# Centreline and cross-glacier variability in air temperature on an Alpine glacier

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#### Can we use the environmental lapse rate?

Moore, 2010; Petersen *et al.*, 2013; Ayala *et al.*, 2015).

time.



Valle d'Aosta, Italy (2800-3445 m asl.). Weather stations and T-loggers (Tinytag- accuracy  $\pm 0.35^{\circ}$ C) were distributed along the centreline and at lateral positions during 2015 (Figure 1). Data on wind speed and other meteorological variables were also available at both weather stations.

Best data availability was split into July-August (JA) and August-September (AS) sub-periods for analysis.

## Initial results

VTGs became shallow under the warmest ambient conditions (red lines in Figure 2) and were poorly explained by elevation ( $R^2 = 0.05$ ). Lateral variability was also larger under such conditions. On average however, VTGs were generally steeper than prescribed by the ELR (-0.0073°C m<sup>-1</sup> in JA) and well related to elevation (green lines).



Figure 2: The temperature elevation relationship of all stations shown in Figure 1 in JA (left) and AS (right). Elevation dependency is shown for the average of all hours (green) and the upper (red) and lower (blue) 10% of ambient off-glacier air temperatures at site Grand Croux. Shaded areas indicate one standard deviation from the means and the percentiles are given for each sub-period. Axes are identical.

Figure 3: Schematic image for Tsanteleina Glacier and the surrounding area to indicate the dominant sources of wind and the potential effects on near-surface air temperature (see numbers 1 and 2). Wind fields are interpreted from weather station data, wind flow modelling and field observations.



Figure 4: Estimation of centreline stations under warm ambient temperatures using a modified thermodynamic model presented by Ayala et al. (2015) for centreline stations (red squares) and lateral stations (blue squares). The RMSE values are presented for centreline estimation only (red line), centreline estimation including lateral sites and estimation of all sites (blue line). A linear VTG for the centreline is shown by the dashed black line.



#### Flowline estimation model

The presence of valley/slope winds and turbulent mixing can erode katabatic winds from the glacier and lead to warm temperatures on the glacier tongue.

A thermodynamic model (ModGB) as modified by **Ayala** *et al.* (2015) has been used to estimate temperature at given flowline distances under warm ambient conditions.

+ Estimates centreline temperatures better than a linear VTG.

+ Centreline variations similar to Haut Glacier d'Arolla suggesting transferability.

Locally derived parameters required for katabatić conditions

- Lateral variations under the warmest conditions cannot be represented by this model (Figure 4)



# Lateral temperature variations

'Cold spots', hypothesized to be influenced by topographic depressions on the glacier surface, encourage sensible cooling of stagnant air parcels under calm, high pressure conditions (Figure 5).

Such effects led to >2°C cooling relative to the glacier centreline. For turbulent, low pressure conditions, differences across the glacier were very smalĺ.



#### Key messages

Tsanteleina Glacier experiences minimal katabatic effects due to its size (as suggested by **Carturan** *et al.***, 2015**) and thus steep vertical temperature gradients on average.

Lateral temperature variability cannot be reasonably accounted for by existing flowline estimation methods or linear temperature gradients.

Differences >2°C than at similar centreline elevations are potentially very important and should be a focus of future studies to account for distributed temperature in energy balance/temperature-index melt models.

## **References and Acknowledgements**

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Figure 5: Relationship of air temperature differences at lateral sites (relative to centreline temperatures) under different wind speeds measured at weather stations (y-axis) and mean sea-level pressure from ERA Interim reanalysis data (colour-scale). Positive differences are where lateral temperatures are cooler than the centreline.



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