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FIRN CHANGES AT COLLE GNIFETTI REVEALED WITH A HIGH-RESOLUTION PROCESS-BASED PHYSICAL MODEL APPROACH

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COLLE GNIFETTI, 4450 M ASL



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COLLE GNIFETTI, 4450 M ASL

- ◆ Cold firn and ice (Suter and Hoelzle, 2002)
- ◆ Low accumulation rates → oldest ice cores in the Alps
- ◆ Close to European pollution
- ◆ Ice core record threatened by climate change? (Hoelzle *et al.*, 2011)

QUESTIONS

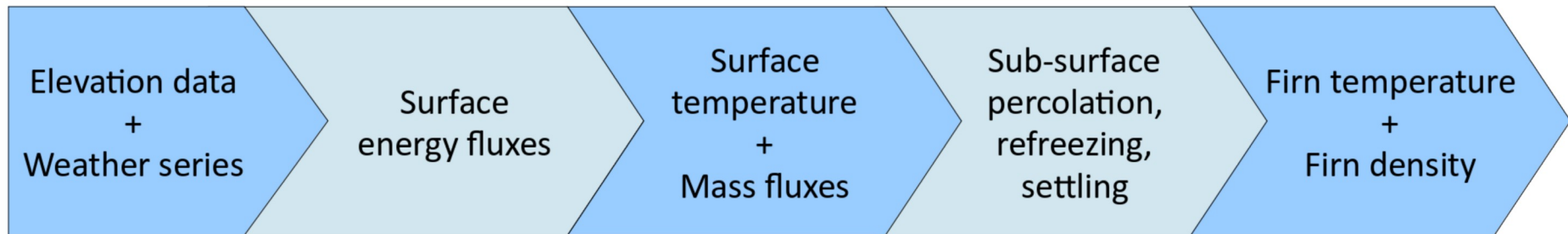
- ♦ Is the firn changing? (Temperature, water infiltration)
- ♦ Which weather conditions lead to surface melt?
- ♦ How does melt happen?



Energy balance
and firn model

ENERGY BALANCE AND FIRN MODEL

- ◆ Coupled model: van Pelt *et al.* (2012, 2019)
- ◆ Gridded (20 m resolution, 250 vertical layers – max 0.1 m each)
- ◆ Parametrized deep percolation: Marchenko *et al.* (2017)
- ◆ Forcing: meteorological series of the Capanna Margherita AWS



CAPANNA MARGHERITA AWS

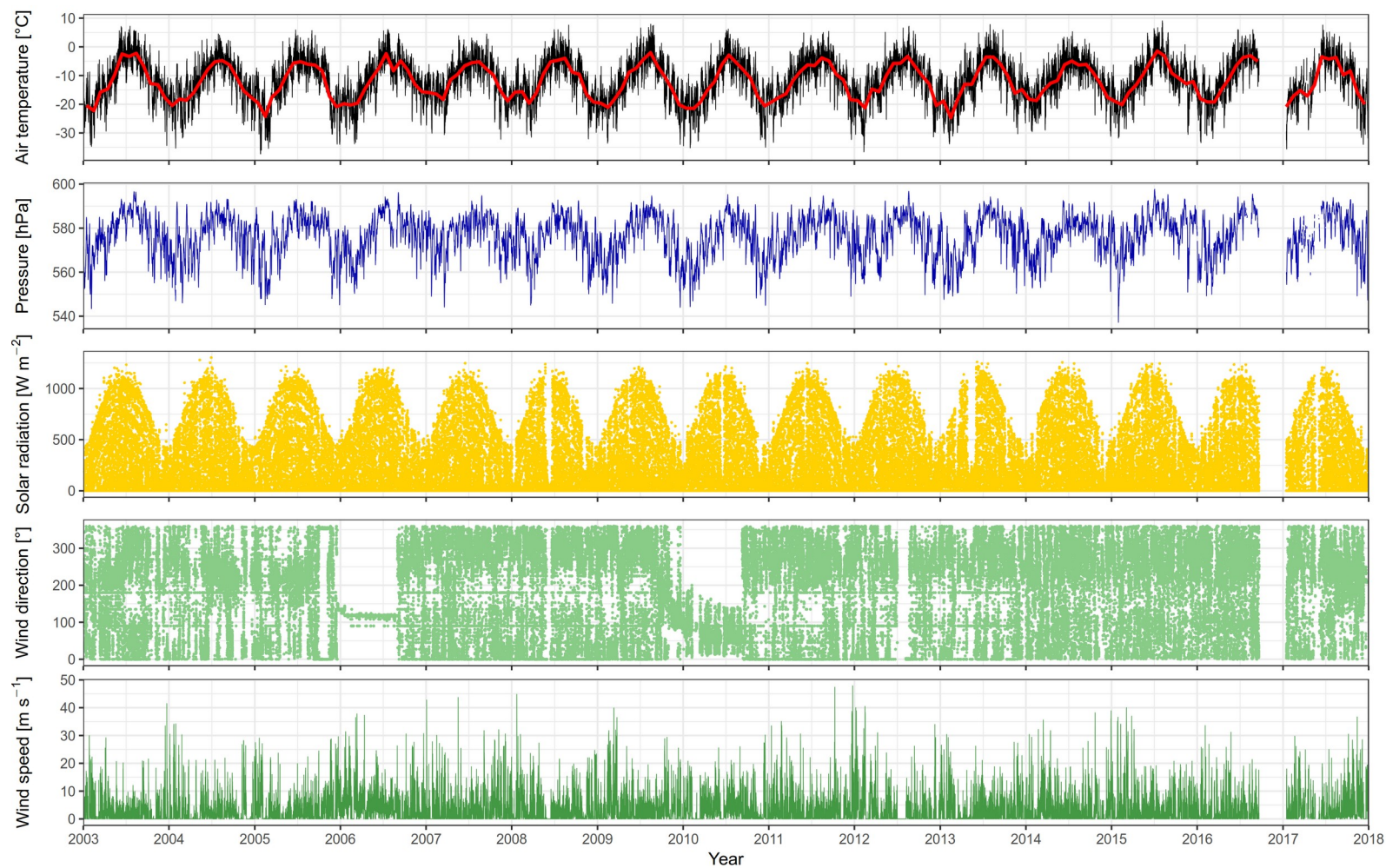


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CAPANNA MARGHERITA AWS

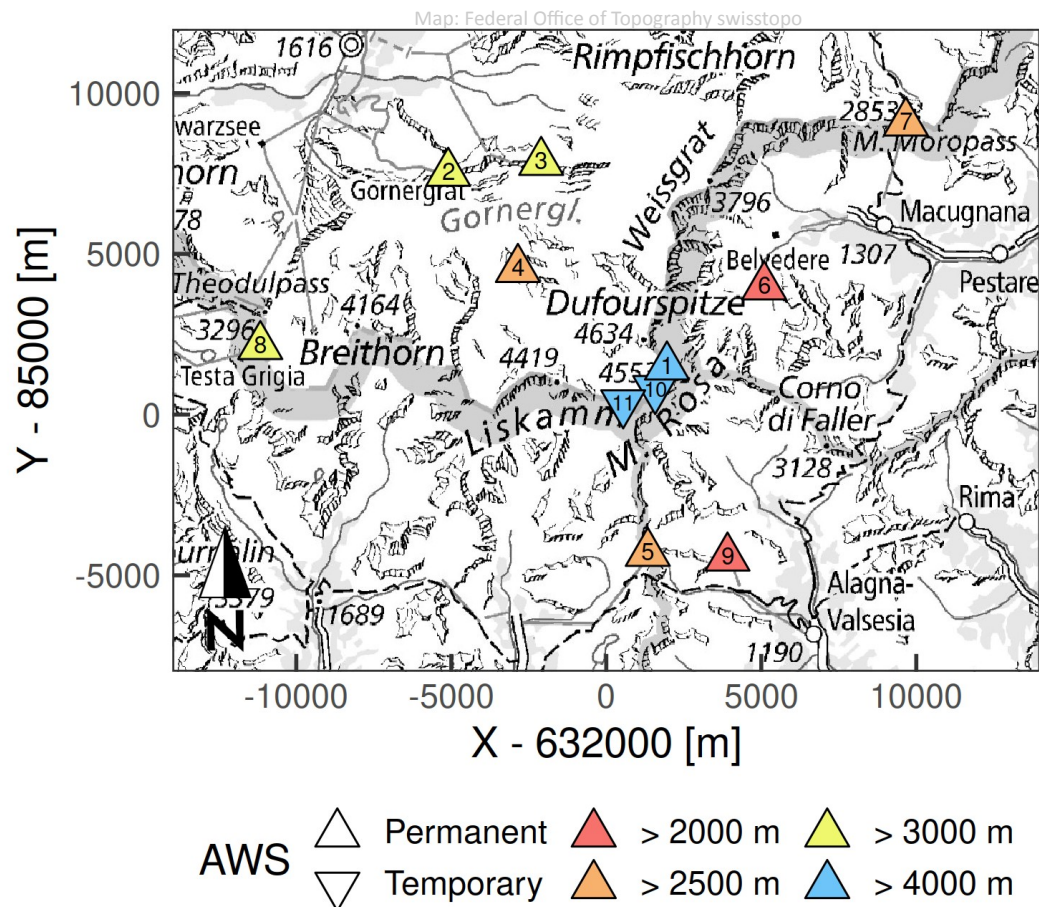
- ♦ Highest permanent AWS in Europe (4560 m a.s.l.)
- ♦ Operational since August 2002
- ♦ Air temperature, atmospheric pressure, global radiation, wind speed and wind direction
- ♦ More info (in Italian): Martorina *et al.* (2003)

CAPANNA MARGHERITA AWS



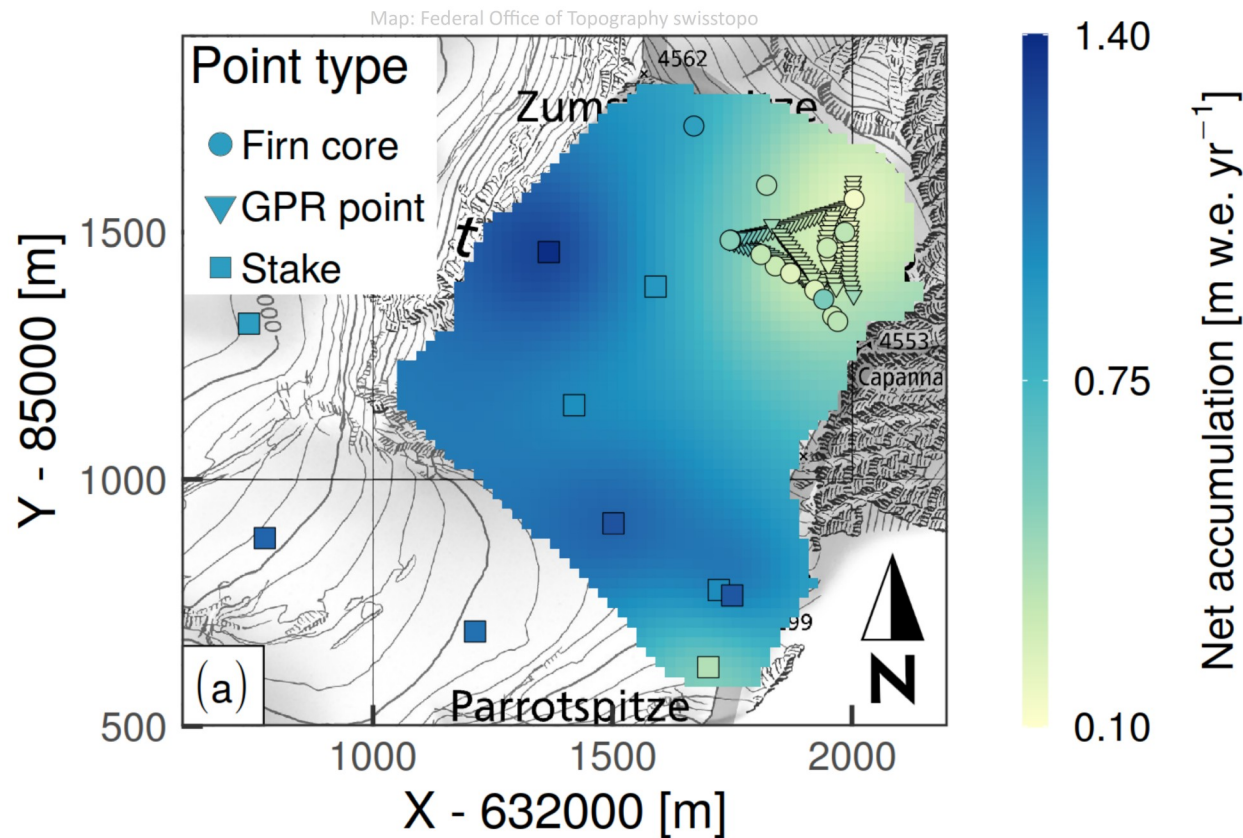
WEATHER INPUT PROCESSING

- ♦ Very high AWS altitude
➡ extreme weather conditions!
- ♦ Frequent anemometer freezes and snow obstructions
- ♦ Extensive quality check and gap-filling with other high-altitude AWS in the region



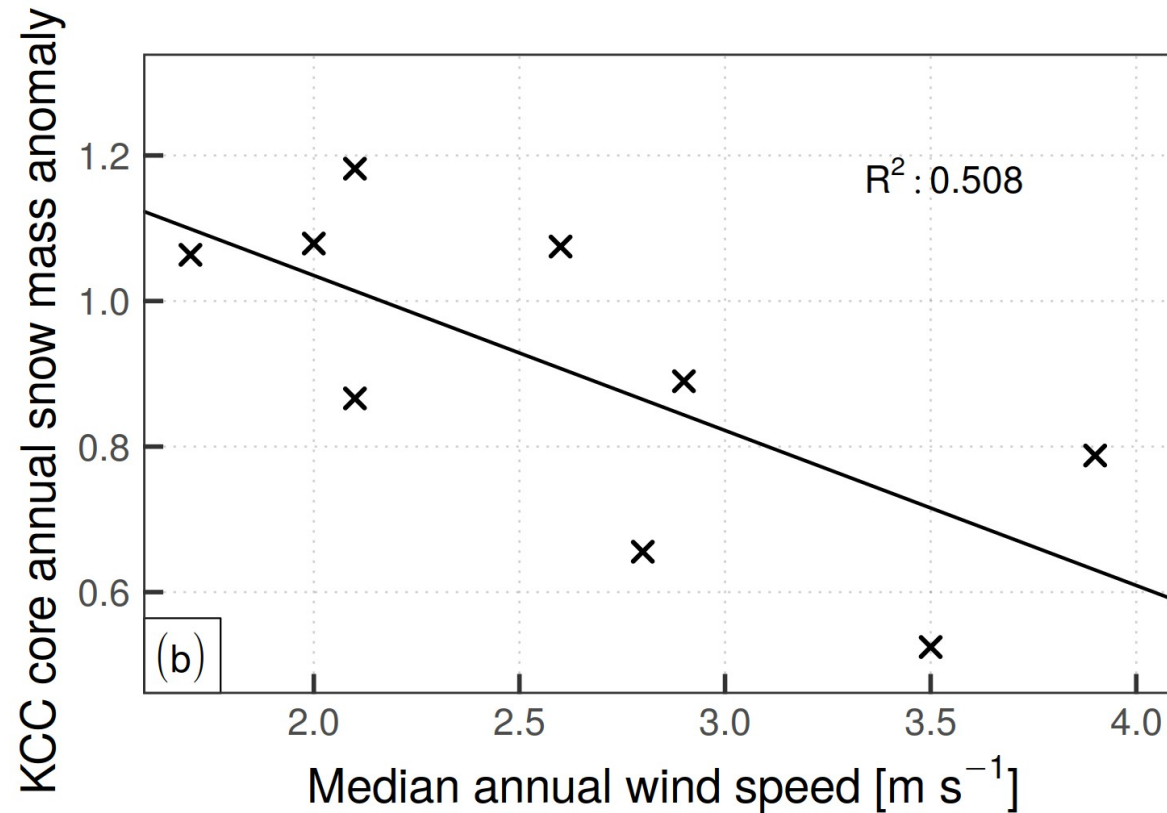
THREE-PHASE ACCUMULATION MODEL

- Grid of long-term net annual accumulation: $C(x,y)$, interpolated from local firn measurements



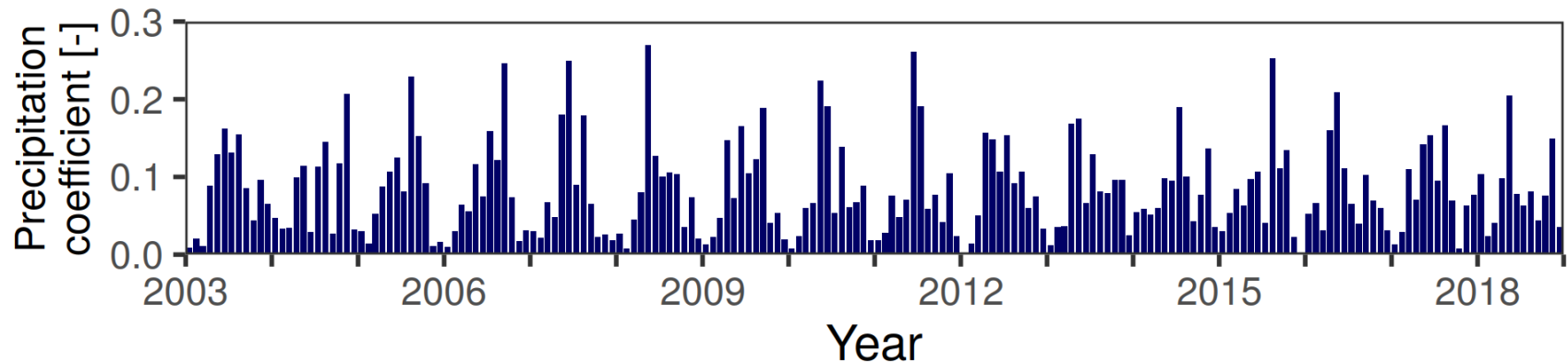
THREE-PHASE ACCUMULATION MODEL

- ◆ Annual anomaly time series for year i : $A(i)$, anti-correlated with wind speed



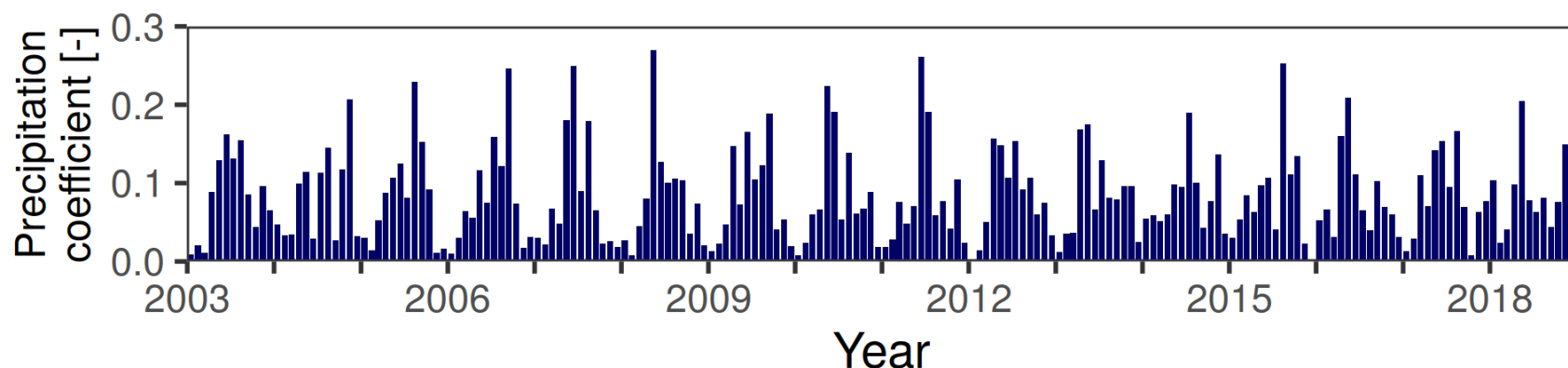
THREE-PHASE ACCUMULATION MODEL

- ◆ Hourly downscaling coefficient: $D(t)$, from lower-altitude rain gauges



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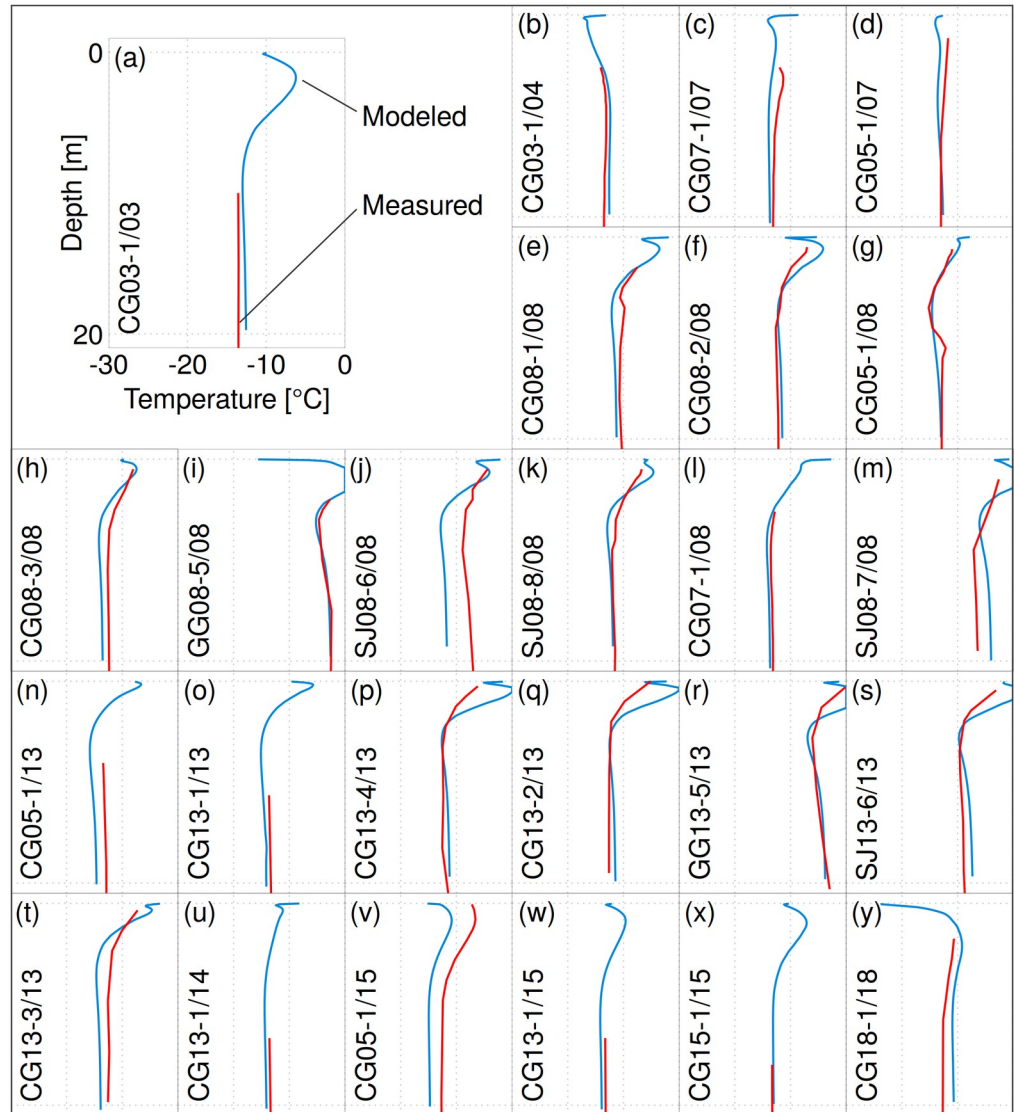


$$P(x, y, t) = C(x, y) A(i) D(t)$$

RESULTS

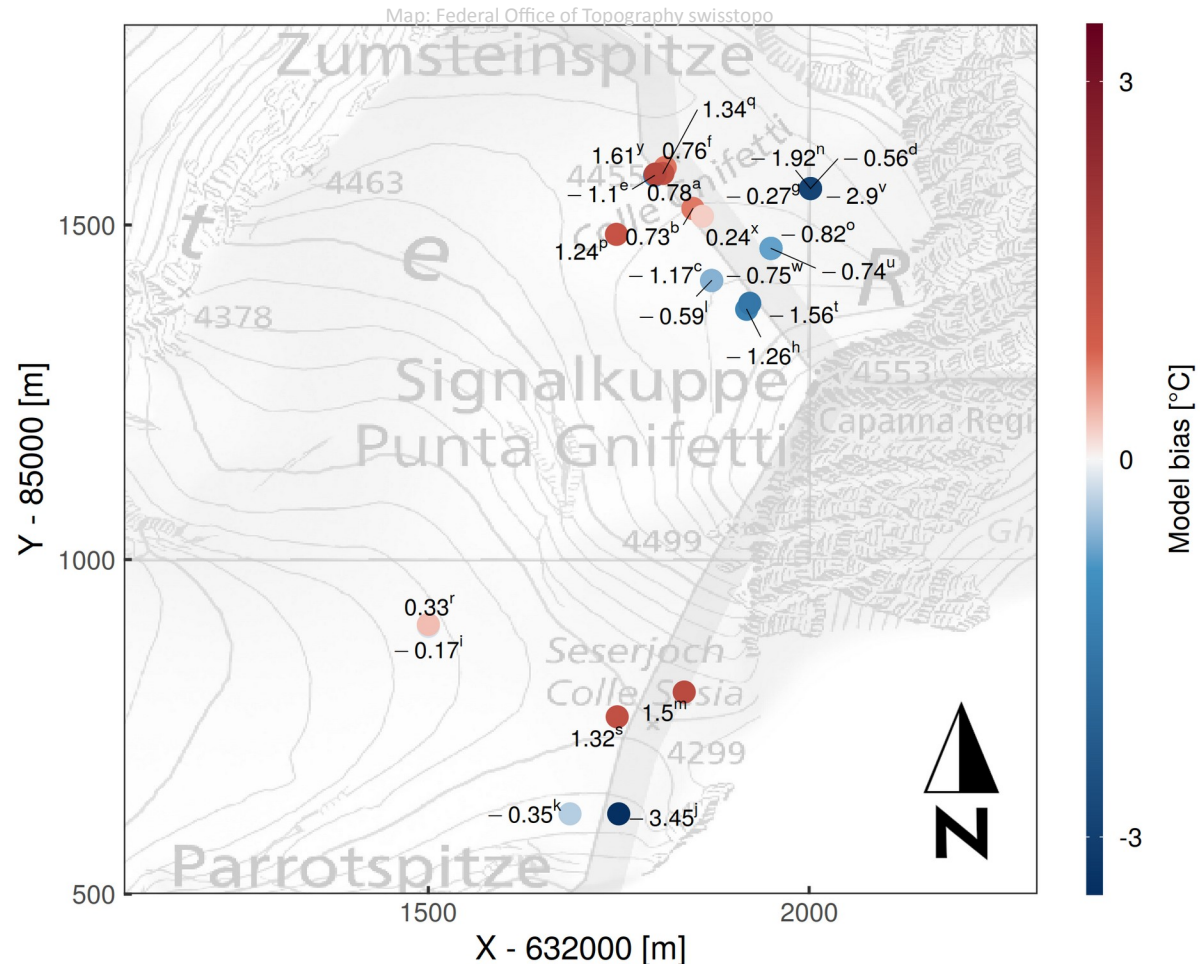
RESULTS: BOREHOLE TEMPERATURES

- ◆ Good match over 25 profile comparisons
- ◆ Near-surface deviations (e.g. (*m*), (*p*), (*q*)) due to excess refreezing?



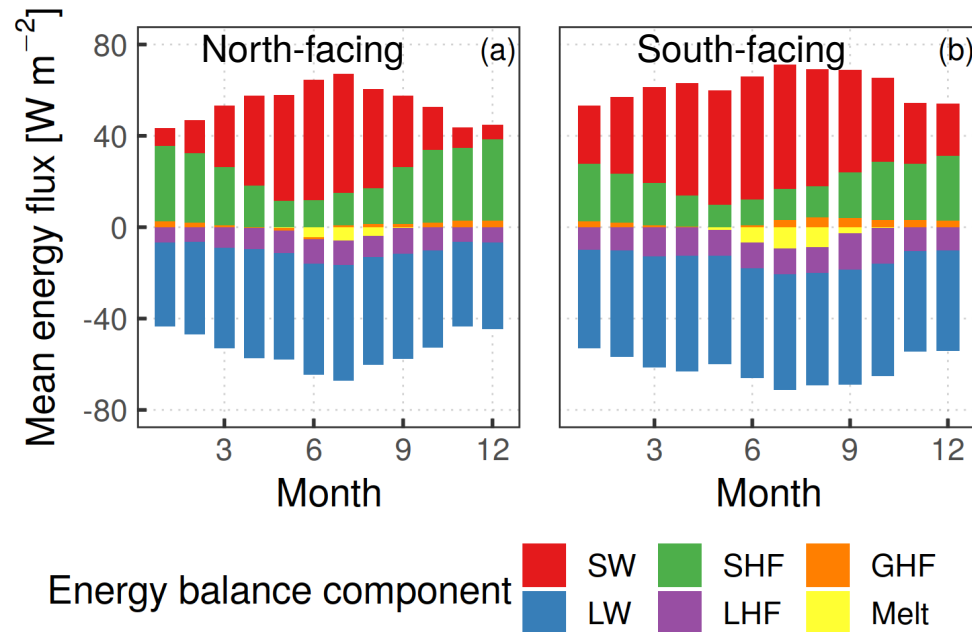
RESULTS: BOREHOLE TEMPERATURES

- ◆ Residuals have a spatial pattern: too cold at north facing locations, and vice-versa
- ◆ Residuals are correlated with incoming radiation, but also with accumulation



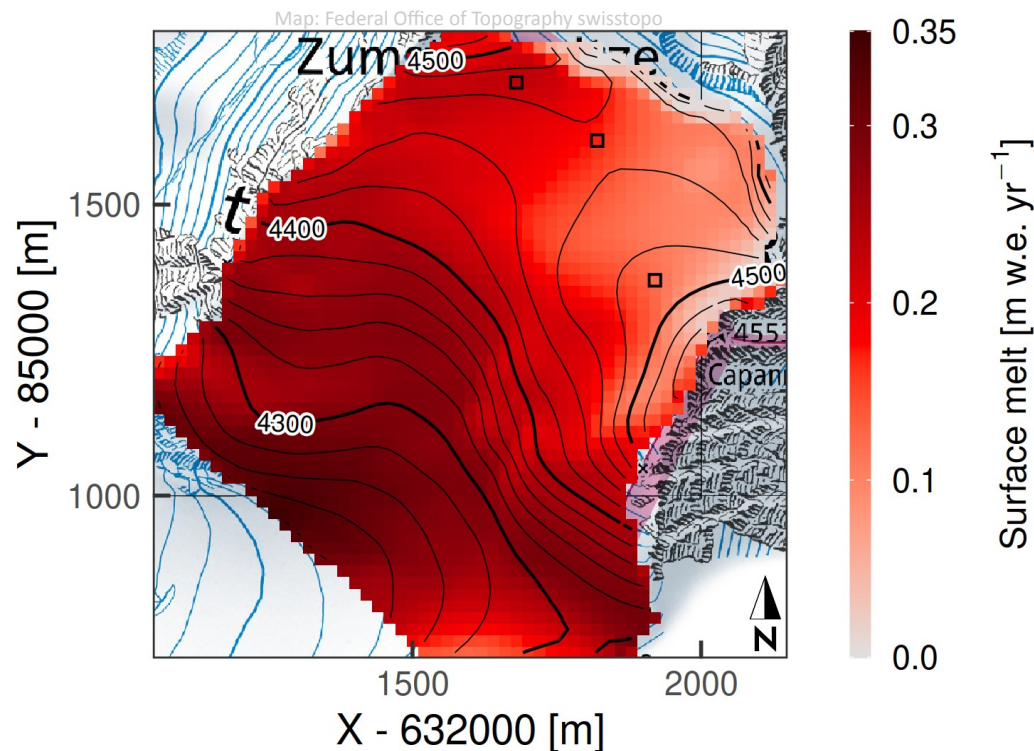
RESULTS: MELT ENERGY

- ◆ Melt happens almost only in summer
- ◆ Melt energy sink is small compared to sublimation



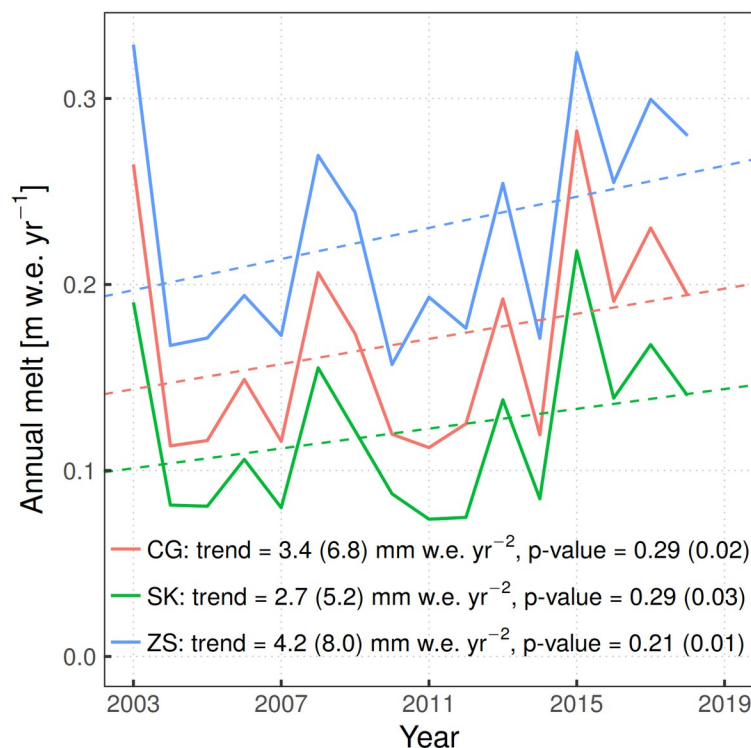
RESULTS: ANNUAL MELT DISTRIBUTION

- ◆ Melt is highly variable in space, following elevation, slope and aspect
- ◆ Almost no melt on north facing slopes above 4450 m a.s.l.



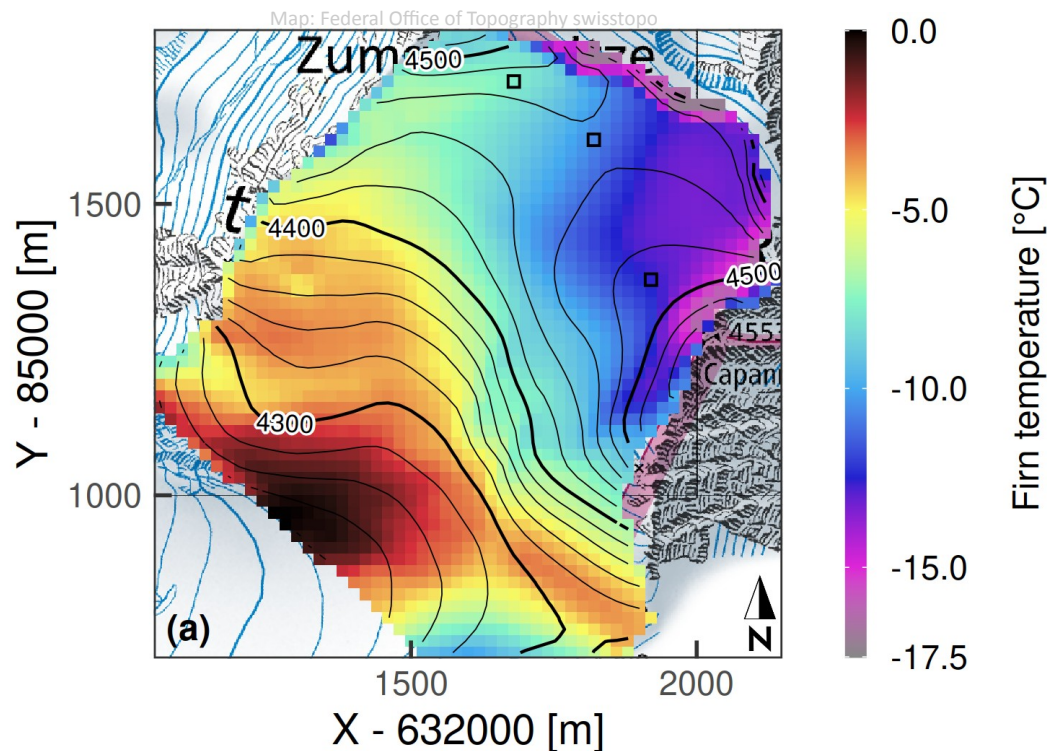
RESULTS: MELT EVOLUTION

- ◆ Melt amounts have a high inter-annual variability, up to ~100 %
- ◆ Annual deviations are consistent across locations and aspects
- ◆ Computed trend is affected by the 2003 heat wave at the start of the series



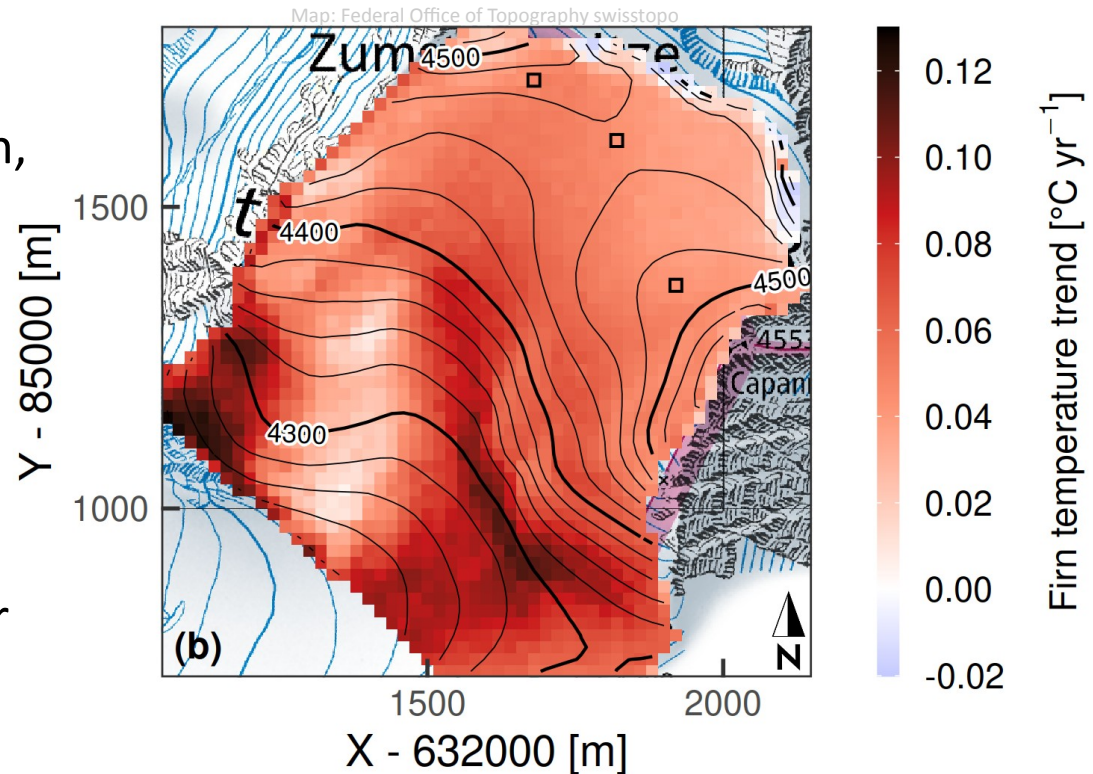
RESULTS: 20 M FIRN TEMPERATURES

- ◆ Temperatures have a regular gradient across the saddle, and a strong variability according to elevation and aspect
- ◆ Near-temperate firn below 4250 m a.s.l.



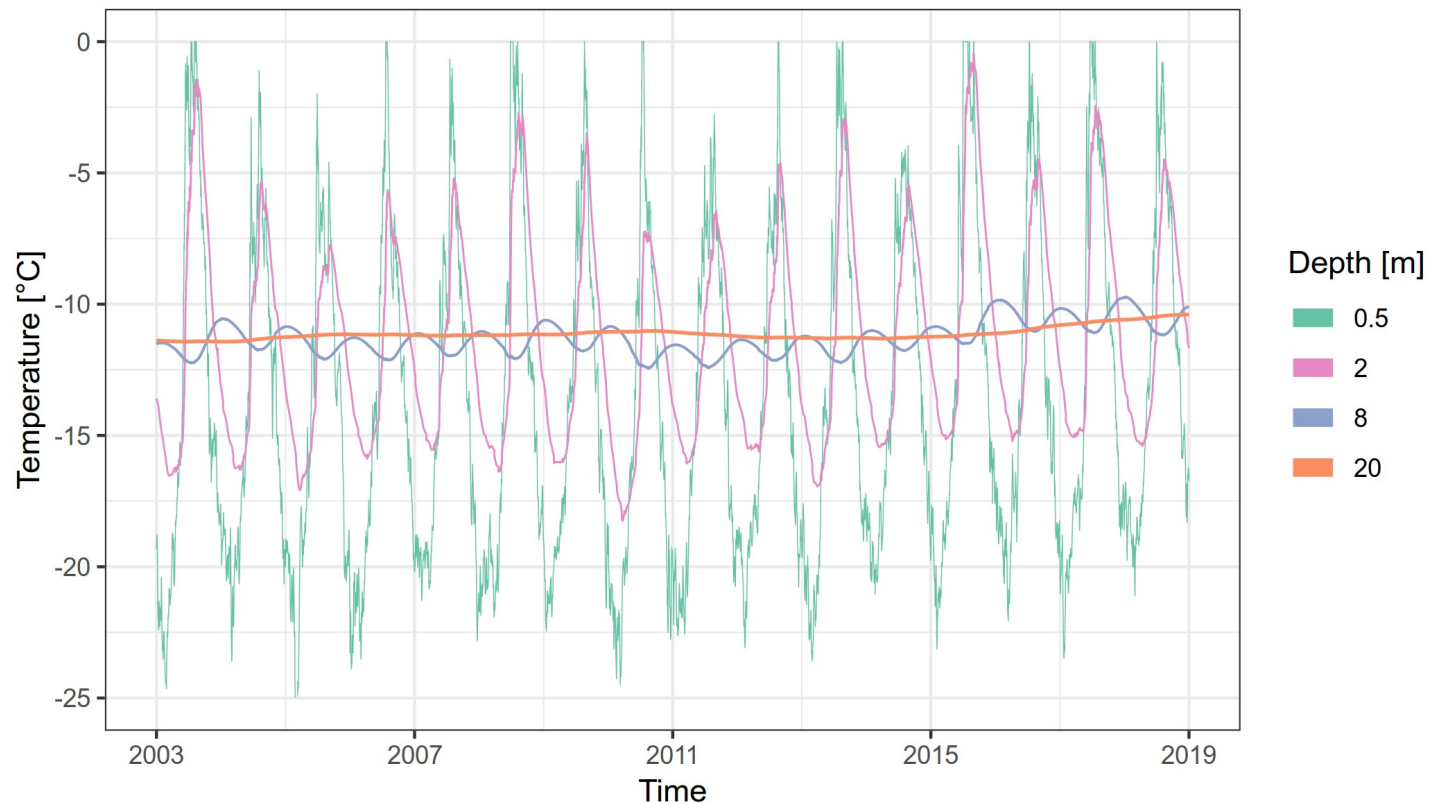
RESULTS: 20 M FIRN TEMPERATURE TRENDS

- ◆ Temperatures are increasing almost everywhere
- ◆ Warming rate is quite uniform in the saddle region, strongly variable below
- ◆ Below 4350 m a.s.l., strong warming in west facing areas, much less on south facing ones
→ relative importance of air temperature and solar radiation in the thermal regime



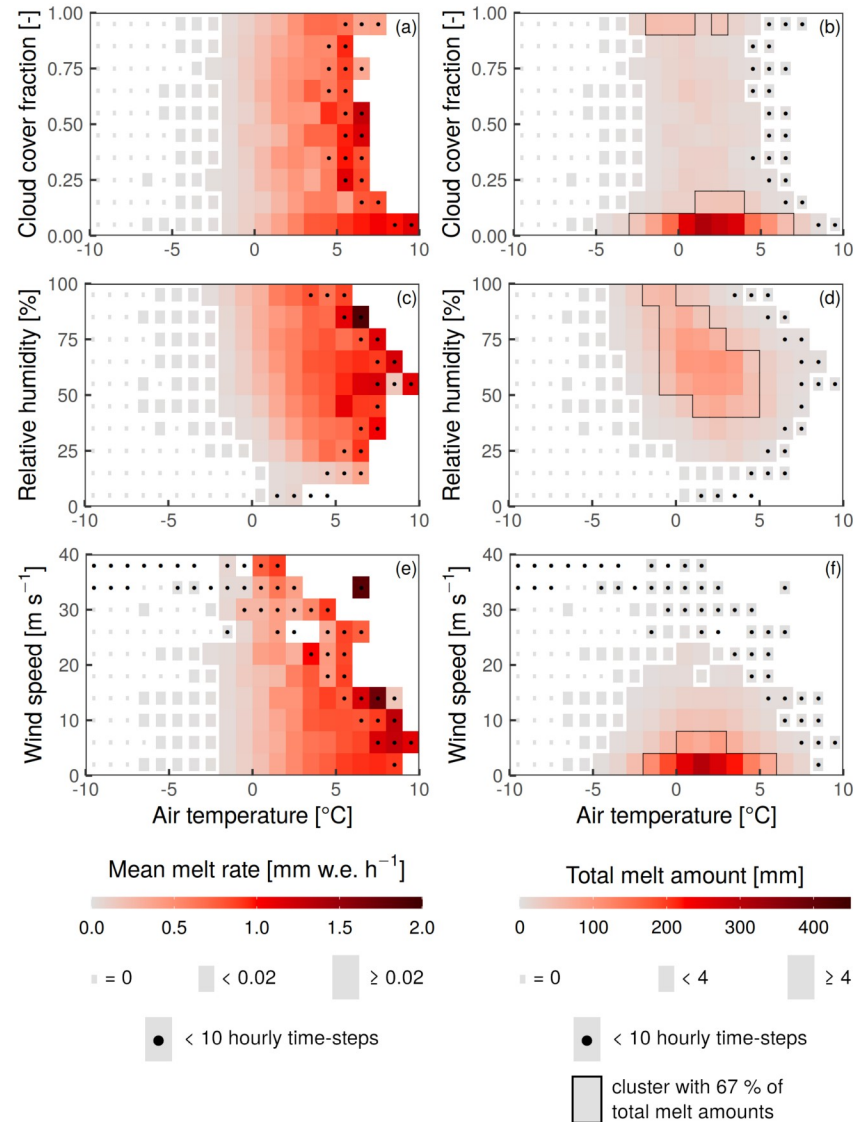
RESULTS: FIRN TEMPERATURE EVOLUTION

- ◆ Annual temperature oscillations are delayed by 6 months at 8 m depth and fully damped by 20 m



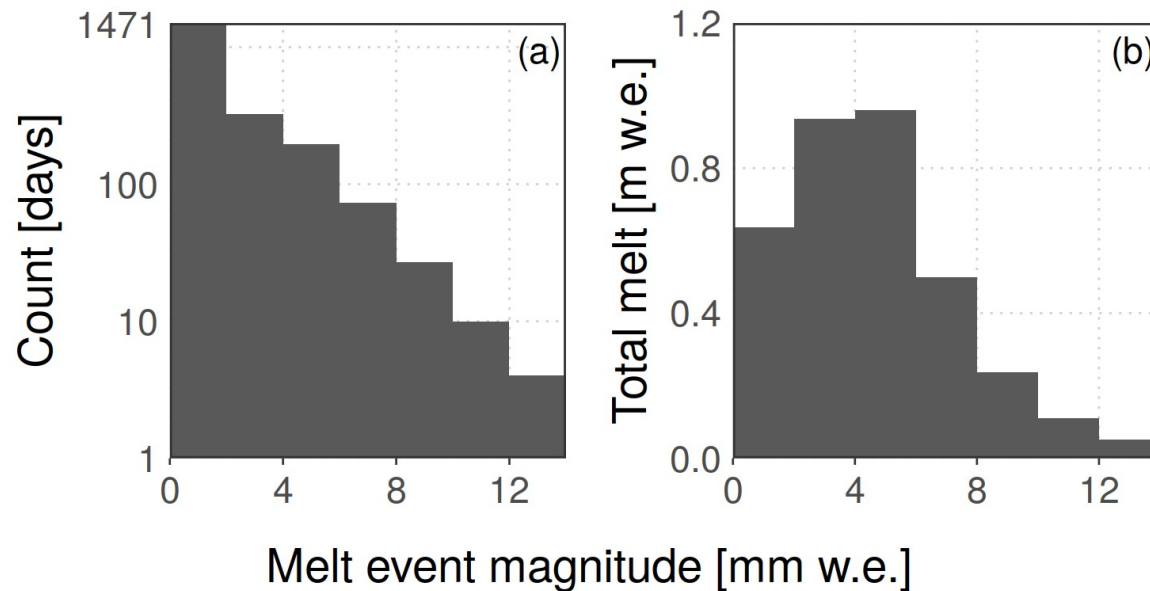
RESULTS: WEATHER CONDITIONS FOR MELT

- ◆ Air temperature is the critical control over melt occurrence and rate
- ◆ Very dry conditions can hinder melt, through sublimation
- ◆ Most of the melt happens under clear skies, between -3 and +6 °C
- ◆ Some melt even at -7 °C!



RESULTS: MELT PATTERNS

- ◆ The vast majority of melt events are tiny, comparable to grain size (event frequency decreases exponentially w.r.t. amount)
- ◆ At such a small scale, many processes are not simulated (e.g. radiation penetration)!
- ◆ This matters for model calibration/validation (melt amounts!)



MAIN TAKEAWAYS

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- ♦ The EBFM performs well on the cold firn of Colle Gnifetti
- ♦ Melt at the Colle is still modest, highly variable, but increasing
- ♦ Firn temperatures are rising, with low variability in the saddle region and high variability at lower elevations – up to 3x the atmospheric warming rate
- ♦ Air temperature and atmospheric humidity are the main controls over melt occurrence and intensity
- ♦ Melt happens already at negative air temperatures!
- ♦ “Micro-melt events” appear to be a frequent occurrence

Firn changes at Colle Gnifetti revealed with a high-resolution process-based physical model approach

[tc-2020-367](#) 

Under review at The Cryosphere



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