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Seasonal Snow Cover Monitoring and Snowmelt Detection in the Pyrenees Using Sentinel-1/2 and MODIS in Google Earth Engine

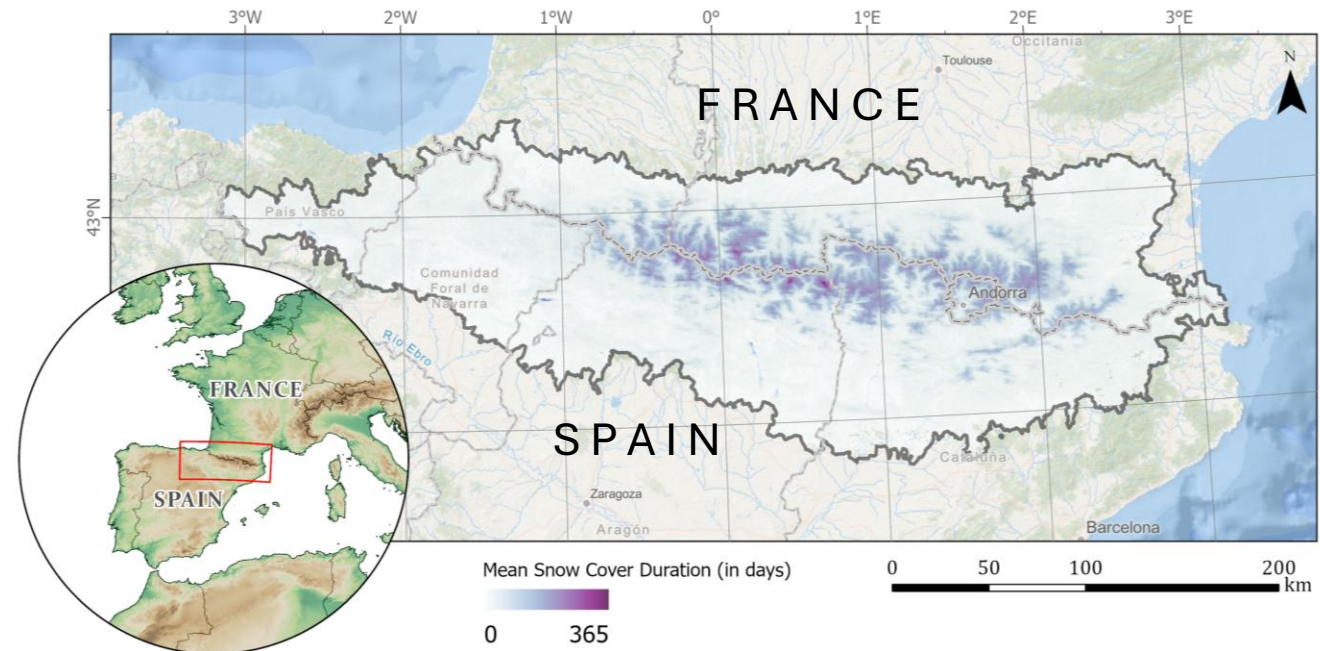
Adrián Melón-Nava and Pablo Ezquerro Martín
Pyrenean Institute of Ecology (IPE-CSIC)

INARCH Workshop 2026
Kananaskis, Alberta (Canada)
September 8-10, 2026



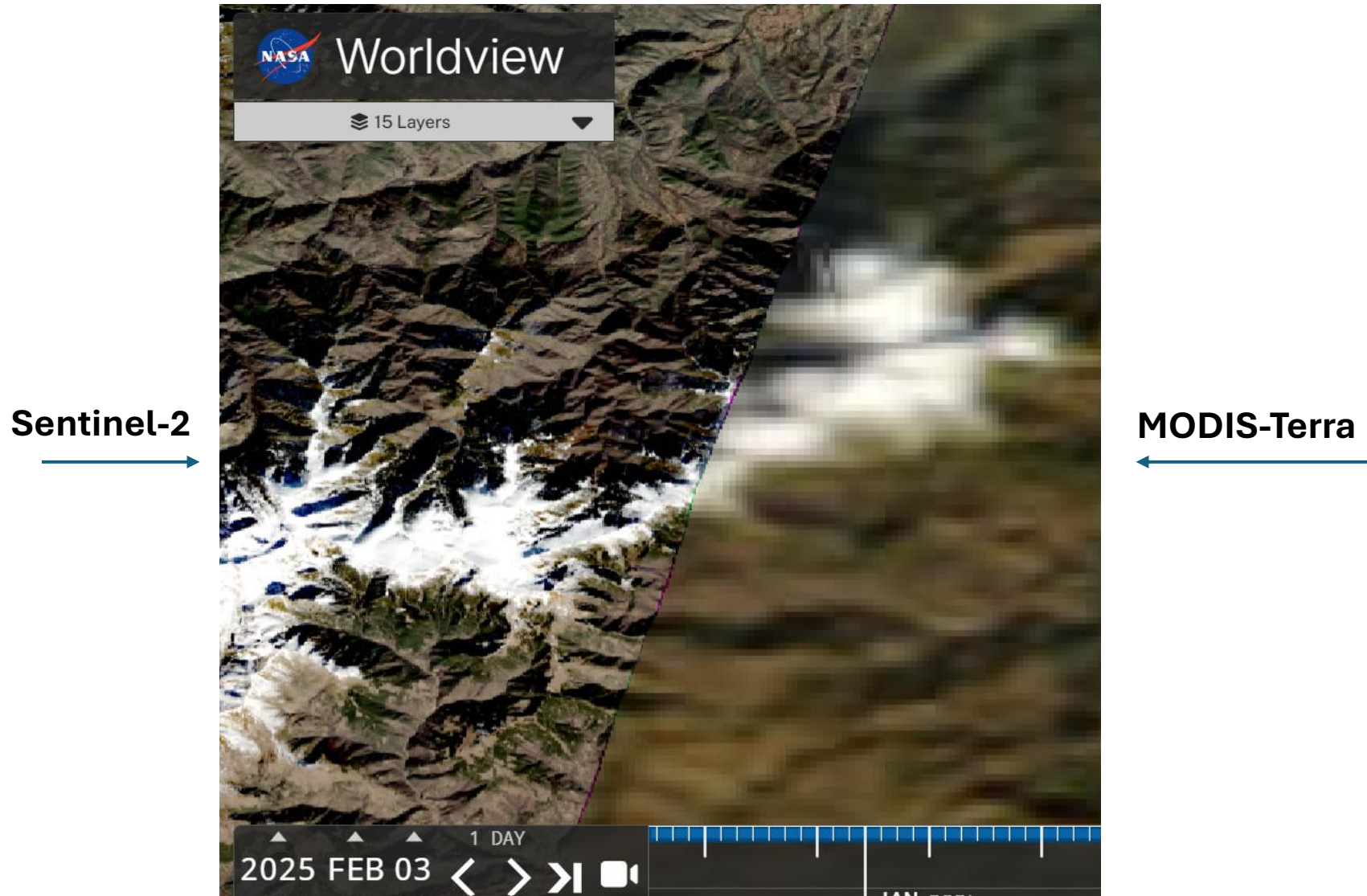
The Challenge of Pyrenean snow monitoring

- **Why Multi-Sensor Integration?**
- **Optical sensors are frequently obstructed.** Cloud cover, terrain shadows, and forest cover limit observations from Sentinel-2, Landsat, and MODIS.
- **Radar also has limitations.** Sentinel-1 can acquire data through clouds, but its performance is constrained by dry-snow conditions and topographic effects.
- **Multi-sensor, cloud-based approaches** can overcome these complementary limitations and improve snow monitoring. Their performance is evaluated in experimental catchments.
- **Pyrenean snowpack** regulates downstream water availability and is highly sensitive to climate warming.



Multi-Sensor Integration

Satellite sensors differ in **spatial**, **temporal**, and **spectral resolution**



Multi-Sensor Integration

Satellite products are **integrated** using Google Earth Engine to overcome individual sensor limitations

Cloud Computing Infrastructure



Massive processing without local downloads via JavaScript/Python APIs.

Sensor Synergy Matrix

	Spatial Resolution	Temporal Frequency	Cloud Penetration
Optical Hierarchy Sentinel-2	High (10m - 20m)	Medium (5 Days)	None
Optical Hierarchy Landsat 5-8	Medium (30m)	Low (8-16 Days)	None
Optical Hierarchy MODIS / VIIRS	Low (250m - 500m)	High (Daily)	None
Radar Integration Sentinel-1 (SAR)	High (10m - 40m)	Medium (6 Days)	Complete (100%) - Detects structural snowpack changes

Google Earth Engine for Large-Scale Satellite Image Processing

Google Earth Engine is a cloud-based computing platform for analyzing geospatial data. It provides access to collections of satellite imagery and geographic datasets

Key features

Large-scale data processing without the need to download data.
JavaScript and Python APIs, as well as the rgee package for R.
A library of algorithms for spatial analysis and remote sensing.

Platform access

<https://code.earthengine.google.com/>

Dataset catalog

<https://developers.google.com/earth-engine/datasets>

The Earth Engine Public Data Catalog



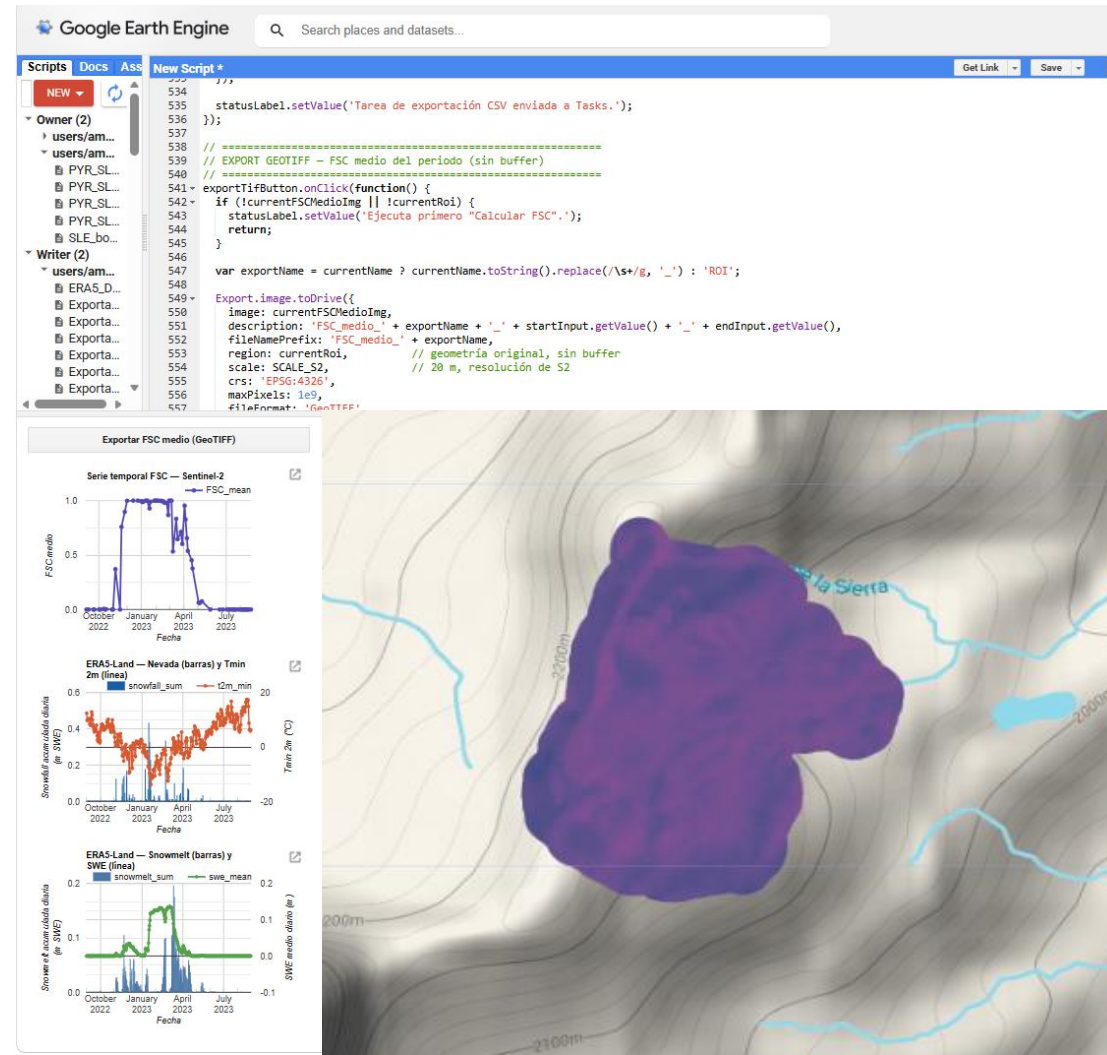
> 200 public datasets

> 5 million images

> 4000 new images every day

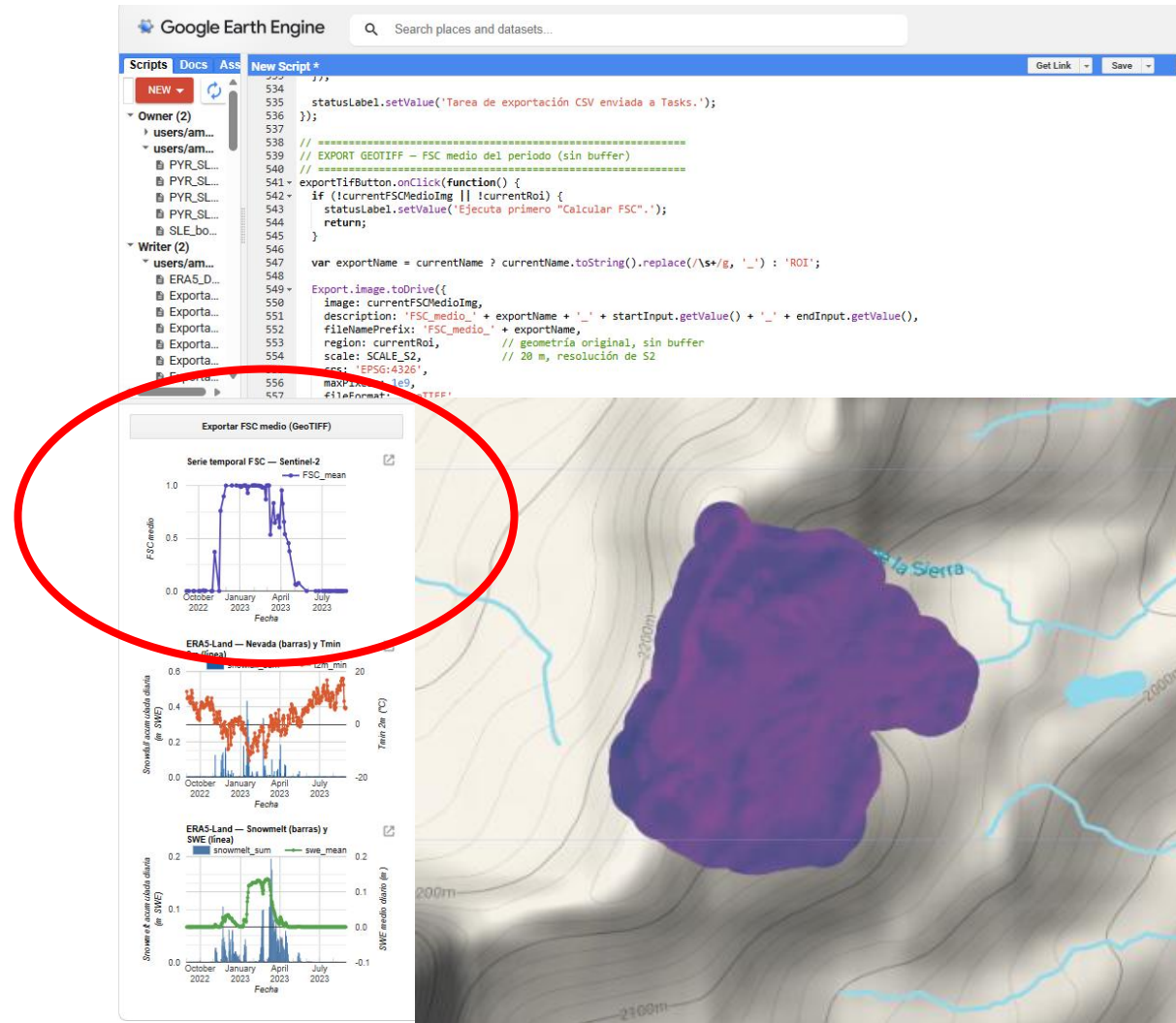
> 5 petabytes of data

Google Earth Engine for Large-Scale Satellite Image Processing



Experimental catchment scale: Extraction of snow-cover frequency in Izas catchment

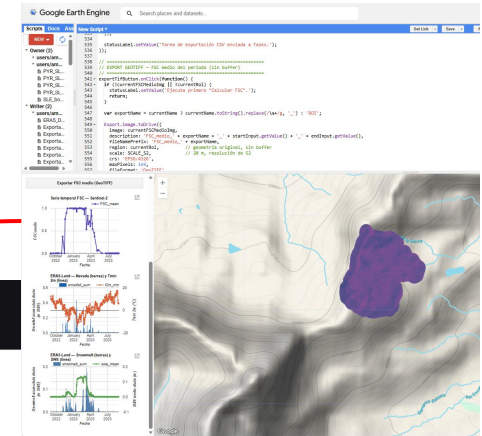
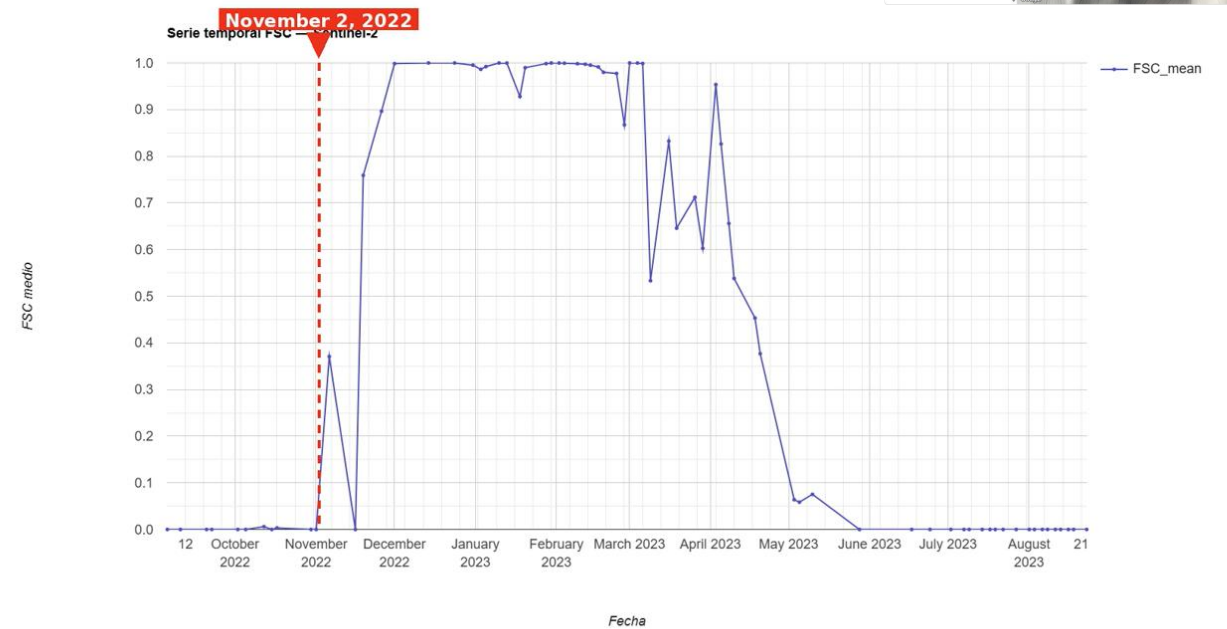
Google Earth Engine for Large-Scale Satellite Image Processing



Experimental catchment scale: Extraction of snow-cover frequency in Izas catchment

Google Earth Engine for Large-Scale Satellite Image Processing

IZAS — snow cover evolution — November 2, 2022



Snow cover satellite observations can be compared with in situ time-lapse cameras

Potential integration of S1-S2 for snow melt detection in wet snow areas



Sentinel-2 (optical)

Detects snow extent
(from visible light).



Blocked by
clouds

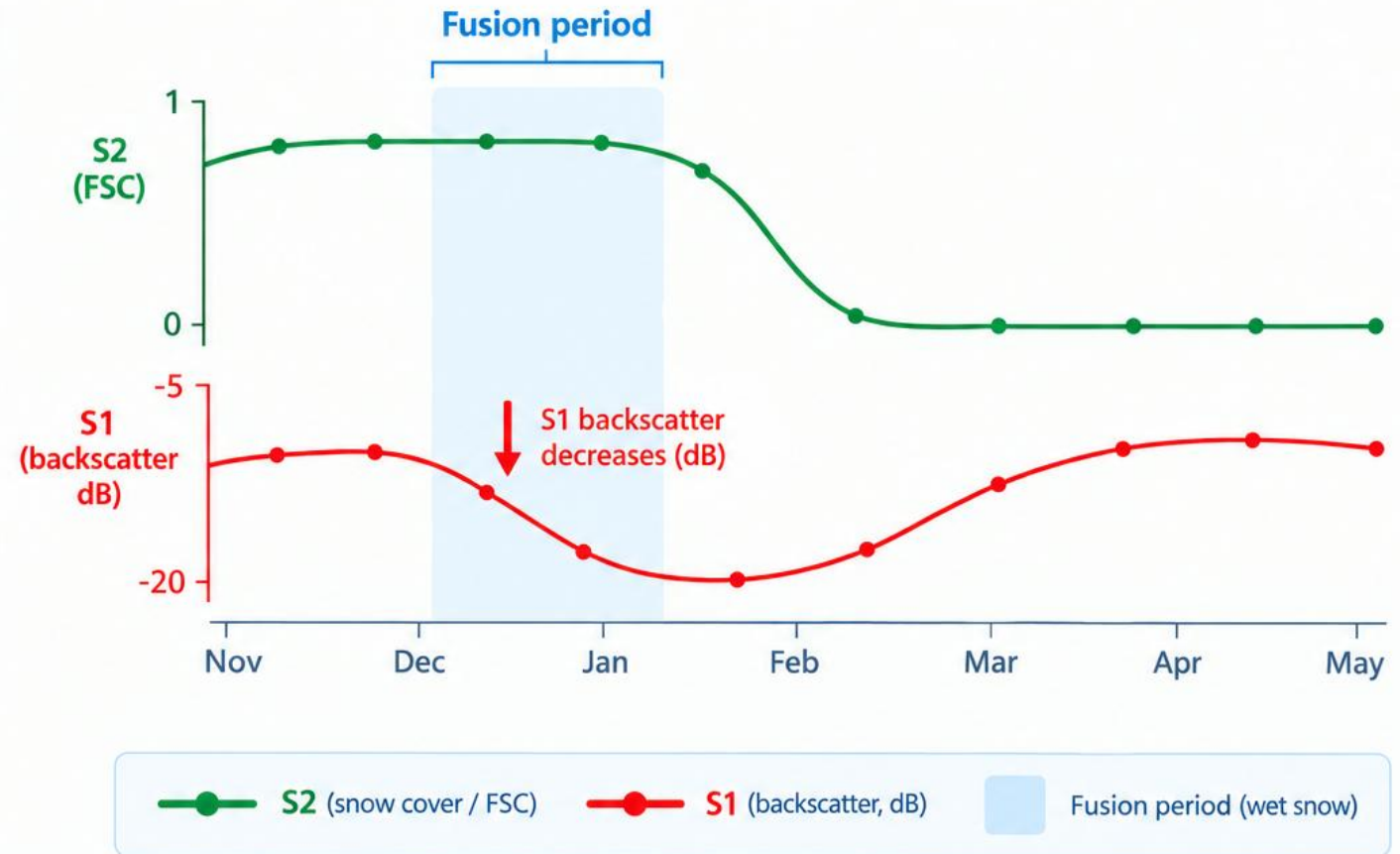


Sentinel-1 (SAR)

Detects snow physical state
(even under clouds).



Sees changes
in backscatter
(↓ dB during melt)



S2 shows snow extent (but misses the fusion period).

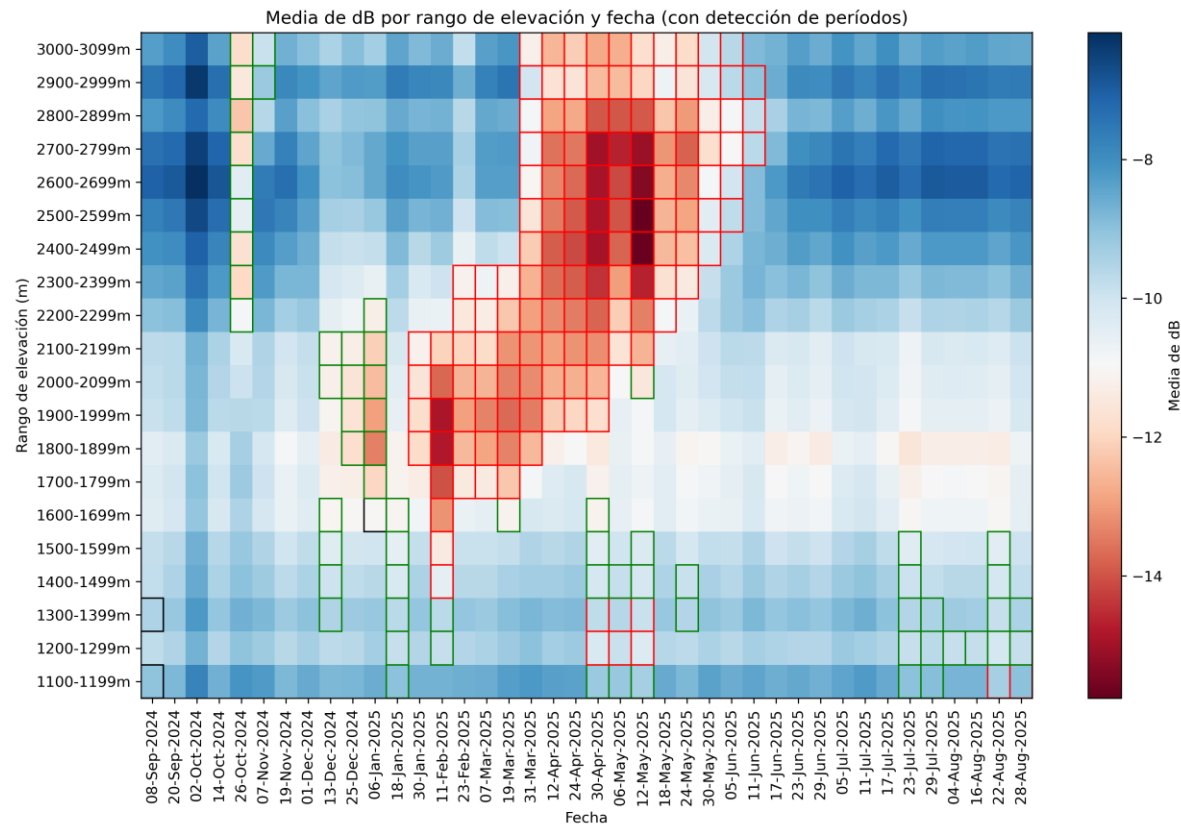
S1 detects the physical change in snow (lower backscatter in dB).

Potential integration of S1-S2 for snow melt detection in wet snow areas

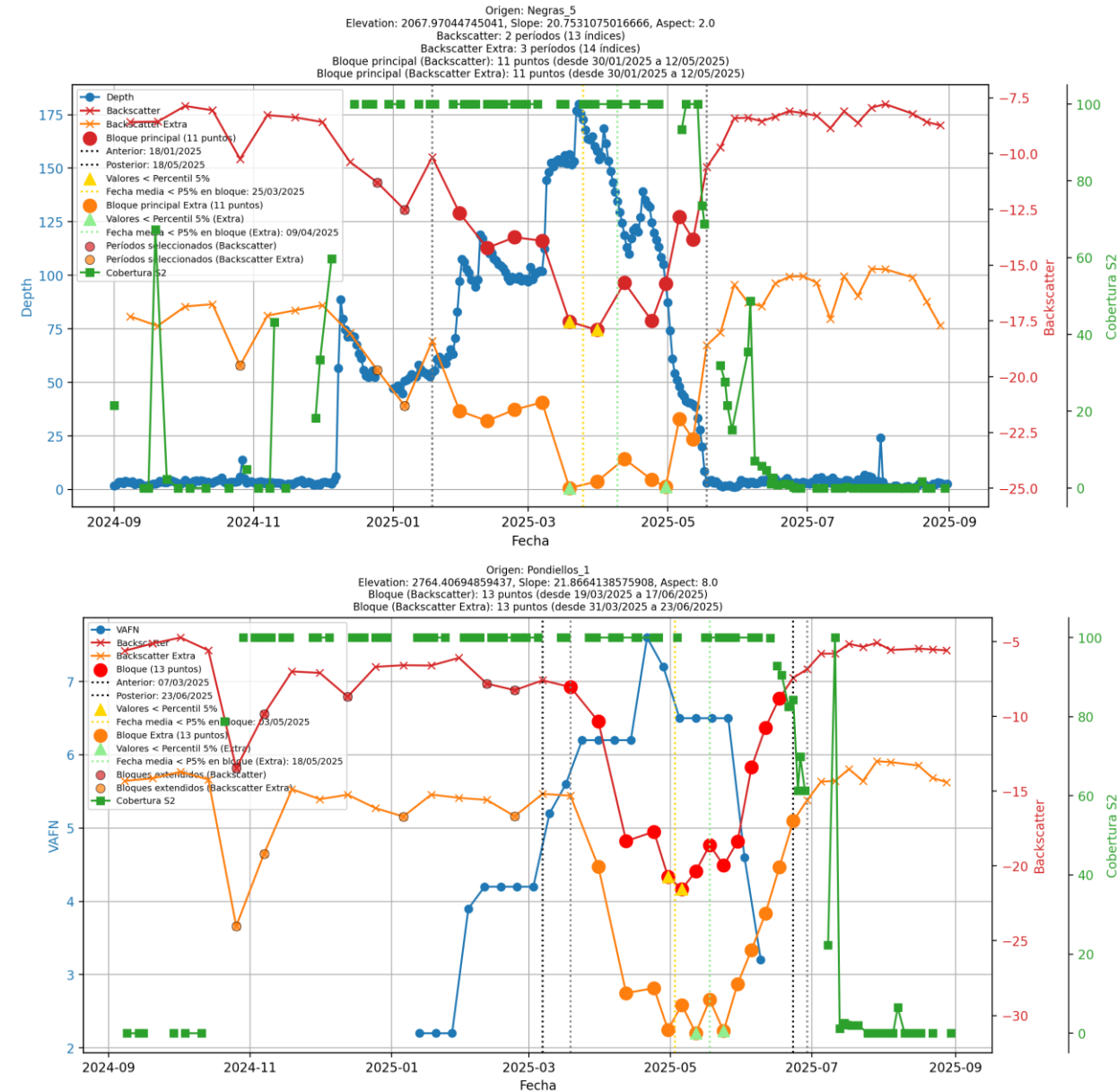
Melting period and early melting periods detection

Runoff start detection

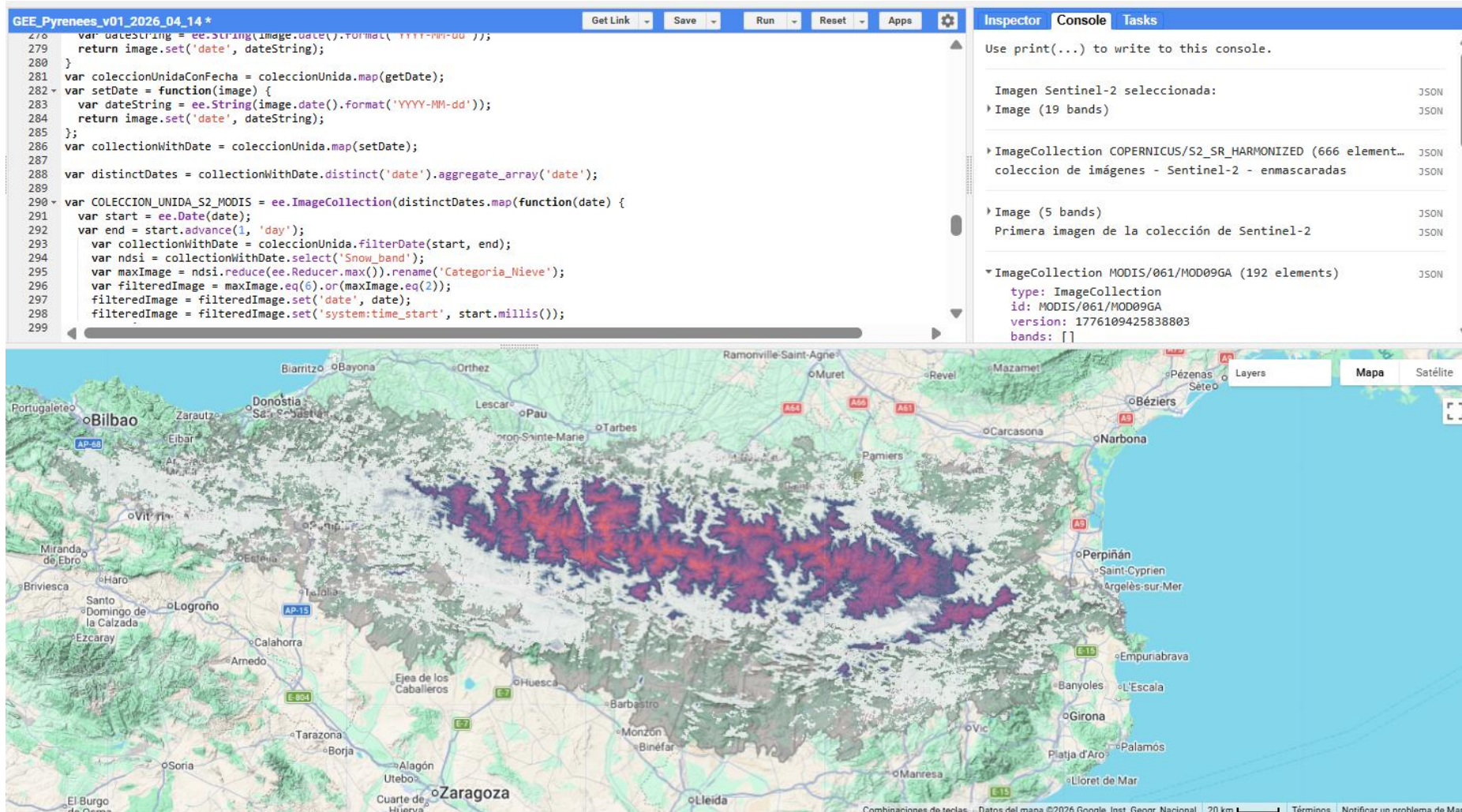
Comparison with SD measurements and LWE from model



Spatiotemporal heatmap of mean S-1 backscatter (dB), binned into 100-m elevation intervals. Season 24/25

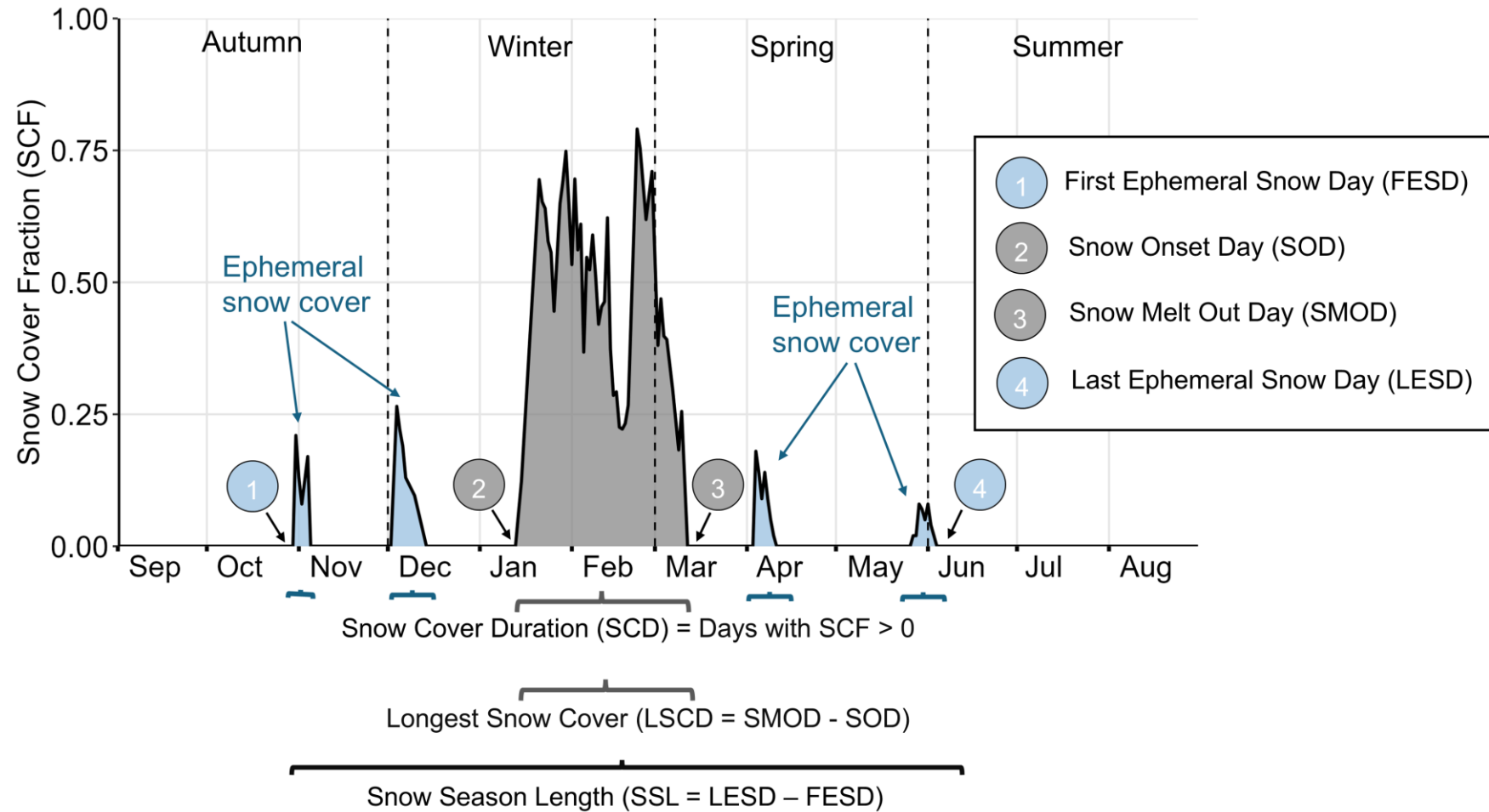


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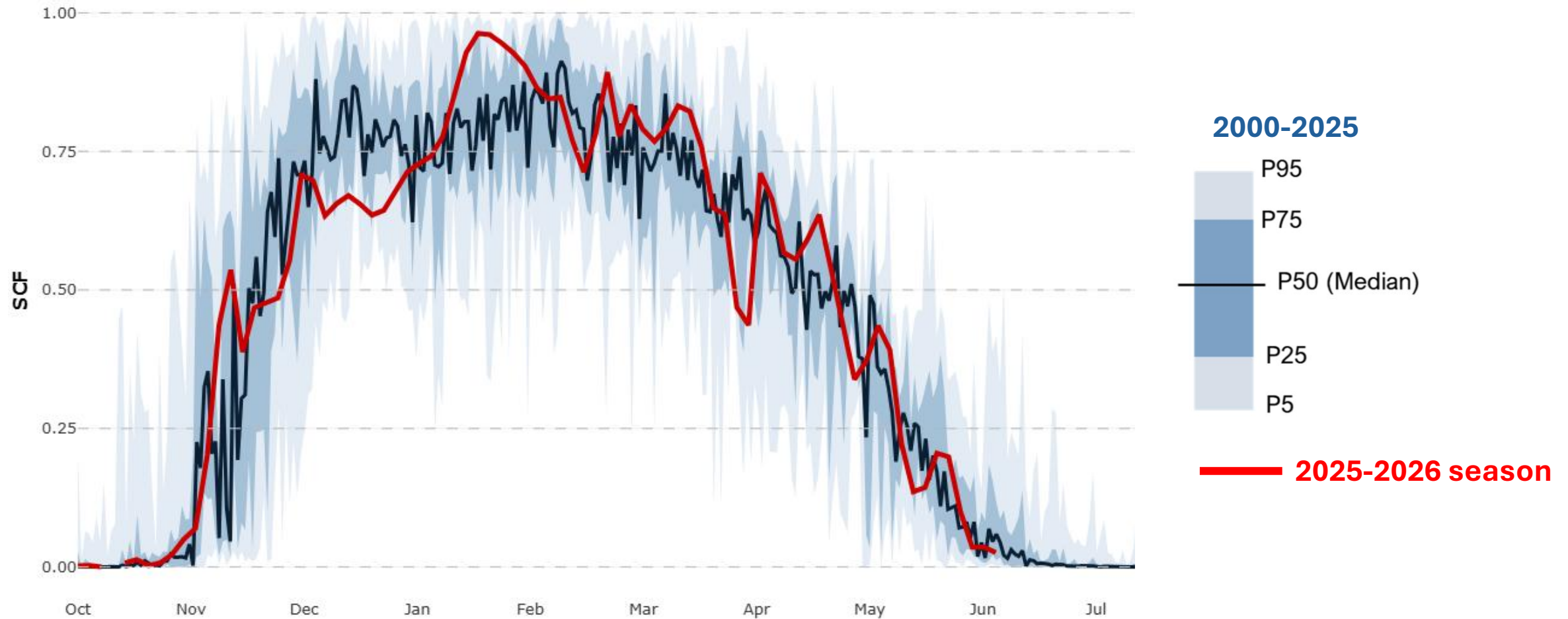
Regional scale: Extraction of snow-cover frequency across the Pyrenees.

Google Earth Engine for Large-Scale Satellite Image Processing



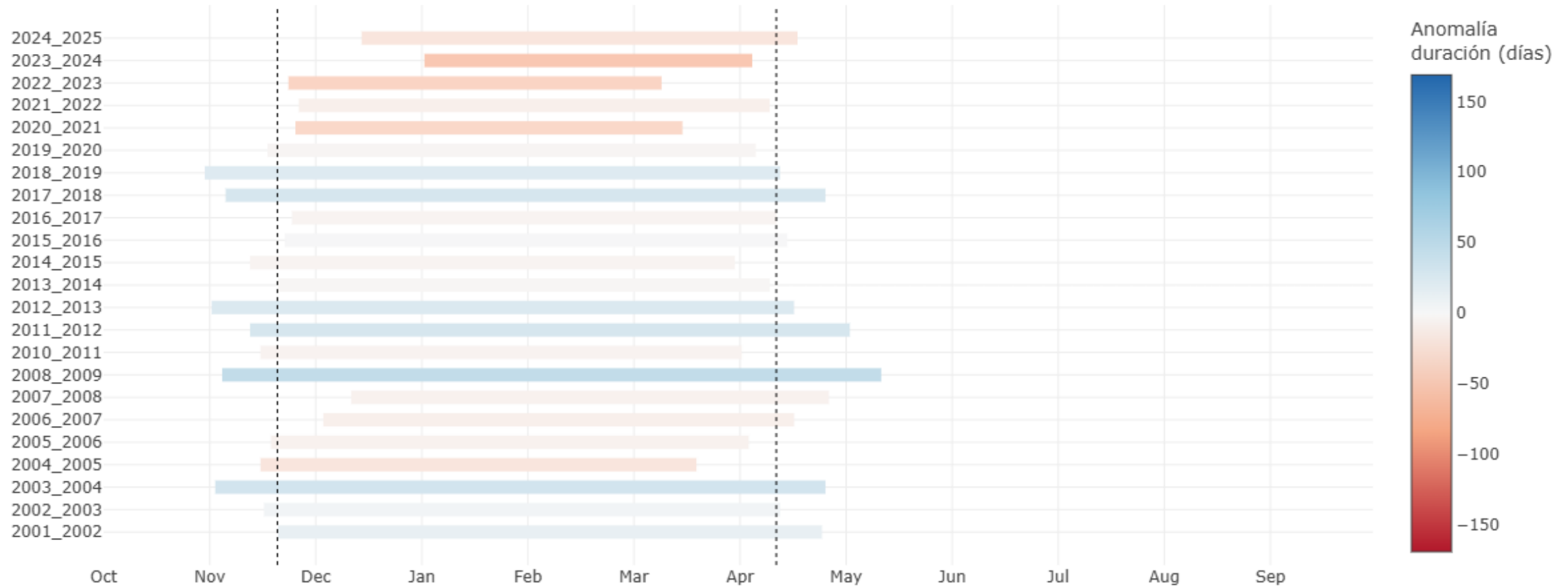
What percentage of my study area is covered by snow each day? In a theoretical season...

Google Earth Engine for Large-Scale Satellite Image Processing



Regional scale: Snow Cover Fraction climatology in **Andorra** (2000-2025).
Black line: median. Red line indicates 2025-2026 season.

Google Earth Engine for Large-Scale Satellite Image Processing



Regional scale: Identification of Snow Onset Day (SOD) and Snow Melt-Out Day (SMOD)

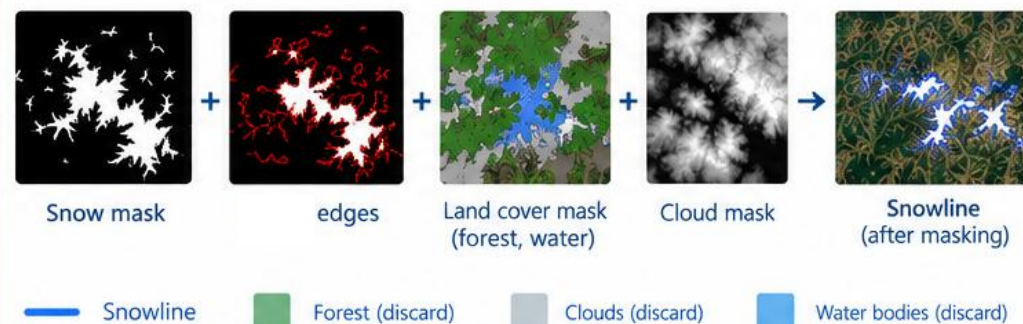


Snowline Elevation (SLE) detection in the Pyrenees

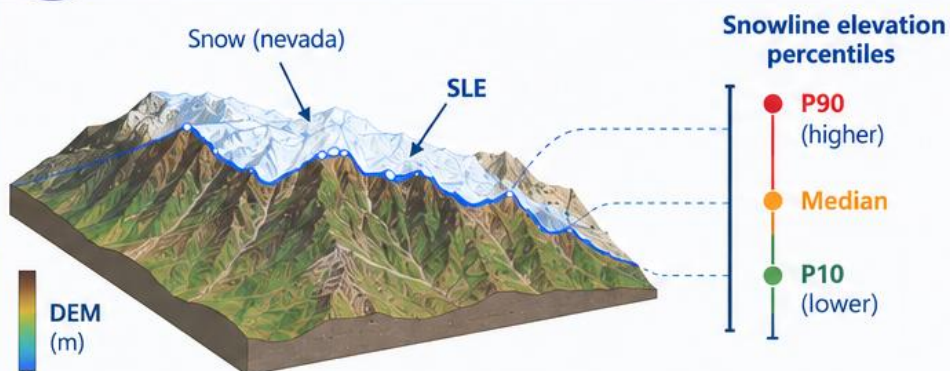
1 Snow cover mapping



2 Snowline extraction

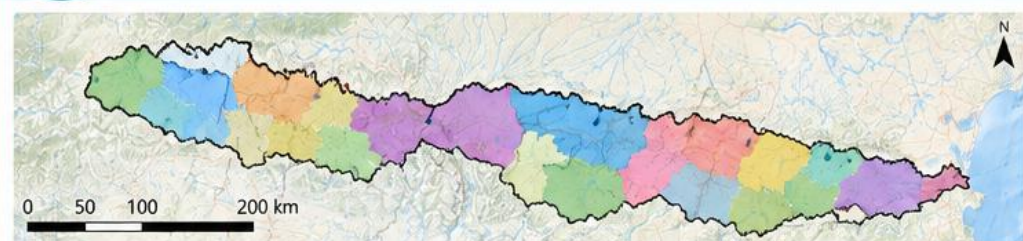


3 Elevation assignment

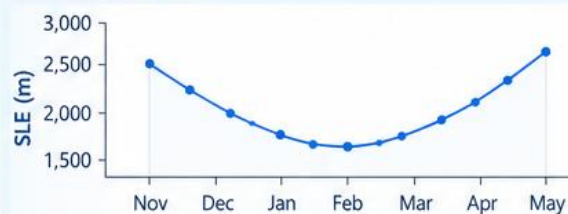


- Close percentiles → uniform snowlines
- Widely separated percentiles → strong topographic/orientation effects

4 Temporal and spatial aggregation



SLE annual cycle



Time series analysis & anomaly detection

- Detect anomalies and long-term changes



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THANK YOU!

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- <https://ee-amelon00.projects.earthengine.app/view/inarch---dem>