Osservazioni in situ della radiazione solare e della temperatura delle rocce in alta quota

Rockfall risk mitigation in the Alps
PRIN Rockfall project

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Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
Consiglio Nazionale delle Ricerche

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PRIN Rockfall project: Background and motivation

- Rockfalls are among the most common instability processes in high-mountain environments, affected by the progressive rock strength degradation.
- In recent years, a growing number of slope failures have been documented at high elevations in the Alps.

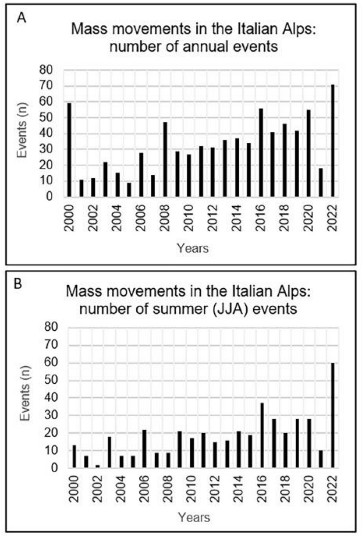
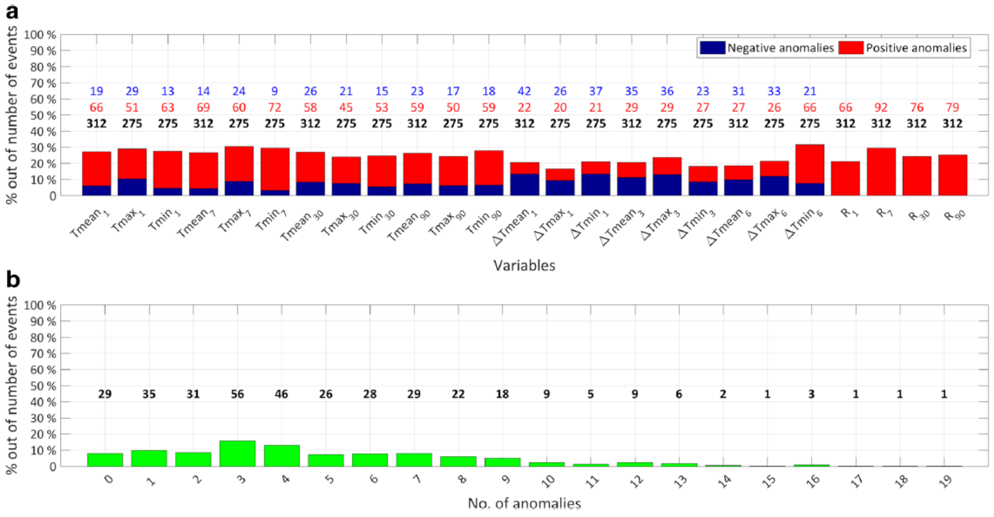


Fig. 5. Mass movements inventory in the Italian Alps. A, number of annual events; B, number of summer events (JJA: June, July and August).

Nigrelli et al., 2024

The highest number of events occurred in 2022 (71 events), and an evident trend towards an increase over the years and during summer was found.



Paranunzio et al., 2018

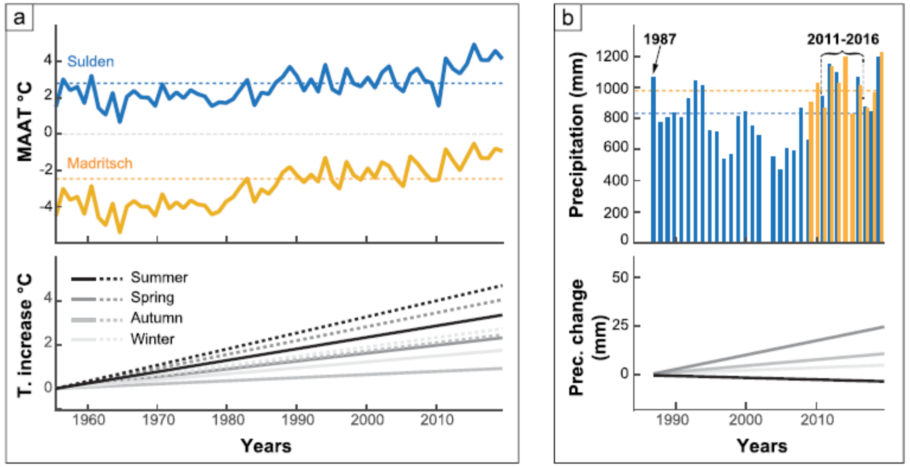


FIGURE 5 (a) Mean annual air temperature for Sulden and Madritsch stations (upper panel) with seasonal linear trends obtained by the "fit" Matlab algorithm (lower panel). In the upper panel, dotted lines represent the climatic reference MAAT (1981–2010; 3PClim database). In the lower panel, dotted lines represent measurements at Madritsch station, whereas continuous lines show measurements at Sulden. (b) Cumulative annual precipitation for the two stations (upper panel), with seasonal linear trends valid for the Sulden station only (lower panel). Colors follow the same scheme as in (a) [Color figure can be viewed at wileyonlinelibrary.com]

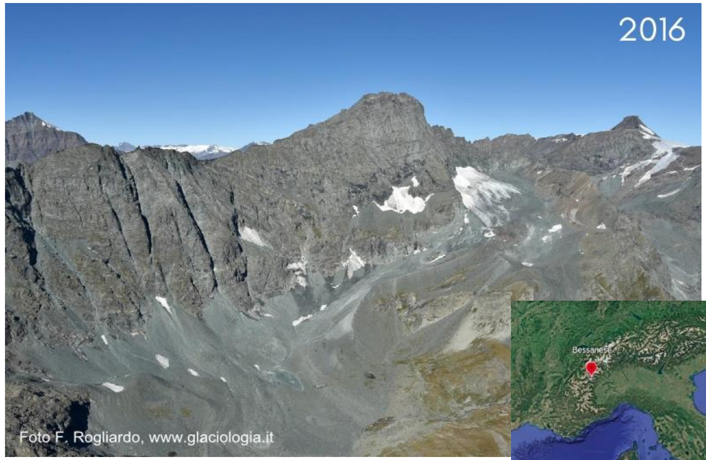
Savi et al., 2018

Changes in mean and extreme air temperatures and precipitation have proven to be important preparatory and triggering factors for slope instability in the mountain cryosphere.

PRIN Rockfall project

The frequency of natural instability processes on high-elevation mountain slopes is closely linked to climate warming (Fischer et al., 2013; Paranunzio et al., 2015; Mourey et al., 2019; Nigrelli & Chiarle, 2021, 2023).

Recently, research has begun to examine whether ***variations in rock temperature also influence slope instability.*** (Viani 2020, Draebing 2021, Nigrelli 2022, Laute 2025).



Aim of the project:
Risk mitigation in the Alps

Bessanese glacier basin

INRiM contributes to this project, guaranteeing the accuracy and traceability of the ***temperature observations***

Metrology approach

evaluation of uncertainties

"associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand"
(JCGM 100:2008).

"Pera" (meaning "rock" in the local dialect).

Bessanese Uja, (Spigolo Murari), at 3473 m a.s.l.

Rock temperature measurements at 10 cm, 30 cm and 50 cm depths.

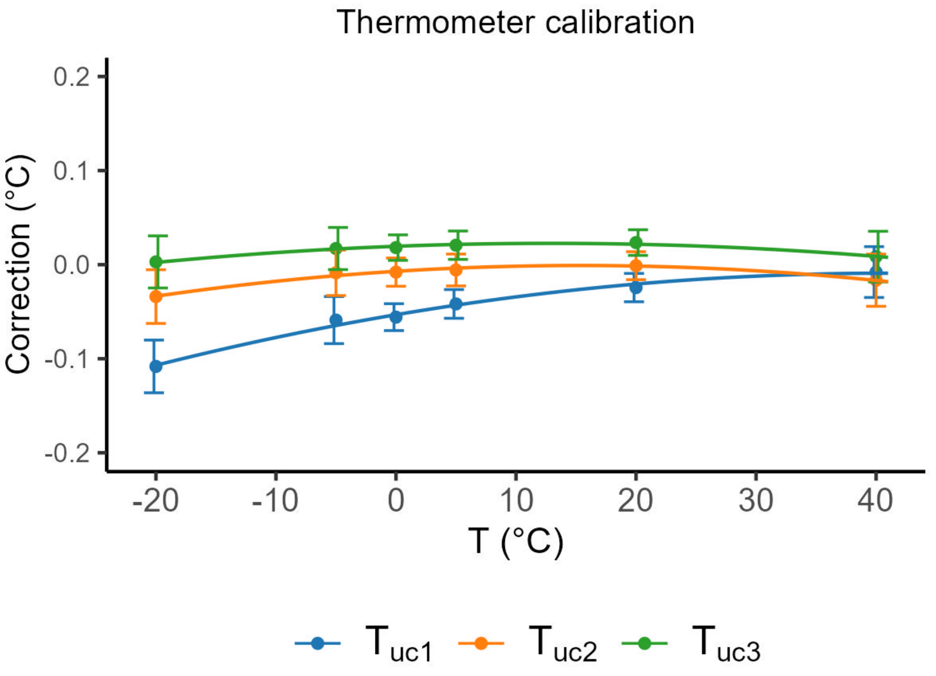
Thermometer calibration

The calibrations were performed by comparison with reference thermometers traceable to the ITS-90 scale

Calibration function

$$C = T - T_{TUC} = aT_{TUC}^2 + bT_{TUC} + c$$

T represents the air temperature and T TUC is the temperature measured by the thermometer under calibration. a, b and c are the coefficients of the model.



T_{ref}	T_{uc1}		T_{uc2}		T_{uc3}	
	C	U_T	C	U_T	C	U_T
(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)
-19.84	-0.11	0.03	-0.03	0.03	0.00	0.03
-5.01	-0.06	0.03	-0.01	0.02	0.02	0.02
-0.03	-0.06	0.01	-0.01	0.02	0.02	0.01
4.93	-0.04	0.02	-0.01	0.02	0.02	0.02
19.97	-0.02	0.02	0.00	0.01	0.02	0.01
39.80	-0.01	0.03	-0.02	0.03	0.01	0.03

With a coverage factor $k = 2$, expressed with the 95 % confidence level

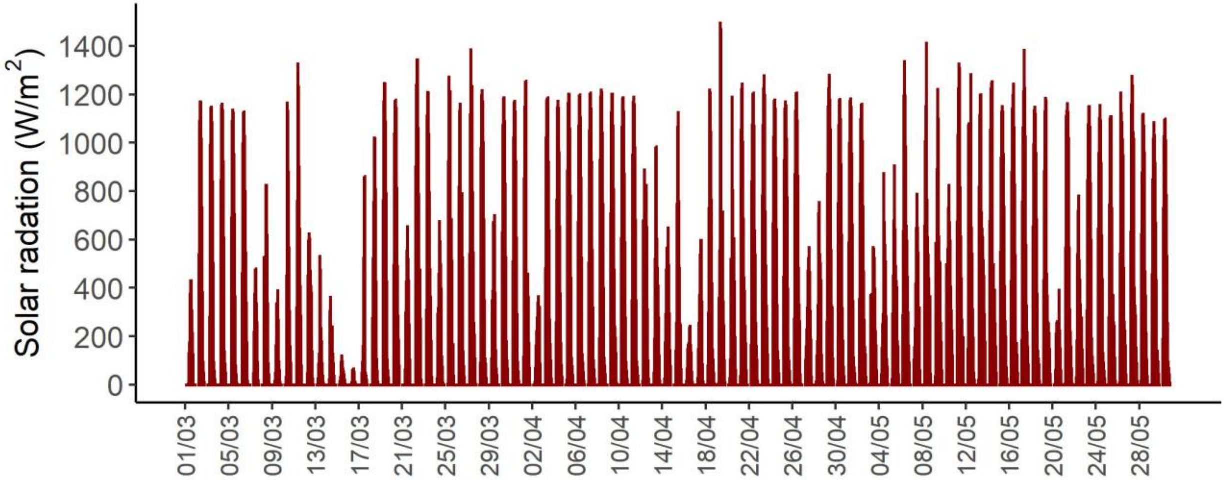
The higest contributions to the expanded uncertainty, U_T, are:

- The resolution of the thermometer under calibration.
- The calibration result from the reference thermometers.
- The stability and homogeneity of the thermostatic bath.
- The interpolation curve.

Thermometer calibration

Knowing the uncertainty of rock temperature measurements

- Increase confidence in the data.
- Improve data comparability (space and time).
- Provide a more robust understanding of the rock temperature evolution.



Expanded uncertainty of temperature values: 0.03 °C ($k = 2$)

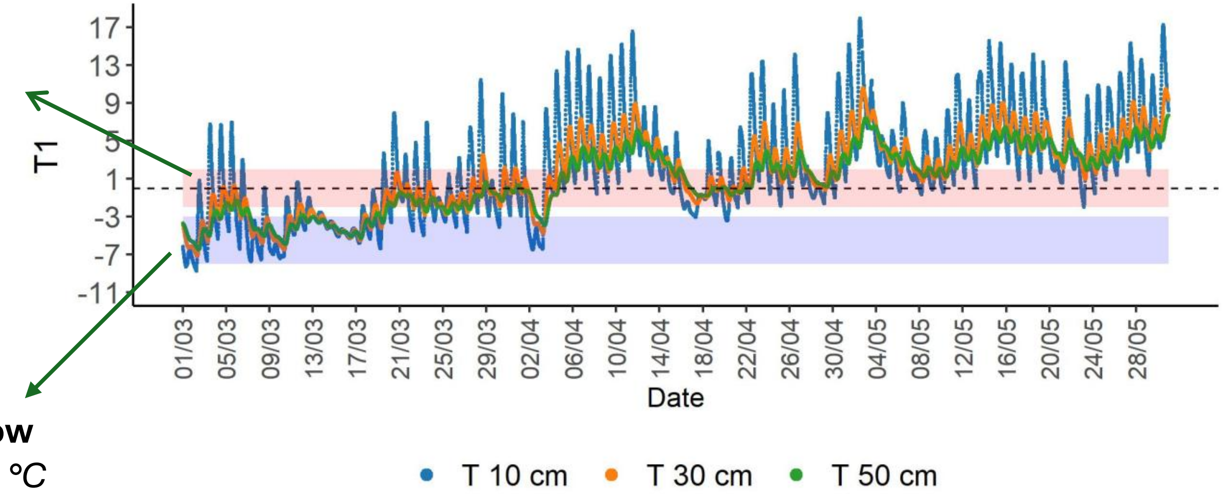
Effective freeze-thaw days

T above 2 °C, followed by a subsequent T below 2 °C

Volumetric expansion

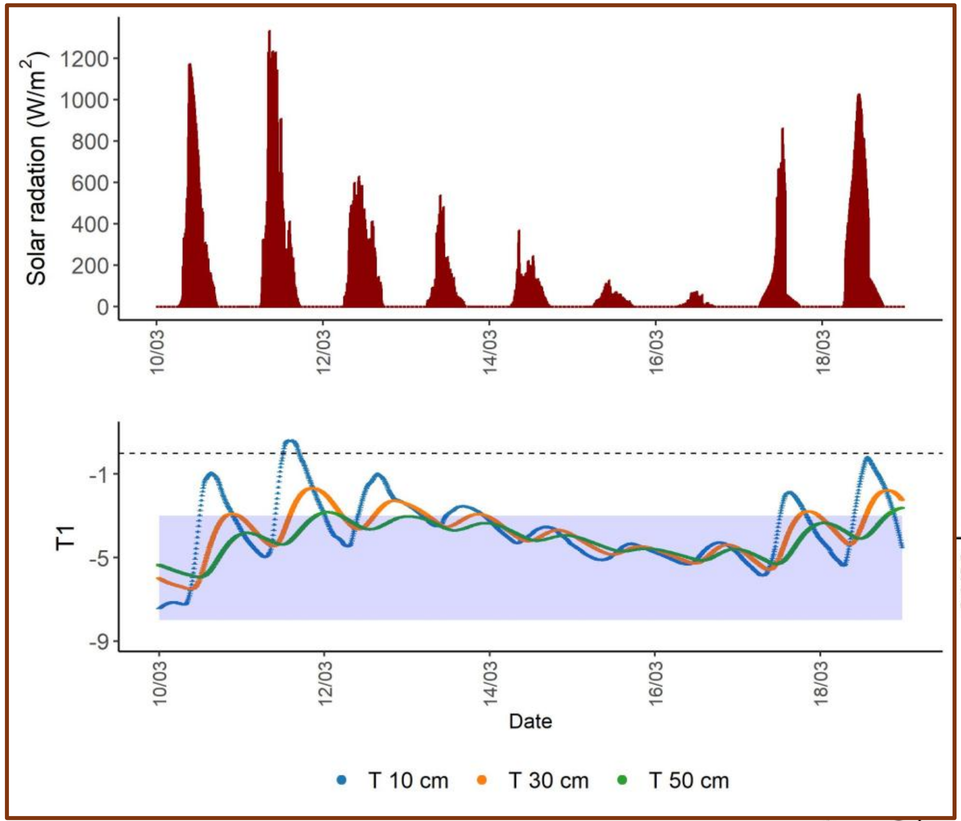
Frost-cracking window

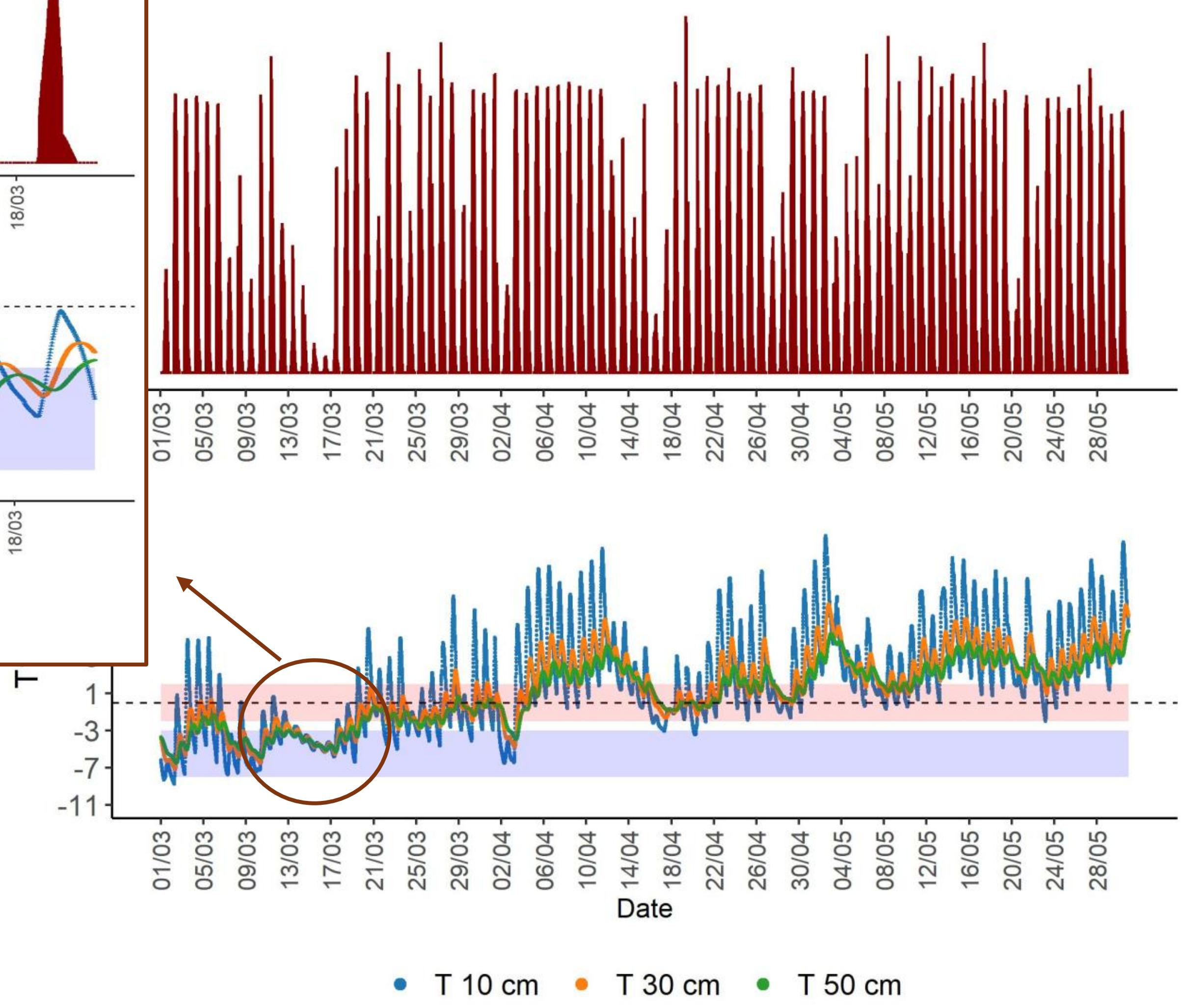
T between -3 °C and -8 °C



Data every 10 minutes

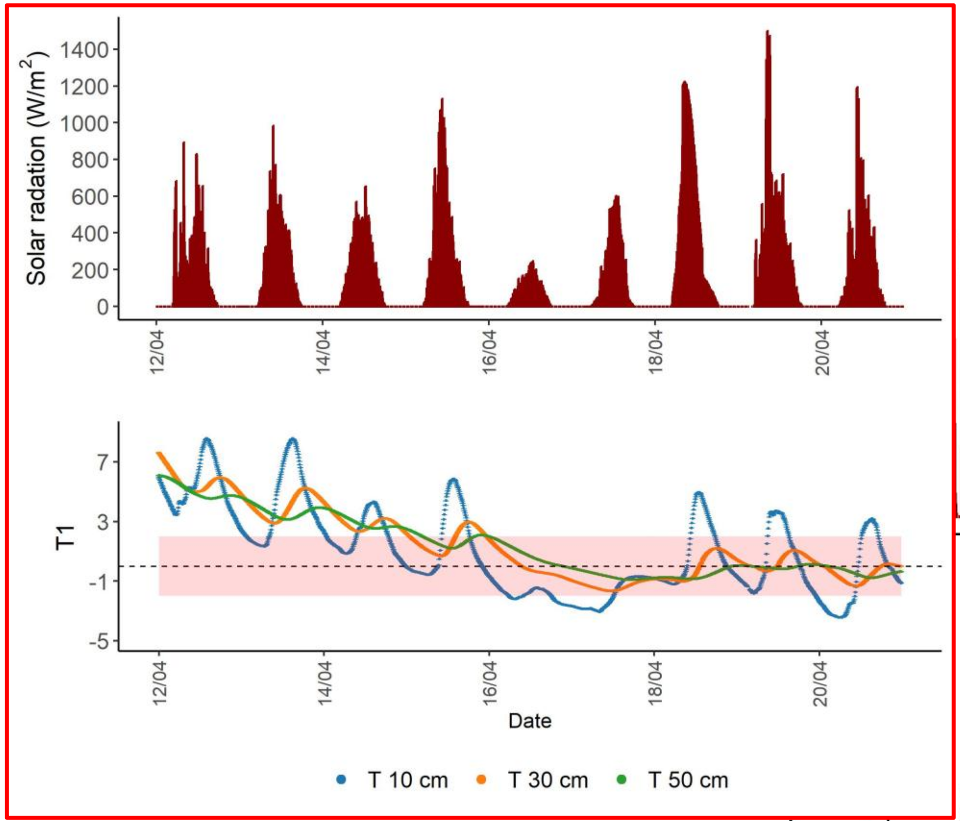
Thermometer calibration

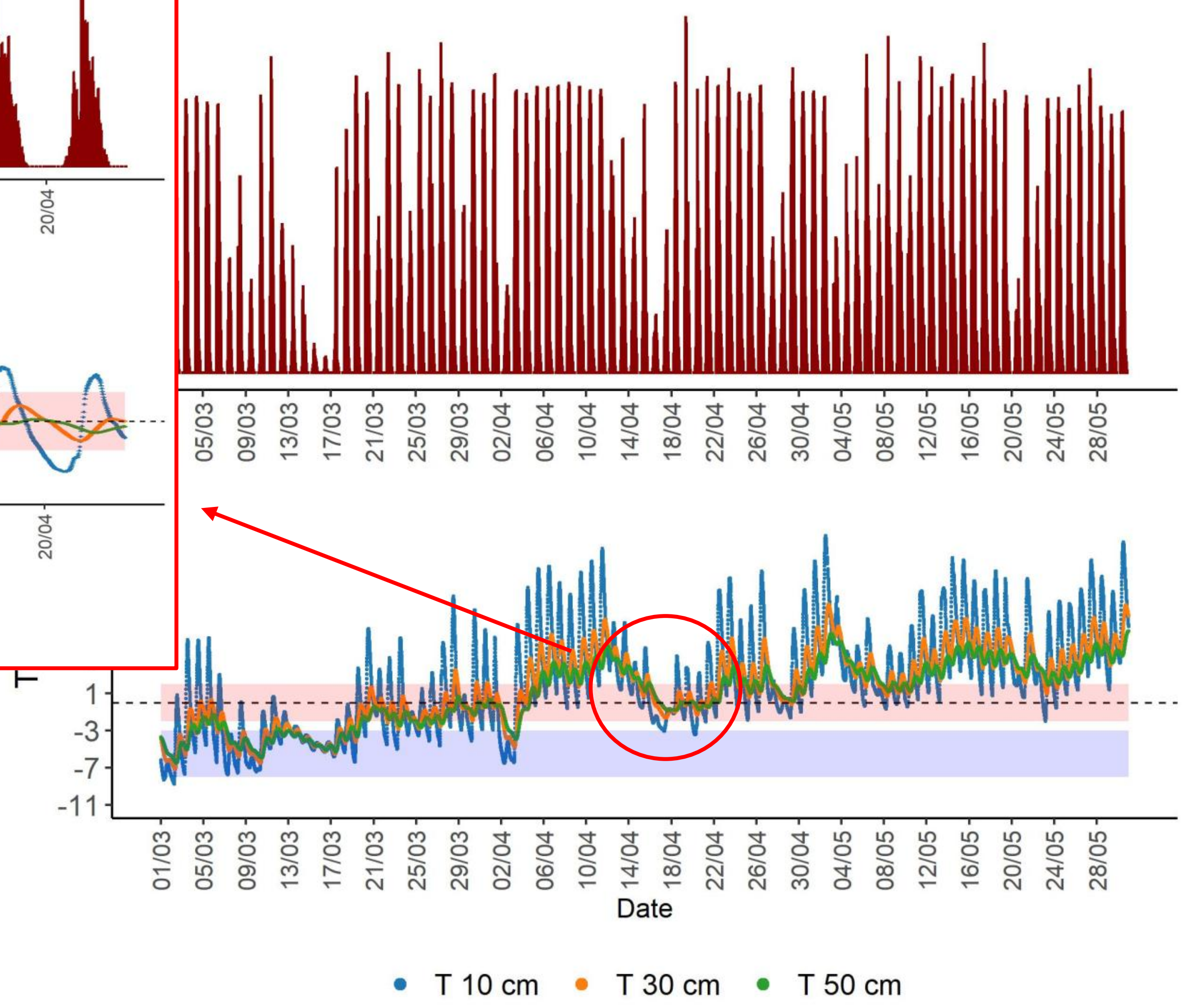




Data every 10 minutes

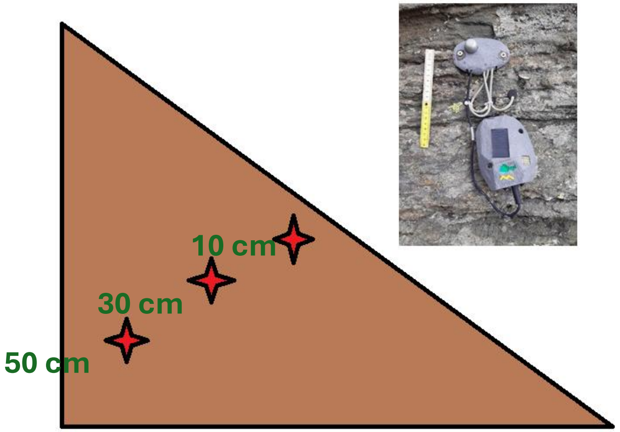
Thermometer calibration





Data every 10 minutes

Rock temperature gradient



Mean daily evolution of the rock temperature gradient

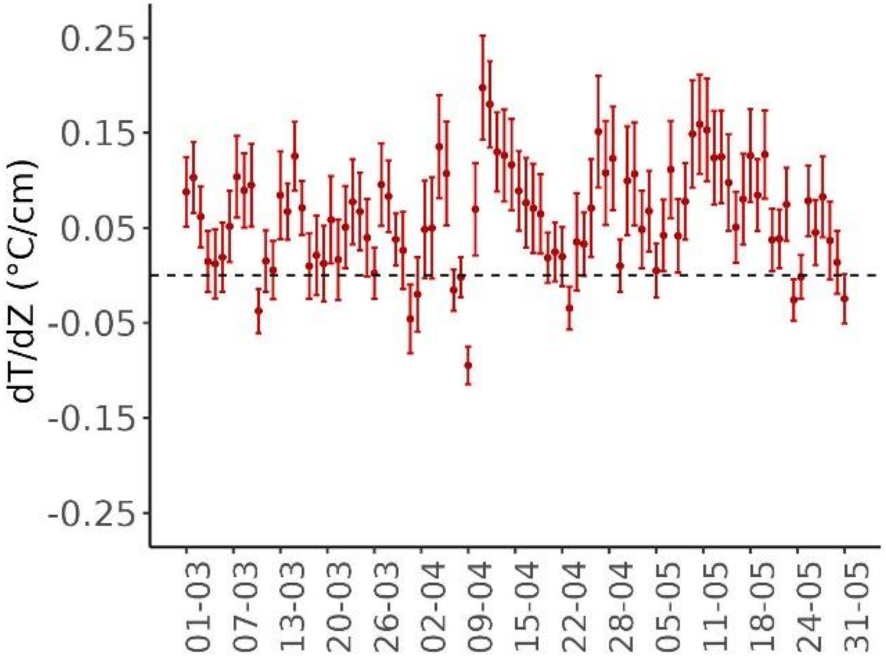
$$\frac{\delta T}{\delta Z} = \frac{T_{-30\ cm} - T_{-10\ cm}}{-20\ cm}$$

rock temperature gradient
≈
thermal stress of the rock
(more susceptible to cracking)

Evalution of uncertainty:

$$u_c^2\left(\frac{\delta T}{\delta Z}\right) = \left(\frac{-1}{20}\right)^2 u^2(\delta T) \rightarrow u_{disp}^2(\delta T) + 2u_{cal}^2(T)$$

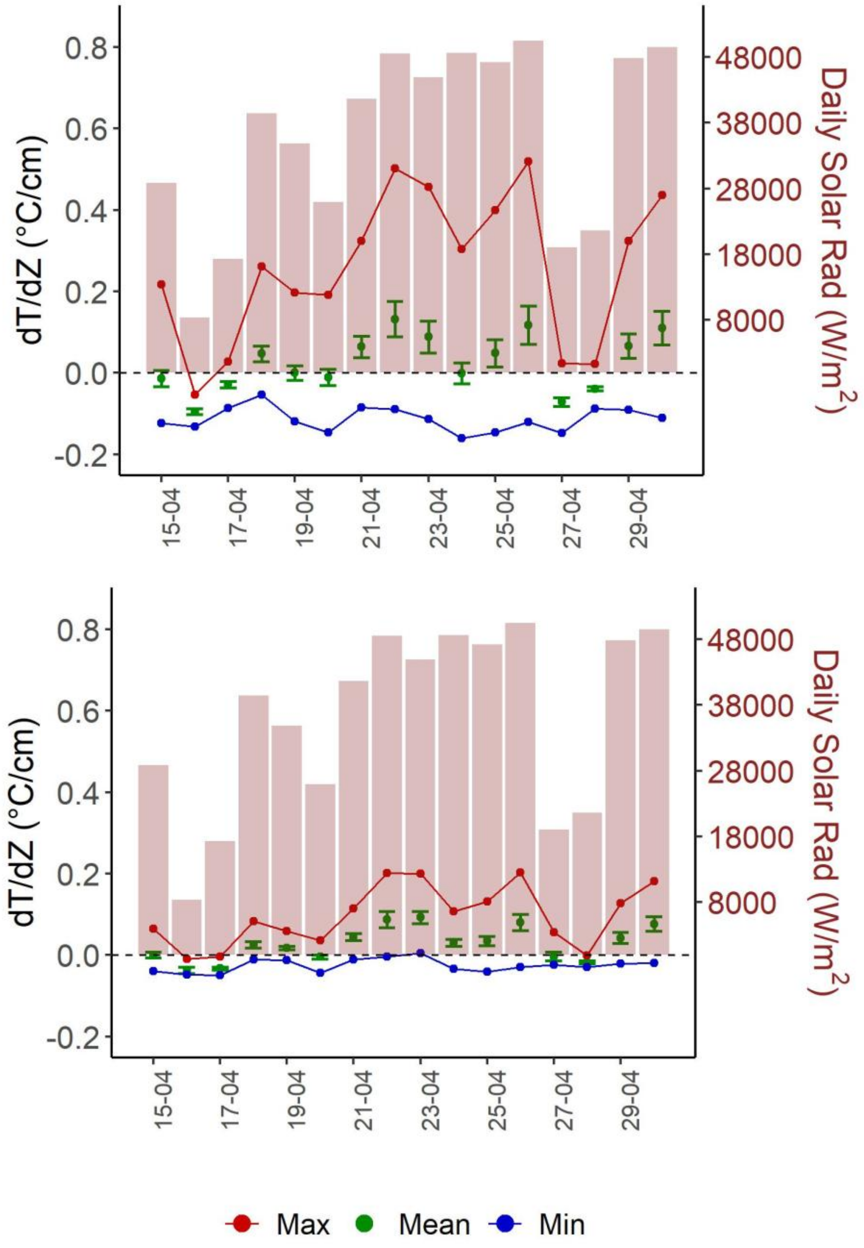
$$U\left(\frac{\delta T}{\delta Z}\right) = 2u_c\left(\frac{\delta T}{\delta Z}\right)$$



Mean daily evolution of the rock temperature gradient

$$\frac{dT}{dZ} = \frac{T_{-30\ cm} - T_{-10\ cm}}{-20\ cm}$$

$$\frac{dT}{dZ} = \frac{T_{-50\ cm} - T_{-30\ cm}}{-20\ cm}$$




16/04/2025 14:40

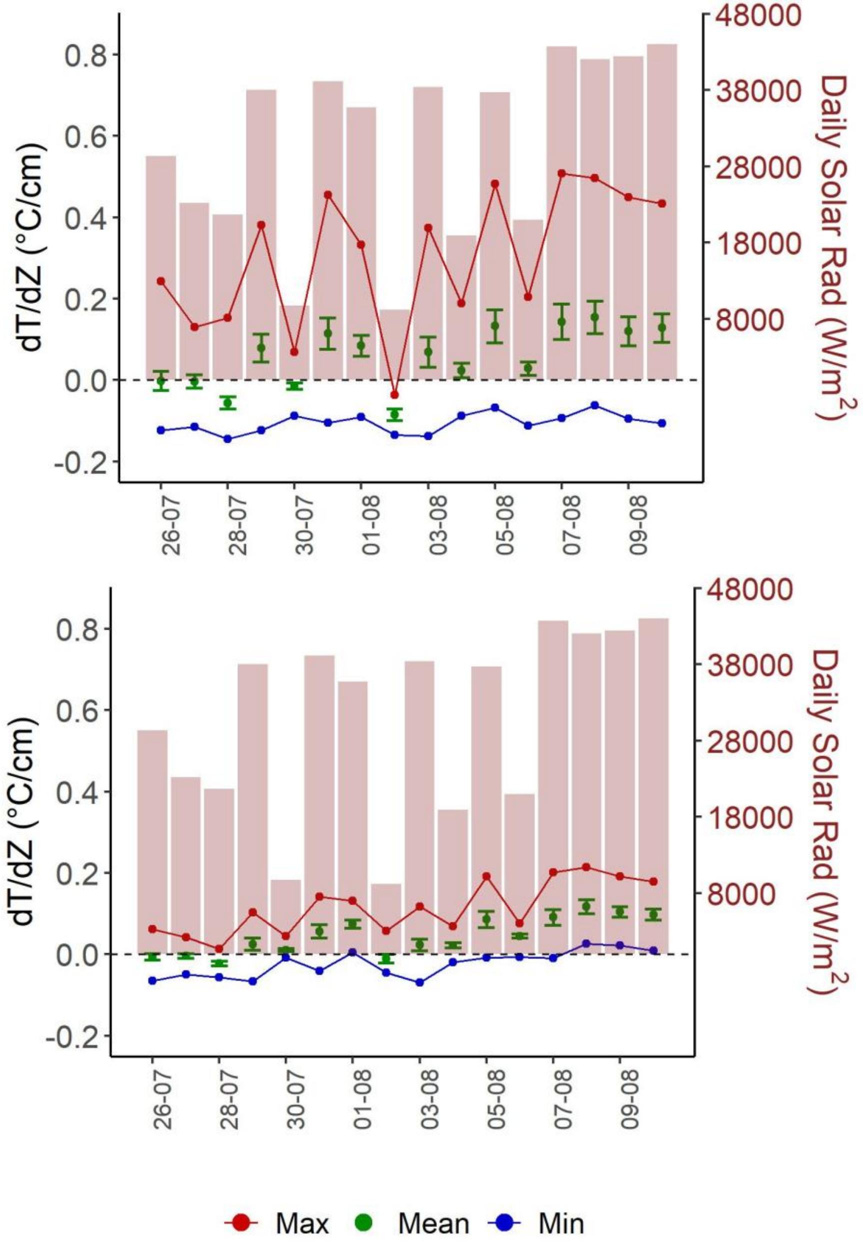

25/04/2025 14:40


28/04/2025 13:00

Mean daily evolution of the rock temperature gradient

$$\frac{dT}{dZ} = \frac{T_{-30\ cm} - T_{-10\ cm}}{-20\ cm}$$

$$\frac{dT}{dZ} = \frac{T_{-50\ cm} - T_{-30\ cm}}{-20\ cm}$$



31/07/2025 13:00

02/08/2025 15:00

08/08/2025 14:40

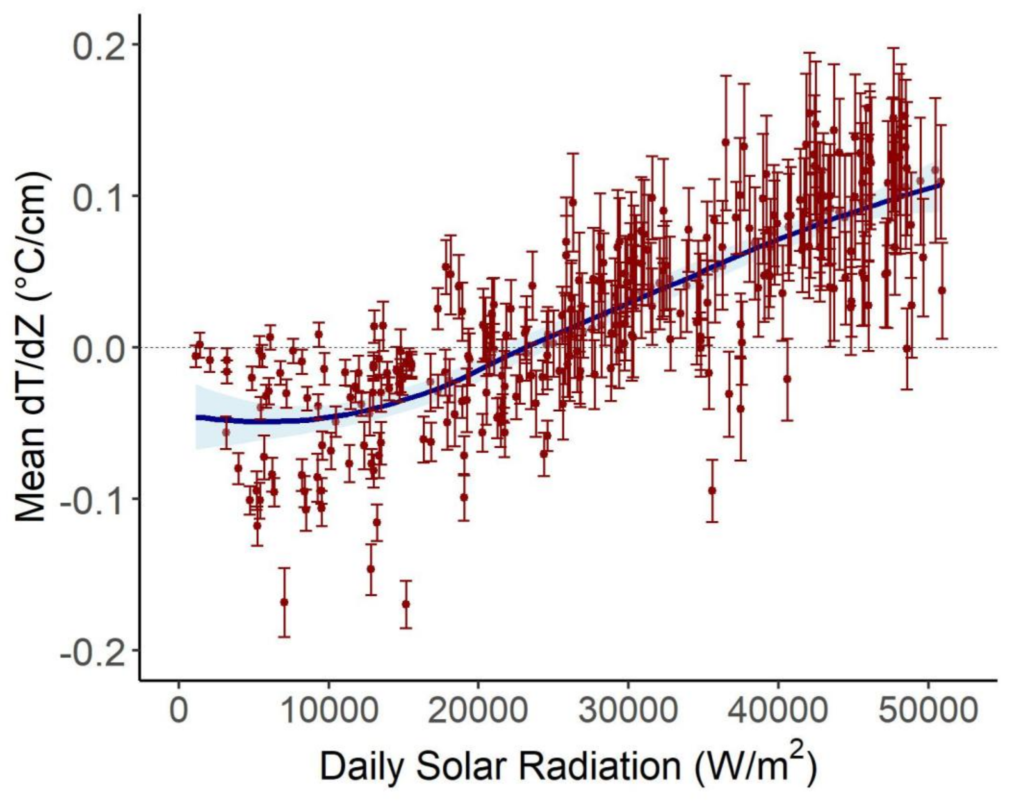
Influence of solar radiation on rock temperature measurements

- ✓ The higher the amount of solar radiation received by the rock surface, the higher the gradient of Trock.
- ✓ ***The uncertainty of dT/dZ depends on the amount of solar radiation observed at the rock surface.***

⇓

The higher the radiation received by the surface, the greater the dispersion of the gradient of T rock

Period: 01/09/2024 – 31/08/2025



Thermal gradient between 30 and 10 cm

Results from Eppes et al. (2016) emphasize **the role of solar-induced thermal stresses** in relation to the mechanical preconditioning of rocks, making them ***more susceptible to cracking.***

The ***maximum range of daily deformation*** does not **coincide** with the warmest times of the year, but rather with ***the greatest daily temperature range***, typically in March-April and October-November. **These periods may be times when rock damage at crack tips is most likely to occur.** *Collins, B., Stock, G. (2016)*

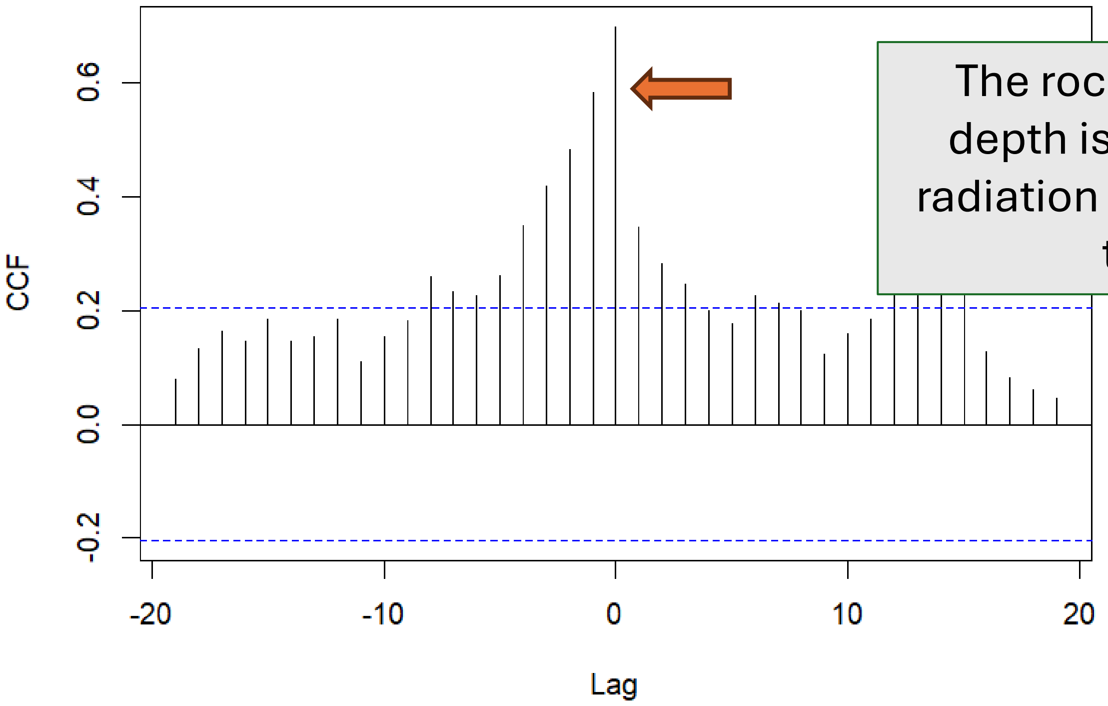
Influence of solar radiation on rock temperature measurements

Cross-correlation analysis: evaluate the temporal relation between the solar radiation and temperature series

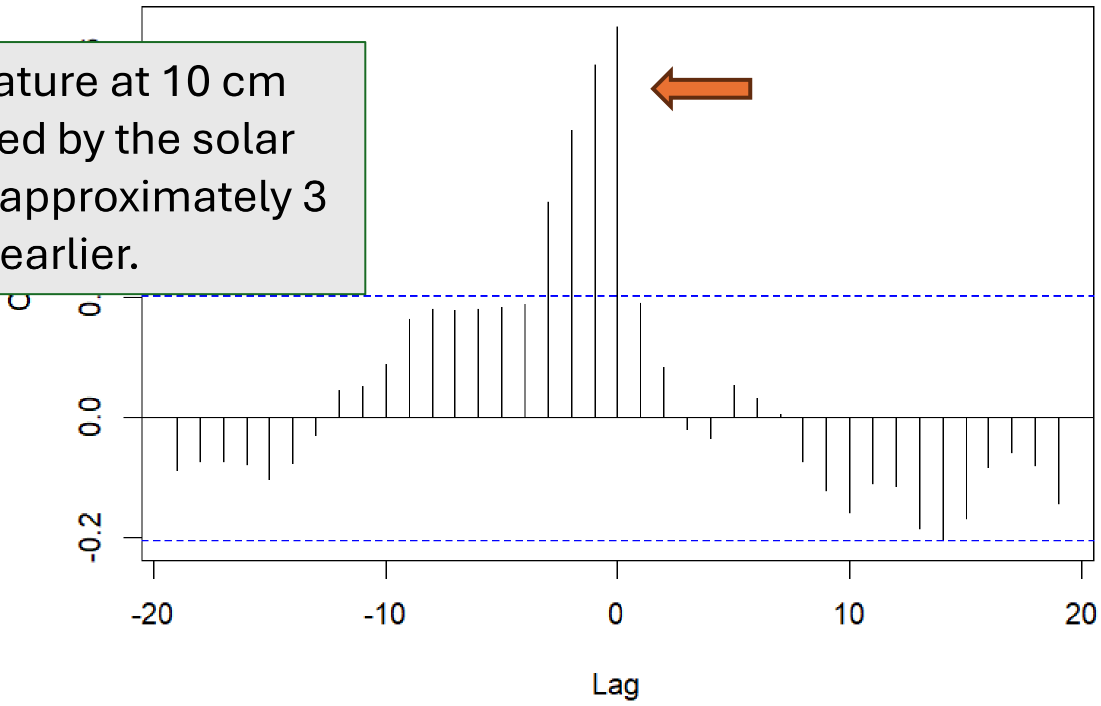
how much one series interferes with the behavior of another (Santos *et al.*, 2024; Filho, 2014).

Daily solar radiation amount and daily mean rock temperature at 10 cm

Spring



Summer



The rock temperature at 10 cm depth is influenced by the solar radiation received approximately 3 to 5 days earlier.

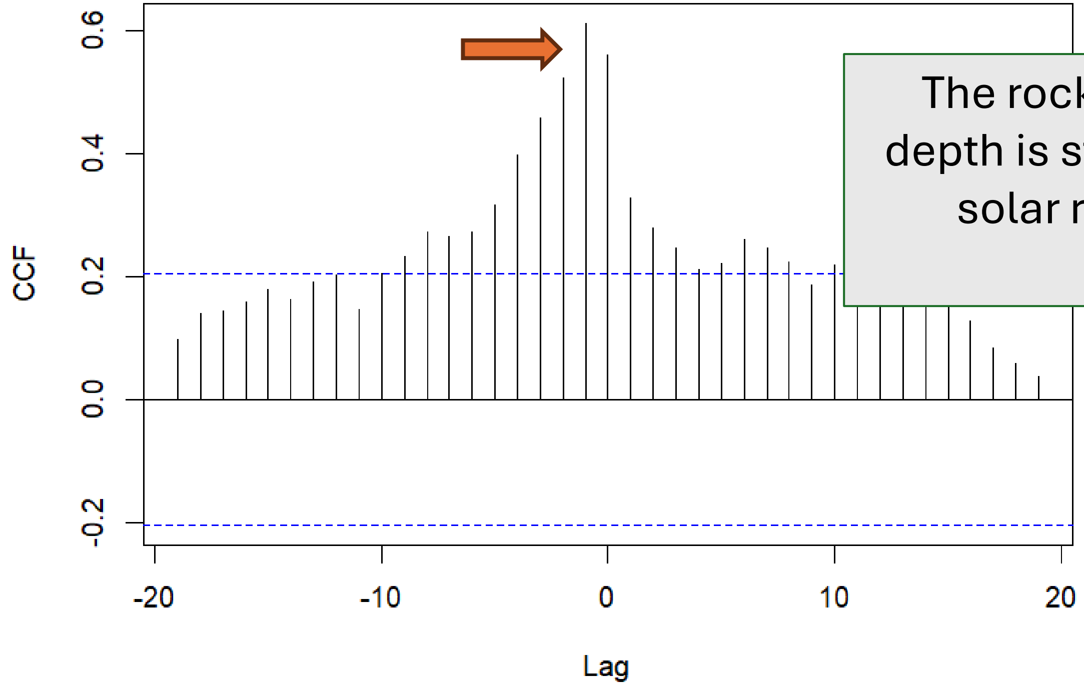
Influence of solar radiation on rock temperature measurements

Cross-correlation analysis: evaluate the temporal relation between the solar radiation and temperature series

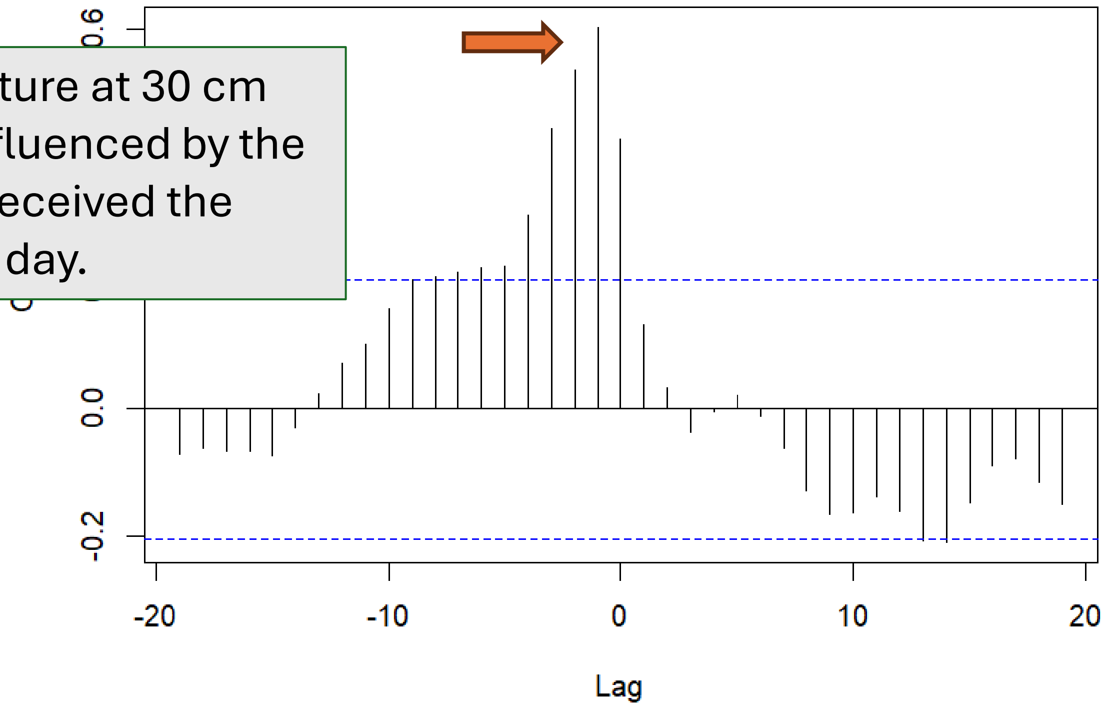
how much one series interferes with the behavior of another (Santos *et al.*, 2024; Filho, 2014).

Daily solar radiation amount and daily mean rock temperature at 30 cm

Spring



Summer



The rock temperature at 30 cm depth is strongly influenced by the solar radiation received the previous day.

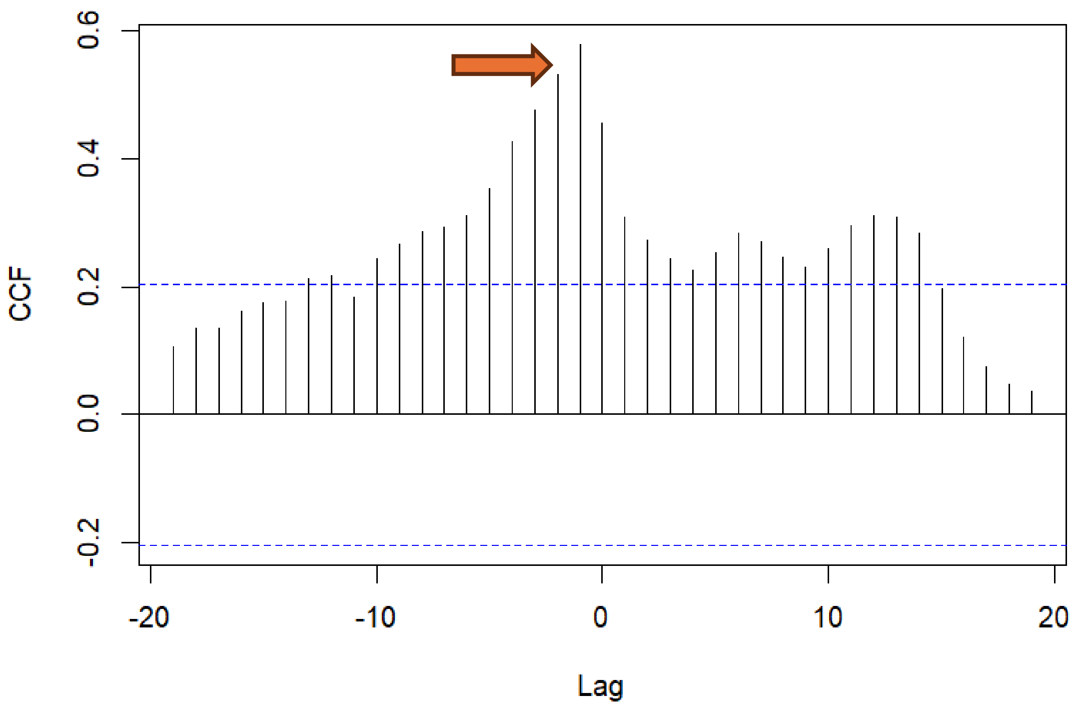
Influence of solar radiation on rock temperature measurements

Cross-correlation analysis: evaluate the temporal relation between the solar radiation and temperature series

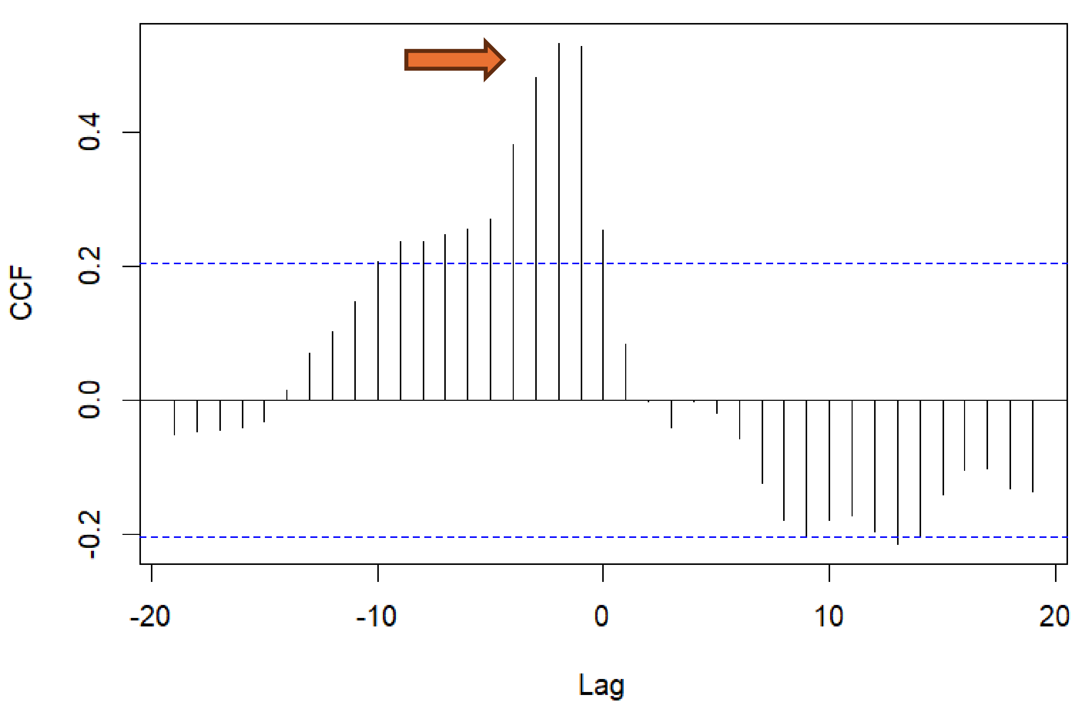
how much one series interferes with the behavior of another (Santos *et al.*, 2024; Filho, 2014).

Daily solar radiation amount and daily mean rock temperature at 50 cm

Spring



Summer



Conclusions

The work has a metrological approach, focusing on the laboratory calibration of the thermometers and the uncertainty of the measurements.

Guarantee traceability of the measurements, enhance the reliability of the data and the comparability of the rock temperature measurements.

Pera measures the solar radiation and the rock temperature at different depths in the same geographic point.

The radiative component has a significant role in modulating the temperature of the rock.

Future research

Improve the knowledge of temperature measurements in high mountains: Atmospheric parameters, such as wind speed and air temperature, will be studied to understand their influence on rock temperature.

Thanks for your attention!

Grazie
Gracias

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Finanziato dall'Unione europea NextGenerationEU
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