Estimate of the Snow Water Equivalent for the Barasona Reservoir

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1. Introduction

The Barasona reservoir is one of the three main **water supplies** for the Aragon and Catalonia Irrigation District, the principal provider for a total 98.000 ha, including 37 municipalities and thousands of agricultural holdings and livestock farms. With an area of 1535 km², its basin lies in the Central Pyrenees, and it is largely a **snow-dominated catchment**. During these last years, the Pyrenees have suffered several **drought episodes**, that have severely affected not only the mountain system itself, but also the regions that depend on its water supply, both economically and ecologically. Thus, it is of great interest to have a correct understanding of the reservoir's hydrological processes.

Recently, the irrigation community has expressed their interest in acquiring data of the available **snow water equivalent (SWE)** at the basin at a higher precision. Snow, as opposed to rain, is a water resource whose main contribution is already determined by the beginning of thaw, so it represents a minimum water volume available that does not depend on future meteorological events, which is crucial for decision-making to the irrigation community.

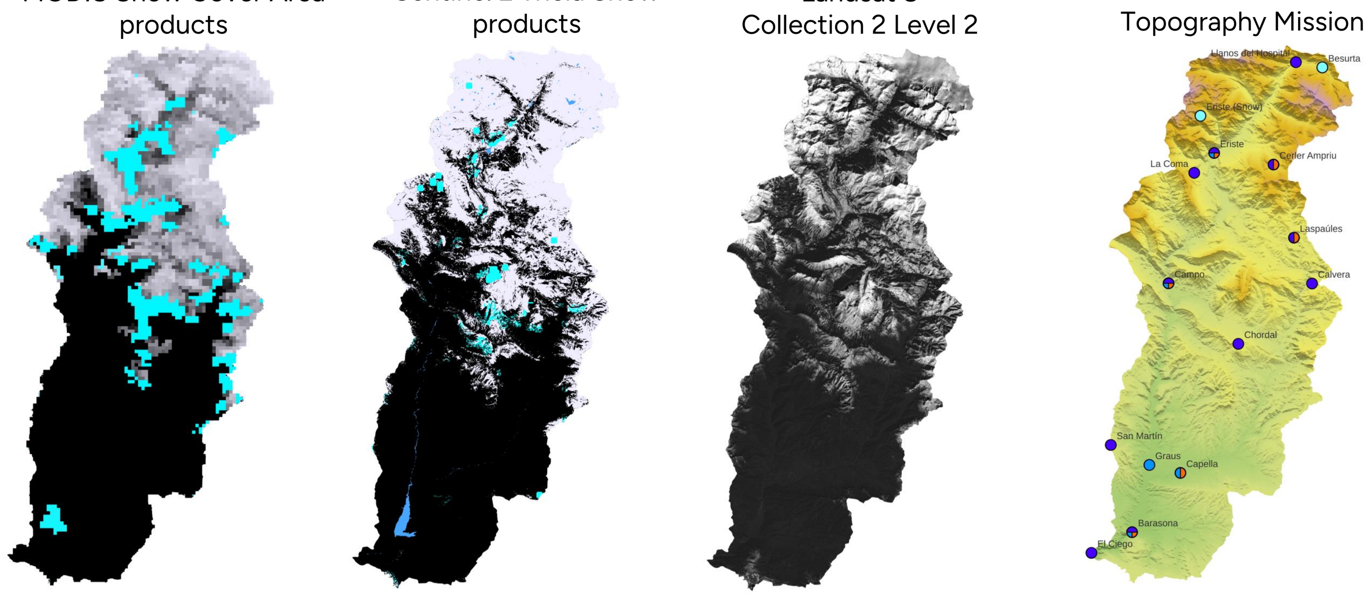
The objective of this project is to **estimate the SWE available** for the Barasona reservoir and the beginning of thaw using remote imaging data combined with in situ information both in the **short and long term**.

2. Data sources

The study period has been set to **14 years** (2009-2023).

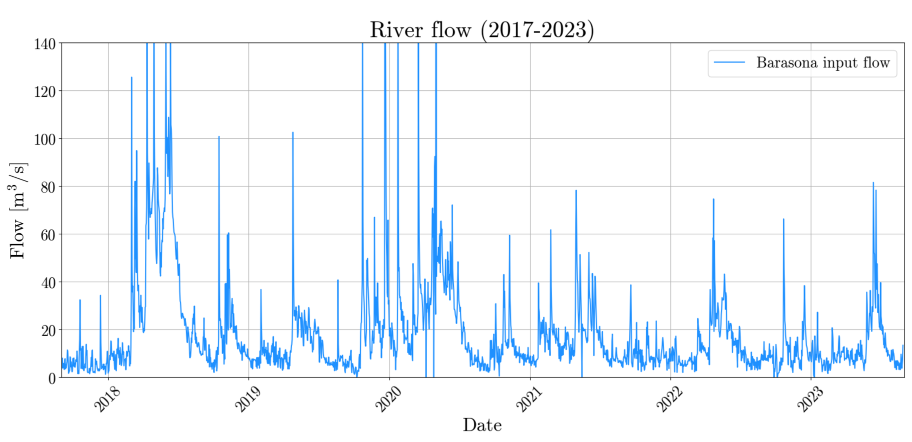
Snow cover data from 3 sources — Digital Elevation Model (DEM)

MODIS Snow Cover Area products — Sentinel 2 Theia Snow products — Landsat 8 Collection 2 Level 2 — Shuttle Radar Topography Mission



In-situ data: 4 variables extracted at 15 locations (indicated in the DEM map).

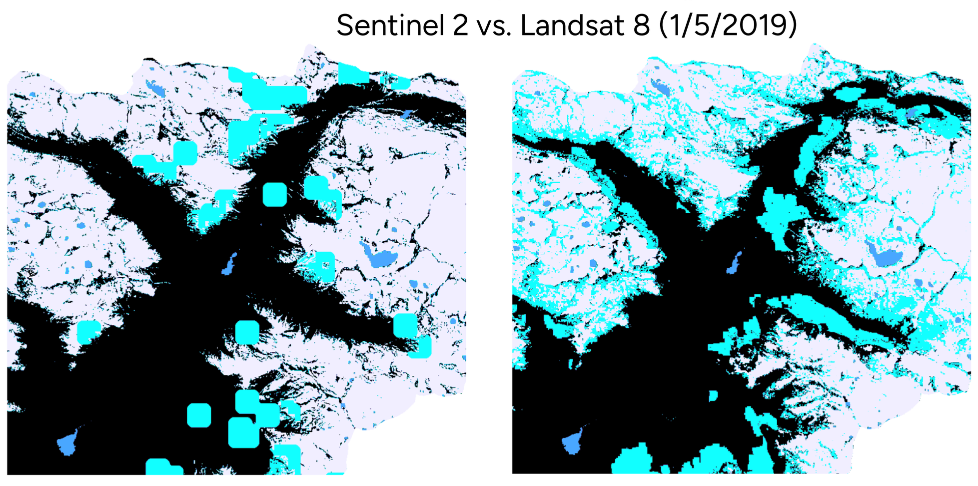
- Rainfall (purple)
- Temperature (orange)
- River flow (blue)
- Snow height (cyan)



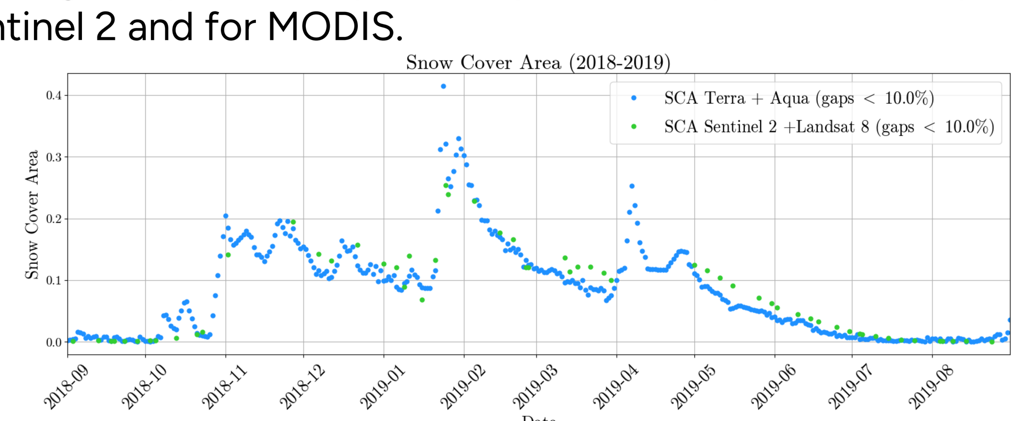
3. Data processing

The snow cover information from Landsat 8 is retrieved using the **Normalized Difference Snow Index**, based on the proceedings of Gascoin et al. (2012)[1].

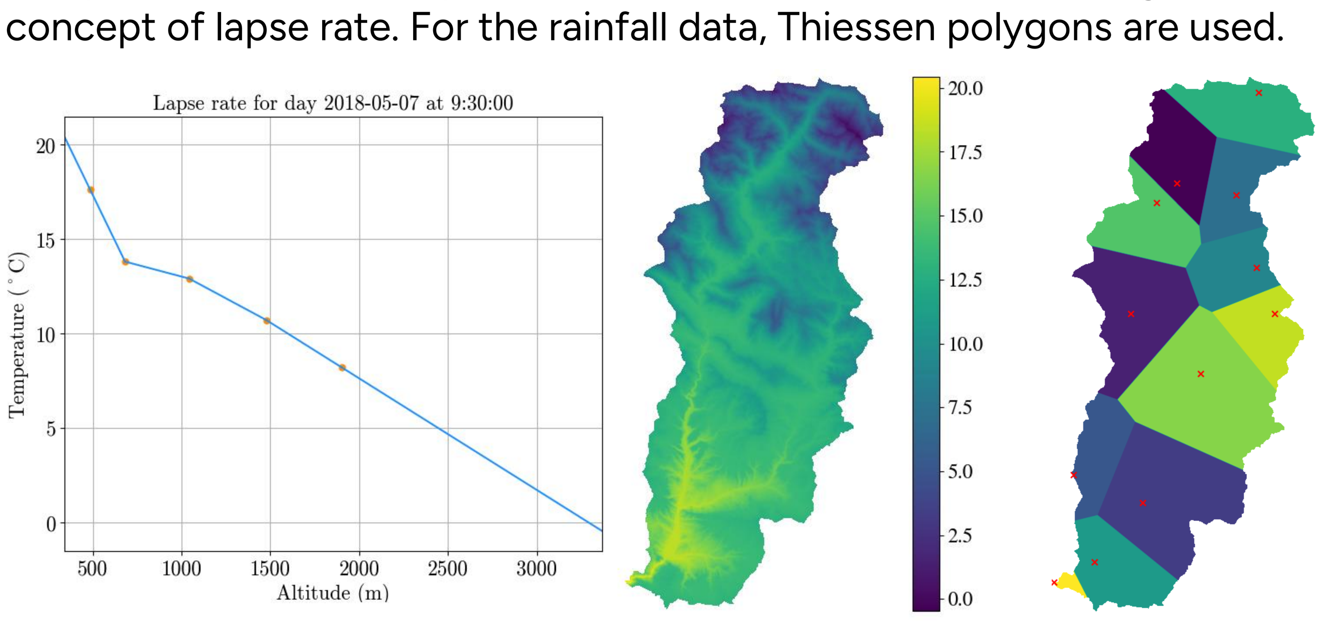
Sentinel 2 vs. Landsat 8 (1/5/2019)



A cloud-filling temporal interpolation process is performed separately for Landsat 8 and Sentinel 2 and for MODIS.



Temperature data is expanded to the rest of the basin using the DEM and the concept of lapse rate. For the rainfall data, Thiessen polygons are used.

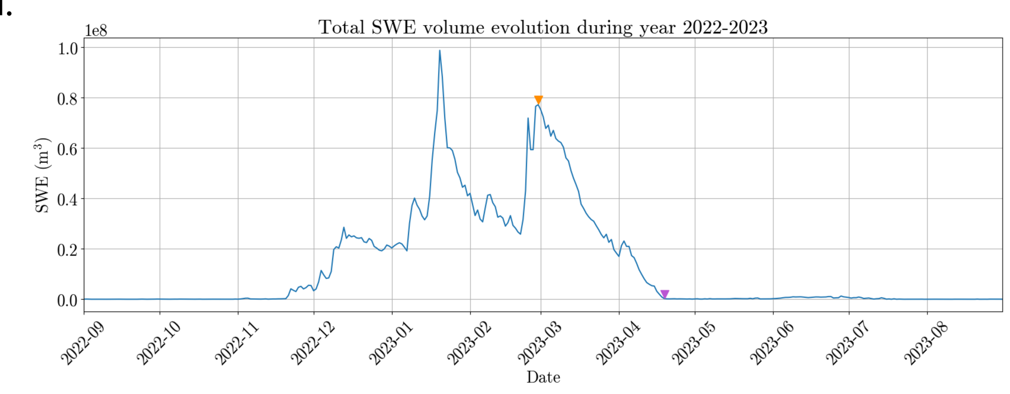


The in-situ data applied to the whole region can be then divided into altitude-defined Hydrological Response Units (HRUs).

4. Methodology & Results

Long term predictions

Combining the DEM, snow cover maps and snow height data, the SWE evolution can be estimated.

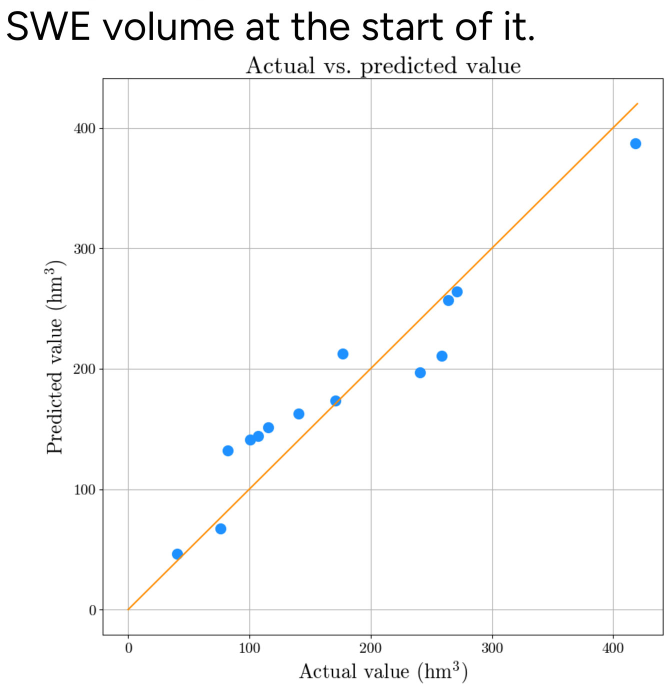


By analyzing the peaks, the average date of the beginning and end of the snowmelt season can be determined, as well as the initial SWE volume at the start of it.

The amount of water arriving at the Barasona reservoir during the snowmelt season can be then computed as the sum of the rainfall during that period and the SWE at its start, factored by two **run-off coefficients**:

$$\Delta V_{Snowmelt} = c_R \cdot V_{Rainfall} + c_S \cdot V_{Snow}$$

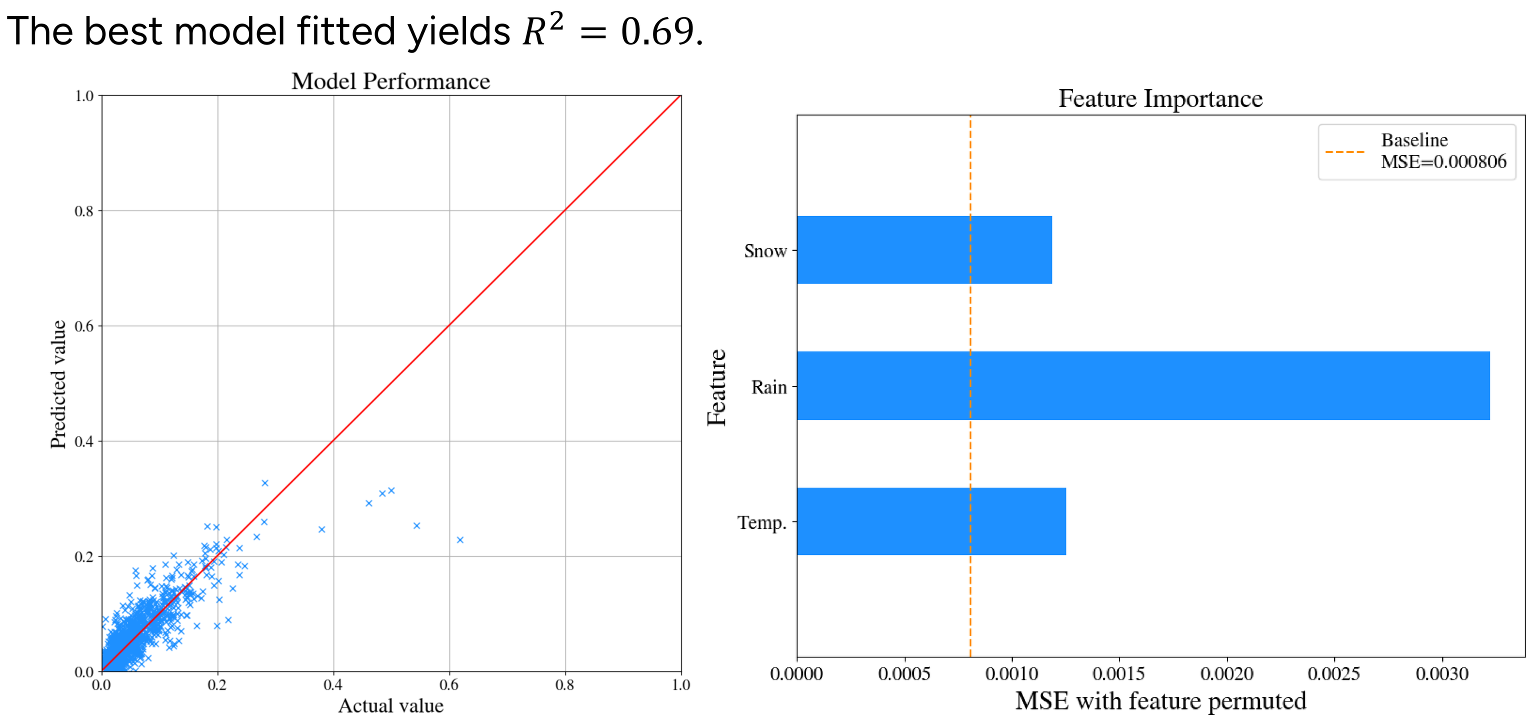
A **least-squares fitting regression** is performed on the yearly data to retrieve the values of these coefficients.



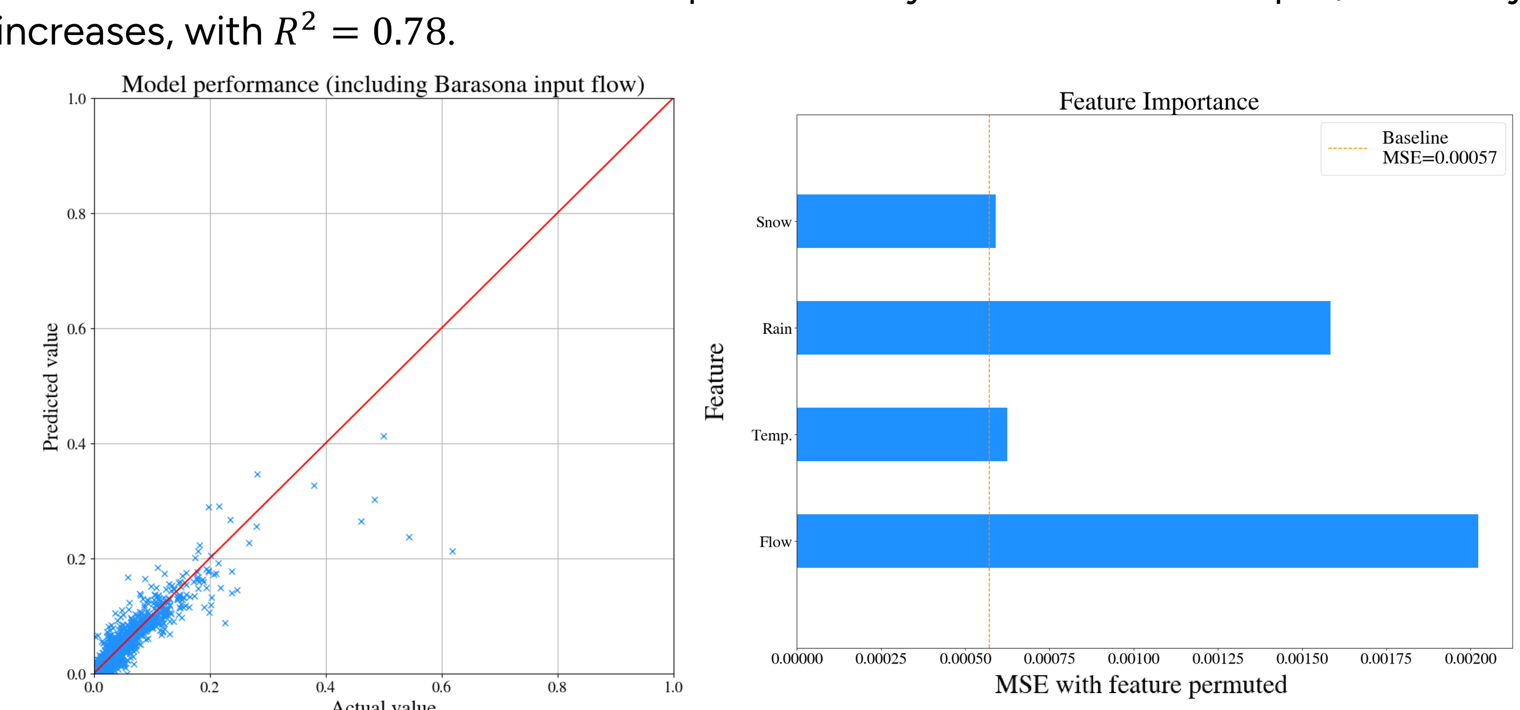
Short term predictions

A **Long Short-Term Memory** (LSTM) Neural Network to predict the daily river flow at the Barasona reservoir is trained with the rainfall, temperature and the SWE derived earlier.

The best model fitted yields $R^2 = 0.69$.



If the Barasona river flow from the previous days is used as an input, accuracy increases, with $R^2 = 0.78$.



Dividing the input data into the defined HRUs does not provide a significative improvement, with $R^2 = 0.69$.

5. Conclusions

The SWE available for the Barasona reservoir has been **successfully estimated** for the past 14 years, utilizing data from 15 different in-situ sensors and from three remote sensing sources.

The average date for the beginning and end of thaw can be estimated as the **23rd of March** and the **26th of May**. There is a large interannual variability in the initial SWE volume, ranging from 48.8 hm³ during years of drought to 228.7 hm³ when snow is most abundant, with an average of **120.3 hm³** and a standard deviation of 58.15 hm3 .

The run-off coefficients for the Barasona reservoir have been estimated as $c_R = 0.31$ and $c_R = 0.32$, with $R^2 = 0.90$, meaning that only around **30%** of the water entering the basin during the snowmelt season eventually reaches the reservoir.

The LSTM Neural Network **accurately predicts** the incoming daily flow for the Barasona reservoir, with $R^2 = 0.69$, that increases to $R^2 = 0.78$ when the flow from the previous days is fed to the model. In this case, the division into HRUs does not provide an increase in accuracy.

[1] Gascoin, S., Grizonnet, M., Bouchet, M., Salgues, G., and Hagolle, O.: *Theia Snow collection: high-resolution operational snow cover maps from Sentinel-2 and Landsat-8 data*, Earth Syst. Sci. Data, 11, 493–514, 2019.