The understanding of global warming influences on the temperature behaviour on mountainous areas

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Introduction

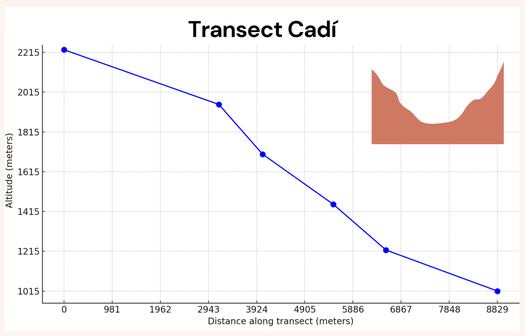
The vertical temperature profiles in well drained valleys tend to be similar to that of the free atmosphere, since drainage avoids the developing of a Cold Air Pool (CAP). On the contrary, closed basins are prone to the formation of CAP, where temperature profiles may be more strongly influenced by boundary layer processes, which decouples the behaviour of the lower part of the basin from that of the free atmosphere.

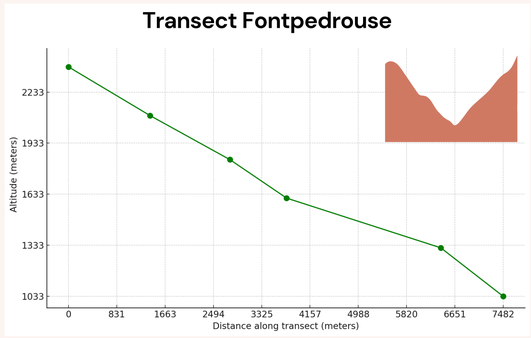
The aim of this research is to study the behaviour of two nearby transects with different valley shapes: Cadí (Cerdanya valley) and Fontpedrouse (Conflent valley), in order to compare the cold air drainage and stagnation influence during the night and relate it with synoptic forcings. In fact, in this study an statistical relationship is given in order to relate synoptic types with the CAP signal.

Transects

Spread across the **Cerdanya** basin and **Fontpedrouse** valleys, fifty HOBO U23-001 sensors (temperature & relative humidity) were deployed in several elevational transects. The network deliberately includes slopes with differential aspects and land-use, and covers a range from 1000 m asl up to around tree line (~2.100-2.400 m asl).

Two transects are compared in this study, including **Cadí** which is located in the main valley (U-shape) and more prone to experience CAP, and **Fontpedrouse** which is located in a deep V-shaped valley open to the Mediterranean Sea. Both have the same northerly aspect.





Methodology

CAP strength

Synoptic stability

→ SEM Relates stochastically the synoptic indices with CAP →

Project the probabilistic relationships to the future

- On both the Cadí and Fontpedrouse transects, six sensors measured air temperature (at 2m height) at 06 UTC, spaced roughly every 250 m from 1000 to 2400 m above sea level (asl).
- The lapse rate was calculated for Fontpedrouse (representing free atmosphere conditions) and Cadí (representing inner valley conditions) using the gradient from the best-fit linear regression. By subtracting the slope of Cadí from that of Fontpedrouse, we obtained a measure of **stability** or **CAP formation**, which we called deriva.
- Additionally, we considered the temperature differences between the Cadí profile sensors and the Fontpedrouse sensors interpolated using the Fontpedrouse regression model at the same heights for Cad2, Cad3, Cad4, Cad5, and Val3. These **residuals** show whether Cadi sensors are warmer or colder than predicted based on the free air profile.

- We classified the daily **synoptic patterns** into 13 types representing the most significant synoptic structures in the western Mediterranean (Miró et al, 2020).
- We used Self-Organizing Maps (**SOM**) to reduce the cases related to each of these 13 types to 64 (for each type), with the goal of eliminating uninformative or spurious cases.
- For each type with these 64 cases, we developed a stability index by combining measures of vorticity and geopotential height, referred to as the **vor_index**.
- Each day is categorized by its synoptic type and assigned a **vor_index** value.

- Structural Equation Modeling (**SEM**) was used to relate the obtained synoptic stability index (**index_vor**) and the CAP index (**deriva**). SEM stochastically relates variables linearly rather than deterministically, allowing for statistical inference.
- When the linear relationship is insufficient, non-linear relationships are calculated and added as variables to improve the relationship between index_vor and deriva. These non-linear relationships are calculated using a machine learning software called **Feyn** from Abzu.

- Structural Equation Modeling (**SEM**), constructed using **ERA5** and observed values, can be further applied to projections given by the **CORDEX** models. The index_vor can be calculated using the **CORDEX** simulations for the future. The main challenge will be obtaining the distribution of **deriva**.
- Given the Gaussian nature of the variables, the idea is to construct a linear regression relating **index_vor** (and other variables) with **deriva**. This approach will approximate the distribution of **deriva**, also taking into account the R^2 value.

ACKNOWLEDGEMENTS: To SMC for supporting the campaign of measurements in Cerdanya anc for the comments provided and specially to Marta Balagué for improving the presentation. Also we want to thank Meritxell Pagès, passed away 10 years ago, who was the promoter of this campaign.

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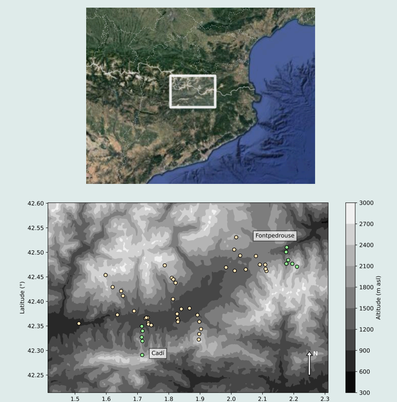
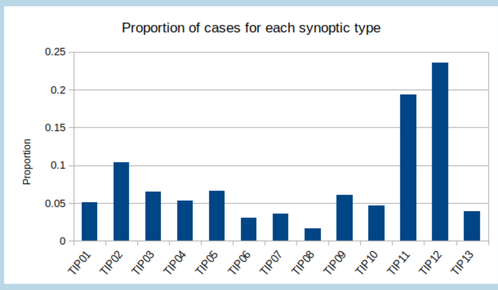
Area of study

Cerdanya is one of the largest valleys in the Pyrenees, singularly oriented ENE to WSW, 35 km long and 9 km wide. The bottom of the valley is about 1000 m above sea level (asl) and it is surrounded by mountain ranges rising to above 2900 m asl.

This configuration makes the Cerdanya basin prone to the formation of regular CAP (Pepin and Kidd, 2006, Pagès et al, 2017). The Cerdanya is, together with Arctic Lapland and Kilimanjaro, an area chosen by the University of Porsmouth to study the evolution of the climate in mountain zones,



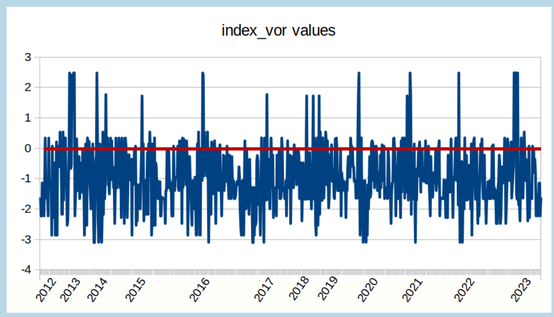
Results



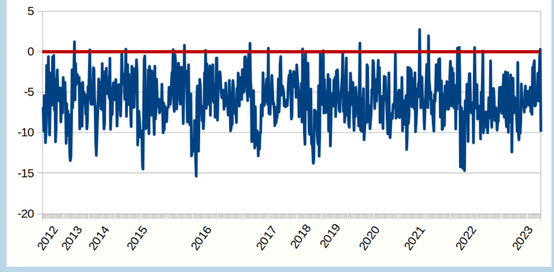
Using the ERA5 reanalysis, each day is classified as one of 13 synoptic types. The main types related with stronger CAP are **TIPO2** (Anticyclonic with West Advection aloft) and **TIP12** (Undetermined), and to a lesser extent **TIPO9** (South-West Advection) (Miró et al, 2020). This graph shows. the proportion of the different synoptic types along the studied period (2012-2023).

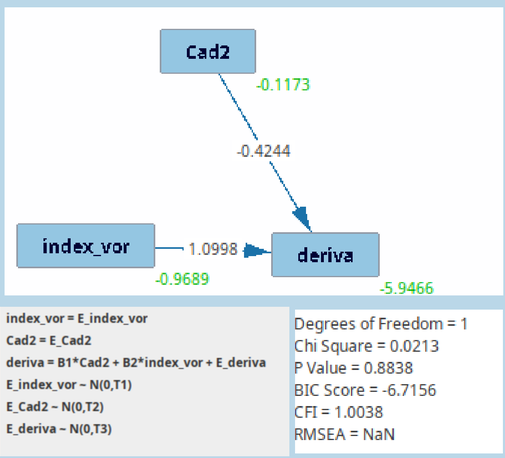
Example for TIP12, strongly associated with formation of CAP

index_vor is calculated using the data obtained from SOM. This reduces the total cases to 64 for each of the 13 synoptic types. This example is for TIP12. Negative values are related to stability.



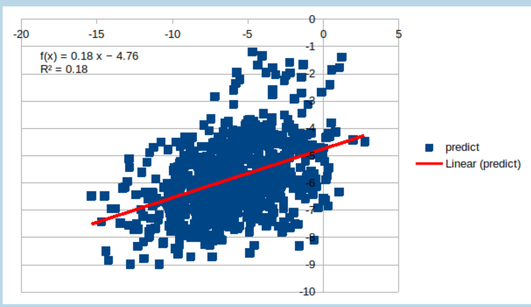
Evolution of the **deriva,** which is obtained from the difference between the regression gradients of Fontpedrouse and Cadí. Negative values are related to the presence of CAP (much more positive slope in Cadí relative to Fontpedrouse). The strongest CAP tends to be in the winter months.

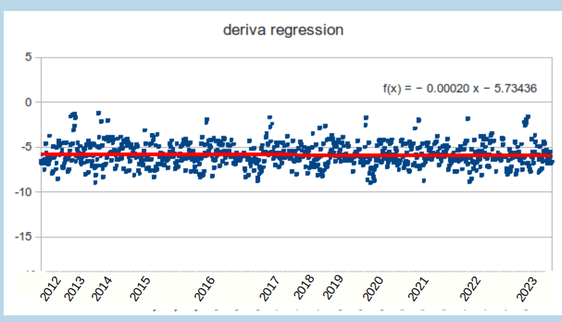


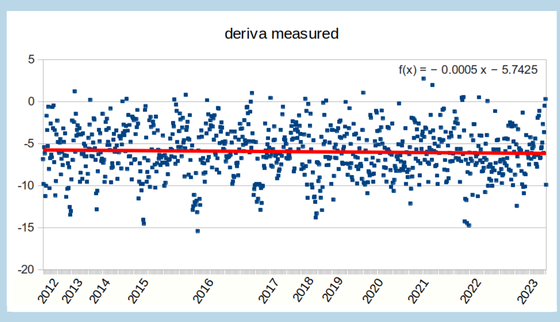


The figure on the right shows the relationship between measured deriva and the one inferred from **Cad2** and **index_vor**. Although the R^2 is very low there is a significant relationship.

There is a direct causal relationship between **deriva** and **index_vor** (more stability is related to more CAP); **deriva** is also causally related to **Cad2**, which represents the temperature residual respect the Fontpedrouse transect at the highest elevation sensor below the summit of the Cadí transect. In this case as **Cad2** increases, the stronger the stability conditions.







Despite the differences between the measured deriva and the inferred values using **index_vor** and **Cad2,** both show an analogous tendence.

Conclusions and Future work

The results suggest that by applying causal inference, a stochastic relationship can be found between synoptic forcing and local measured variables such as CAP. In future we may assume that such relationships may remain stable, even though synoptic conditions themselves may change.

Future work can then predict changes in the long term mean CAP, by using CORDEX simulations, with the aim of identifying tendencies depending on different climate scenarios which predict changes in synoptic conditions.

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