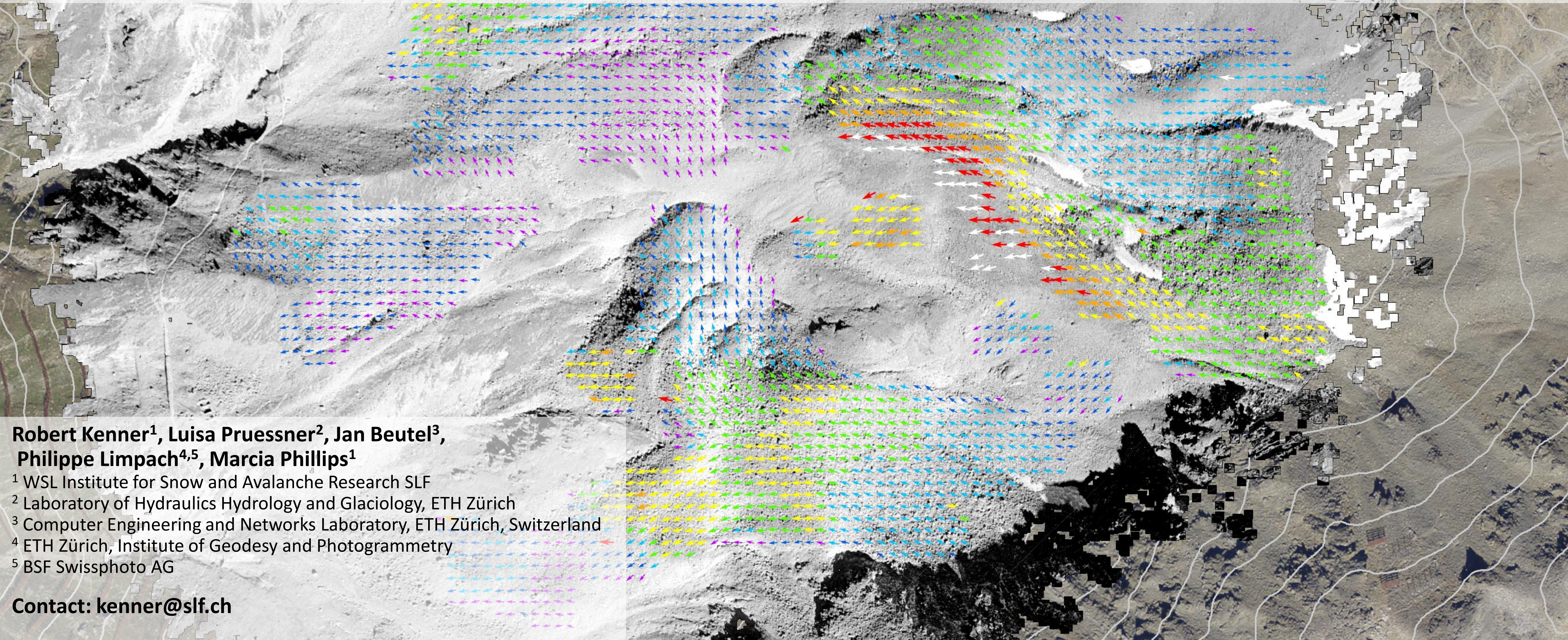
Why rock glacier deformation velocities correlate with both ground temperatures and water supply at multiple temporal scales



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Motivation & Research Question

Both, ground temperature and rock glacier hydrology are referred to by the literature as controlling rock glacier velocity variations. How can the observed temporal correlations between all 3 parameters be explained?

Methods and Datasets

- Borehole ground temperatures (GT) provided by swiss permafrost monitoring network (PERMOS) → Indications on melt & freeze processes and lateral heat flows (infiltrating water)
- permanent GPS timeseries, LidaR Data and aerial images on rock glacier kinematics
- Weather stations provide information on precipitation, snow cover & air temperatures.

Sites

4 rock glaciers in the Swiss Alps:

Schafberg (Photo right); Ritigraben; Murtèl; Muragl

The time between the end of the autumn zero curtain (zc) and the start of spring zc in which the active layer of rock glaciers is frozen (T < -0.1°C) varies strongly between the years (bottom line in table).

	Schafberg at 3.2 m depth				Ritigraben at 2.5 m depth						Murtèl at 2.5 m depth			Muragl at 2.2 m depth		
	End ZC autumn	Start ZC spring	T < -0.1°C [days]	MADV [% of 2013]	End ZC autumn	Start ZC spring	T < -0.1°C [days]	MADV [% of 2000]	T < -0.1° C [days]	MADV [% of 2000]	End ZC autumn	Start ZC spring	T < -0.1°C [days]	End ZC autumn	Start ZC spring	T < -0.1°C [days]
1995											12.11.1994	30.05.1995	199			
1996											12.11.1995	28.05.1996	198			
1997											22.11.1996	30.05.1997	189			
1998	07.03.1998	08.06.1998	93								30.11.1997	27.05.1998	178			
1999	11.02.1999	07.07.1999	145								01.12.1998	01.06.1999	182			
2000	15.02.2000	14.07.2000	150								08.12.1999	17.05.2000	161			
2001	16.04.2001	24.05.2001	38											10.03.2001	26.05.2001	77
2002	11.01.2002	16.05.2002	125								17.11.2001	14.06.2002	209	26.12.2001	30.05.2002	155
2003	12.03.2003	03.05.2003	52		26.10.2002	10.05.2003	196				23.11.2002	06.05.2003	164			
2004	06.02.2004	18.05.2004	102		17.10.2003	13.05.2004	209				04.11.2003	09.06.2004	218			
2005	09.01.2005	15.05.2005	126		16.11.2004	19.05.2005	184		199	177.6	24.11.2004	28.05.2005	185	31.12.2004	04.06.2005	155
2006	23.12.2005	05.05.2006	133		20.11.2005	20.05.2006	181				18.11.2005	26.05.2006	189			
2007	15.01.2007	16.04.2007	91		21.11.2006	28.04.2007	158				15.11.2006	02.05.2007	168			
2008	24.12.2007	17.05.2008	145		09.11.2007	15.05.2008	188		180 ↓	234.9 ↑	29.10.2007	29.05.2008	213			
2009	14.03.2009	13.05.2009	60		26.11.2008	19.05.2009	174				22.11.2008	26.05.2009	185			
2010	24.02.2010	25.04.2010	60 →	44.5	07.11.2009	26.05.2010	200				02.11.2009	13.06.2010	223			
2011	18.02.2011	04.04.2011	45 ↓	71.2 ↑	12.11.2010	11.05.2011	180				05.11.2010	13.05.2011	189			
2012	03.01.2012	13.05.2012	131 ↑	44.0 ↓	16.11.2011	10.05.2012	176		178 ↓	265.0 ↑	07.11.2011	07.06.2012	213	11.12.2011	02.06.2012	174
2013	23.02.2013	07.05.2013	73 ↓	100.0 ↑	11.11.2012	12.05.2013	182 ↑	265.0			19.12.2012	18.06.2013	181	26.01.2013	22.05.2013	116
2014	11.03.2014	28.04.2014	48 ↓	130.1 ↑	29.11.2013	25.05.2014	177 ↓	342.7 ↑						10.02.2014	05.06.2014	115
2015	25.02.2015	24.04.2015	58 →	145.2 ↑	21.11.2014	05.05.2015	165 ↓	406.3 ↑			16.01.2014	04.06.2014	139			
2016	30.12.2015	12.04.2016	105 ↑	102.4 ↓	18.12.2015	25.05.2016	159 ↓	402.5 →			24.11.2015	11.06.2016	200	22.01.2016	04.05.2016	103
2017	16.01.2017	14.05.2017	118 ↑	78.5 ↓	10.11.2016	21.05.2017	192 ↑	345.0 ↓			22.11.2016	27.05.2017	186	30.01.2017	11.05.2017	101
2018											08.11.2017	23.05.2018	196			
Minima	23.12.	04.04.	38		17.10.	28.04.	158				29.10.	02.05	139	11.12	04.05.	77
Maxima	16.04.	24.05.	145		18.12.	26.05.	209				16.01	18.06	223	10.03	05.06.	174
Difference	**114**	**50**	**107**		**62**	**28**	**51**				**79**	**47**	**84**	**89**	**32**	**97**

This duration during which the active layer is frozen, negatively correlates with the mean annual deformation velocity (MADV) of the rock glaciers. (See arrows in columns “T < -0.1°C” and “MADV”)

	Schafberg at 3.2 m depth				Ritigraben at 2.5 m depth						Murtèl at 2.5 m depth			Muragl at 2.2 m depth		
	End ZC autumn	Start ZC spring	T < -0.1°C [days]	MADV [% of 2013]	End ZC autumn	Start ZC spring	T < -0.1°C [days]	MADV [% of 2000]	T < -0.1° C [days]	MADV [% of 2000]	End ZC autumn	Start ZC spring	T < -0.1°C [days]	End ZC autumn	Start ZC spring	T < -0.1°C [days]
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1997											22.11.1996	30.05.1997	189			
1998	07.03.1998	08.06.1998	93								30.11.1997	27.05.1998	178			
1999	11.02.1999	07.07.1999	145								01.12.1998	01.06.1999	182			
2000	15.02.2000	14.07.2000	150								08.12.1999	17.05.2000	161			
2001	16.04.2001	24.05.2001	38											10.03.2001	26.05.2001	77
2002	11.01.2002	16.05.2002	125								17.11.2001	14.06.2002	209	26.12.2001	30.05.2002	155
2003	12.03.2003	03.05.2003	52		26.10.2002	10.05.2003	196				23.11.2002	06.05.2003	164			
2004	06.02.2004	18.05.2004	102		17.10.2003	13.05.2004	209				04.11.2003	09.06.2004	218			
2005	09.01.2005	15.05.2005	126		16.11.2004	19.05.2005	184		199	177.6	24.11.2004	28.05.2005	185	31.12.2004	04.06.2005	155
2006	23.12.2005	05.05.2006	133		20.11.2005	20.05.2006	181				18.11.2005	26.05.2006	189			
2007	15.01.2007	16.04.2007	91		21.11.2006	28.04.2007	158				15.11.2006	02.05.2007	168			
2008	24.12.2007	17.05.2008	145		09.11.2007	15.05.2008	188		180 ↓	234.9 ↑	29.10.2007	29.05.2008	213			
2009	14.03.2009	13.05.2009	60		26.11.2008	19.05.2009	174				22.11.2008	26.05.2009	185			
2010	24.02.2010	25.04.2010	60 →	44.5	07.11.2009	26.05.2010	200				02.11.2009	13.06.2010	223			
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2013	23.02.2013	07.05.2013	73 ↓	100.0 ↑	11.11.2012	12.05.2013	182 ↑	265.0			19.12.2012	18.06.2013	181	26.01.2013	22.05.2013	116
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2015	25.02.2015	24.04.2015	58 →	145.2 ↑	21.11.2014	05.05.2015	165 ↓	406.3 ↑			16.01.2014	04.06.2014	139			
2016	30.12.2015	12.04.2016	105 ↑	102.4 ↓	18.12.2015	25.05.2016	159 ↓	402.5 →			24.11.2015	11.06.2016	200	22.01.2016	04.05.2016	103
2017	16.01.2017	14.05.2017	118 ↑	78.5 ↓	10.11.2016	21.05.2017	192 ↑	345.0 ↓			22.11.2016	27.05.2017	186	30.01.2017	11.05.2017	101
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Maxima	16.04.	24.05.	145		18.12.	26.05.	209				16.01	18.06	223	10.03	05.06.	174
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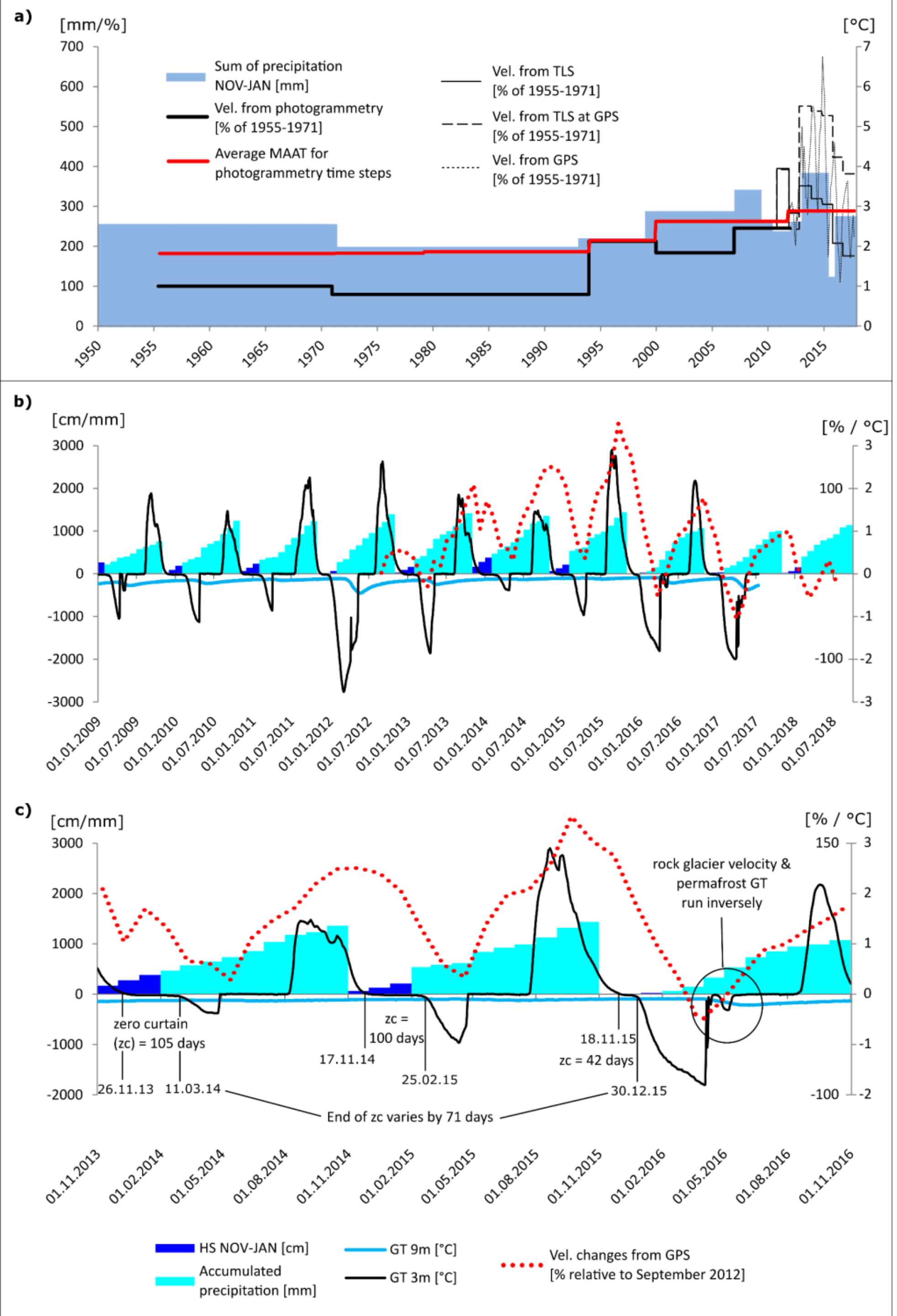
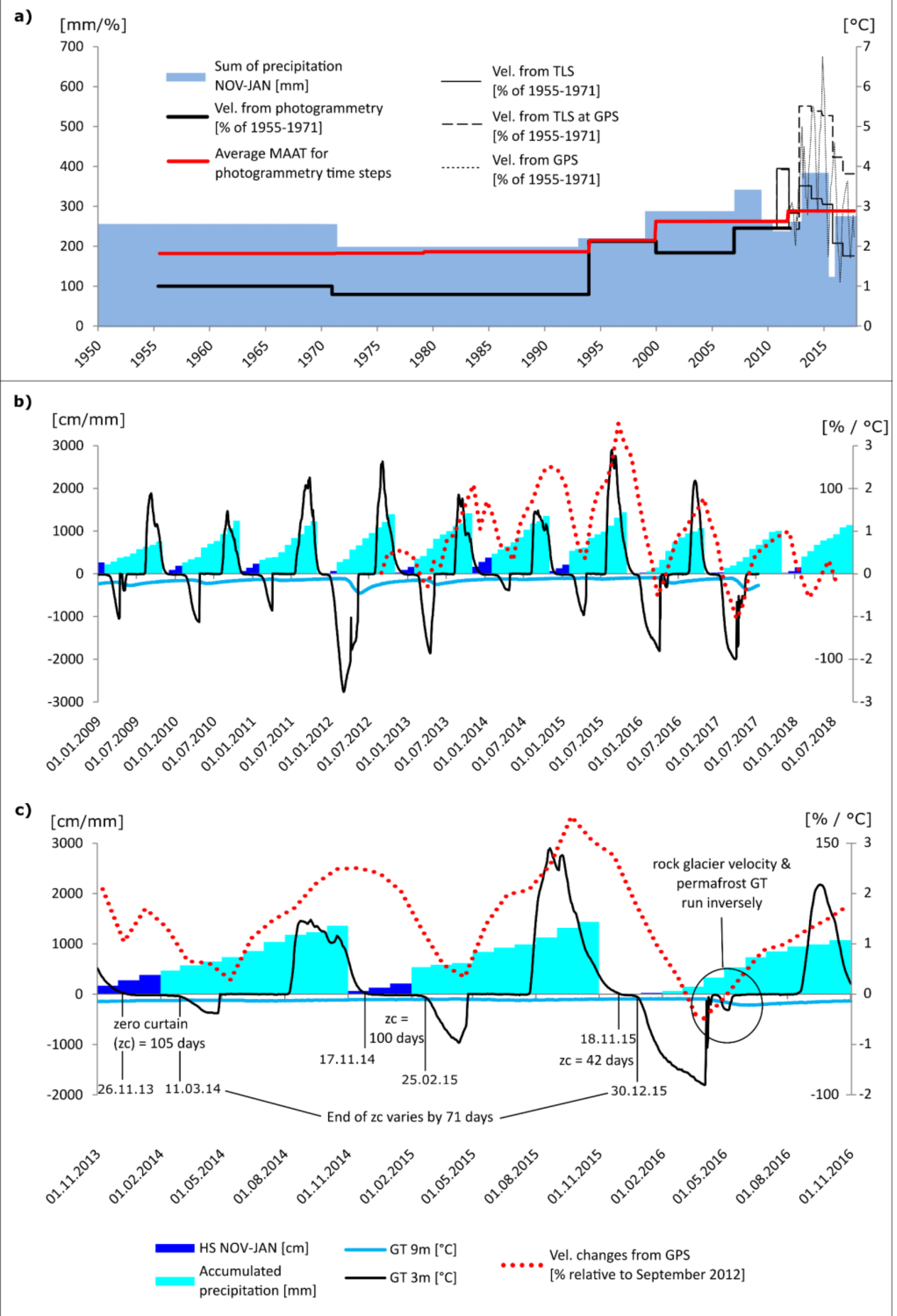


- Next to the start date of snow melt, the thickness of the early winter snow cover mainly controls the length of the period with an frozen active layer (b & c).

- Snow poor early winters cause long freezing periods and are followed by a rock glacier deceleration (b & c).

- Of course, longer freezing periods cause lower winter GT of the permafrost body as well.

- Especially in the case of warm rock glaciers, these winter permafrost temperatures are decisive for the mean annual GT (MAGT) as the summer temperatures show a zero curtain and do not have strong interannual variations.



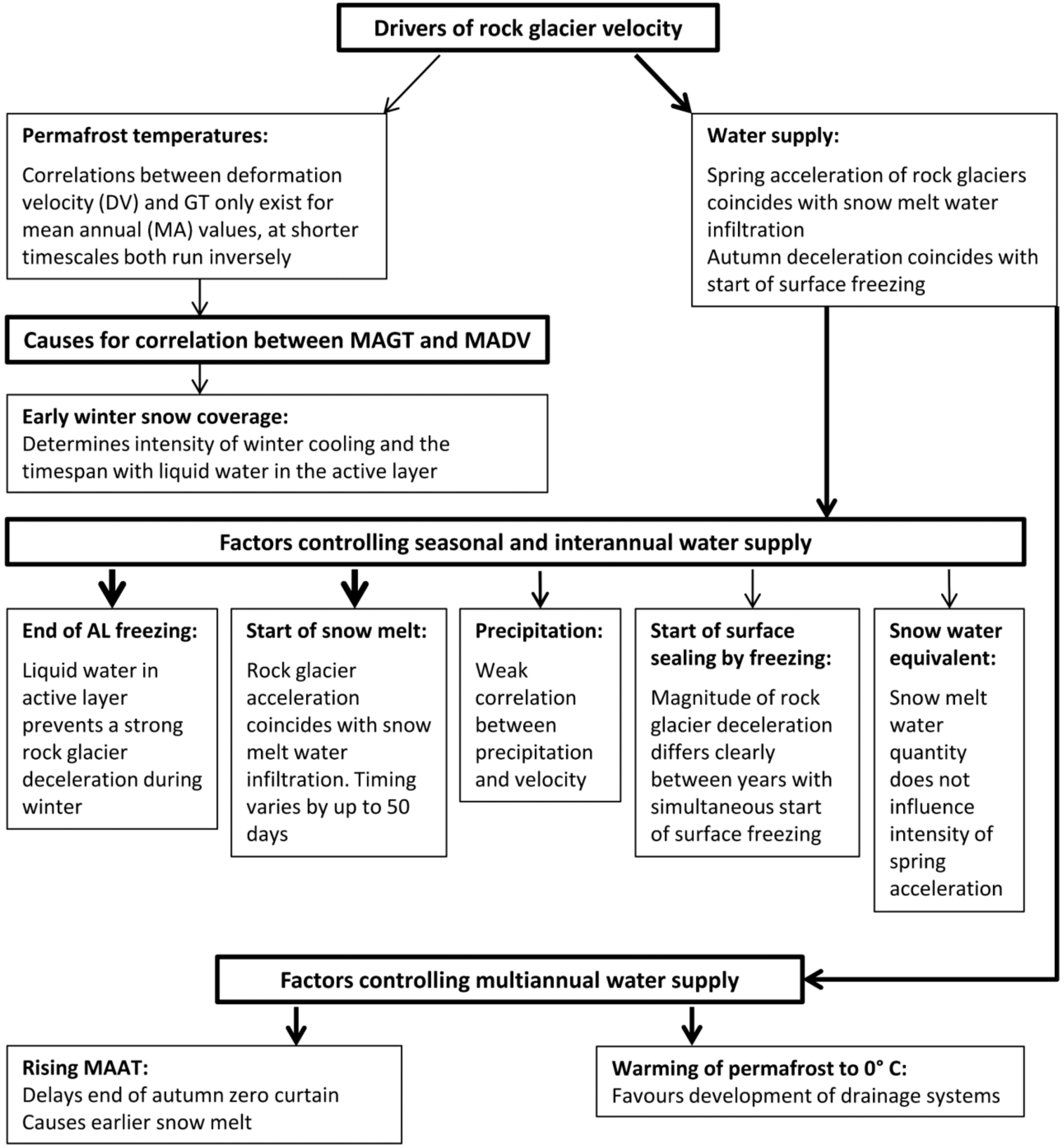
- Thus correlations of MADV and GT over different time scales can be found

- **These correlations are however not causally determined in a rigorous way!**

- Figure c (circle) shows how DV and GT run inversely!

- The actual driver for the DV is not temperature but the efficiency of water supply to the rock glacier shear horizon (Kenner et al., 2017; Cicoira et al., 2019).

- This water supply is influenced by winter GT, especially by the duration of the period in which the active layer is frozen.



For more information see:

Kenner, R., Pruessner, L., Beutel, J., Limpach, P., & Phillips, M. (2020). How rock glacier hydrology, deformation velocities and ground temperatures interact: Examples from the Swiss Alps. *Permafrost and Periglacial Processes, 31*(1), 3-14. doi:10.1002/ppp.2023

References:

Cicoira, A., Beutel, J., Faillettaz, J., Gärtner-Roer, I., & Vieli, A. (2019). Resolving the influence of temperature forcing through heat conduction on rock glacier dynamics: a numerical modelling approach. *The Cryosphere, 13*(3), 927-942. doi:10.5194/tc-13-927-2019

Kenner, R., Phillips, M., Beutel, J., Hiller, M., Limpach, P., Pointner, E., & Volken, M. (2017). Factors Controlling Velocity Variations at Short-Term, Seasonal and Multiyear Time Scales, Ritigraben Rock Glacier, Western Swiss Alps. *Permafrost and Periglacial Processes, 28*(4), 675-684. doi:10.1002/ppp.1953