

Table S1. Characteristics of the studied glaciers in the Lunana region, Bhutan Himalaya, and summary of the differential GPS surveys in 2004 and 2011. The glacier areas are based on ALOS PRISM images acquired in 2010 (Nagai et al., 2016). The mean slopes are based on ASTER GDEM2. The numbers of survey points are obtained from the 1 m grid DEMs.

Glacier	Area (km ²)	Mean slope (degree)	Date of survey		Number of survey points	
			2004 (MM/DD)	2011 (MM/DD)	2004	2011
Thorthormi	13.16	0.1	10/02, 03, 05	09/18	25388	25752
Lugge	10.93	11.8	10/06	09/20	8114	17900
Lugge II	3.18	14.7	10/09	09/21	5052	13991
Off glacier			09/29–10/10	09/18–22	38171	64608

Table S2. Dates of the ASTER images used for the surface flow velocity analysis and length of the measurement period.

Pre image (YYYY/MM/DD)	Post image (YYYY/MM/DD)	Length of measurement period (Day (year))
2002/10/22	2003/07/21	273 (0.75)
2006/02/03	2007/01/30	362 (0.99)
2007/01/30	2008/01/01	337 (0.92)
2008/01/01	2009/12/12	712 (1.95)
2009/12/12	2010/10/12	305 (0.83)

Table S3. Details of the ASTER images used for the thermal resistance calculation in this study.

Acquisition date (YYYY/MM/DD)	ASTER granule ID
2002/10/22	AST3A10210220448051102020056
2003/07/21	AST3A10307210446080407230013
2005/09/28	AST3A10509280446011110140033
2006/02/03	AST3A10602030445411110140028
2006/12/04	AST3A10612040446231110140026
2007/05/06	AST3A10705060441001110140025
2007/10/29	AST3A10710290440431110140023
2010/10/12	AST3A11010120446391110140074

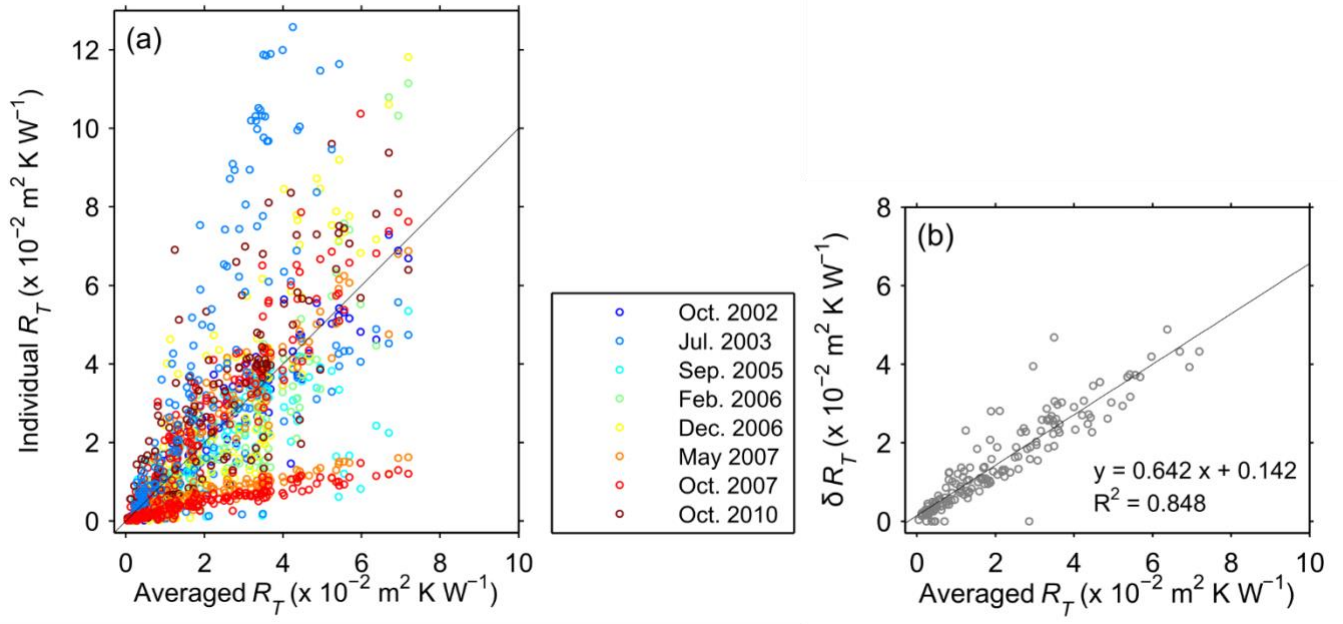


Figure S1. (a) Scattergram of thermal resistance (R_T) of the multitemporal ASTER data against their average, which is used to calculate the degree of ice melt under the debris-covered surface of Thorthormi, Lugge, and Lugge II glaciers. (b) Standard deviations (δ) of thermal resistance.

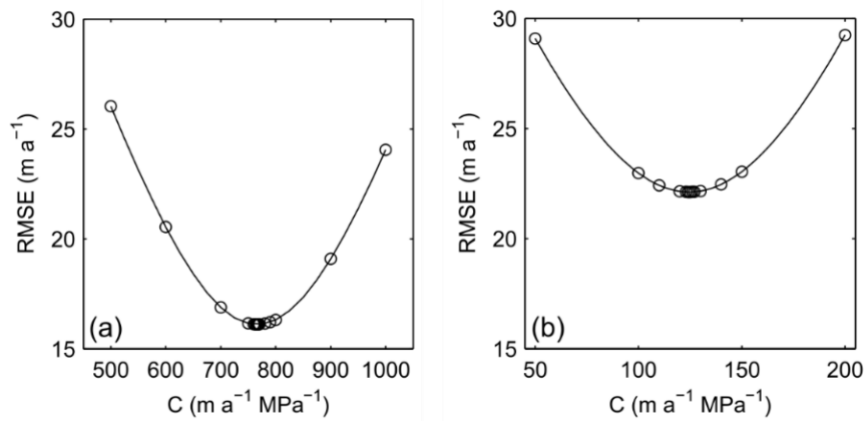


Figure S2. RMSEs between the modelled and measured surface flow velocities of (a) Thorthormi and (b) Lugge glaciers, modelled with a changing sliding coefficient (C).

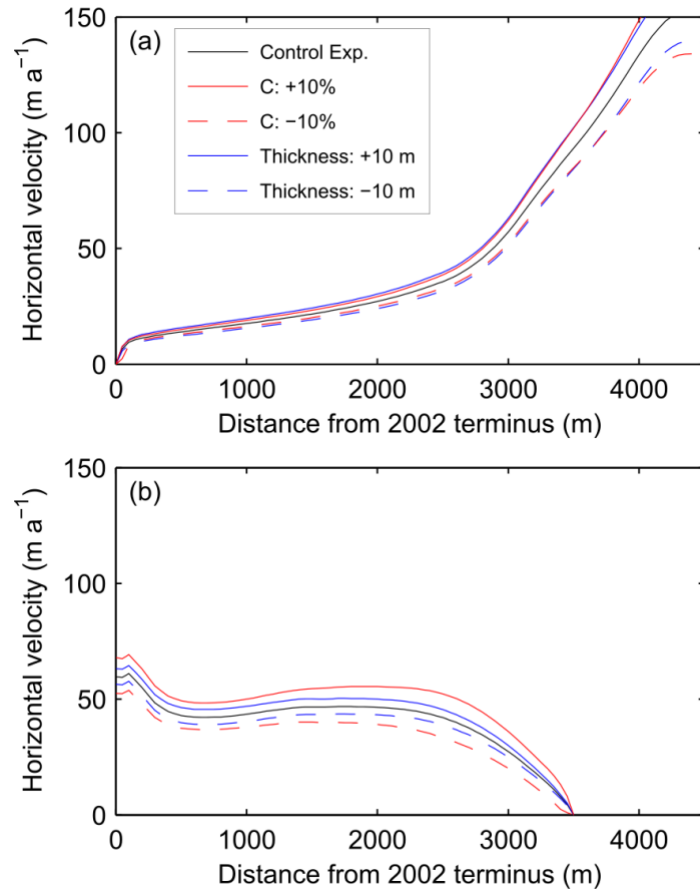


Figure S3. Sensitivity of the horizontal flow velocity of (a) Thorthormi and (b) Luggé glaciers due to a change in the sliding coefficient (C) of $\pm 10\%$ (red lines) and a change in ice thickness of ± 10 m (blue lines). The black line is the control experiment.