Three-dimensional surface velocity variations of the Argentière glacier monitored with a high-resolution continuous GNSS network

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Abstract

Glacier dynamics exhibit substantial variability in response to climate forcing. To better understand the effects of this forcing, it is essential to provide continuous deformation measurements that must be long-term (over a full or several melt seasons) and high-resolution (from daily to sub-daily). GNSS monitoring represents a valuable means to apprehend basal sliding mechanisms better and provide high-resolution 3D constraints on physical models of glacier flow. In this study, we investigate motions and deformations of the Argentière Glacier in the French Alps at 2400 m altitude, derived from up to 12 permanent GNSS stations continuously operating since April 2019, covering two melting seasons. We present the results (i) over relatively long timescales (days to months) using the static positioning approach to evaluate mean variations and compare to the independent measurements mentioned above, and (ii) kinematic approach to focus on high temporal resolution velocity variations during specific short-term events that cannot be seen from the static processing. The horizontal surface velocities on daily time scales reveal spring acceleration due to meltwater followed by steadily high velocities over the summer and significant episodic accelerations in the fall in response to the storm events. The GNSS confrontation with other independent observations also allows analyzing the surface motions that combine horizontal speed-ups with uplift due to bed separation of the glacier.

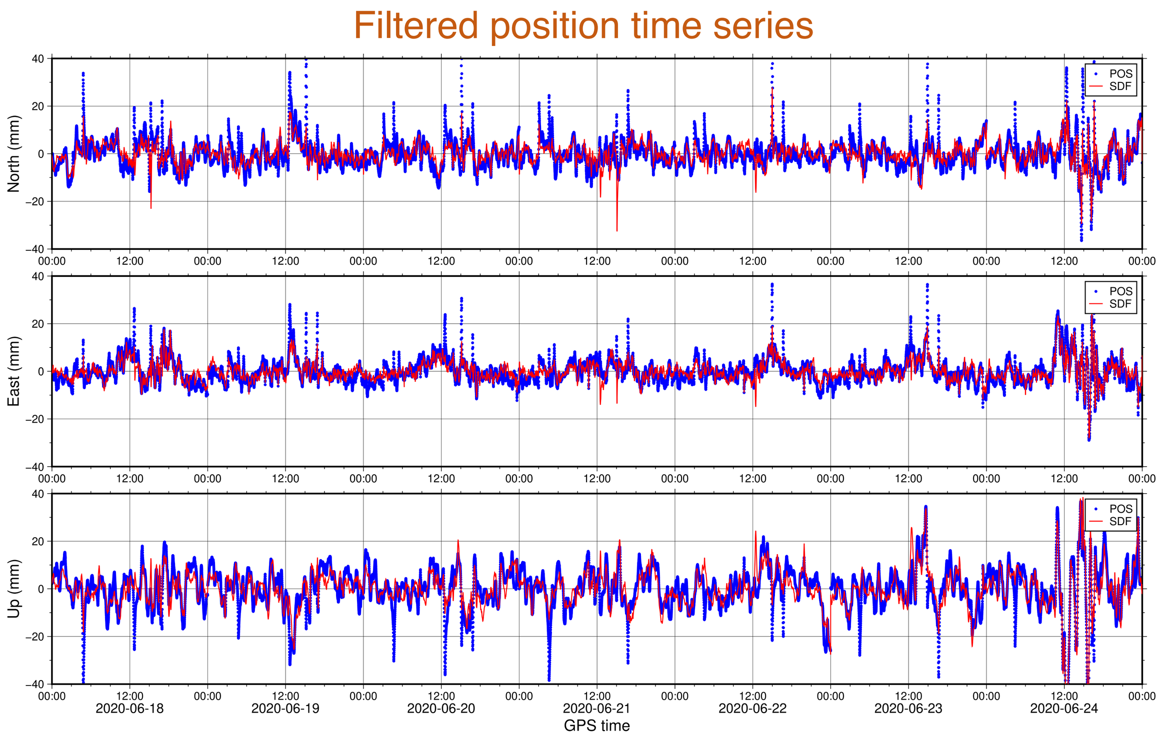
GNSS observations

- Up to 13 permanent stations recording since April 2019
- Aluminum mast several meters deep in the ice
- GAMIT/GLOBK (static):
  - 24-hour LC solutions
  - 13 reference stations (IGS14 EURA)
  - Horizontal σ ±5 mm
  - Vertical σ ±10 mm
- TRACK (kinematic):
  - 30-second L1 observables
  - from 0.7 to 3 km apart from the reference station ARGR
  - Low Pass filtering and Sliding Average (Bartholomew et al., 2012)
  - empirically derived velocity uncertainty ±1 mm/hour

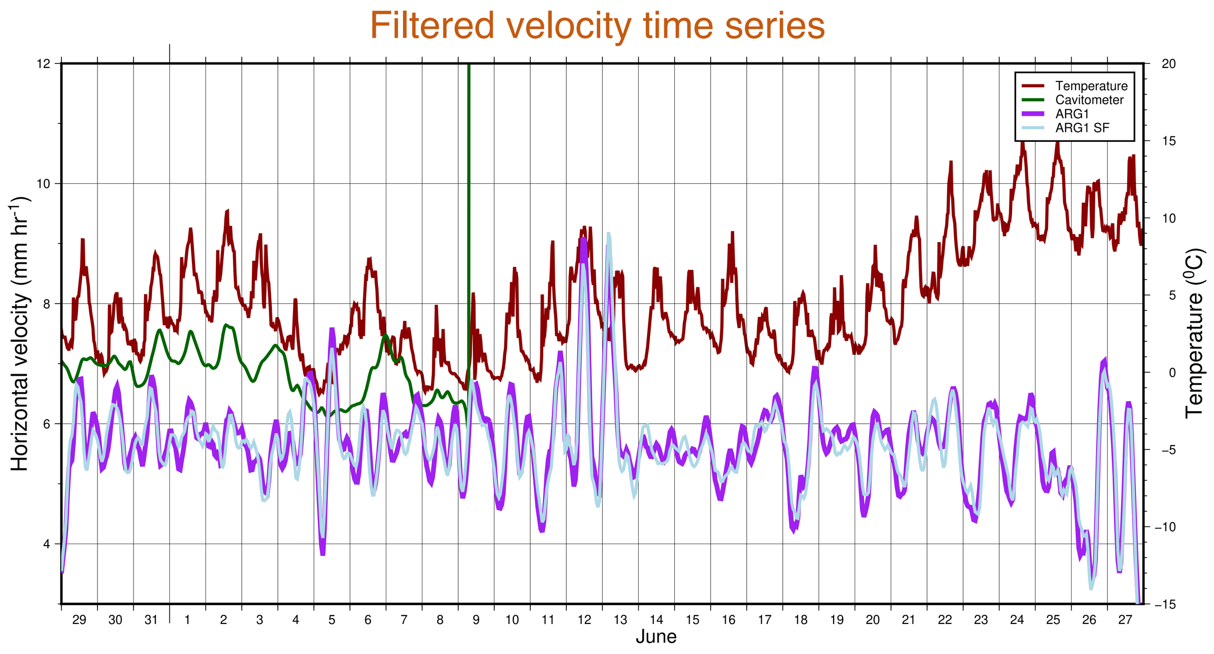
Sidereal filtering

- **Sidereal day:** 23 h 56 m 04 s (Choi et al., 2004)
- **Midified sideral day:** 23h 55m 54s (Ragheb et al., 2006)
- **Sidereal day in our experiment:** 23h 56m 00s

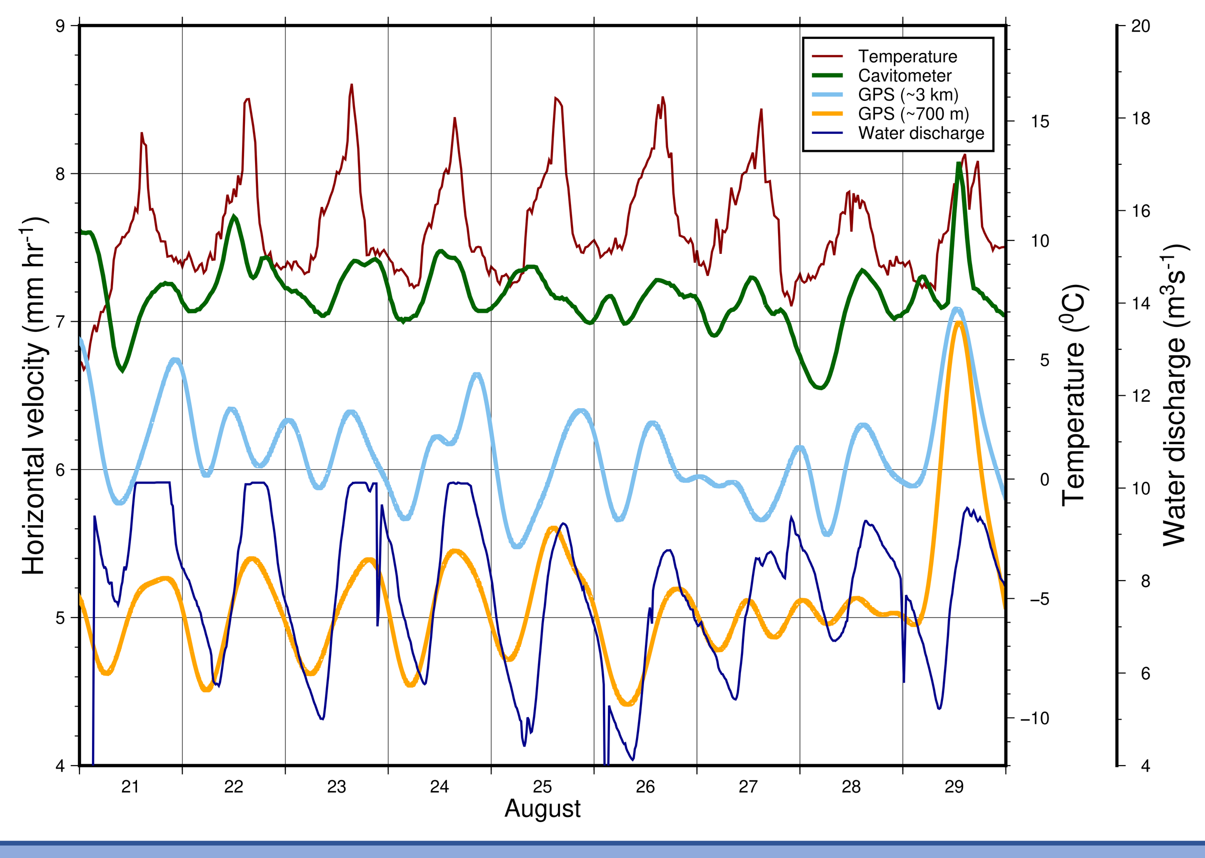
Filtered position time series



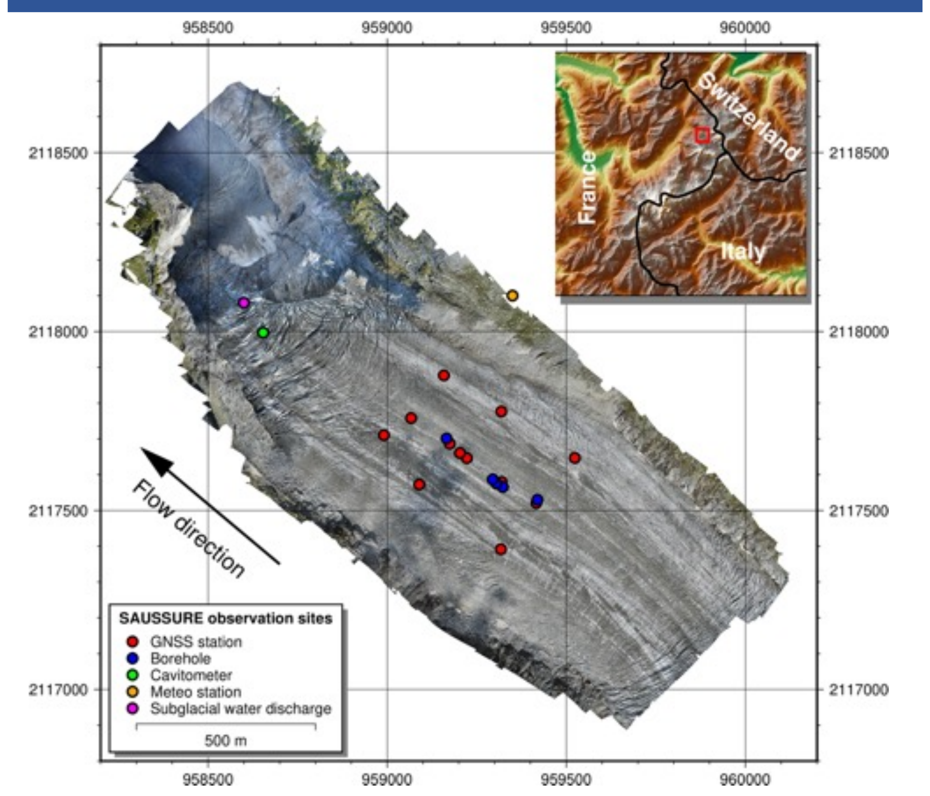
Filtered velocity time series



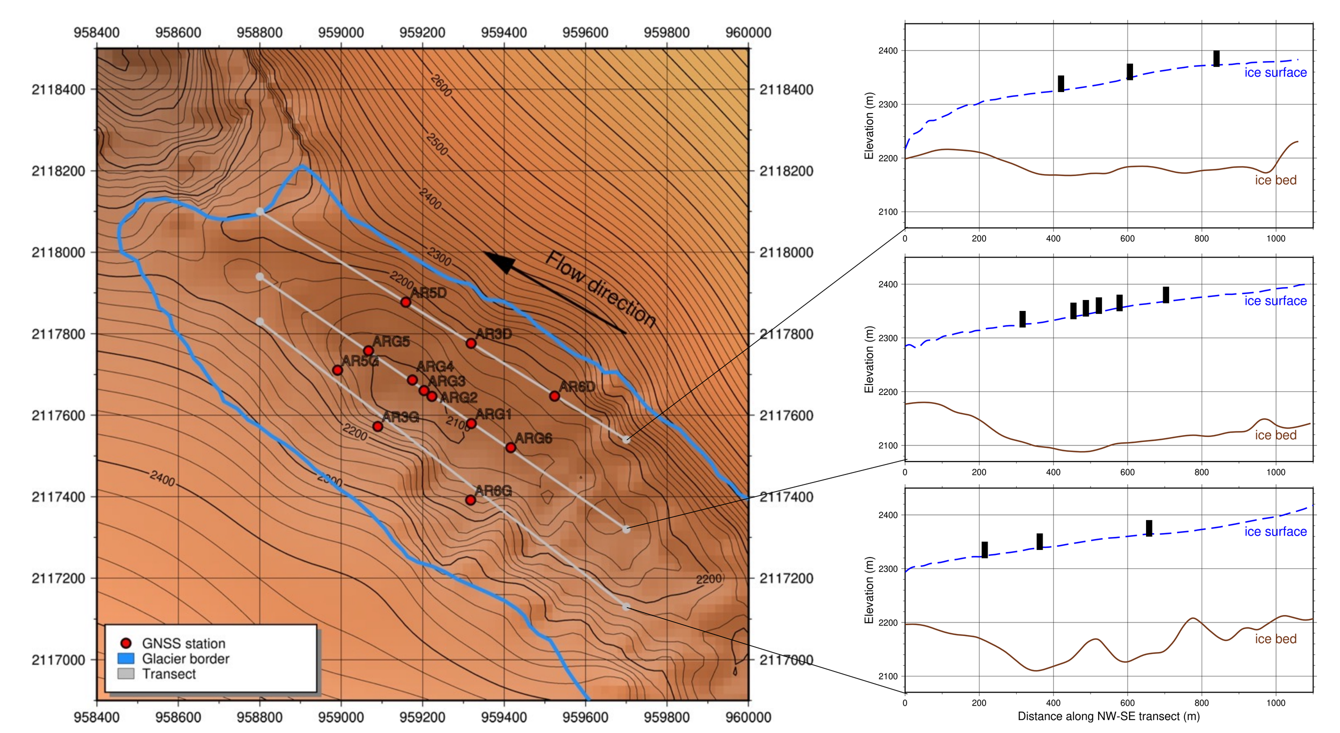
Diurnal cycles



Site characteristics

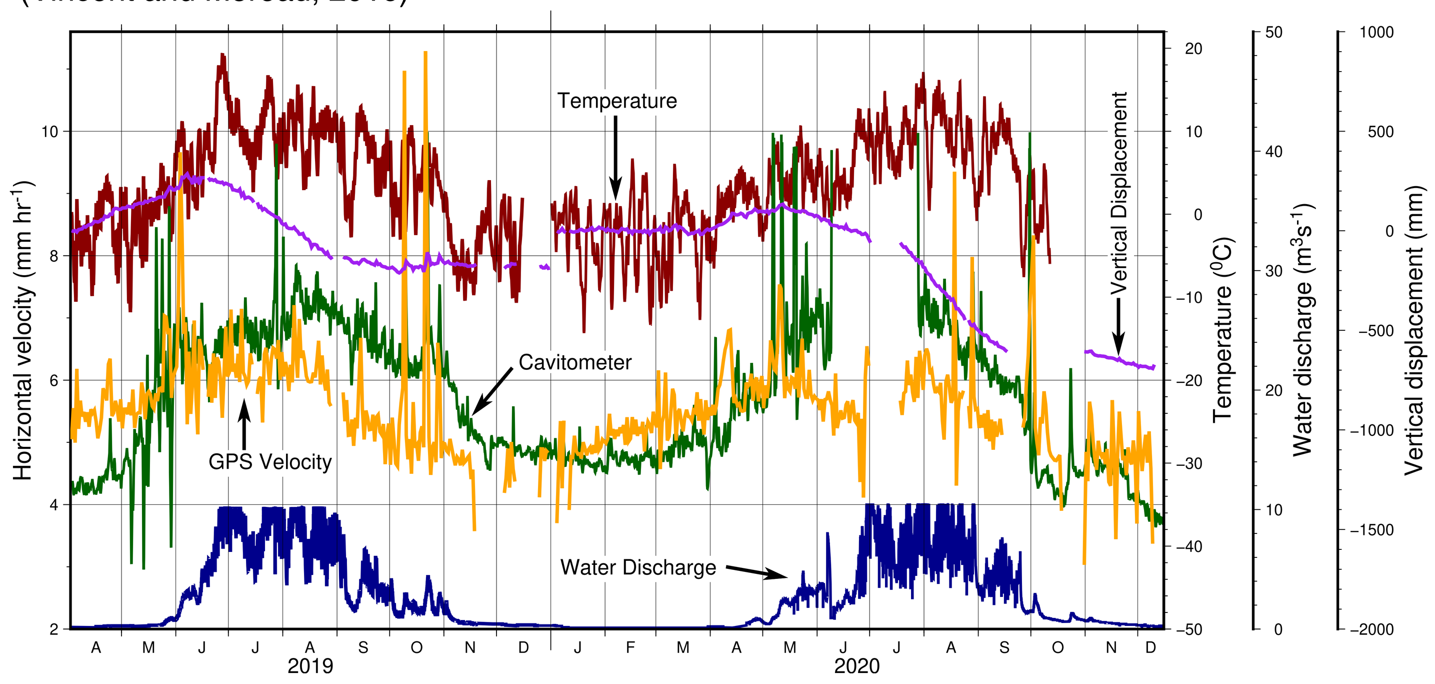


Topography



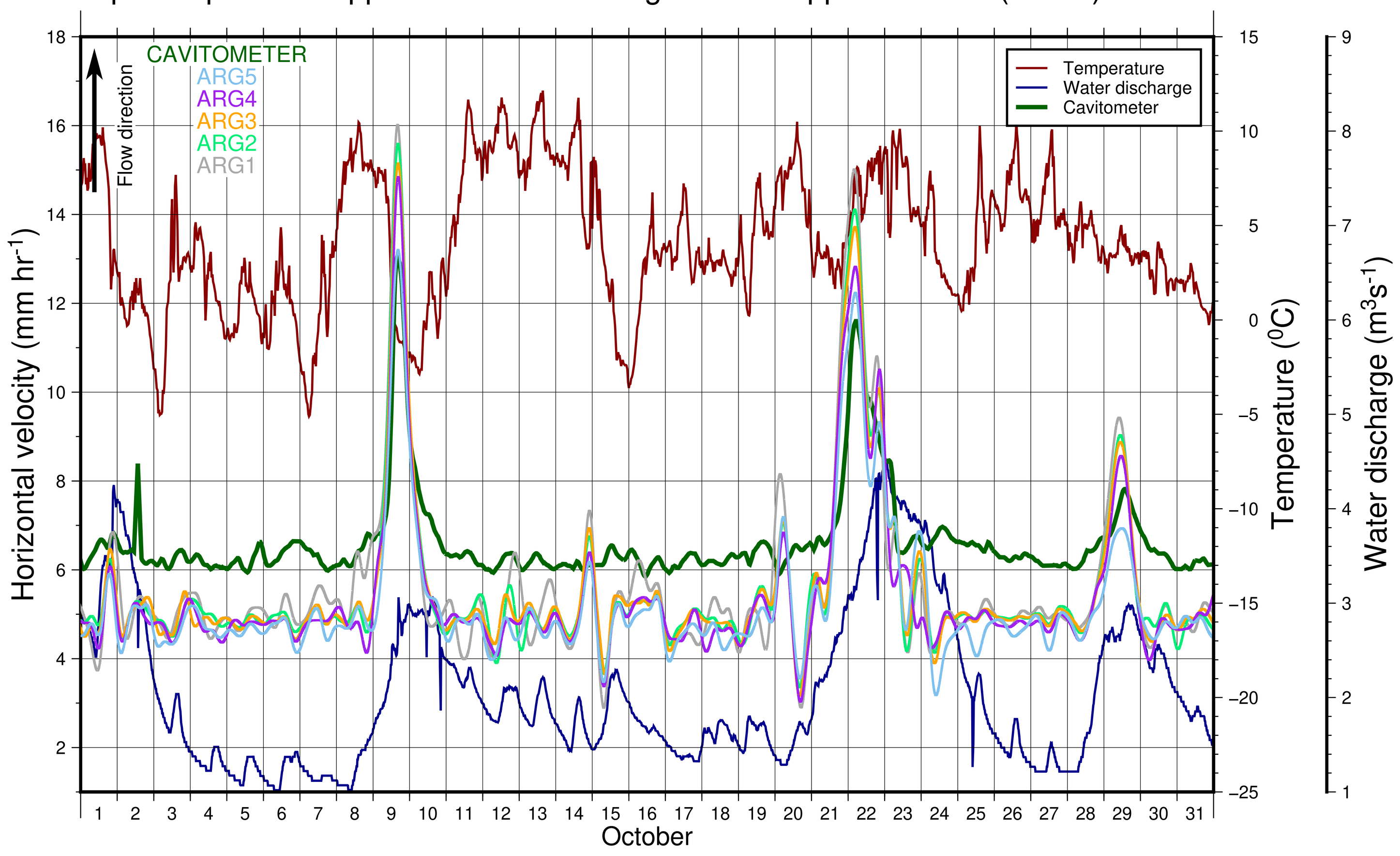
Seasonal variations

- Spring acceleration is accompanied with vertical uplift due to «**bed separation**» and a **vertical strain** (Anderson et al., 2004)
- The **surface ice-flow velocity** increases at the end of spring and remains in the vicinity of 6 mm h^{-1} over summer, while **cavitometer** velocity keeps rising until August, reaching almost 8 mm h^{-1} (Vincent and Moreau, 2016)

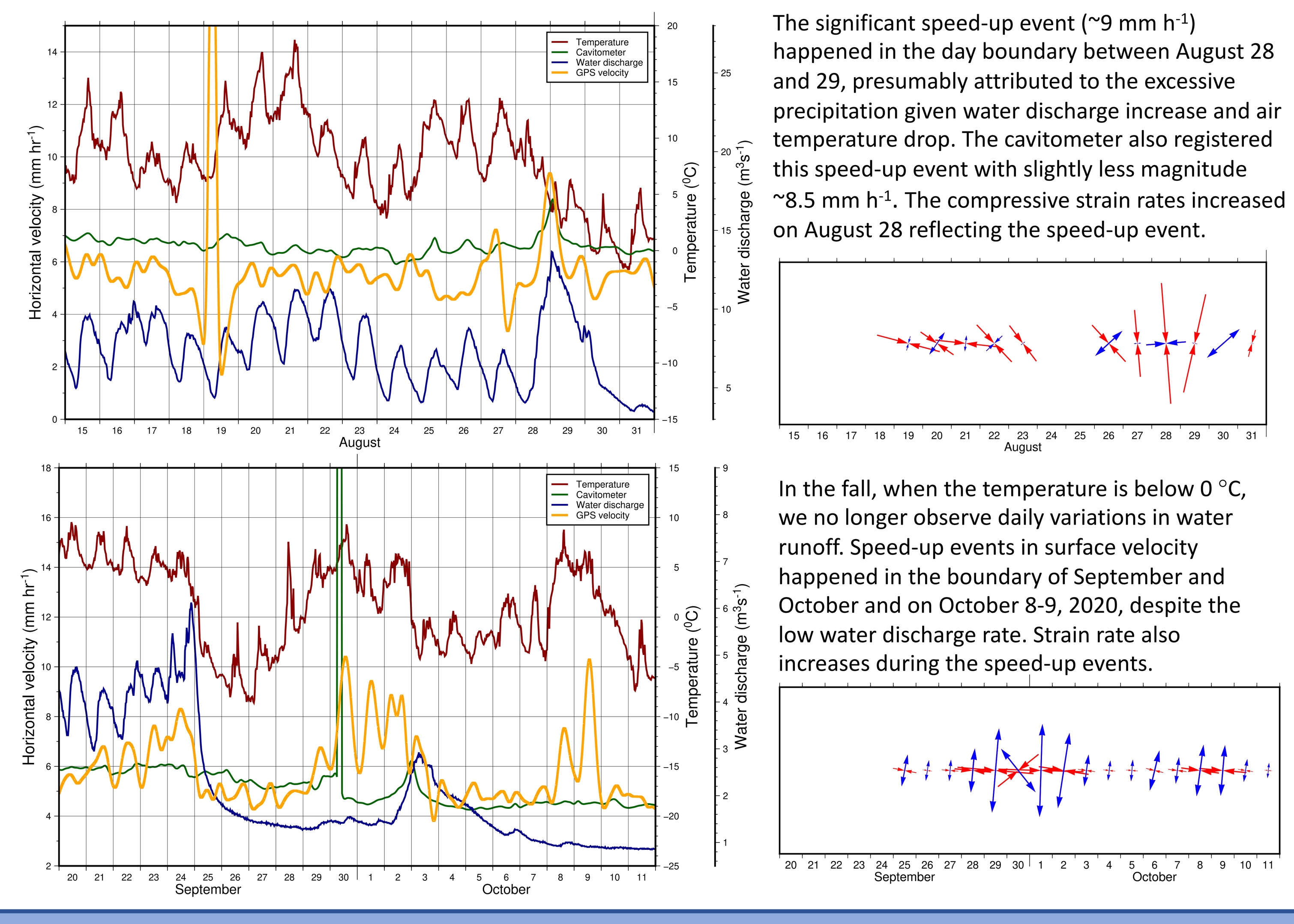


Temporal agreement

- Uppermost stations are **moving faster** than lower stations at each spike, presumably due to the bump just in front of ARG5 (see the bedrock topography at the "Topography" section)
- The speed-up event happens **in order** starting from the uppermost site (ARG1)



Speed-up events and strain rate changes



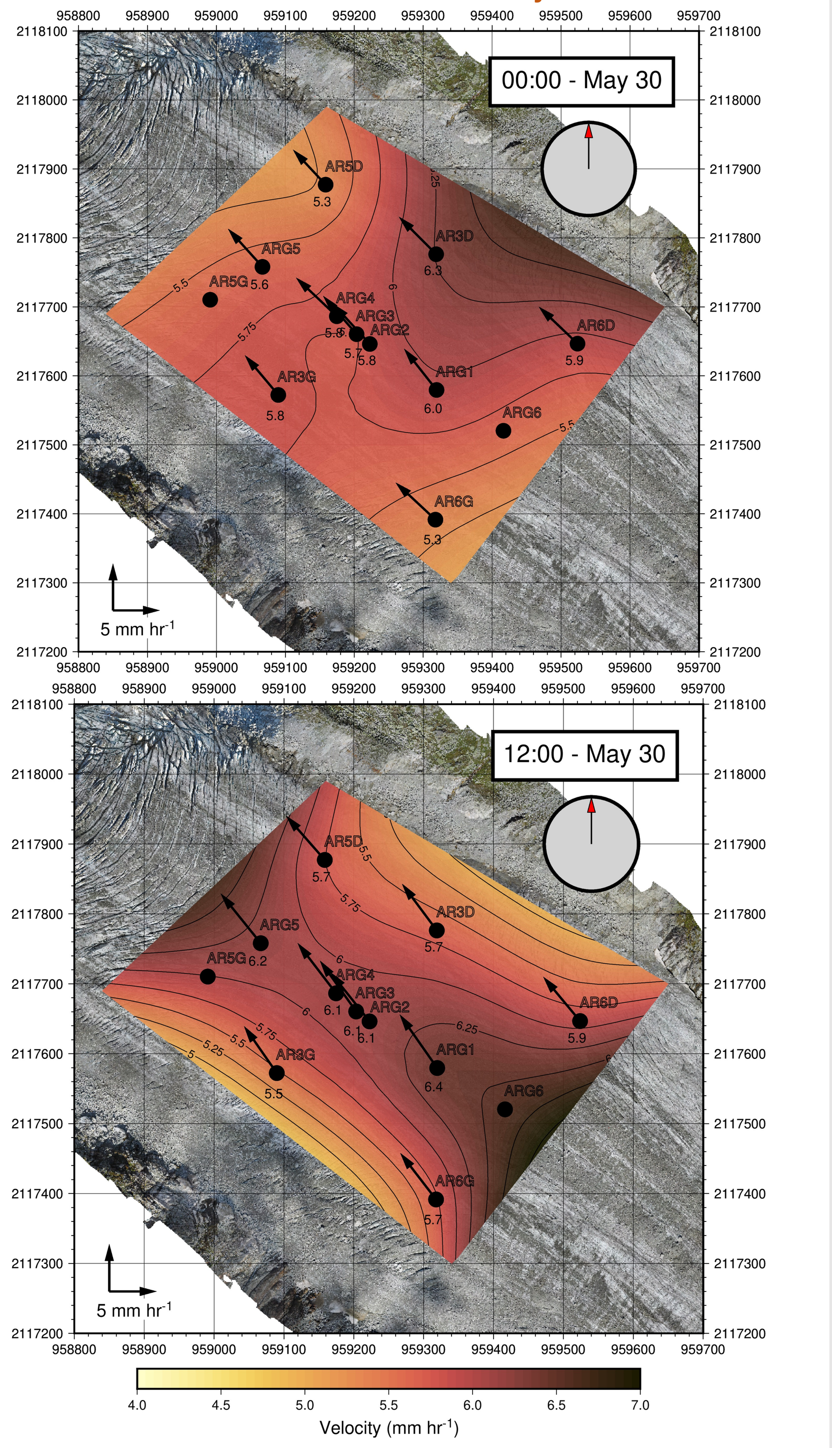
The significant speed-up event (~9 mm h^{-1}) happened in the day boundary between August 28 and 29, presumably attributed to the excessive precipitation given water discharge increase and air temperature drop. The cavitometer also registered this speed-up event with slightly less magnitude ~8.5 mm h^{-1}. The compressive strain rates increased on August 28 reflecting the speed-up event.

In the fall, when the temperature is below 0 °C, we no longer observe daily variations in water runoff. Speed-up events in surface velocity happened in the boundary of September and October and on October 8-9, 2020, despite the low water discharge rate. Strain rate also increases during the speed-up events.

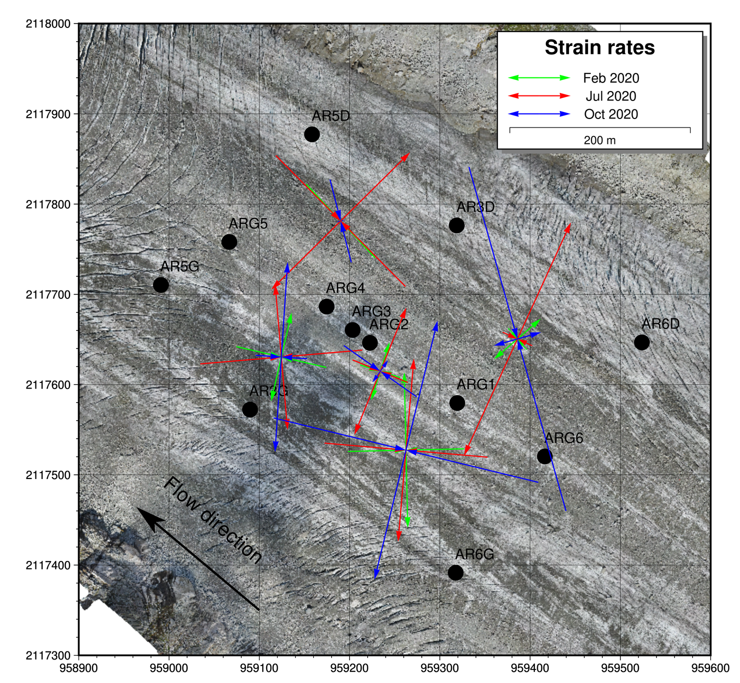
Spatial variations

- Different **velocity distributions** in day (laminar flow) vs night-time (crevasses effect)
- Bedrock **topography** governs the vertical displacement

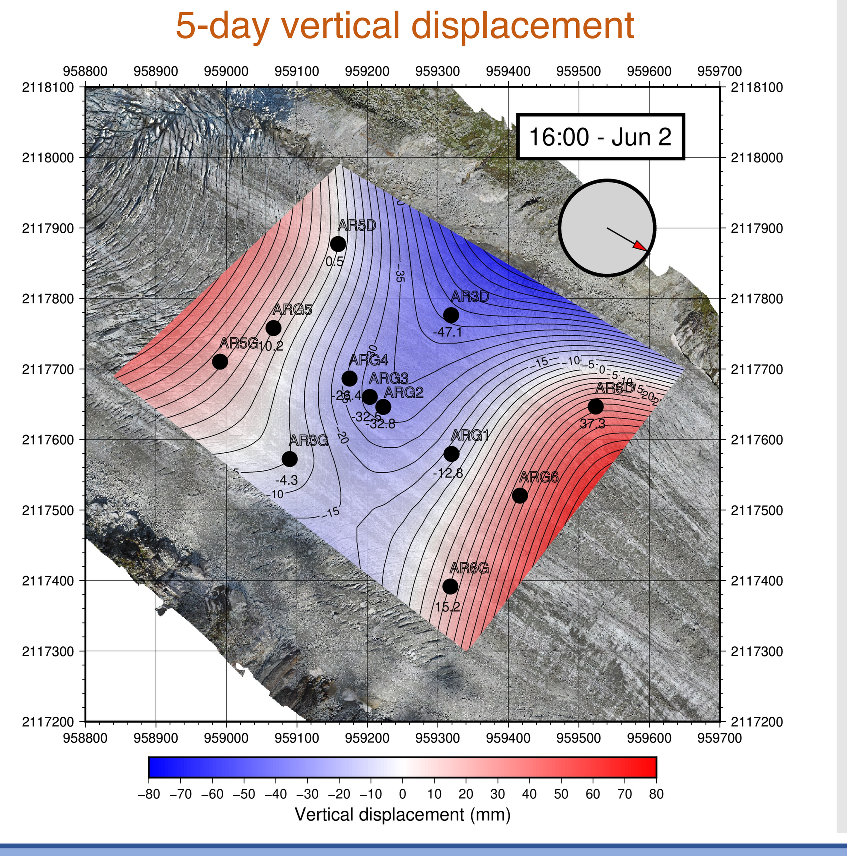
Horizontal velocity



Strain rates



5-day vertical displacement



Conclusion

- **Significant displacement measurements on all-time scales validated by comparison with independent observations**
- **Sidereal filtering smoothes the position time series however does not have a significant impact on velocity**
- **Subglacial velocity at the terminus increases until the end of summer, whereas the ice surface accelerates only in spring**
- **Uppermost stations are moving faster than lower stations having the earliest response to the acceleration**
- **Two different mechanisms of the speed-up events**

Reference

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