Ice thickness measurements of the debris-covered Ngozumpa glacier, Nepal Himalaya

Lindsey Nicholson, Fabien Maussion, Christoph Mayer, Hamish Pritchard, Astrid Lambrecht, Anna Wirbel, and Christoph Klug

Why do we care?

Glacier ice volumes in High Mountain Asia (HMA) are largely unmeasured, but we need up-to-date information on this to assess how glaciers of this region, and their contribution to freshwater supply and sea level rise, are set to change.

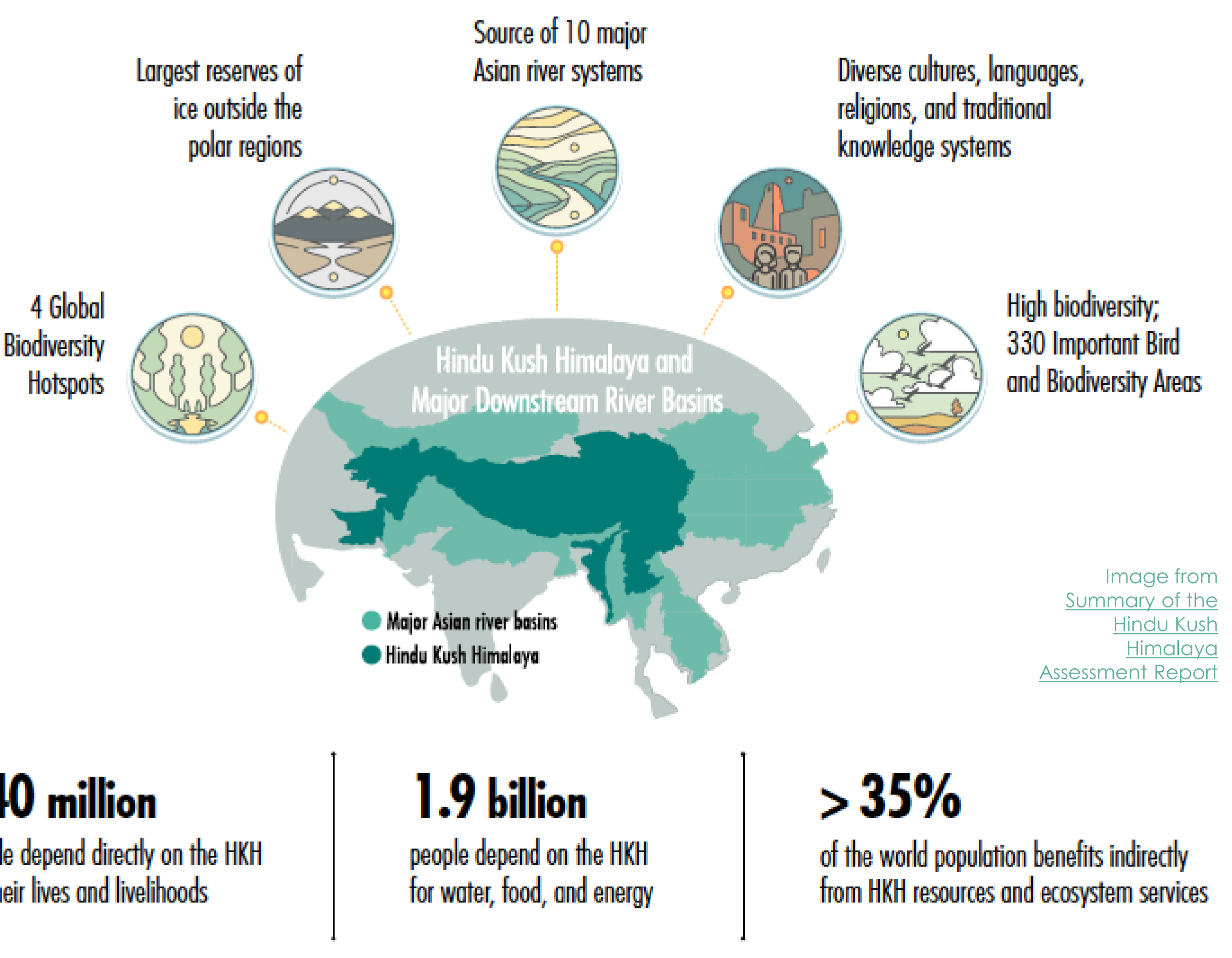


Image from Summary of the Hindu Kush Himalaya Assessment Report

240 million people depend directly on the HKH for their lives and livelihoods

1.9 billion people depend on the HKH for water, food, and energy

> 35% of the world population benefits indirectly from HKH resources and ecosystem services

Recently, a modelled global ice thickness estimate (Farinotti et al., 2019) showed that HMA contained 27% less ice than previous estimates → glacier area will halve by 2060, a decade earlier than previously thought.

These models use glacier surface topography and principles of ice flow dynamics to invert for local ice thickness, but none are optimised for debris-covered glaciers, which comprise up to 30% of the glacierized area in parts of HMA (Scherler et al., 2018), and have anomalously long, low-angled, stagnating termini.

So, the key question we want to answer is: **how well do these models work for debris-covered glaciers?**

What did we do?

We measured the ice thickness at several cross- and long-profiles over the debris-covered tongue of Ngozumpa glacier, Nepals largest debris-covered glacier, using low frequency ground penetrating radar, and then we compared our results to the global modelled ice thickness data, which is available as a supplement to the Randolph Glacier Inventory (RGI) v 6.0.

Measured data:
only sparse coverage

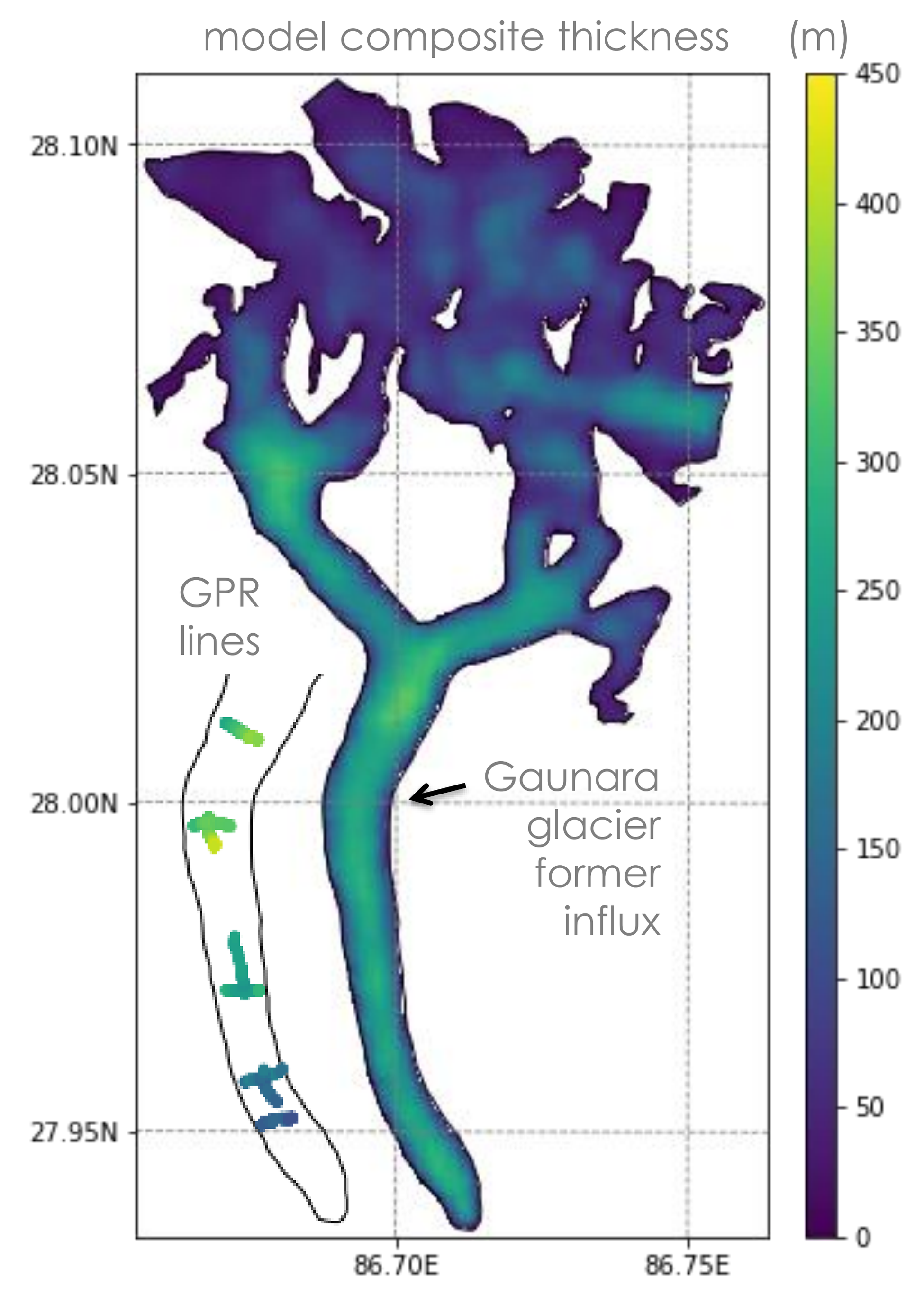
- Data all within the debris-covered area
- Uppermost measurements are in an area that satellite data shows is still flowing
- Cannot measure to the very glacier margin due to signal interference moraines

Modelled data:
offers a thickness field for the whole RGI glacier outline

Model data is a composite of 4 individual models:

1. Huss and Farinotti (2012)
2. Frey and others (2014)
3. Maussion and others (2019)
4. Fürst and others (2017)

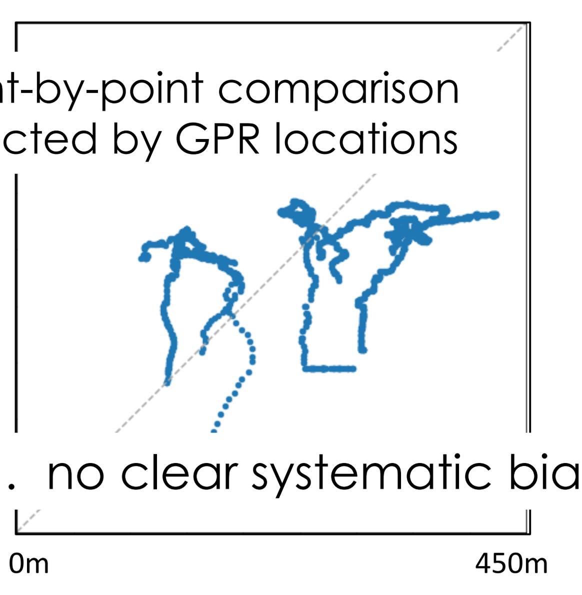
What do the results show?



Maximum measured ice thickness of 423m just below the former confluence of Gaunara Glacier. Otherwise, the GPR data show ice thickness decreasing downglacier to a minimum of 110 m ca. 2km from the terminal moraine.

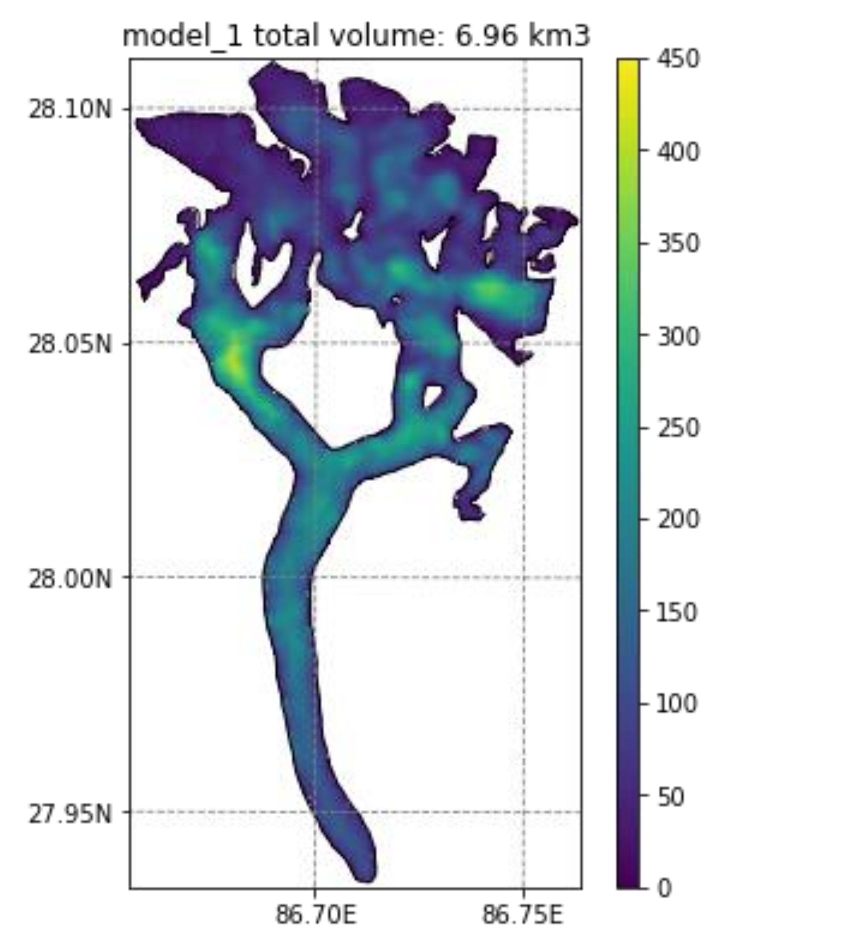
Model composite misses thickest ice as the now disconnected tributary glacier is not in the model scenario. Model shows more consistent thickness throughout the debris-covered tongue.

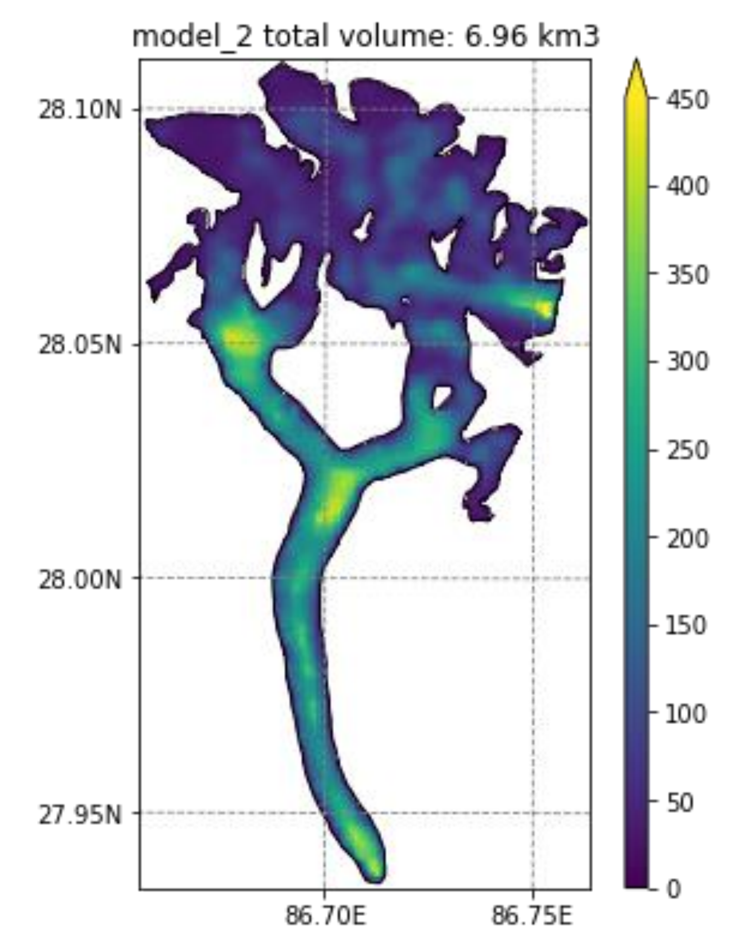
Point-by-point comparison affected by GPR locations

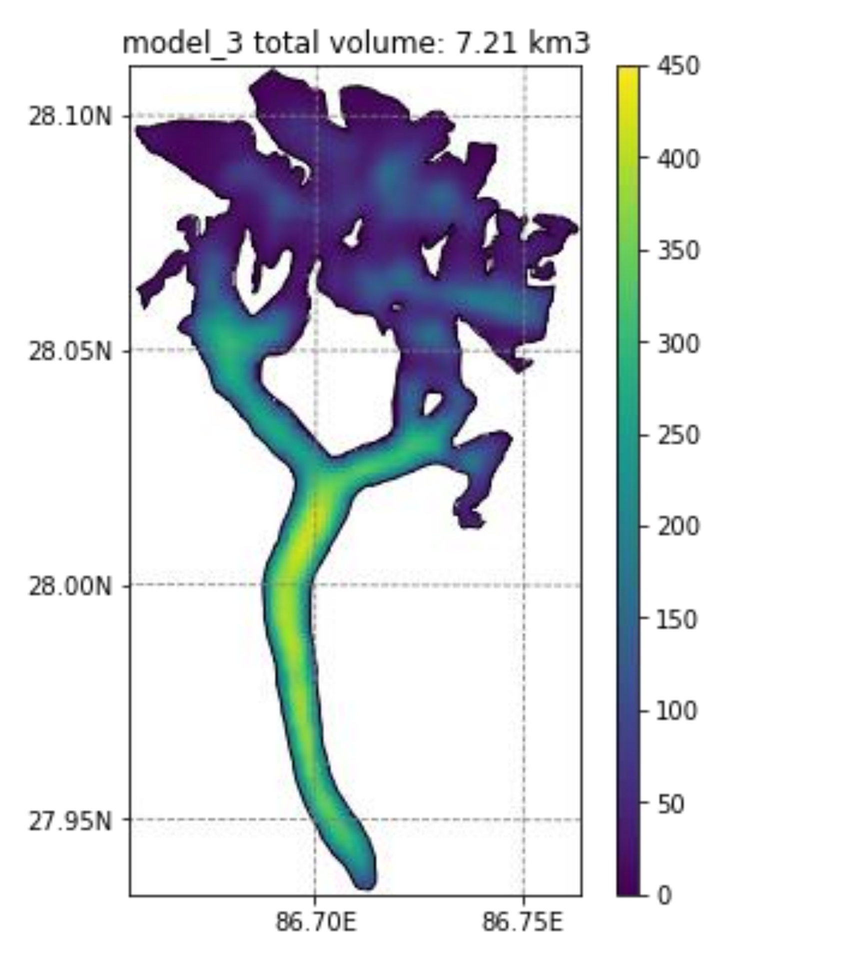


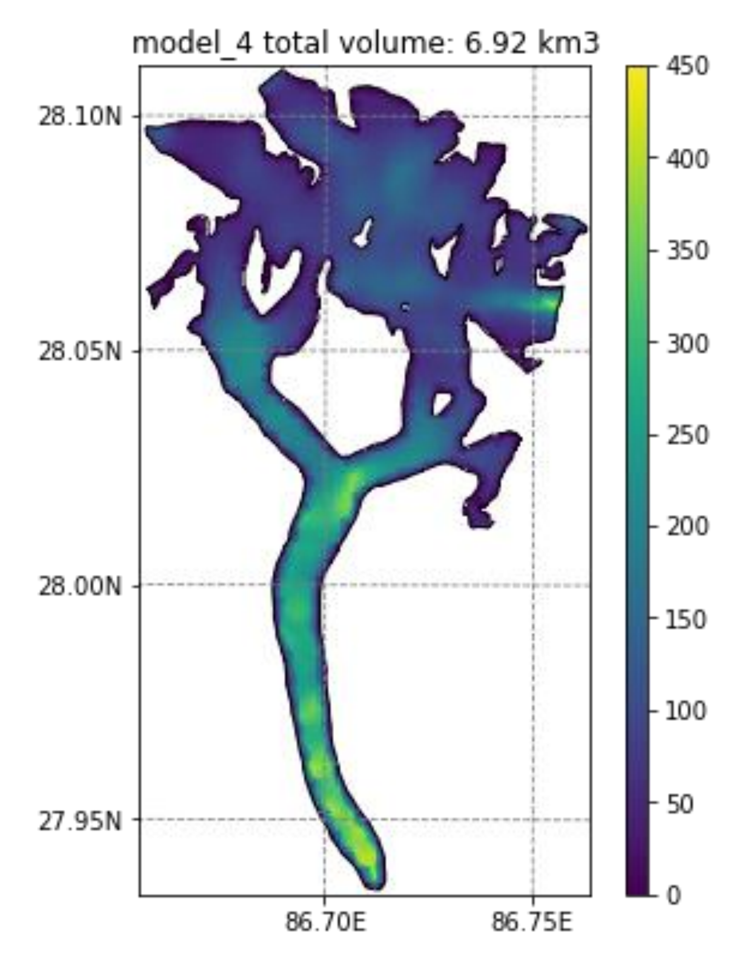
… no clear systematic bias.

Comparing the 4 individual models shows how each model recreates thickness for the debris-covered tongue: Models agree with each other regarding total ice volume (similar principles in model), but patterns of thickness between models differ and none of the models match the measured thickness very well.







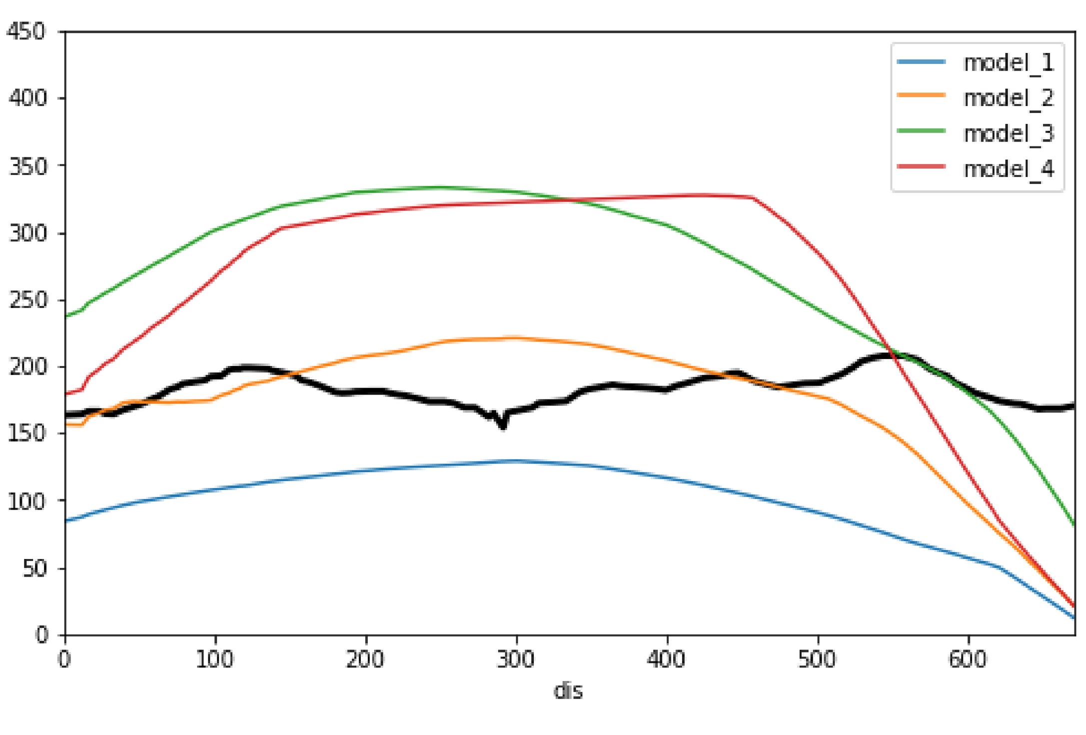


Model 1 has the best correlation, but largest bias; Models 2 and 3 perform best in terms of RMSE and MAD, and Model 4 has lowest bias, but poor correlation.

	composite	1	2	3	4
RMSD	79.02	132.71	92.46	99.84	107.22
MAD	69.54	119.58	80.00	82.12	90.95
R2	0.12	0.59	0.04	0.39	0.06
BIAS	-21.09	-119.58	-34.62	77.65	13.86

Examining the cross profiles shows that measured data is more flat across the glacier than the quasi parabolic cross sections made by the models.

This example is from the lowest cross- profile on Ngozumpa.



Implications

- Local bed thickness in part a function of former glacier state cf. formerly confluent tributary glaciers
- Models of ice thickness need adapting for debris-covered glaciers
- Optimizing models needs more ice thickness data for debris-covered glaciers

Next steps

- An extended version of this analysis will soon be submitted as a Brief Communication to The Cryosphere.
- This field data and new helicopter-borne dataset from British Antarctic Survey from same area → development of improved ice thickness models suitable for estimating ice volumes in the Himalaya.

University of Innsbruck, Bavarian Academy of Sciences, British Antarctic Survey
Austrian Science Fund (FWF) Grant P28521

https://lindseynicholson.org lindsey.nicholson@uibk.ac.at @linznicholson