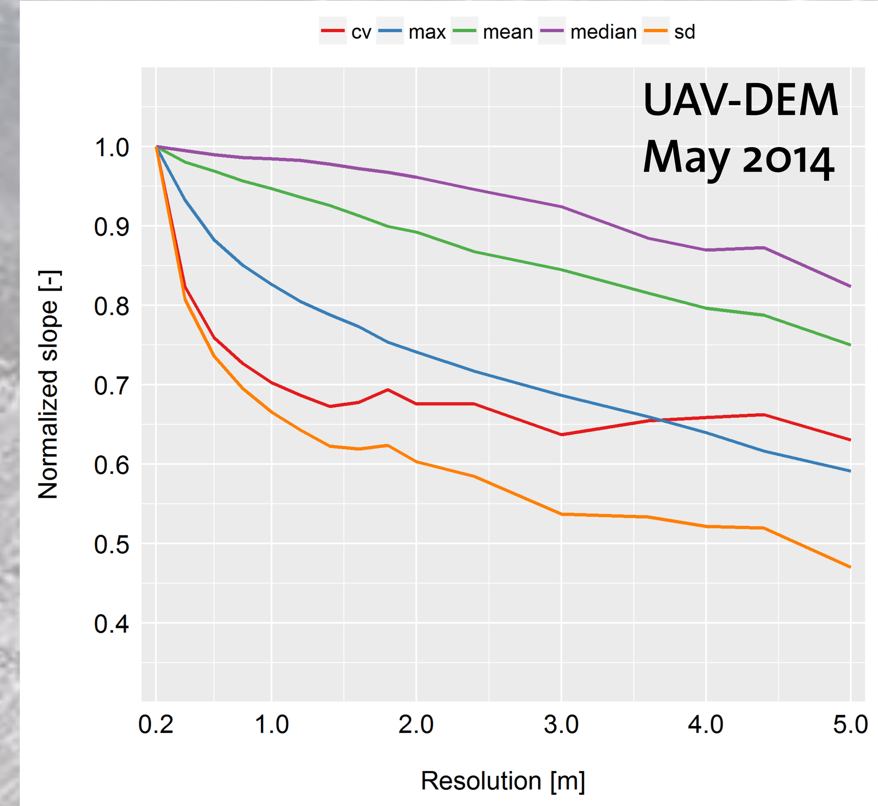


Figure 5: Effect of resolution on mean slope of single ice cliff.

– Topography–

High resolution DEMs:
-UAV-DEMs of 0.2m (static model) – 0.6m (dynamic model) resolution (Immerzeel et al., 2014)
-SPOT 6 DEM of 3m at glacier scale approach
ASTER (30m) for radiation modelling of far topography

– Cliff outlines–

Manually derived from SPOT 6 Orthoimage (April 2014) ≈400 cliffs for entire catchment

– Meteorological input–

AWS on Lirung Glacier
-hourly and seasonal lapse rates for T_{air} on debris-covered glacier tongues (Steiner & Pellicciotti, 2016) and in the valley (Heynen et al., 2016)
- **Debris $T_{surface}$ derived from T_{air}** based on seasonally piece-wise regression (Steiner & Pellicciotti, 2016)

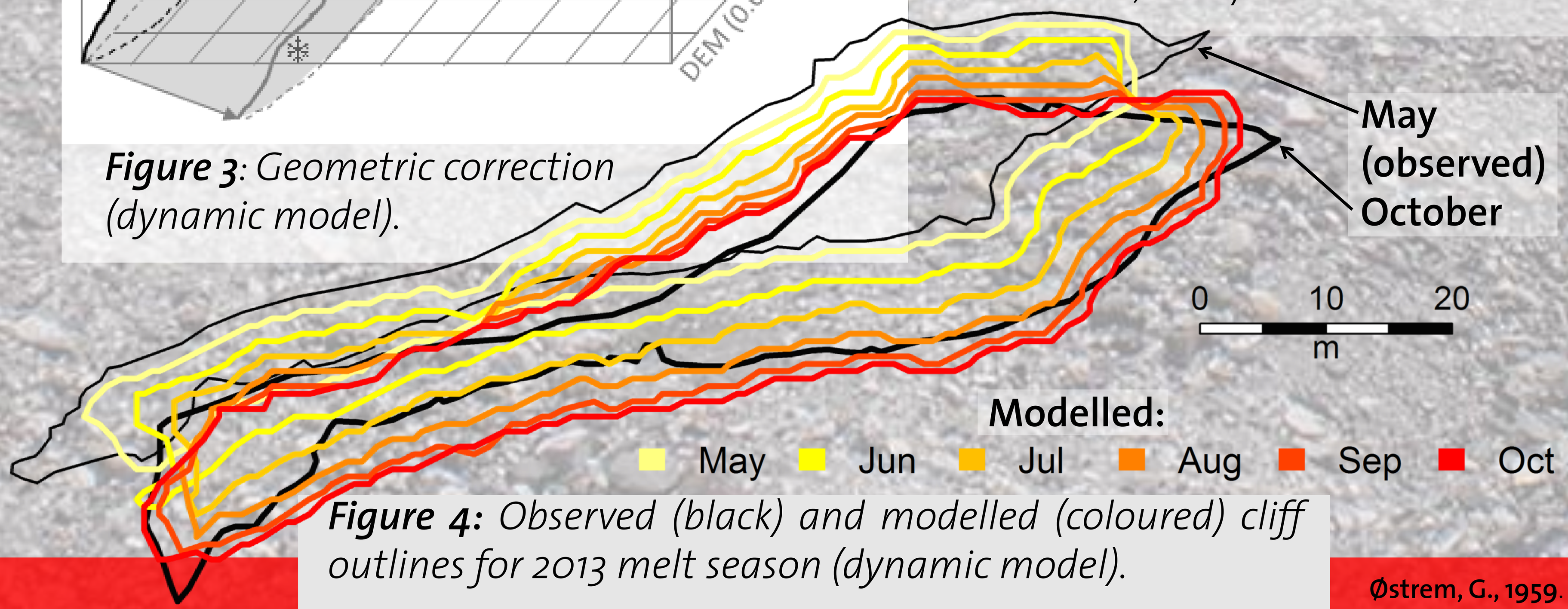


Figure 4: Observed (black) and modelled (coloured) cliff outlines for 2013 melt season (dynamic model).

4. Results

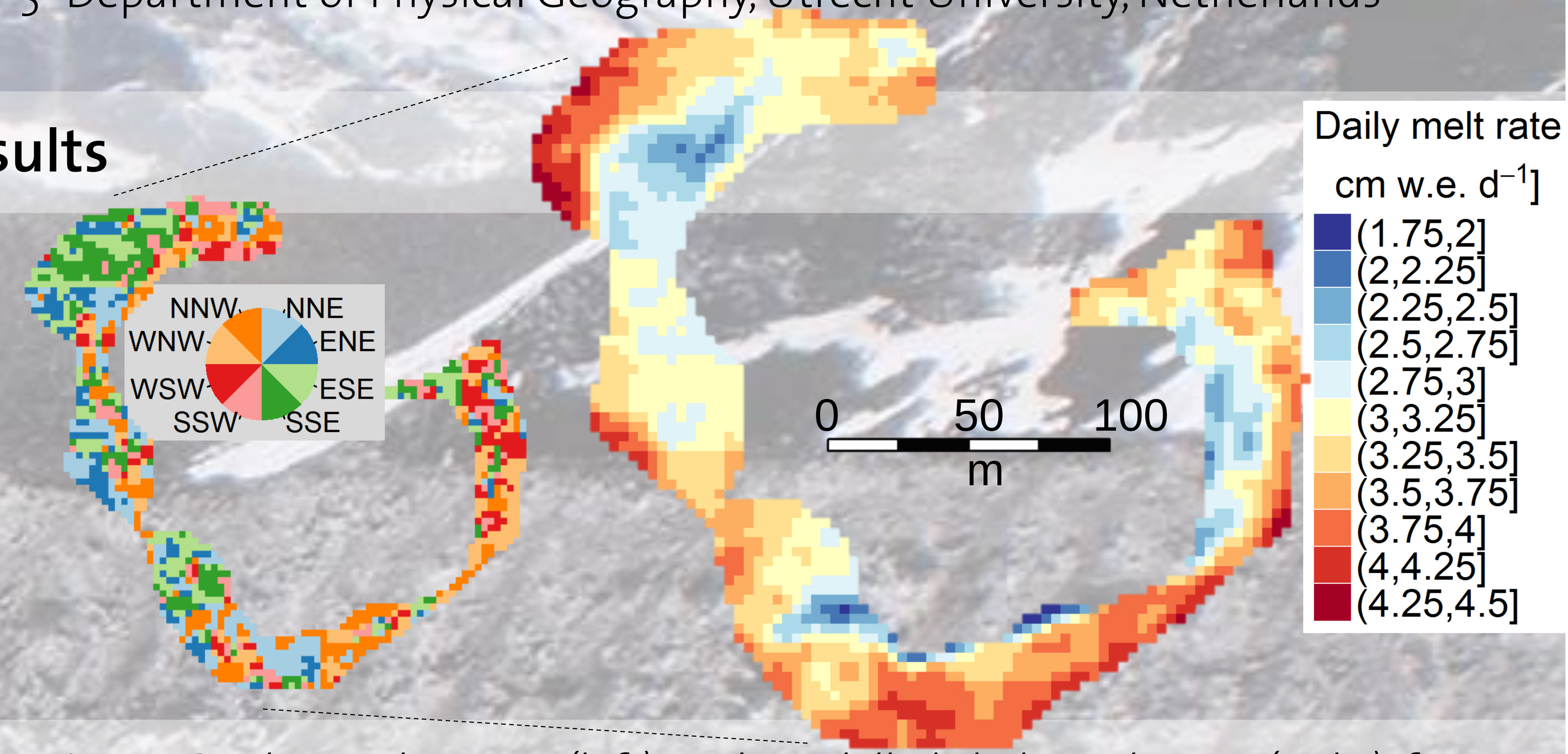
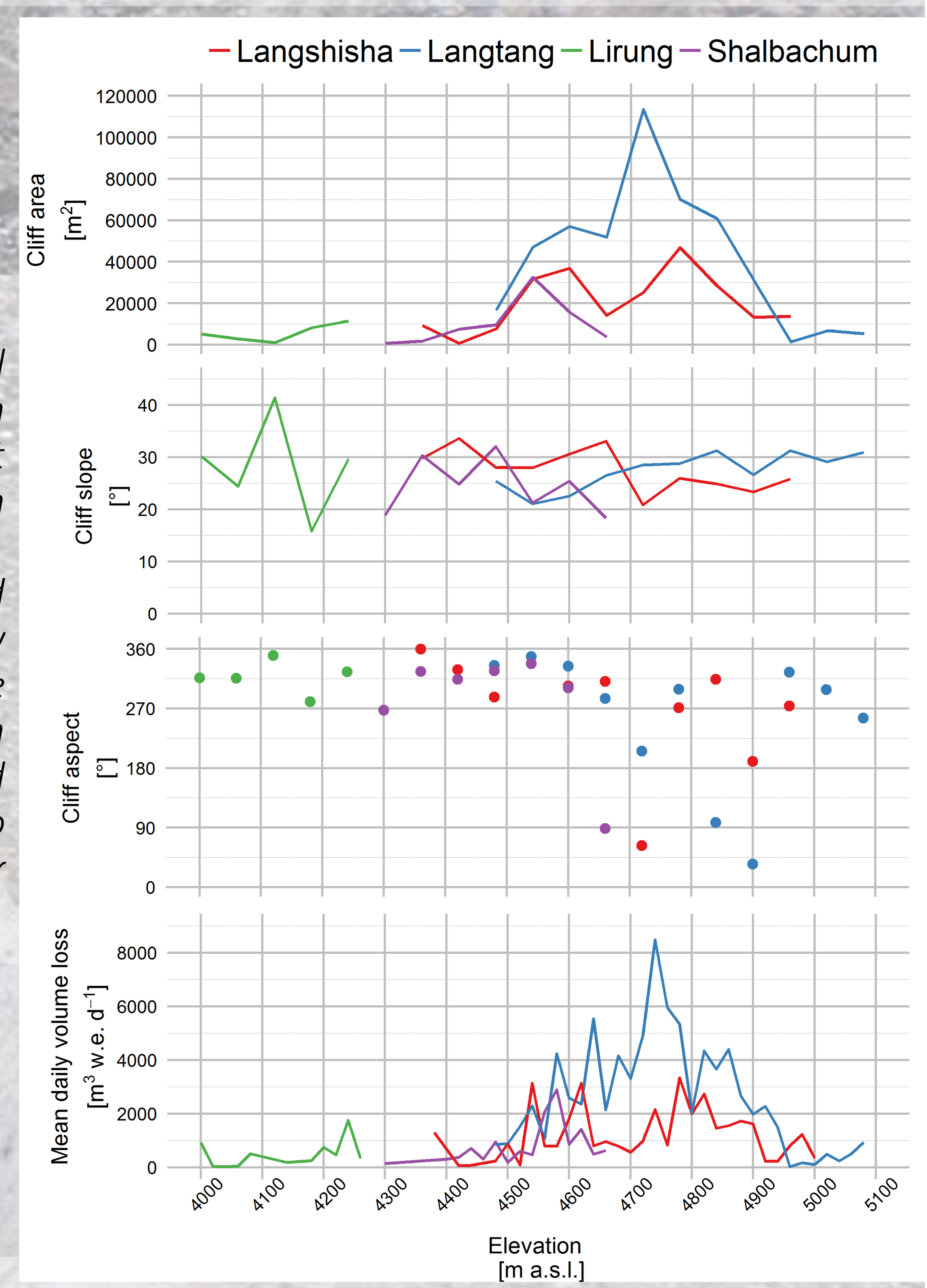


Figure 6: Observed aspect (left) and modelled daily melt rate (right) for one cliff on Langtang Glacier in pre-monsoon 2014 (static model).

SCALE

Figure 7: Top: Observed total cliff area and mean slope and aspect per 20m elevation band. Bottom: Modelled (static) mean daily volume loss of ice cliffs per 20m elevation band from May to October 2014 for four glaciers.



5. Conclusions

1) A static model can reproduce the spatial patterns of energy fluxes and short-term melt rates accurately, showing high spatial variability (Fig. 6)
2) For long-term simulations, update of the geometry is crucial, and is controlled by differential ablation (Fig. 6) and recovering by debris (Fig. 4)
3) Application of the static model leads to realistic patterns of total melt with elevation but seems to overestimate volume losses

Outlook: – Comparison to geodetically derived mass losses at the glacier scale
– Implementation of geometric correction at the glacier scale (resolution effect, Fig. 5)

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