

# LGM Tibetan Plateau glaciers were not much larger than today

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## INTRODUCTION

The palaeoglaciology of the Tibetan Plateau has been an elusive and disputed topic, with reconstructions ranging from restricted mountain glaciers to a plateau-wide ice sheet. Here we use glacial geological data to investigate the extent of past glaciations and to constrain the palaeoclimate.

## METHODOLOGY

To constrain the extent of past glaciations on a plateau-scale we have compiled a glacial boulder dataset of  $^{10}\text{Be}$  exposure ages and distance to present-day glacier or parent glacier headwall.

To constrain the palaeoclimate we use a high-resolution higher order 3D glacier model forced with static climate perturbations of the present-day climate.

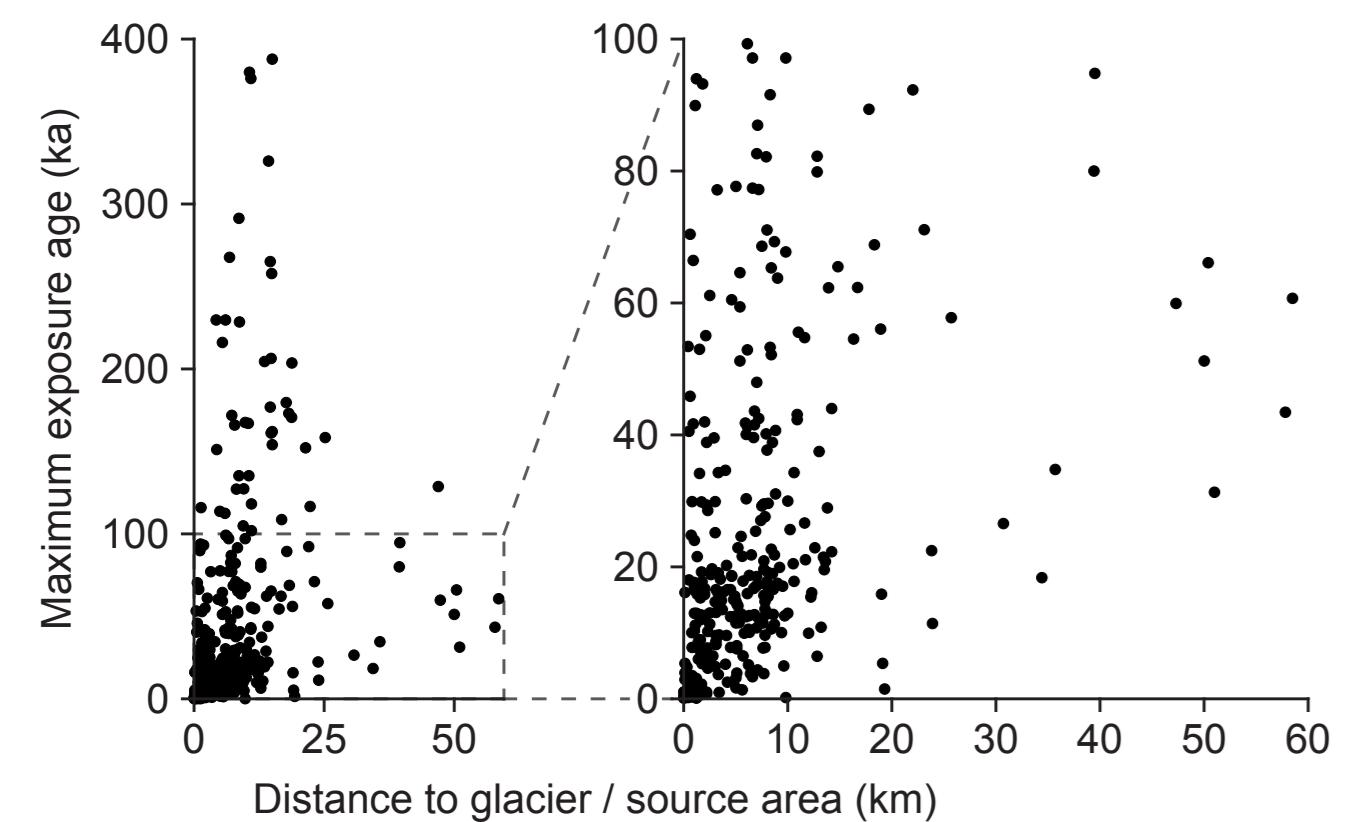
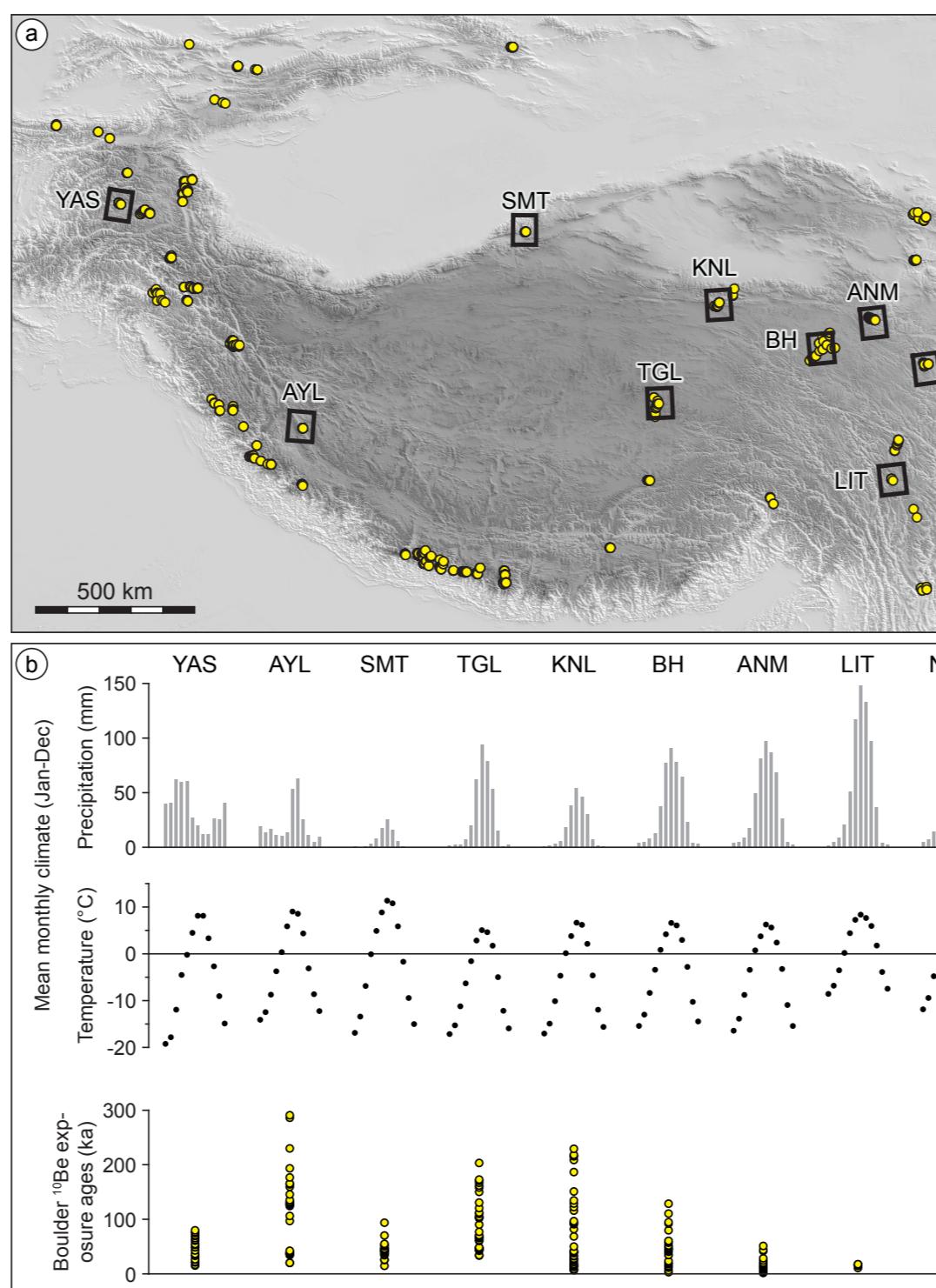


Fig. 1. Maximum boulder  $^{10}\text{Be}$  apparent exposure age (cf. Heyman et al. 2010) for all dated sites on the Tibetan Plateau (mostly moraine ridges;  $n = 343$ ) and their distance to present-day glacier or parent glacier headwall. See Fig. 2 for location of the boulders.

## GLACIAL GEOLOGY

The location of the boulders constrain the extent of past glaciations and the exposure ages constrain the chronology. A large majority of all glacial boulders dated by  $^{10}\text{Be}$  on Tibetan Plateau are located less than 10 km away from present-day glaciers or the parent glacier headwall, indicating deposition by glaciers not much larger than today (Fig. 1). The exposure ages range up to 400 ka indicating restricted glaciation over long time spans (Figs. 1-3).



## GLACIER MODEL

We have used the model for nine domains across the Tibetan Plateau. The domain is 200 x 200 grids with a grid resolution of 15 seconds (c. 380 x 460 m). We employ the WorldClim data (Hijmans et al. 2005) as present-day climate with stepwise (temp: 0.1 K / prec: 10%) climate perturbations to attain a best fit to present-day glaciers and to expand glaciers over sites with boulder  $^{10}\text{Be}$  exposure ages (Figs. 4-6).

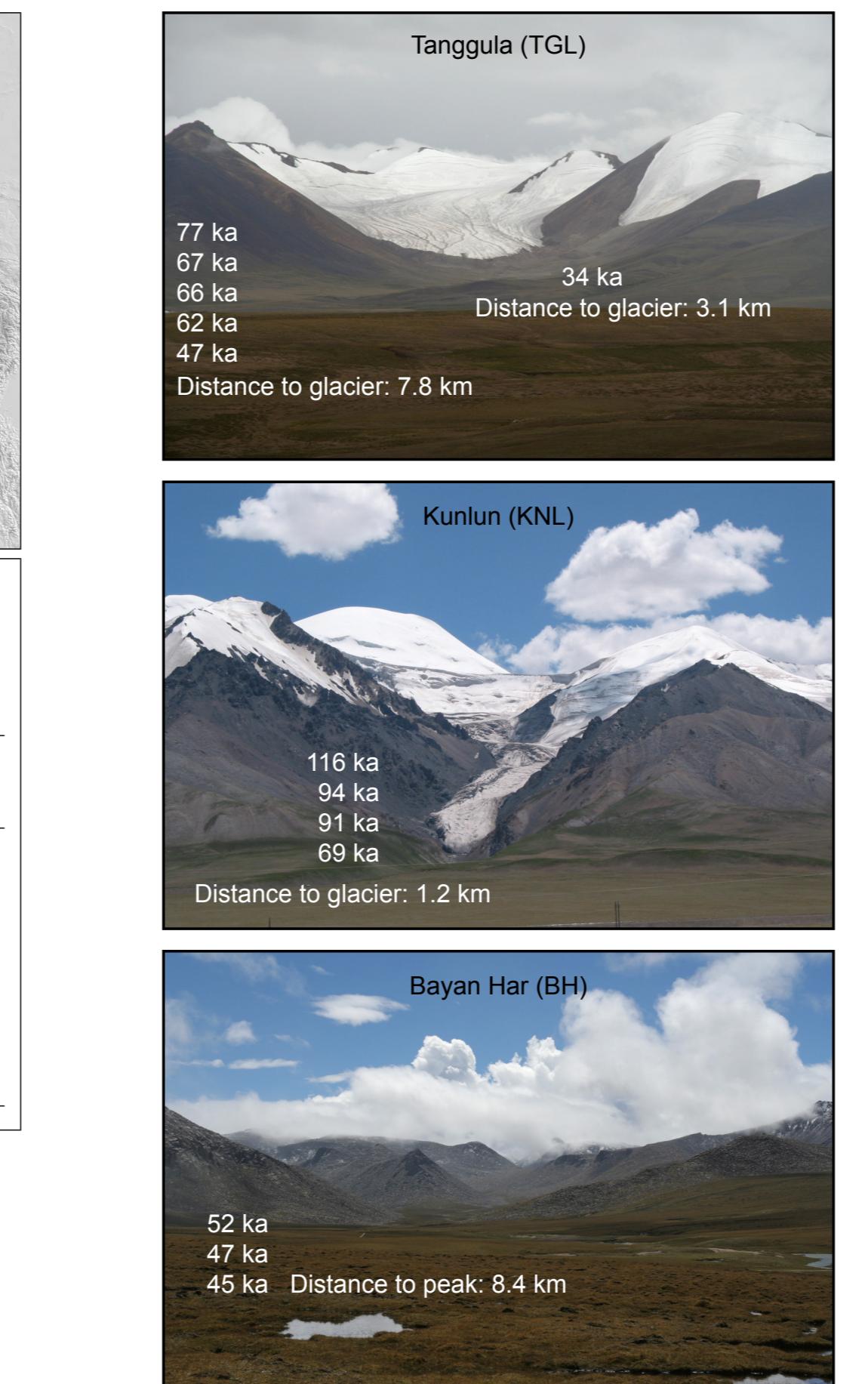


Fig. 3. Old exposure ages (significantly older than the global LGM) close outside present-day glaciers in the Tanggula Shan and Kunlun Shan and close to the parent glacier headwall in Bayan Har Shan. See Fig. 2 for location of the sites.

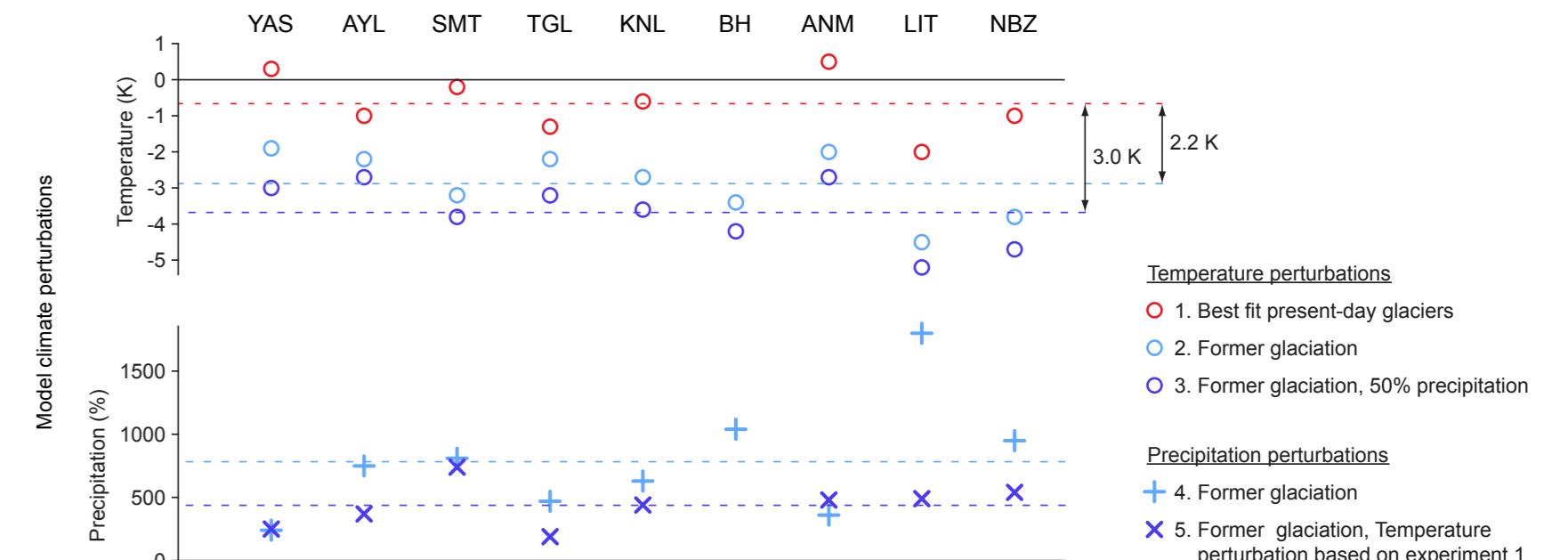


Fig. 4. Climate perturbations from the five experiments (1-5) performed on the nine domains. Dashed lines mark the average value of each experiment. See Fig. 2 for locations of the domains, and Fig. 5 for the modelled glacier outlines.

## PALAEOCIMATE CONSTRAINTS

The glacier model reproduces the present-day glaciers with temperature perturbations between +0.5 K and -2.0 K (Figs. 4 and 5), lending credibility to the modeling approach. To expand glaciers over the boulders with  $^{10}\text{Be}$  exposure ages temperature perturbations of 1.9-5.2 K or precipitation perturbations of 240-1800% are required. The average temperature perturbation difference between modelled present-day glaciers and expanded glaciers is 2.2 K (100% precipitation) or 3.0 K (50% precipitation) indicating that the cooling required to expand glaciers over dated sites is not very large.

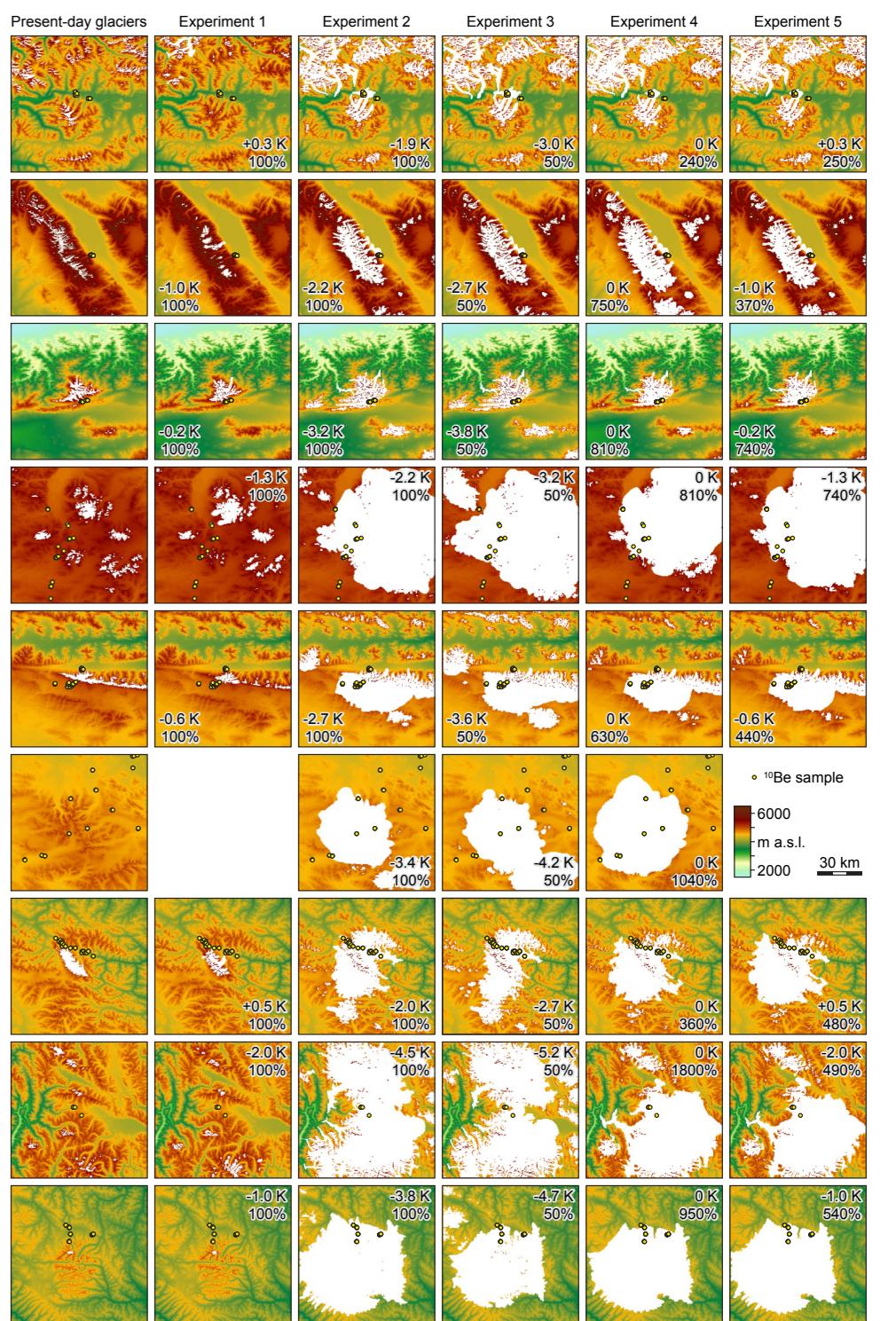


Fig. 5. Present-day and modelled glaciers (experiment 1-5) for the nine domains. Temperature (K) and precipitation (%) perturbations are given for each experiment. For each experiment the model was run 5000 years forward. The Bayan Har domain lacks present-day glaciers and experiments 1 and 5 were therefore not performed for this domain. See Fig. 2 for location of the domains and Fig. 4 for experiment description.

## CONCLUSIONS

A large number of boulders, constrained by  $^{10}\text{Be}$  exposure dating to post- as well as pre-LGM ages, are located close outside present-day glaciers and indicate that past glaciations have been very restricted.

A high resolution glacier model forced by climate perturbations and used for nine locations across the Tibetan Plateau indicates limited climate shifts during past glaciations. To produce glaciers more extensive than were present during the LGM it is enough to lower the temperature by 2-4 K.

## References

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Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A, 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25, 1965-1978.