

Life and death of ice cliffs and lakes on debris covered glaciers - insights form a new dataset



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Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

why ice cliffs and supraglacial lakes?

- a possible explanation for more rapid ablation of debris covered tongues than initially expected (Gardelle et al. 2012/2013, Scherler et al. 2011)
- indication of subglacial drainage patterns (Gulley and Benn, 2007)
- an indication of the glacier's state?

we have come a long way ...

- ... from no mention of ice cliffs or lakes on debris covered glaciers (Mattson et al. in *1980s*) to first notes and measurements (Sakai et al. *1998*, Benn et al. *1999*) and still minor significance in Hambrey et al. *2008*

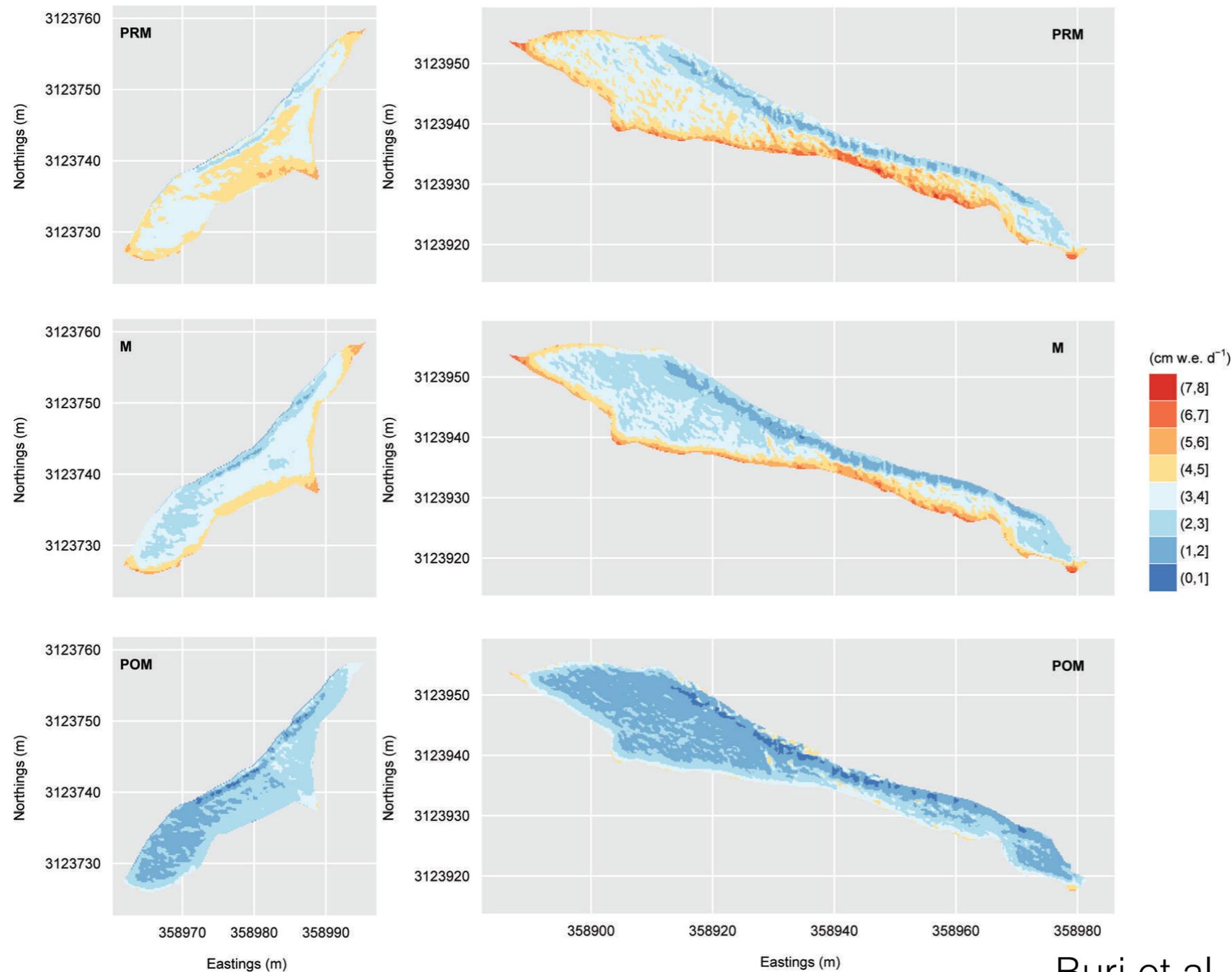
during the authors' pre-monsoon visit in 2003, a time of little surface melting, were characterised by scattered, commonly frozen, small ponds (Figs. 8c and 11a). Some ponds had near-vertical cliffs several metres high revealing debris bands. Occasionally debris was observed to fall from the cliff edge or the debris bands, indicating some melt-back. Undercutting of the base of ice cliffs in one of the larger ponds on Lhotse Glacier resulted in calving of several metre-high blocks (Fig. 8c). Few prominent supraglacial streams were evident, but englacial drainage was illustrated by seepage through the lower right-lateral moraine of Khumbu Glacier, suggesting
- ... to specific energy balance studies (Sakai et al. *2002*, Reid and Brock *2014*, Steiner et al. *2015*, Buri et al. *2016*) and dedicated observations

today we are at the point scale ...



Steiner et al. 2015
Reid et al. 2014
Sakai et al. 1998/2000

and with still some uncertainties at the cliff scale ...



Buri et al., Annals of Glaciology, 2016

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A high-altitude mountain landscape featuring a rocky, scree-covered slope in the foreground. Several large, irregular patches of snow are scattered across the terrain, some appearing to be remnants of a glacier or snowfield. The background shows more rugged, snow-dusted mountain peaks under a clear sky. The overall scene is desolate and mountainous.

what about the glacier and catchment scale ...

-> Posters today by
Pascal Buri (X3.271 on cliffs)
Evan Miles (X3.266 on lakes)

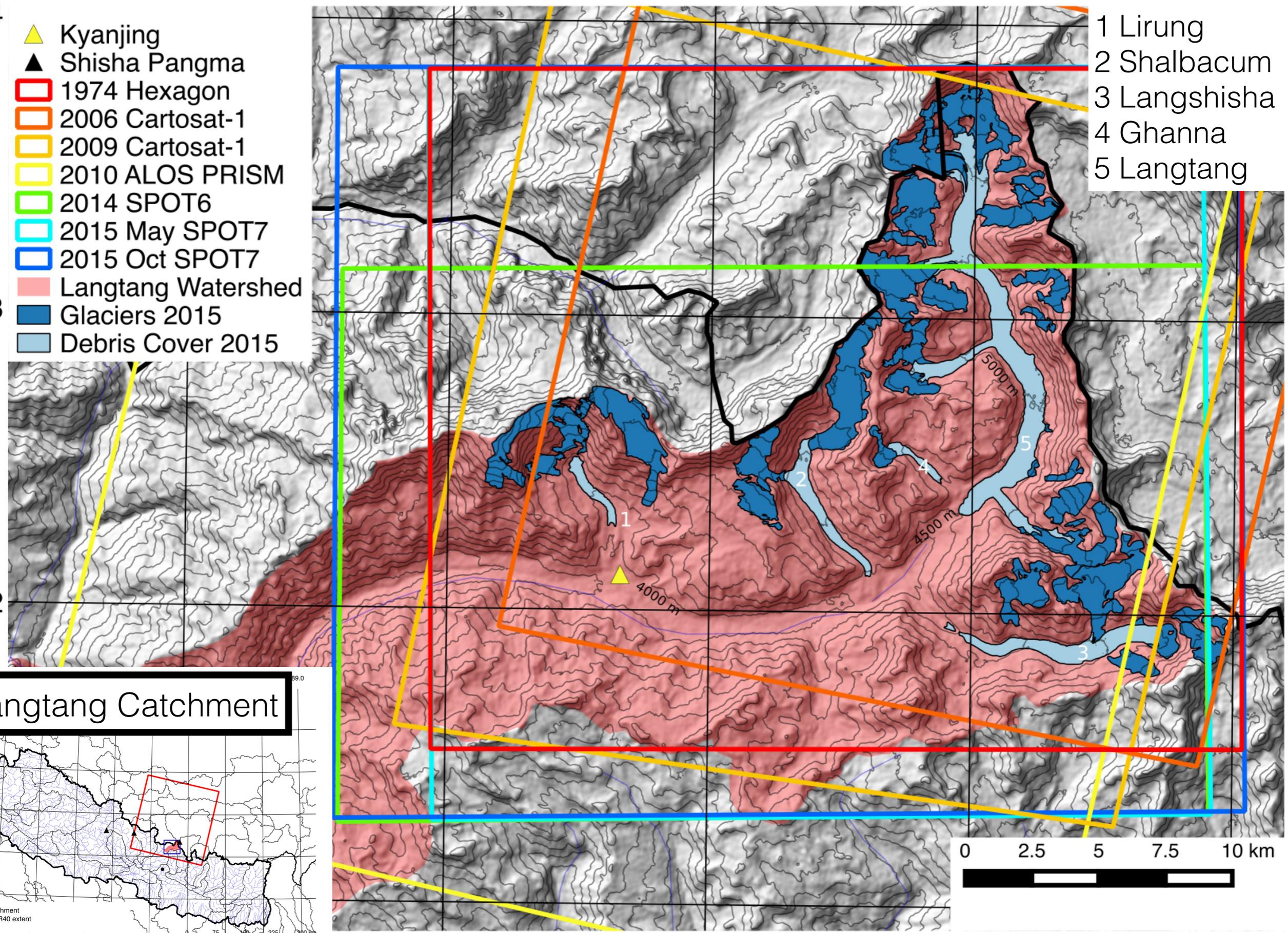
28.4

- ▲ Kyanjing
- ▲ Shisha Pangma
- ▭ 1974 Hexagon
- ▭ 2006 Cartosat-1
- ▭ 2009 Cartosat-1
- ▭ 2010 ALOS PRISM
- ▭ 2014 SPOT6
- ▭ 2015 May SPOT7
- ▭ 2015 Oct SPOT7
- ▭ Langtang Watershed
- ▭ Glaciers 2015
- ▭ Debris Cover 2015

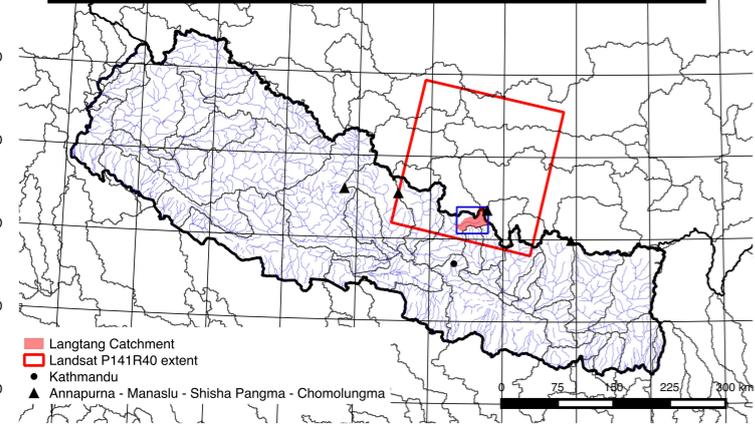
28.3

28.2

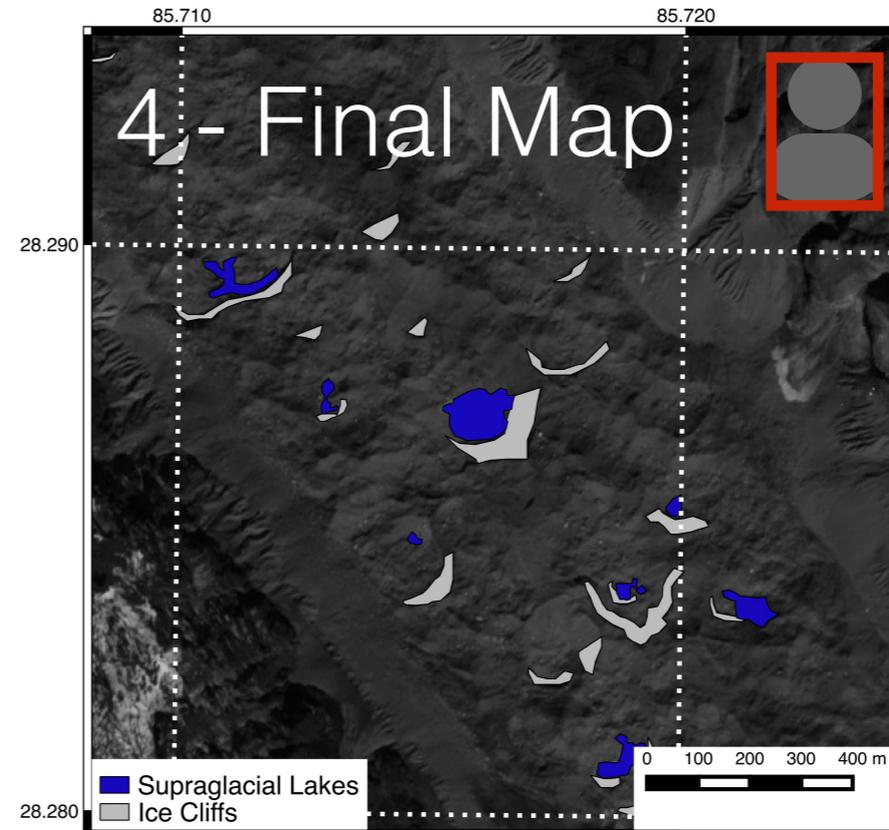
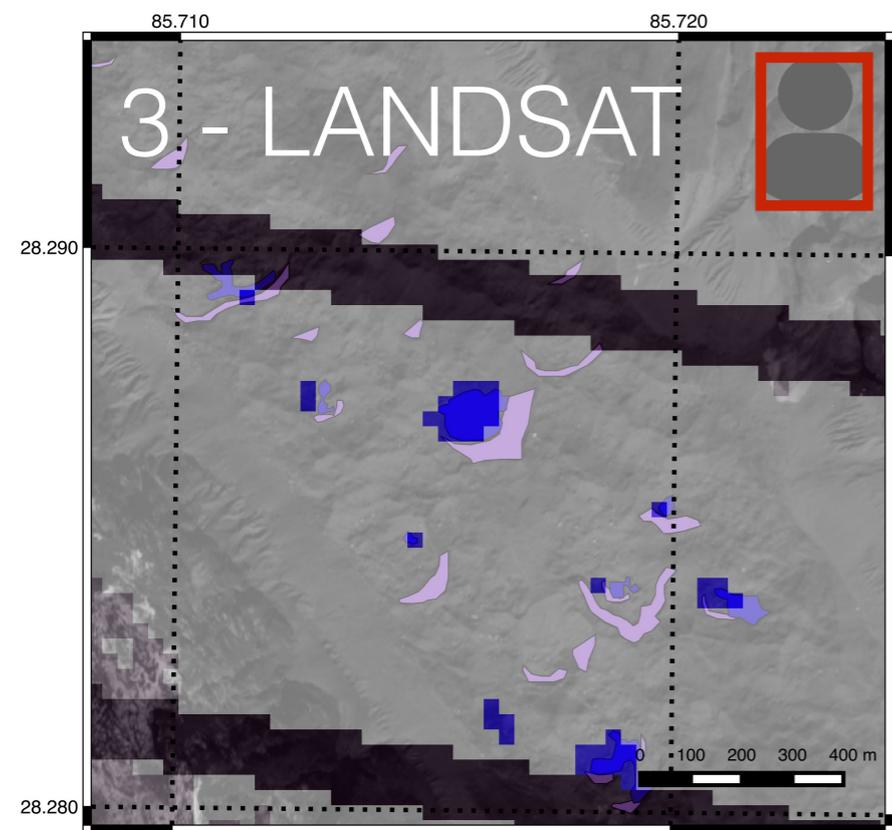
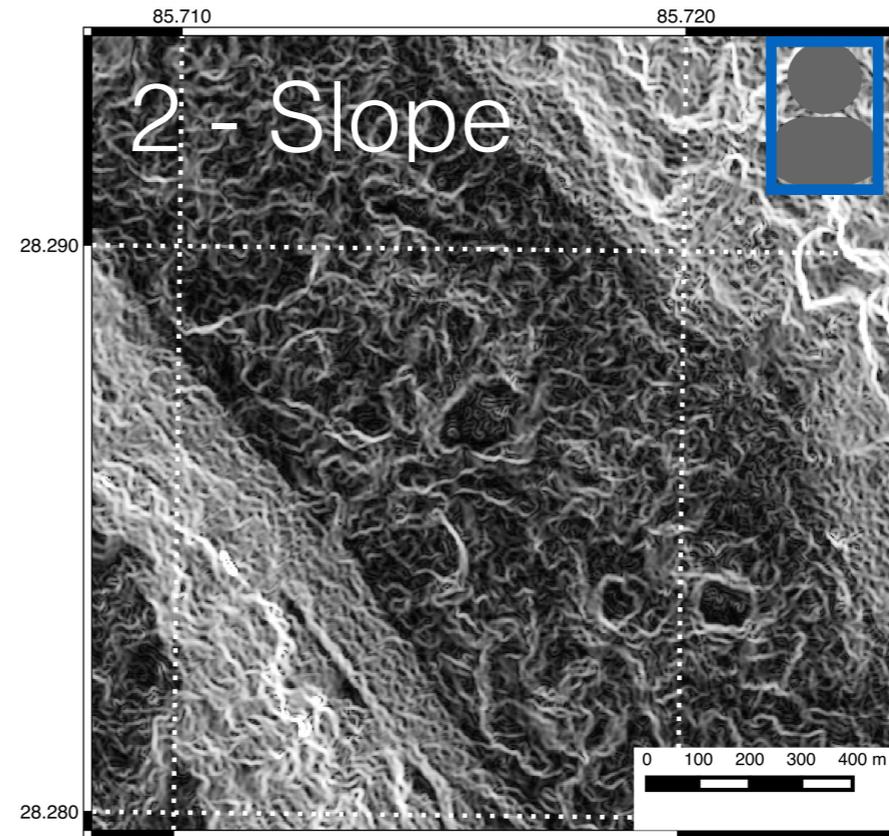
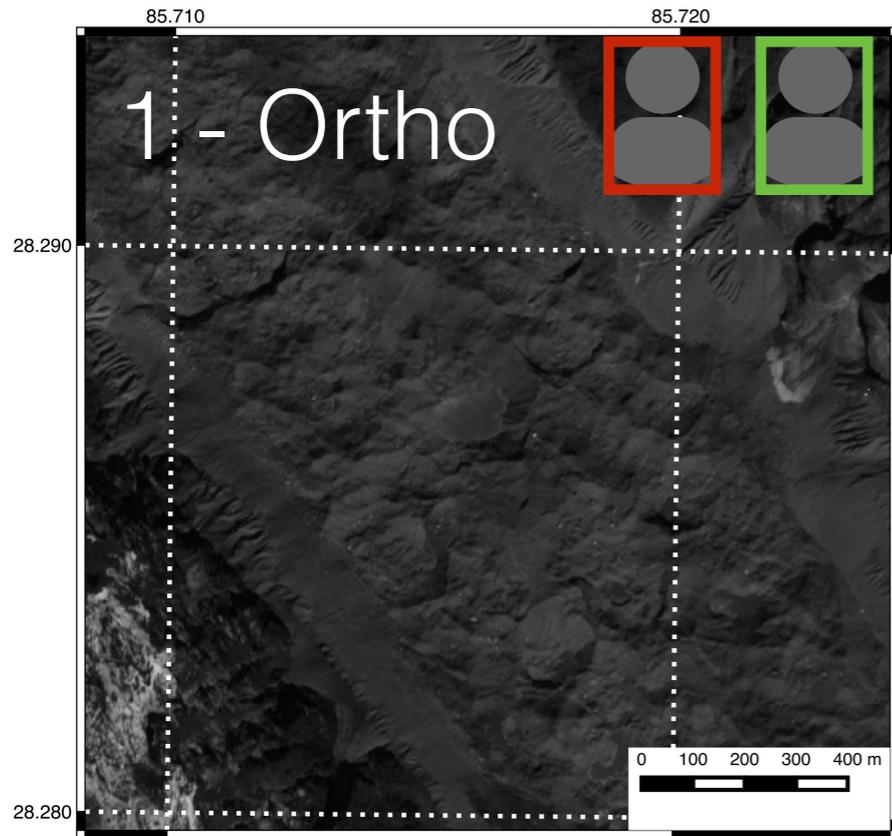
- 1 Lirung
- 2 Shalbacum
- 3 Langshisha
- 4 Ghanna
- 5 Langtang



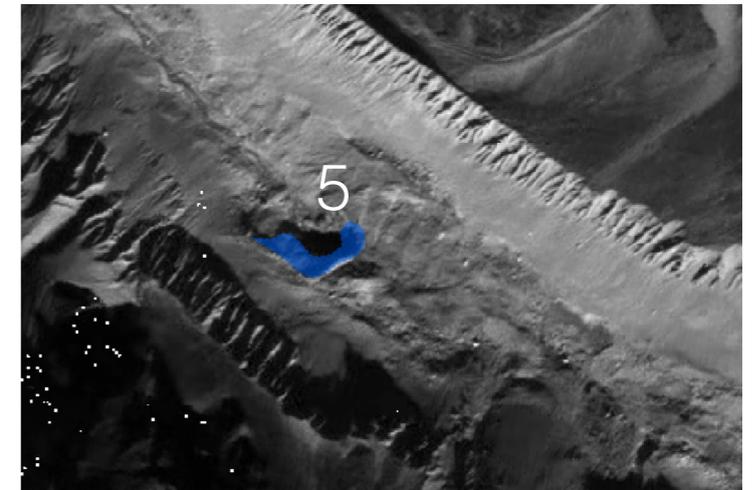
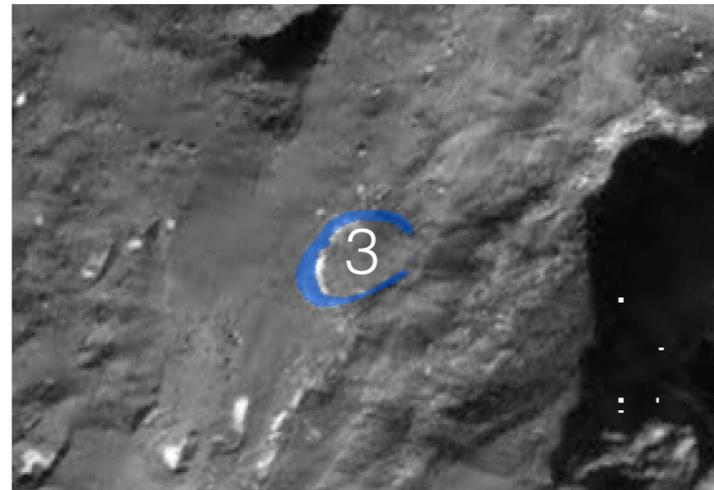
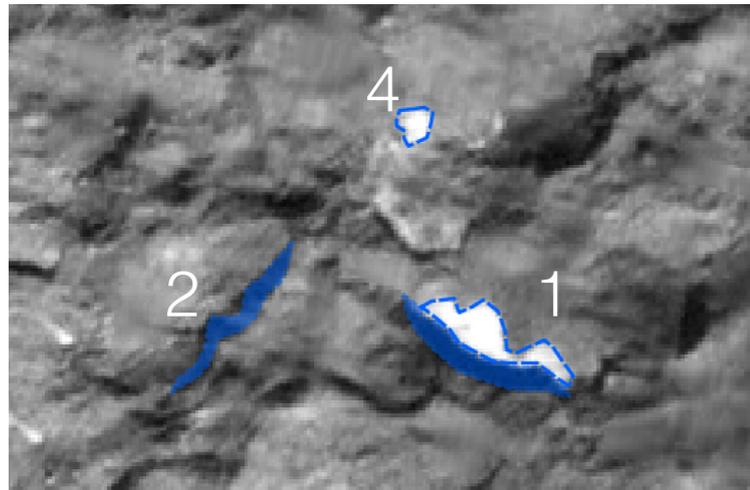
Langtang Catchment



Classification of Cliffs and Lakes

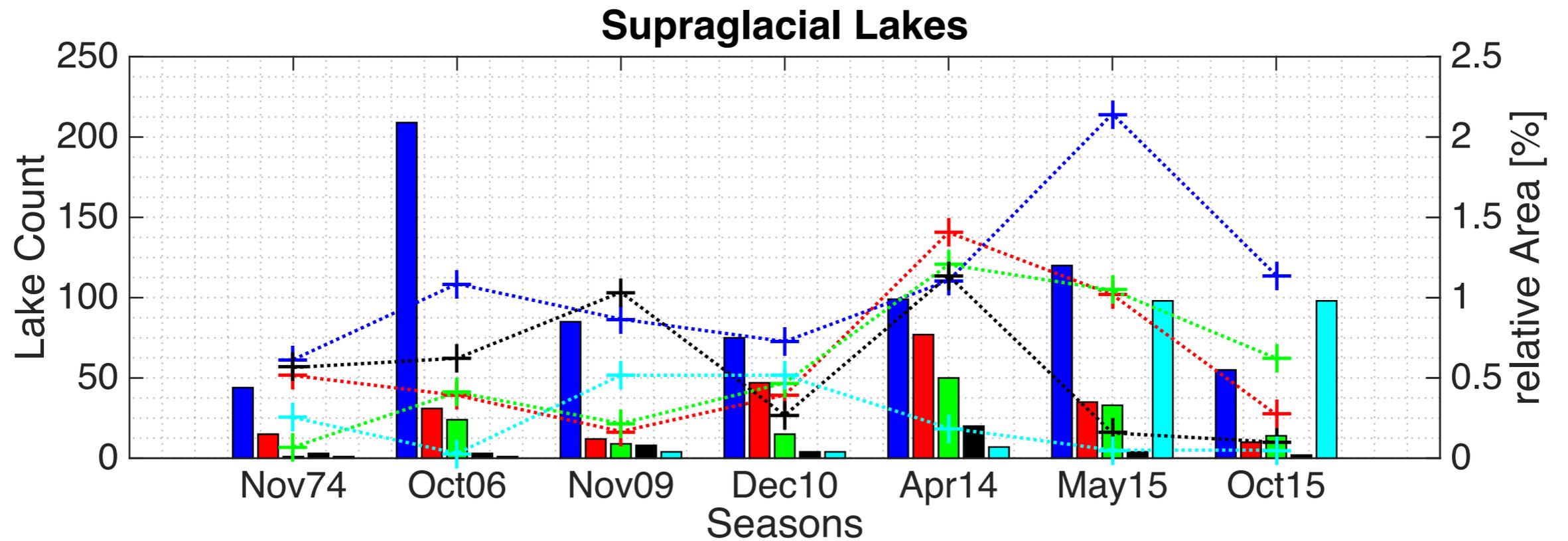
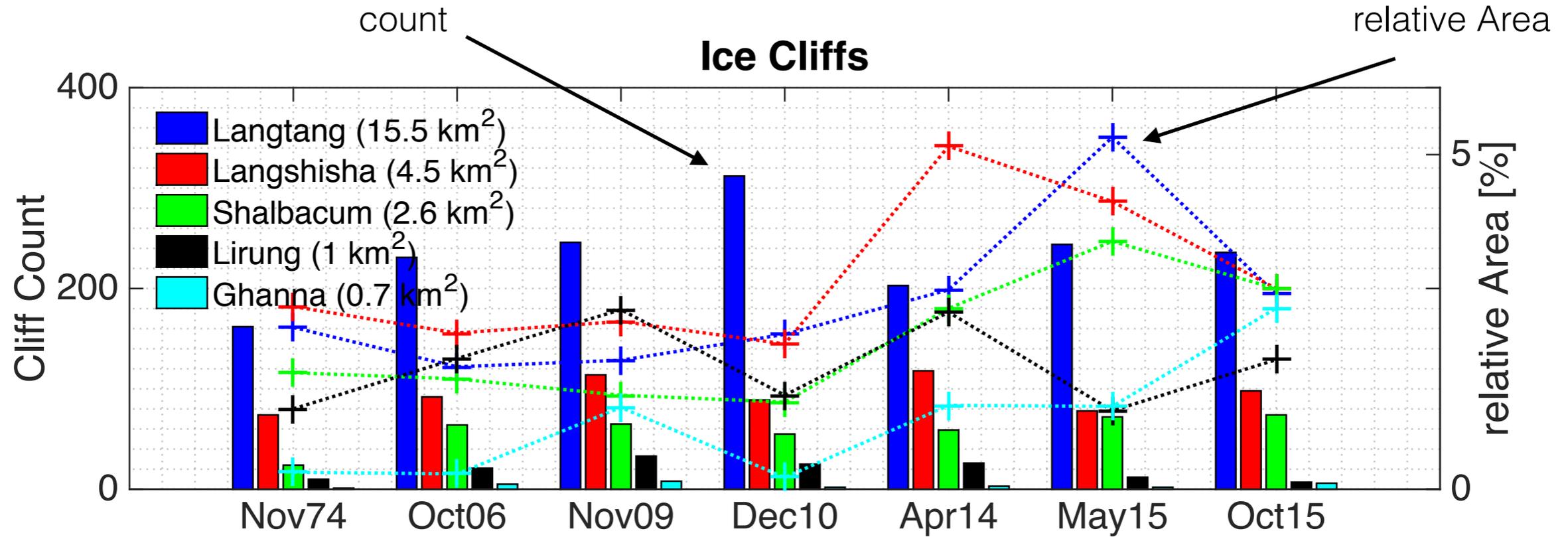


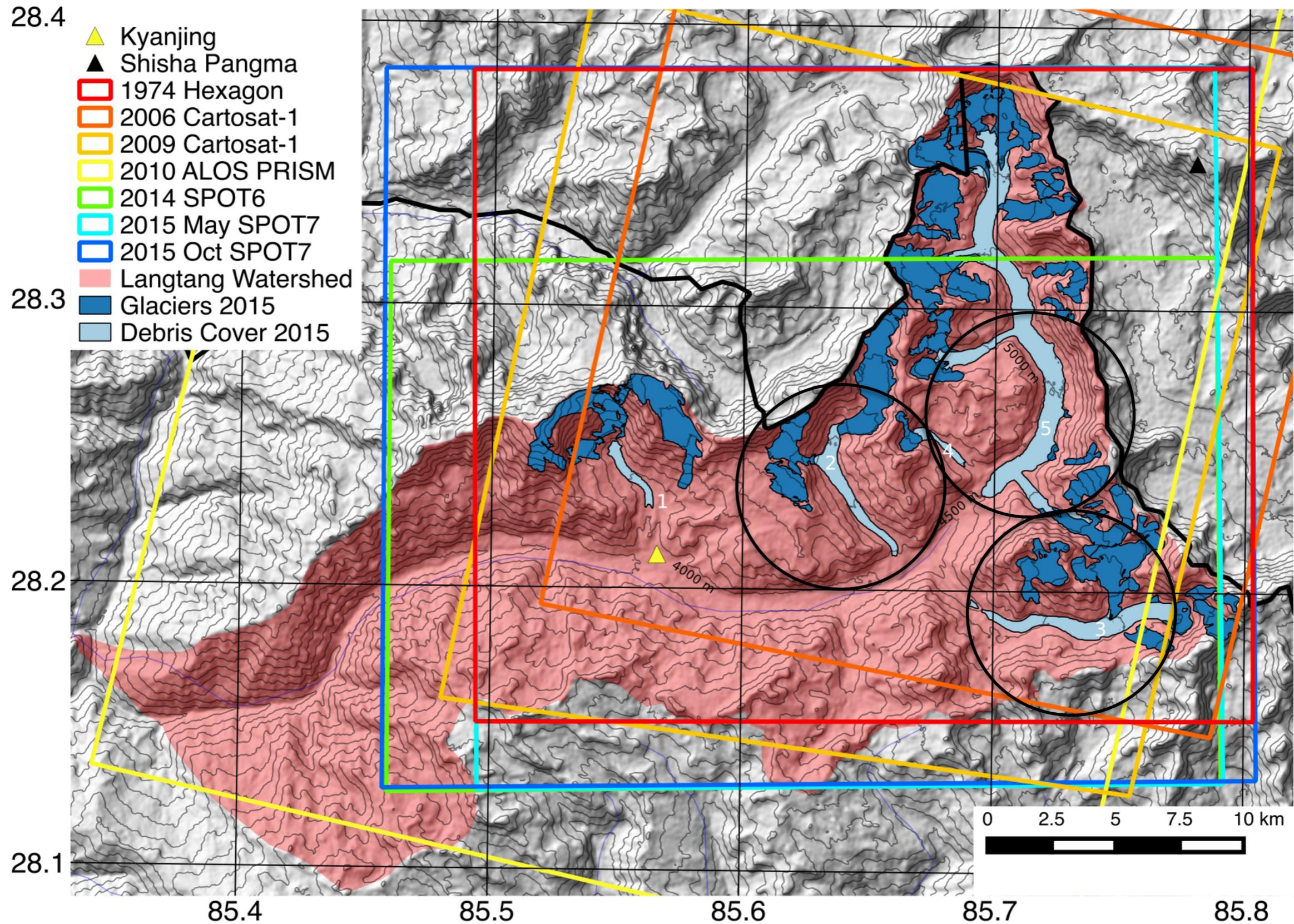
Classification of Cliffs and Lakes



- Lateral/Longitudinal Cliff with (1) / without lake (2)
- Circular Cliff with / without lake (3)
- Lake with / without (4) respective Cliff Type
- Terminal Cliffs / Lake (5)

400 cliffs / season
100 - 200 lakes / season





28.4

28.3

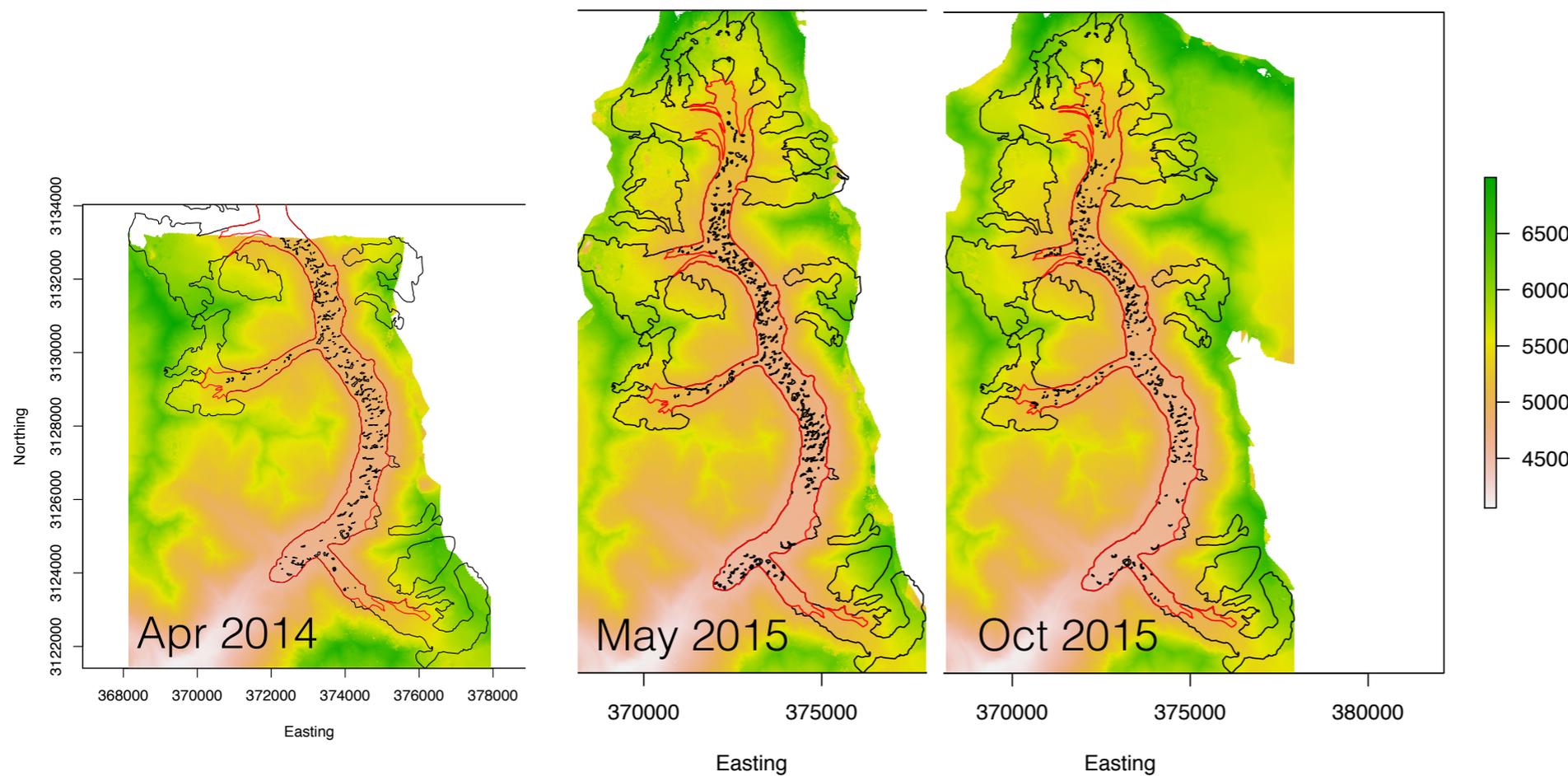
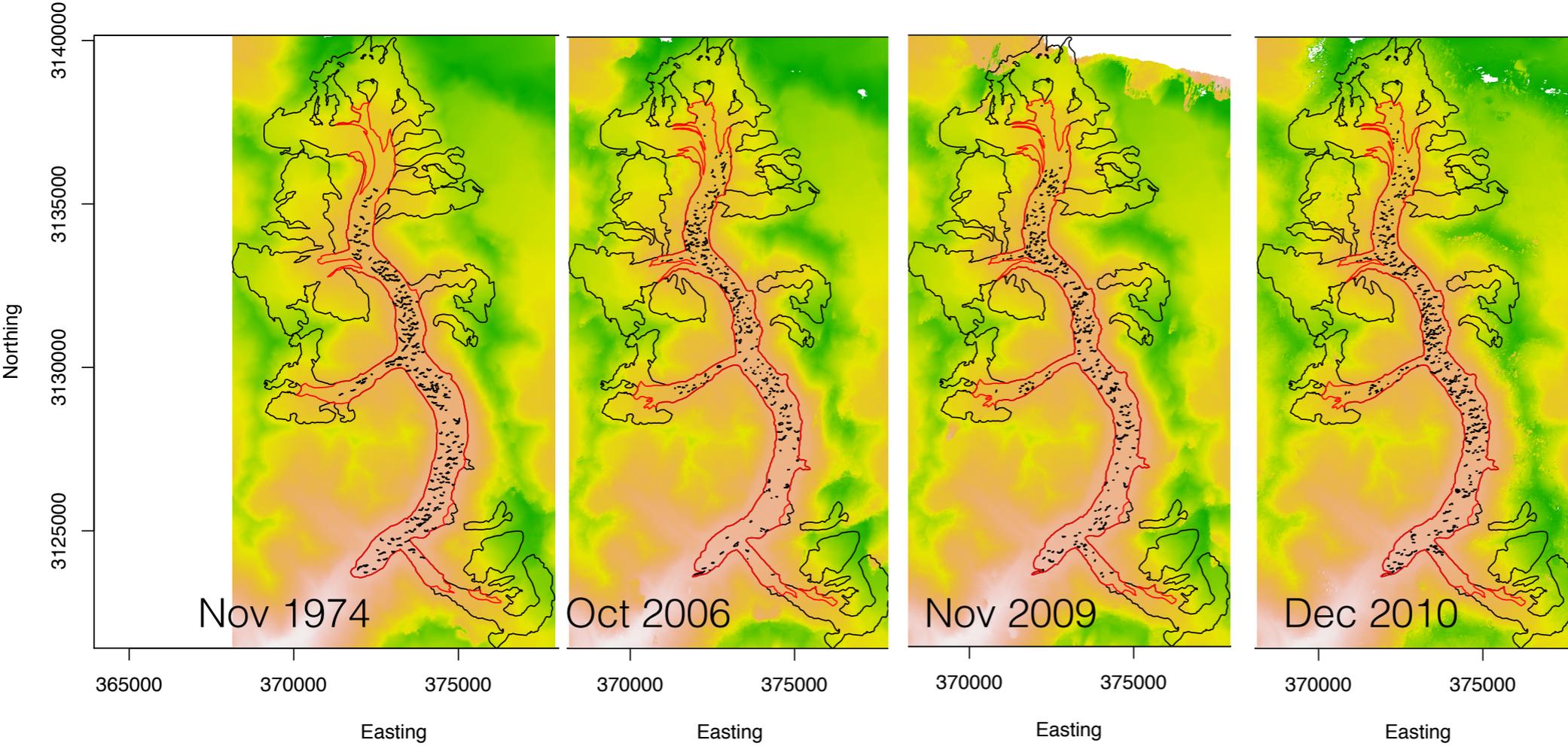
28.2

28.1

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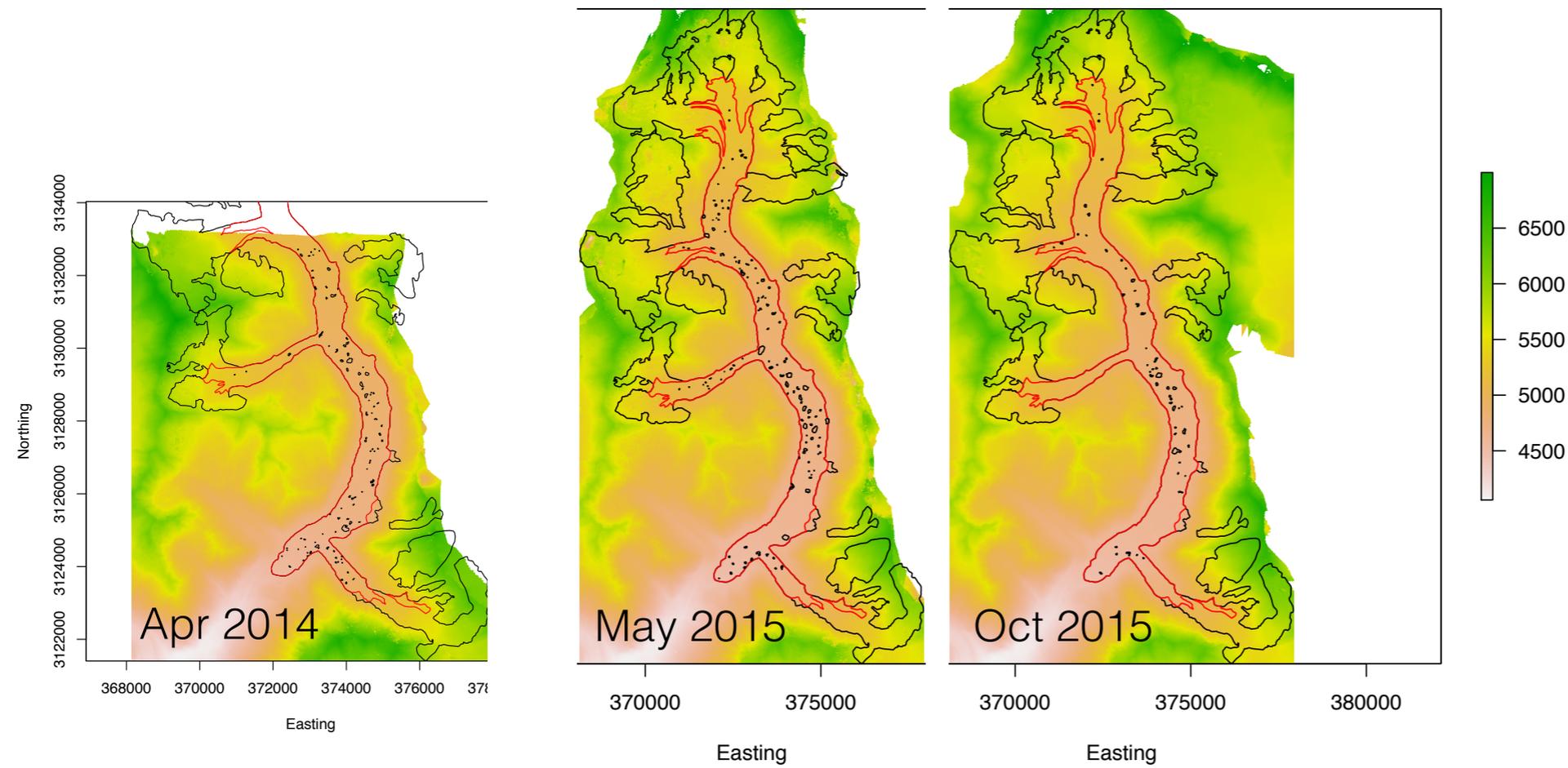
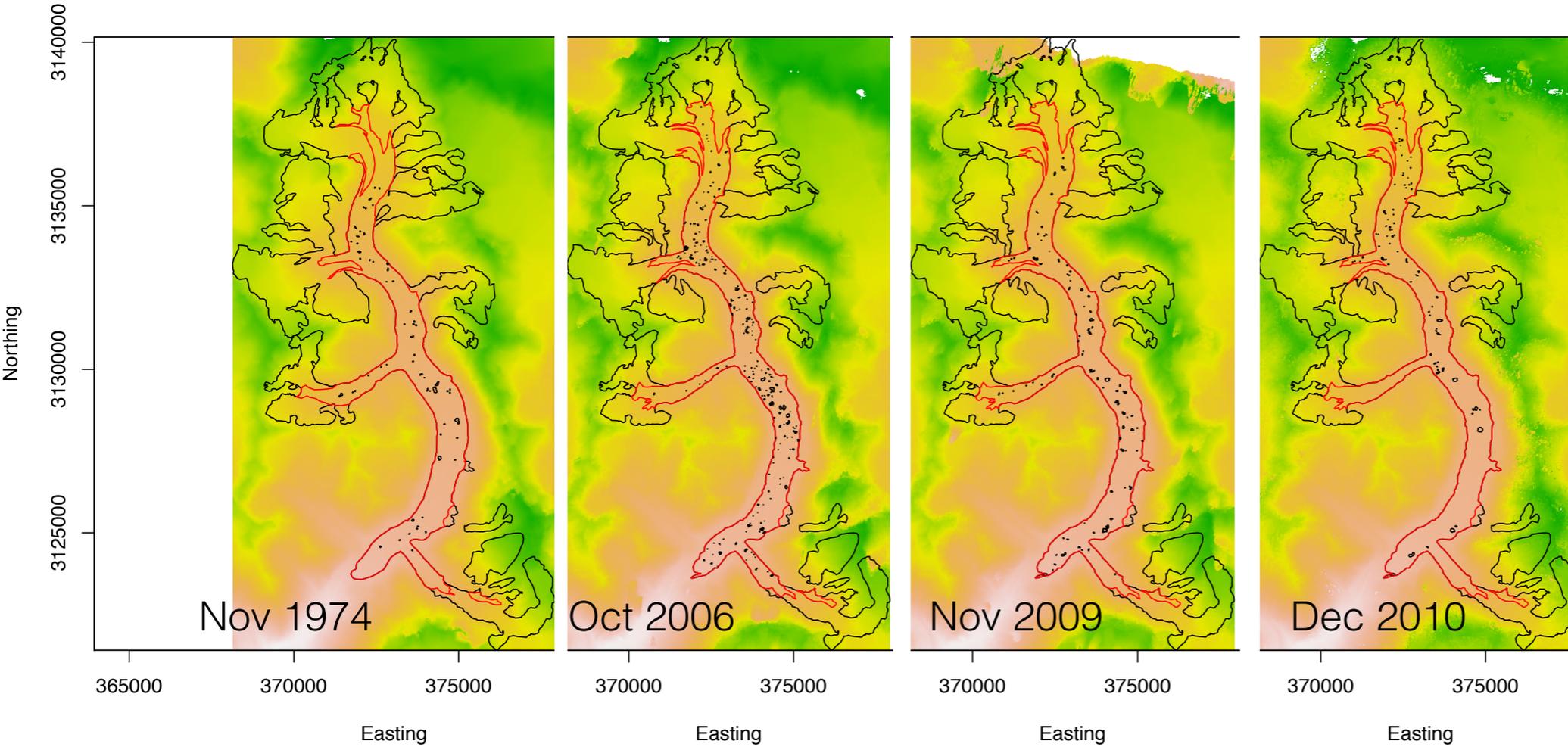
Cliffs

- strong spatial variability
- no clear seasonal variability

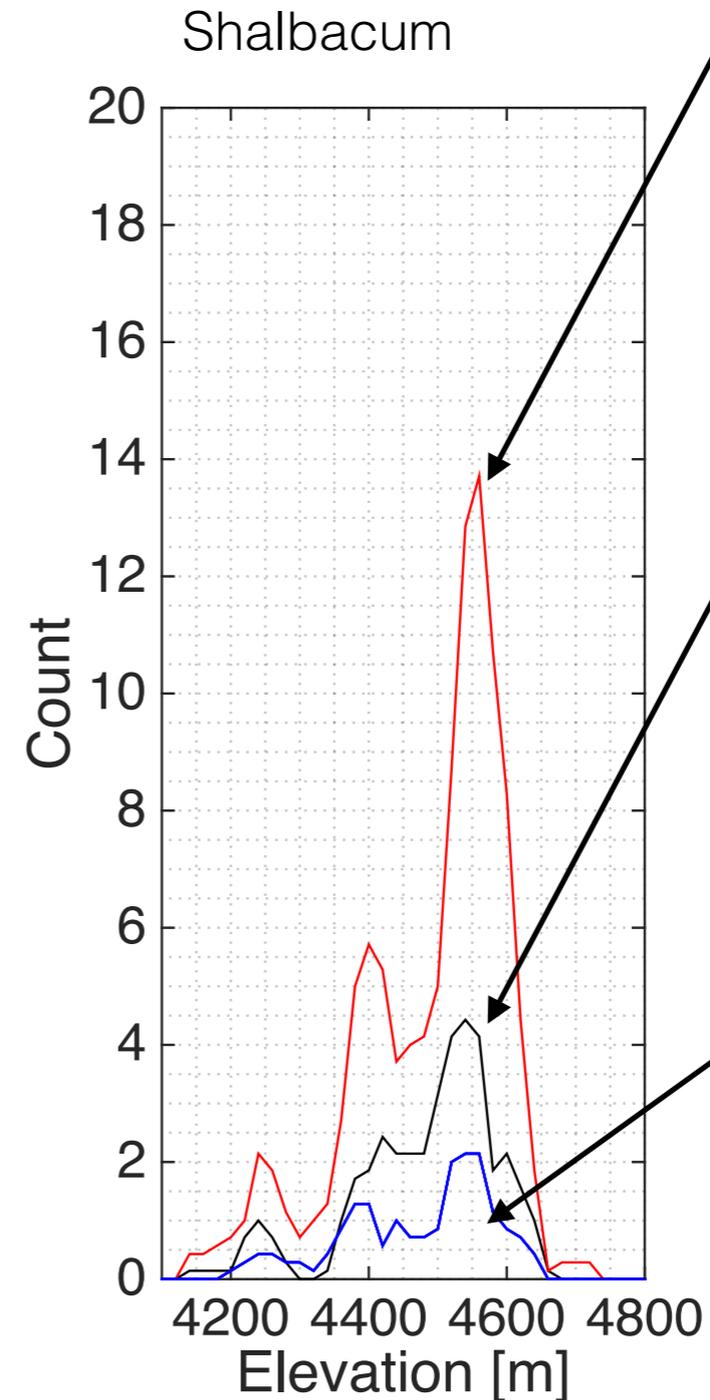
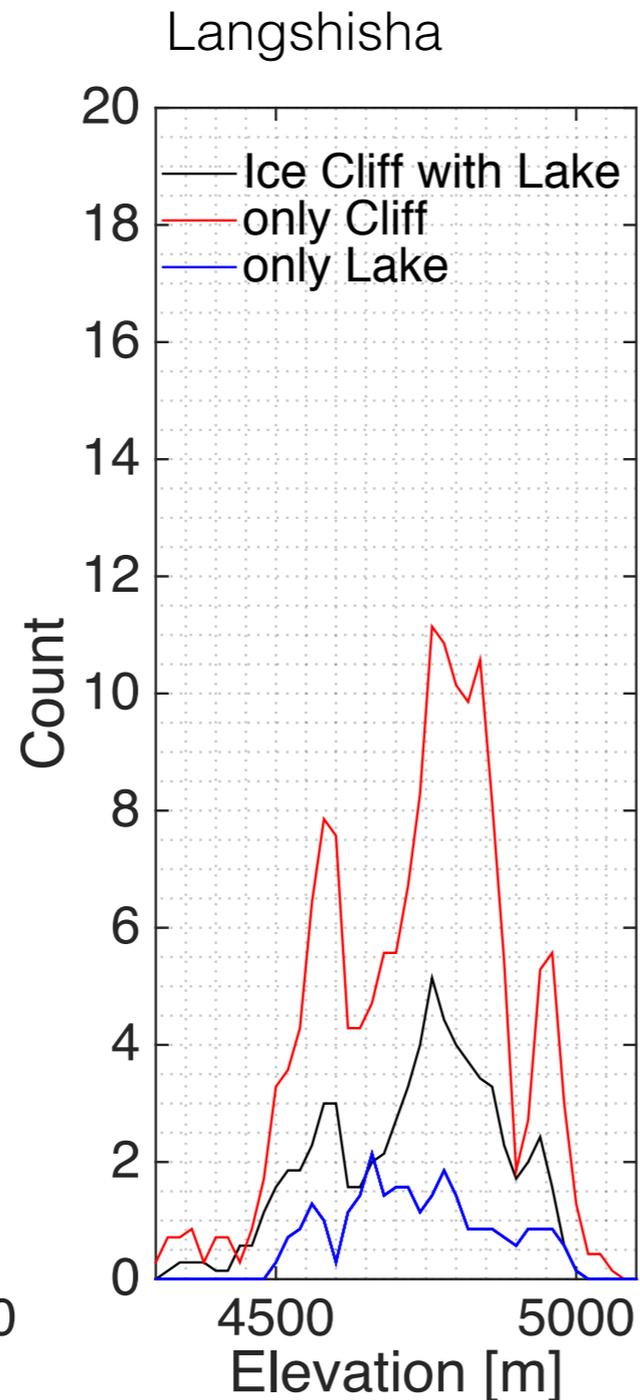
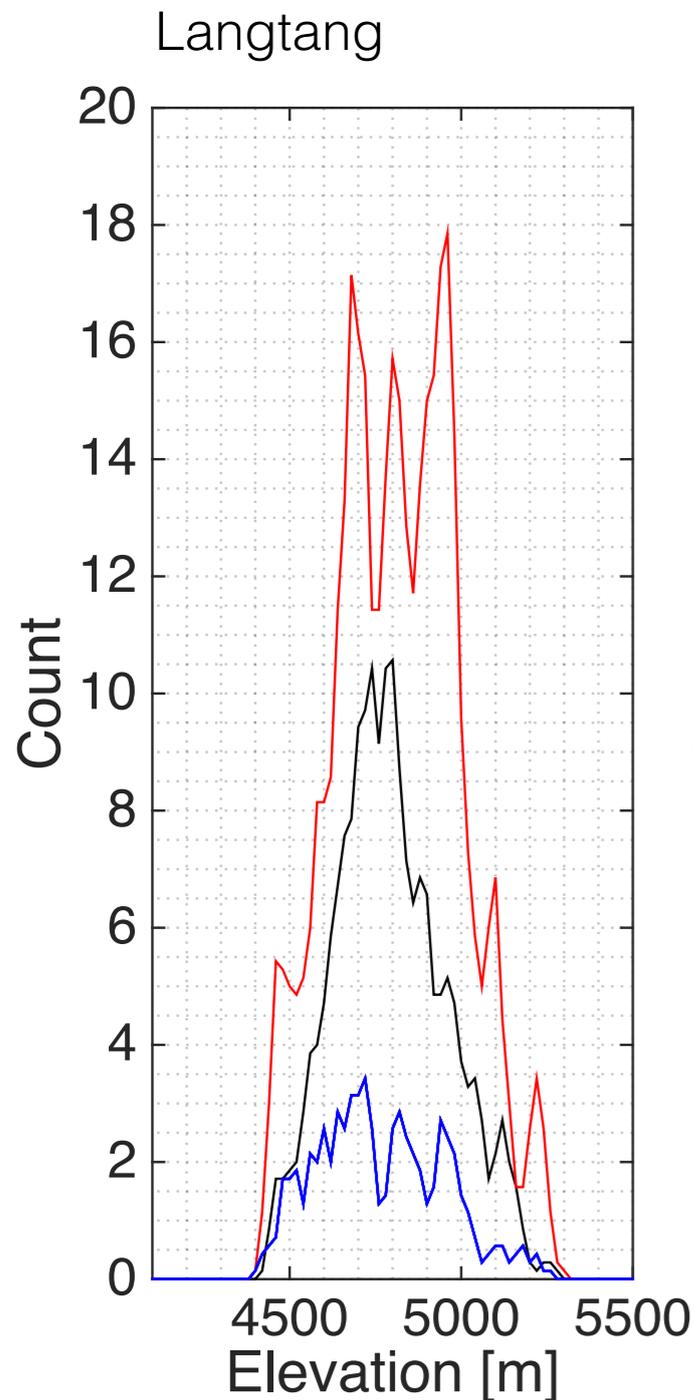


Lakes

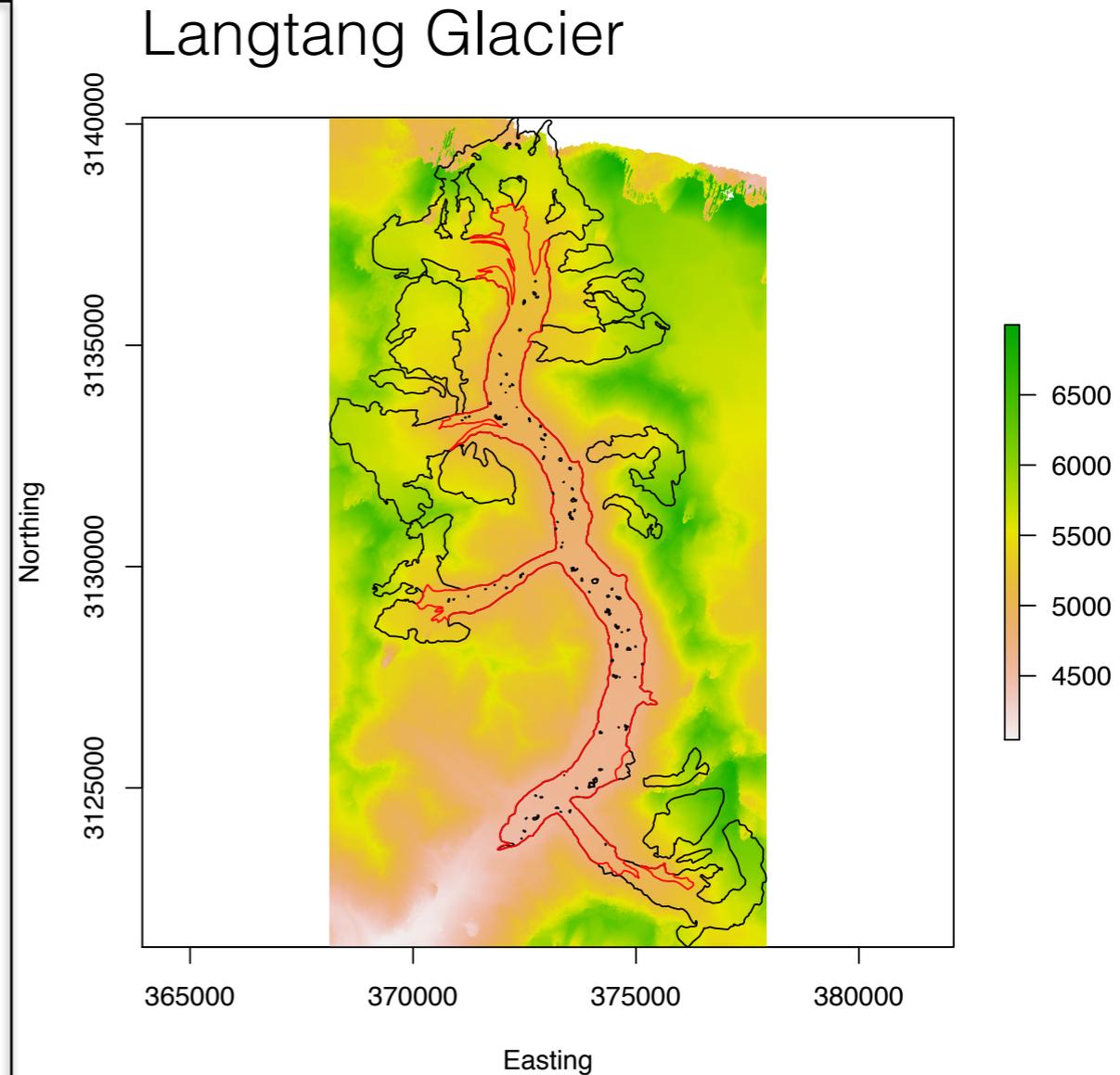
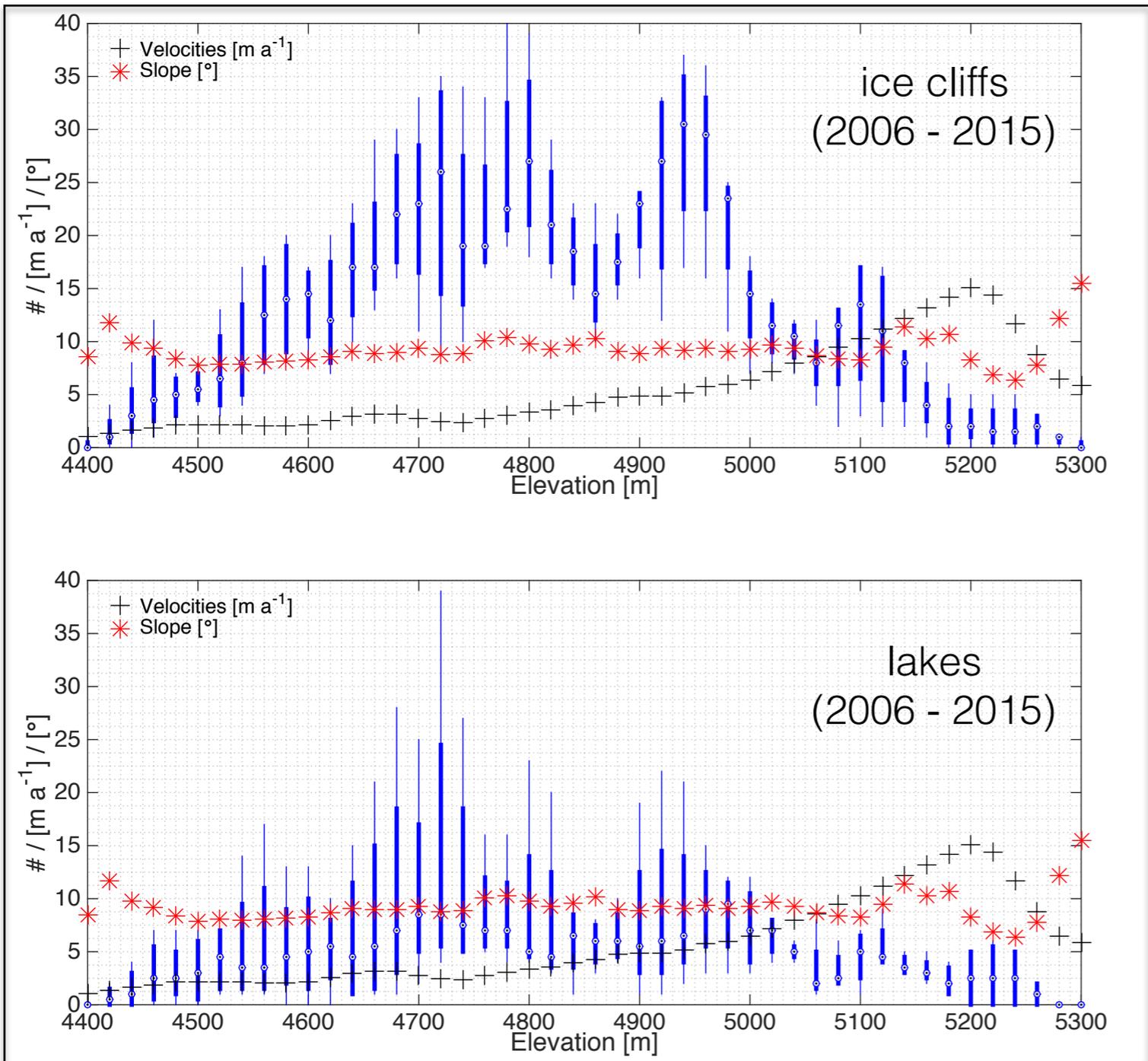
- strong seasonal variability
- difficult to extract spatial trend



Elevation Distribution of Cliff/Lake Features

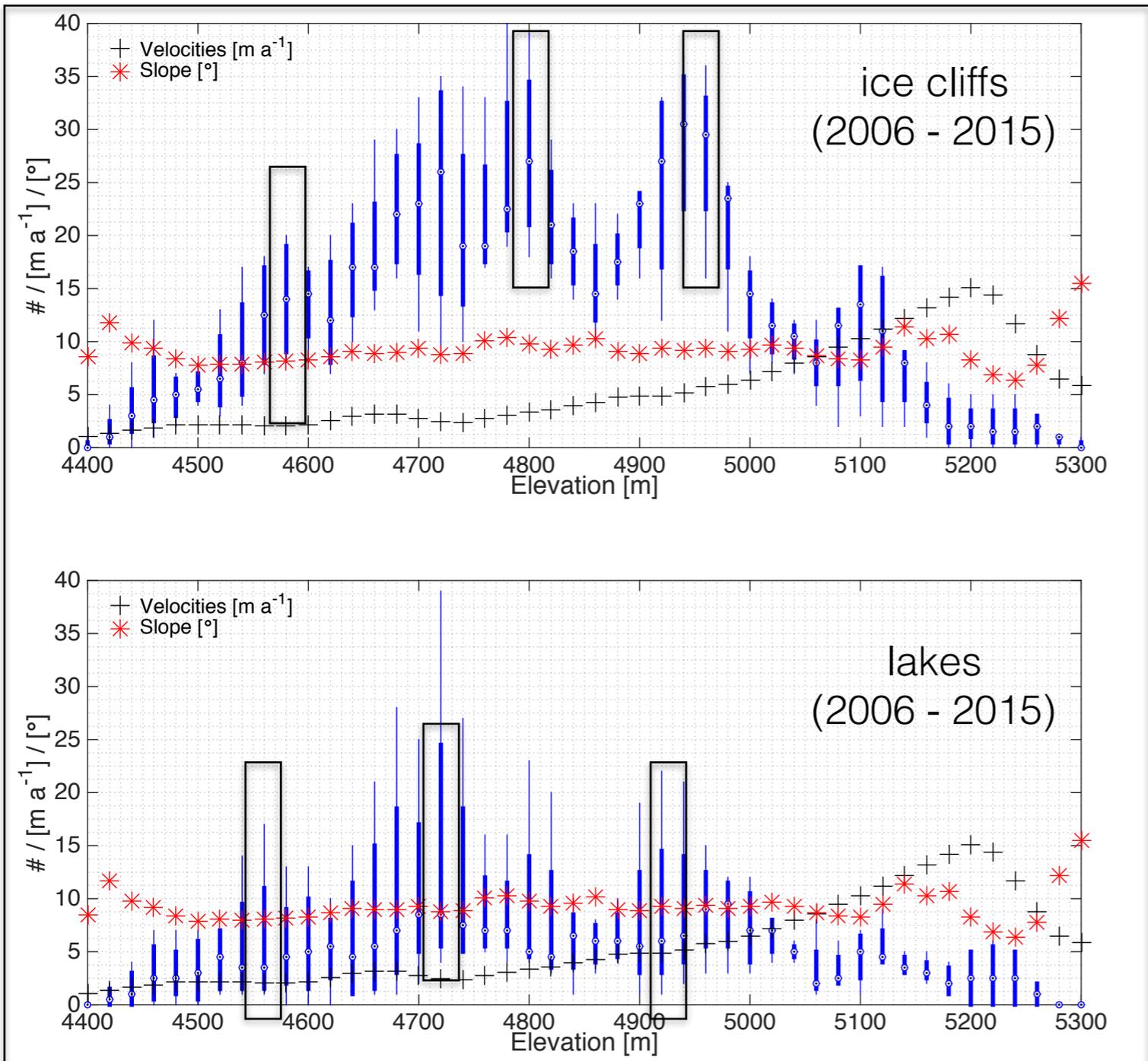


where do ice cliffs and lakes appear?

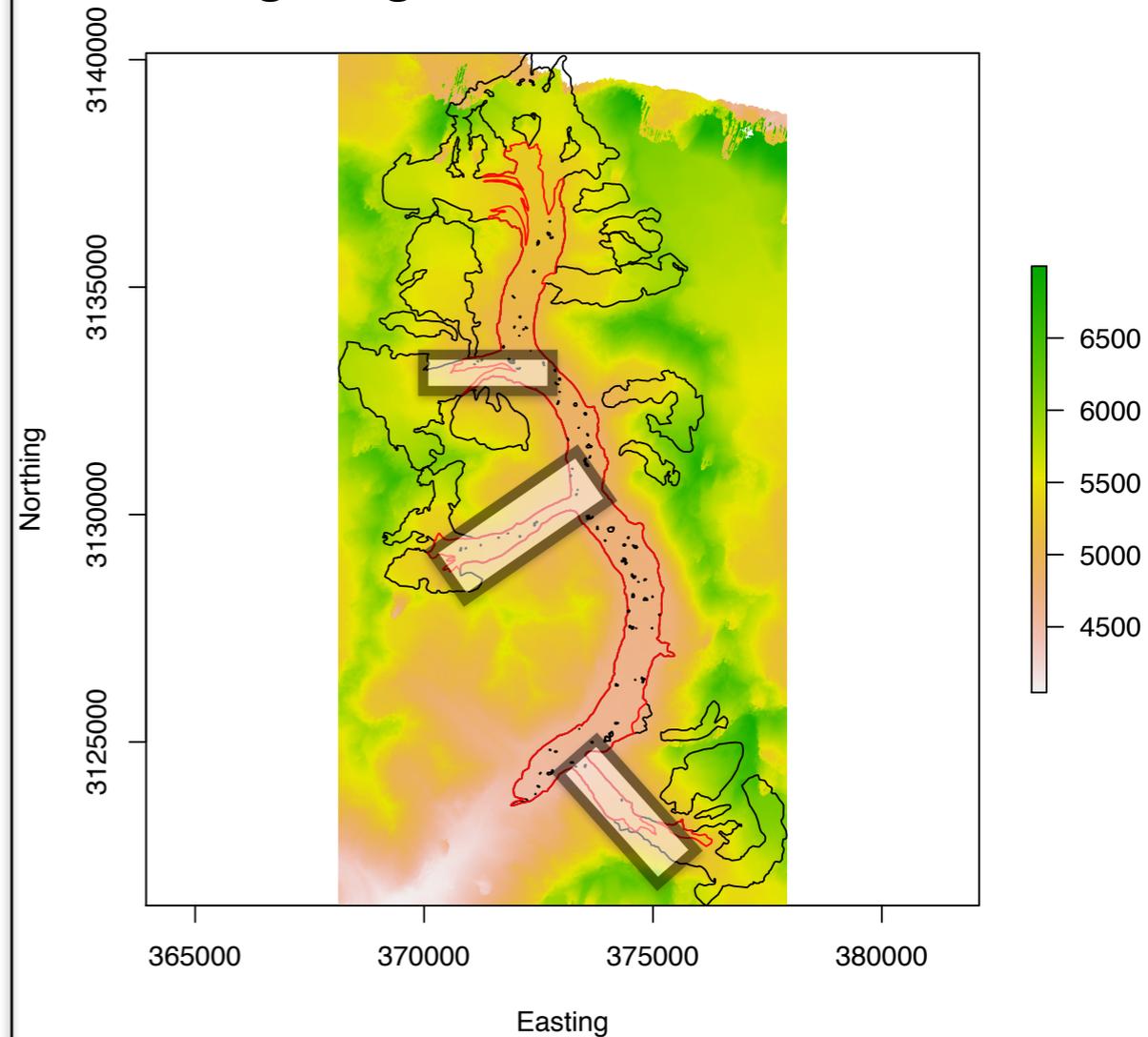


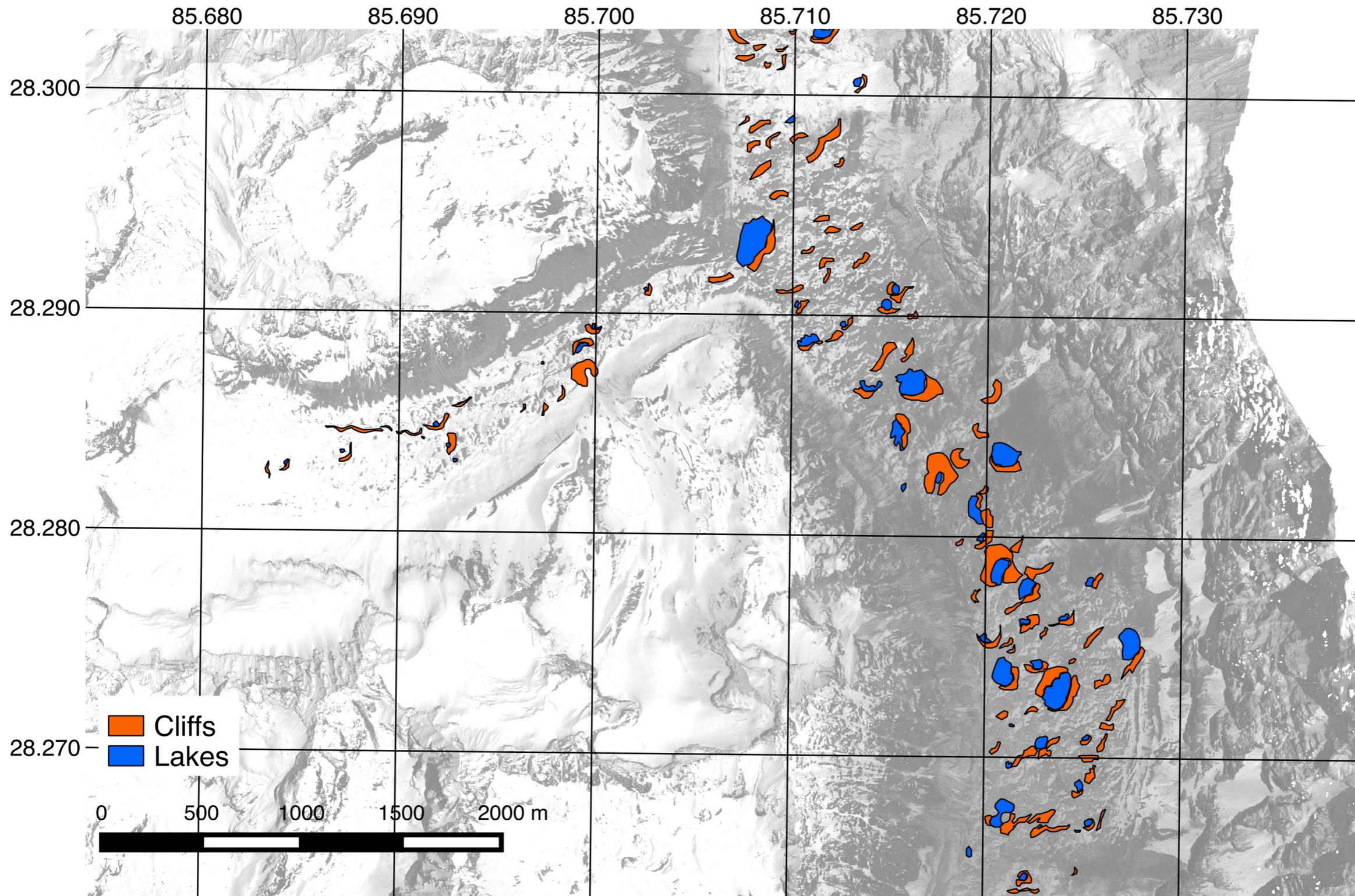
- tributary glaciers and increased hydrological activity

tributaries glaciers



Langtang Glacier

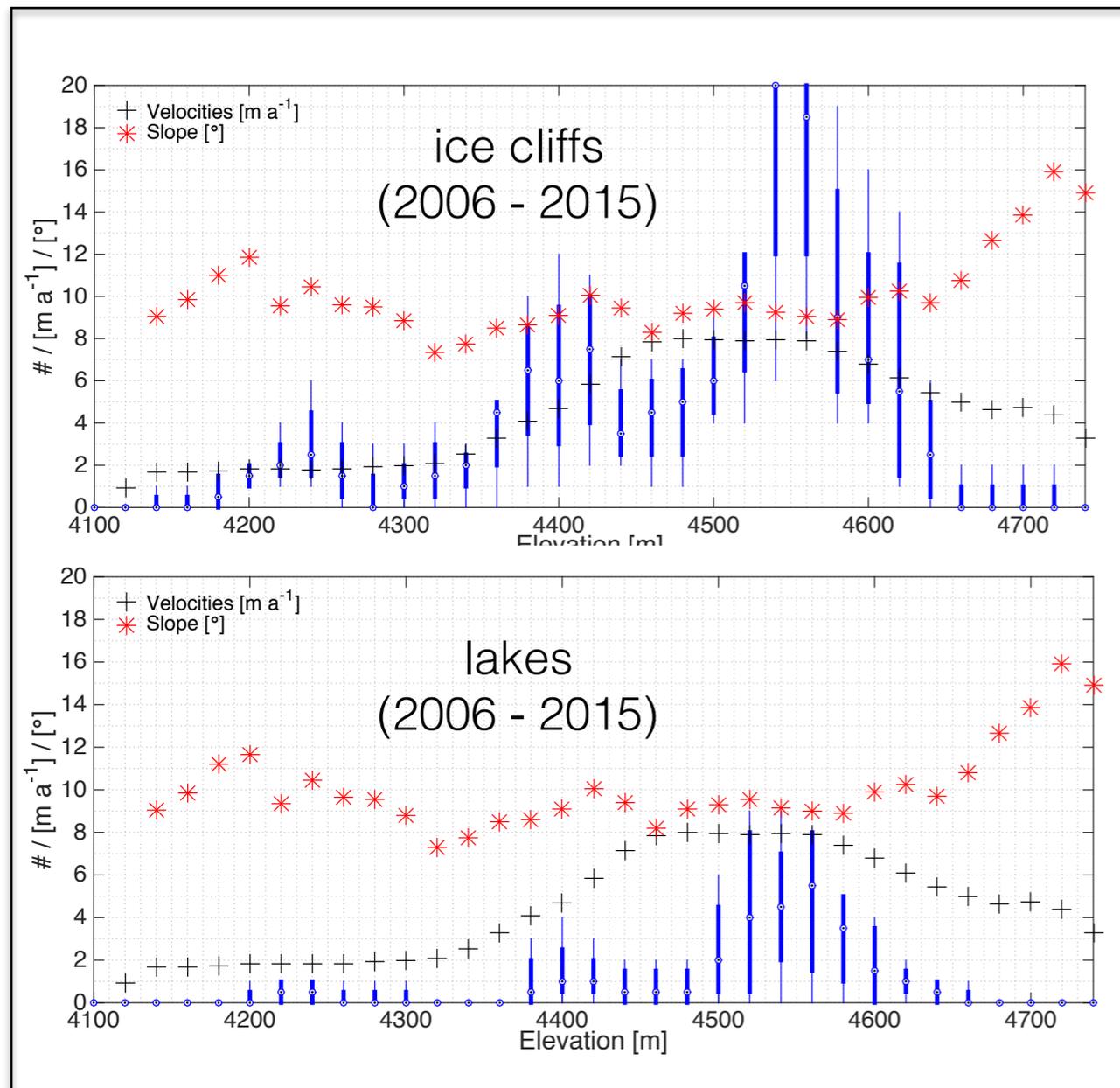




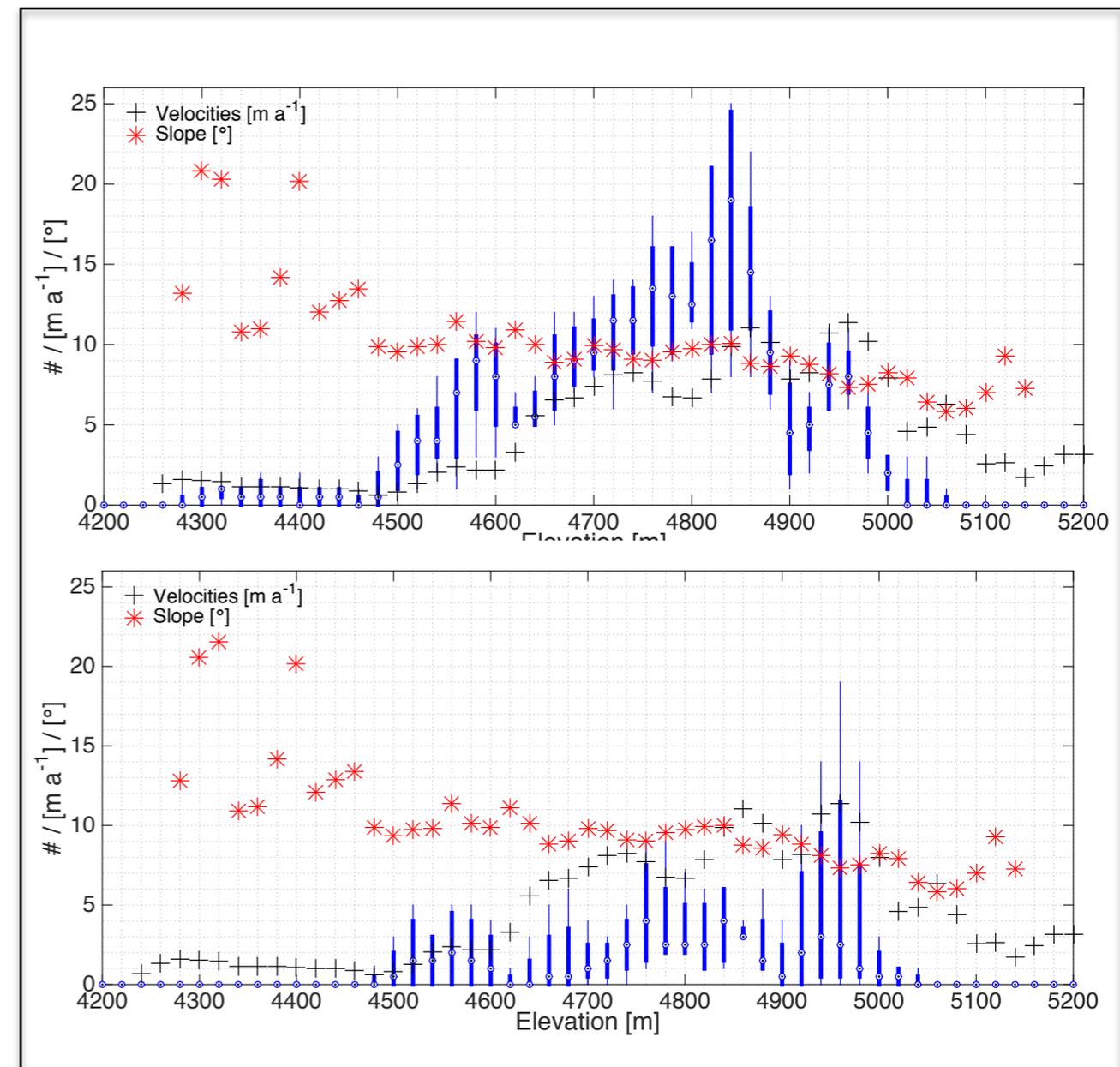
Langtang and tributary, May 2015

- velocities and mean surface slope
- smaller glaciers, higher variability in velocities

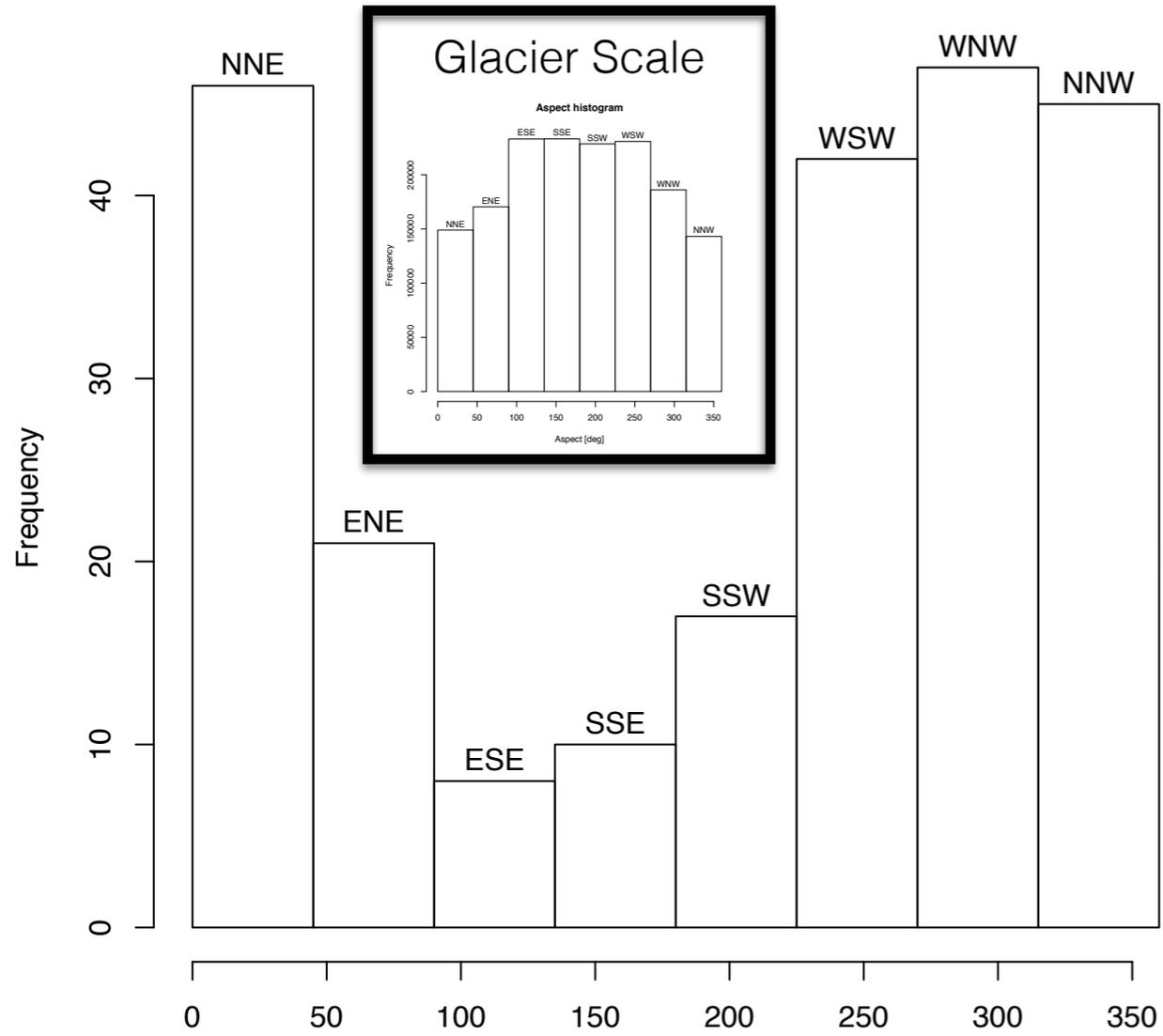
Langshisha Glacier



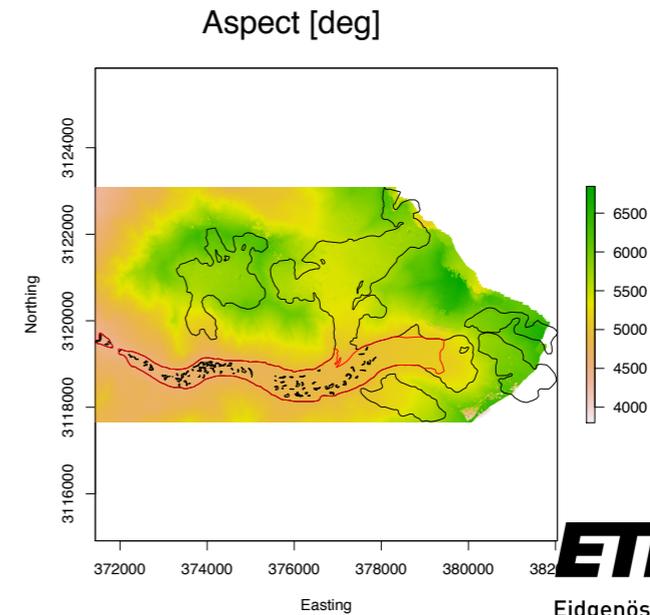
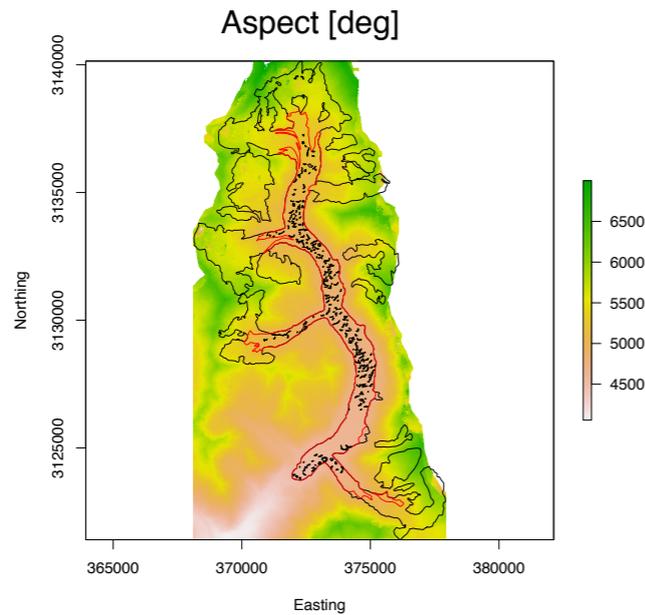
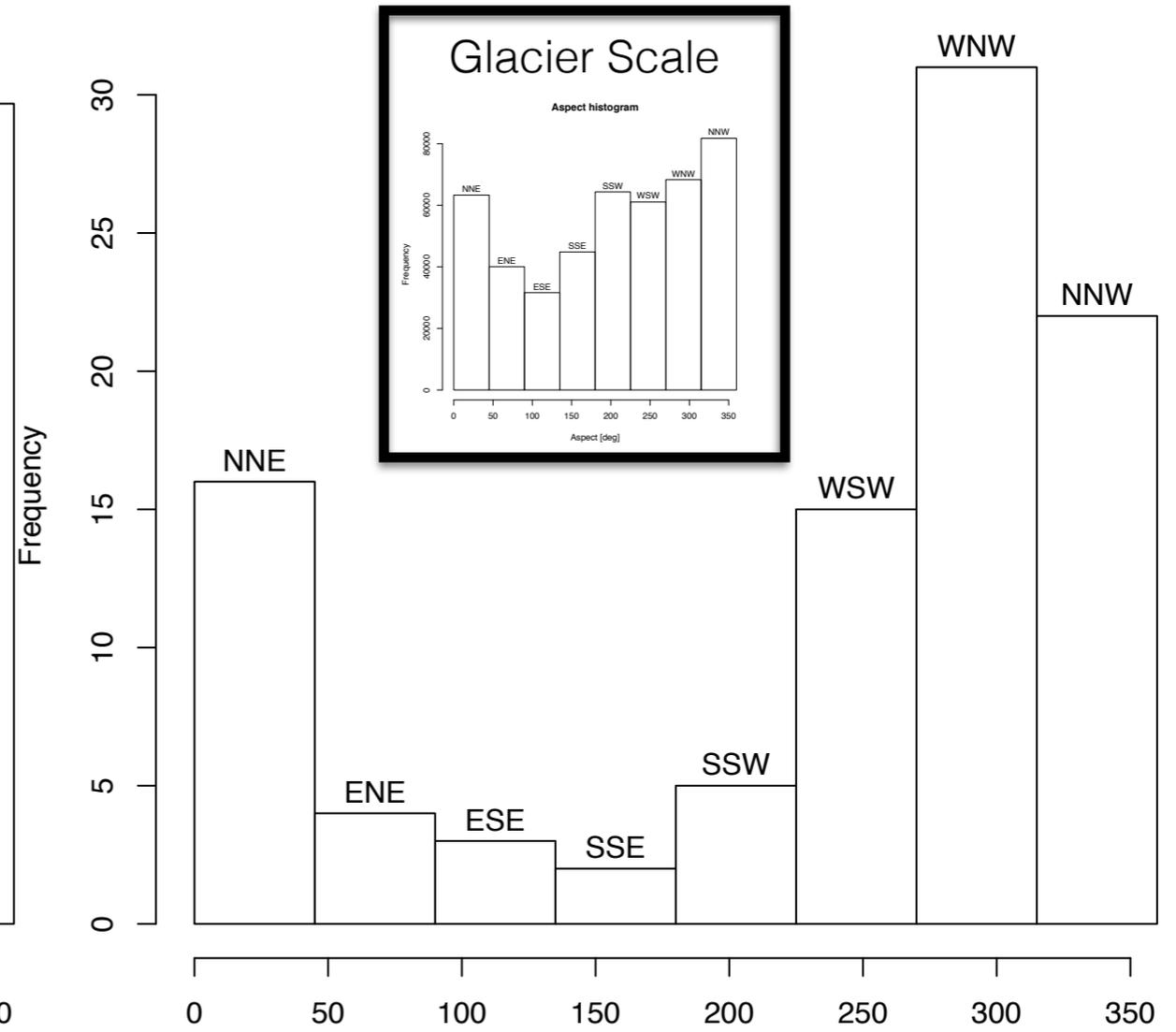
Shalbacum Glacier

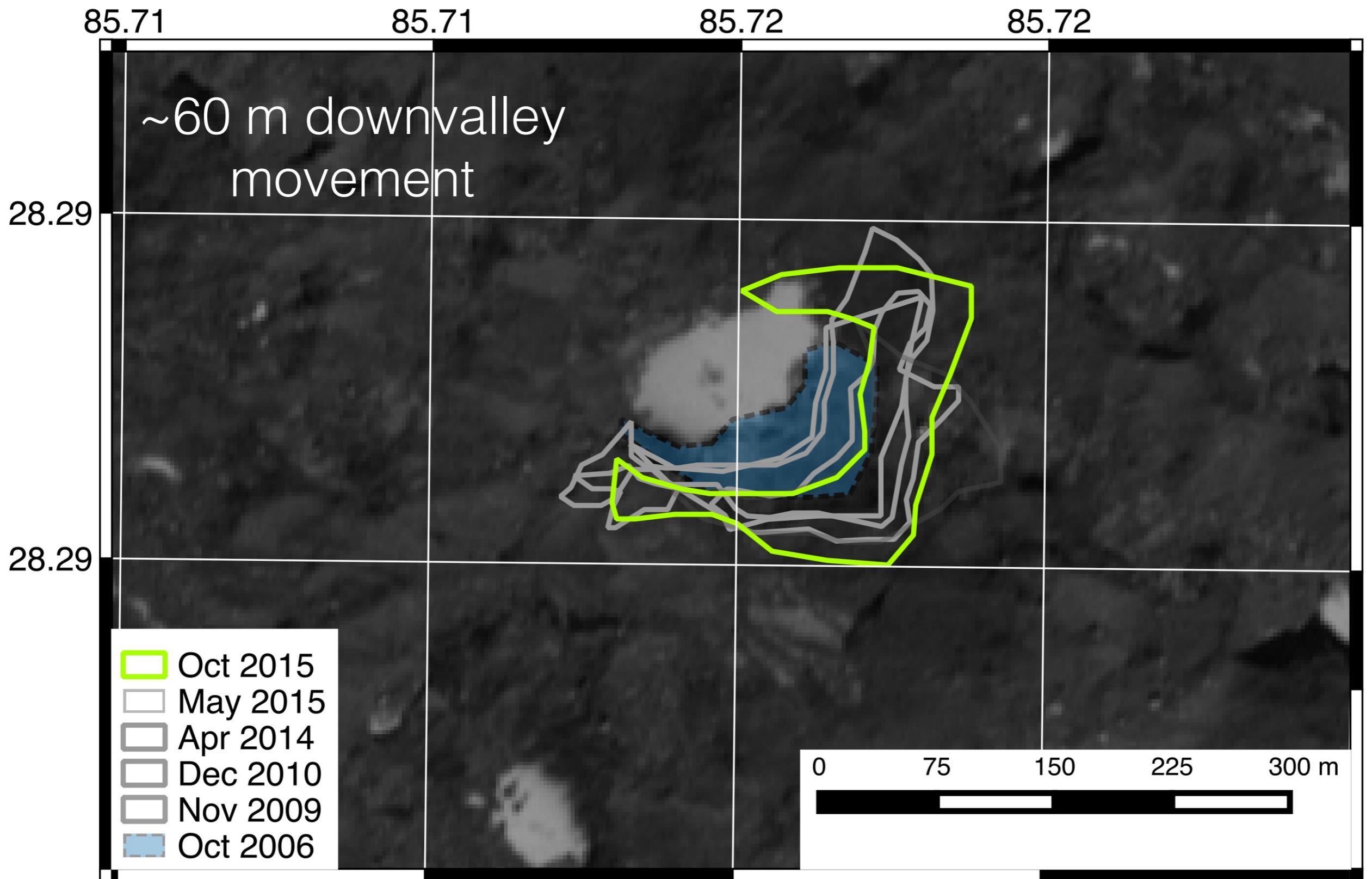


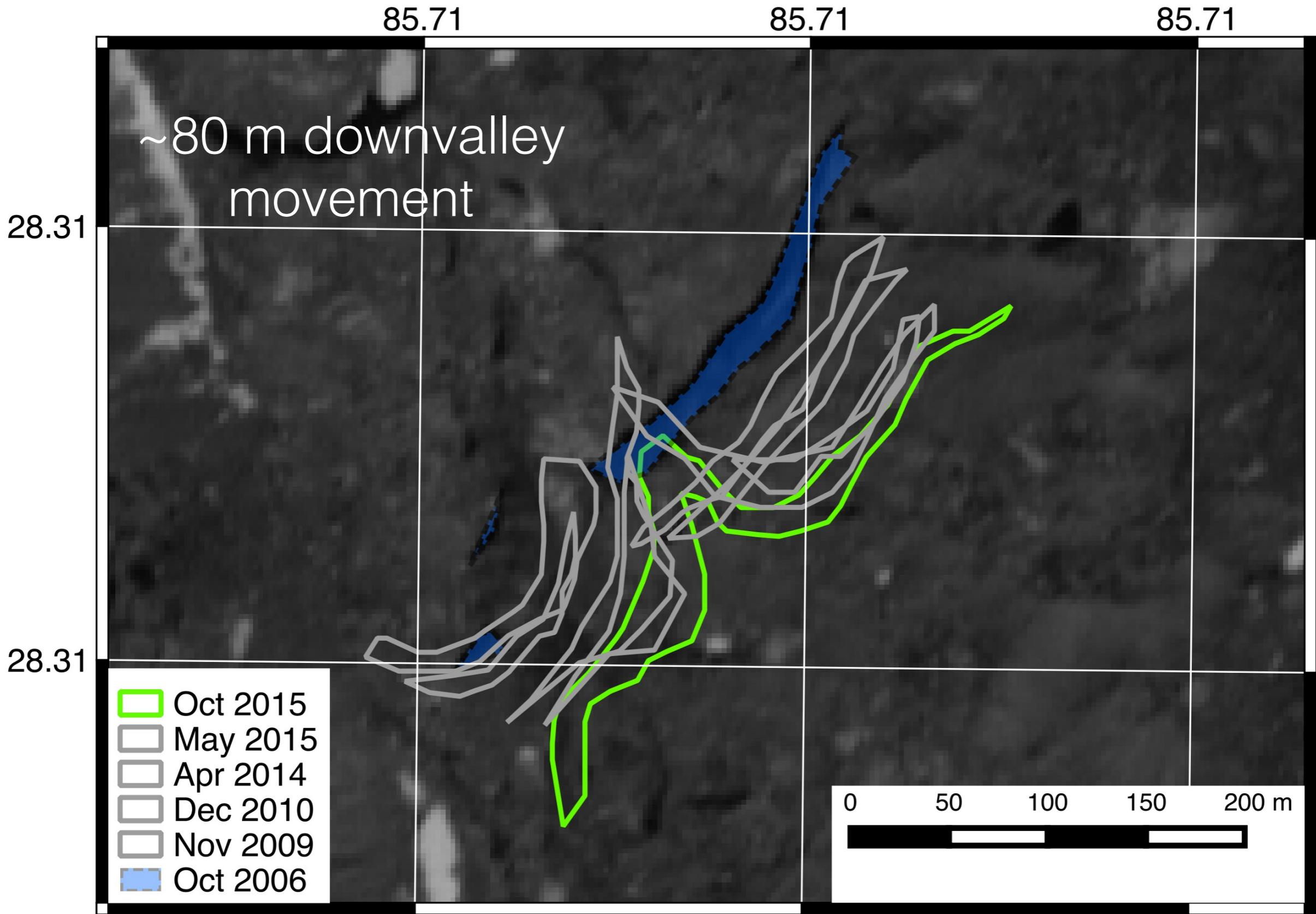
Aspect histogram

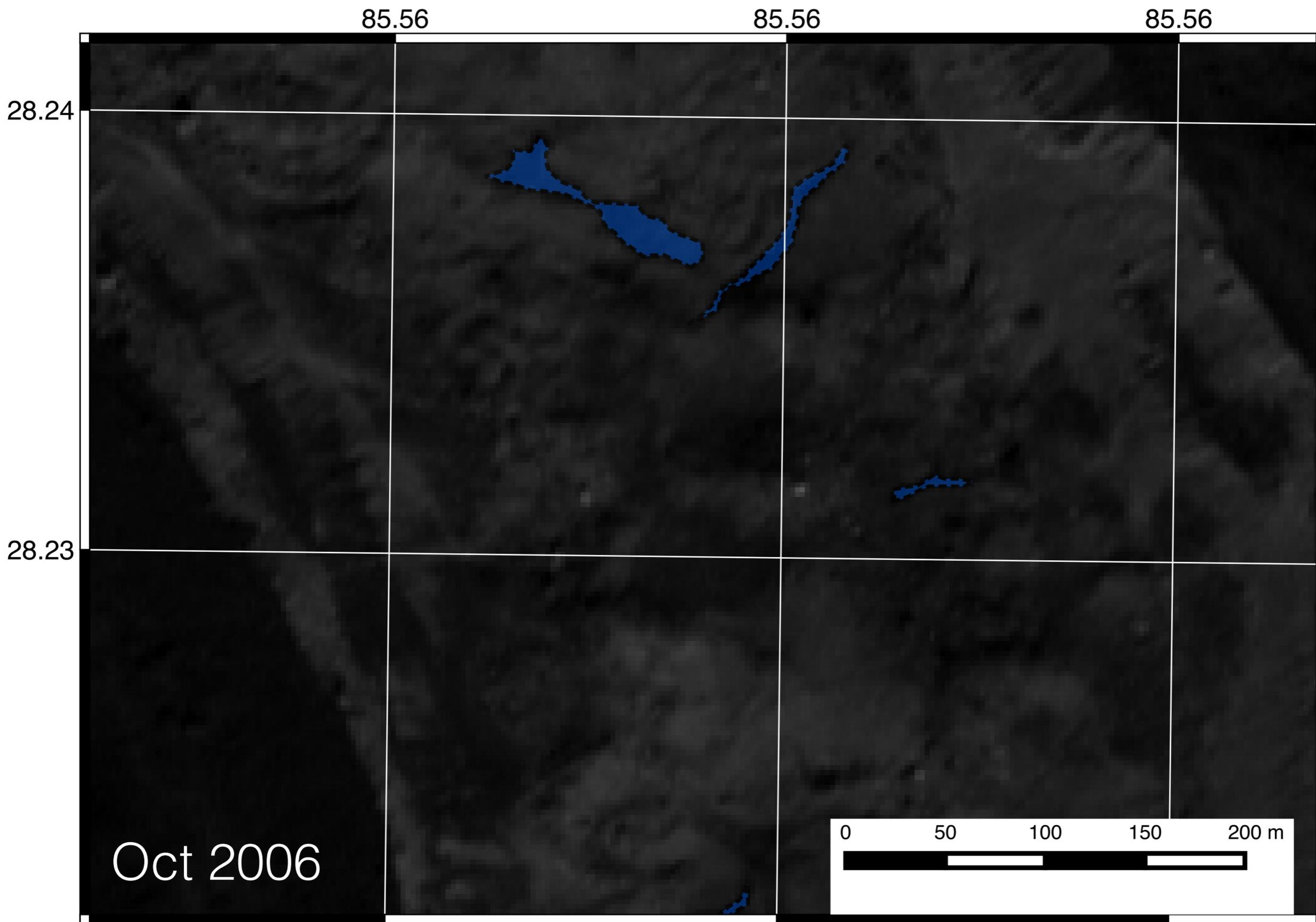


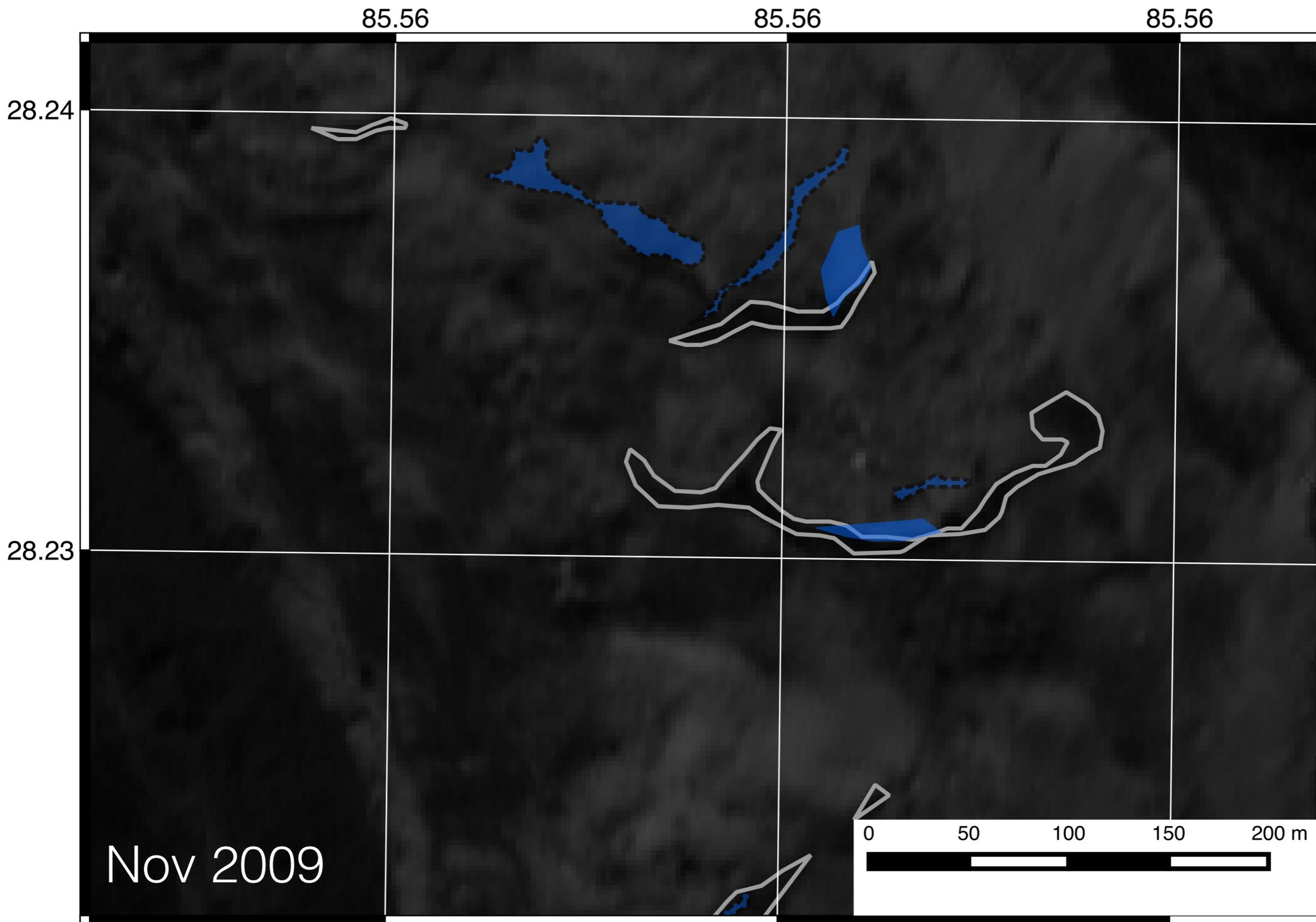
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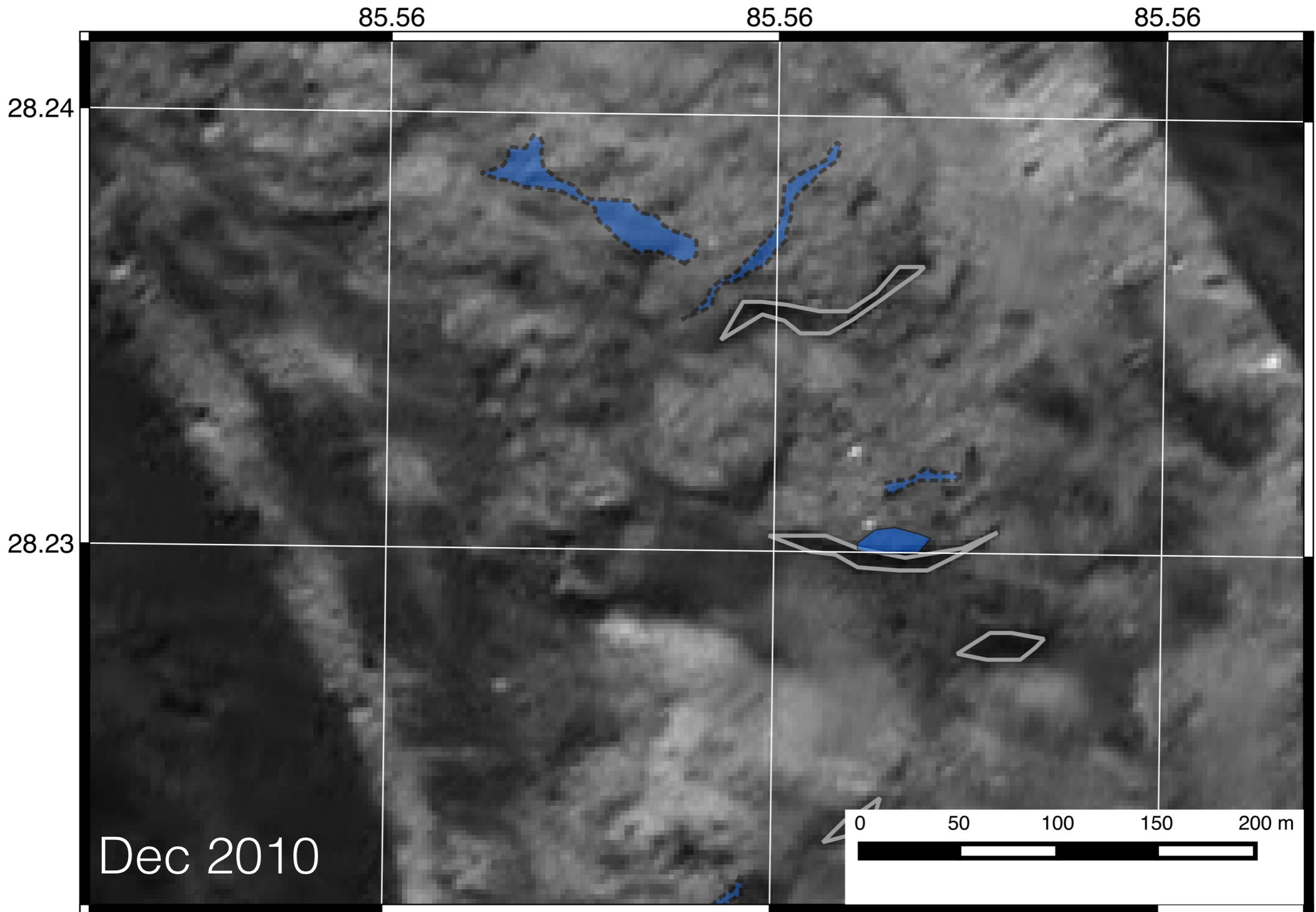


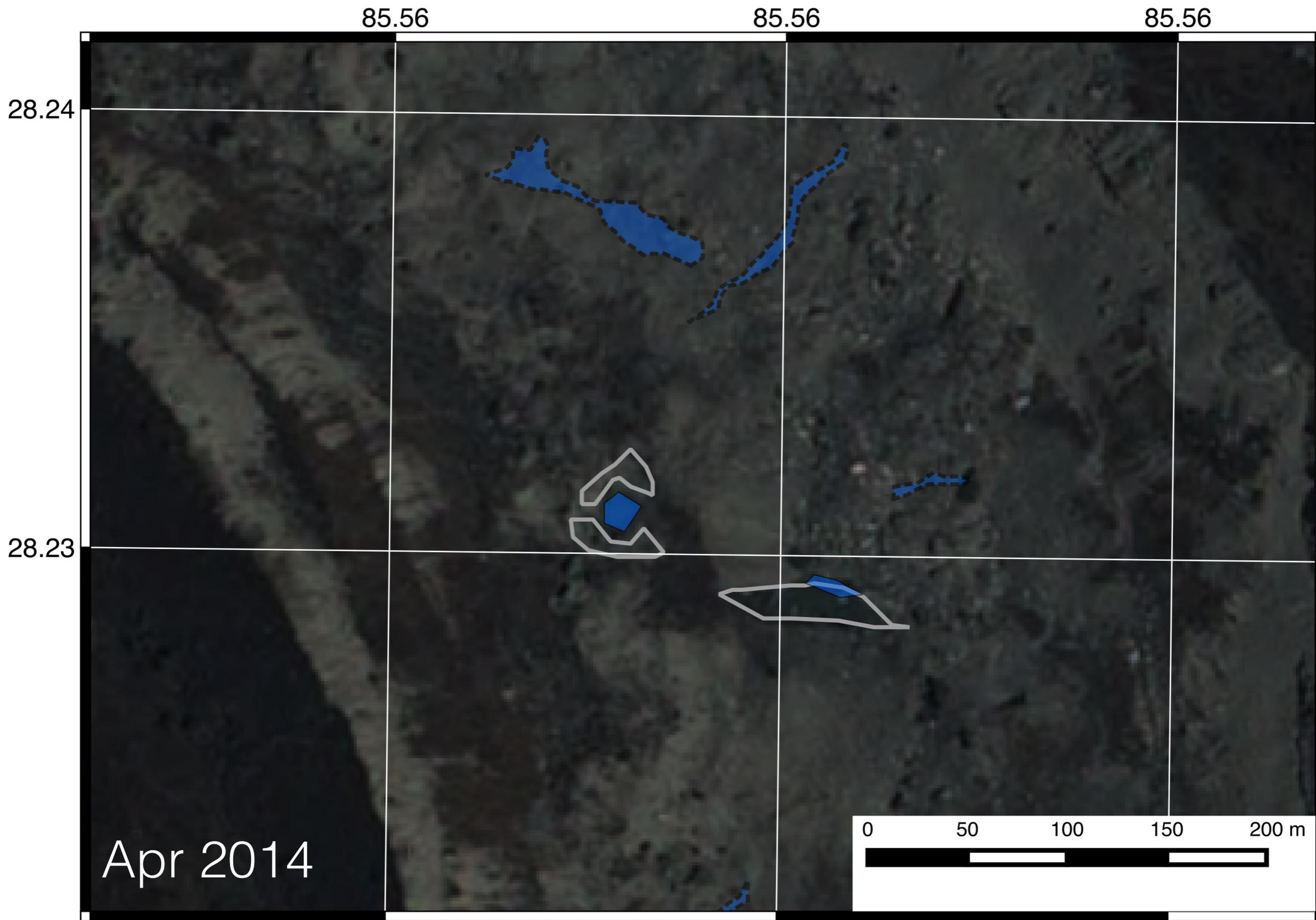


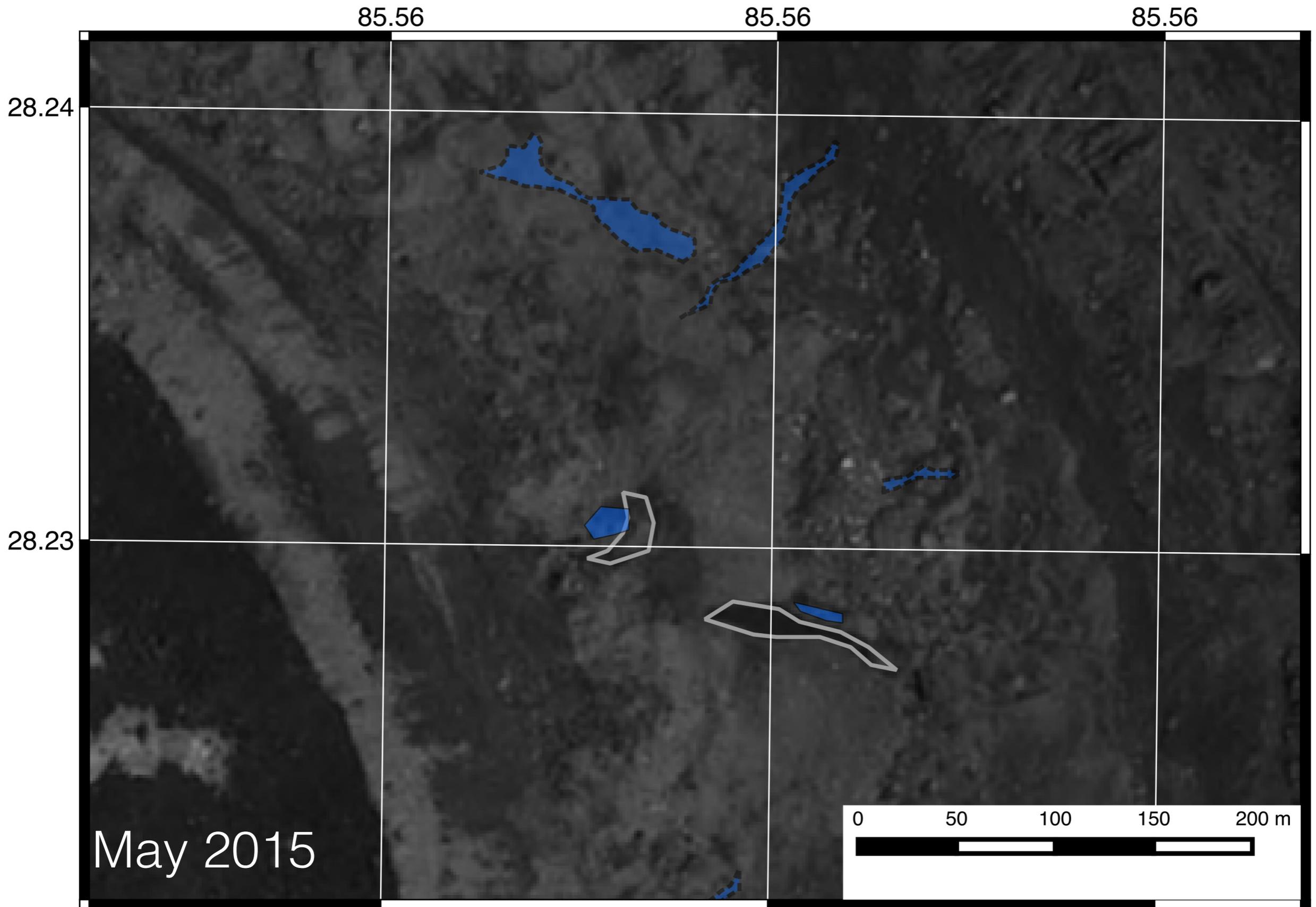


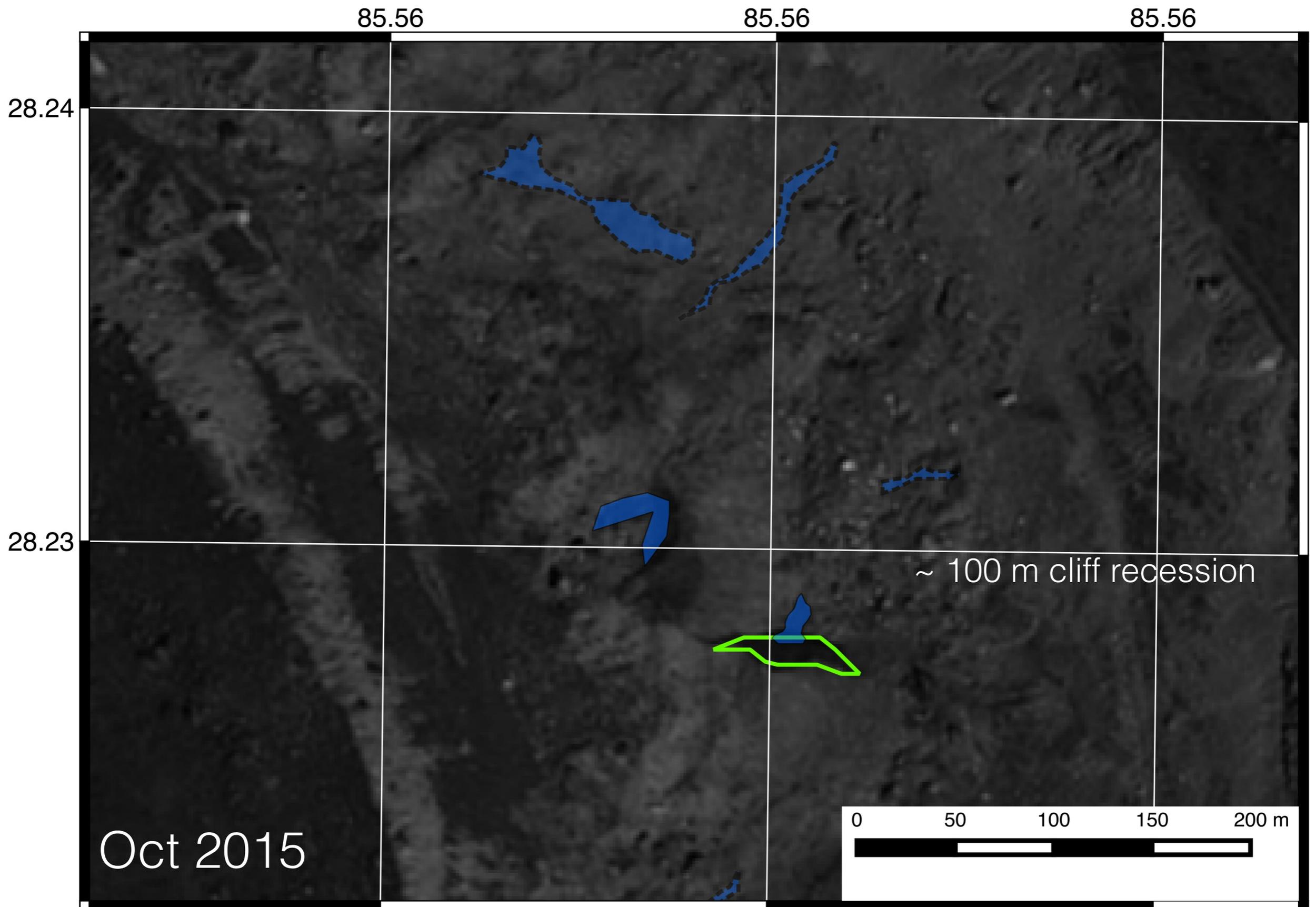












Conclusions

- no clear long term trend in numbers/area of ice cliffs and supra glacial lakes
- strong seasonal variability for lakes and spatial heterogeneity for lakes and cliffs
- surface velocities likely a good indicator of occurrence
- theory of preferential exposition (towards the North) obvious on all glaciers
- backwasting rates over multiple years correspond well with rates measured in the field during three seasons

Future Plan

- closer investigation of distribution and temporal change of different cliff and lake types
- determine ice cliffs/lakes from freely available imagery (Landsat, Sentinel) -> machine learning with available high-res data

Supplementary Slides

deposits on glacier surface

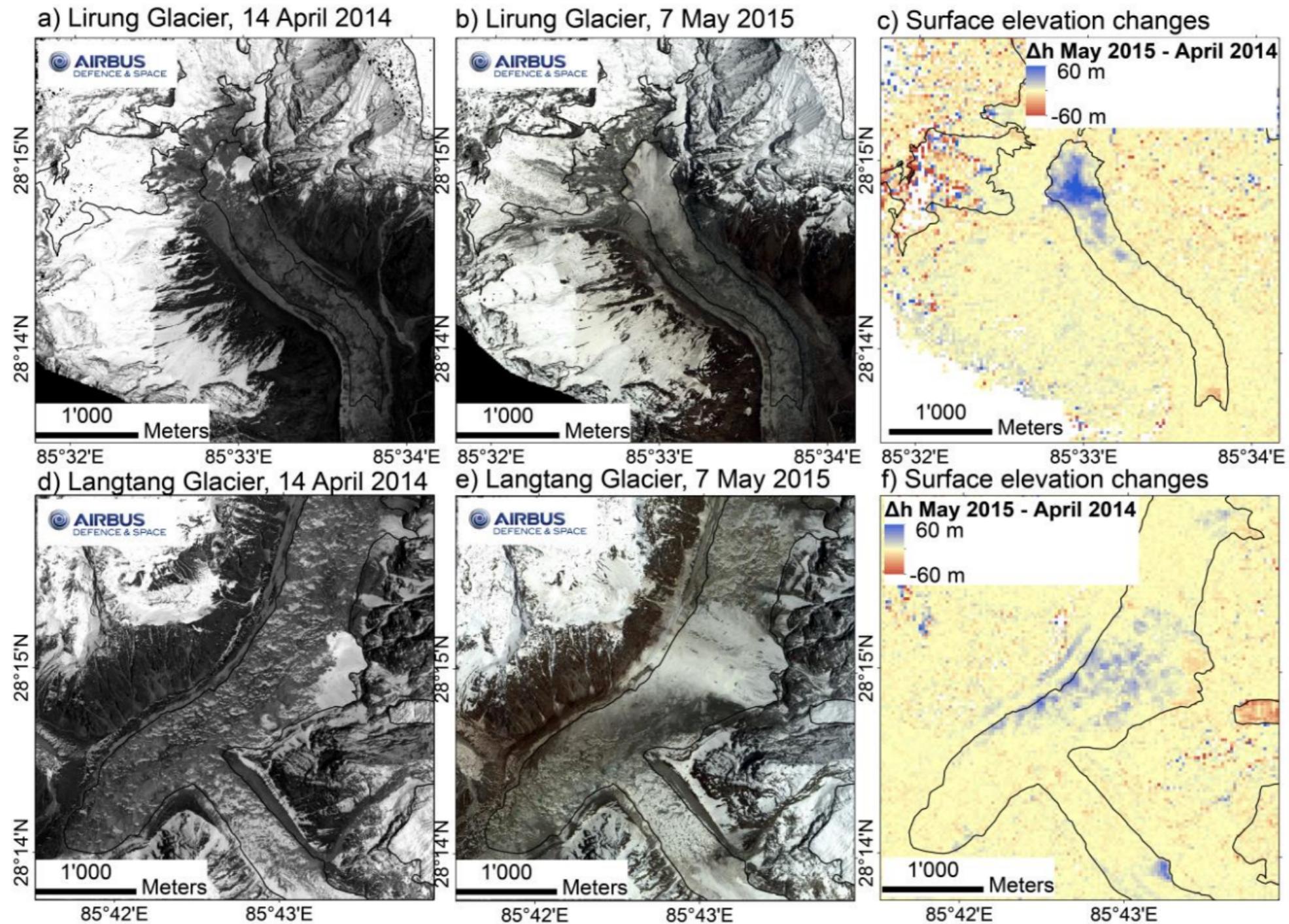
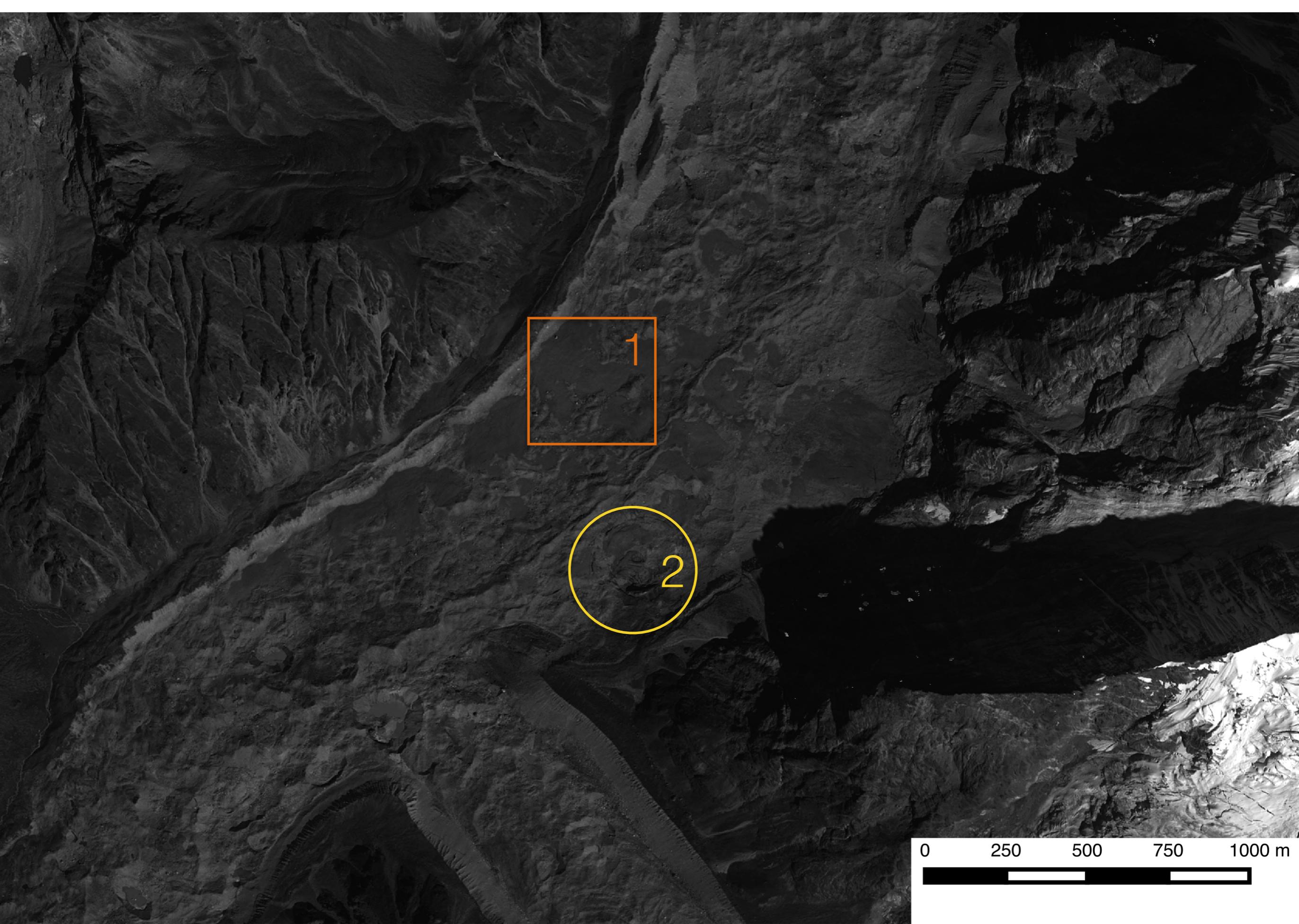


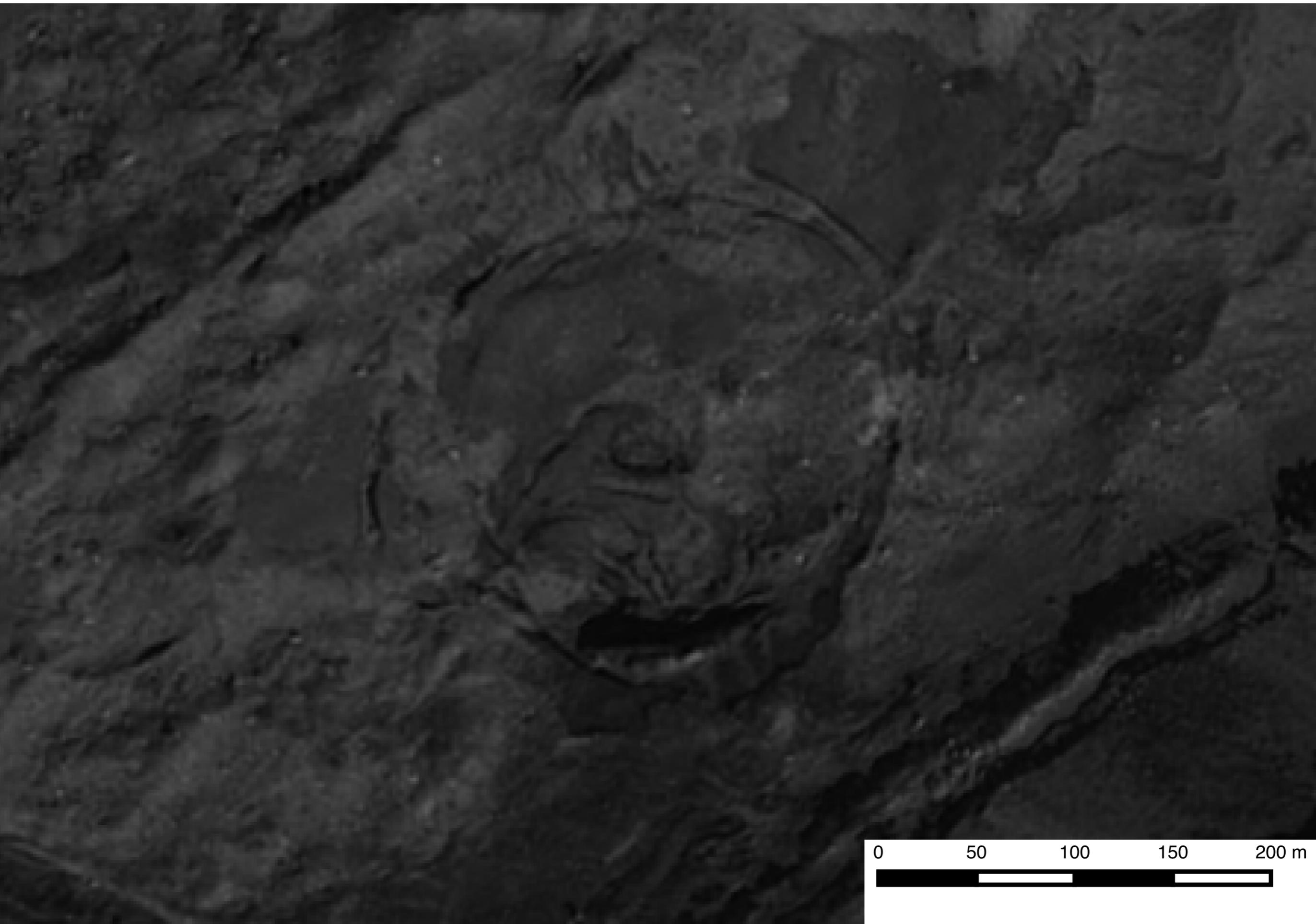
Figure 12. Avalanche affected sections of Lirung and Langtang glacier, pre- and after the earthquake on 25 April 2015, and corresponding surface elevation changes (Δh). Imagery

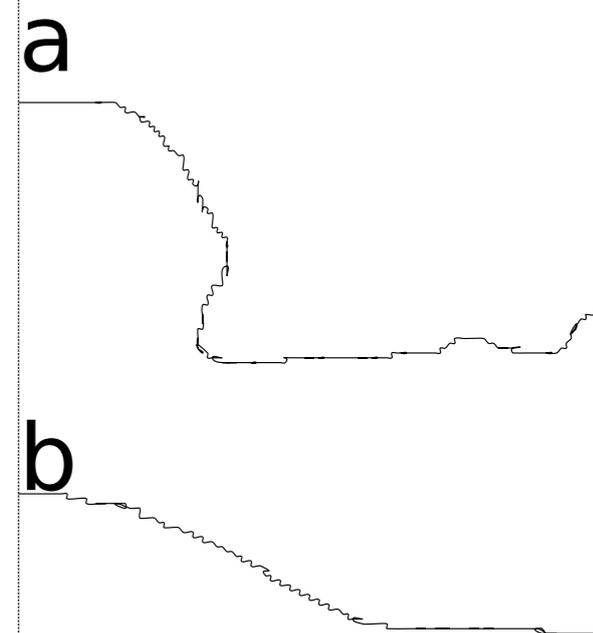
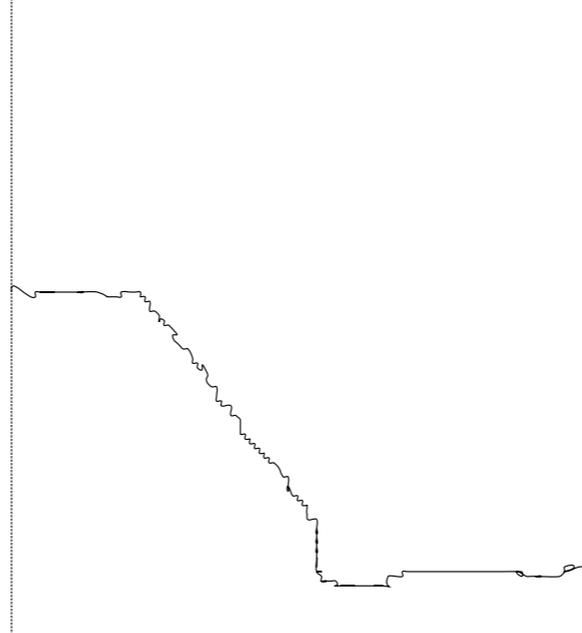
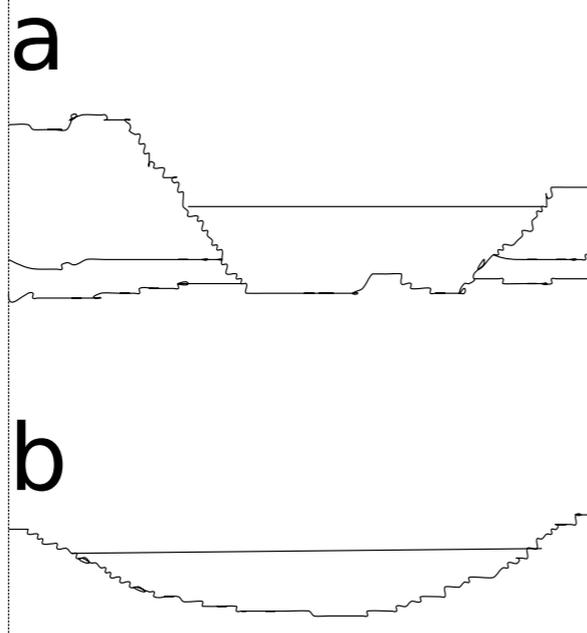
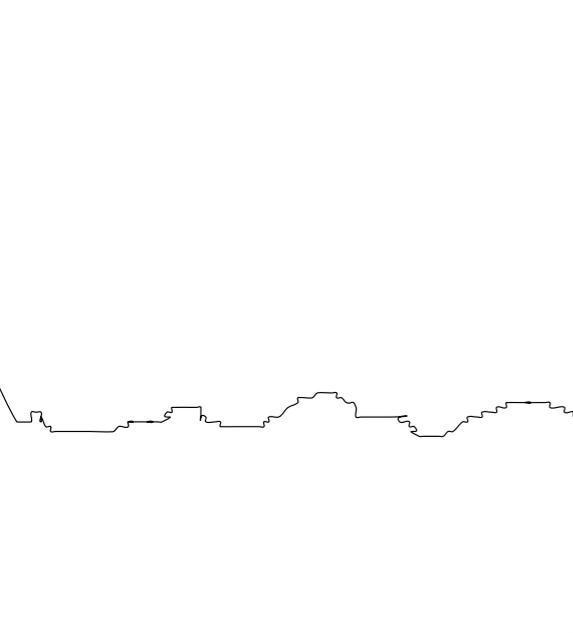
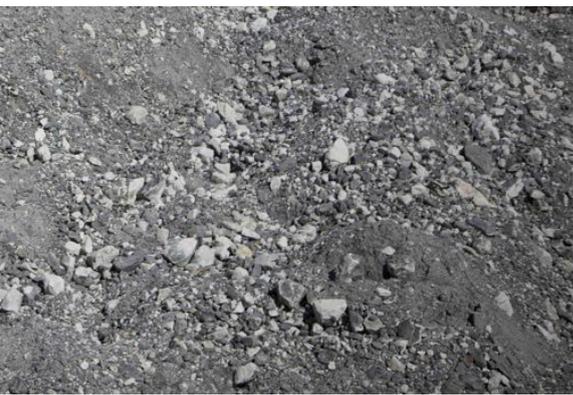


1

2

0 250 500 750 1000 m



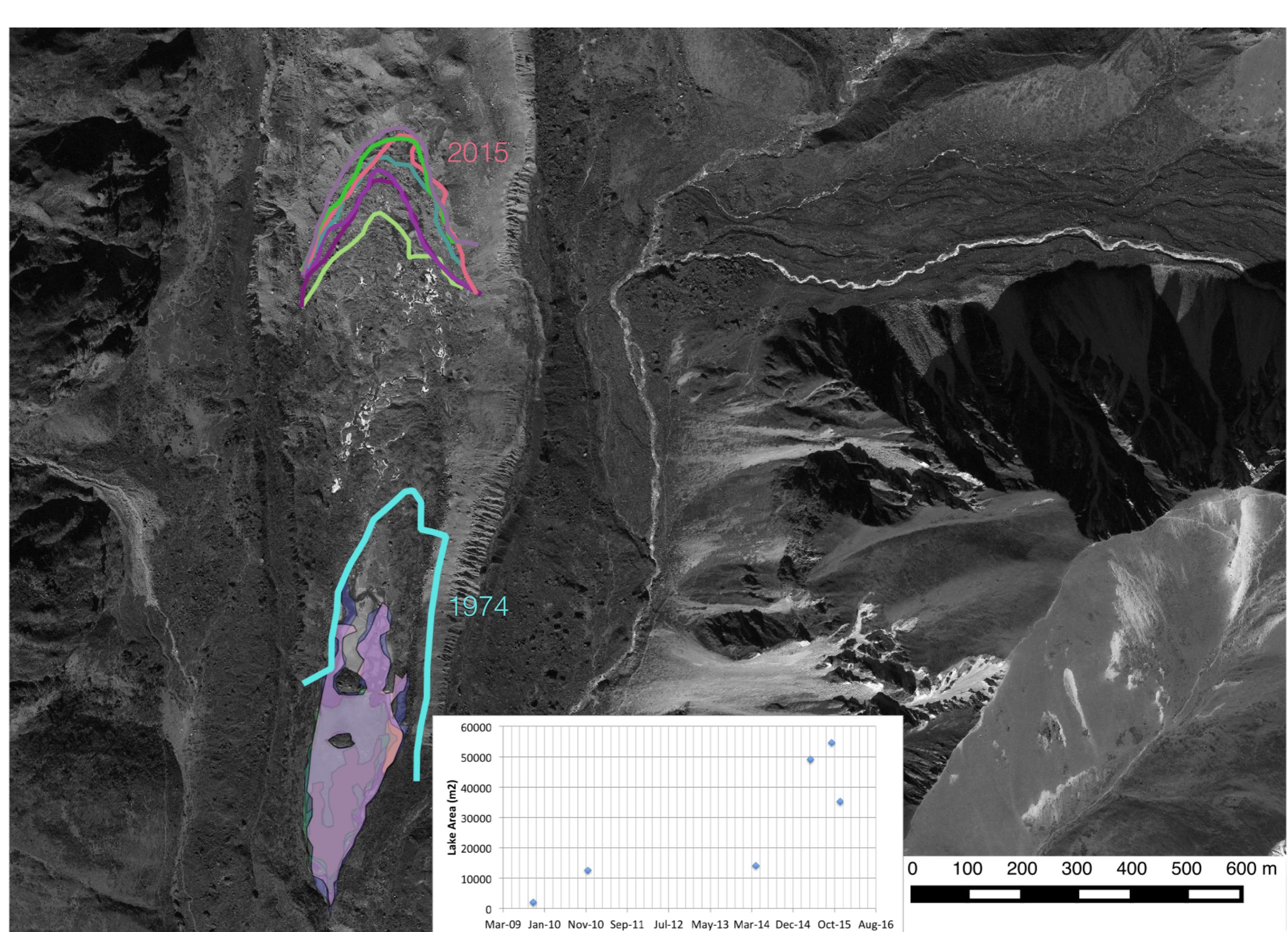


Stage 1

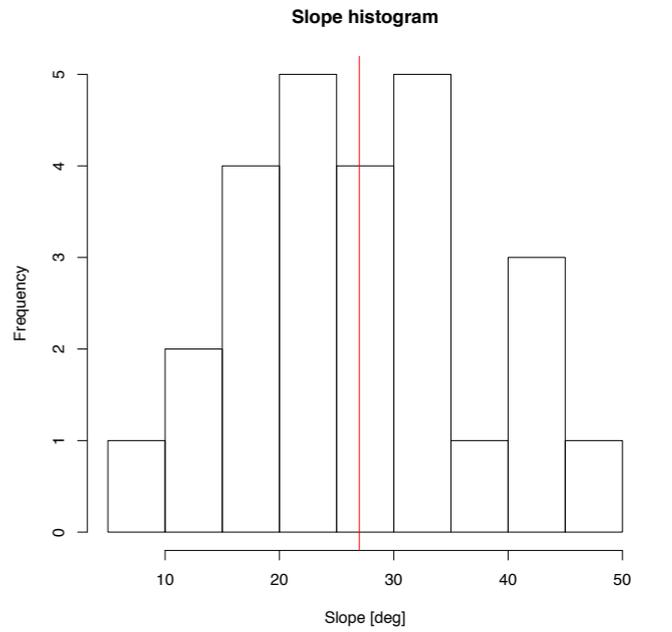
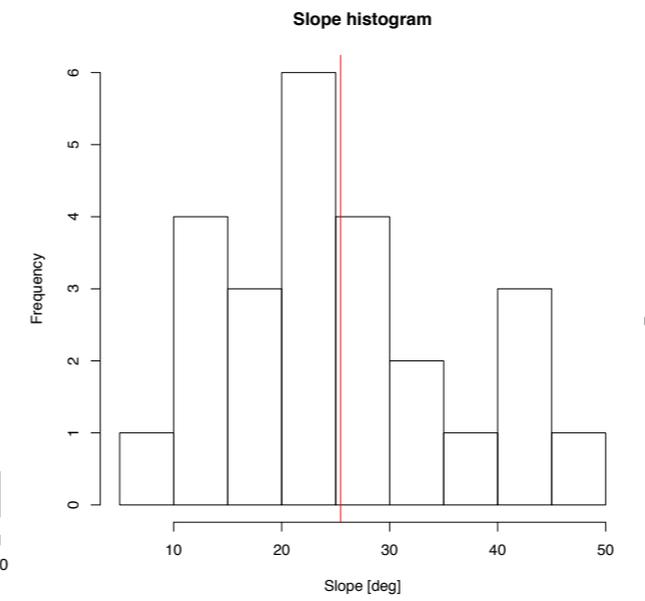
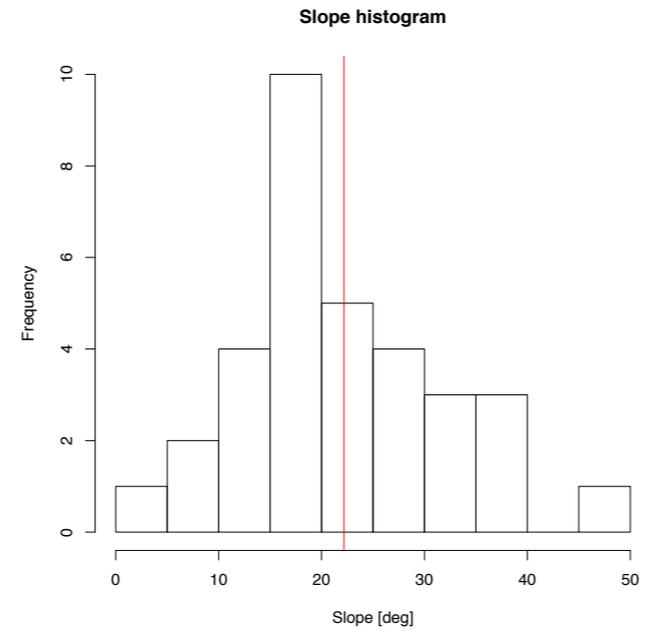
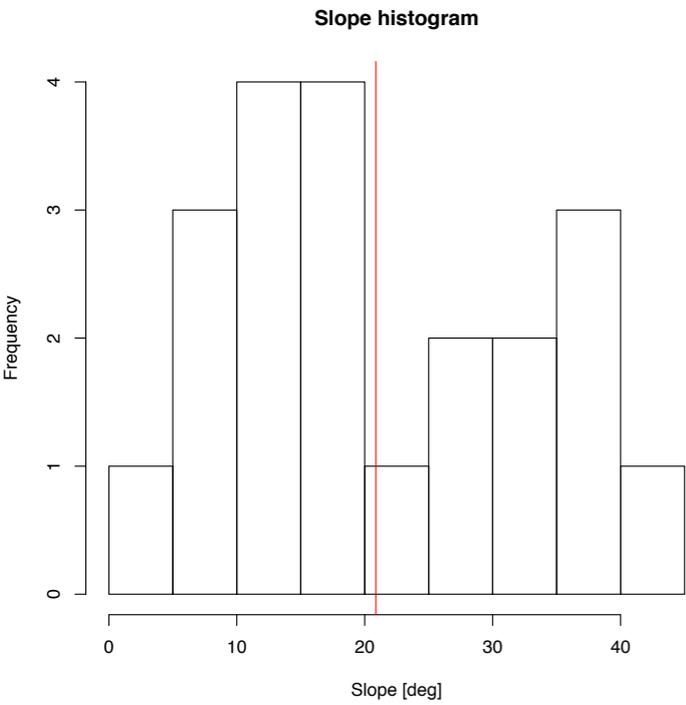
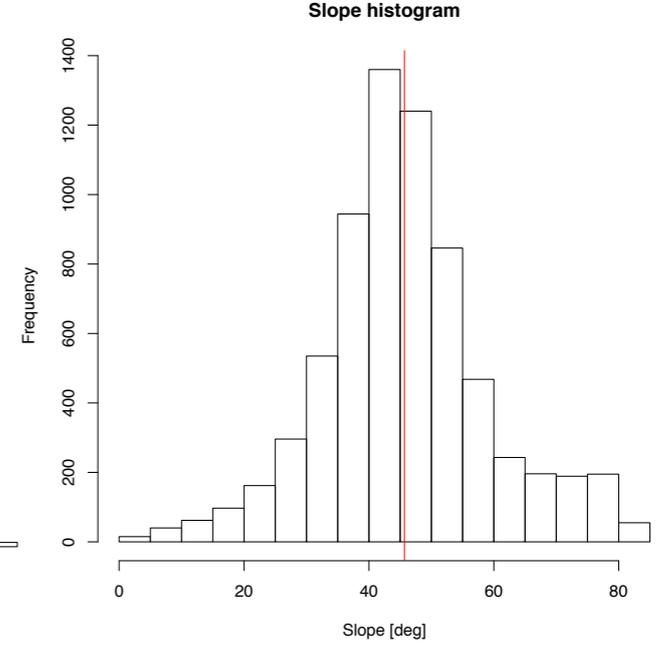
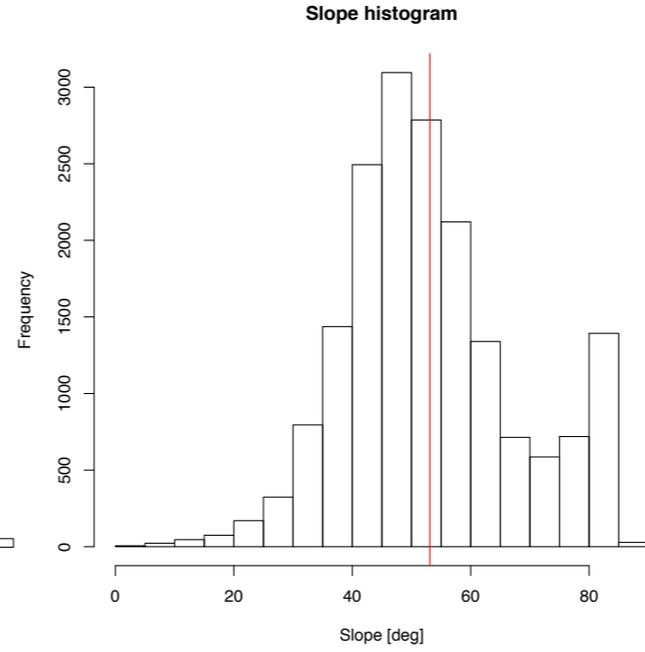
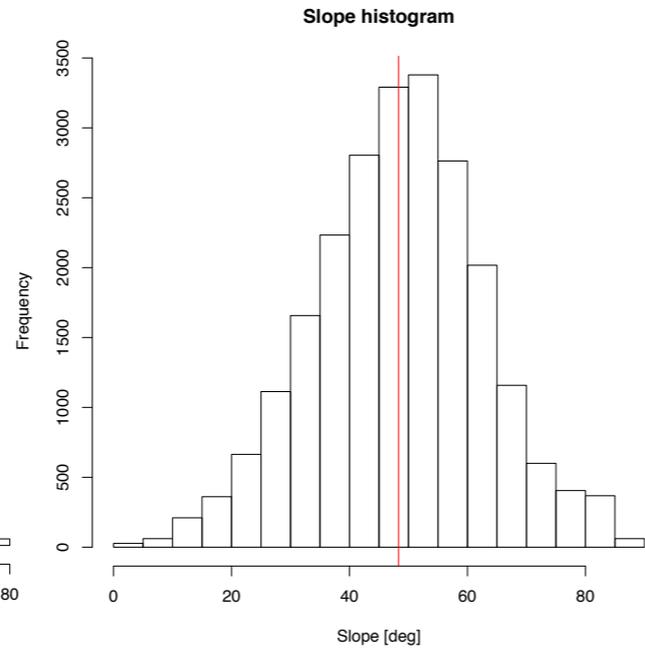
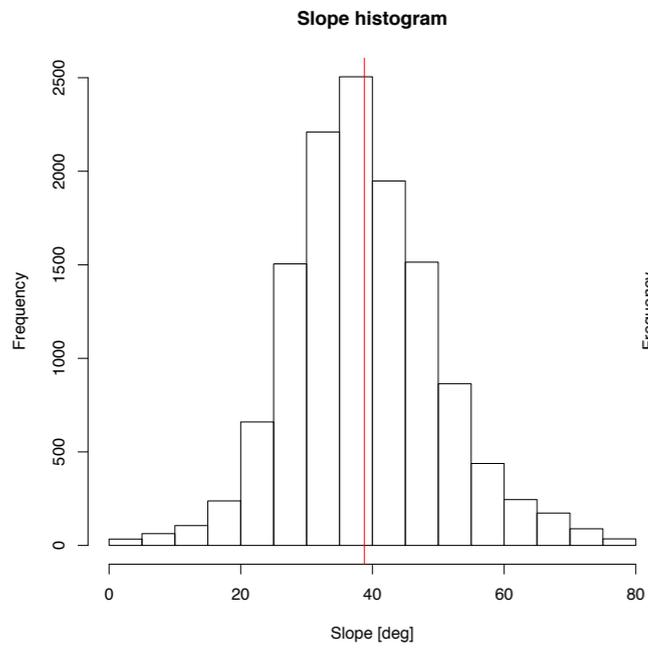
Stage 2

Stage 3

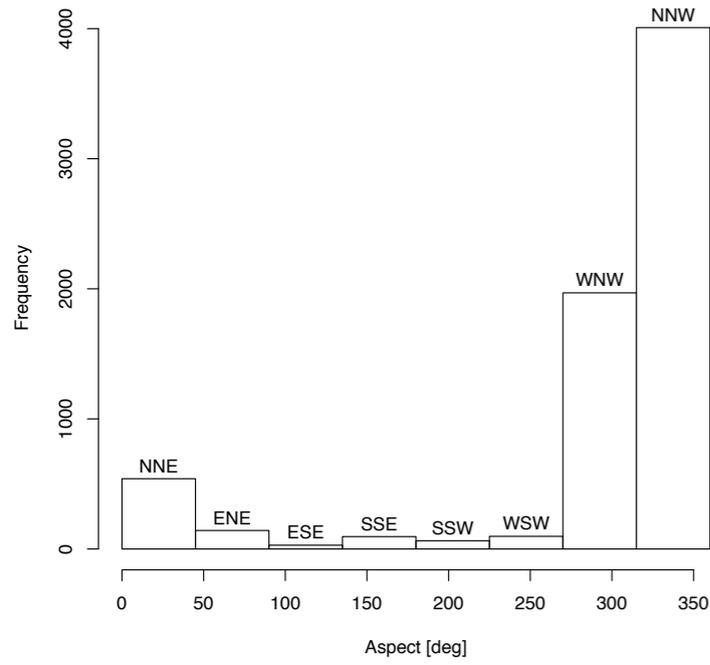
Stage 4



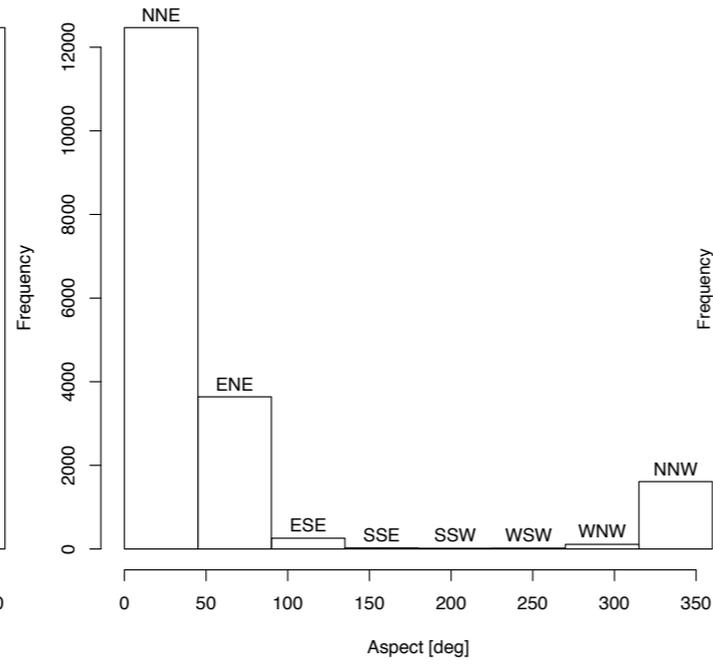
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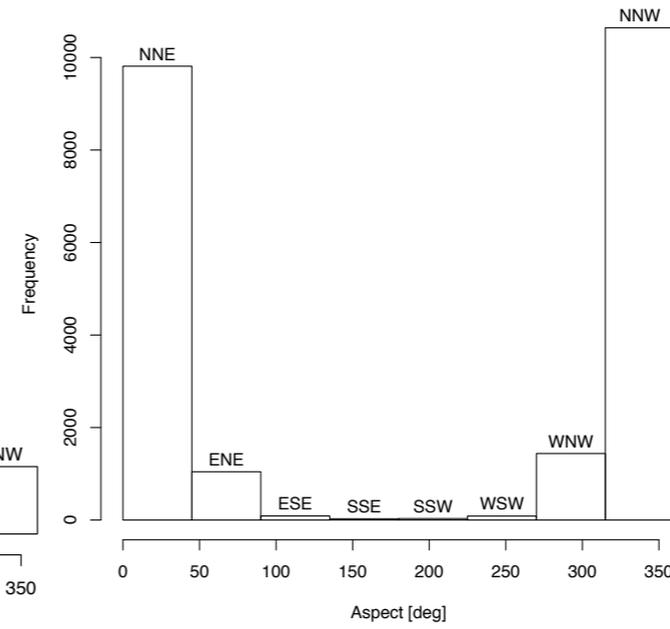
Aspect histogram



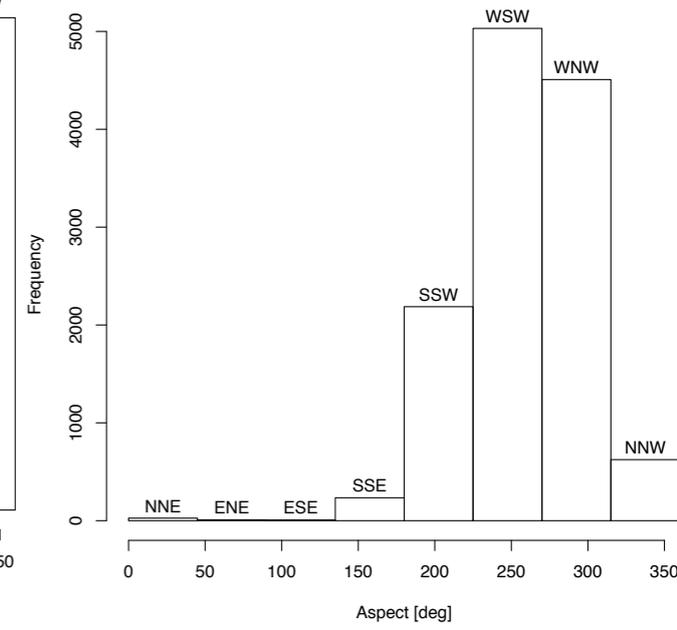
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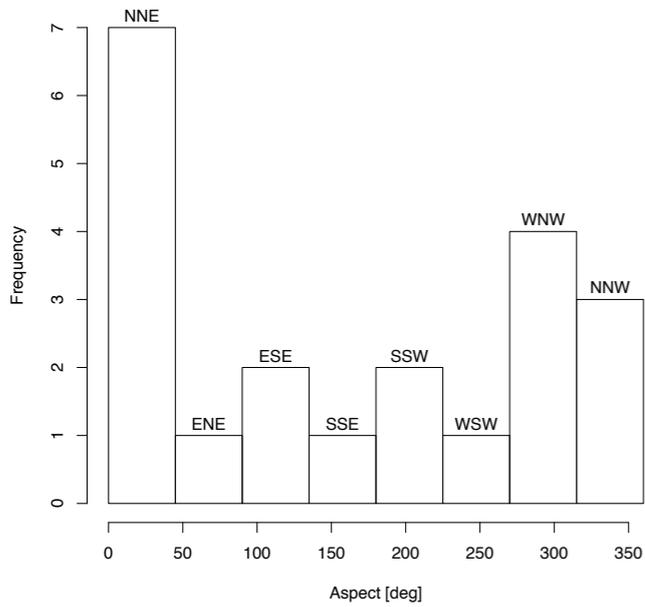
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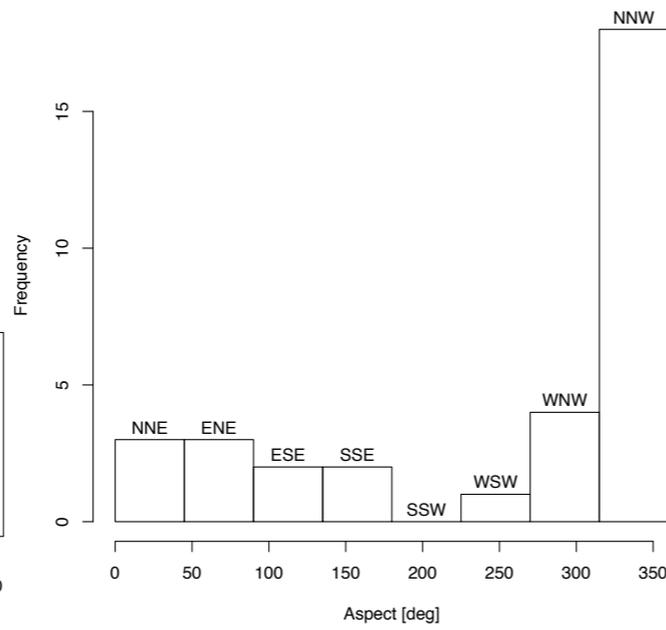
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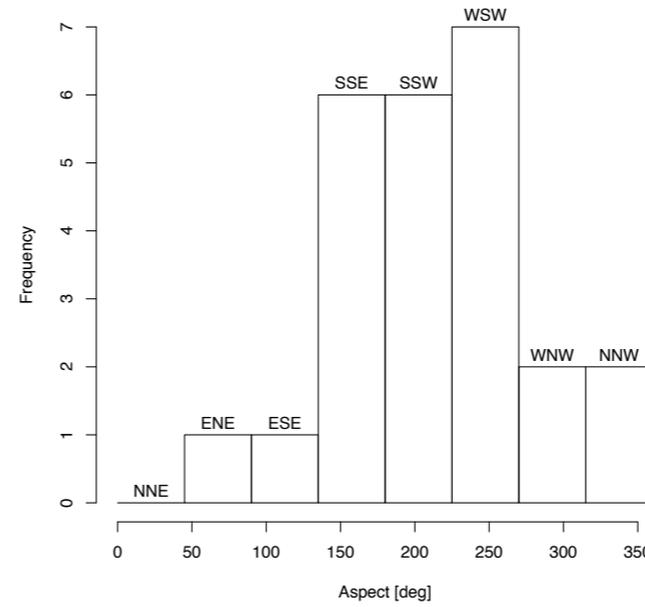
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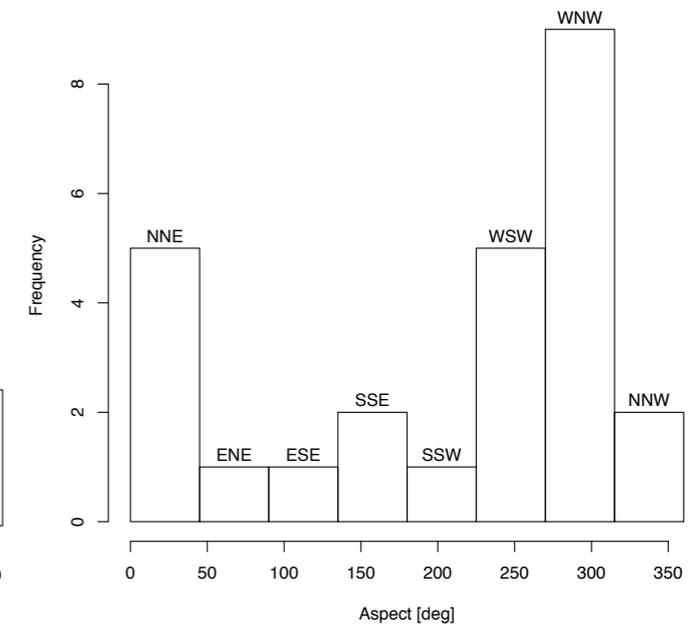
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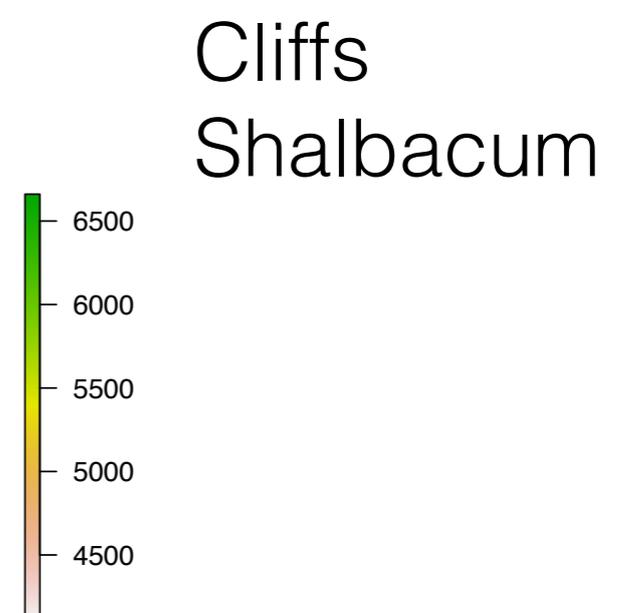
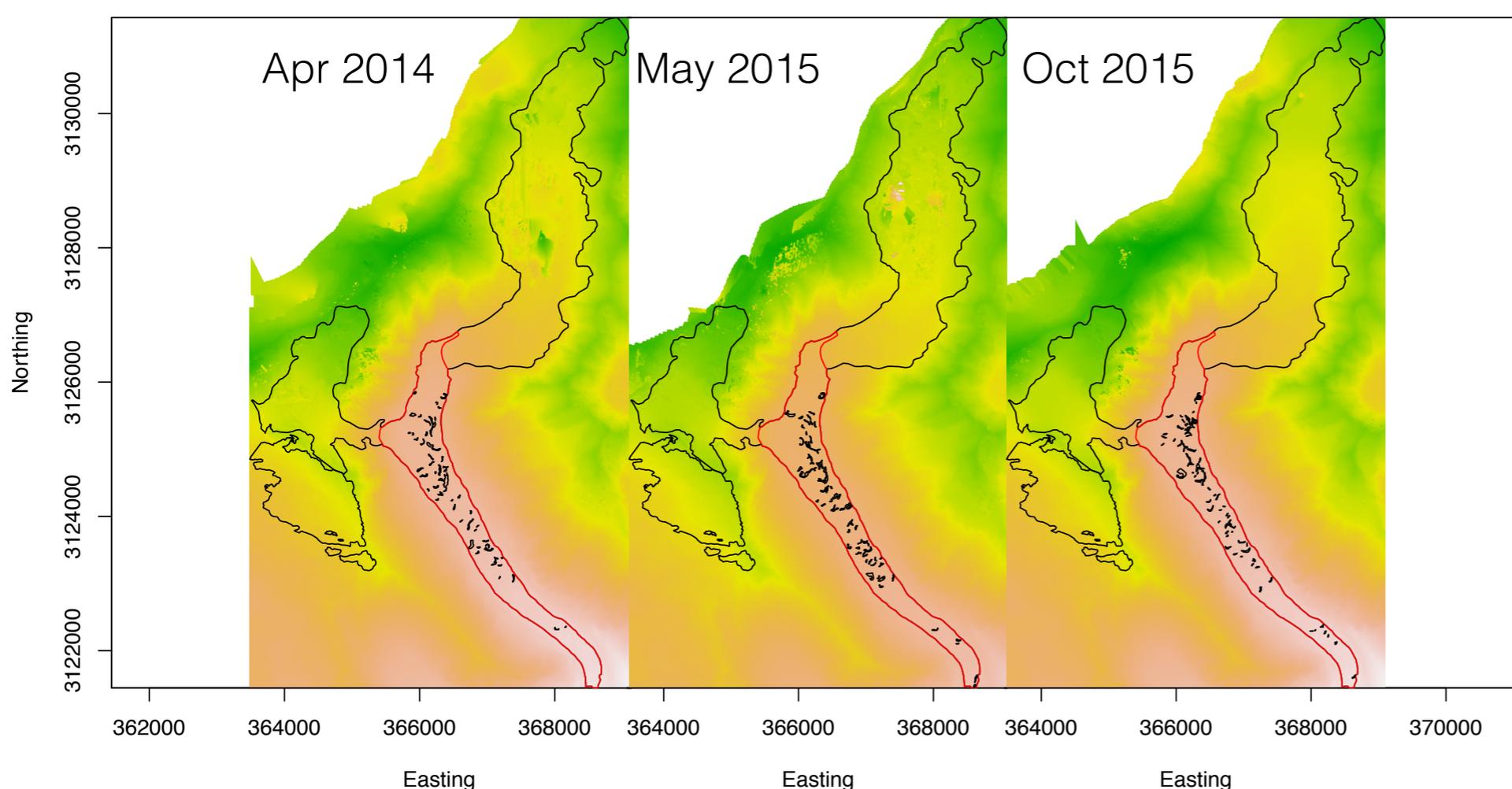
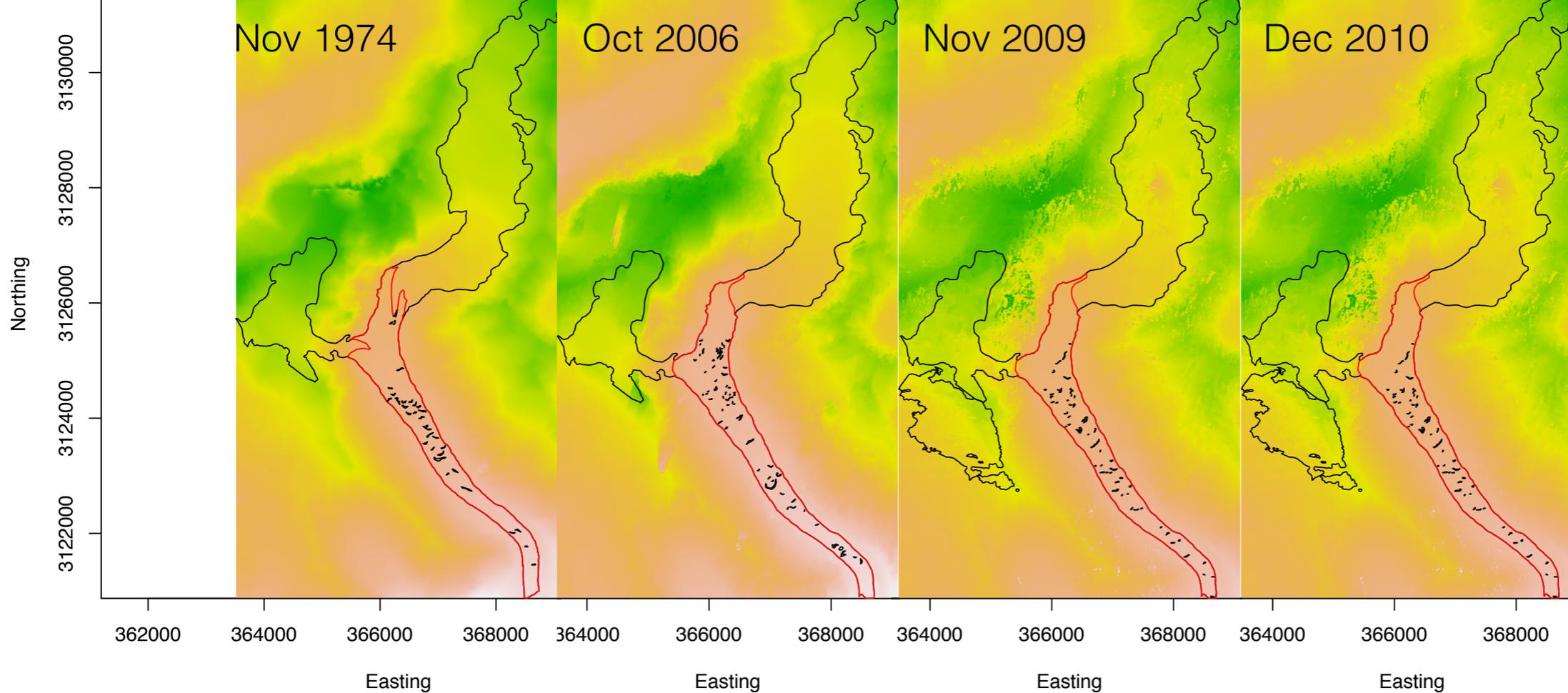


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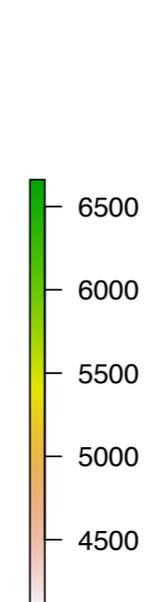
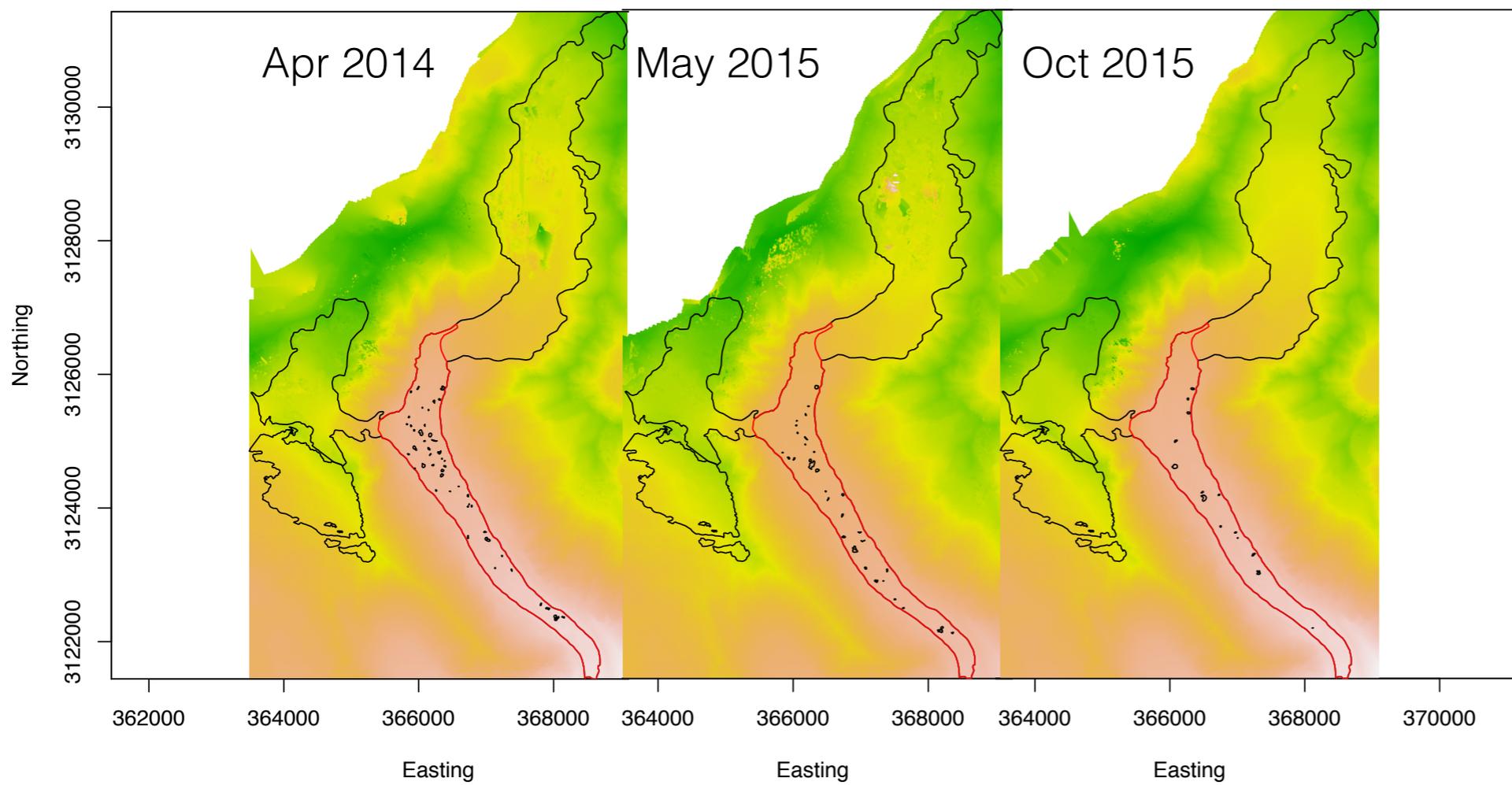
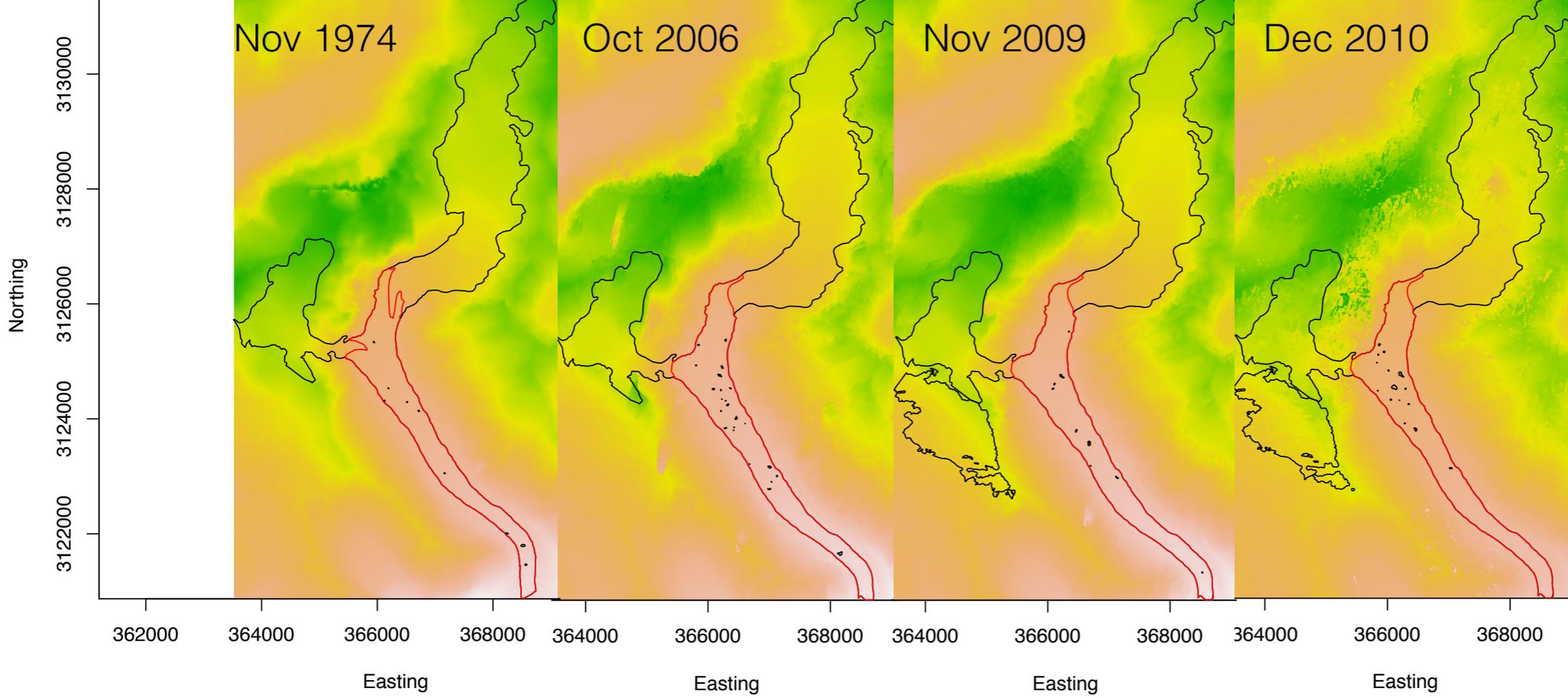


Aspect histogram

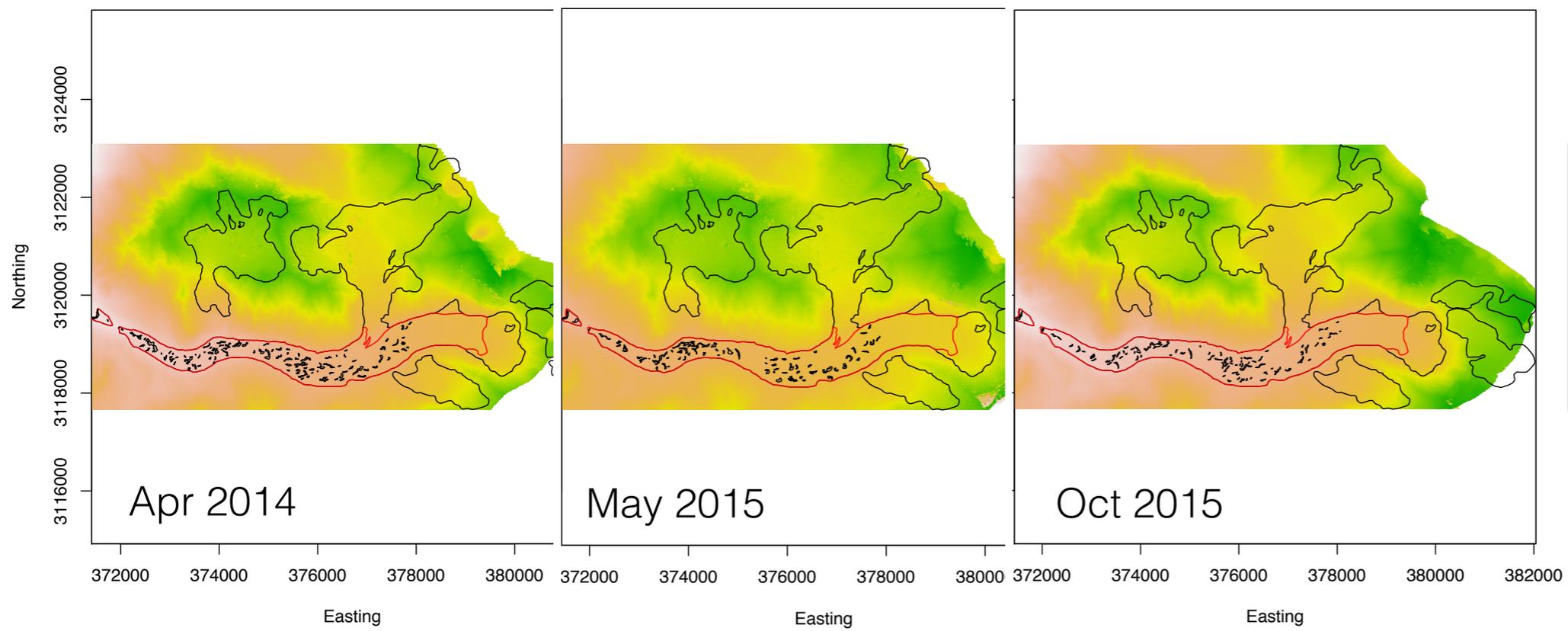
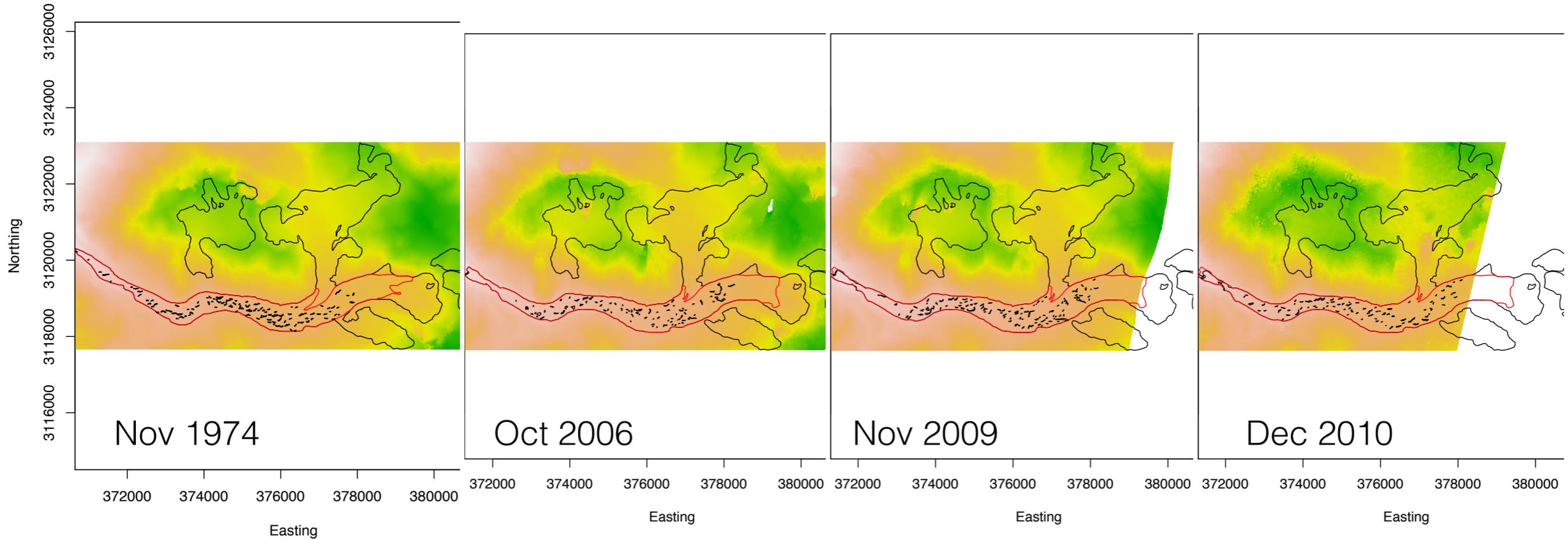




Cliffs Shalbacum



Lakes Shalbacum



Cliffs Langshisha

