Volcanic impacts on glacier surface velocity of Cone glacier using Sentinel-2 data

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This presentation participates in OSPP

Outstanding Student & PhD candidate Presentation contest

Abstract

Social media

EGU22-3569

Volcanic impacts on glacier velocity

What is our work about?

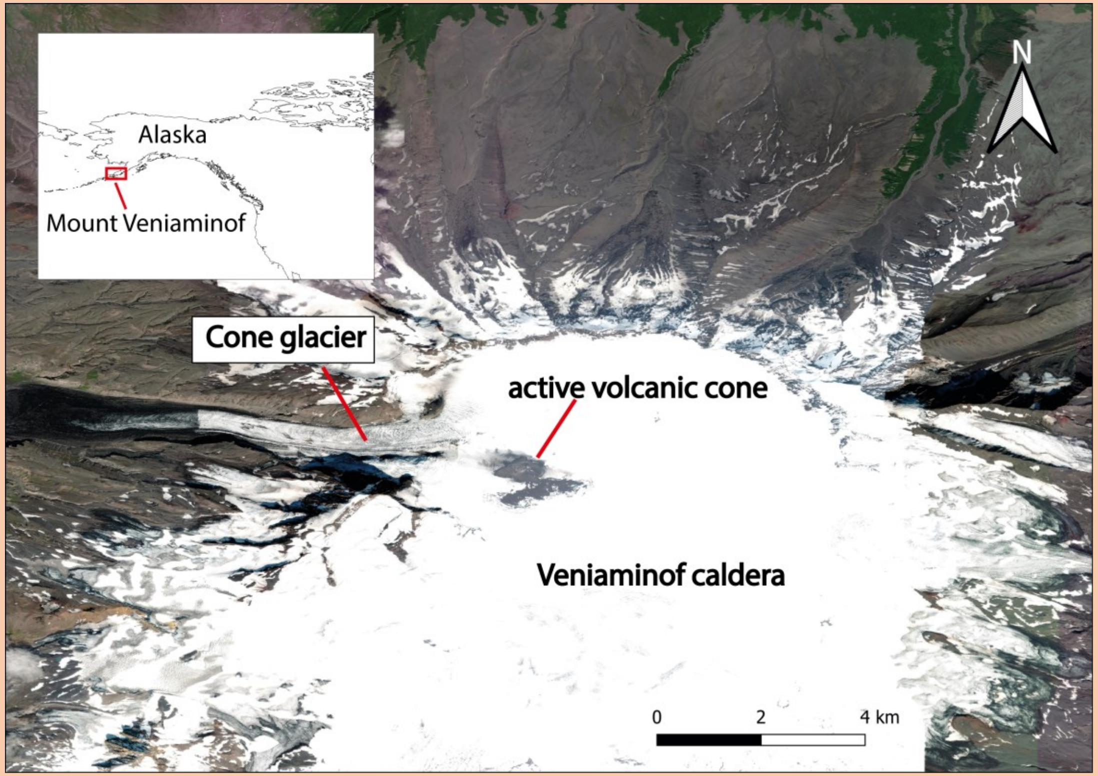
- Glaciers located on active volcanoes ("volcanic glaciers")
- Volcano-glacier interaction (e.g. increased subglacial meltwater production)

➢ "volcanic" glacier expected to flow faster/advance during or even **prior** to volcanic activity

Research question

Can we see changes in the surface velocity of Cone glacier before an eruption on Mount Veniaminof?

Mount Veniaminof



[1,2]

Mount Veniaminof

Mt Veniaminof

- One of the largest and most active volcanoes in the Aleutian Arc (located between Alaska and Russia)
- 2507-m high stratovolcano with 8x10 km ice-filled caldera
- Active volcanic cone in western part of caldera close to **Cone glacier**
- Focus of this work:

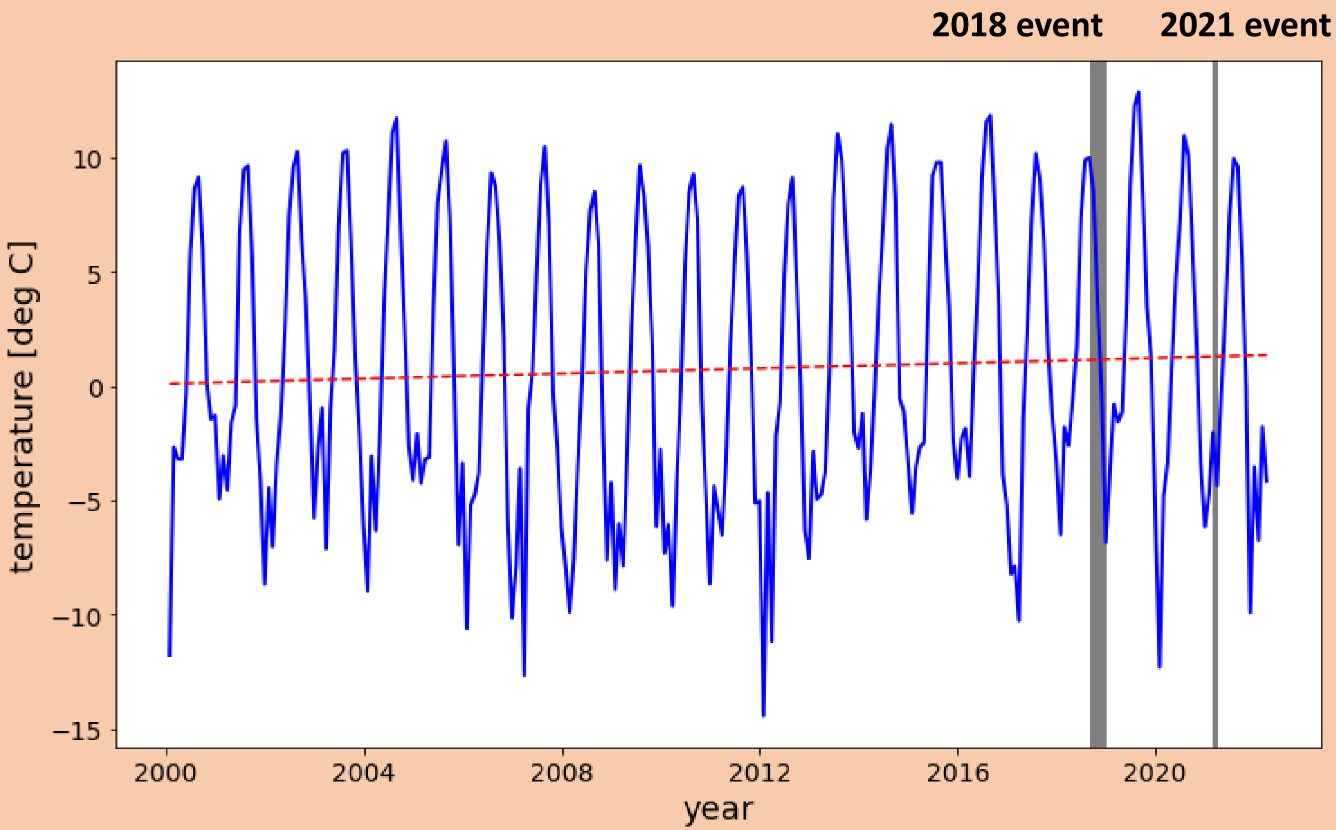
2018 volcanic event (VEI: 2): September-December 2018

2021 volcanic event (VEI: 1): March/April 2021

➢ Strombolian events; both with reported ash emissions, lava effusion and lava interaction with snow/ice

Aleutian climate and glaciers

Temperature curve for Cone glacier



➢ Temperature data: KNMI monthly re-analysis temperature data [3]

Aleutian climate

- cool, windy and wet climate
- Eastern Aleutians: general shift towards warmer climate since 1977 (Rodionov et al. 2005)
- Some stations in vicinity of Mt Veniaminof reported decreases in mean annual temperature for period from 1977-2004 (Molnia et al. 2007)

→ Slight increase in air temperature [0.06°C/year] for Cone glacier from 2000-now (dashed line, see left)

Aleutian glaciers

- All larger valley and outlet glaciers in Aleutian range reported to thin/retreat (Molnia et al. 2007)

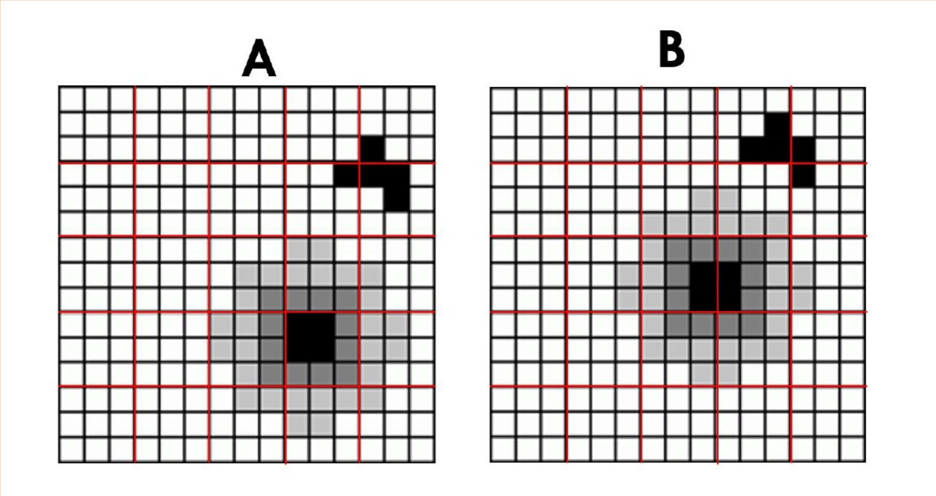
→ Cone glacier **stagnant** for time period from 2016-now

Feature tracking on Sentinel-2 images


[4]

Sentinel-2 satellite

Feature tracking



[5]

- Tracking of displacement of irregularities on the glacier surface on a series of satellite images (e.g. crevasses, debris)
- Measured displacement and time difference between images → velocity
- Our work: ~100 satellite images from 2016-2022

Software

Glacier Image Velocimetry

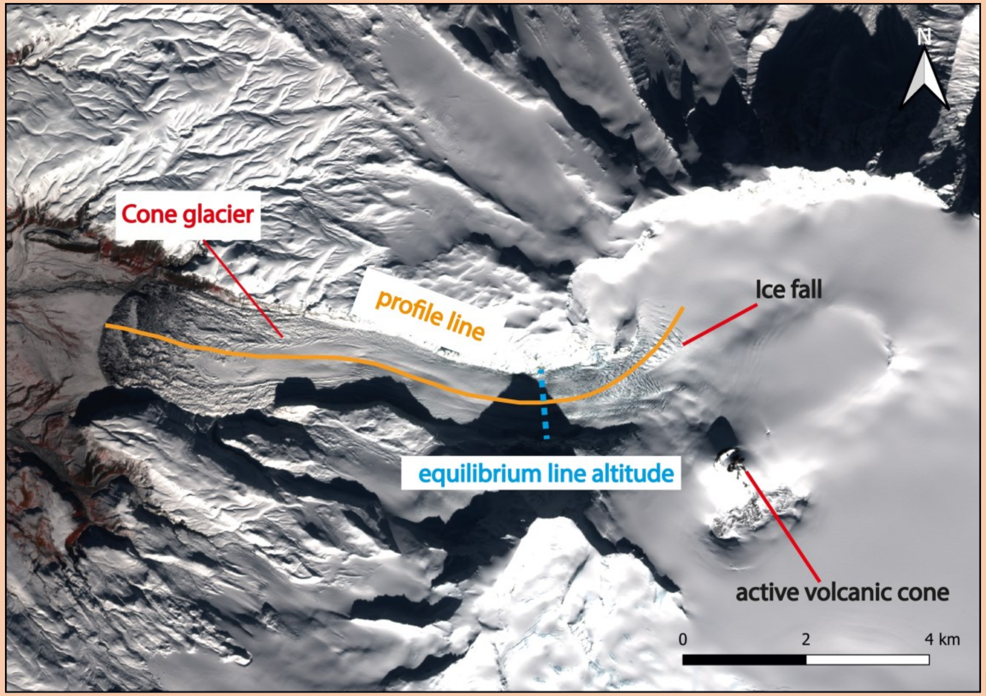
[5]

van Wyk de Vries et al. 2021

- Rapid calculation of displacements for hundreds of image pairs
- Derivation of monthly velocities from displacement fields

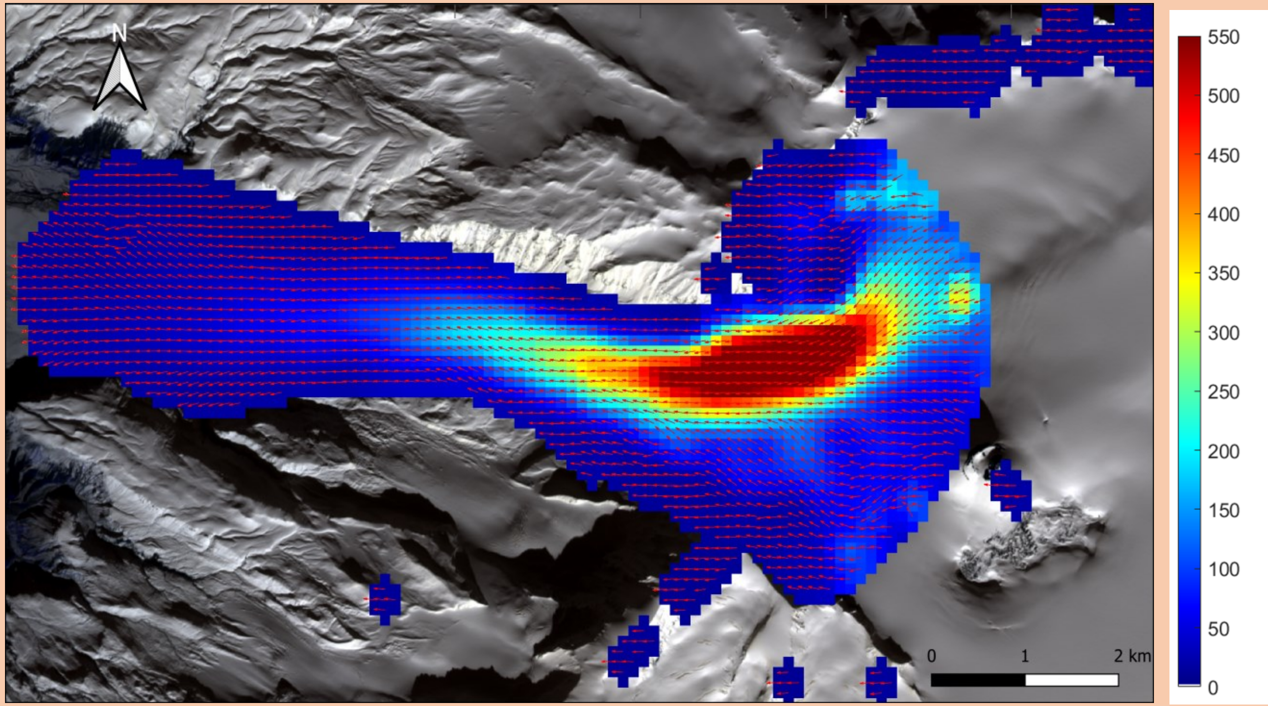
Mean velocity and flow direction

Cone glacier overview



[6]

Velocity field



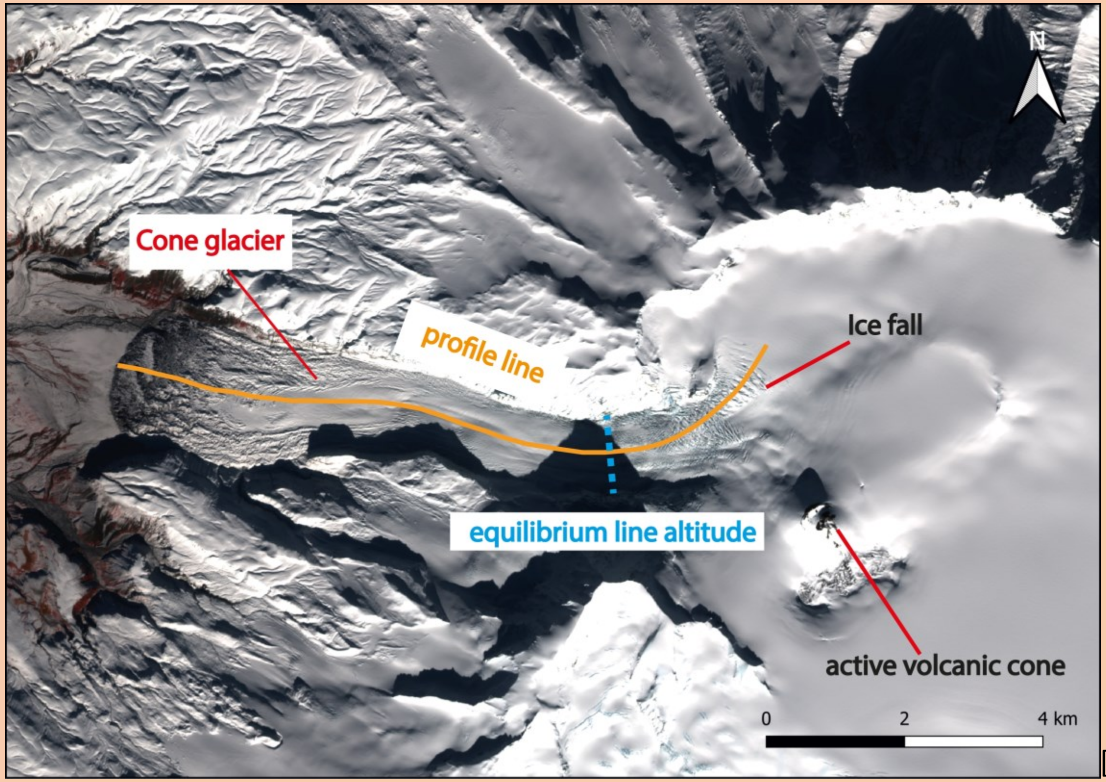
[*]

- **High velocity zone in ice fall area**
- **Main inflow of ice to Cone glacier from north-east**

[*] background image from Copernicus Sentinel data [2020] (see [6])

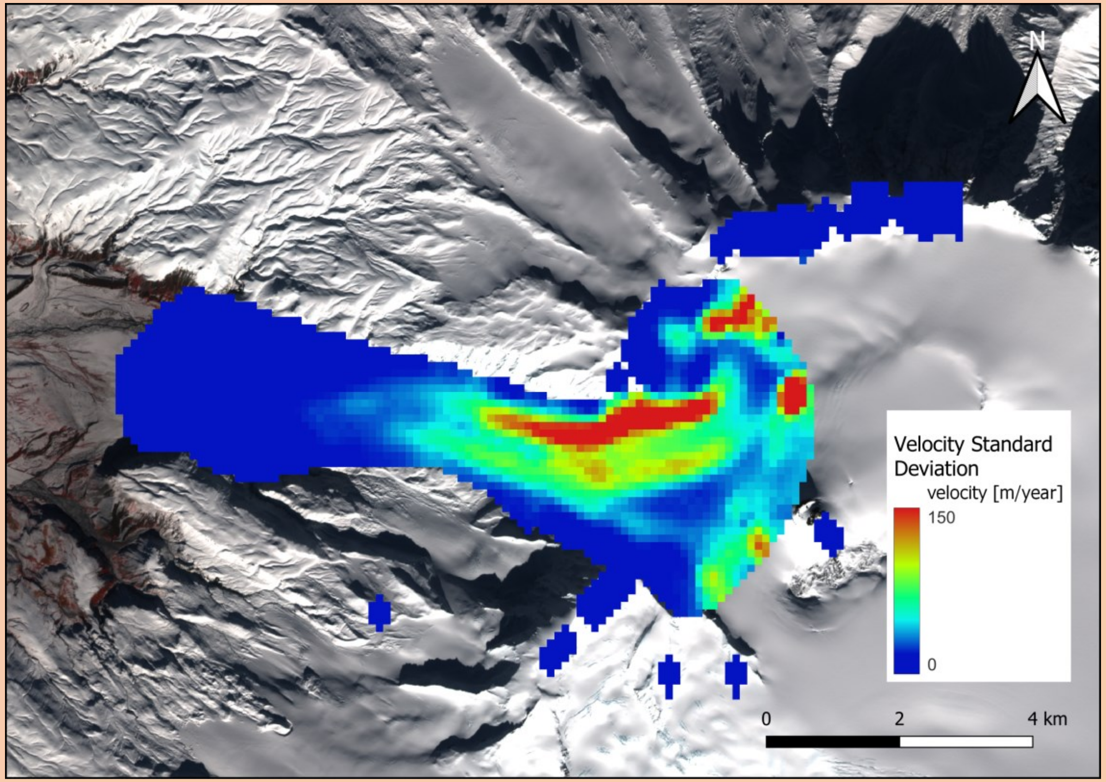
Velocity accuracy

Cone glacier overview



[6]

Velocity standard deviation



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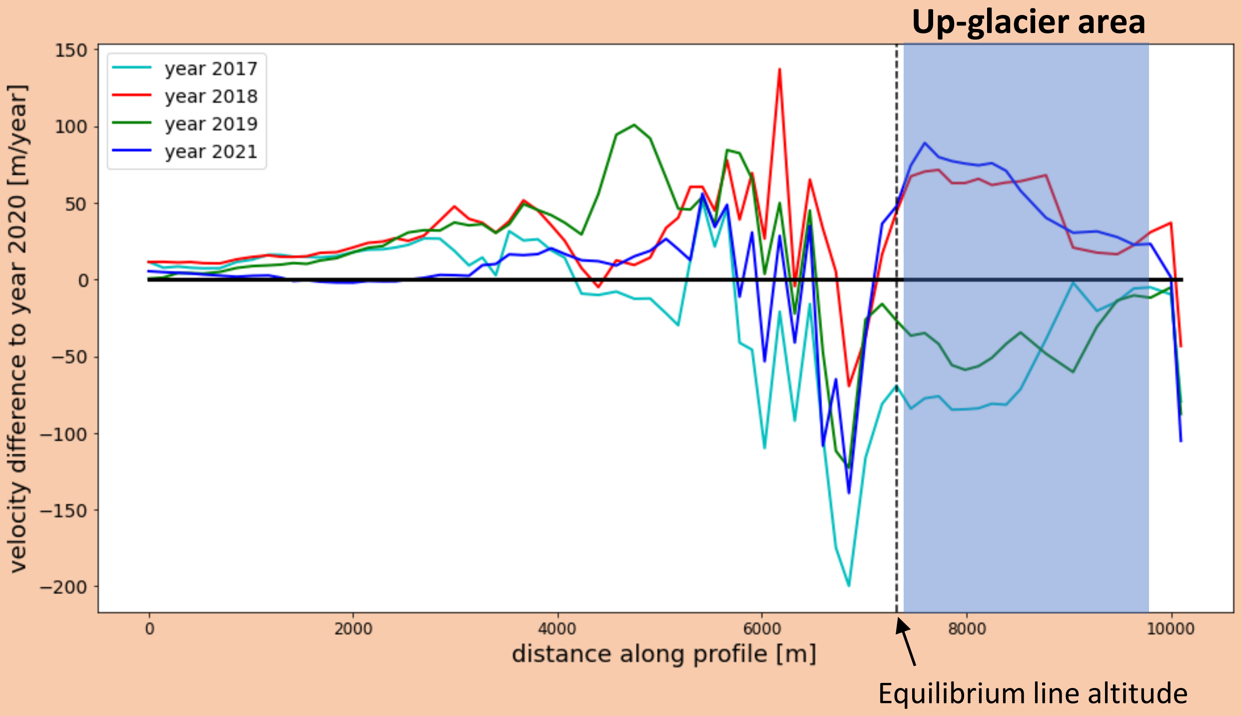
- Larger standard deviation for higher velocities in ice fall area

[*] background image from Copernicus Sentinel data [2020] (see [6])

Velocities along profile line

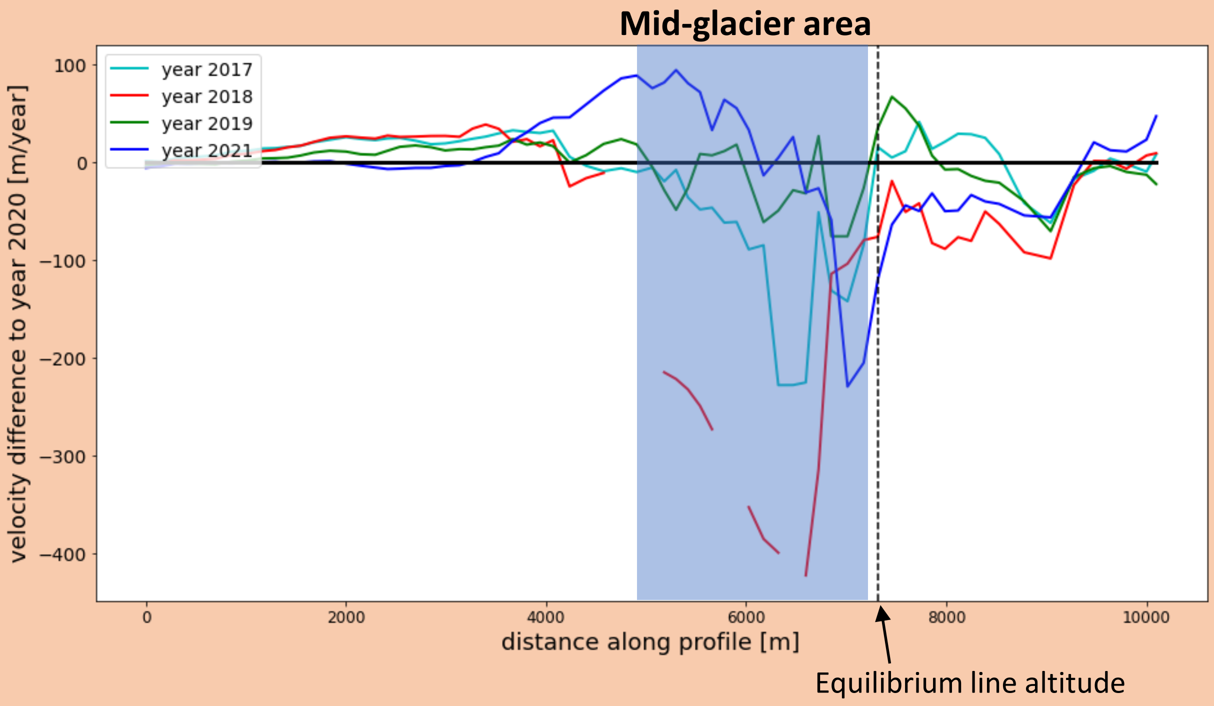
- Years with volcanic activity: 2018 and 2021

March velocity deviation from 2020



- Higher velocities in March for both years with active volcanic phases (2018 and 2021) for up-glacier areas (above equilibrium line altitude)

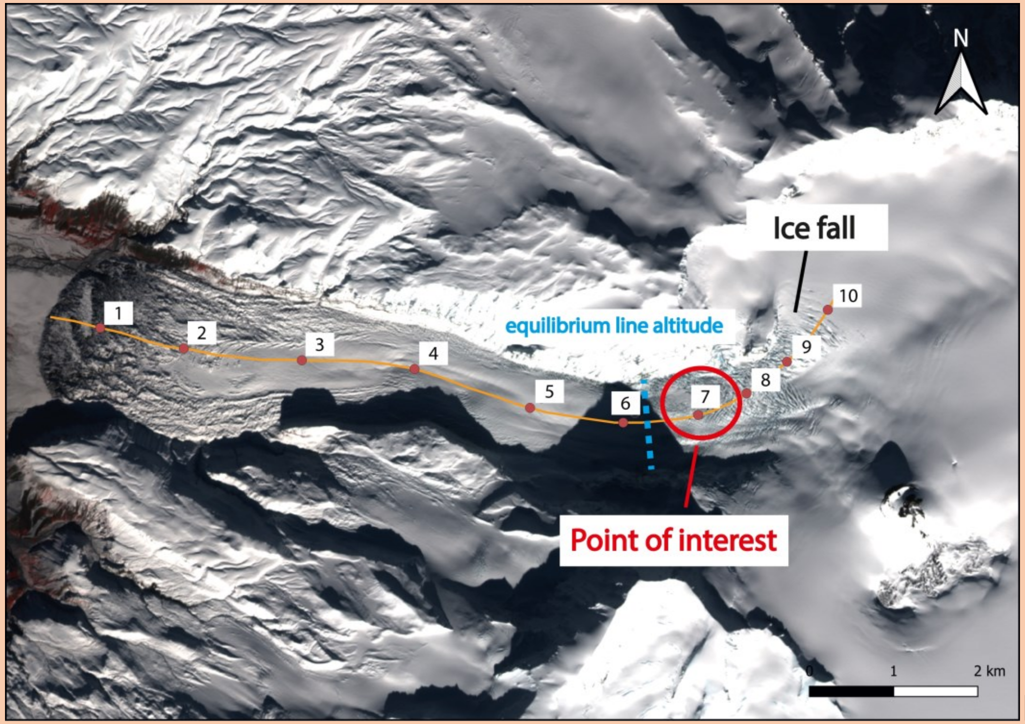
October velocity deviation from 2020



- Slower velocities for October 2018 (during active volcanic phase) especially for mid-glacier areas (below equilibrium line altitude)

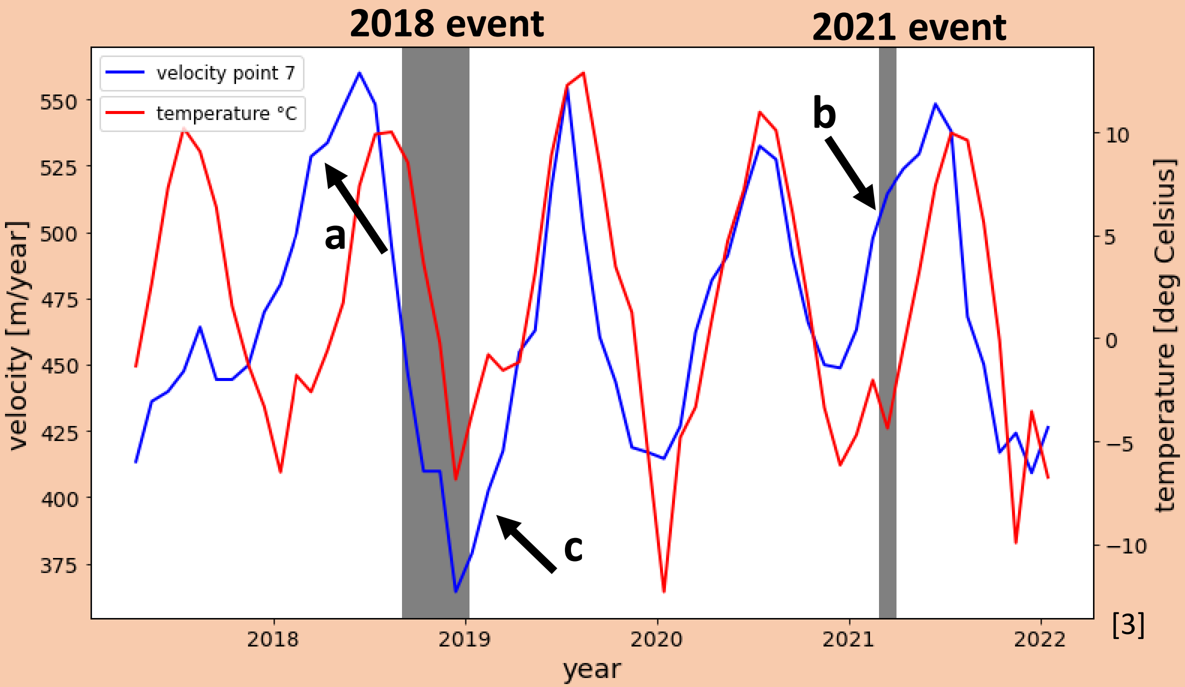
Glacier velocity time-series

Points along profile line



[6]

Velocity time series vs temperature

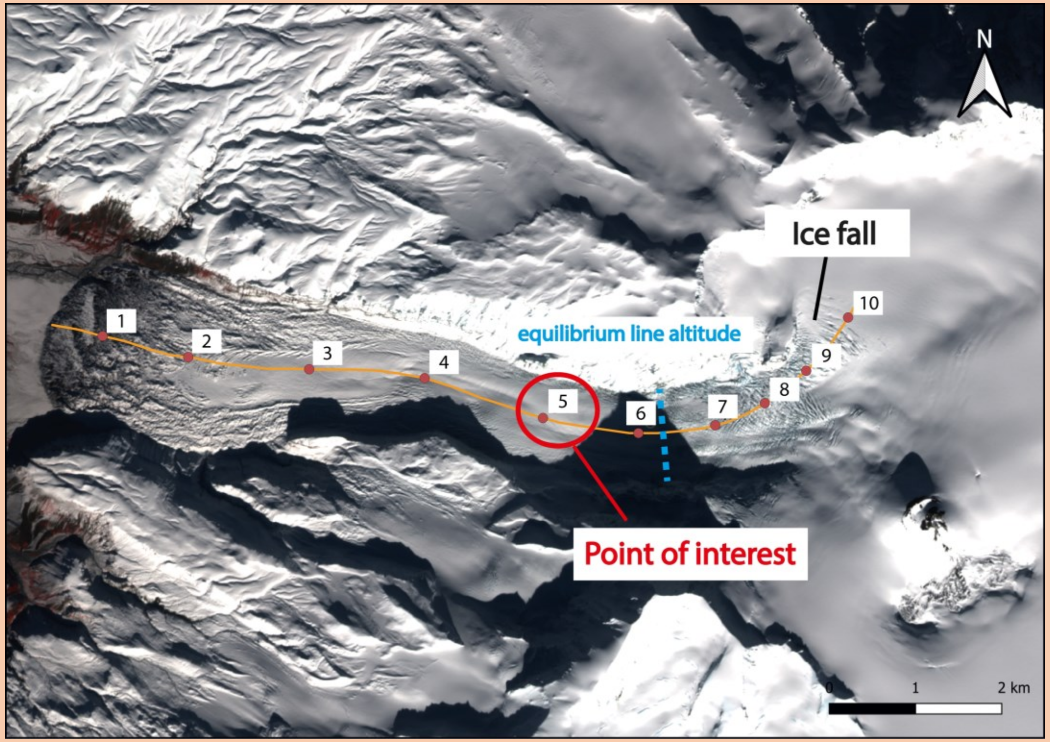


[3]

- Clearly visible seasonal cycle of glacier surface velocity (R^2 = 0.257)
- shift of velocity curve to higher velocities prior to 2018 and 2021 active volcanic events = **pre-event speed-up** (a,b)
- Amplified seasonal slow-down **during/after** 2018 event (c)

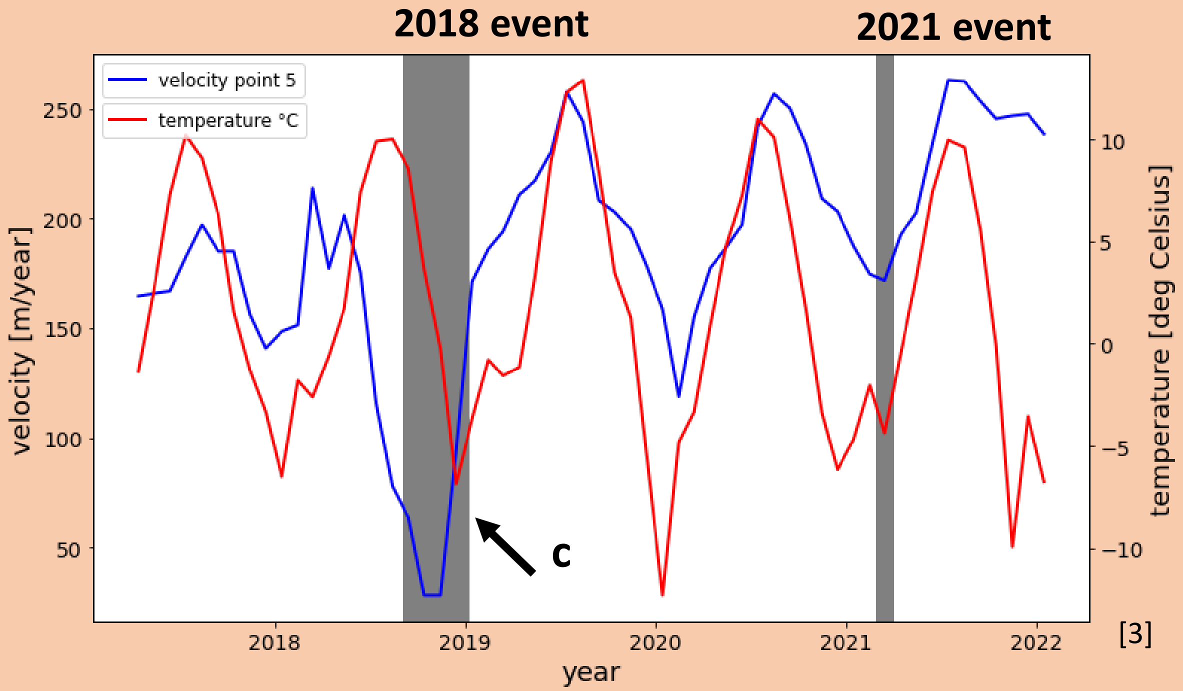
Glacier velocity time-series (2)

Points along profile line



[6]

Velocity time series vs temperature

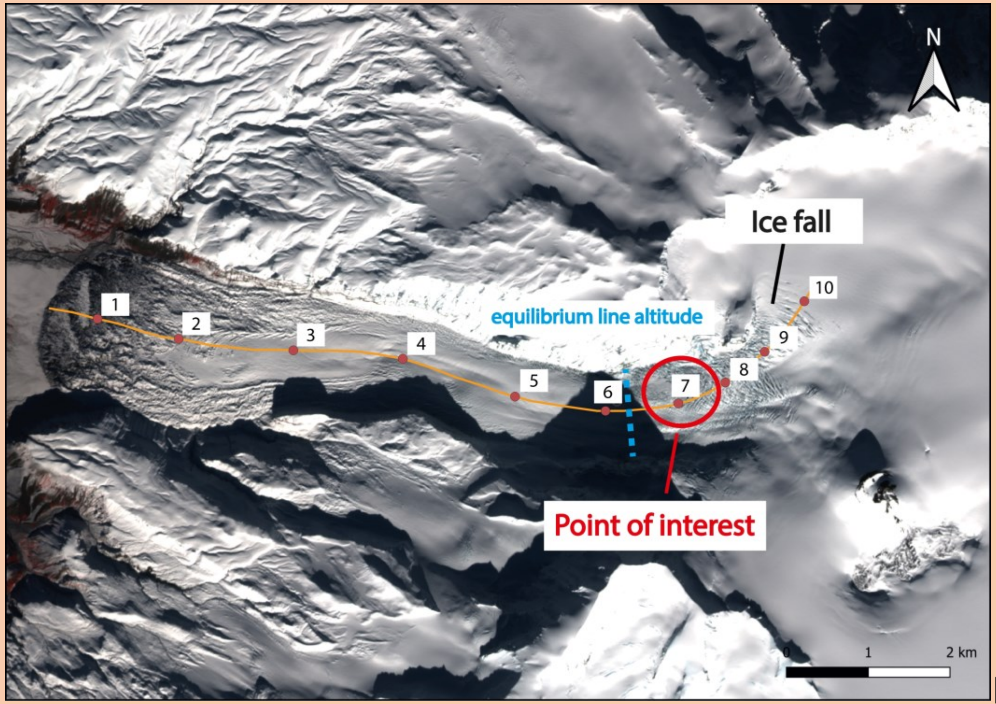


[3]

- Attenuated seasonal cycle of glacier surface velocity below equilibrium line altitude ($R^2 = 0.035$)
- Pre-event speed-up no longer visible (compare a,b; previous slide)
- Amplified seasonal slow-down **shortly before/during** 2018 event (c)

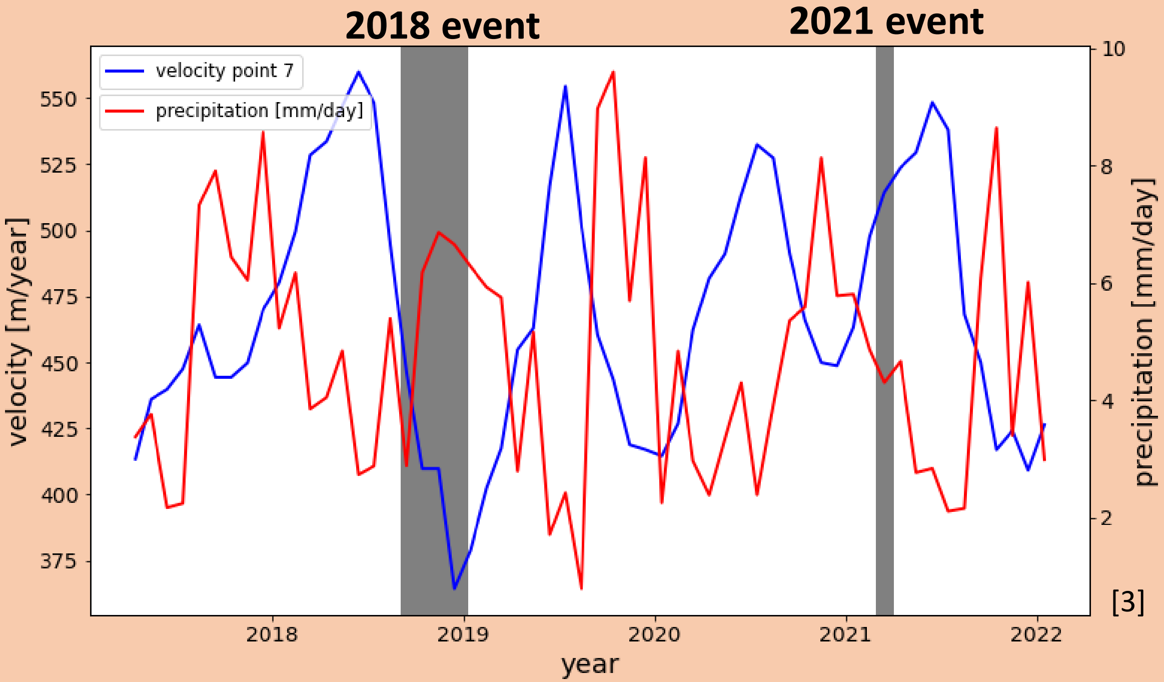
Glacier velocity time-series (3)

Points along profile line



[6]

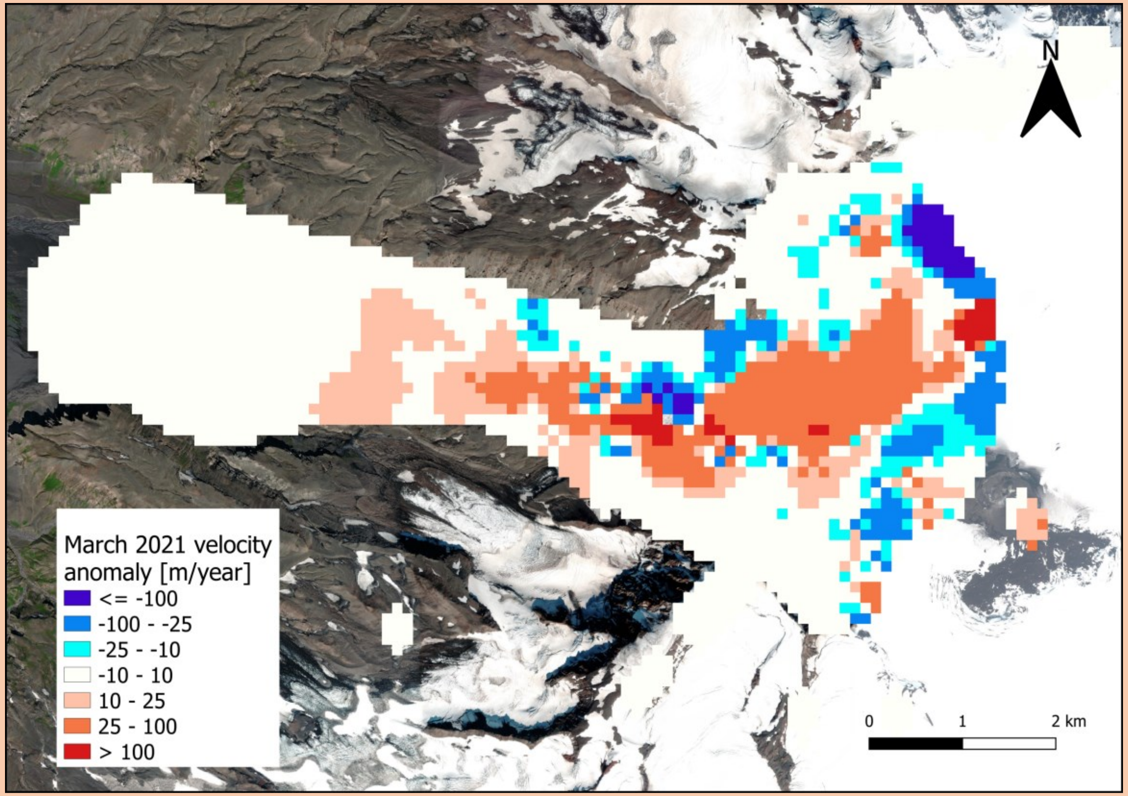
Velocity time series vs precipitation



[3]

- Slightly inverse relationship between velocity and precipitation (R^2 = 0.198)

Velocity anomalies 2021 volcanic active period



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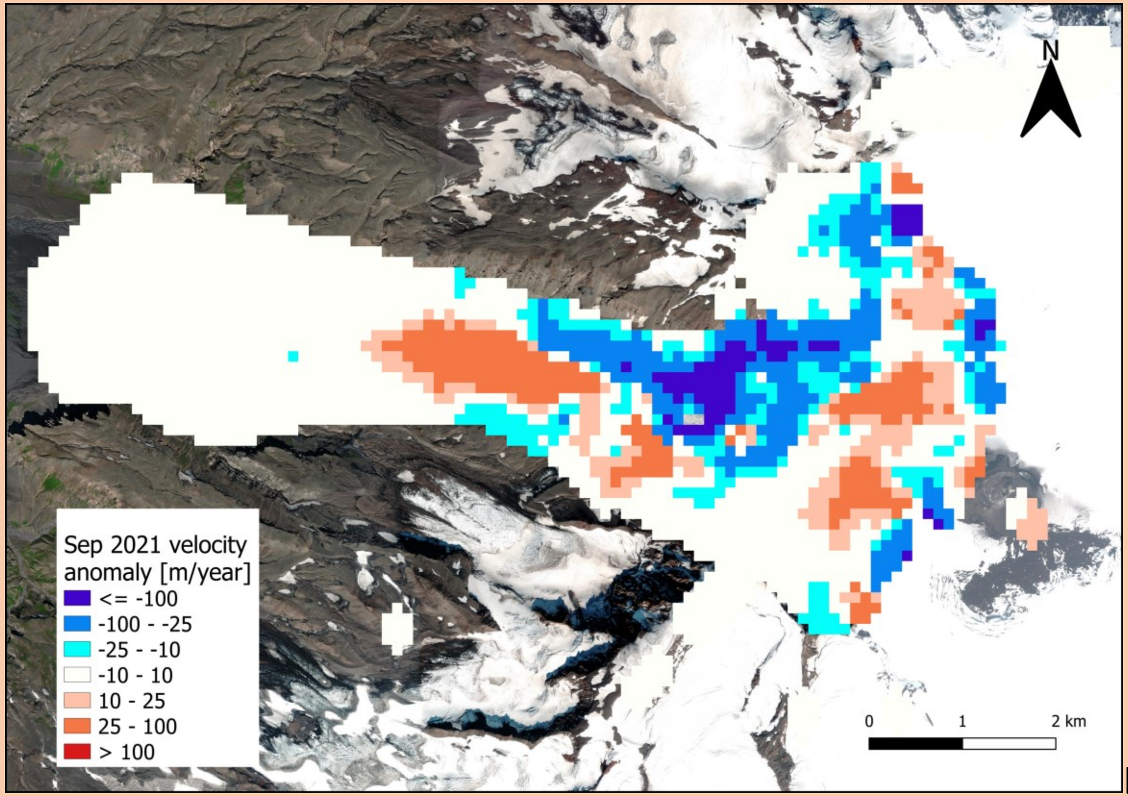

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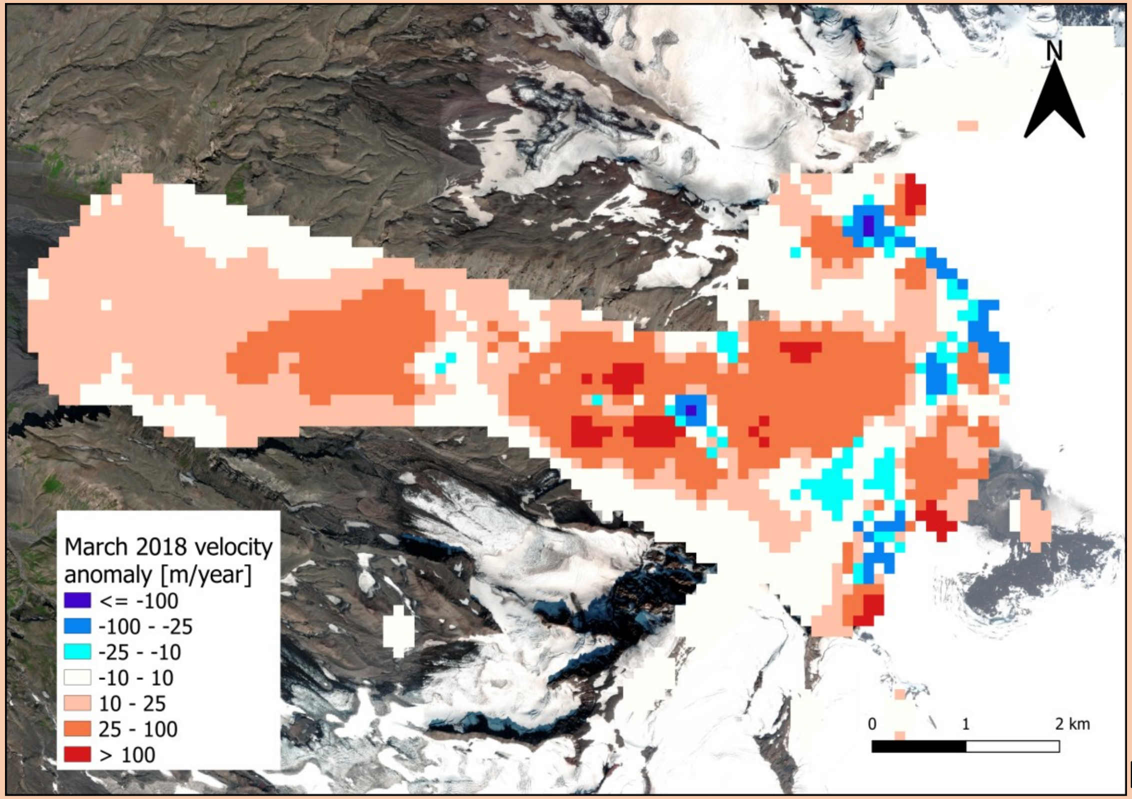
- March 2021 minus March 2020 velocity
- Up to ~100 m/year higher velocities in early months of a year with volcanic activity for **mid- to up-glacier areas (incl. ice-fall area)**

- Sep 2021 minus Sep 2020 velocity
- Up to ~150m/year slower velocities in late months of a year with volcanic activity for **mid- to up-glacier areas (incl. ice-fall area)**

[*] background image from ESRI satellite (ArcGIS/World Imagery) (see [1])

Velocity anomalies 2018 volcanic active period



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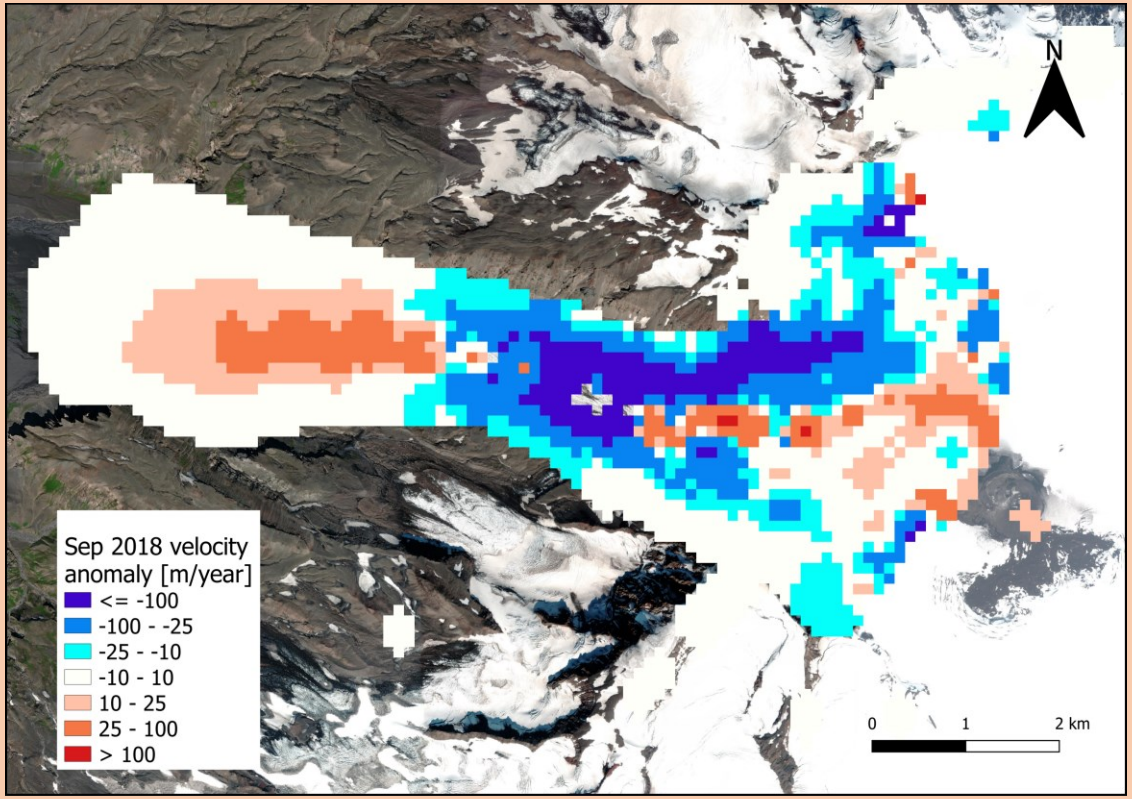

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- March 2018 minus March 2020 velocity
- Up to ~100 m/year higher velocities in early months of a year with volcanic activity for **mid- to up-glacier areas (incl. ice-fall area)**

- September 2018 minus September 2020 velocity
- Up to ~200 m/year slower velocities in late months of a year with volcanic activity for **mid- to up-glacier areas (incl. ice-fall area)**

[*] background image from ESRI satellite (ArcGIS/World Imagery) (see [1])

Summary

Down-glacier areas

- Lack of seasonality for glacier velocities

Mid- to up-glacier areas

- Seasonal cycle of glacier velocity visible in ice-fall area (signal attenuated further down-glacier)
- Higher velocities roughly until June for years with active volcanic phases compared to year 2020 without volcanic phase (incl. ice-fall area)
- Amplified seasonal slow-down for late months of the year (incl. ice-fall area)
- **Pre-event speed-up** present in ice-fall area for both years with active volcanic phases

Possible implications

For down-glacier areas:

- Cone glacier being stagnant and independence of glacier velocity from temperature and precipitation indicates that other factors (such as variations in geothermal flux) provide subglacial meltwater at base of glacier all year round

→ homogeneous glacier surface velocity

For mid- to up-glacier areas (velocity variations present):

- Closing of subglacial drainage system in winter
- Increased geothermal flux and subglacial melting during years with active volcanic phases meets a non-well established subglacial drainage system

➢ higher velocities early in the year

- Additional meltwater generated early in a year with an active volcanic phase enlarges subglacial water pathways

➢ lower velocities later in the year

- Higher amplitude of velocity anomaly during ~ 4 months lasting 2018 event could represent higher quantity of meltwater routed in subglacial pathways if compared to ~1 month lasting 2021 event

Possible implications

Answer to research question

- Pre-event speed-ups presumably limited to glacier areas with less evolved subglacial drainage system (e.g. above the equilibrium line altitude and/or in ice fall areas)

➢ **Possible use of Sentinel-2 data to detect glacier velocity changes before an imminent volcanic eruption**

References

- [1] ESRI Satellite (ArcGIS/World_Imagery); https://server.arcgisonline.com/ArcGIS/rest/services/World_Imagery/MapServer/tile/{z}/{y}/{x}
- [2] Basemap: “World Continents”. ESRI; https://www.arcgis.com/home/item.html?id=57c1ade4fa7c4e2384e6a23f2b3bd254
- [3] KNMI explorer, https://climexp.knmi.nl/selectfield_rea.cgi?id=someone@somewhere; *Generated using Copernicus Climate Change Service information [2022]*
- [4] ESA, https://www.esa.int/Applications/Observing_the_Earth/Looking_ahead_to_Sentinel-2
- [5] Van Wyk de Vries, M. and Wickert, A. D.: Glacier Image Velocimetry: an open-source toolbox for easy and rapid calculation of high-resolution glacier velocity fields, The Cryosphere, 15, 2115–2132, https://doi.org/10.5194/tc-15-2115-2021, 2021 (supplementary material: GIV_User_Manual_English)
- [6] Copernicus Sentinel data [2020]
- Molnia, B. F. (2007) ‘Late nineteenth to early twenty-first century behavior of Alaskan glaciers as indicators of changing regional climate.’ *Global and Planetary Change*, 56(1–2) pp. 23–56.
- Rodionov, S. N., Overland, J. E. and Bond, N. A. (2005) ‘Spatial and temporal variability of the Aleutian climate.’ *Fisheries Oceanography*, 14(s1) pp. 3–21.