

Basal speed and deformation velocity in an alpine temperate glacier from high resolution borehole tilt measurements and GNSS surface velocity observations

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Additional material for CR 3.3 vEGU 2021

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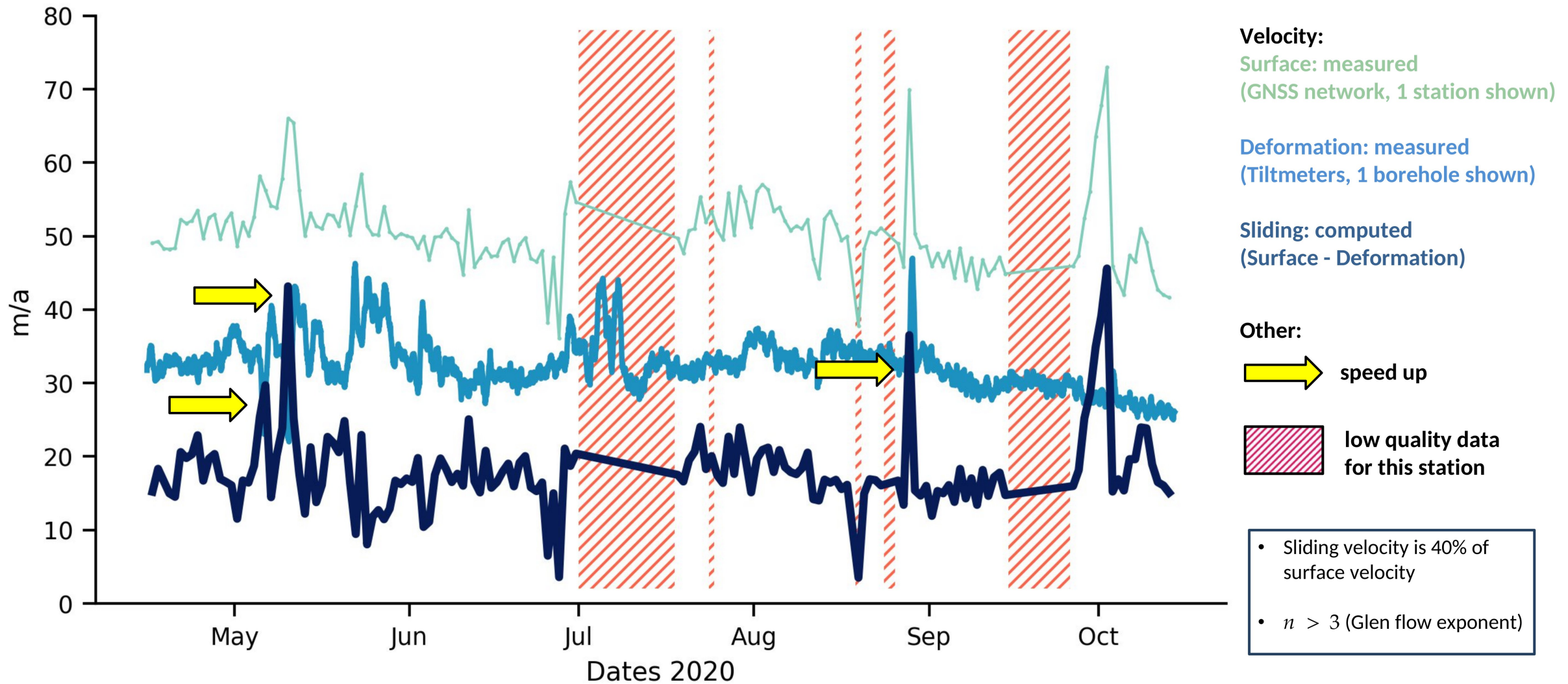
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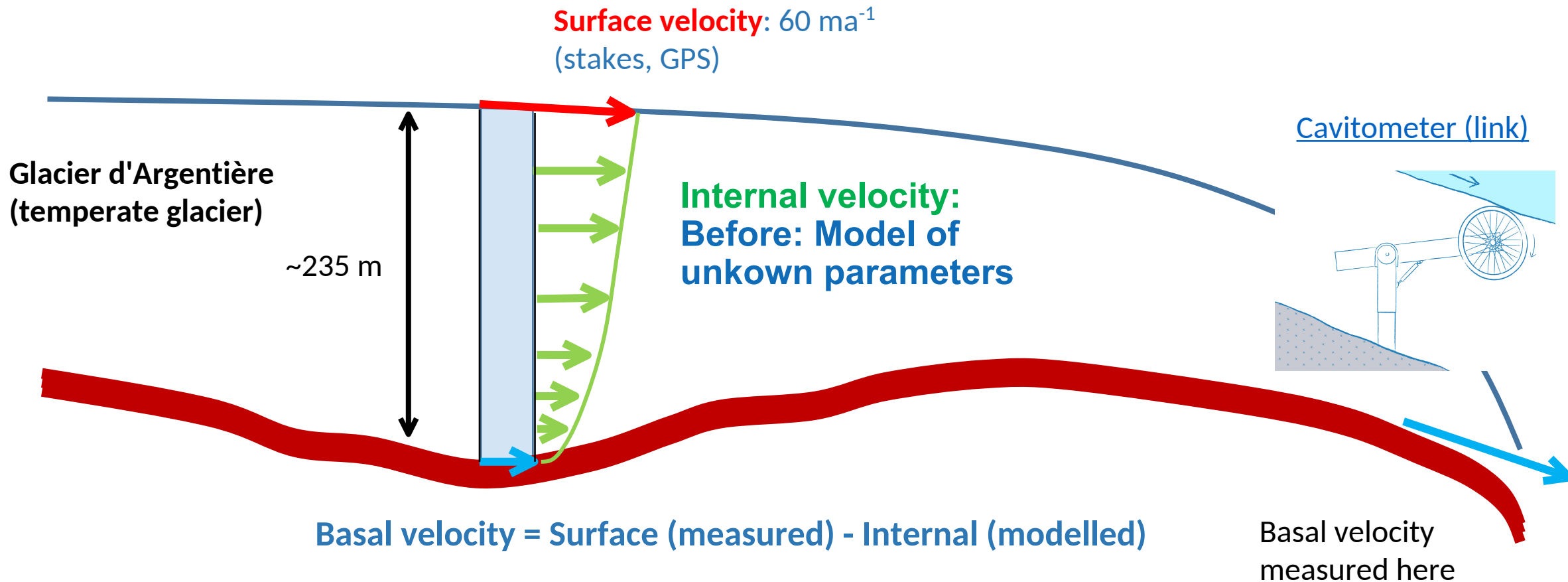
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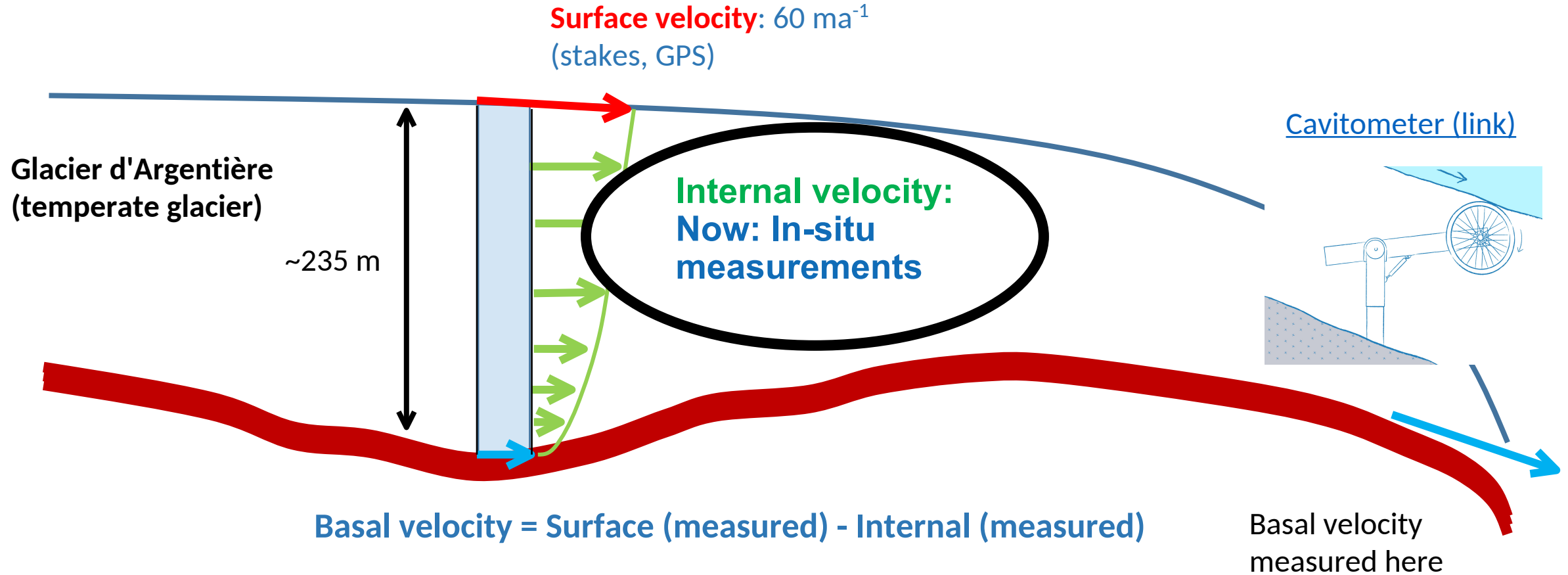
One melt season of sliding on an alpine temperate glacier



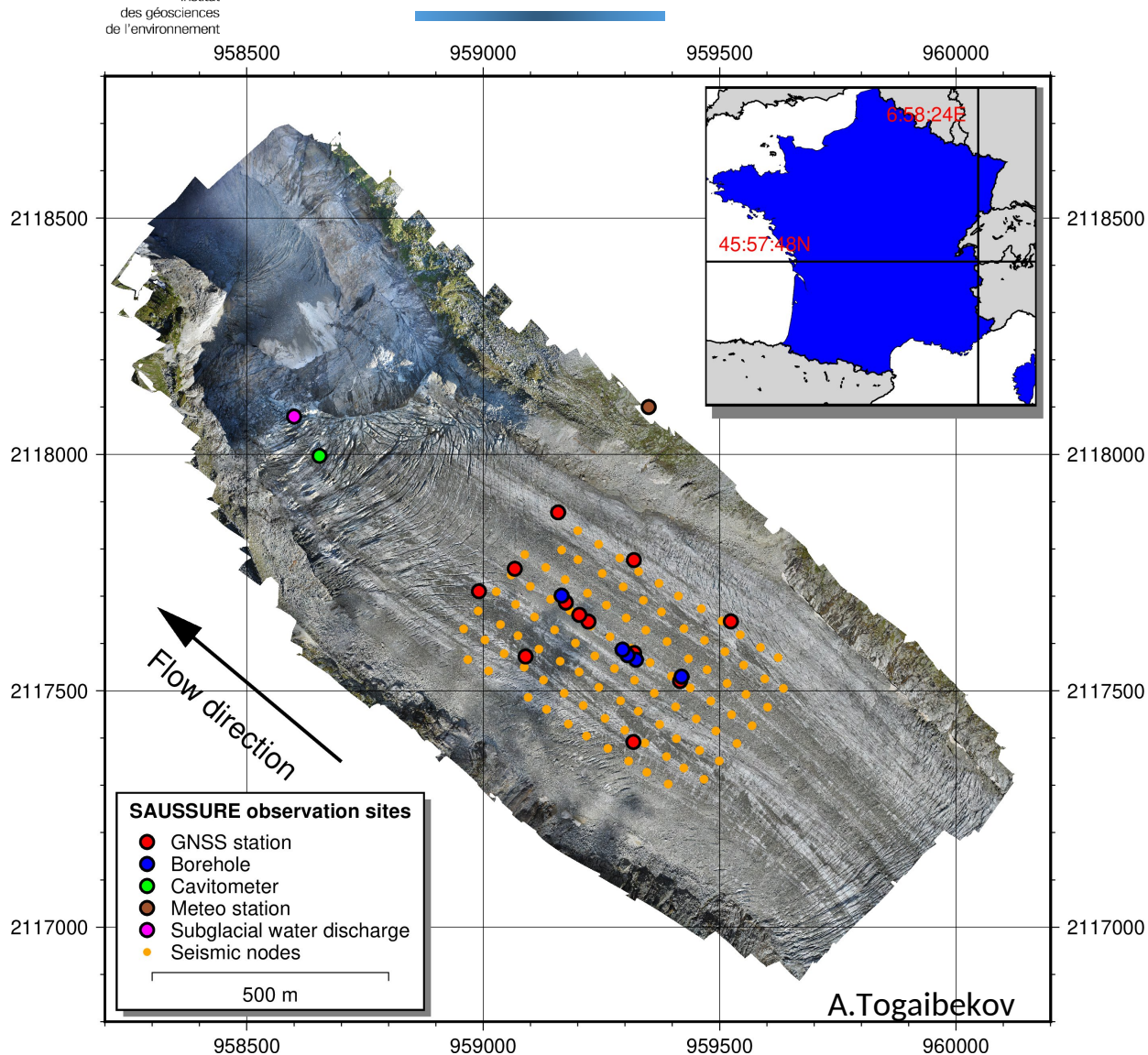
Context and objective



Context and objective



Field campaign and instruments



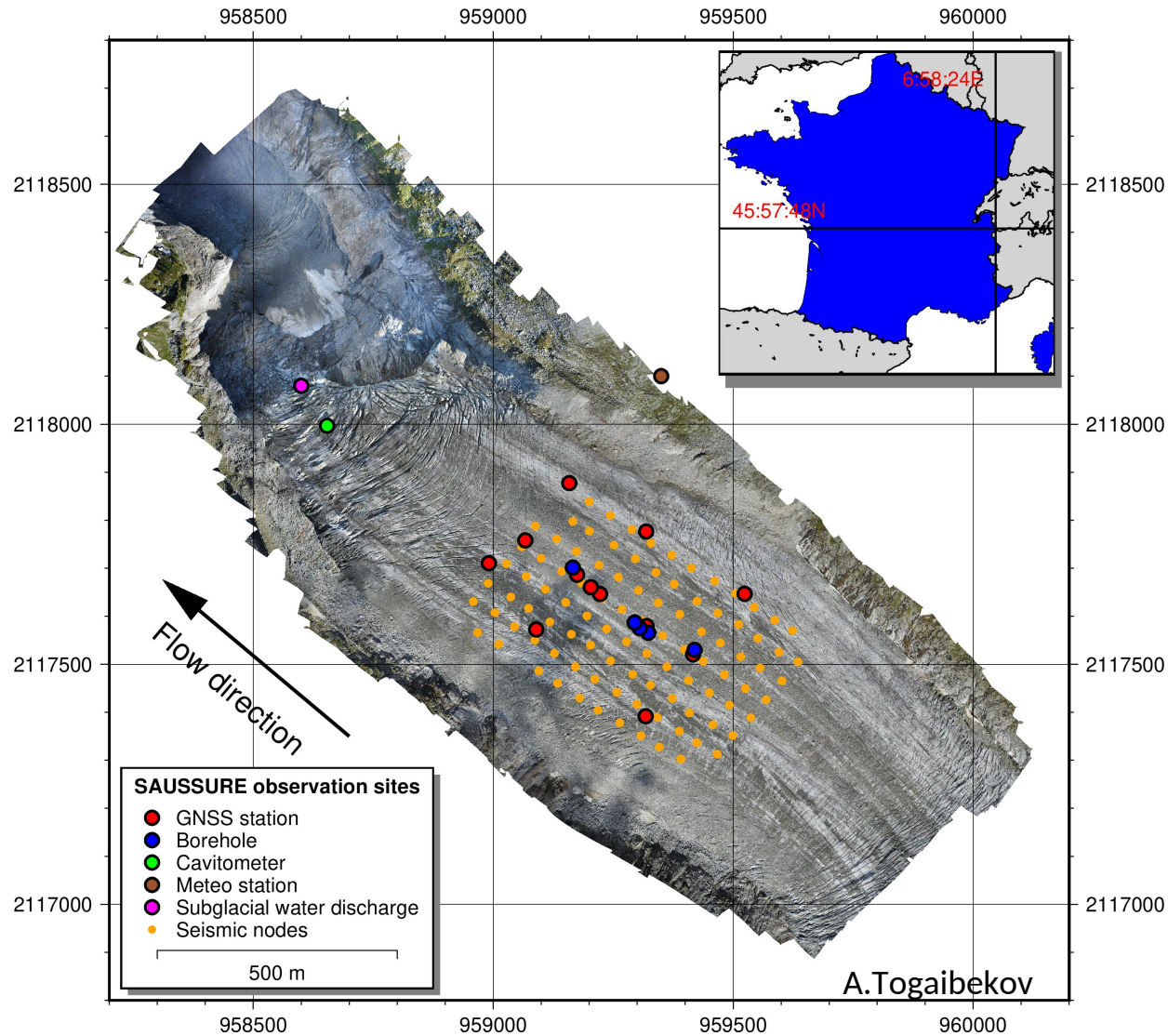
GNSS stations:

Data acquisition every 30 seconds

Details of the analysis in the content presented in EGU21 session CR 2.4 Geophysical and in-situ methods for snow and ice studies by Anuar Tobageikov et al:

[LINK HERE TO THE VIDEO](#)

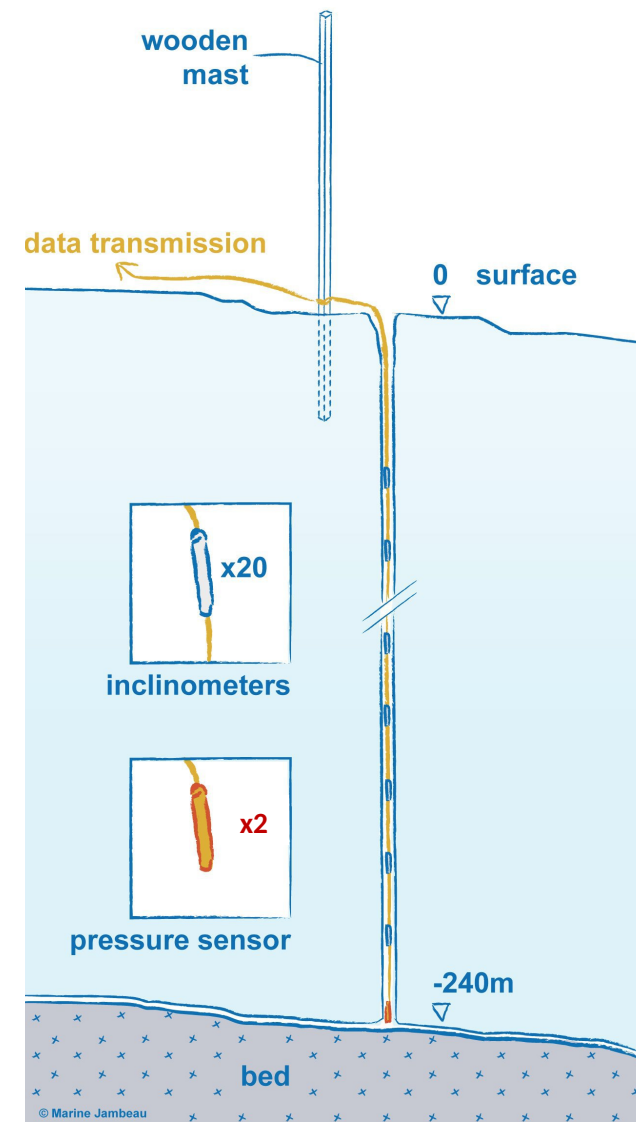
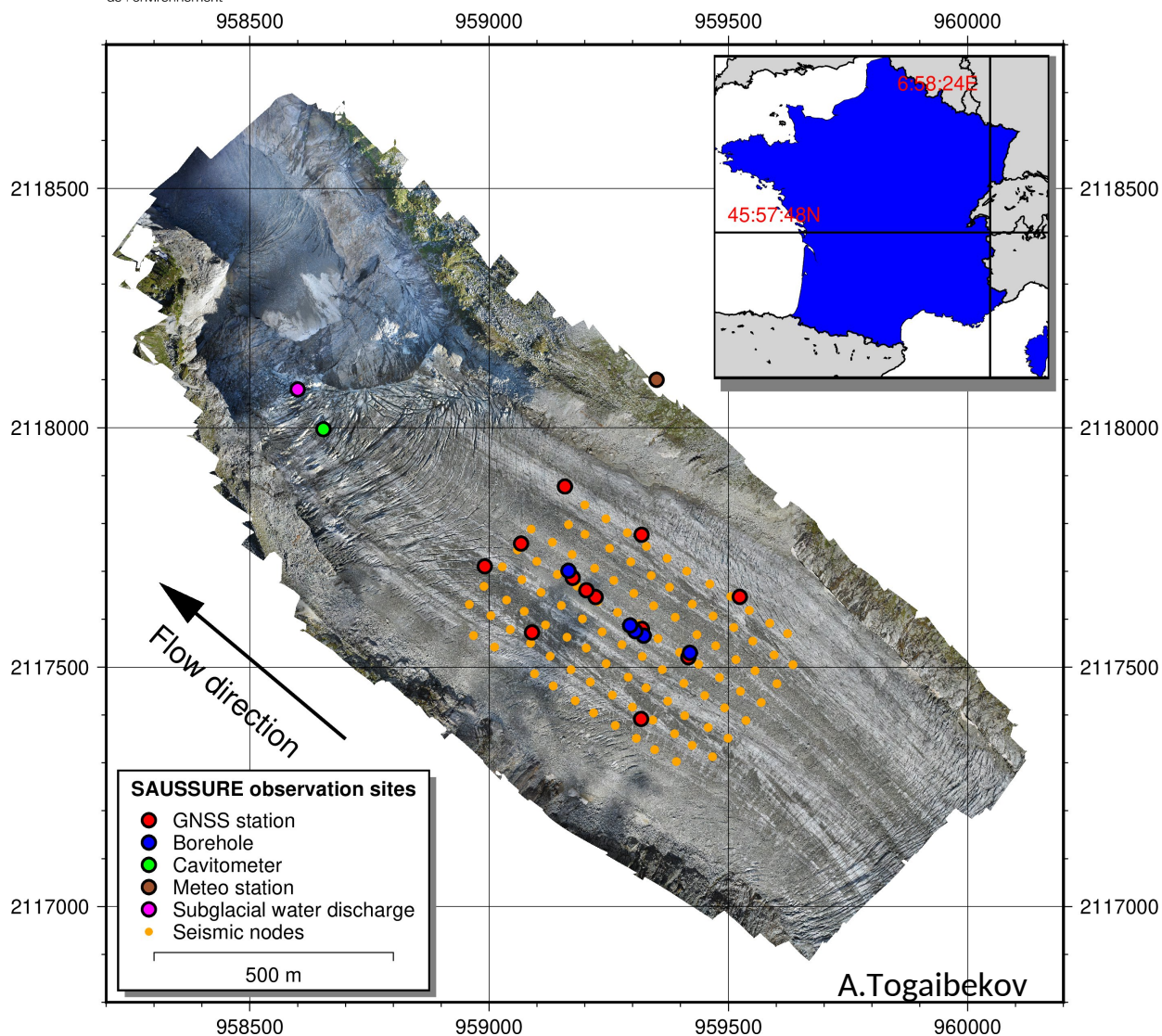
Field campaign and instruments



[Boreholes \(link to the comic of the campaign\)](#)



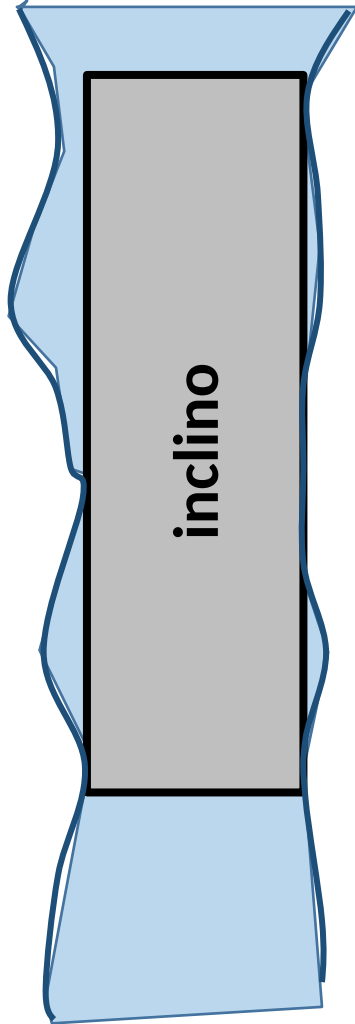
Field campaign and instruments



Data acquisition
every 30 minutes

More than 1 year
of data!

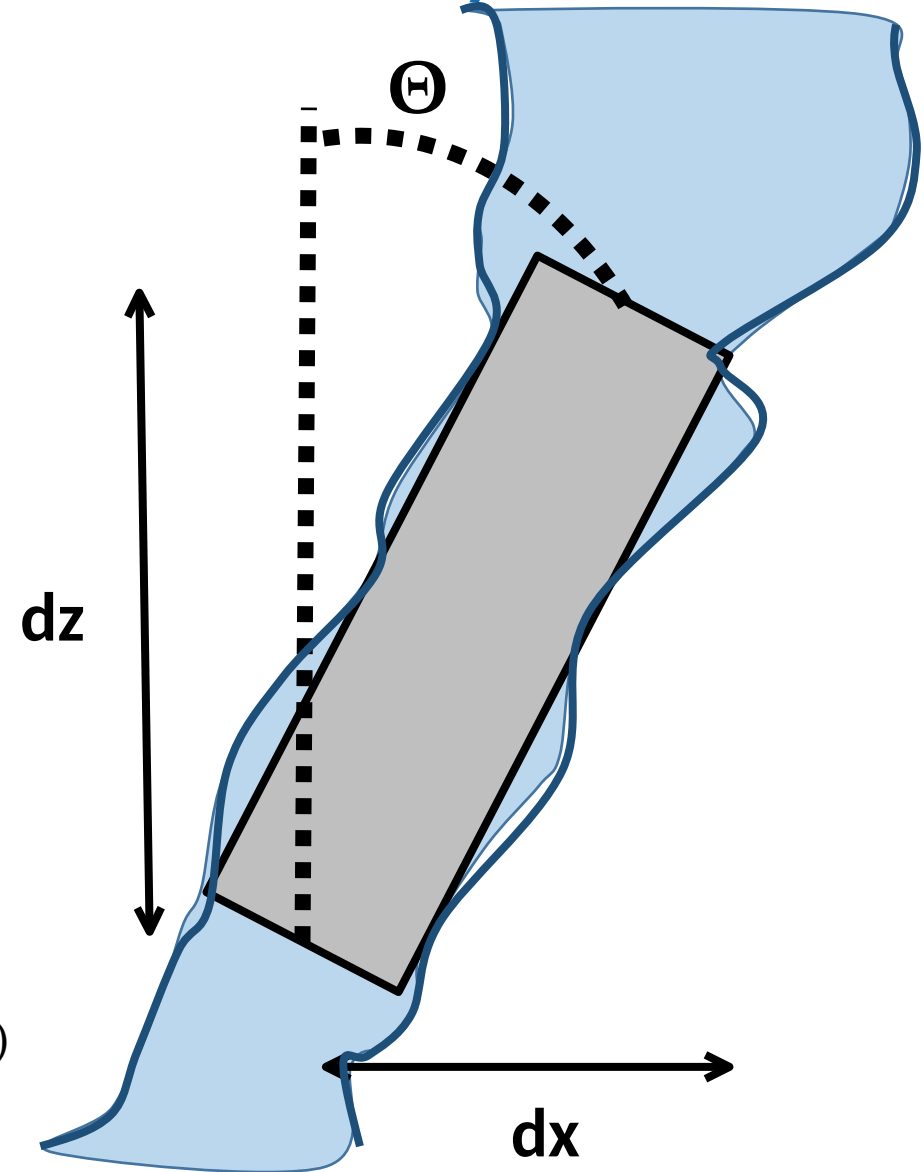
From tilt to velocity (SIA model)



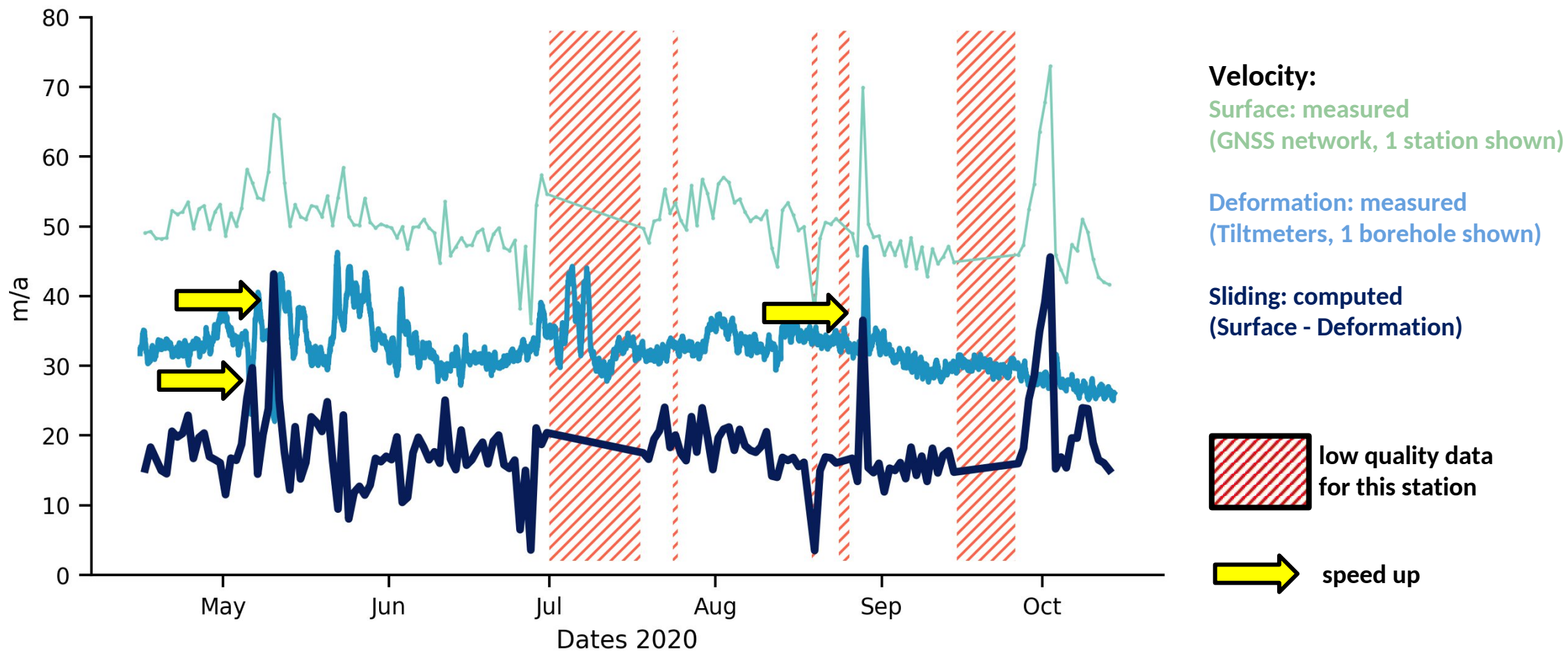
$$\frac{d \tan(\Theta)}{dt} = \frac{1}{H} \frac{dx}{dz} = \frac{du}{dz}$$

$$\int_0^H \frac{du}{dz} dz = u_d$$

- a) 2D: u , x and z are in the same plane
- b) No compression or extension ($\dot{\epsilon}_{xx} = 0$)
- c) Results shown with $dt = 1$ day



Velocities time series during 2020's melt season



SIA bias

Short term accelerations/decelerations: Not covered in steady-state models

Seasonal variation: higher deformation during melt season

Note: The tilt is recorded at high accuracy. The cumulative experimental error in the velocity is ~ 1 m/a, not enough to explain this seasonal behaviour

Is this behaviour really happening? Is there a bias in the model?

SIA bias: solution

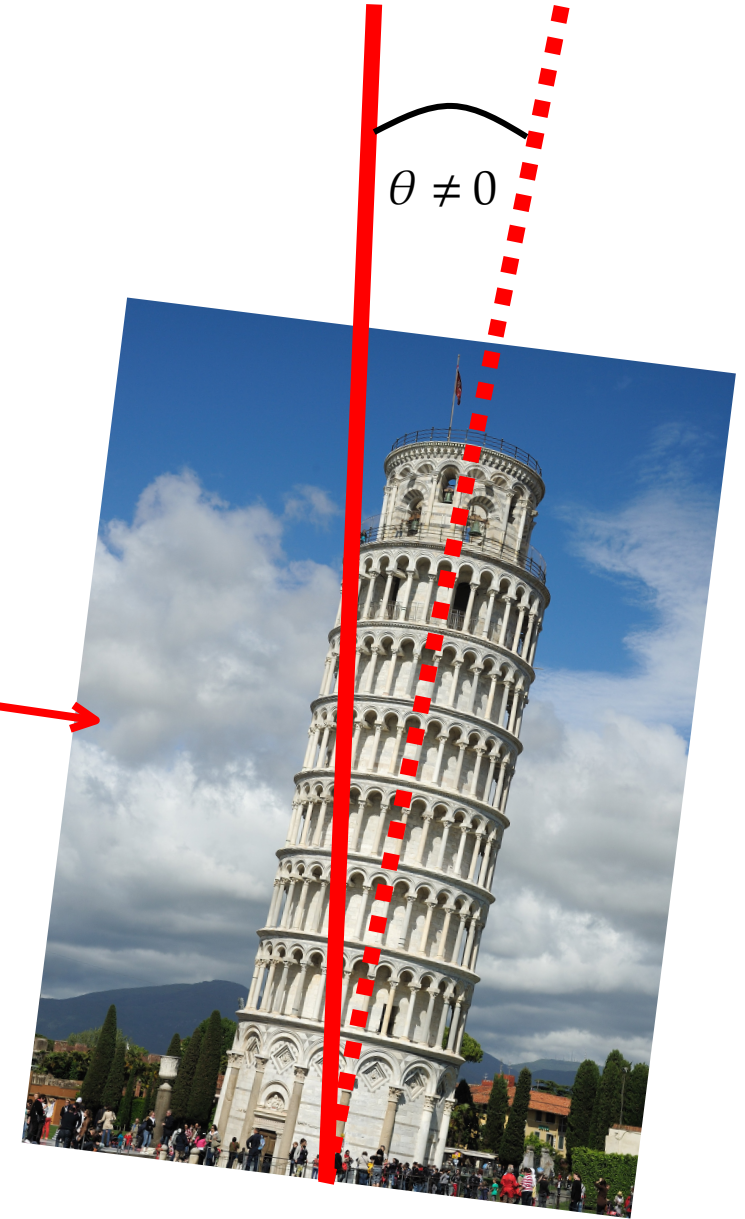
Use the model developed in Keller and Blatter (2012, *J. Glaciol.*), Gudmunsson et al. (1999, *Ann. Glaciol.*)

Advantages:

1. Shear ($\dot{\epsilon}_{xz}$) and compression/extension ($\dot{\epsilon}_{xx}$)
2. Effect of not having tiltmeters in a vertical plane

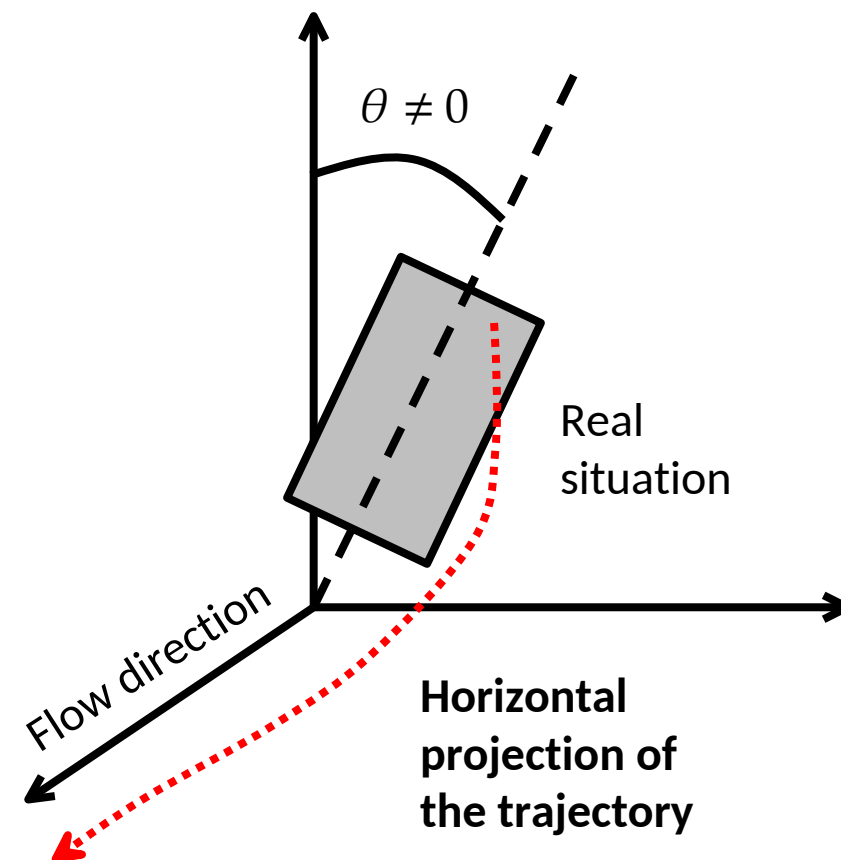
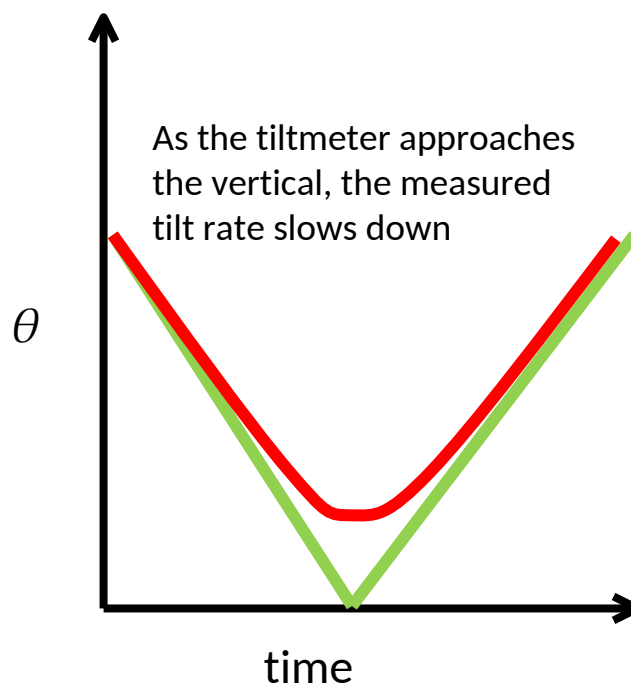
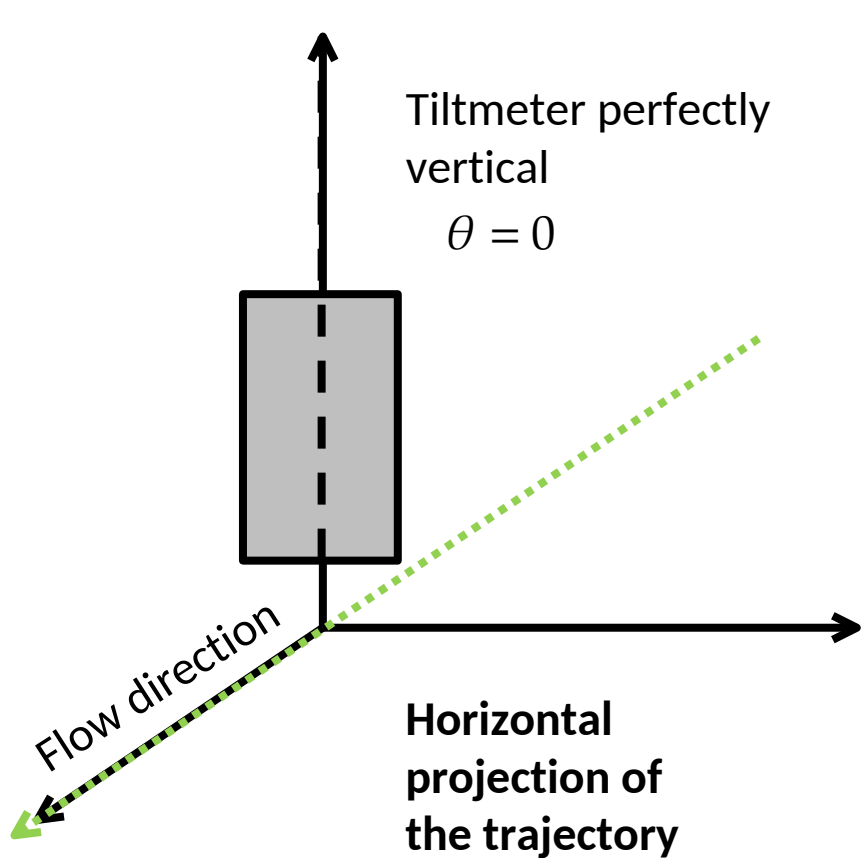
Drawback:

1. Assumes constant strain field



SIA bias: solution

Use the model developed in Keller and Blatter (2012, *J. Glaciol.*), Gudmunsson et al. (1999, *Ann. Glaciol.*)



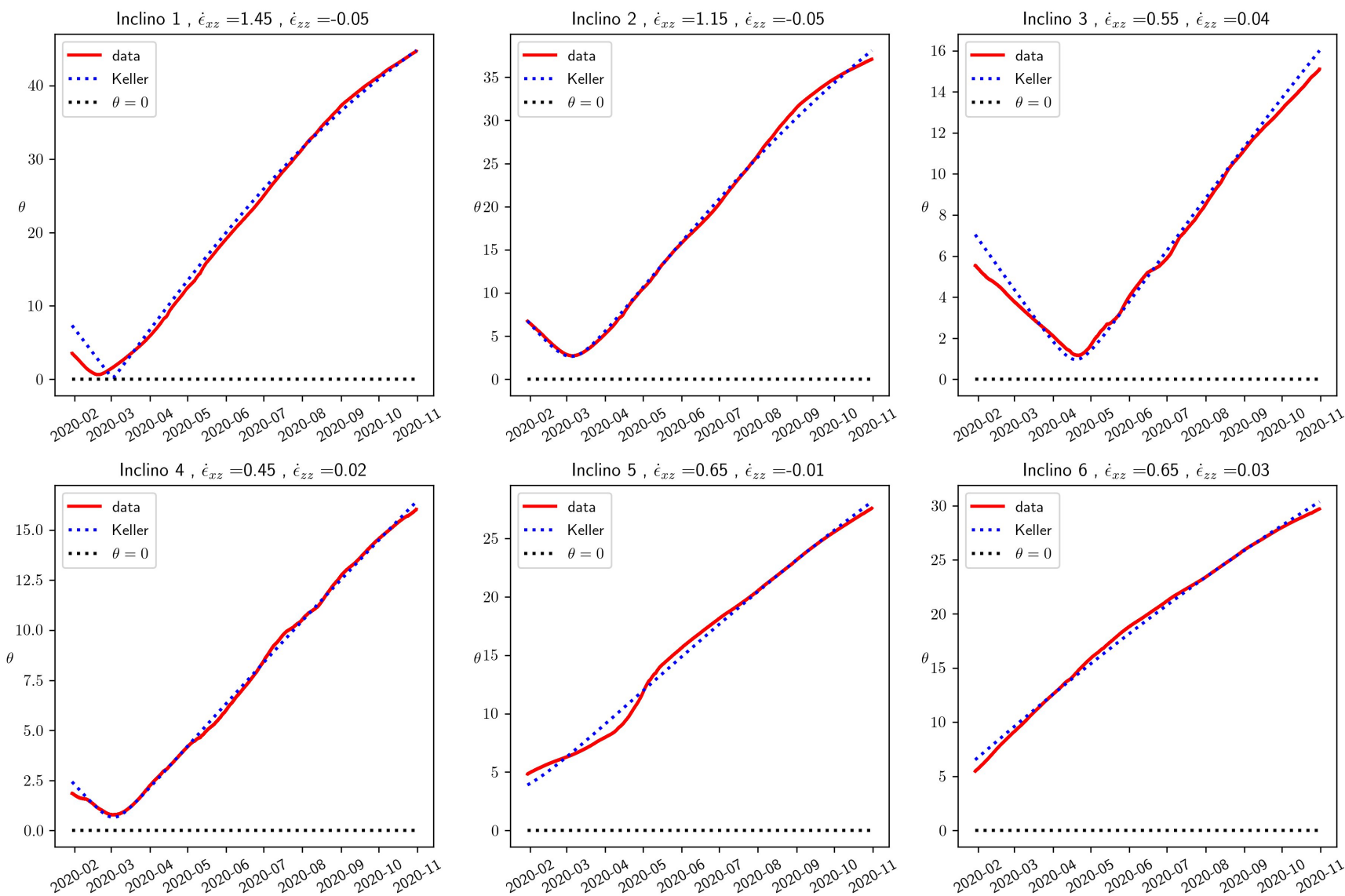
Example: February to November 2020

Measured tilt curves

vs

modeled tilt curves

Notice the tilt curves are rather smooth, no sudden peaks as in Gudmunsson et al. (1999)



Example: February to November 2020

Now we use our method to compute the du/dz on the fitted tilt curves

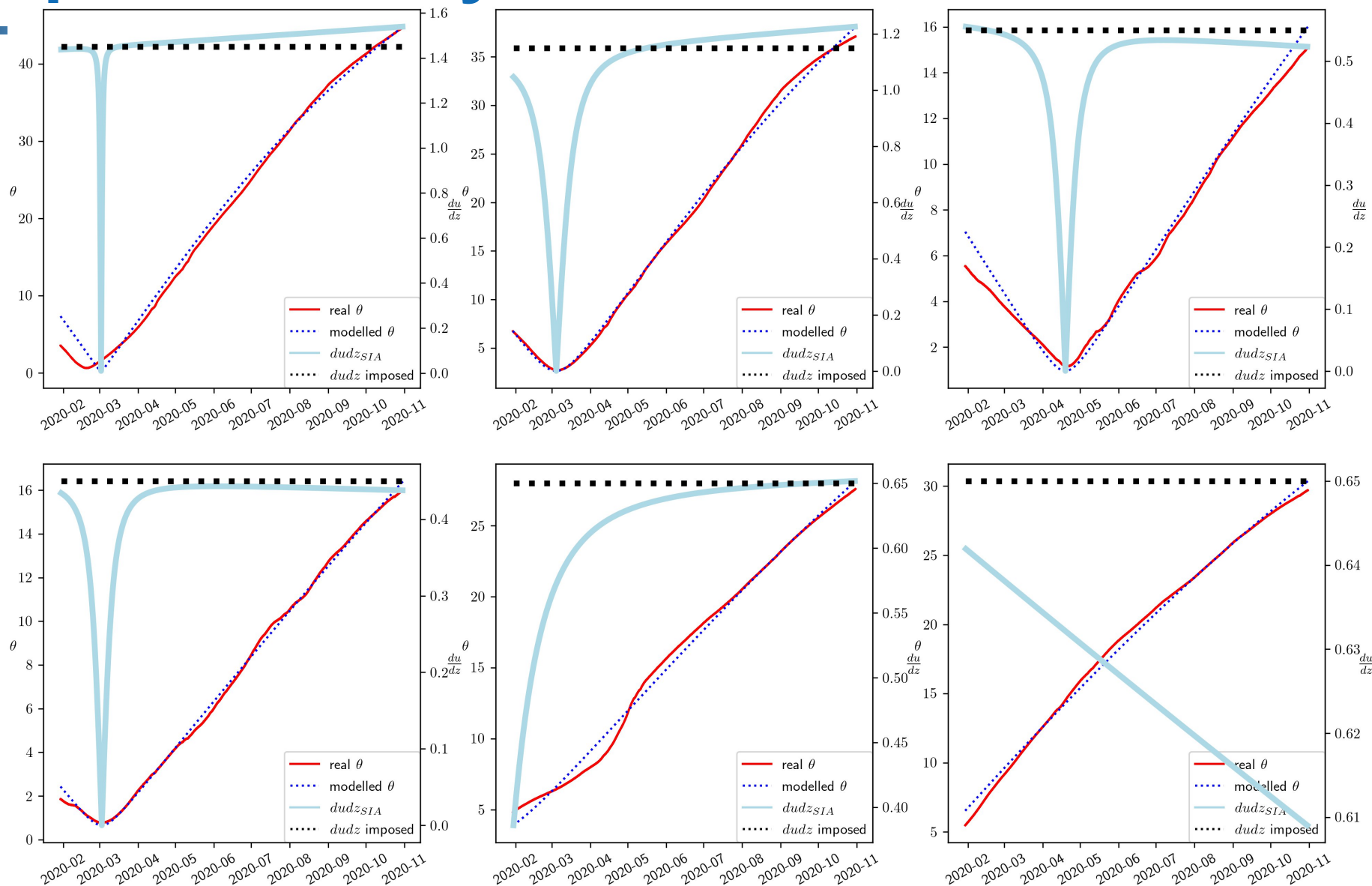
Imposed $dudz$

vs

SIA $dudz$

Inclinos 1 - 4:
SIA underestimates strain rates around minimum tilt

Inclino 6:
If ratio θ is high, SIA does not provide a constant
(low impact, fortunately)



Example: February to November 2020

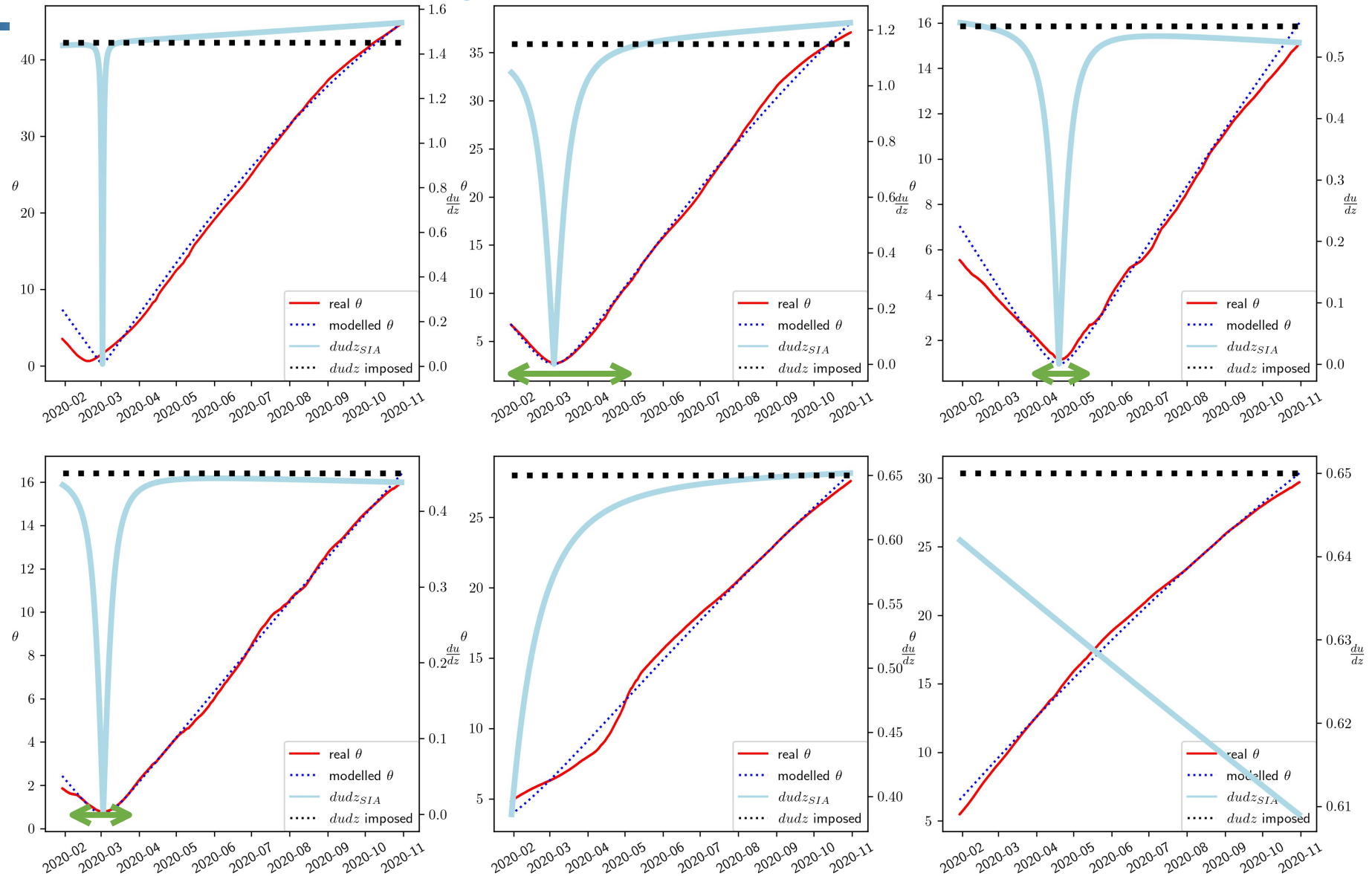
Now we use our method to compute the du/dz on the fitted tilt curves

Imposed $dudz$

vs

SIA $dudz$

'High' bias in January - April period



Melt season average deformation (SIA)

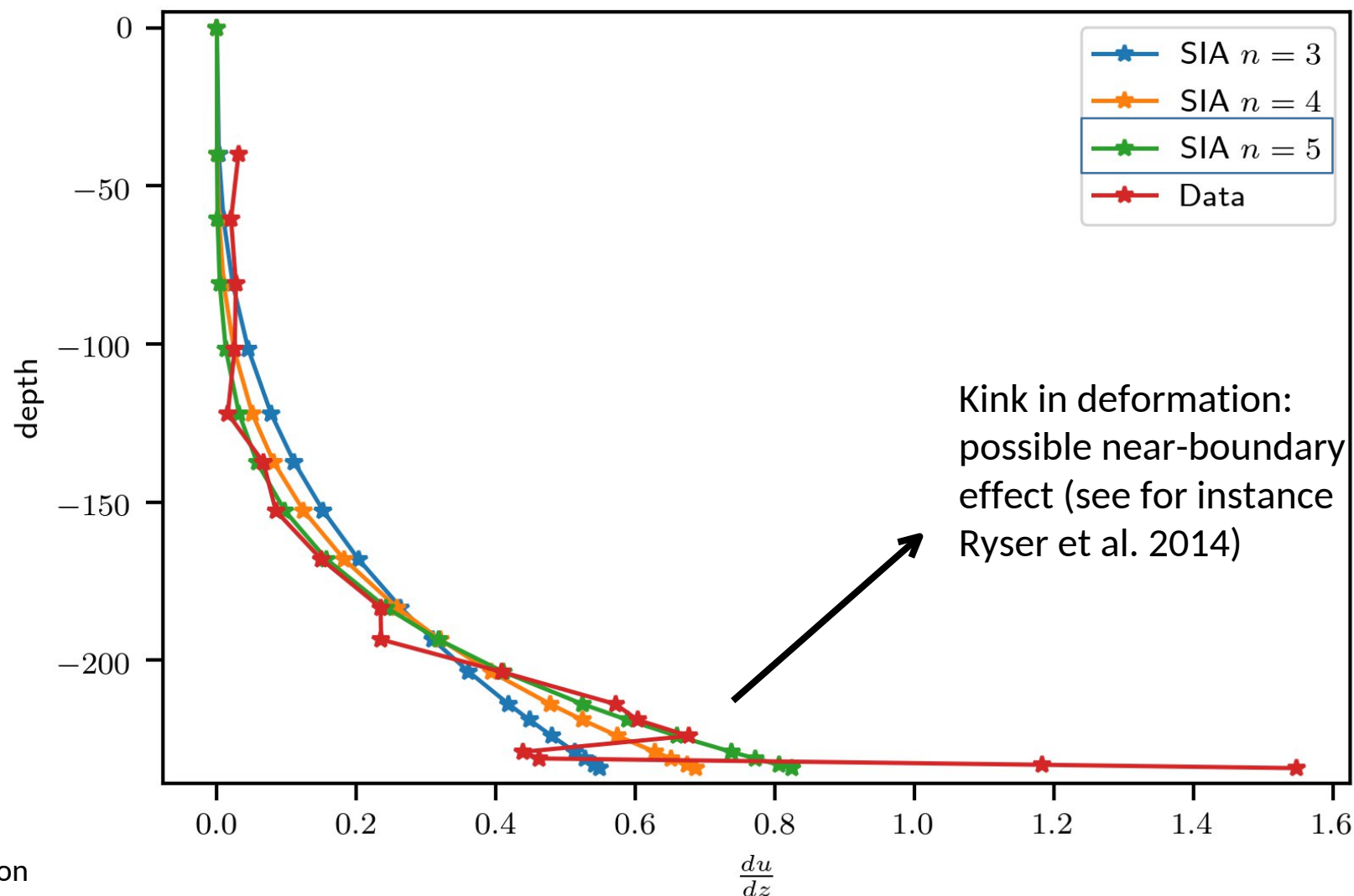
Results from SIA during melt season:

Viscosity is adjusted so
that the total deformation velocity
is equal to the average
deformation velocity

(mean u_d) = 32 m/a

i.e. The area to the left of each
curve is the same

note: annual averages give $n \sim 3.4$ due to the
underestimation of deformation before melt season



Thank you very much!

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ANR