UNIVERSITAS FRIBURGENSIS

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ALPINE CRYOSPHERE AND GEOMORPHOLOGY

# The evolution of ground surface temperatures and rock glacier dynamics in the Furggentälti (Gemmi, VS)

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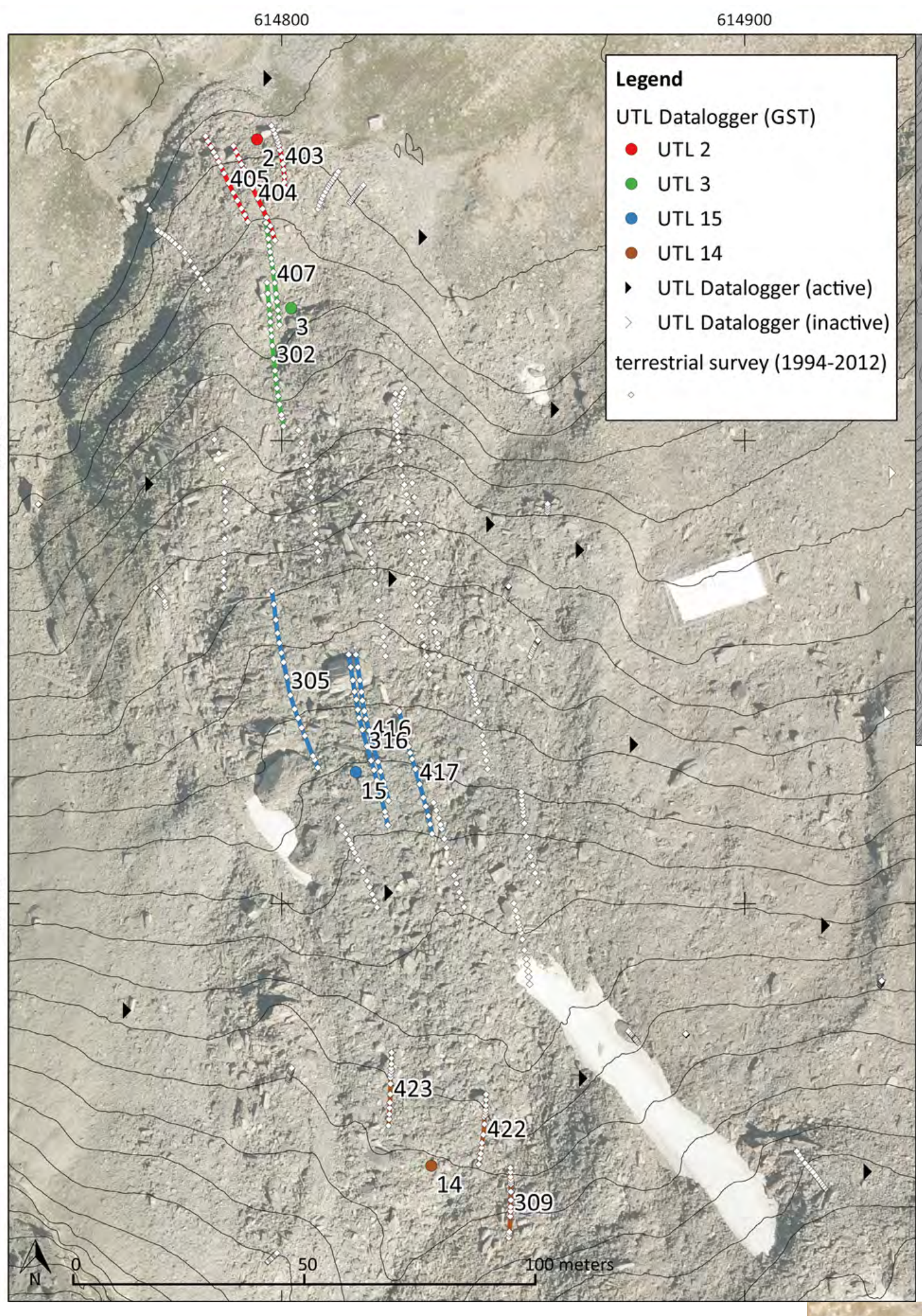
## Almost 25 years of permafrost research

In the western part of the Swiss Alps near the Gemmipass, a long-term permafrost monitoring site (fig. 1) has been installed by the University of Berne in 1987 to observe the further development of three rock glaciers and different periglacial processes and landforms. *[5,6]*

Situated in a relatively warm and wet climate at elevation levels between 2450 and 2850 m asl., this test area became one of the longest permafrost-related temperature and kinematics time series in the Swiss Alps and owns the "reference site" status within the national permafrost monitoring network PERMOS.

The main objective of the current research in this area is to improve the understanding of the rock glacier dynamics regarding the evolution of ground surface temperatures and terrain movements observed during the past two decades. Over the monitoring period several climatic events occurred and the air and ground temperatures and the kinematics as well show considerable changes in long-term and a high seasonal and inter-annual variability (fig. 3-6).



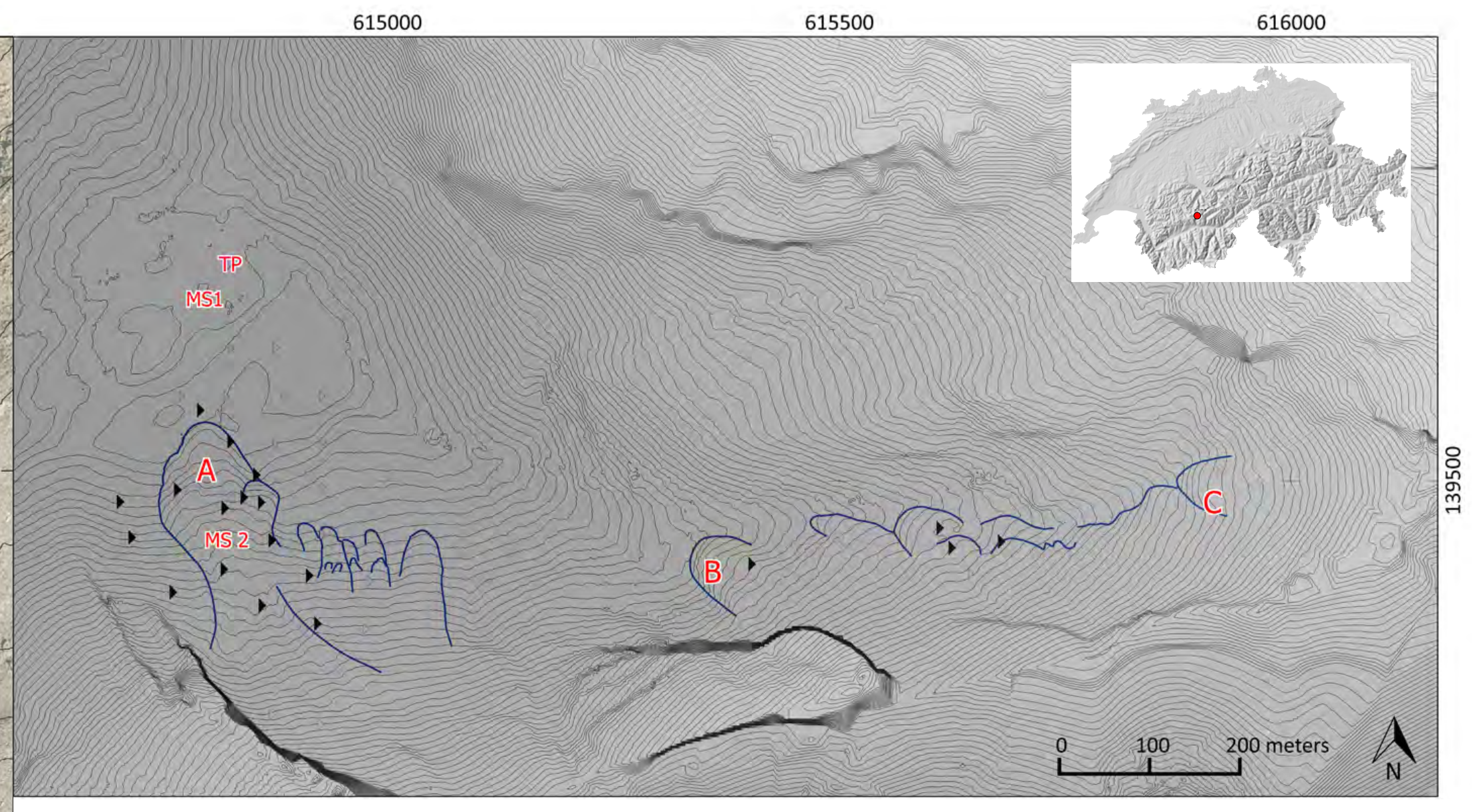
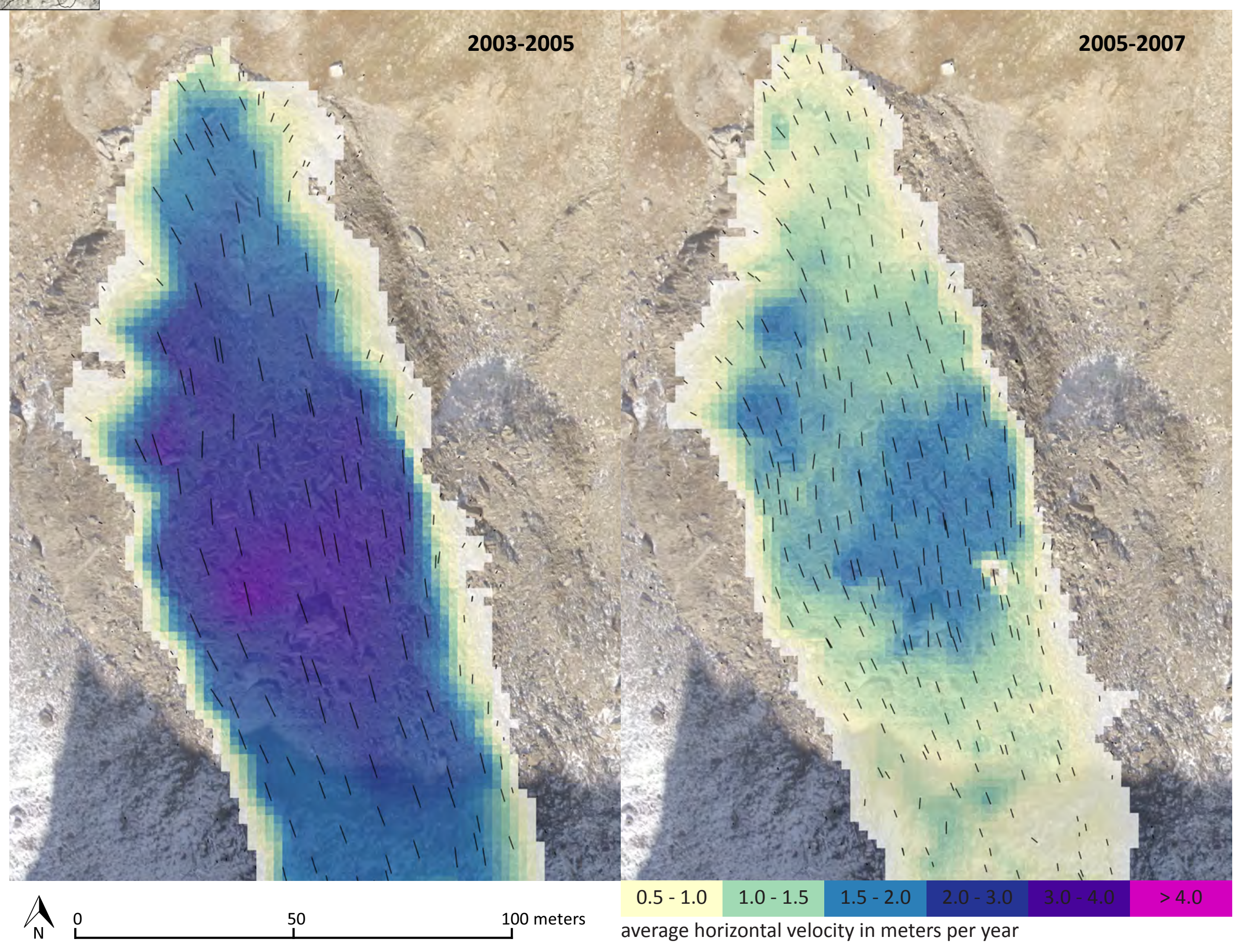


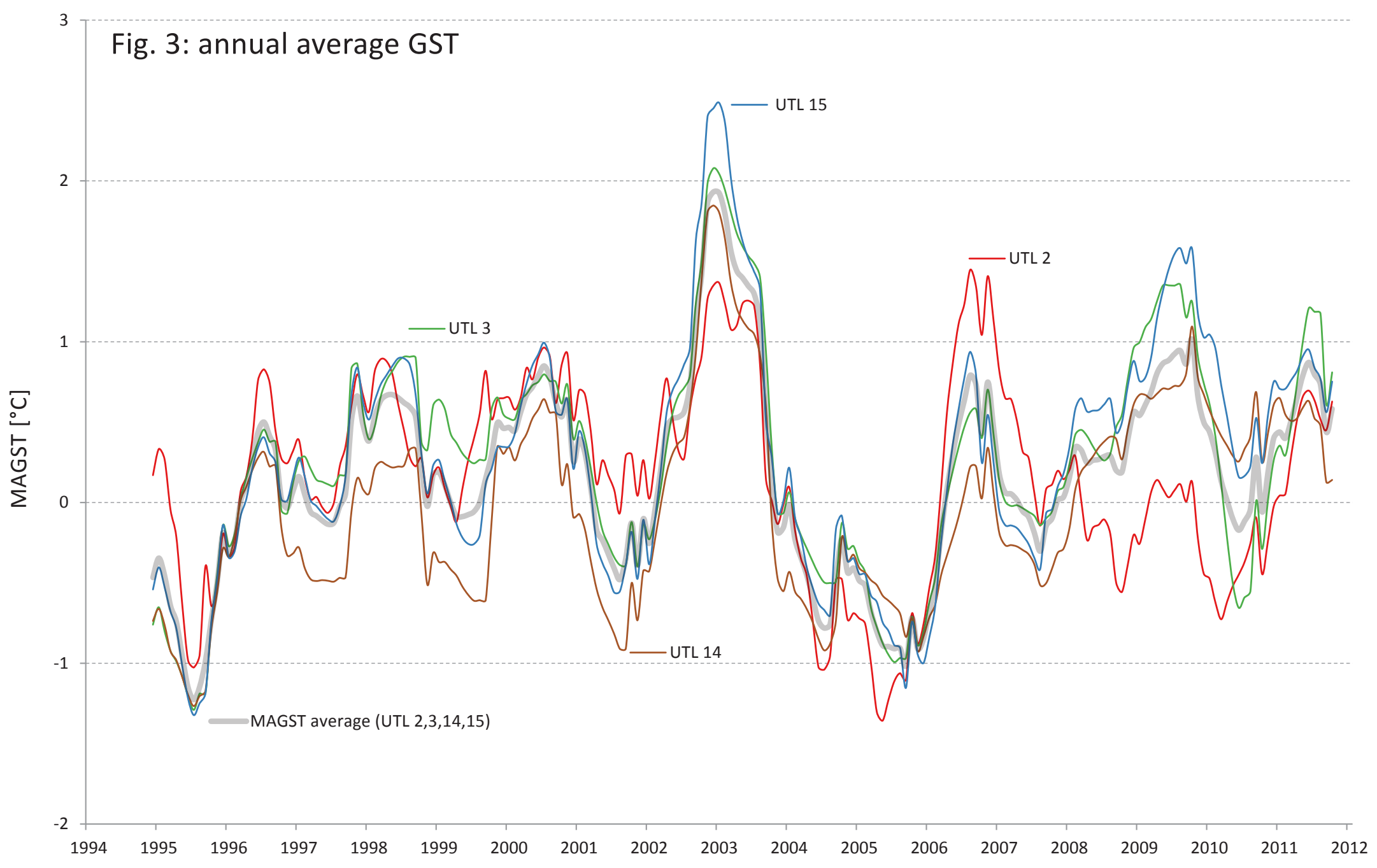
Fig 1 (above): Overview of the study site indicating the three *rock glaciers A, B and C*, important geomorphological features (blue lines), the two local meteo stations (MS1 and MS2, running since 1999/2000) and the temperature profile (TP) measuring the air and ground temperature at 6 different depths since 1988. [5]

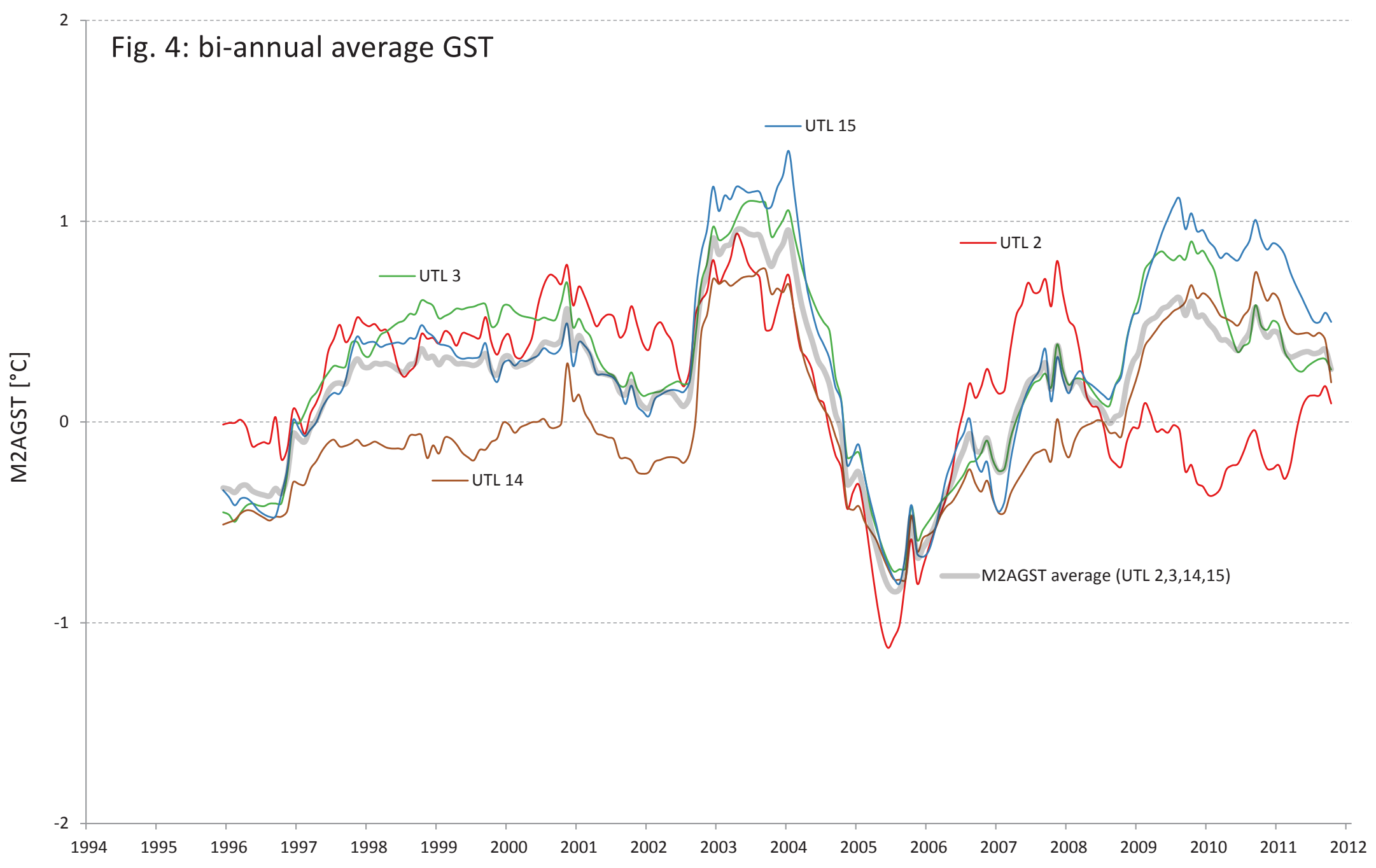
Fig 2 (left): *Rock glacier A* with terrestrial survey points and recent positions of UTL data loggers for GST measurement (the selected data for the other figures are marked in colour). Base map: Orthophoto and 5 m contour lines from 2010 (Flotron AG).

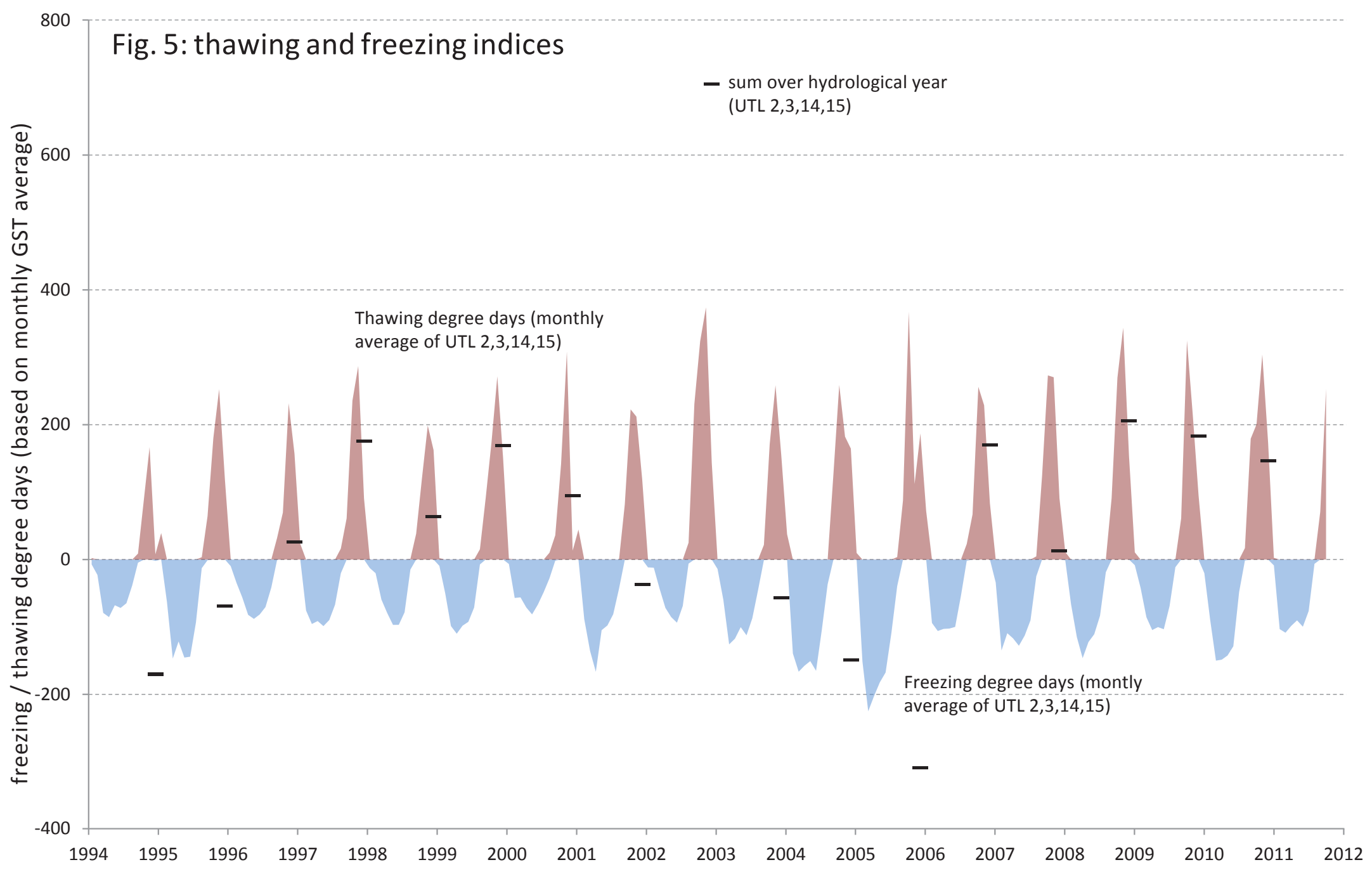
Fig 7 (below): Comparison of interpolated velocity fields (2m grid) *on rock glacier A* measured by means of digital photogrammetry. Base Map: Orthophoto from 2007 (Flotron AG).



## A comparison of ground surface temperatures and rock glacier kinematics







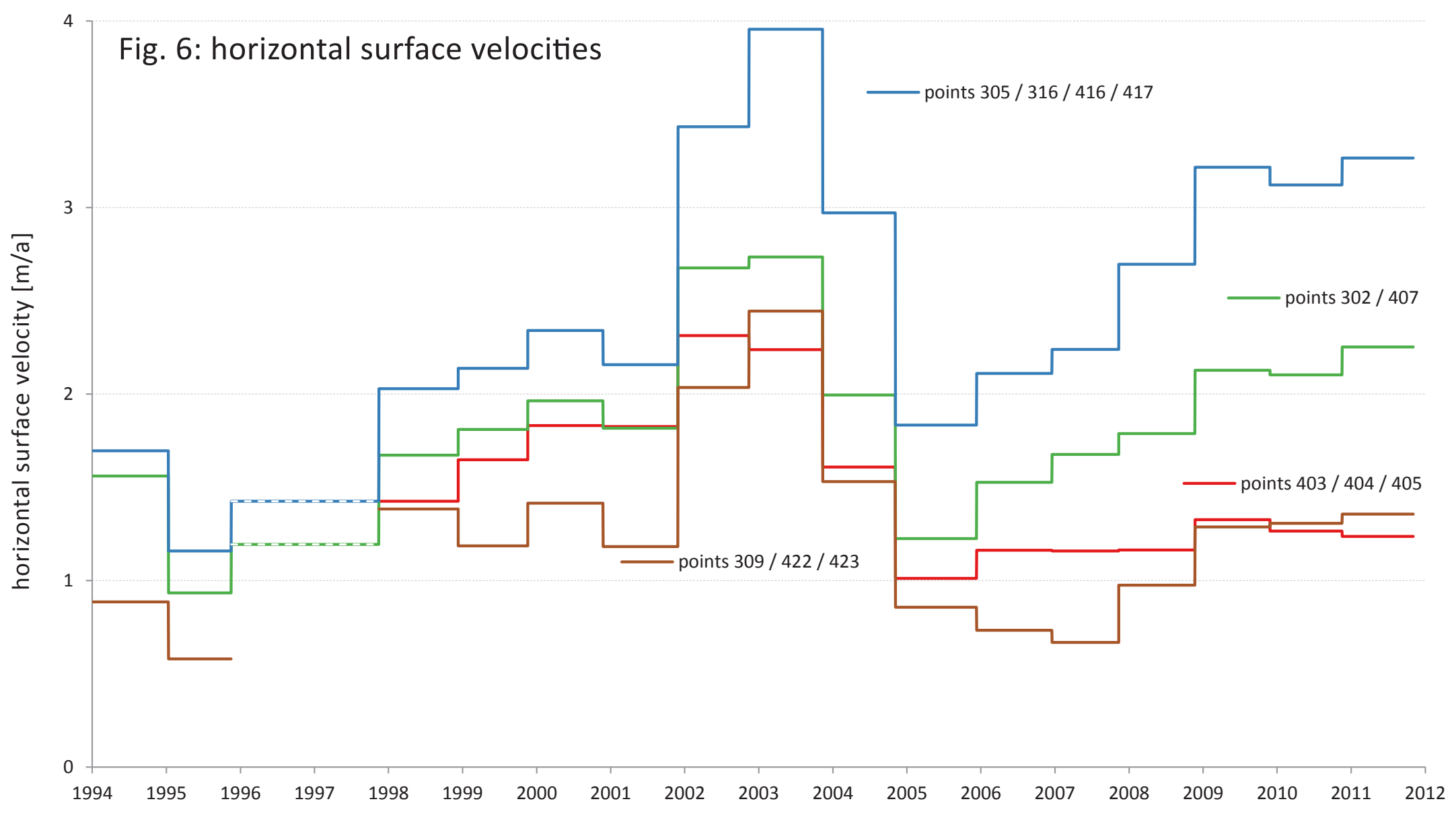


Fig 3: The mean annual ground surface temperature (MAGST) is shown for 4 of the most complete GST time series situated on the longitudinal profile of rock glacier A (fig. 2). Data gaps (about 7-22 % over 18 years, mostly during the maintenance in summer) were reconstructed by multiple linear regressions with other GST data from the Furggentälti and additional permafrost field sites (Sanetsch, Ritord, Réchy) and air temperature measured (fig. 1). The time scale is indicating the end of the hydrological year.

Fig 4: The bi-annual running average GST (M2AGST) of the same UTL data logger as in figure 3, indicates important thermal anomalies on the ground surface.

Fig 5: As an index for the amount and the direction of heat transfer between the ground surface and the atmosphere, the freezing and thawing indices are aggregated as monthly sum in degree days. The black bars indicate the sum over the hydrological year, pointing on impressive differences from year to year.

Fig 6: The mean annual horizontal velocities in meters per year for some survey points (fig. 2) close to the UTL data loggers presented in the graphs above. Normally the surveys took place in august. Since the data from 1997 are missing, the average velocity from 1996 to 1998 is marked as a dotted line. The average annual creep rates between 1985 and 1995 measured by photogrammetry range from 50 cm/y to 1.3 m/y for the the most dynamic parts in the center of the rock glacier.

For the comparison of ground surface temperatures (GST) and rock glacier creep velocities, four of the most complete GST time series were chosen along the longitudinal profile of *rock glacier A* and processed on the basis of monthly average values (fig. 2-4). The aggregation in annual (MAGST) and bi-annual (M2AGST) average values allows to visualize events without the influence of seasonal fluctuations. To determine whether the cooling or the warming period is more important for the overall trends in GST, monthly and annually freezing- and thawing indices can be generated (fig. 5).

## Results

The observation period was rich of climatic events with high variations from year to year. The GST seems to react very sensitive to both, cooling and warming events and is highly influenced by the snow cover. Remarkable are the strong increase in MAGST during the hydrological year 2002/03 due to superposition of a reduced cooling in the precedent winter and the heat wave in summer 2003 (fig. 3). This caused also a strong positive anomaly in the bi-annual mean GST until 2004 (fig. 4). Equally to this positive anomaly, the period from 2004 to 2006 was characterized by a very effective cooling of the ground with a negative sum of the freezing & thawing degree days by the end of the hydrological year (fig. 5).

The activity pattern and the morphology of *rock glacier A* were changing during the last decade: Besides of an overall increase in velocity (fig. 6), some parts at the rock glacier sides seem to become inactive while creep velocities in the center were increasing up to 400% compared to the average velocity before 1990 and thus forming distinctive shear zones (fig. 7). This behaviour was first detected by photogrammetric analysis *[5]* and can now also visually be observed from the images of a newly installed webcam.

## Discussion

The short reaction time between changes in GST and velocities is remarkable. During the periods 1995-2000 and 2005-2010 the temperatures at the ground surface were more or less in the same range and following a similar trend, but the kinematics were different: While velocities are similar in the uppermost part of the rock glacier, acceleration can be observed in the central parts forming distinctive shear zones towards the border.

Probably a mostly temperature-driven creep mechanism is superimposed by landslide-like movement components which are sensitive to melt water infiltration and therefore causing acceleration connected to the snow melt period *[2]*. Compared with findings from other permafrost research sites in the Swiss Alps, the inter-annual variability of rock glacier creep follows a similar pattern *[1]*.

## Conclusions and Perspectives

The spatial pattern of rock glacier creep and the changes in morphology should be observed more in detail. A combined qualitative (using webcam images and terrestrial photographs) and quantitative (using digital photogrammetry) research approach could be suitable for this task. To have a closer look on the influence of melt water infiltration on rock glacier dynamics, terrestrial surveys will be done in future also in spring and autumn and extended to the other rock glaciers in the valley.

In addition to the GST measurements, complementary geophysical investigations will be done in summer 2013 to determine the internal structure of the rock glaciers.
For *rock glacier A* a comparison with electrical resistivity measurements (ERT) and refraction seismics from 2007 and 2008 *[3,7]* will probably lead to further findings about the distribution and evolution of the subsurface ice content.

## Acknowledgements

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