

Remote sensing of the interactions between climate variability and glacier dynamics for an Alpine temperate glacier, from the scale of the decades to hours

The case of the Haut Glacier d'Arolla

Master thesis in Geography
Direction - prof. Stuart Lane


UNIL | Université de Lausanne
Institut des dynamiques
de la surface terrestre

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University of Lausanne

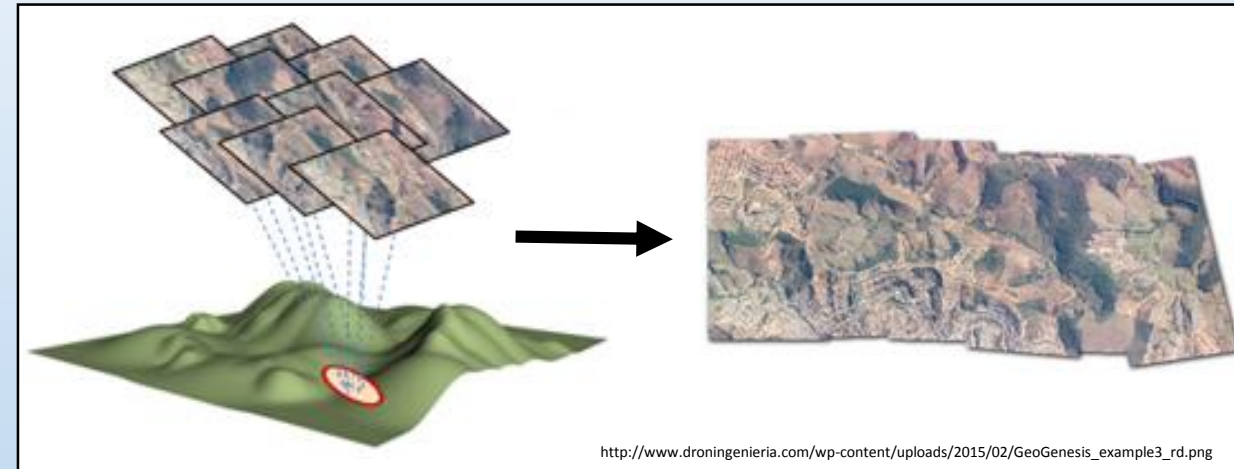
Prix de Quervain 2015

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«... is the acquisition of information about an object or phenomenon **without making physical contact** with the object and thus in contrast to on site observation ... »

[Campbell, J. B. (2002). *Introduction to remote sensing - 3rd Edition*. The Guilford Press]

- Aerial photogrammetry

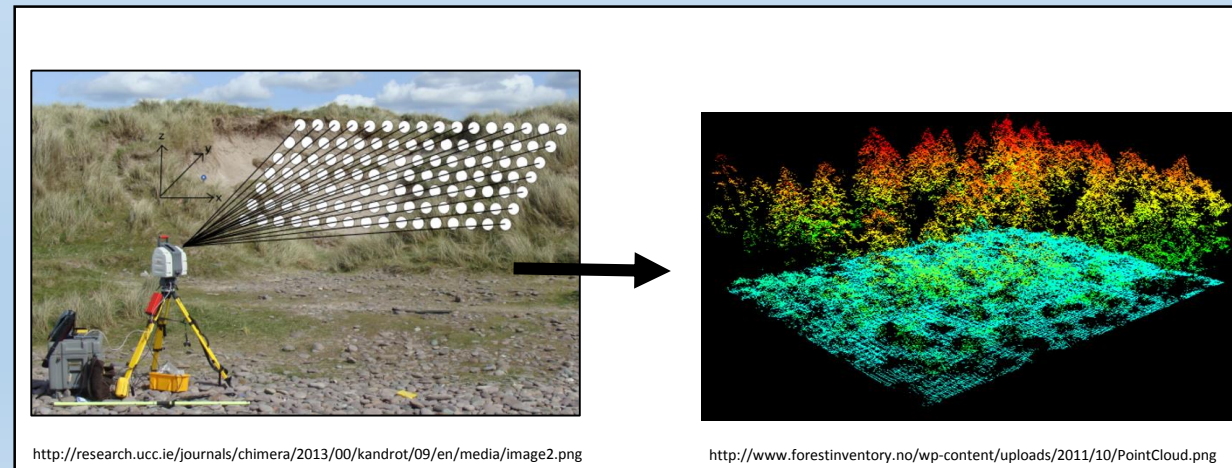
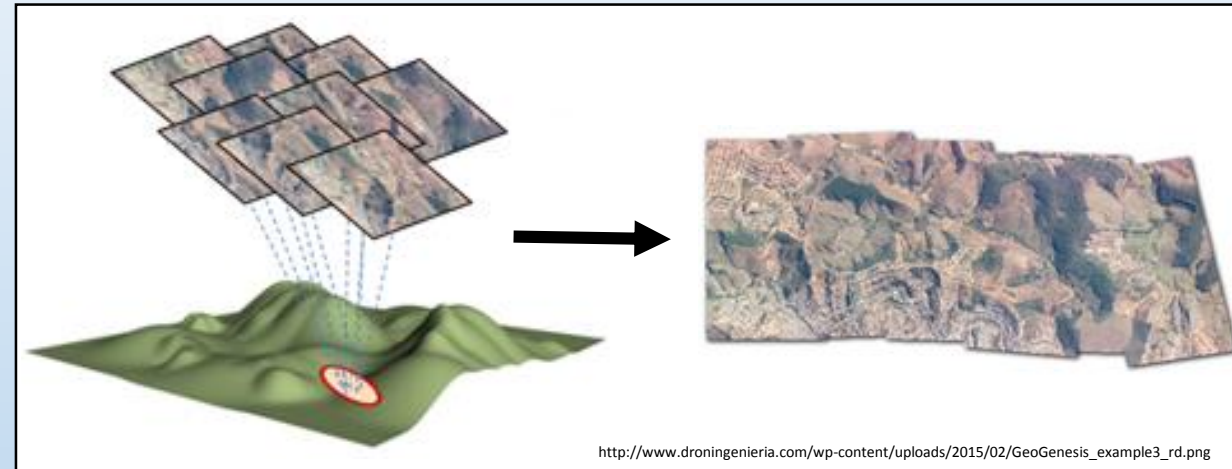


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- Aerial photogrammetry
- Terrestrial laser scanning – LiDAR



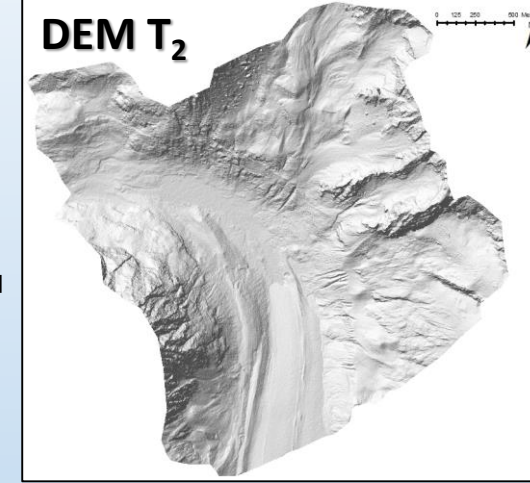
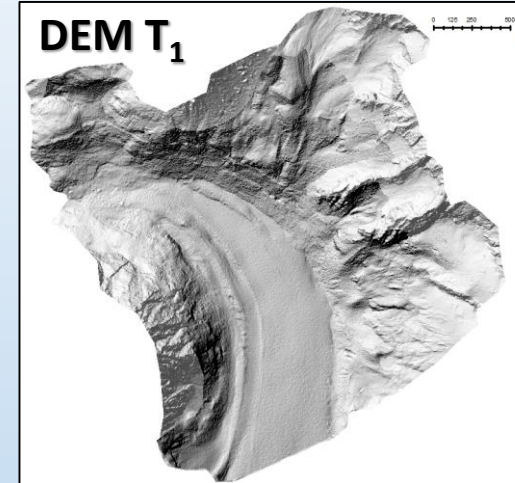
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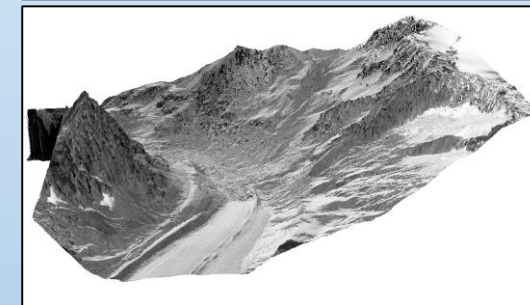
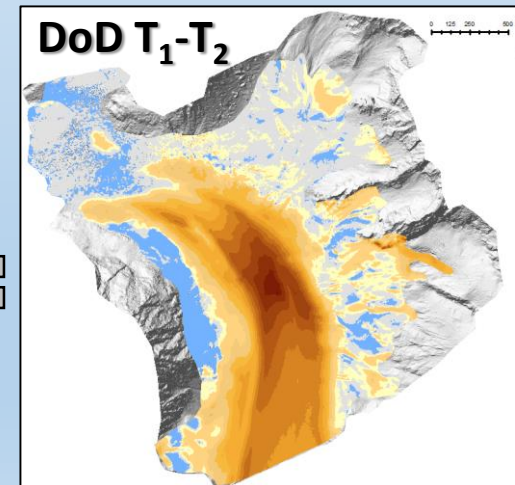
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- Aerial photogrammetry
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❖ **3D topography**
Digital Elevation Model (**DEM**)
DEM of Difference (**DoD**) ($T_1 - T_2$)

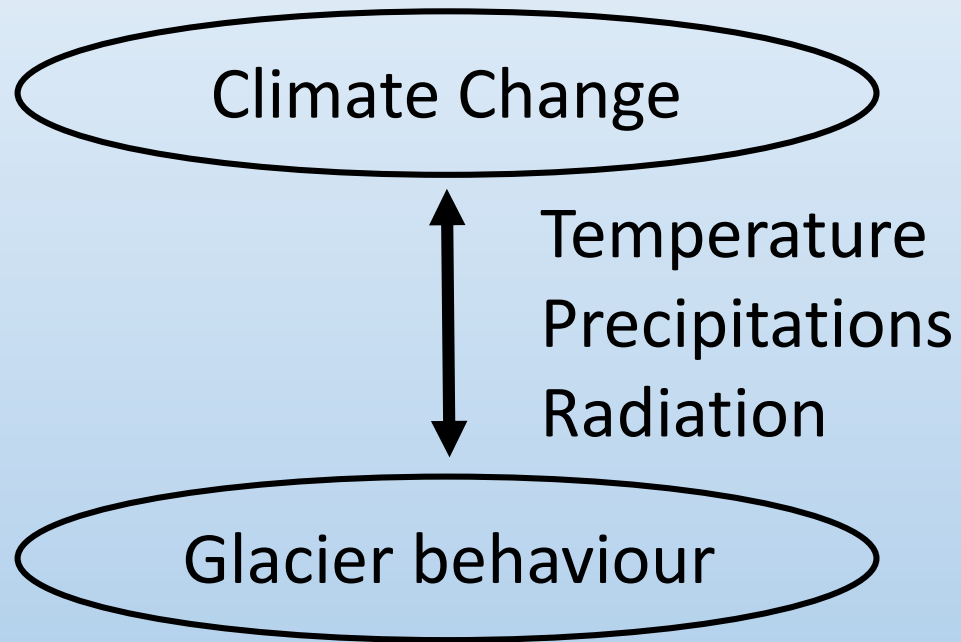


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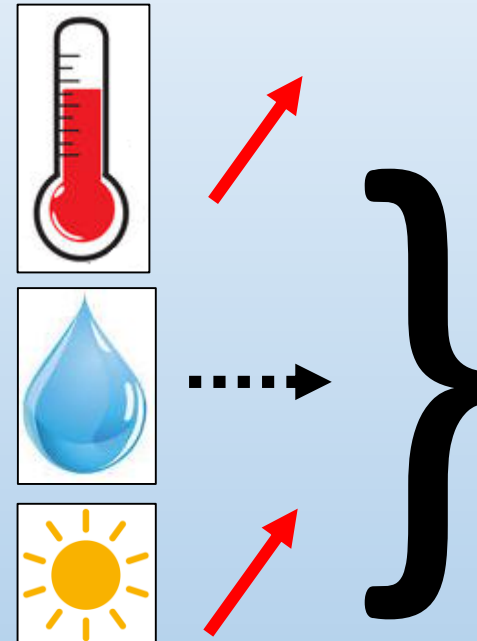


Blue = deposition
Red = erosion

Remote sensing of the **interactions between climate variability and glacier dynamics** for an Alpine temperate glacier, from the scale of the decades to hours;
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→ **Glaciers tend to retreat**



Dumoulin H, Zryd A and Crispini N (2010). *Glaciers: passé-présent du Rhône au Mont-Blanc*. Editions Slatkine

❖ **Better understand the interactions**

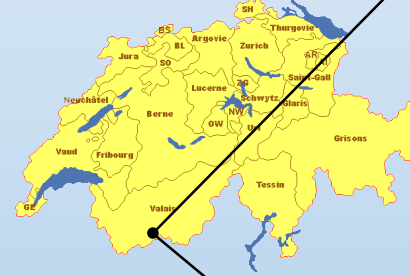
Remote sensing of the interactions between climate variability and glacier dynamics for an Alpine temperate glacier, from the scale of the decades to hours; The case of the Haut Glacier d'Arolla

- Temperate glacier, mean altitude 2980 m
Numerous publications
- But we still don't know:
 - * The recent history
(Not in the VAW – *Swiss glacier monitoring network*)
 - * The surface melt spatial distribution



Remote sensing of the interactions between climate variability and glacier dynamics for an Alpine temperate glacier, from the scale of the decades to hours, The case of the Haut Glacier d'Arolla

- Temperate glacier, mean altitude 2980 m
Numerous publications
- But we still don't know:
 - * The recent history
(Not in the VAW – *Swiss glacier monitoring network*)
→ **Long term**
 - * The surface melt spatial distribution
→ **Short term**



❖ Monitor the Haut Glacier d'Arolla at different time scales

4. Study objectives

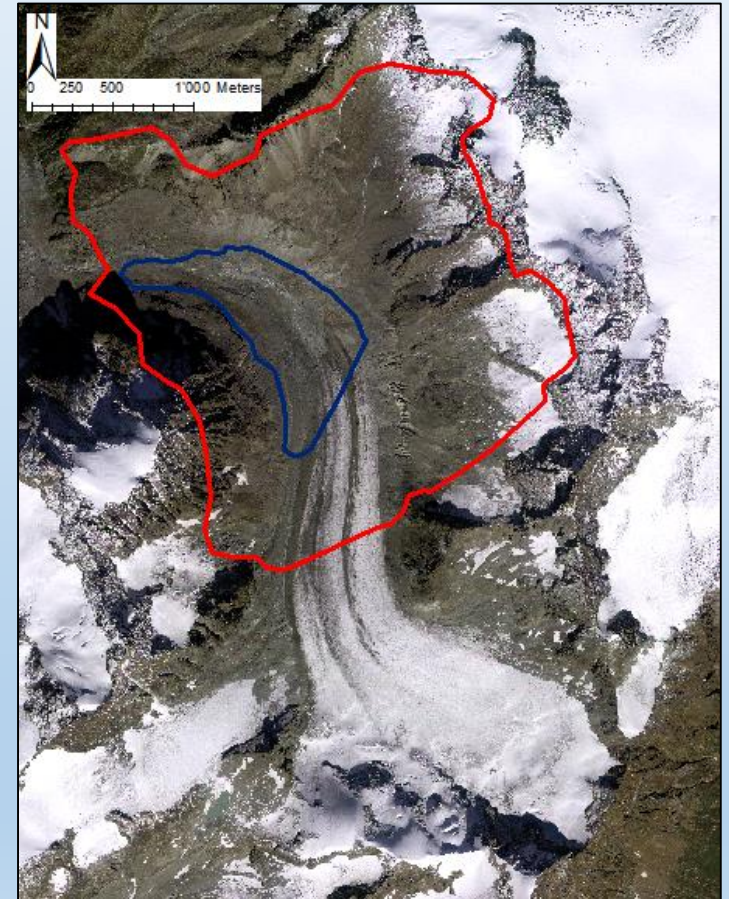
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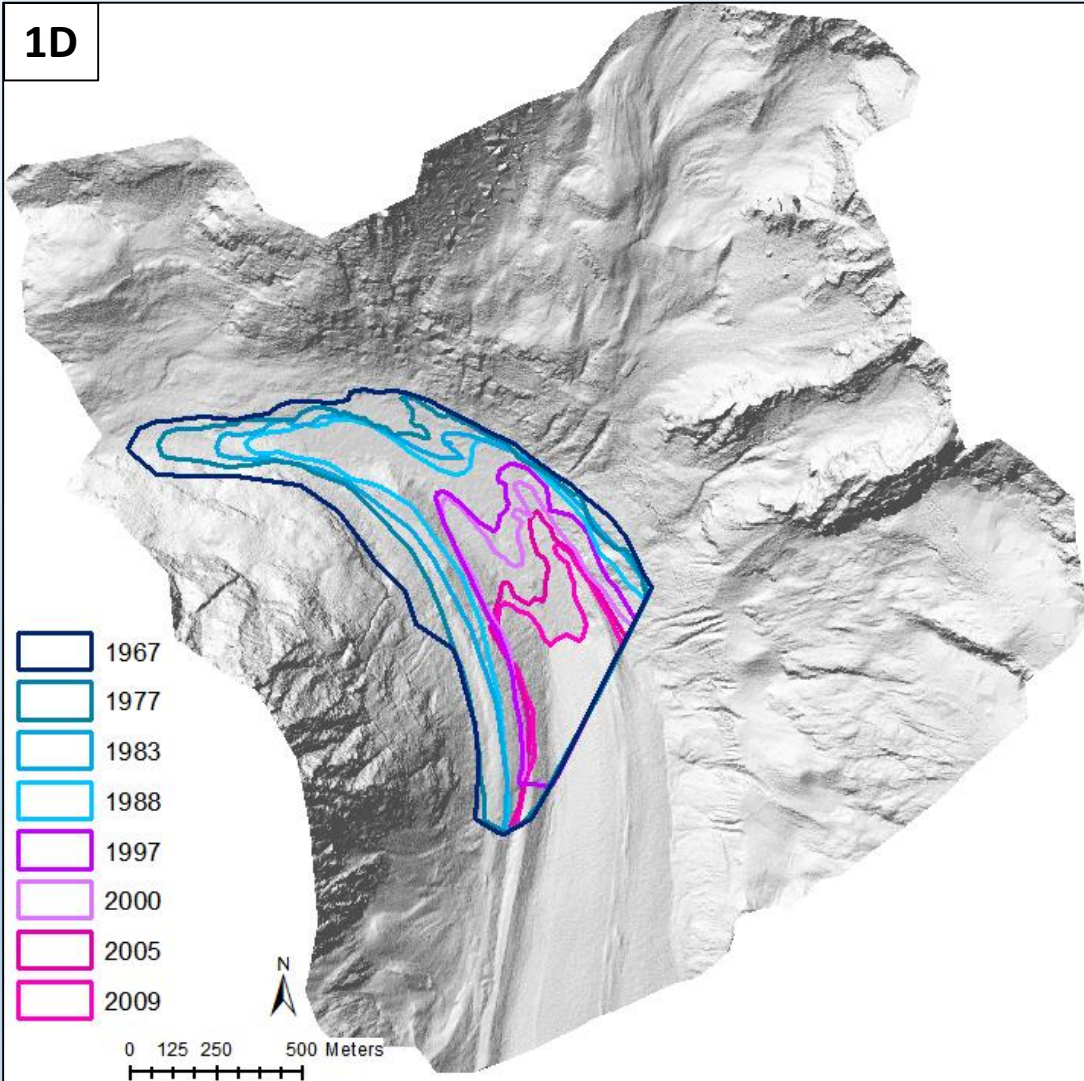
- ❖ 3D topography - Remote sensing
- ❖ Monitor the Haut Glacier d'Arolla at different time scales
- ❖ Better understand the interactions

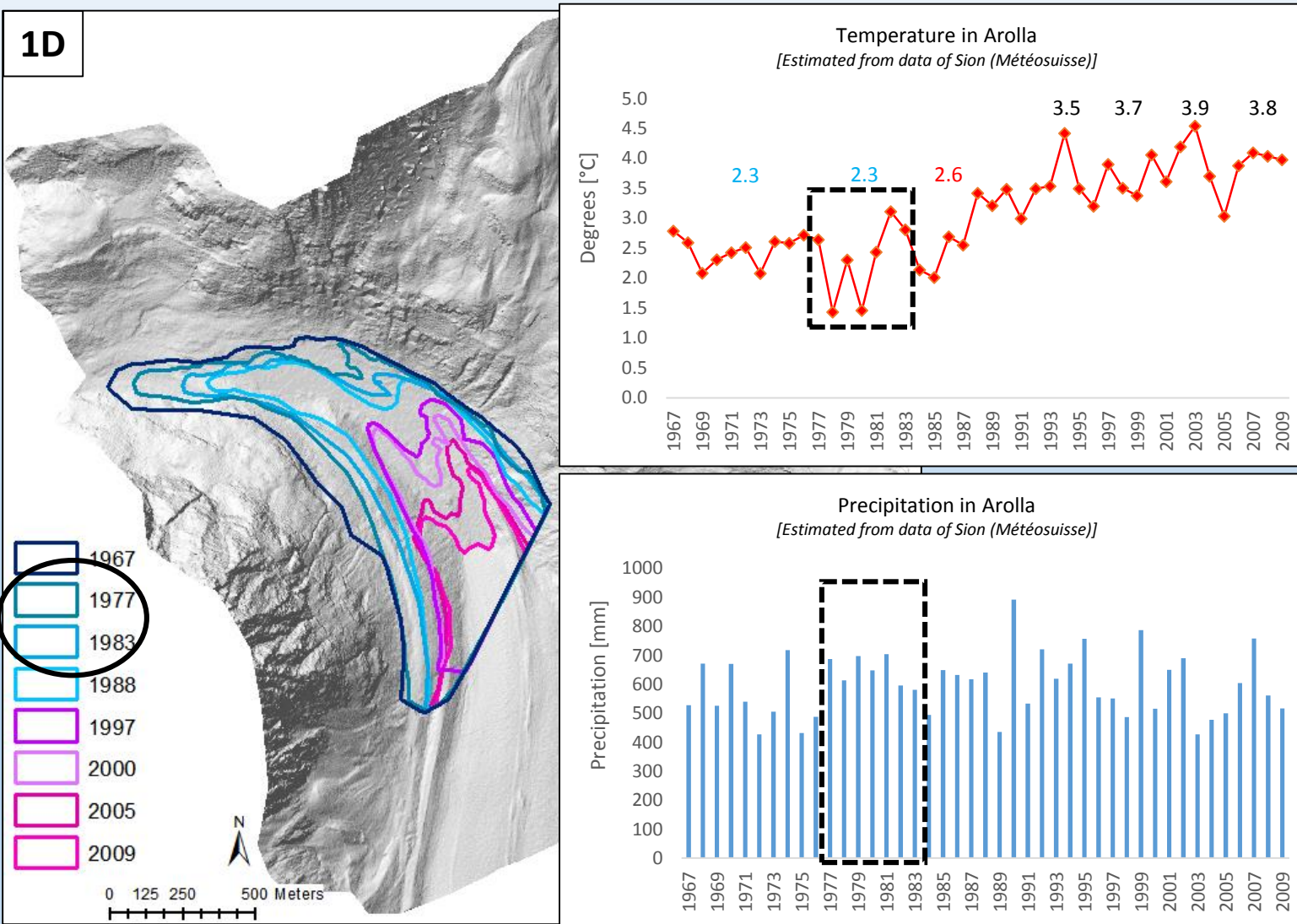


Response of an Alpine valley glacier to climate change at the decadal scale

- ❖ Establish glacier front stages – history (1D)
Establish change in elevation (2D)
Under climate forcing
- ❖ Archival digital photogrammetry
- ❖ Scale of decades, from 1967 to 2009







To advance early 1980s

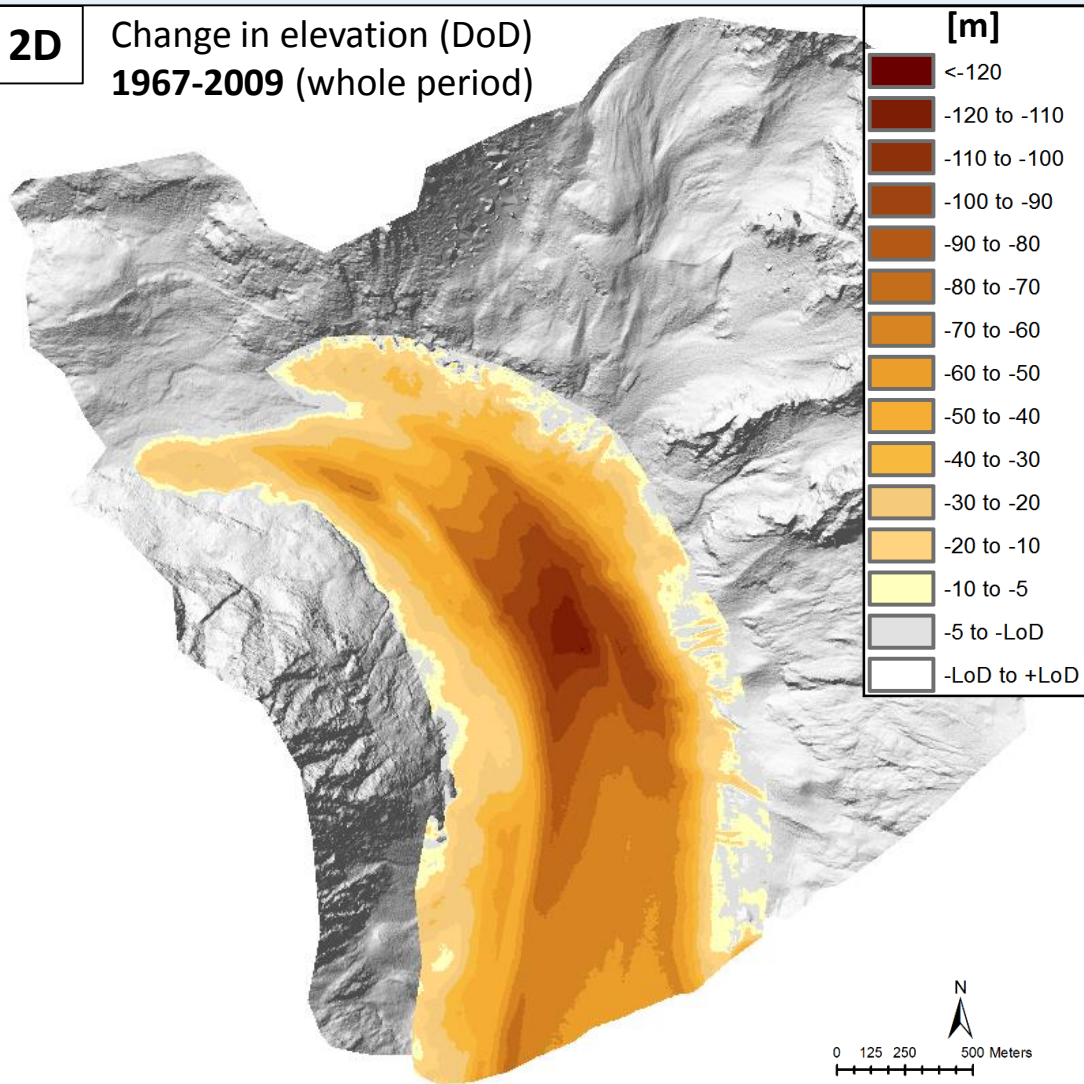
- Snow and ice accumulation > ablation
- Translation accumulation from upstream to downstream = Response time / delay
Function of morphology

→ Not fast enough

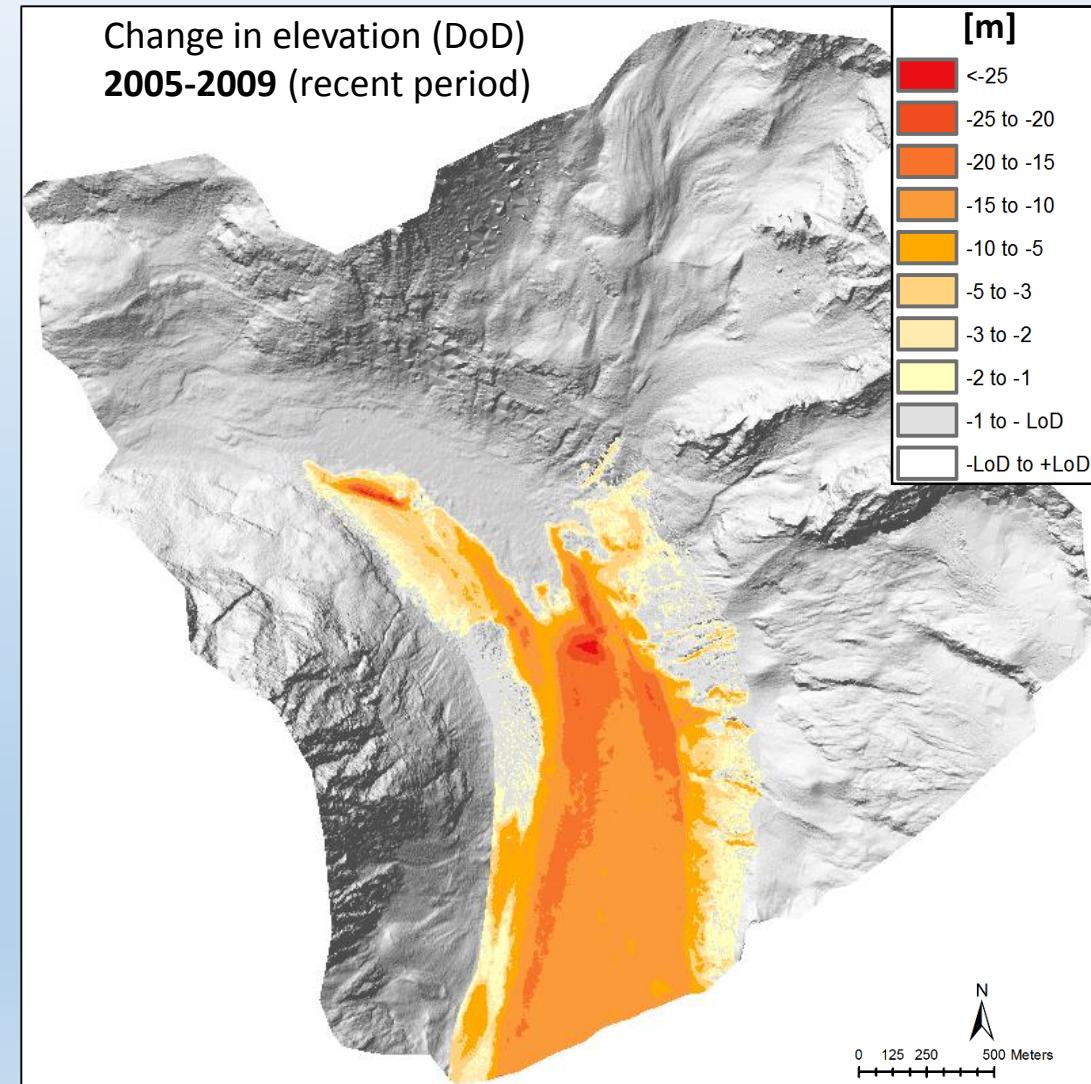
→ Different behaviour of its neighbours

2D

Change in elevation (DoD)
1967-2009 (whole period)

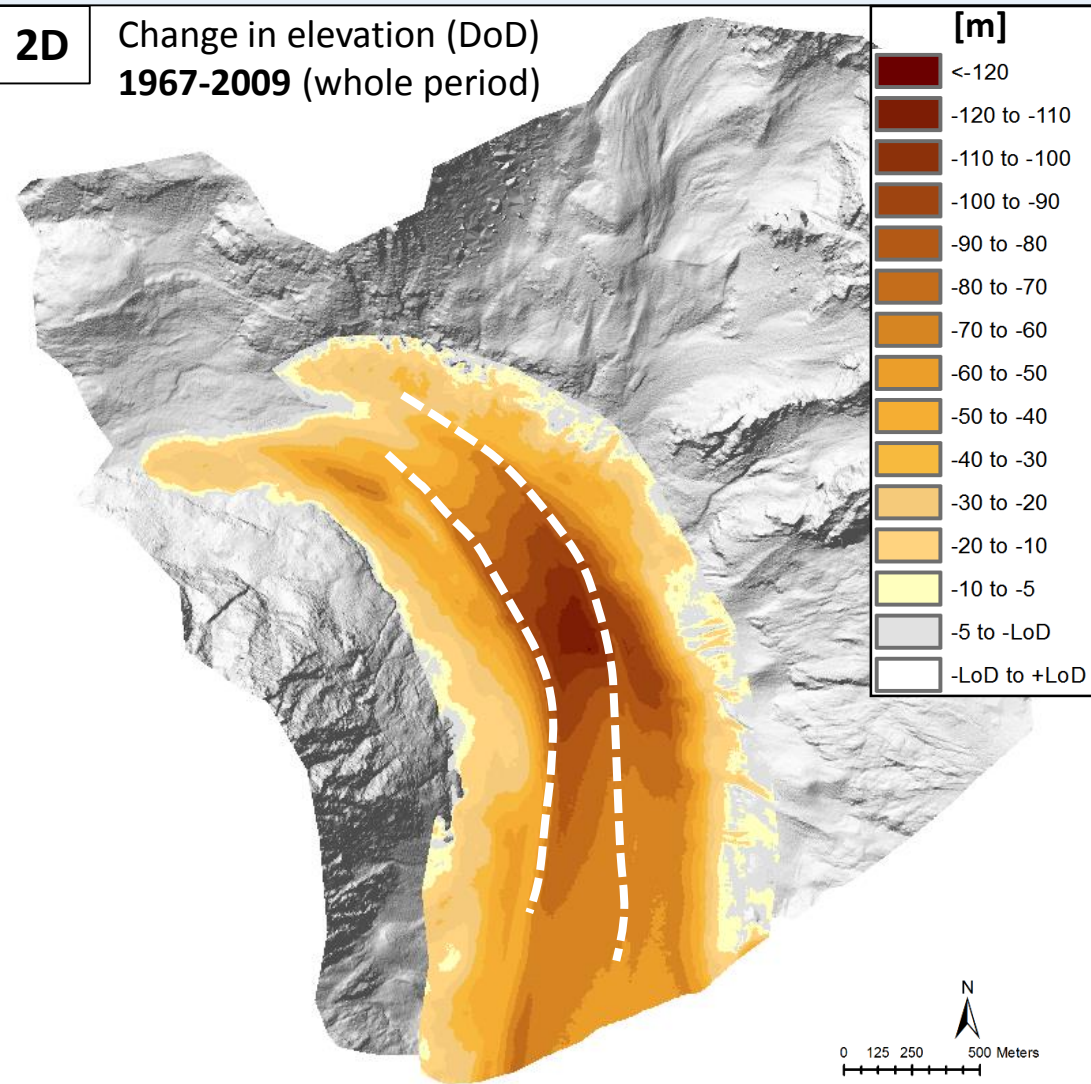


Change in elevation (DoD)
2005-2009 (recent period)

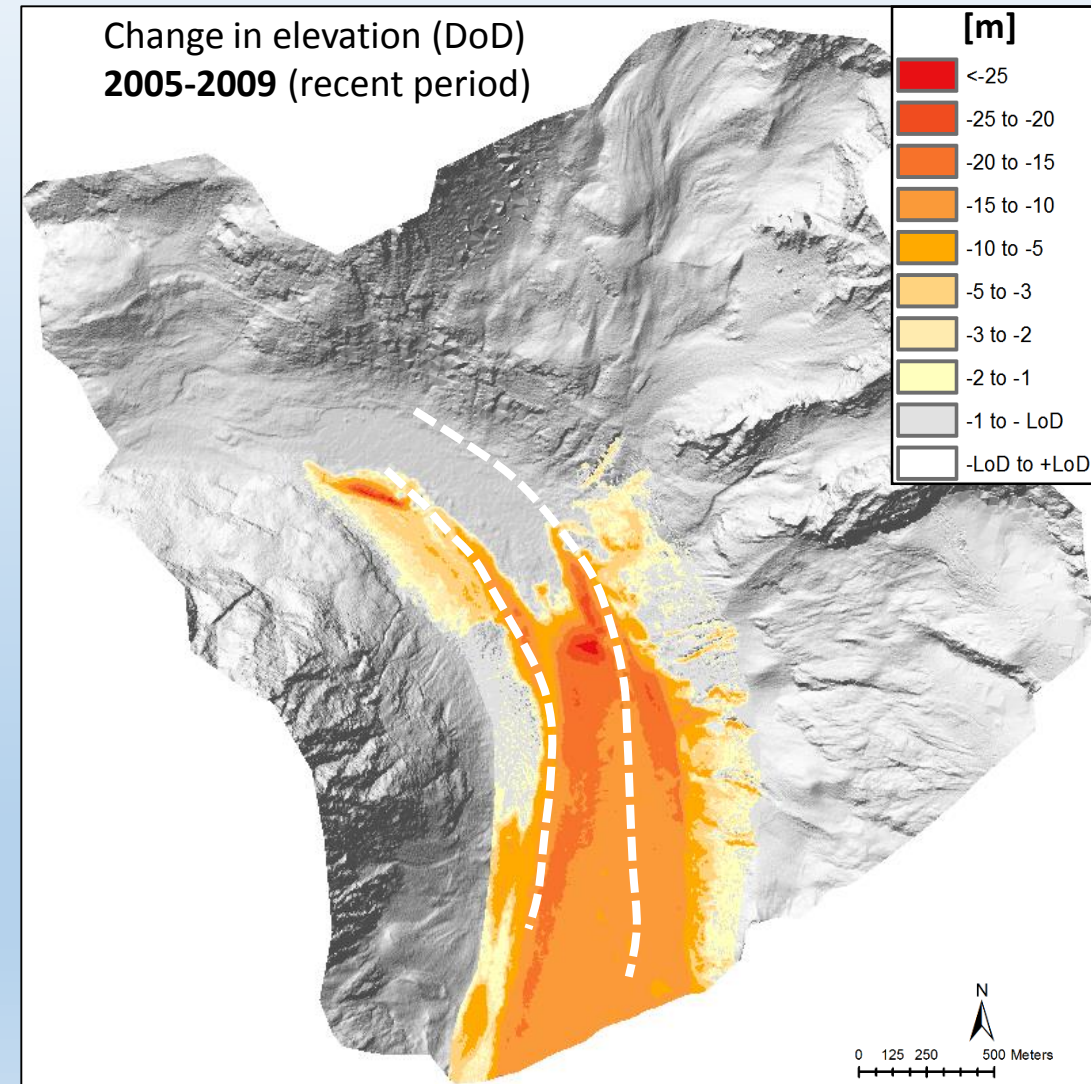


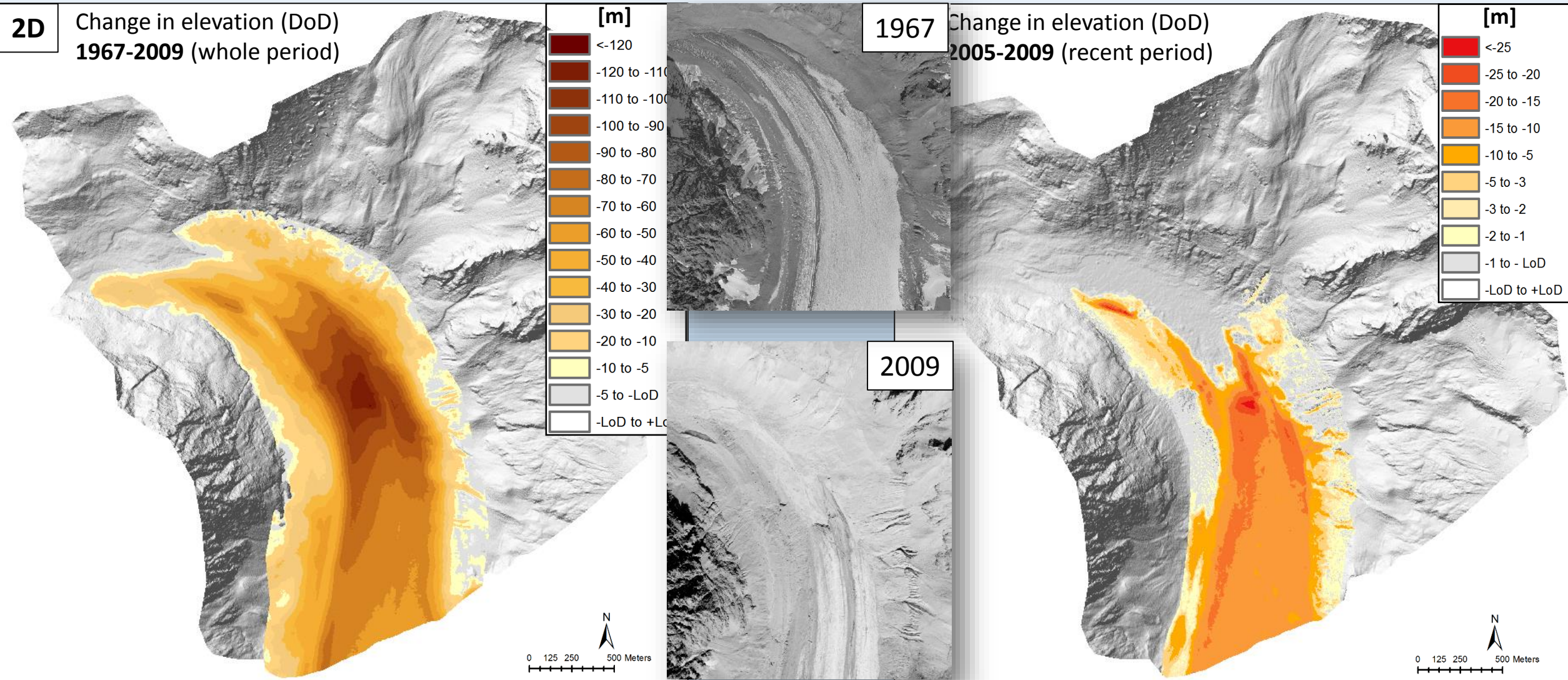
2D

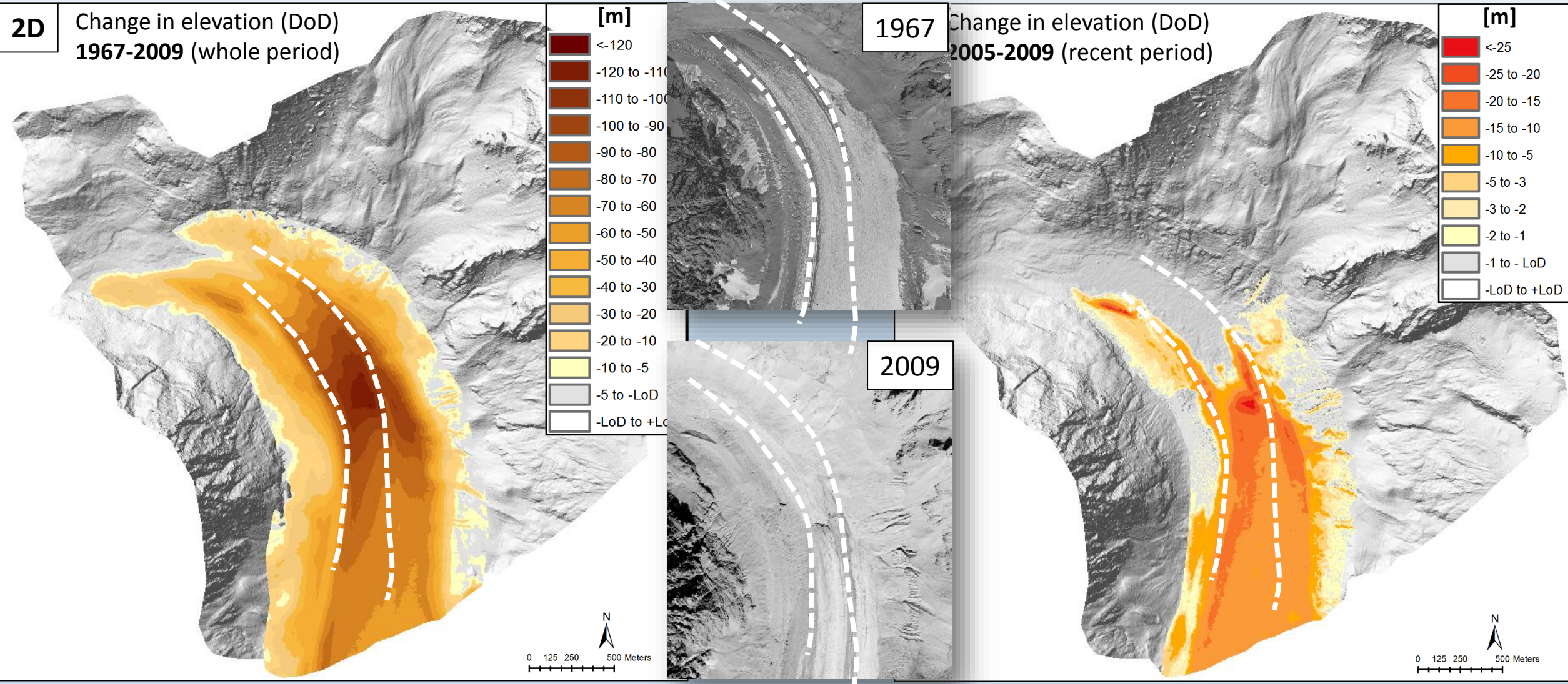
Change in elevation (DoD)
1967-2009 (whole period)



Change in elevation (DoD)
2005-2009 (recent period)







LiDAR measurement of surface melt for a temperate Alpine glacier, at the seasonal and hourly scales

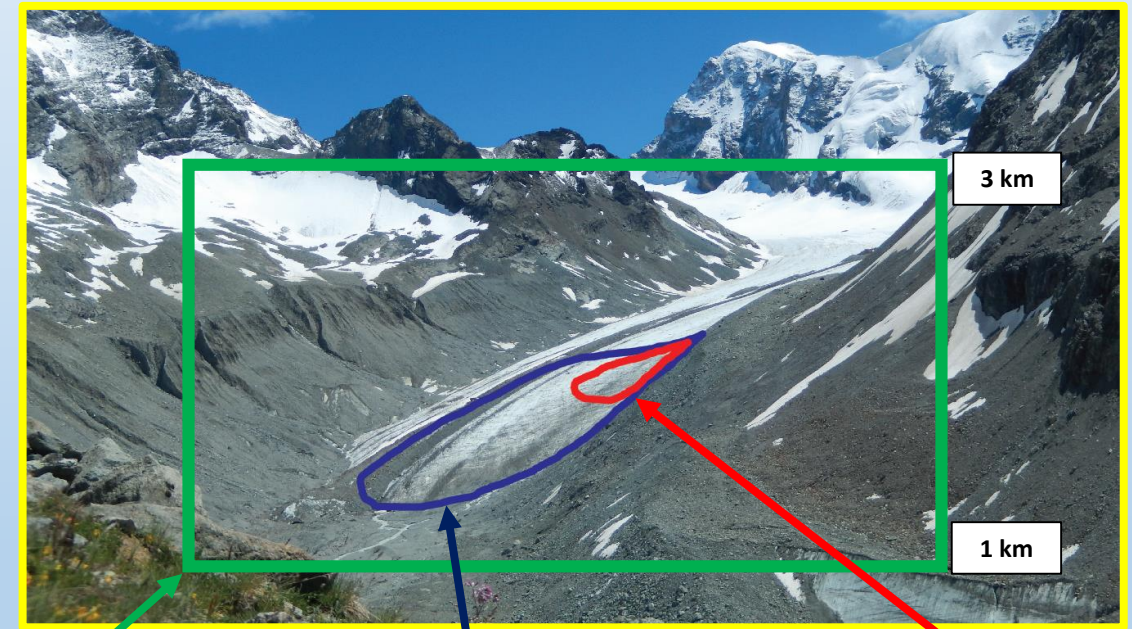
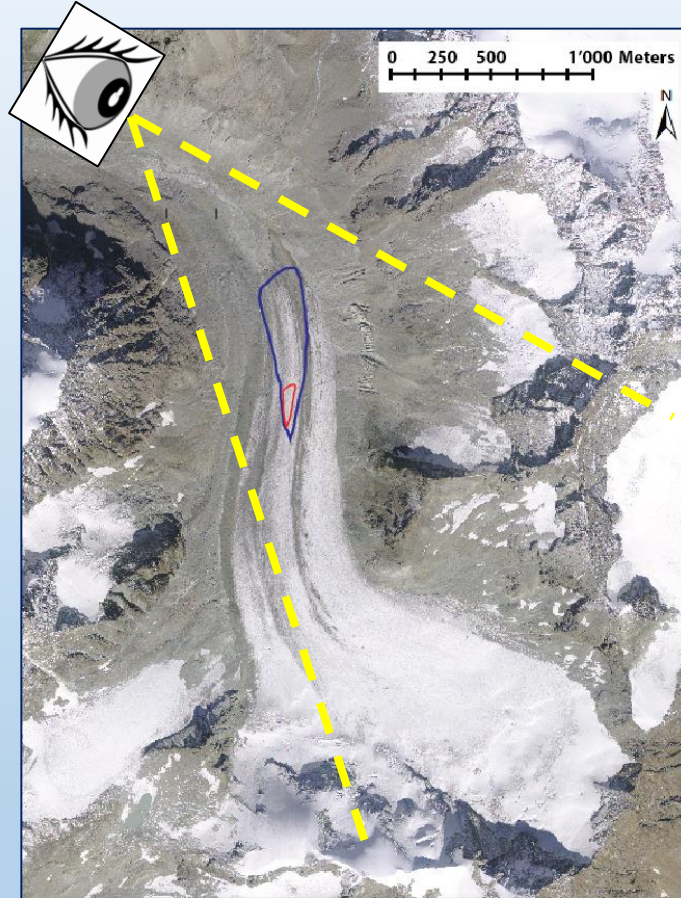
- ❖ Study the glacier surface ablation
Other elements of hydrodynamics
- ❖ Terrestrial laser scanner
LiDAR laser designed for snow and ice
- ❖ Seasonal + intra-daily scales



Seasonal and intra-daily scales / LiDAR

1. Two scales - one point of view

- Seasonal survey
06/07/2013
30/07/2013
05/08/2013
11/08/2013
15/09/2013
- Intra-daily survey
05/08/2013
9h – 17h each hour



Scan window

Seasonal area selected

Intra-daily area selected

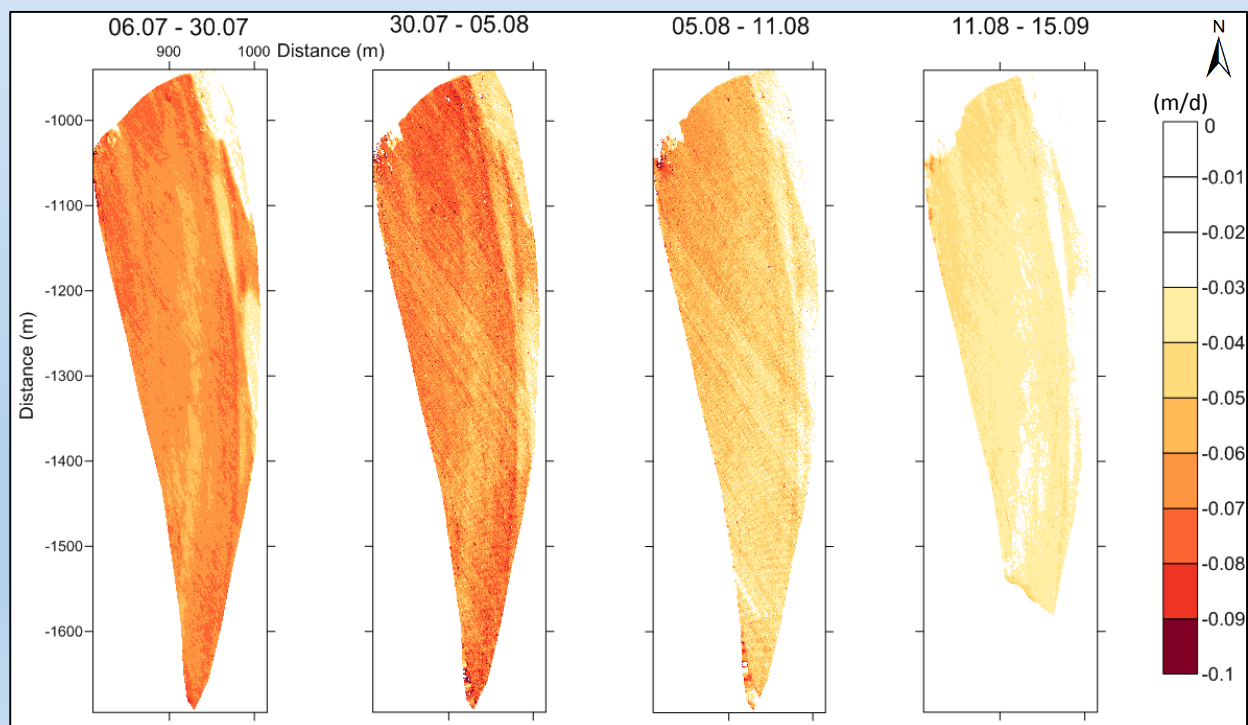
Seasonal and intra-daily scales / LiDAR

2. Result I - Seasonal scale changes

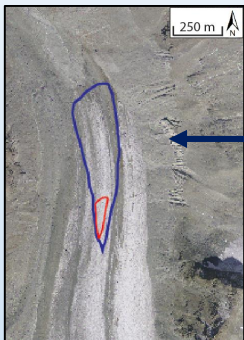


Seasonal survey

DoD by couples of dates, normalised by day

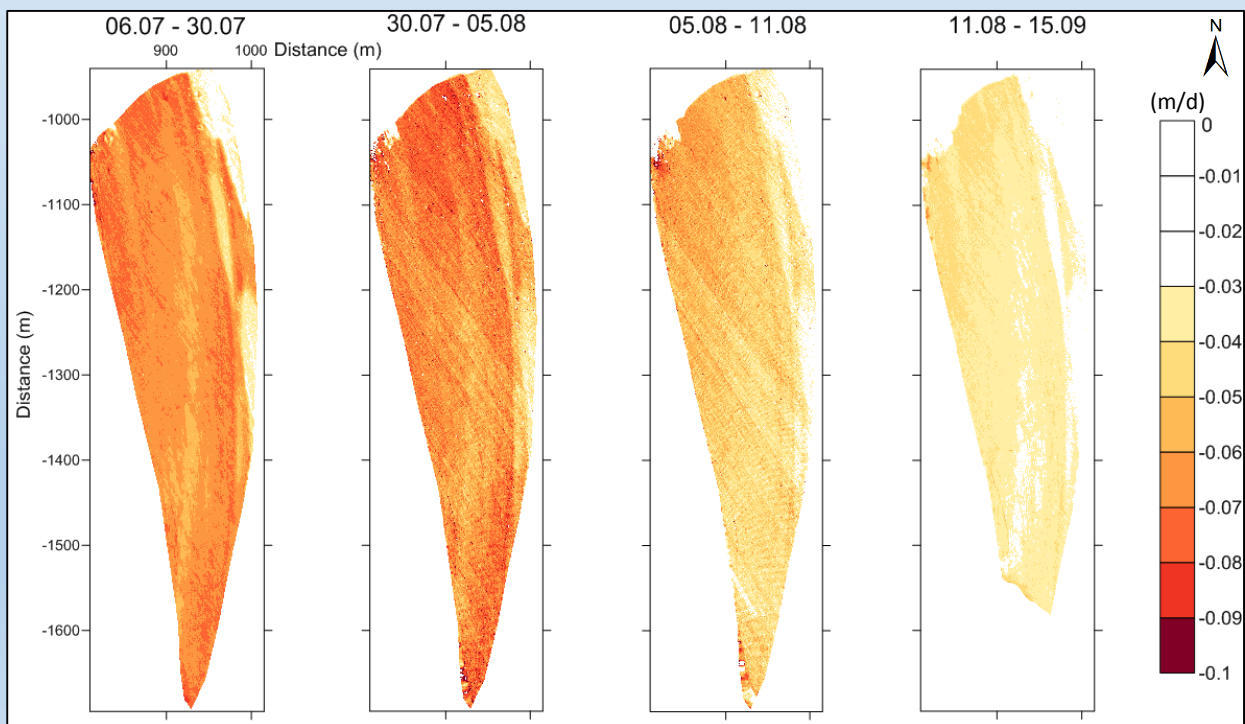


Seasonal area selected



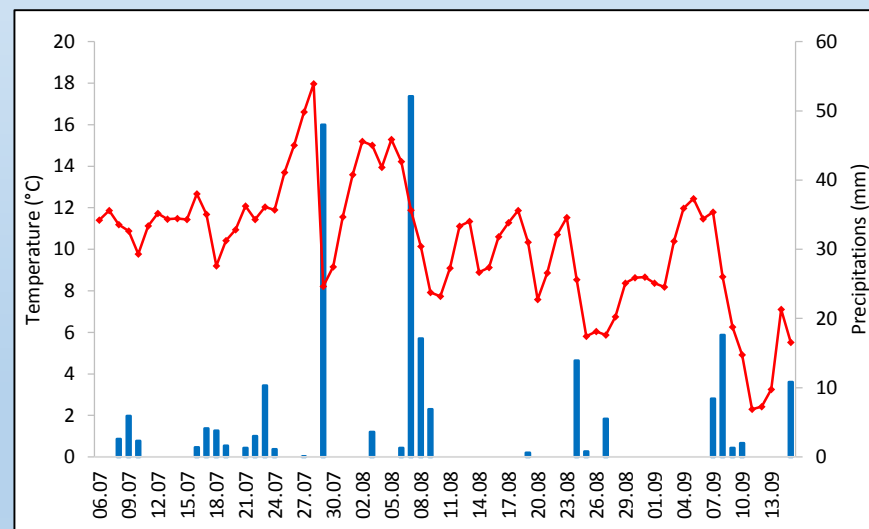
Seasonal survey

DoD by couples of dates, normalised by day



Surface vertical changes at seasonal scale

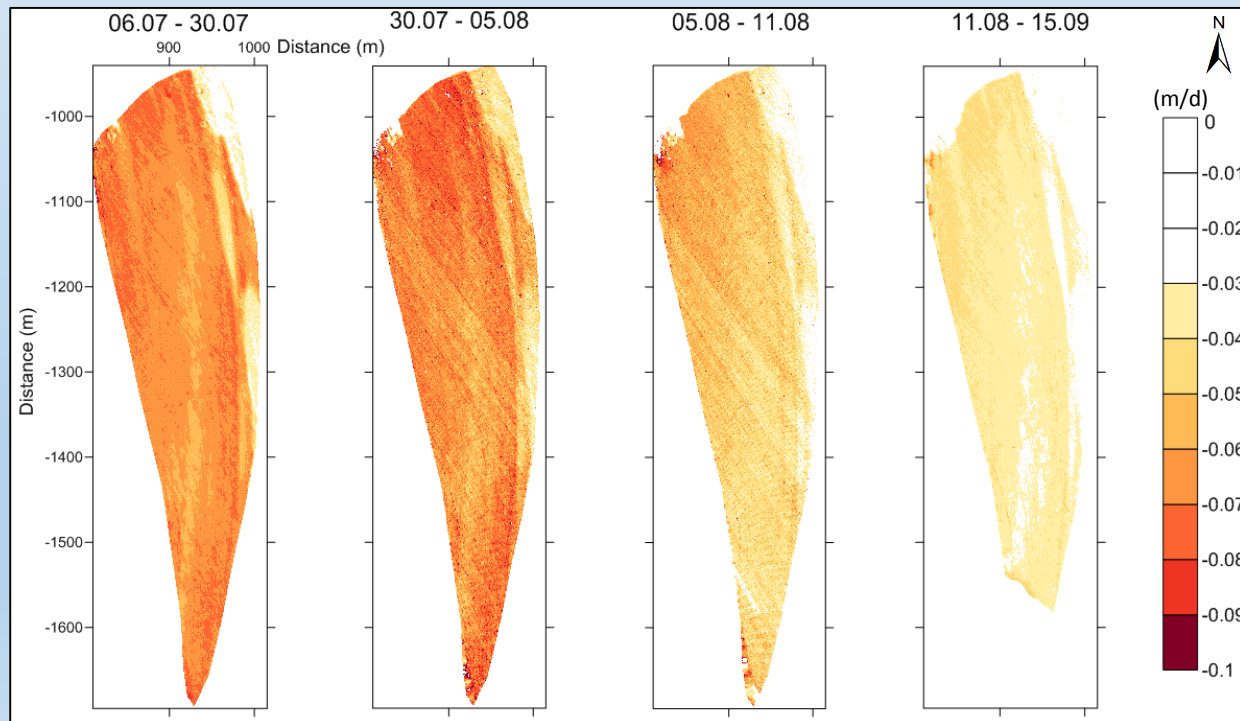
- Relation with seasonal meteorological conditions





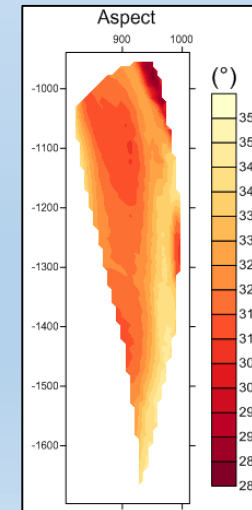
Seasonal survey

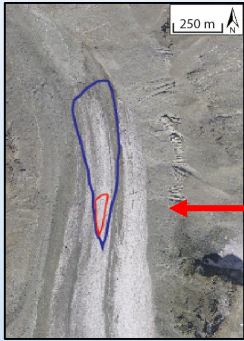
DoD by couples of dates, normalised by day



Surface vertical changes at seasonal scale

- Relation with seasonal meteorological conditions
- Relation with aspect
- Relation with debris cover, moraines
- Diagonal lines – LiDAR artefacts



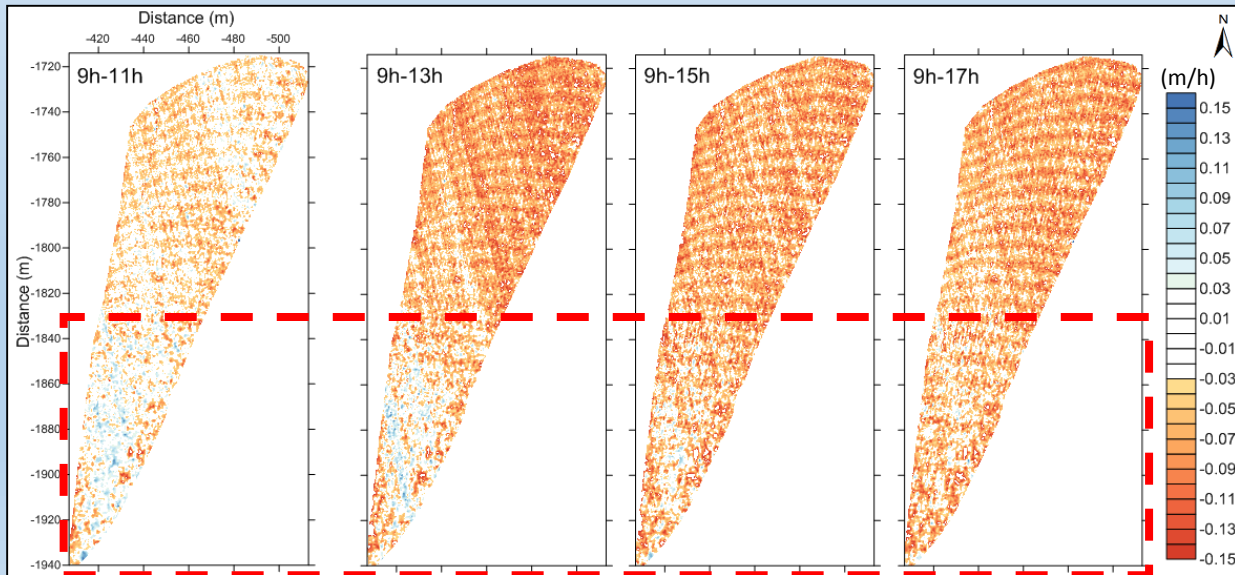


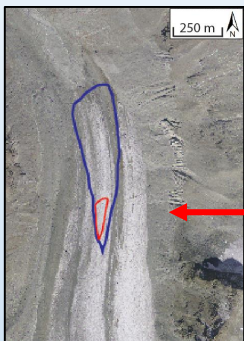
Intra-daily survey concerned = red delimitation

Surface vertical changes at intra-day scale

- Differential melt associated with ogives
- Positive change ?

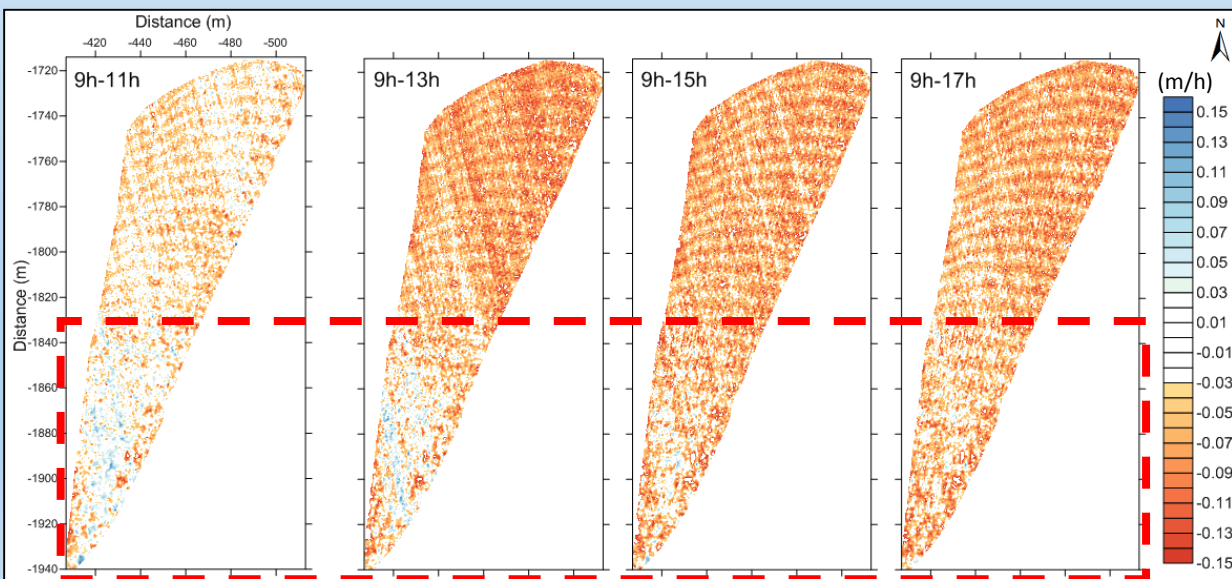
DoD 05/08/2013, 9h to each odd hour, normalised by hour





Intra-daily survey concerned = red delimitation

DoD 05/08/2013, 9h to each odd hour, normalised by hour



Surface vertical changes at intra-day scale

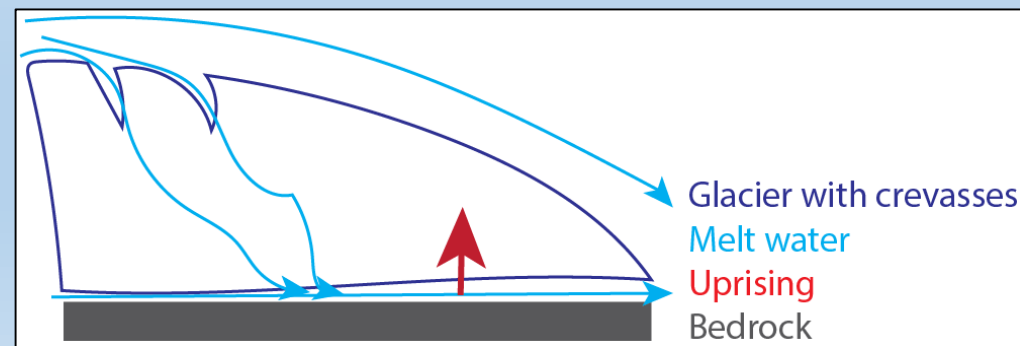
- Differential melt associated with ogives
- Positive change

Hydraulic jacking?

Morphological change of subglacial channels

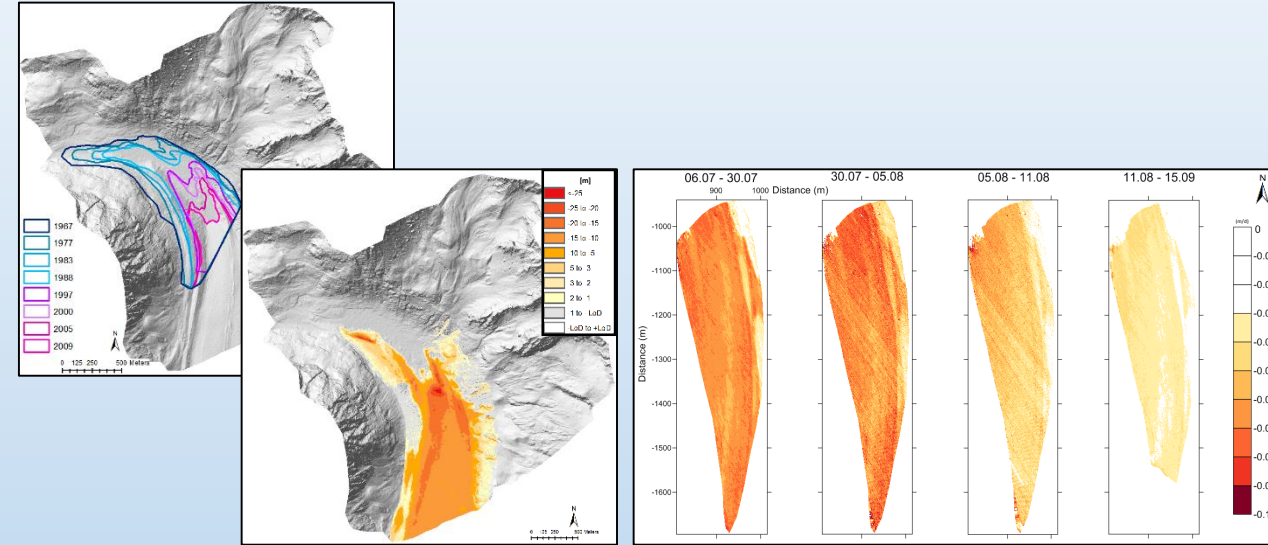
Ice - bed decoupling by water pressure

→ Uplift



Reminders

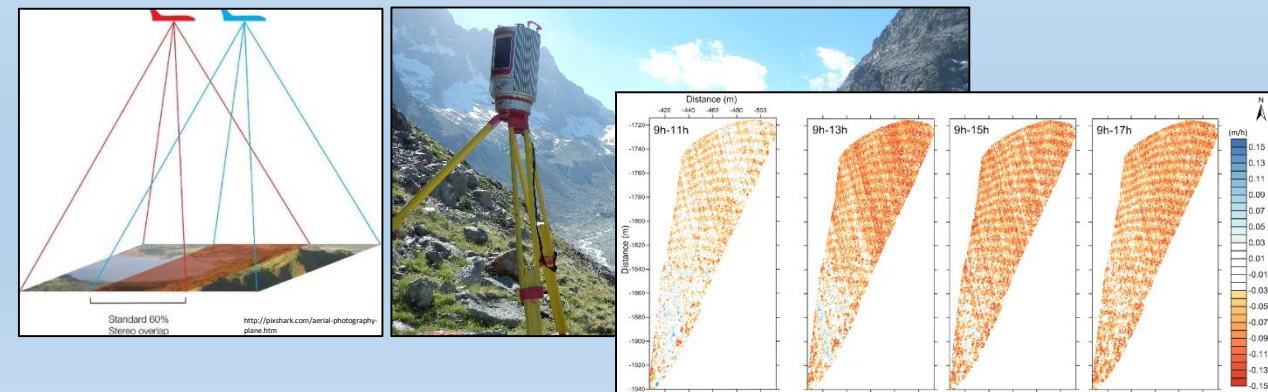
- Haut Glacier d'Arolla in continuous recession since 1967; even during snowier and colder periods
→ Response time
- Melt rates - spatial patterns
→ Climate + debris cover effects
- Glacier dynamics at three time scales
→ Decades, season, intra-day
- Relevance remote sensing methods
- Issue of the hydraulic jacking



1967 → 2009

summer 2013

05/08/2013 – 9h → 17h



Gabbud C., Micheletti N. and Lane S.N. (2015). LiDAR measurement of surface melt for a temperate Alpine glacier at the seasonal and hourly scales. **Journal of Glaciology**, 61(229), 963-974. [10.3189/2015JoG14J226].

Gabbud et al., Response of a temperate Alpine valley glacier to climate change at the decadal scale (in revision). Submitted to: **Geografiska Annaler: Series A, Physical Geography**.

Acknowledgments

- ❖ Herbette Foundation
- ❖ University of Lausanne
- ❖ Federal Office of Topography Swisstopo
- ❖ All the collaborators and colleagues
- ❖ **Prix de Quervain Jury**



Thanks to you!