Air temperature control on snow erosion at a high-elevation site in the Eastern European Alps

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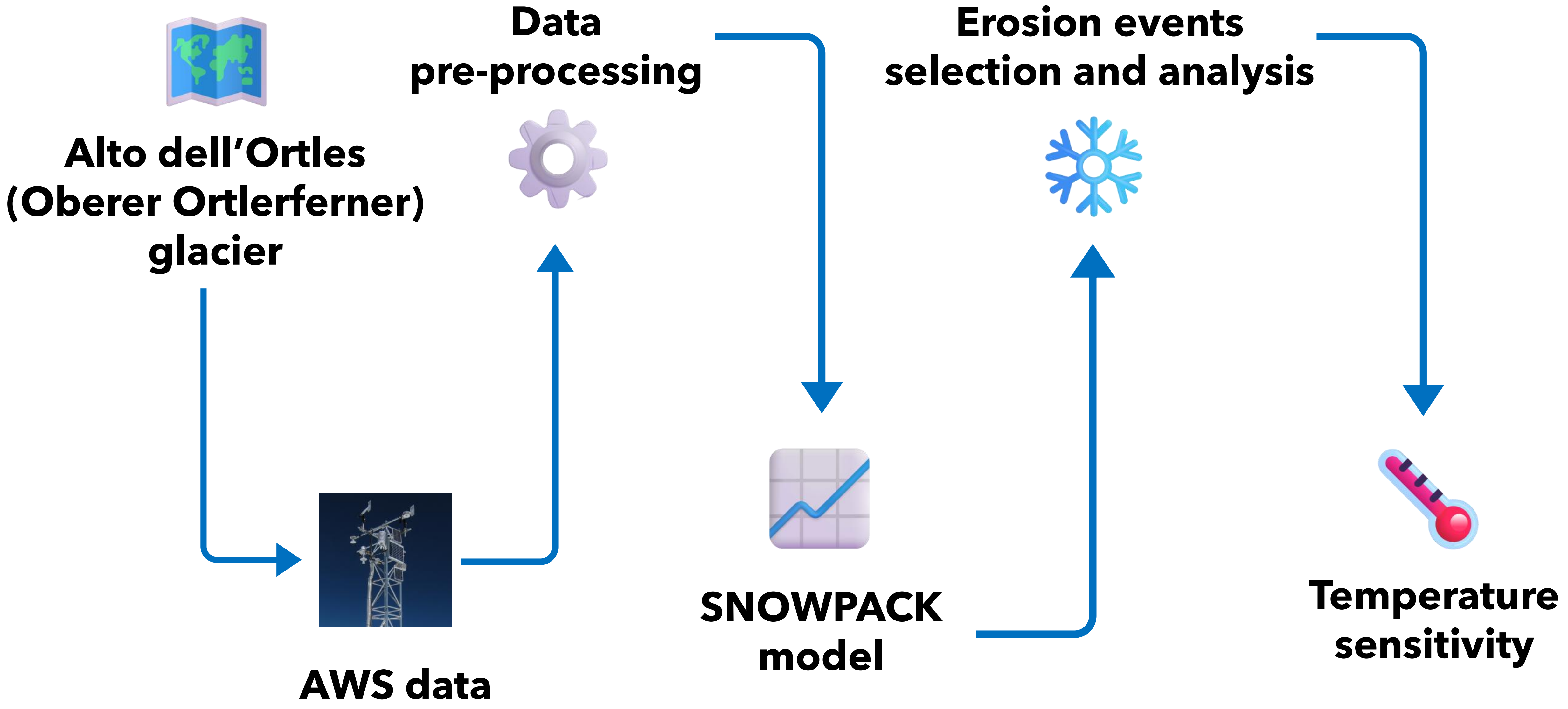
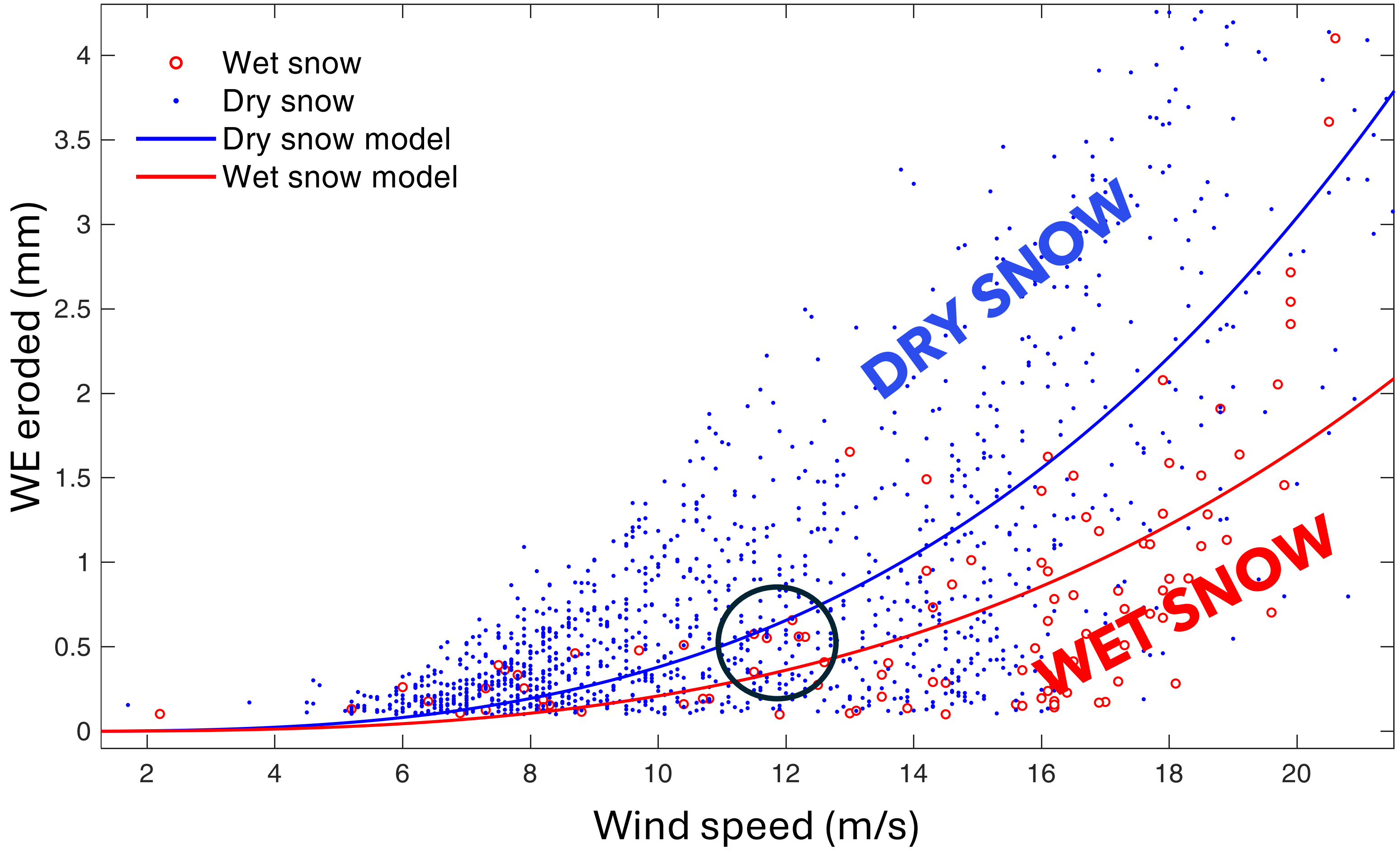
Methodology workflow:



Results preview:



- Wind-driven **snow erosion** at Mt. Ortles **removes about 25%** of the annual snowfall
- **Dry snow erosion is much higher than wet snow erosion.** → At 12 m/s wind speed (avg. wind speed during erosion) dry snow erosion is 83% greater than wet snow erosion
- Erosion shows **strong sensitivity** to temperatures **above 0°C**

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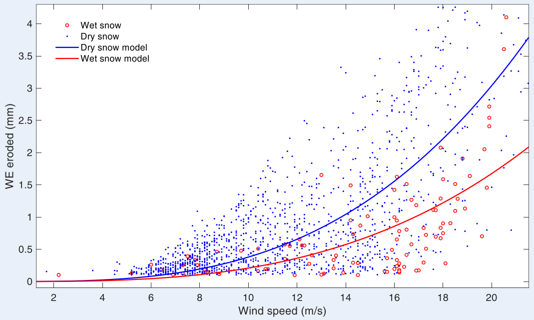
2 min intro

1 The challenge

2 The data

3 The modelling



4 The analysis

Background & motivation

- **Wind speed erosion** processes strongly affect **glacier mass balance** (snow accumulation) especially at high elevation, but are still poorly understood and rarely explicitly implemented in glacier mass balance models.

- Wind erosion is also relevant in paleoclimatic studies, e.g. **ice core records interpretation**. Its dependence on air temperature variability (via snow metamorphism) influences the seasonality of snow accumulation and preservation on glaciers.

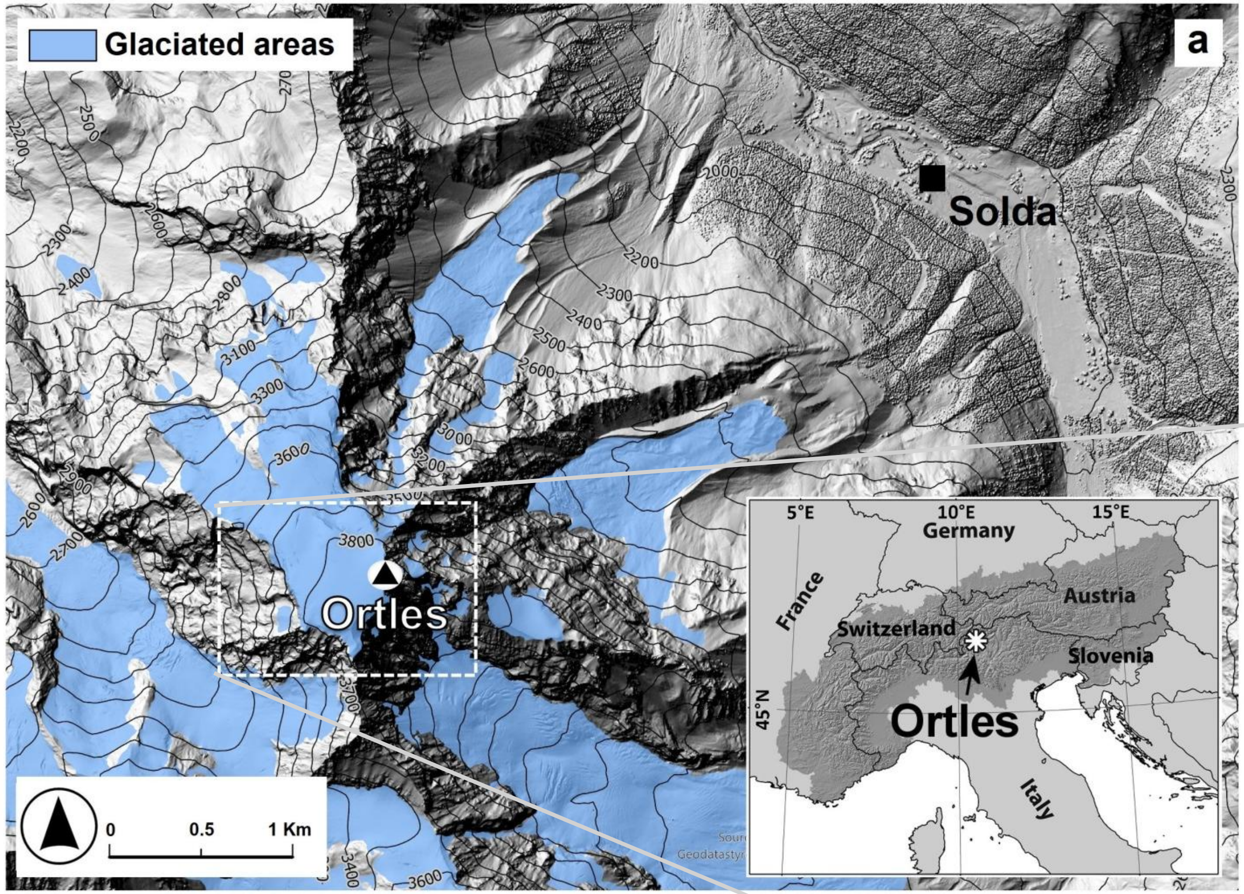
Objectives

To study the **snow erosion** on a **high-elevation glacier** accumulation area and in particular:

Controlling factors on snow erosion

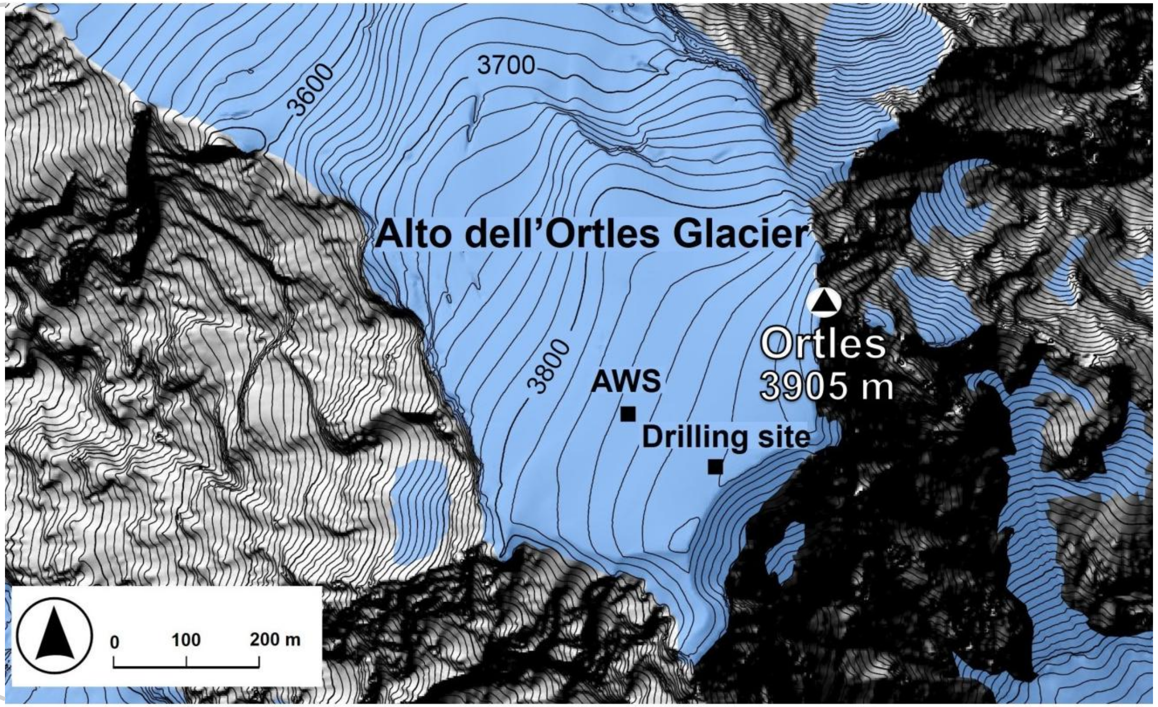
Temperature sensitivity of snow erosion

The study area: Alto dell' Ortles Glacier



Located in **Ortles-Cevedale** Mountain Group: the largest glacierized area in the Italian Alps

Alto dell'Ortles (Oberer Ortlerferner) Glacier area: 1.06 km^2



Ortles Automatic Weather Station (AWS)

Where?

Upper accumulation area of the glacier

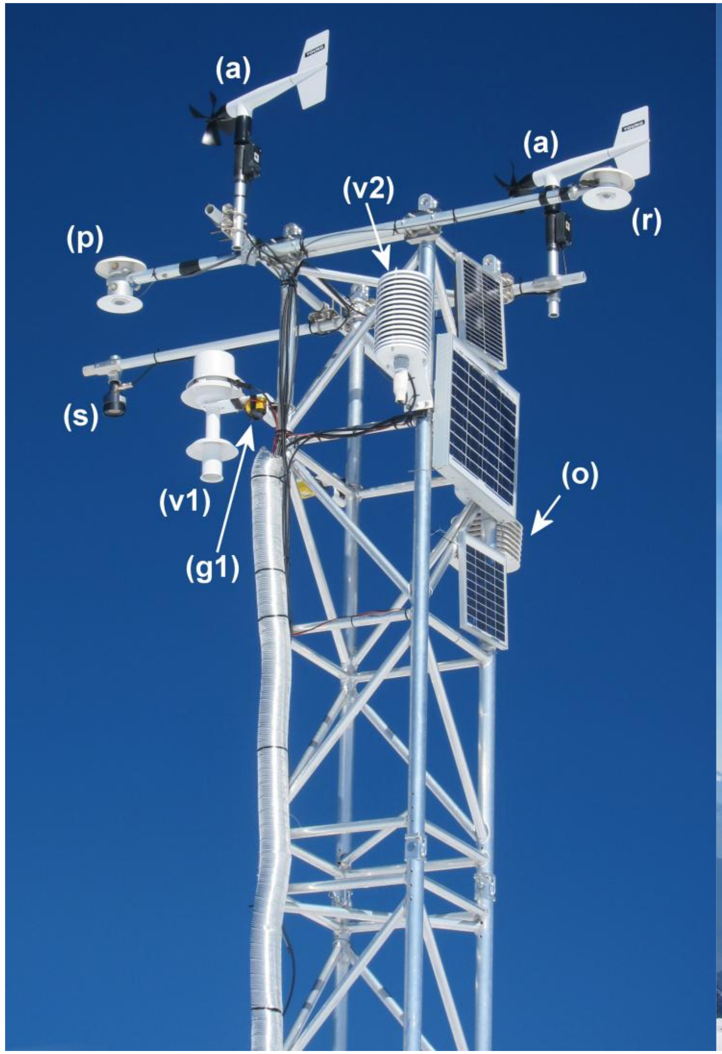
Elevation: 3830 m a.s.l

When?

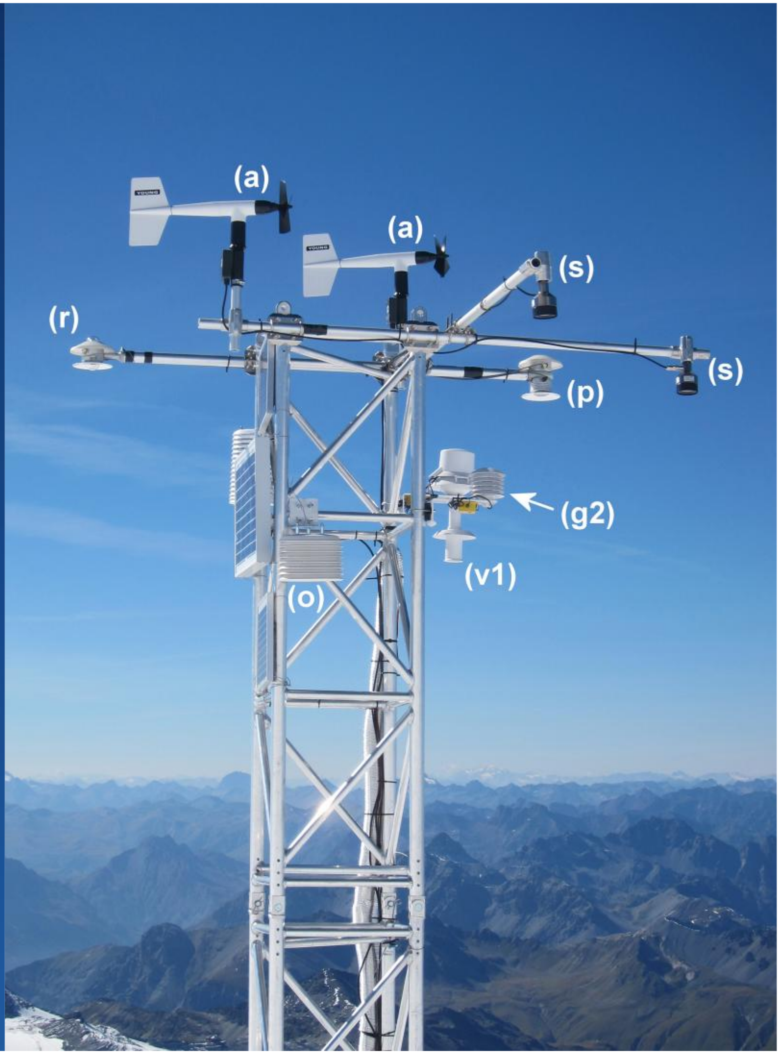
AWS installed in September 2011 and removed in June 2015

Despite the harsh conditions the AWS worked properly without major interruptions

AWS configuration



Seen from West

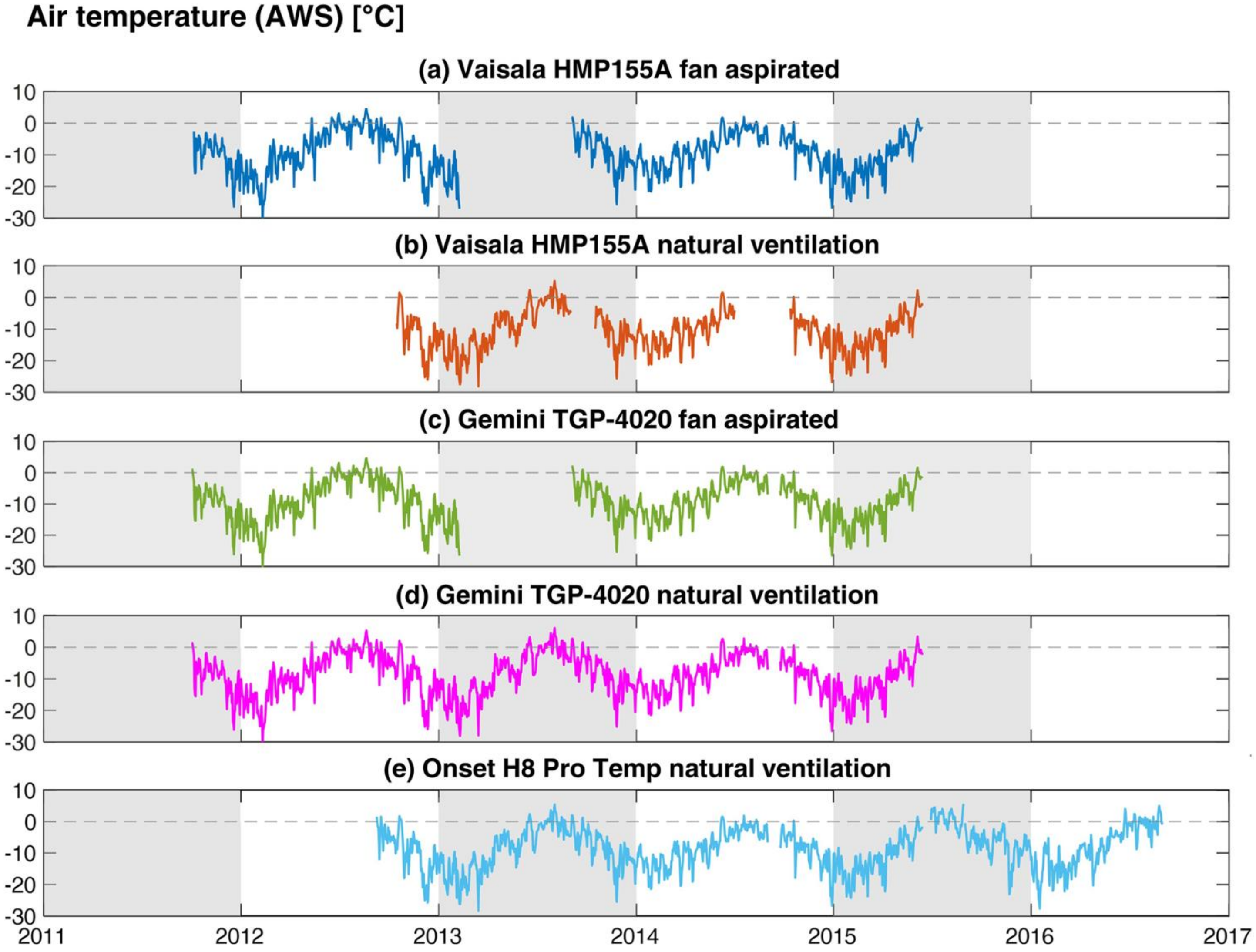


Seen from East

Variables : Air temperature, relative humidity, wind speed and direction, incoming and outgoing longwave radiations, incoming and outgoing shortwave radiations, snow depth.

(a) R. M. Young 05103 anemometers
(p) Delta Ohm LP PIRG 01 pyrgeometers
(r) Delta Ohm LP Pyra 05 radiometers
(s) Campbell Scientific SR50A snow depth sensors
(v1) Vaisala HMP155A inside the R. M. Young 43502 fan-aspirated radiation shield
(g1) Gemini TGP-4020 data logger inside the R. M. Young 43502 fan-aspirated radiation shield
(g2) Gemini TGP-4020 data logger inside the six-plate R. M. Young 41303-5radiation shield with natural ventilation
(v2) Vaisala HMP155A inside the 15-plate Campbell Scientific MET 21 radiation shield with natural ventilation
(o) Onset HOBO H8 Pro Temp data logger inside the eight-plate Davis 7714 radiation shield with natural ventilation.

The air temperature data



Mean annual air temperature

Sensor	Vaisala HMP155A (f.a.)	Vaisala HMP155A (n.v.)	Gemini TGP-4020 (f.a.)	Gemini TGP-4020 (n.v.)	Onset HOBO H8 Pro Temp (n.v.)	Merged (n.v.)
Year						
2012	−8.9		−8.7	−8.6		−8.6
2013				−8.6	−9.0	−8.6
2014	−8.4		−8.2	−8.1	−8.4	−8.1
2015					−8.6	−8.3
2016					−8.1	−7.8

Details on air temperature data available here:

The dataset

Data pre-processing

Raw data

Read data

Data comparison and filtering

Resample data (when needed)

Gap filling

When no other options available use of neighbouring stations:
Beltovo (3328 m a.s.l)
Madriccio (2825 m a.s.l.)

Precipitation data from Solda station (1907 m a.s.l.)

MeteoIO

Filtered, corrected & standardized data

The SNOWPACK model

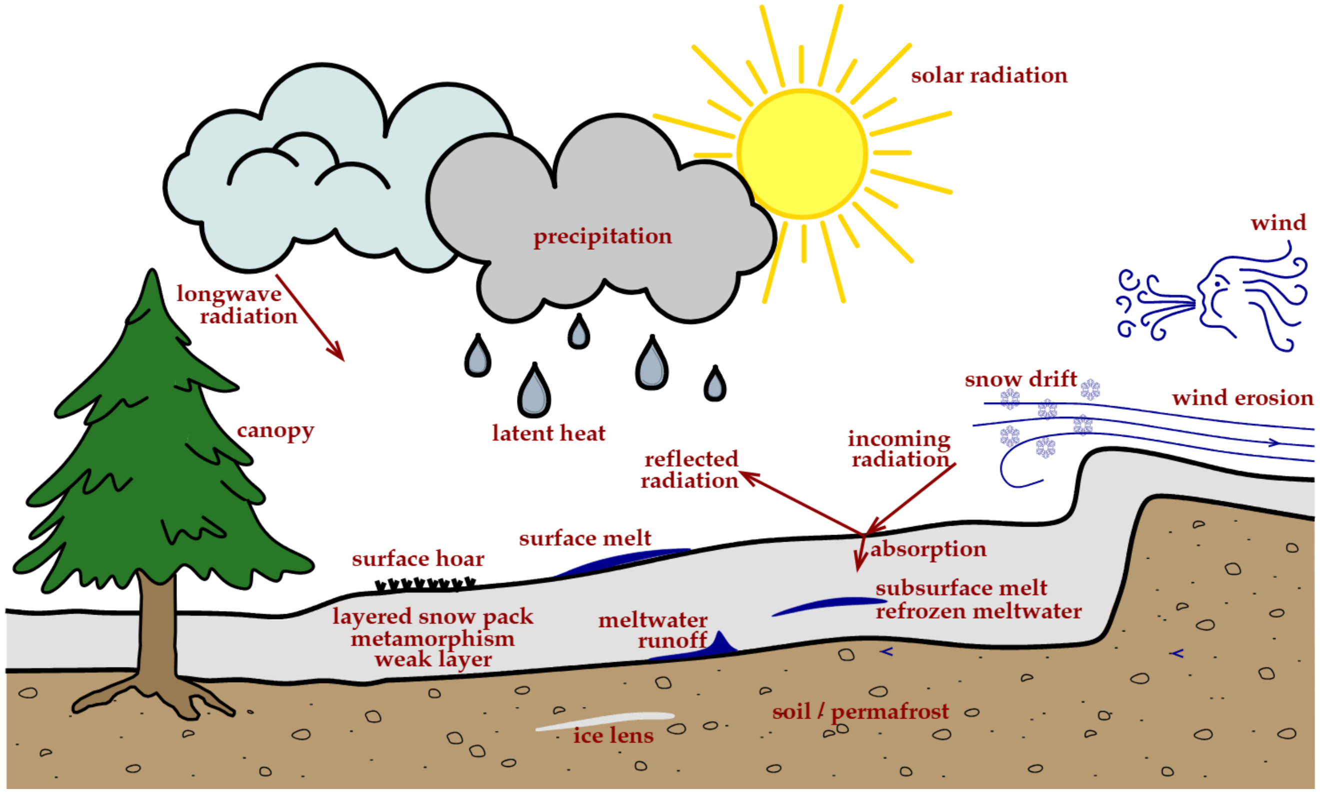


Fig. from https://snowpack.slf.ch/

SNOWPACK model (Lehning et al., 1999):

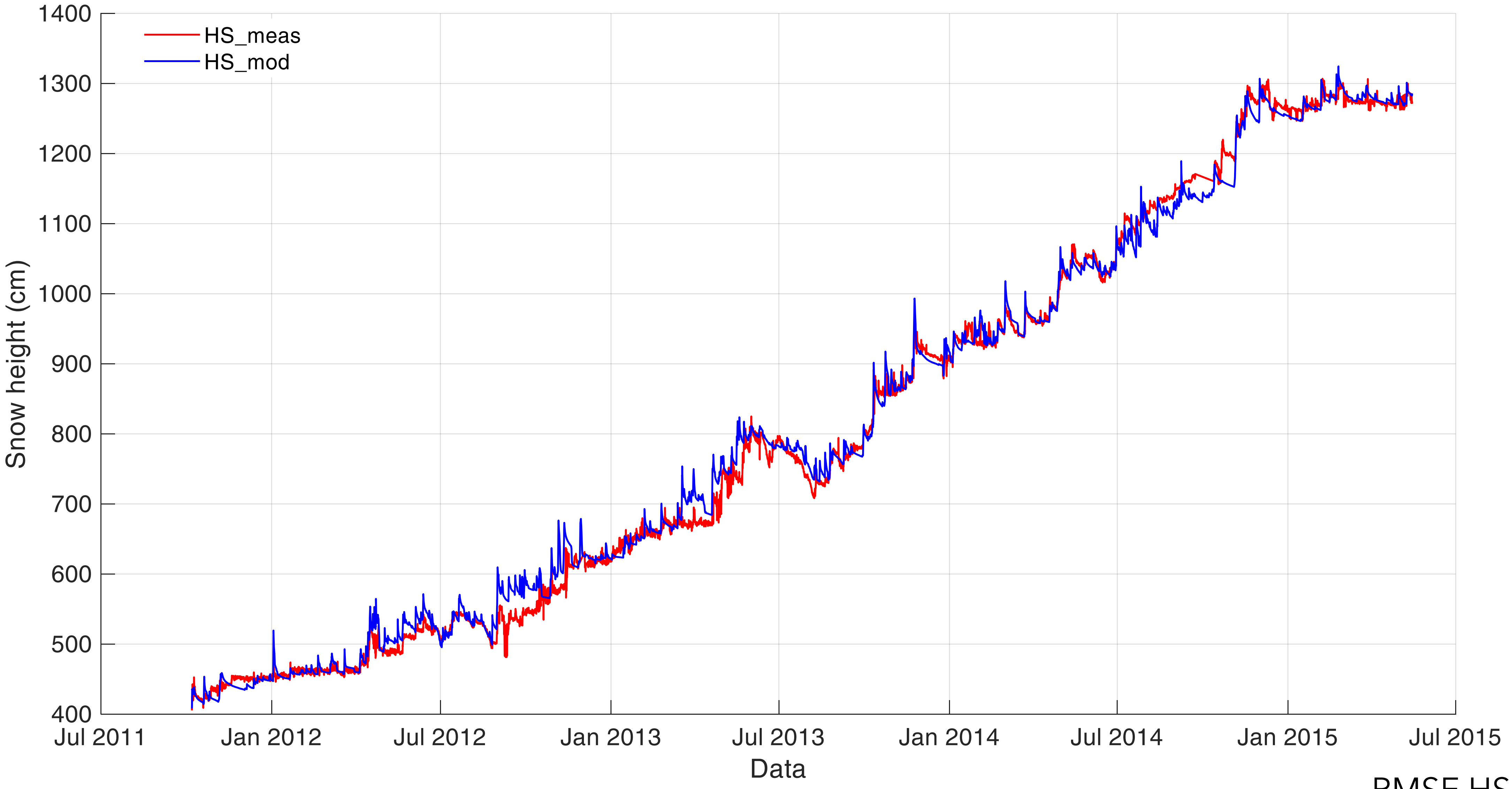
- Simulates snowpack evolution and energy/mass exchange with atmosphere
- Converts snow depth → SWE
- Includes wind-driven snow erosion

Simulation period: Sep 2011 – mid May 2015

Initial conditions setting:

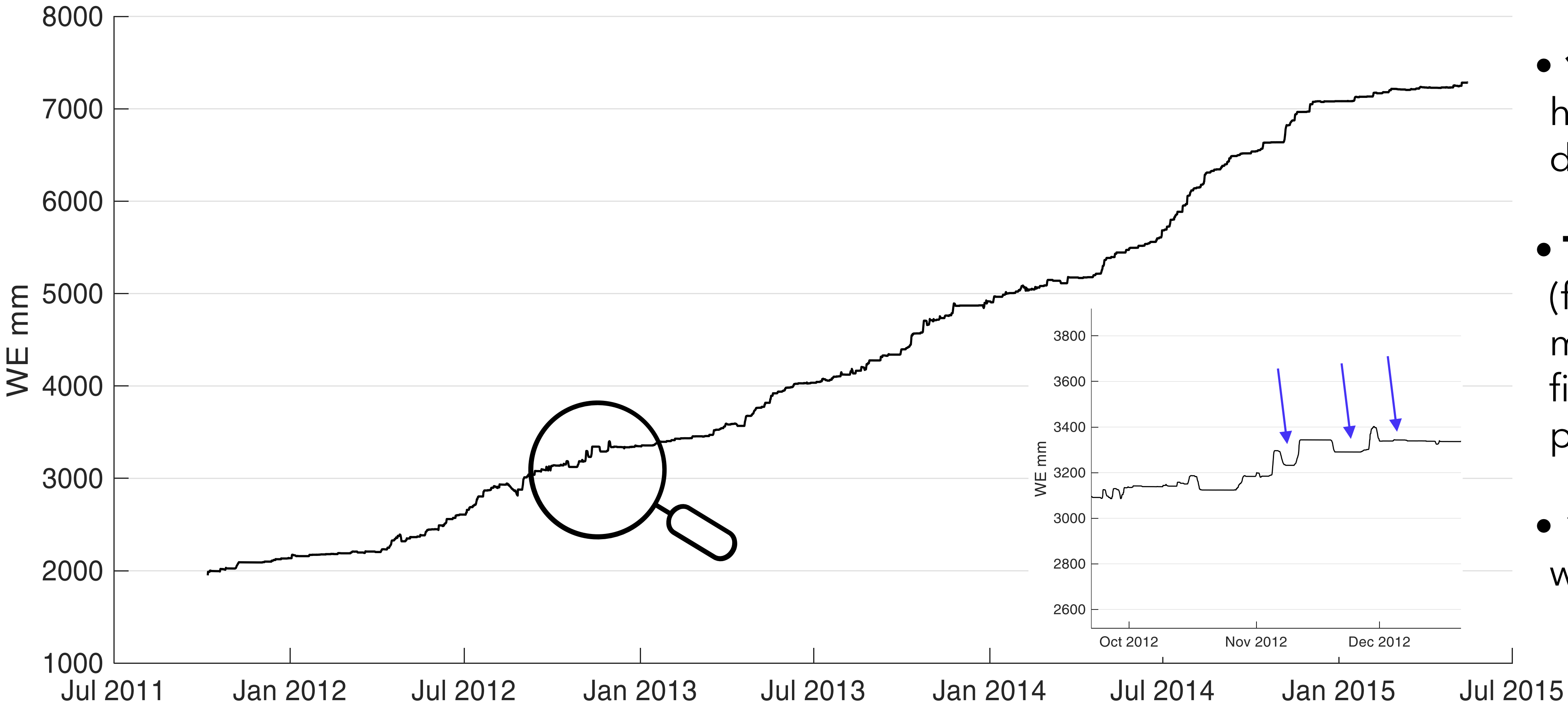
- Firn layer: 4 m thickness
- Model initialization: based on snowpits data from the *Ortles Project* → collected few days before simulation start

Model evaluation against measured data



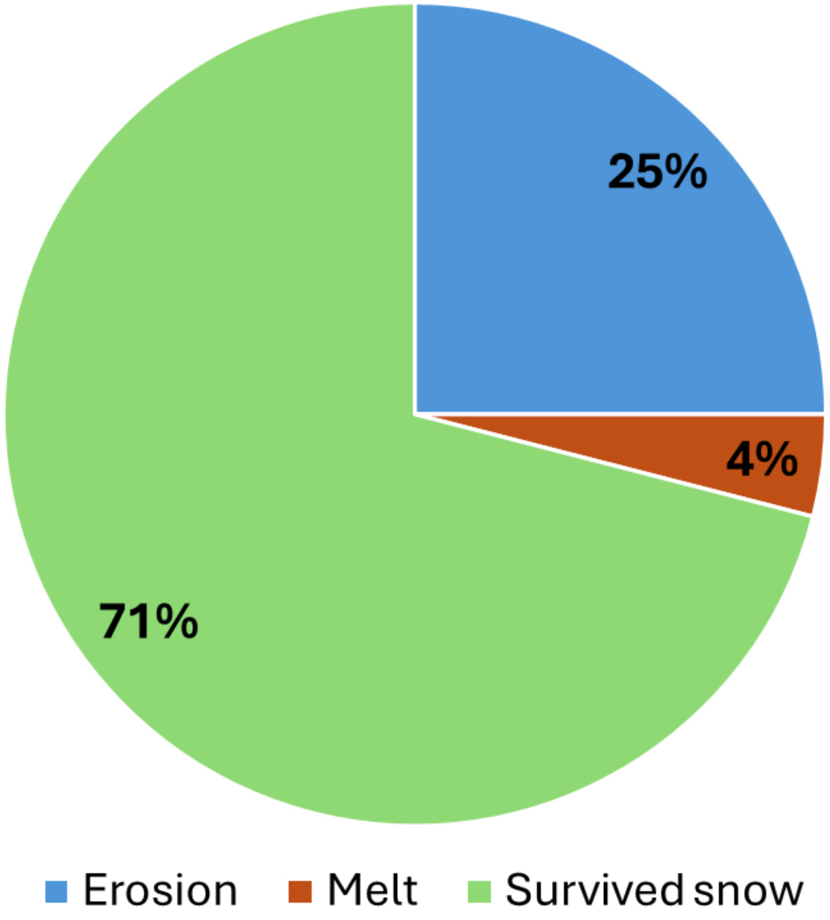
RMSE HS: 22.86 cm
RMSE SWE: 197 mm

Snow erosion events



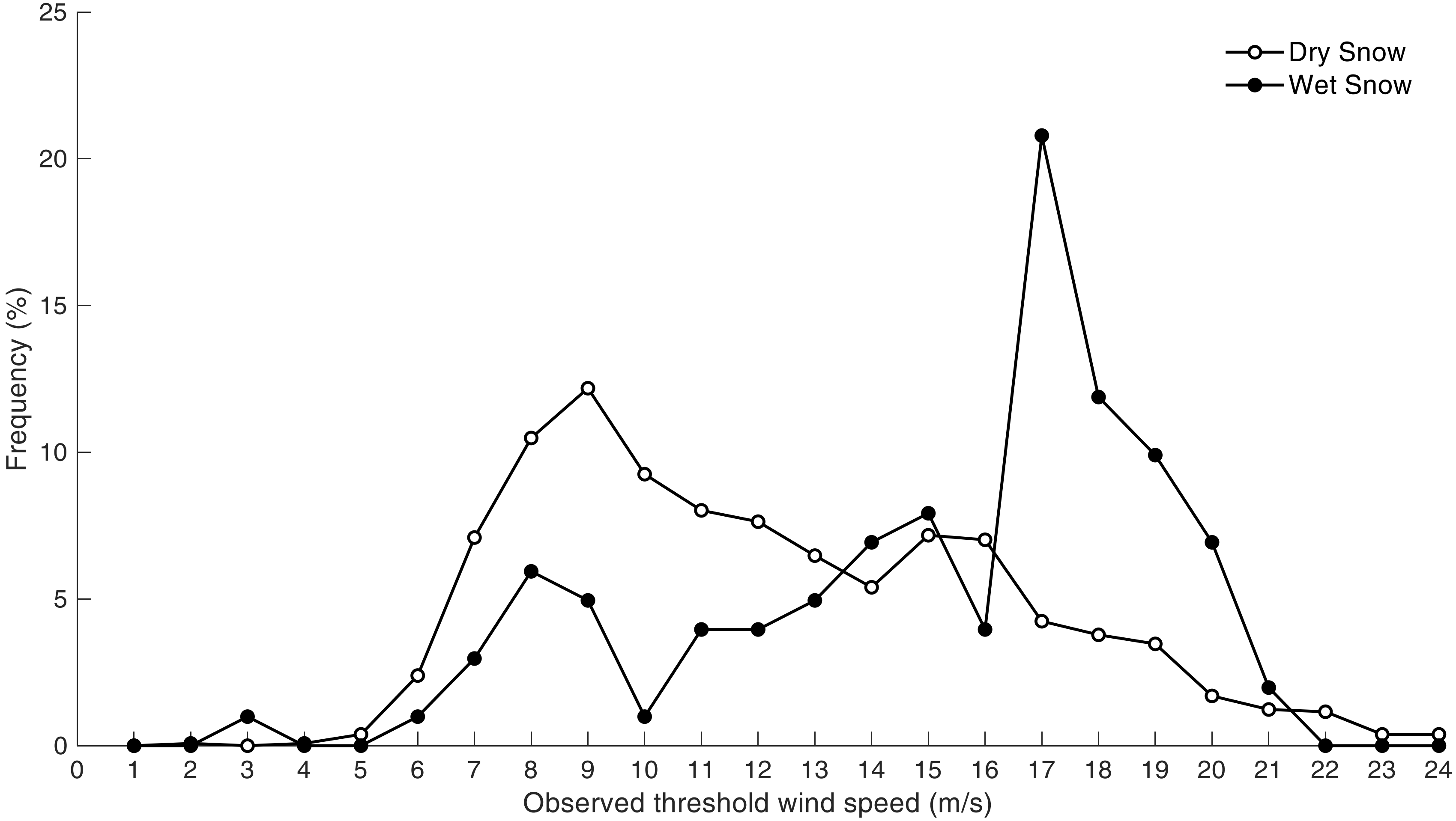
- **1 erosion event** = each hour with erosion (SWE decreases & T < 0°C)
- **Threshold wind speed** (for 1st erosion hour) = mean wind speed of the first erosion hour and the previous hour
- 1367 erosion events (98 wet snow)

Snow erosion impact on mass balance



- Currently snow **erosion** removes ~**25%** of total accumulation

Threshold wind speed

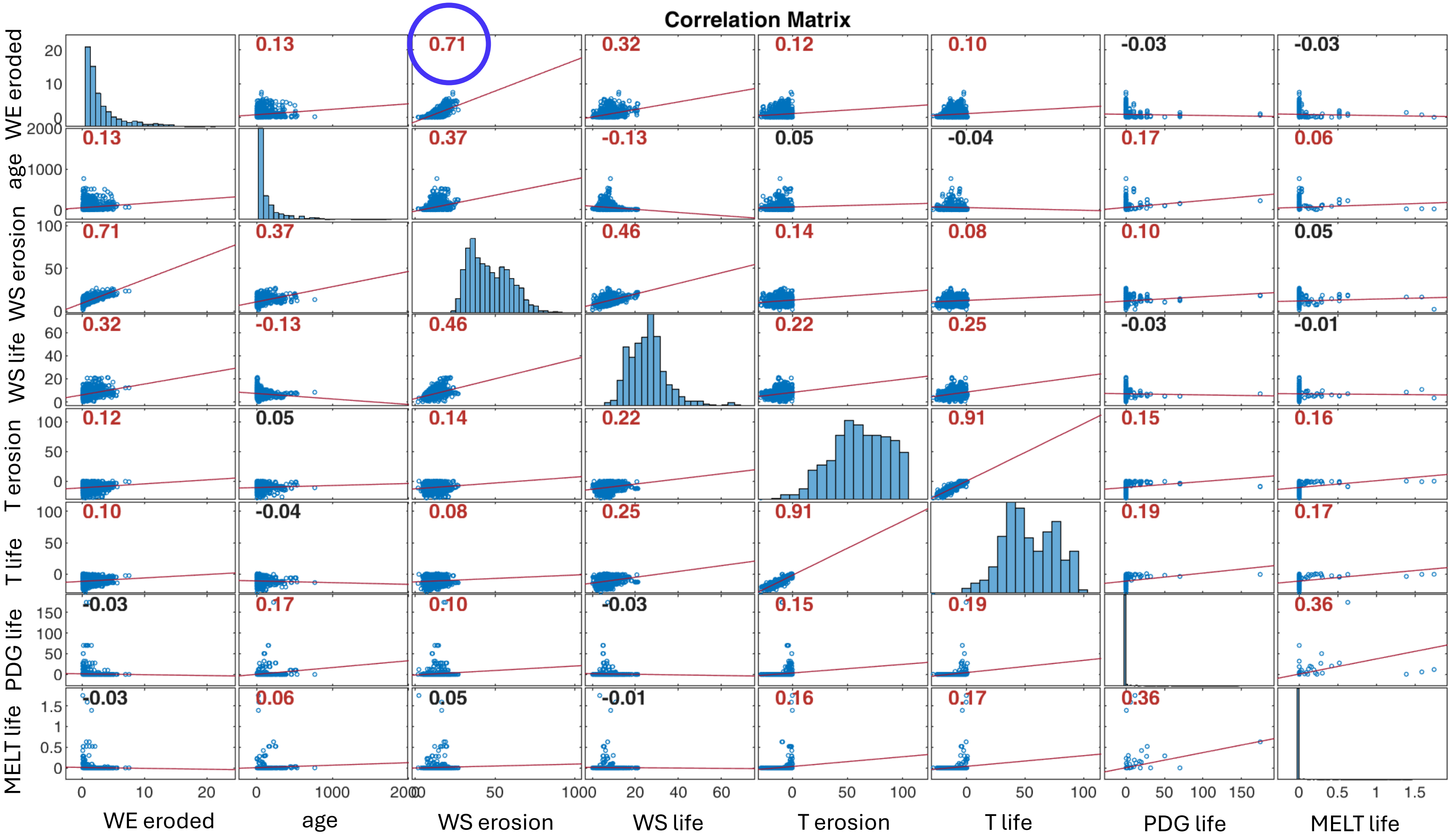


Dry snow avg. threshold wind speed = 9.3 m/s

Wet snow avg. threshold wind speed = 11.2 m/s

Literature thresholds from Li & Pomeroy (1997) are lower: 7.7 m/s for dry snow and 9.9 m/s for wet snow **BUT** we are in different conditions (a glacier at almost 4000 m a.s.l.) this may explain discrepancies.

The analysed variables

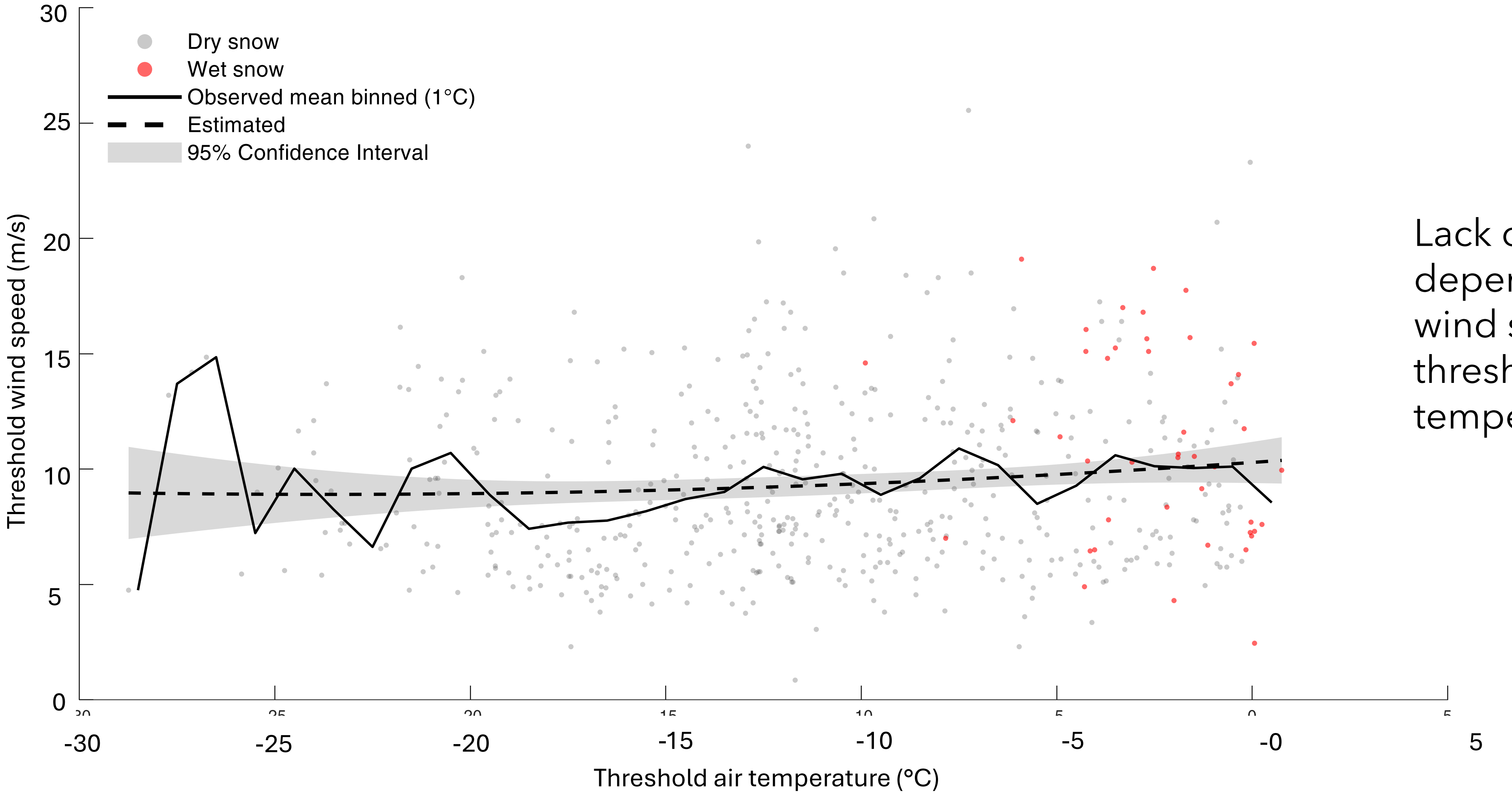


Variables:

WE eroded	WE eroded during the erosion event (mm)
age	Hours from the layer formation (h)
WS erosion	Wind speed during the erosion event (m/s)
WS life	Mean wind speed since the formation of the layer (m/s)
T erosion	Air temperature during the erosion event (°C)
T life	Mean air temperature since the layer formation (°C)
PDG life	Sum of positive degrees since the layer formation (°C)
MELT life	Sum of WE melted since the layer formation (mm)

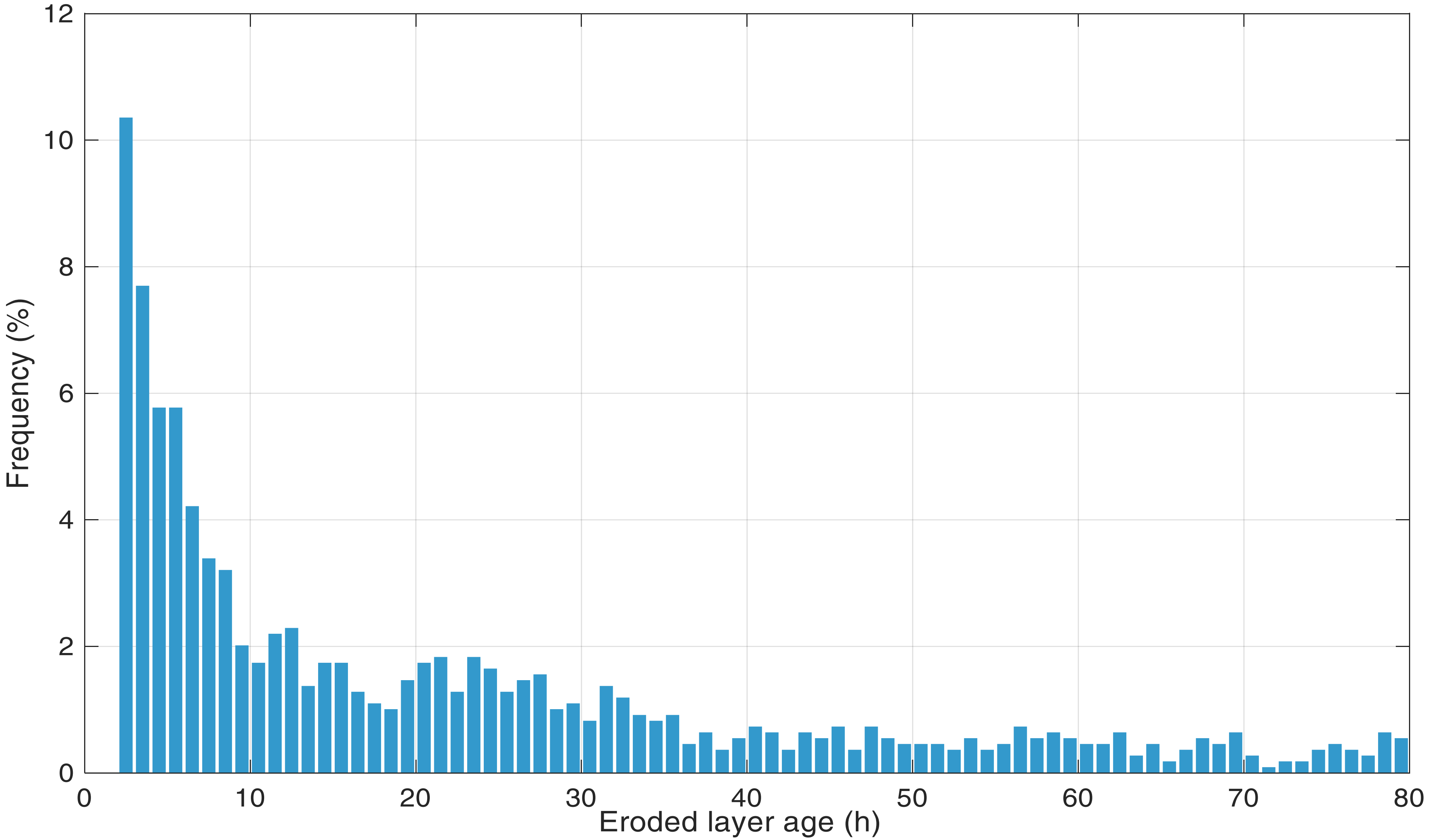
- **Wind erosion** is **highly correlated** with **wind speed**
- No apparent correlation with temperature-related variables

Estimated threshold wind speed and observed mean threshold wind speed: variation with ambient air temperature



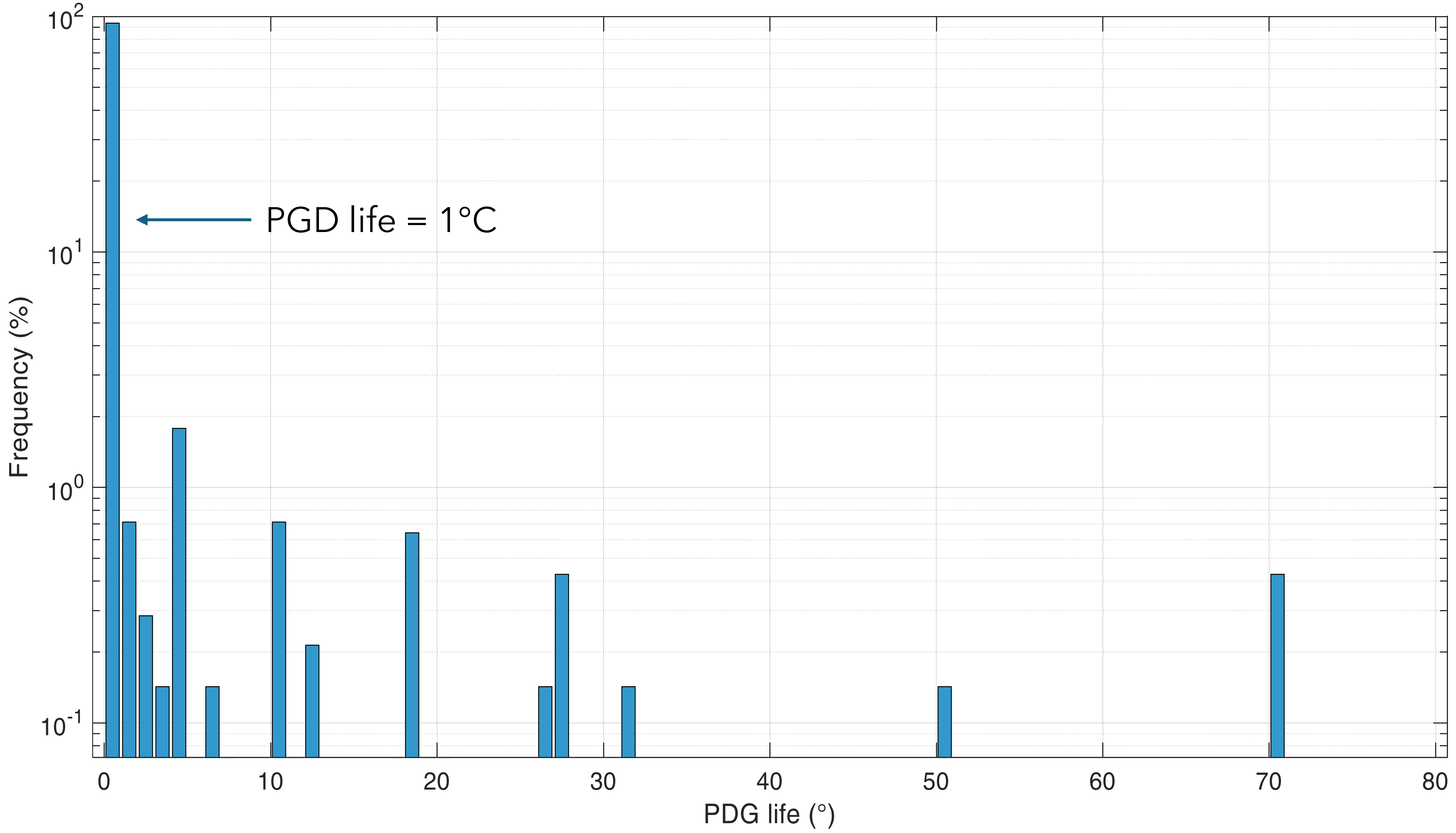
Lack of direct dependency of the wind speed threshold on the air temperature

Frequency distribution of the erosion events by age classes



- Rapid decrease of erosion frequency in the first hours after a snowfall
- 50% of erosion occurs within 12 hours

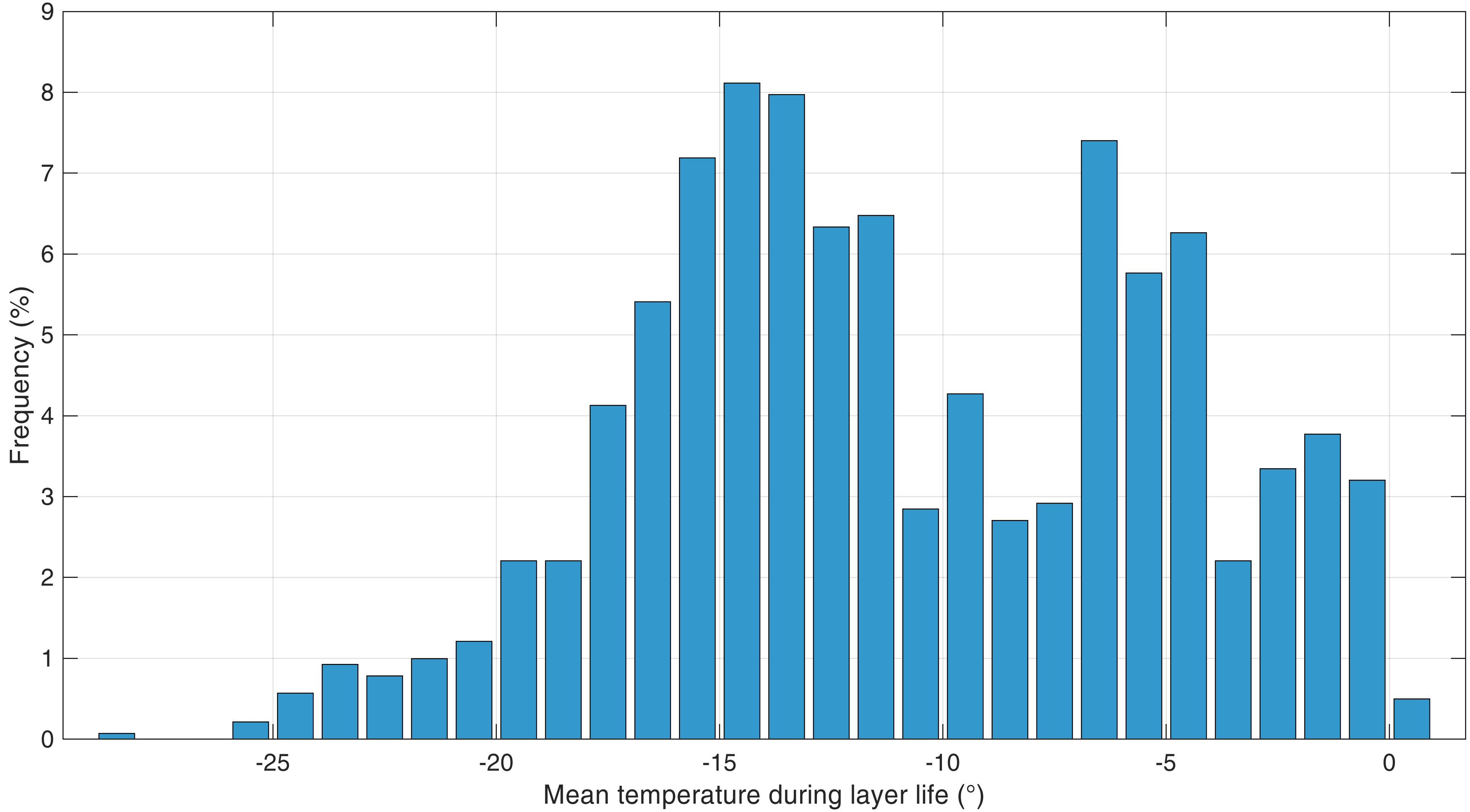
Frequency distribution of the erosion events by classes of positive degrees experienced by the layer since its formation (PDG life)



93% of erosion events have PDG life < 1°C

Positive air temperature strongly inhibit erosion

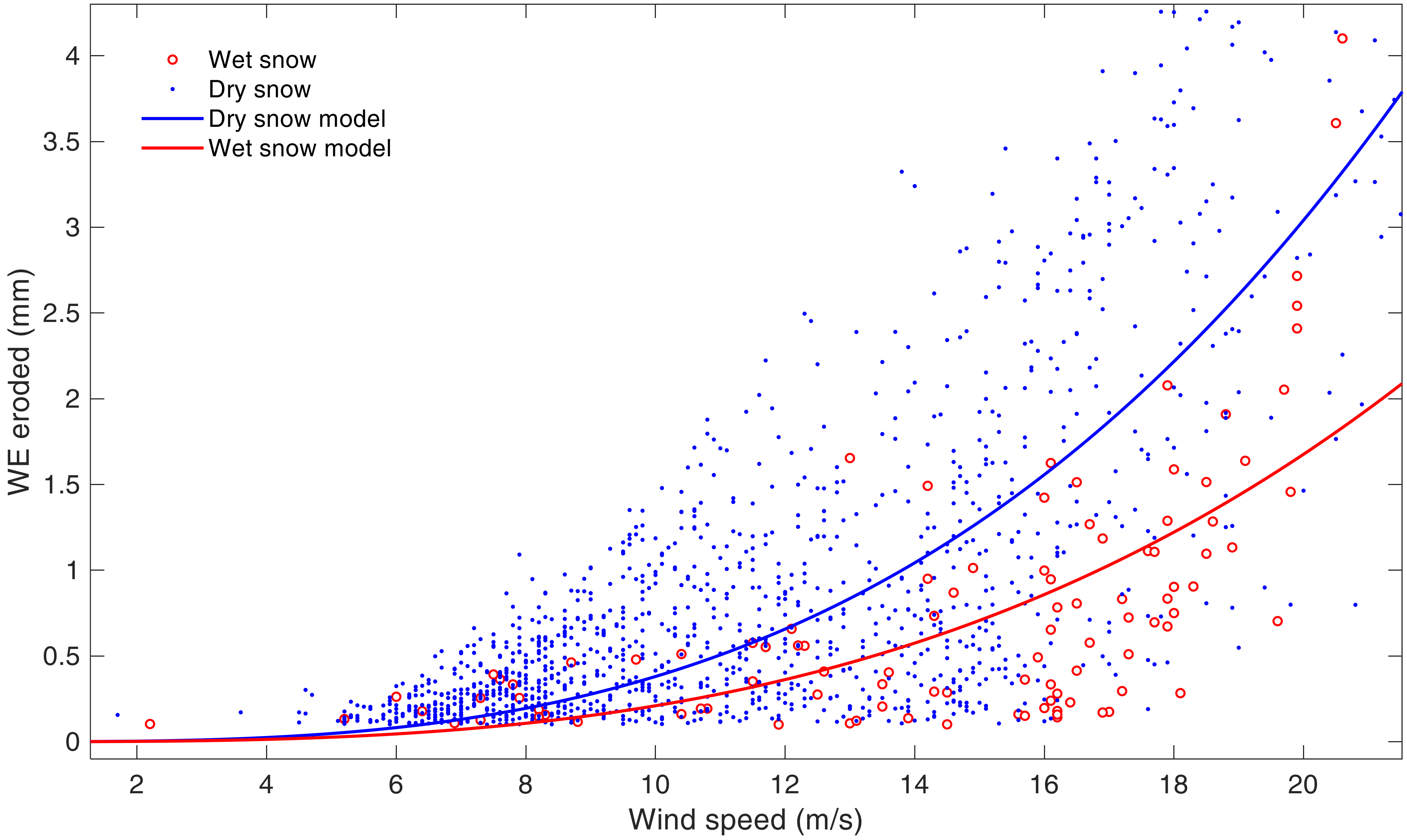
Frequency distribution of the erosion events by classes of mean temperature experienced by the layer since its formation (T life)



Erosion events drop above 0°C of T life

Positive air temperature strongly inhibit erosion

Parametrization of WE eroded as a function of wind speed for wet and dry snow



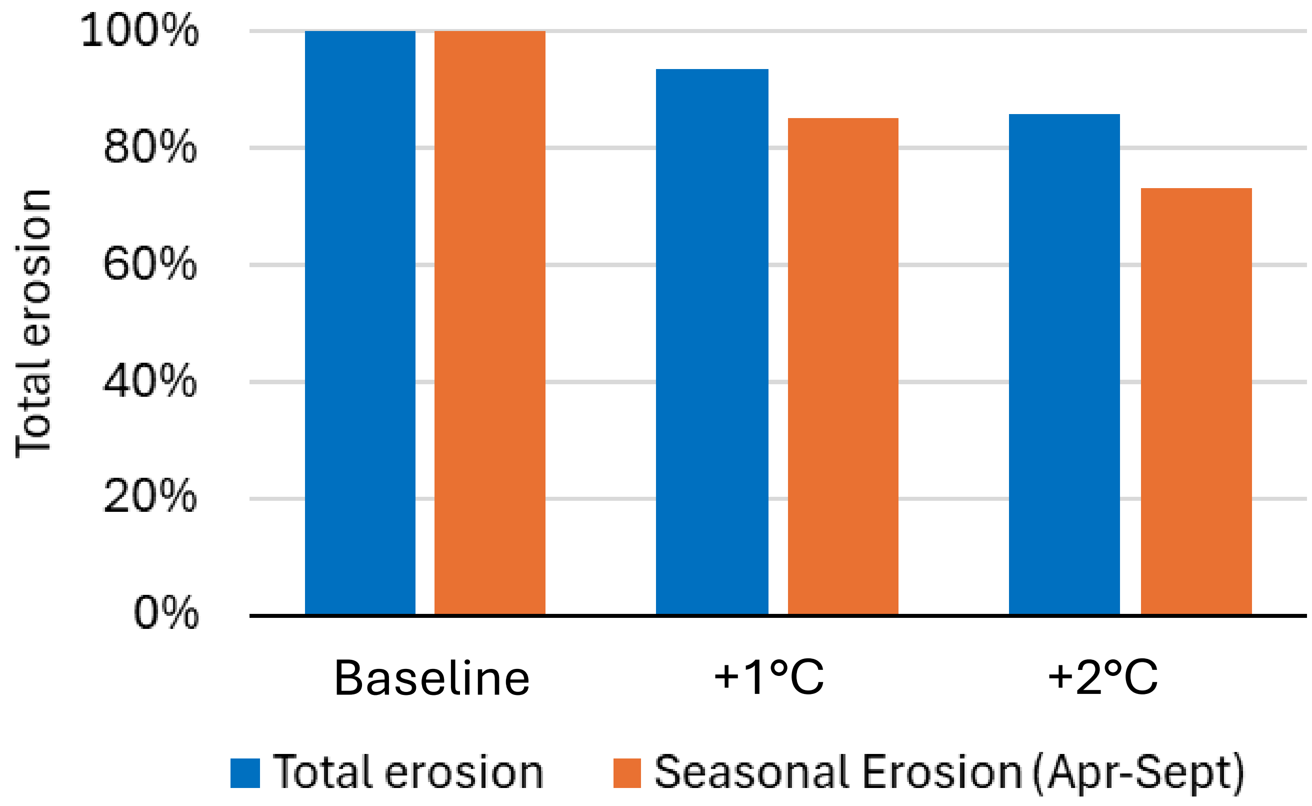
y = 3.8014e-04 * (x^3)

y = 2.0952e-04 * (x^3)

At a wind speed of 12 m/s (mean wind speed during erosion): dry snow shows an erosion rate 83% higher than that of wet snow

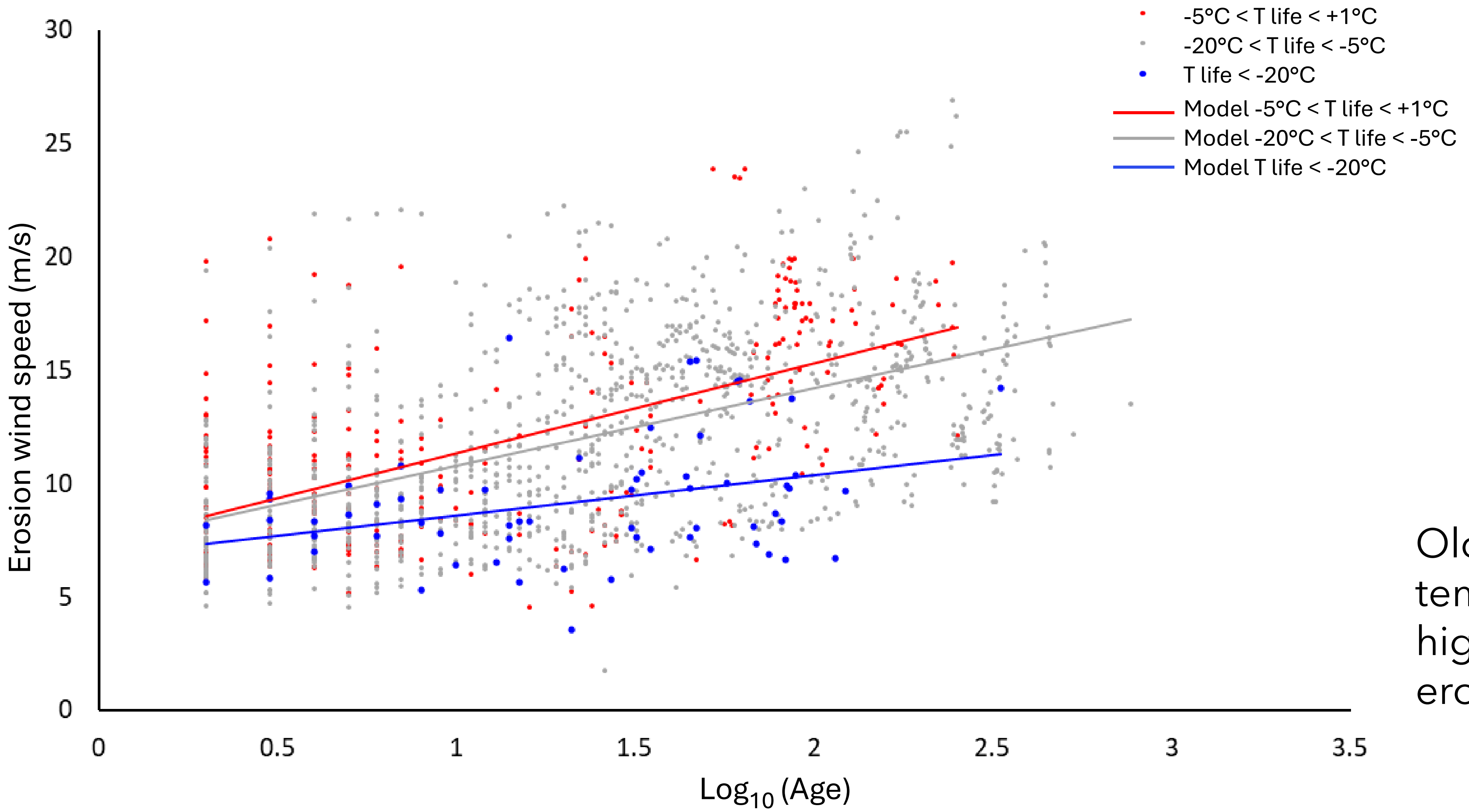
Preliminary results: Impact of +1°C and +2°C air temperature increase on erosion

Cubic model fitted to wet and dry snow. Simulation assumes no erosion events when T life > 0°C.



- **+1°C:**
  - Total erosion decreases by **6.5%**
  - Seasonal erosion (Apr–Sept) decreases by **15%**
- **+2°C:**
  - Total erosion decreases by **14%**
  - Seasonal erosion (Apr–Sept) decreases by **27%**

Next steps: wind speed during erosion as a function of layer age and T life



Older layers and higher temperatures lead to a higher wind speed for erosion

Concluding remarks

- Significant differences between wet and dry snow erosion, even with very small PDG life
- Wind erosion typically occurs within a few hours after snowfall, with frequency dropping sharply thereafter
- The frequency of erosion rapidly goes to zero when T life crosses the zero degrees
- Snow erosion shows high sensitivity to air temperature near the freezing point
- Total (seasonal) temperature sensitivity of snow erosion: +1°C → -6.5% (-15% warm season)
  +2°C → -14% (-27% warm season)

References

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