

Évolution récente des glaciers dans les Pyrénées

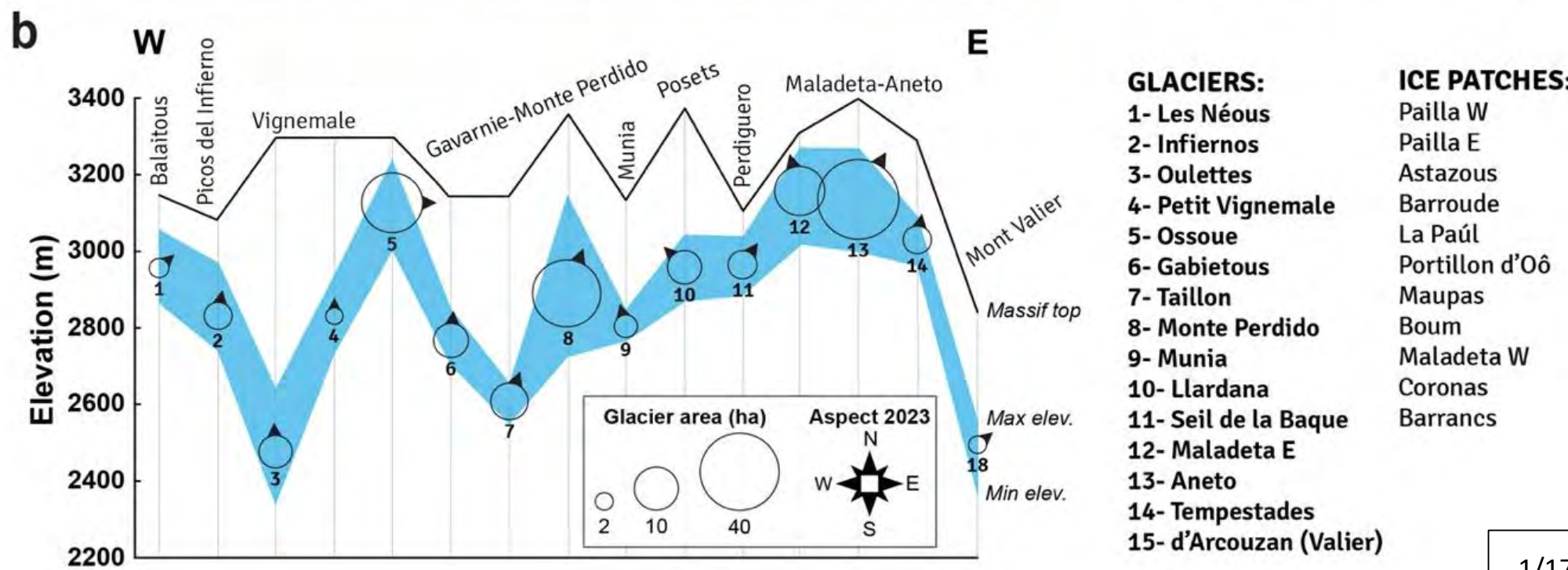
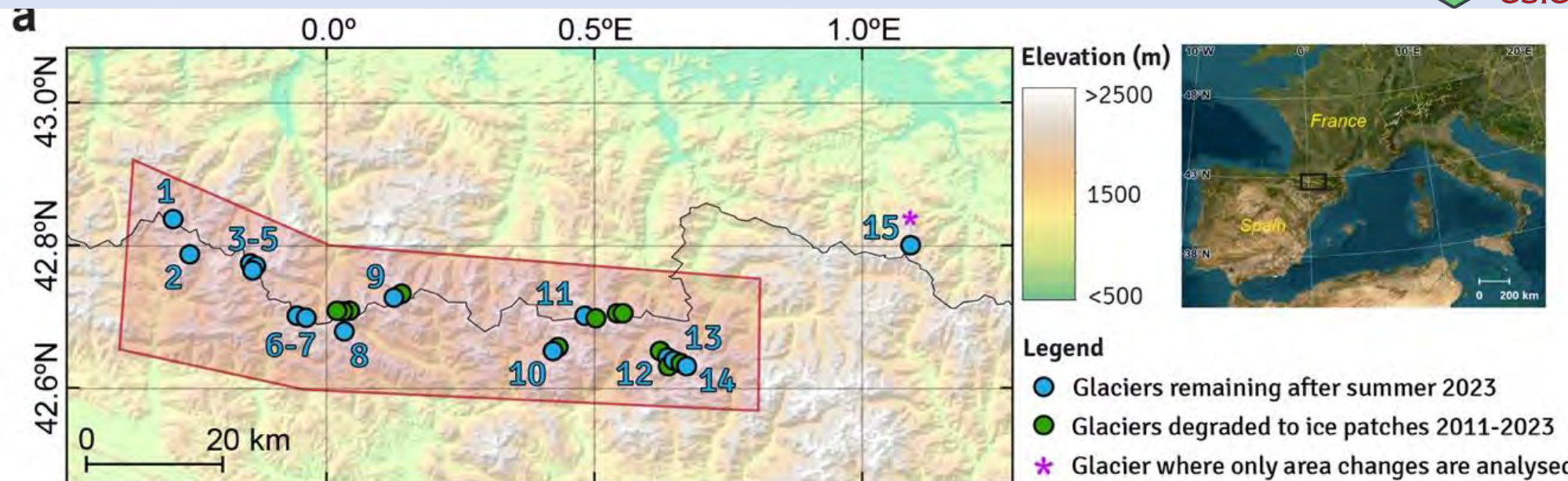


Jesús Revuelto
IPE-CSIC



Eñaut Izagirre
Francisco Rojas-Heredia
Ixeia Vidaller
Esteban Alonso-González
Cesar Deschamps-Berger
Pablo Domínguez
Javier Bandrés
Ibai Rico
Nacho López-Moreno

Where are located
Pyrenean glaciers?



Evolution since Little Ice Age:

ISSN-L: 0373-2568
doi: <http://dx.doi.org/10.3989/Pirineos.2017.172004>

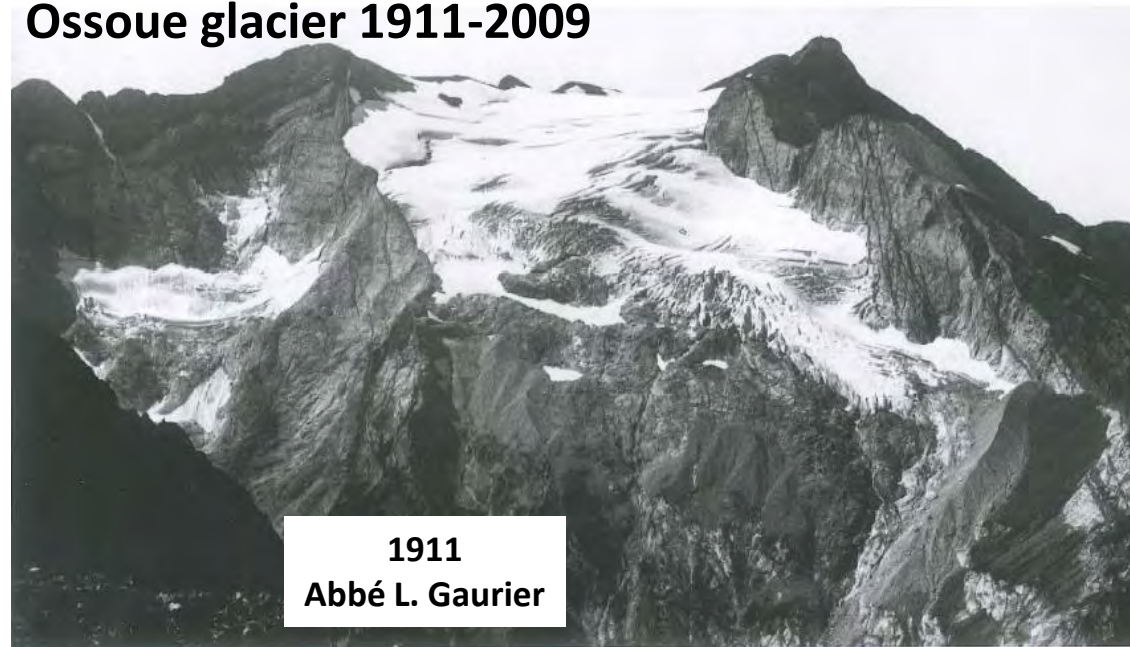
CURRENT GLACIER AREA IN THE PYRENEES: AN UPDATED ASSESSMENT 2016

*Superficie glaciar actual en los Pirineos:
Una actualización para 2016*

Ibai Rico^{1,2*}, Eñaut Izaguirre^{3*}, Enrique Serrano⁴, Juan Ignacio López-Moreno²

1850: 52 glaciers, 2060 ha
1984: 39 glaciers, 810 ha
2011: 24 glaciers, 293 ha
2020: 21 glaciers, 236 ha
2023: 15 glaciers, 143 ha

Ossoue glacier 1911-2009



1911
Abbé L. Gaurier

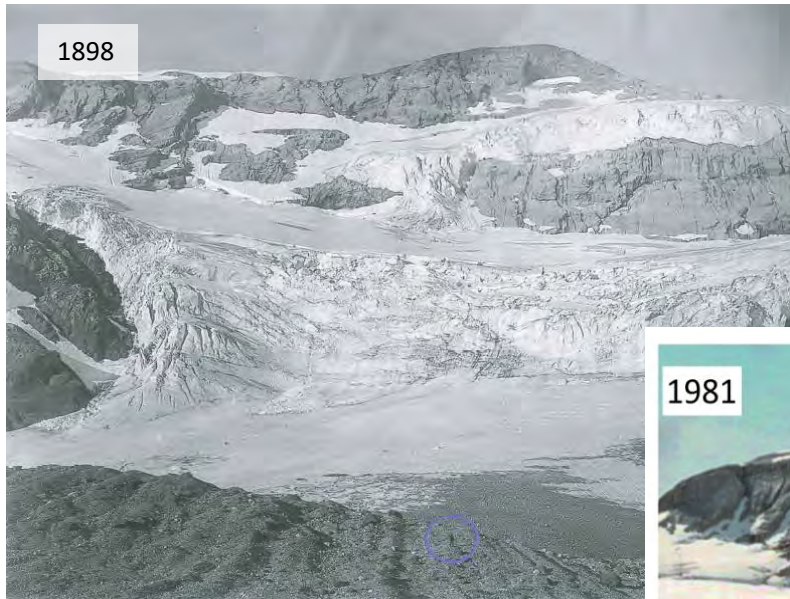


2009
Gabriel Nogué



Pierre René

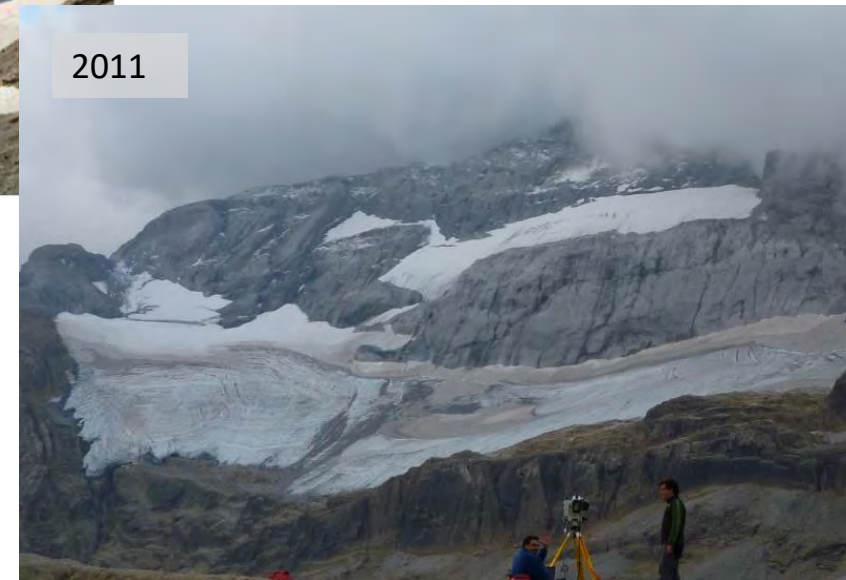
Monte Perdido glacier



1898

Lucien Briet

1981

J.M. García-Ruiz

2011

J. I. López Moreno

Monte Perdido glacier

2011



In **2011** IPE-CSIC began annual monitoring of the evolution of the Monte Perdido glacier. (J.I. López-Moreno and J. Revuelto)

- To understand its current evolution
- To determine its thickness
- To advance the future evolution

2011

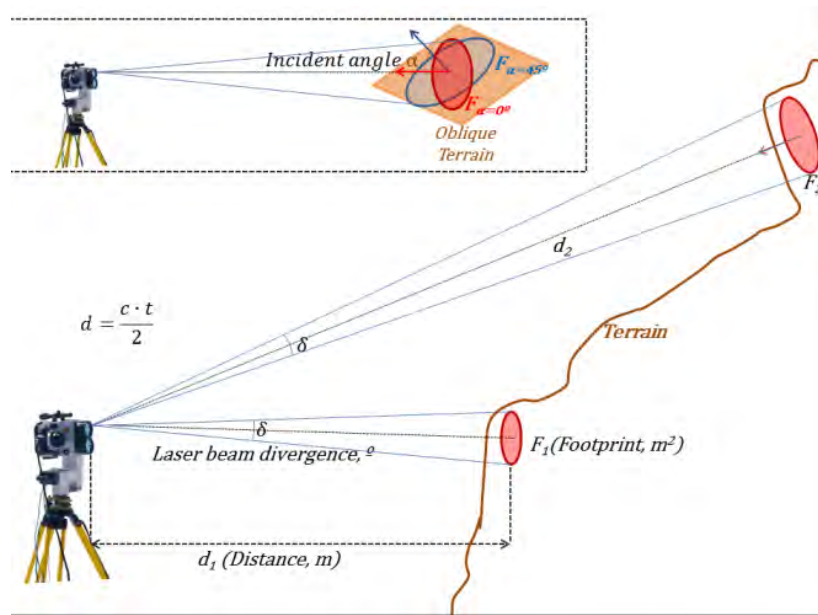


Monte Perdido glacier

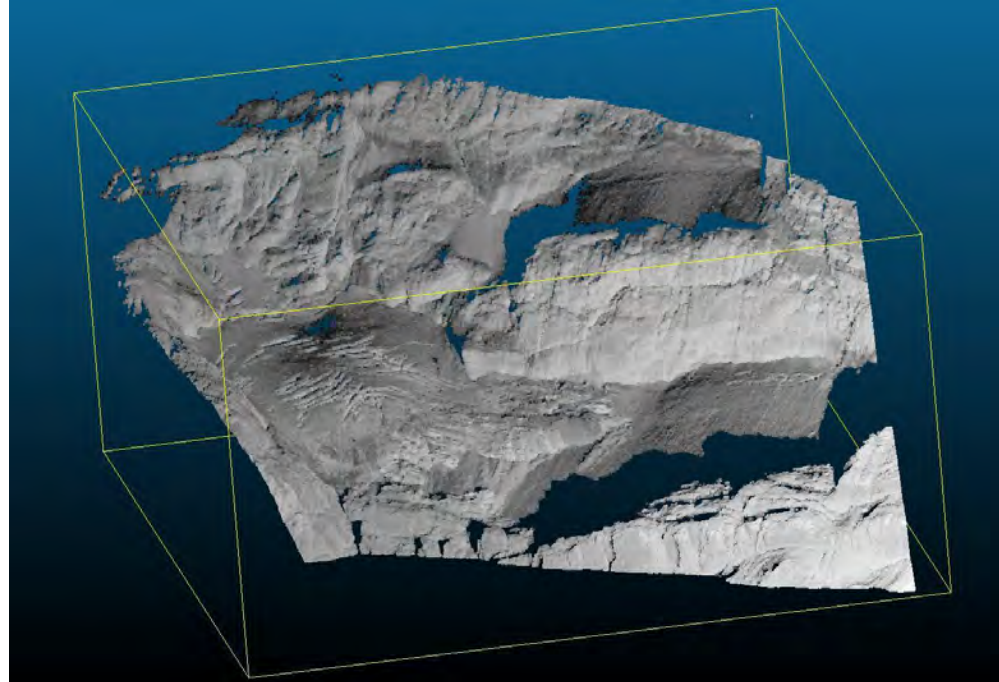
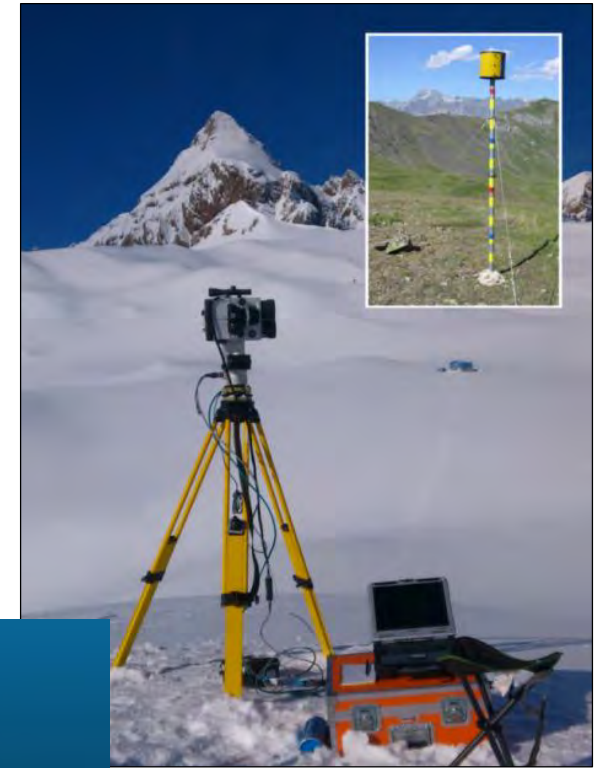
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Surface evolution (area and thickness difference)



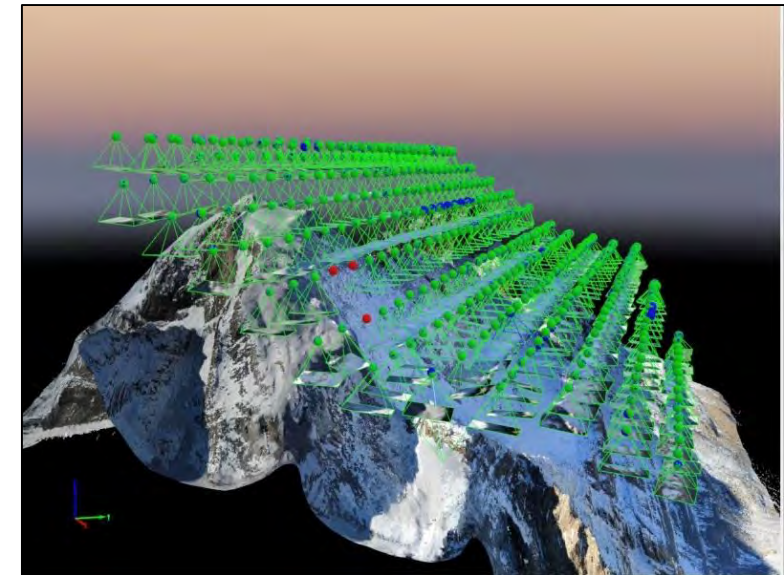
2011-2020
Terrestrial Laser Scanner (TLS)
LiDAR technology



Surface evolution (area and thickness difference)

Since 2020 UAV (SfM and LiDAR)

- More flexibility
- Improved (faster and less terrain shadows)



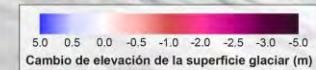
Ossoue (2023-2024)

Cambio de espesor medio = -2.6 m
Pérdida máxima = -4.6 m
Ganancia máxima = +2.9 m

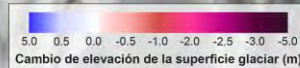
Vignemale
3298 m

**2023-2024
Mean difference**

- Aneto: -0,47 m
- Infiernos +0,5 m
- Llardana +0,1 m
- Ossoue -2,6 m

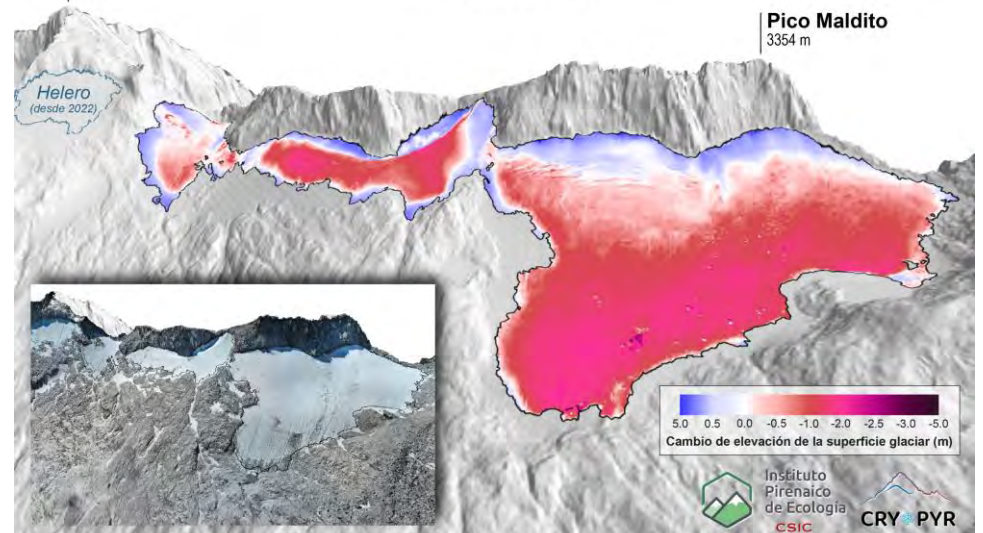
**Infiernos (2023-2024)**

Cambio de espesor medio = +0.9 m
Pérdida máxima = -2.8 m
Ganancia máxima = +5.5 m

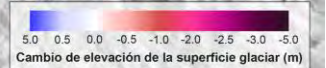
**Aneto (2023-2024)**

Cambio de espesor medio = -0.47 m
Pérdida máxima = -3.9 m
Ganancia máxima = +4.2 m

Aneto
3404 m

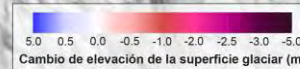
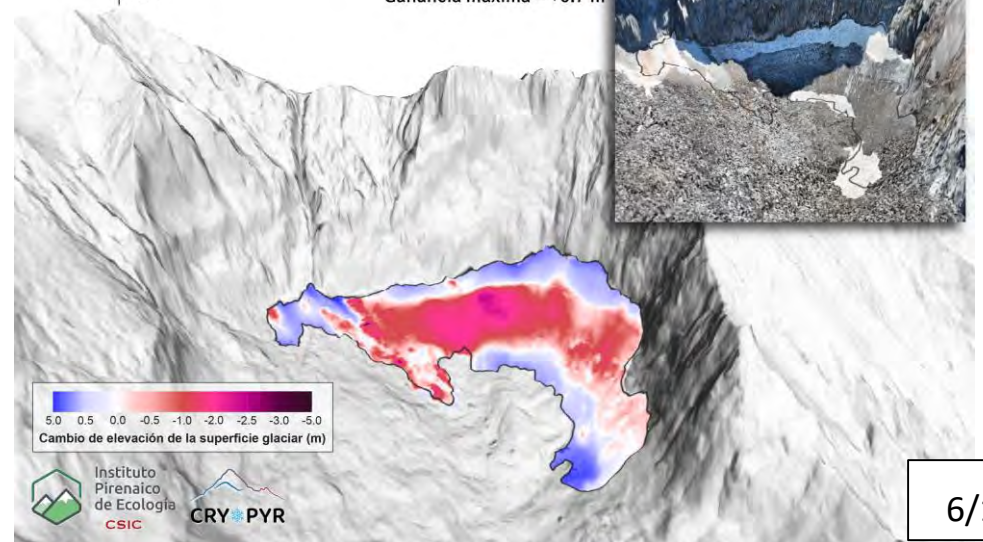


Pico Maldito
3354 m

**Llardana (2023-2024)**

Cambio de espesor medio = +0.1 m
Pérdida máxima = -3.8 m
Ganancia máxima = +6.7 m

Posets
3369 m



Monte Perdido Glacier 2011-2025:

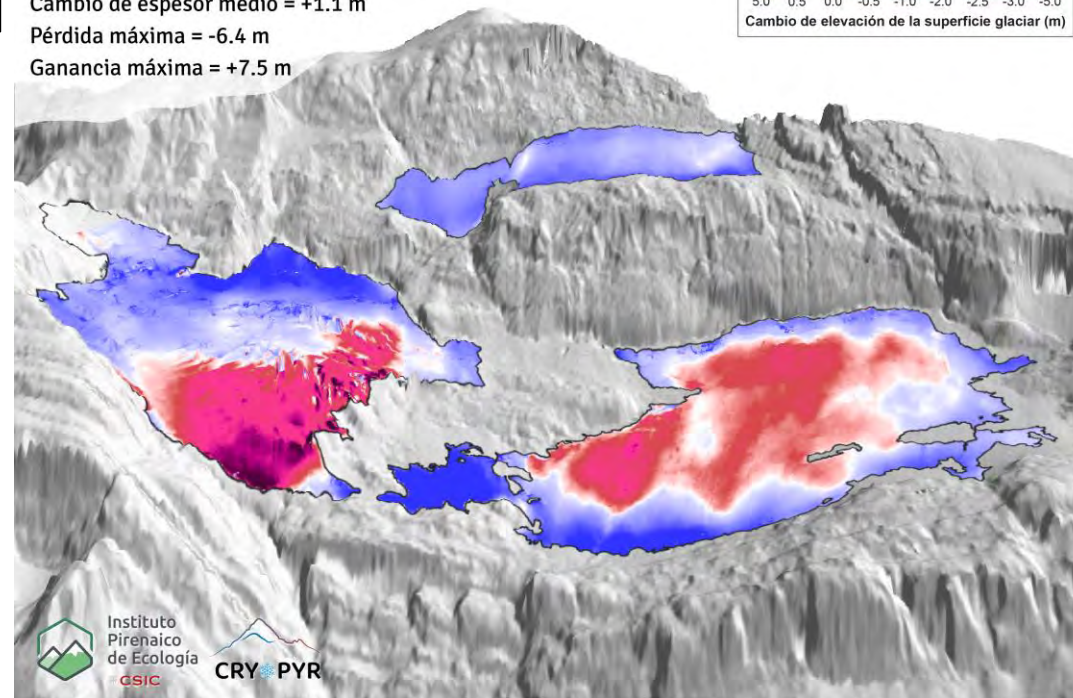
Year	Area (ha)
2011	38,9
2020	34,3
2023	26,5

Glaciar de Monte Perdido (2023-2024)

Cambio de espesor medio = +1.1 m

Pérdida máxima = -6.4 m

Ganancia máxima = +7.5 m

**Annual mean difference**

- 2011-12: -1.8 m
- 2012-13: 0.35 m
- 2013-14: -0.07 m
- 2014-15: -1.7 m
- 2015-16: -0.36 m
- 2016-17: -2.3 m
- 2017-18: 0.87 m
- 2018-19: -1.56 m
- 2019-20: +0.29 m
- 2020-21: -0.86 m
- 2021-22: -3.95 m
- 2022-23: -3.8 m
- 2023-24: 1.1 m (- 0.9 m)
- 2024-25: -1,27 m

2011



2023



Monte Perdido Glacier 2011-2025:

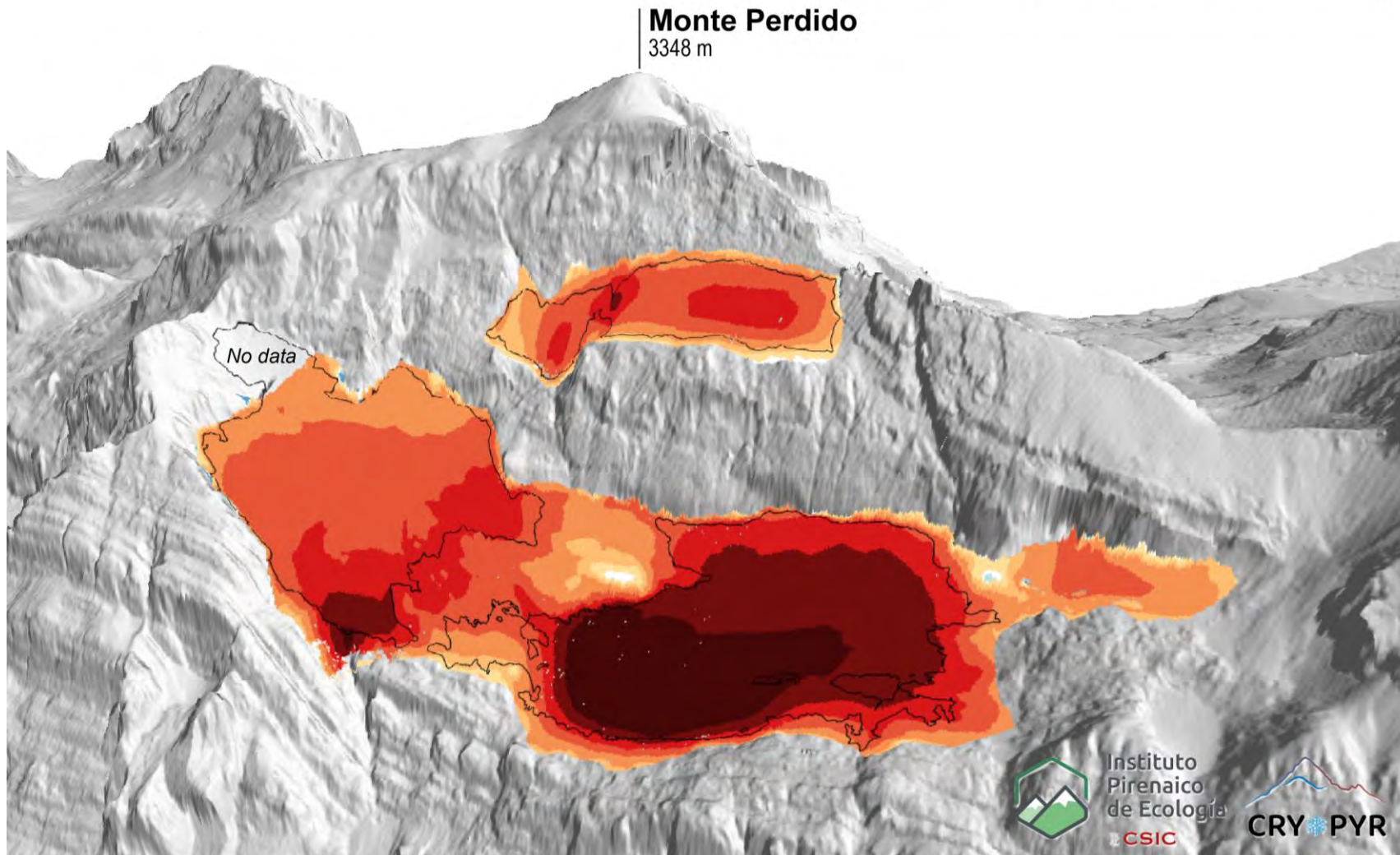
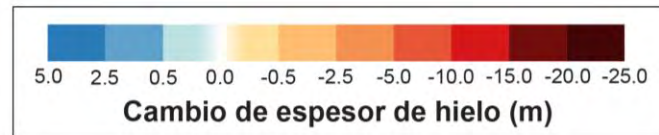
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Monte Perdido Glacier 2011-2025: Mean thickness reduction > 18 m**Annual mean difference**

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RESEARCH LETTER

10.1029/2021GL094339

Toward an Ice-Free Mountain Range: Demise of Pyrenean Glaciers During 2011–2020

I. Vidaller and J. Revuelto are both co-first authors.

I. Vidaller¹, J. Revuelto¹, E. Izagirre^{2,3}, F. Rojas-Heredia¹, E. Alonso-González¹, S. Gascoin⁴, P. René⁵, E. Berthier⁶, I. Rico⁷, A. Moreno¹, E. Serrano⁸, A. Serreta⁹, and J. I. López-Moreno¹

Key Points:

2011–2020:

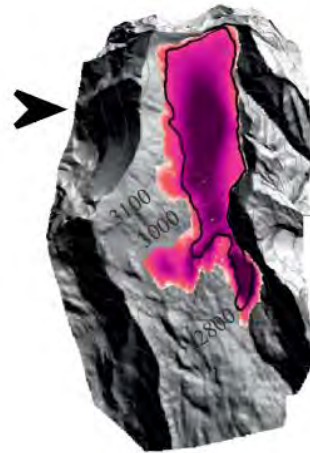
- -23% area
- 3 glaciers disappear (21 total)
- 6.3 m mean thickness loss

Surface evolution: 2011–2020

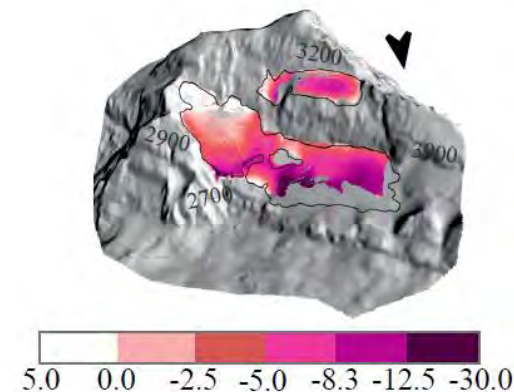
Airborne LiDAR vs UAV

(almost all Pyrenean glaciers)

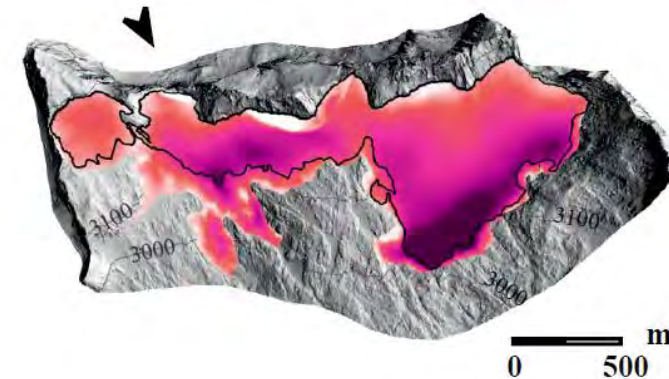
Ossoue glacier



Monte Perdido glacier



Aneto glacier



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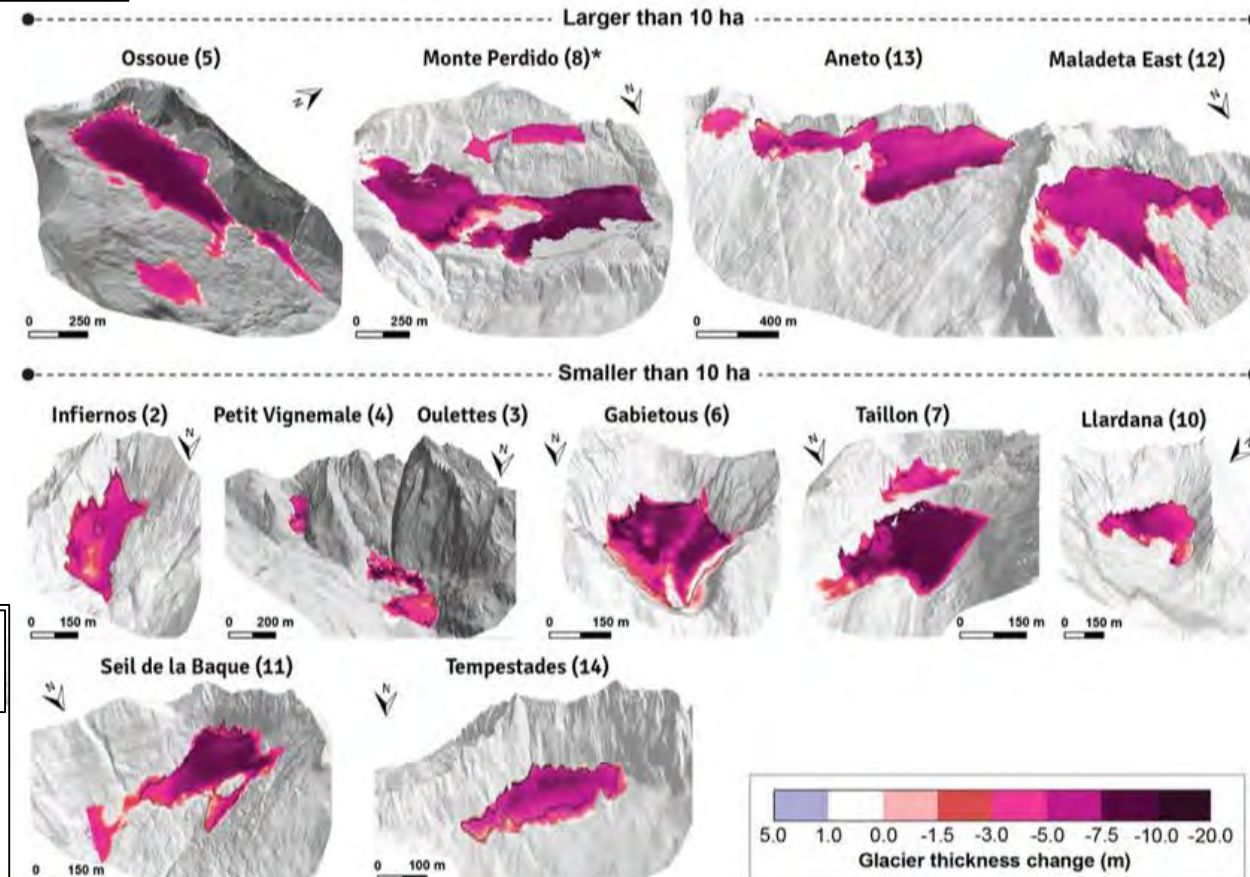
2011–2020:

- -23% area
- 3 glaciers disappear (21 total)
- 6.3 m mean thickness loss

2020–2023:

- -39.8% area
- 6 glaciers disappear (15 total)
- 7.5 m mean thickness loss

Surface evolution: 2020–2023 UAV vs UAV (almost all Pyrenean glaciers)



ORIGINAL ARTICLE

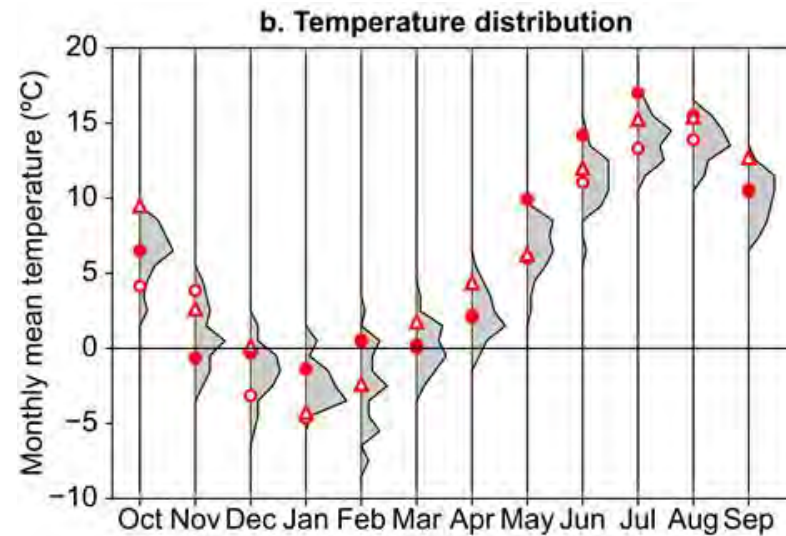
Regional Environmental Change (2024) 24:172
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Pyrenean glaciers are disappearing fast: state of the glaciers after the extreme mass losses in 2022 and 2023

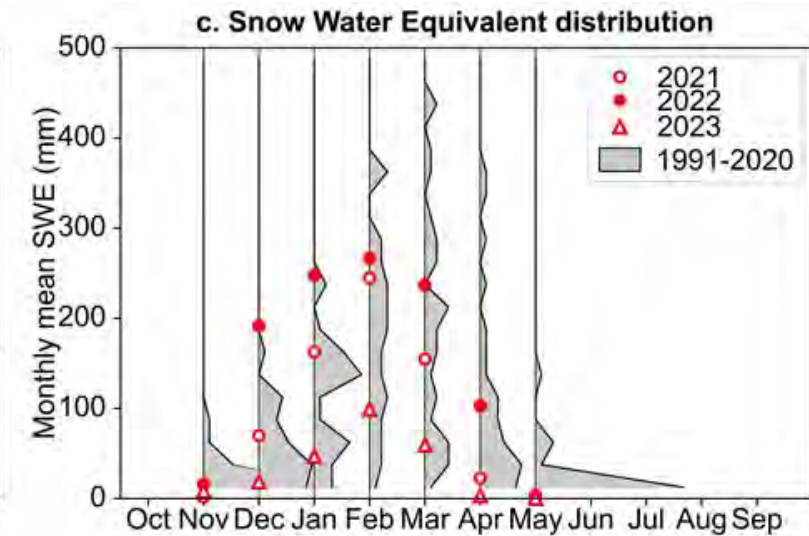
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Years with **high summer temperatures** and very “**early**” **late snowfall** have a very **negative** impact

- **2011-20:**
Thickness loss -0,8 m/year
- **2020-2023:**
Thickness loss -2,5 m/year



ERA-5



ORIGINAL ARTICLE

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Daily evolution? Ossoue glacier

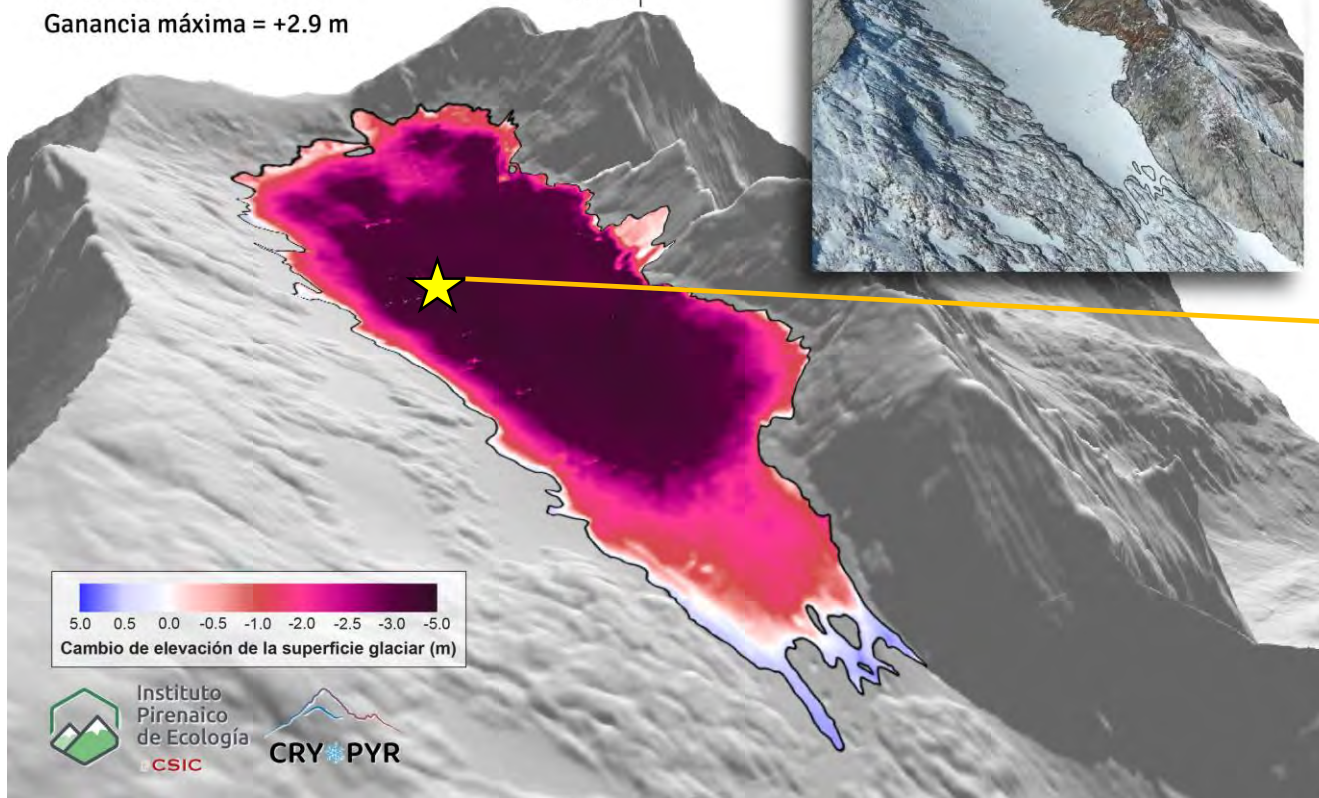
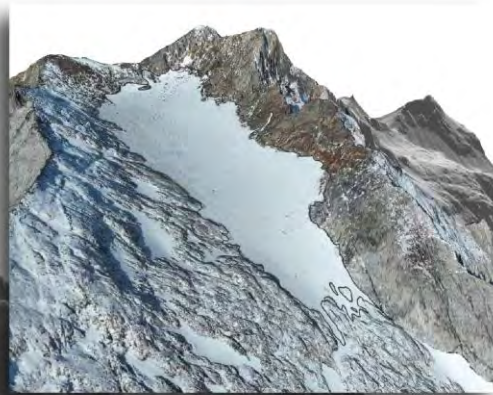
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Vignemale
3298 m



SmartStake: Real time melting dynamics

Daily evolution? Ossoue glacier

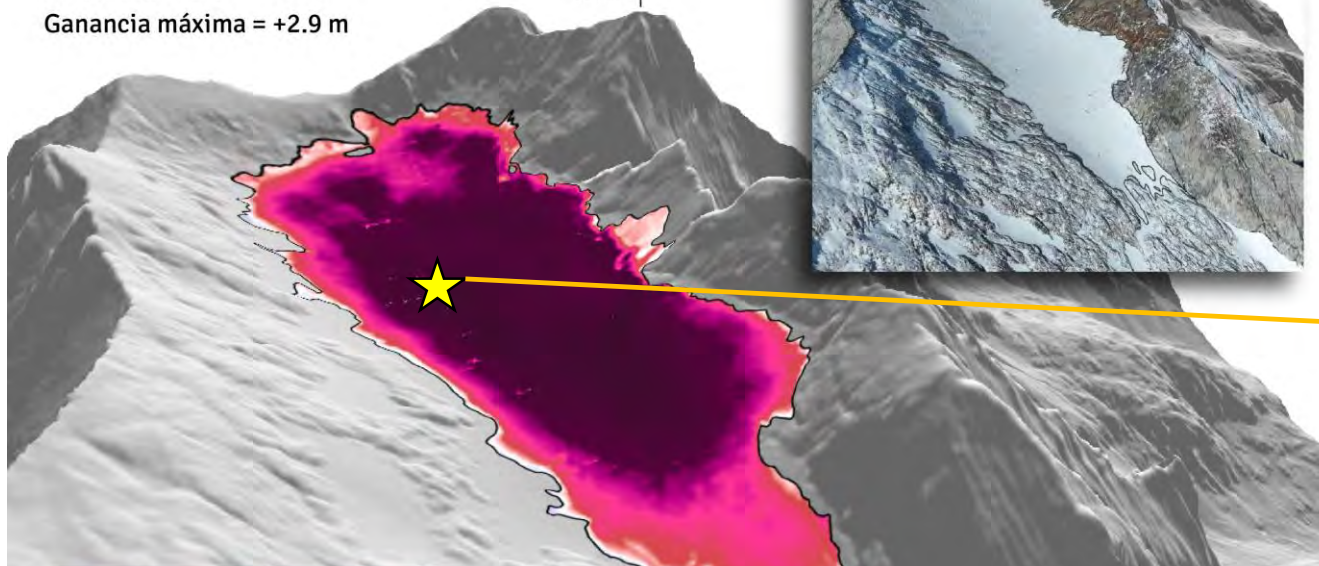
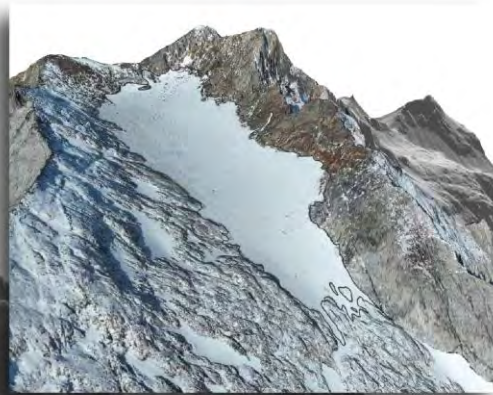
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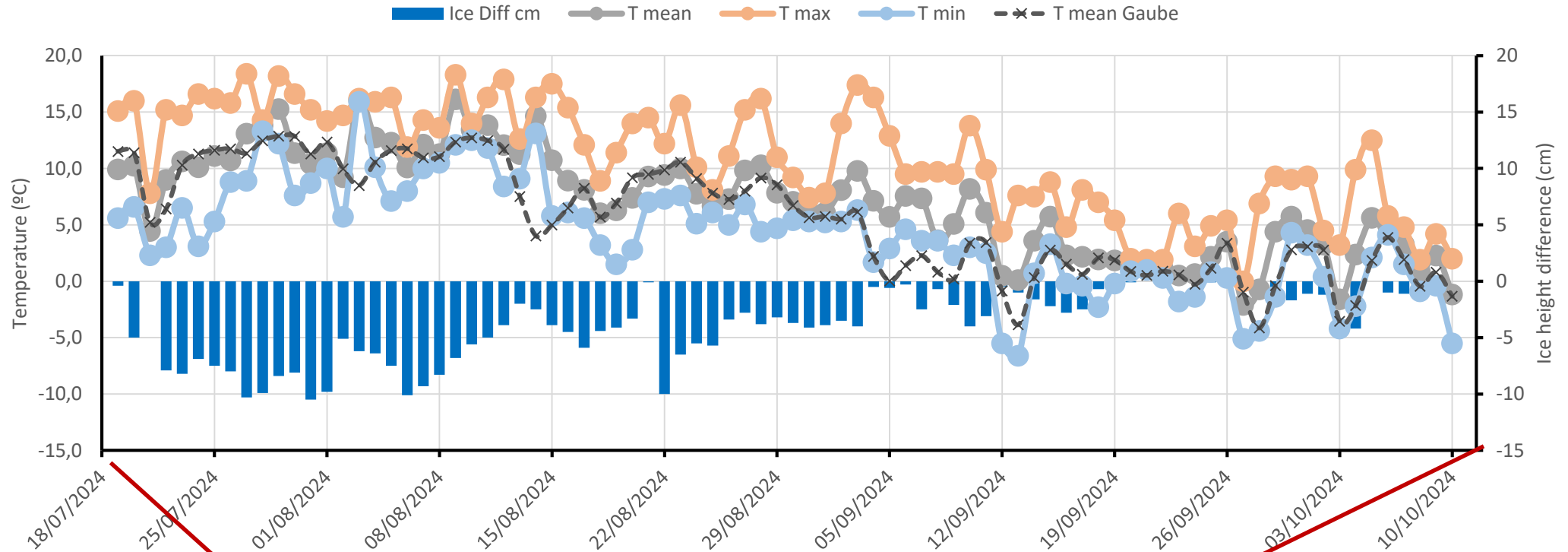
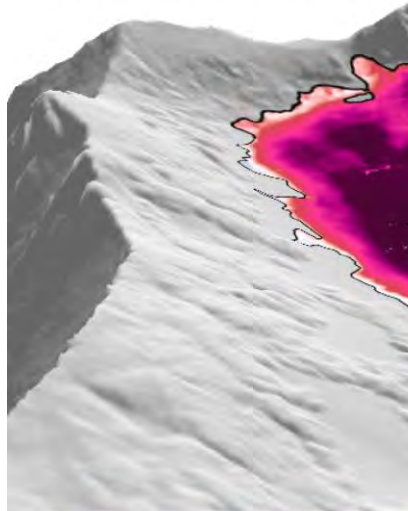
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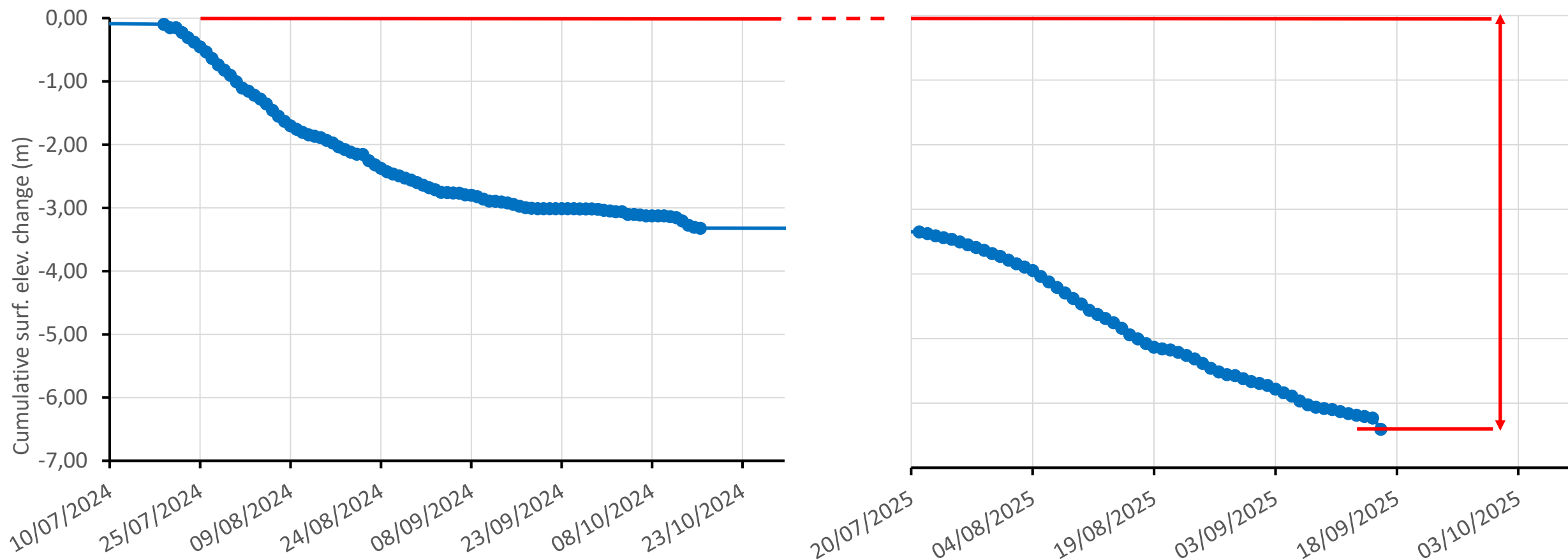
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Daily evolution? Ossoue glacier



From July 2024 to September 2025 > 6m loss

Daily evolution? Ossoue glacier

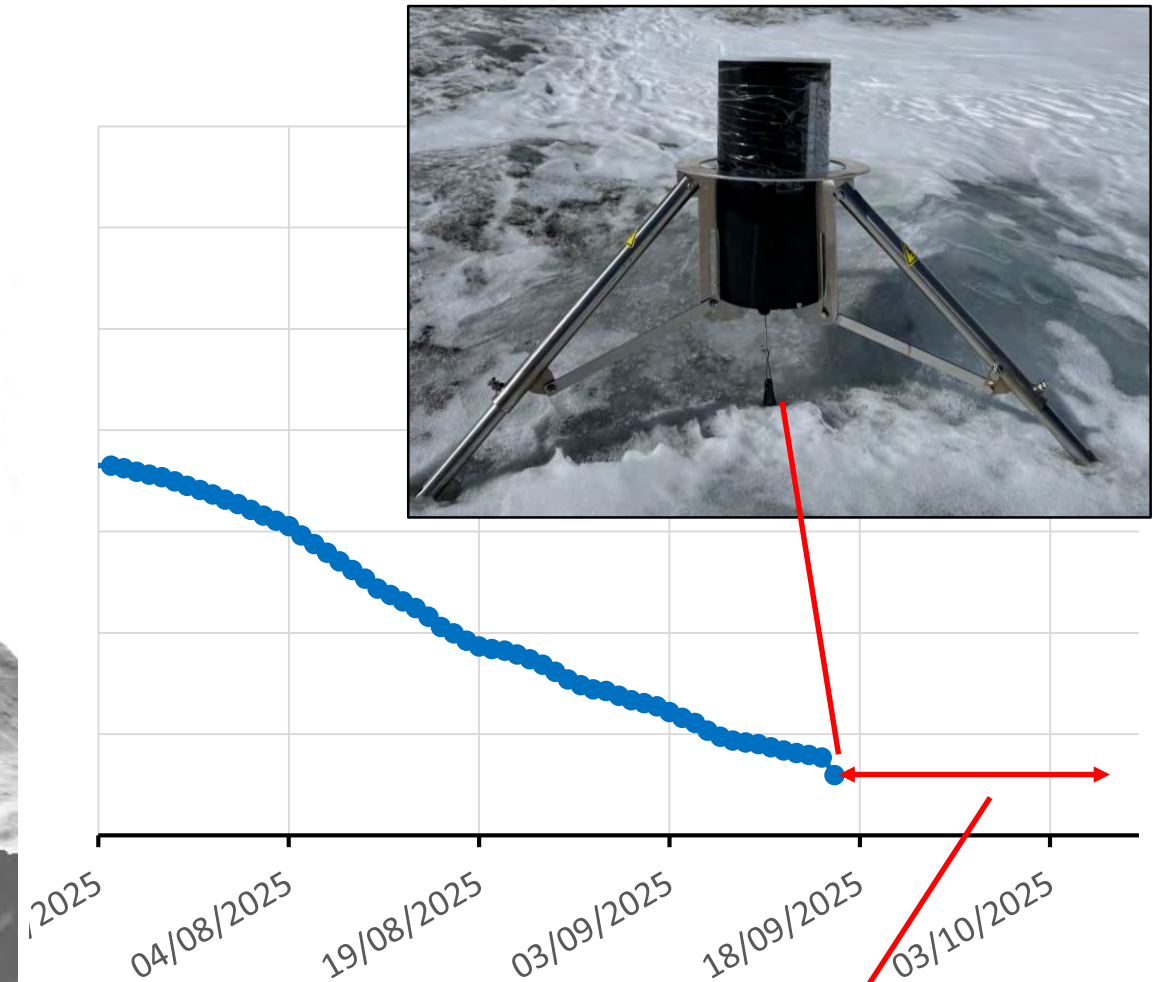
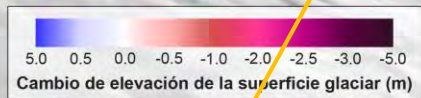
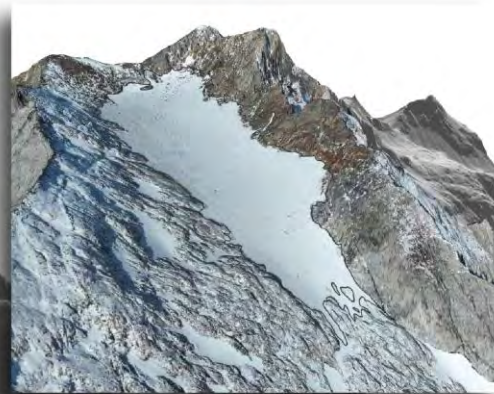
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Vignemale
3298 m



- 14 September to 15 October 2025 → From UAV Surface comparisons: - 1,2 m

From April 2024 to October 2025 > **7.5 m ice loss**

Monte Perdido glacier

2011



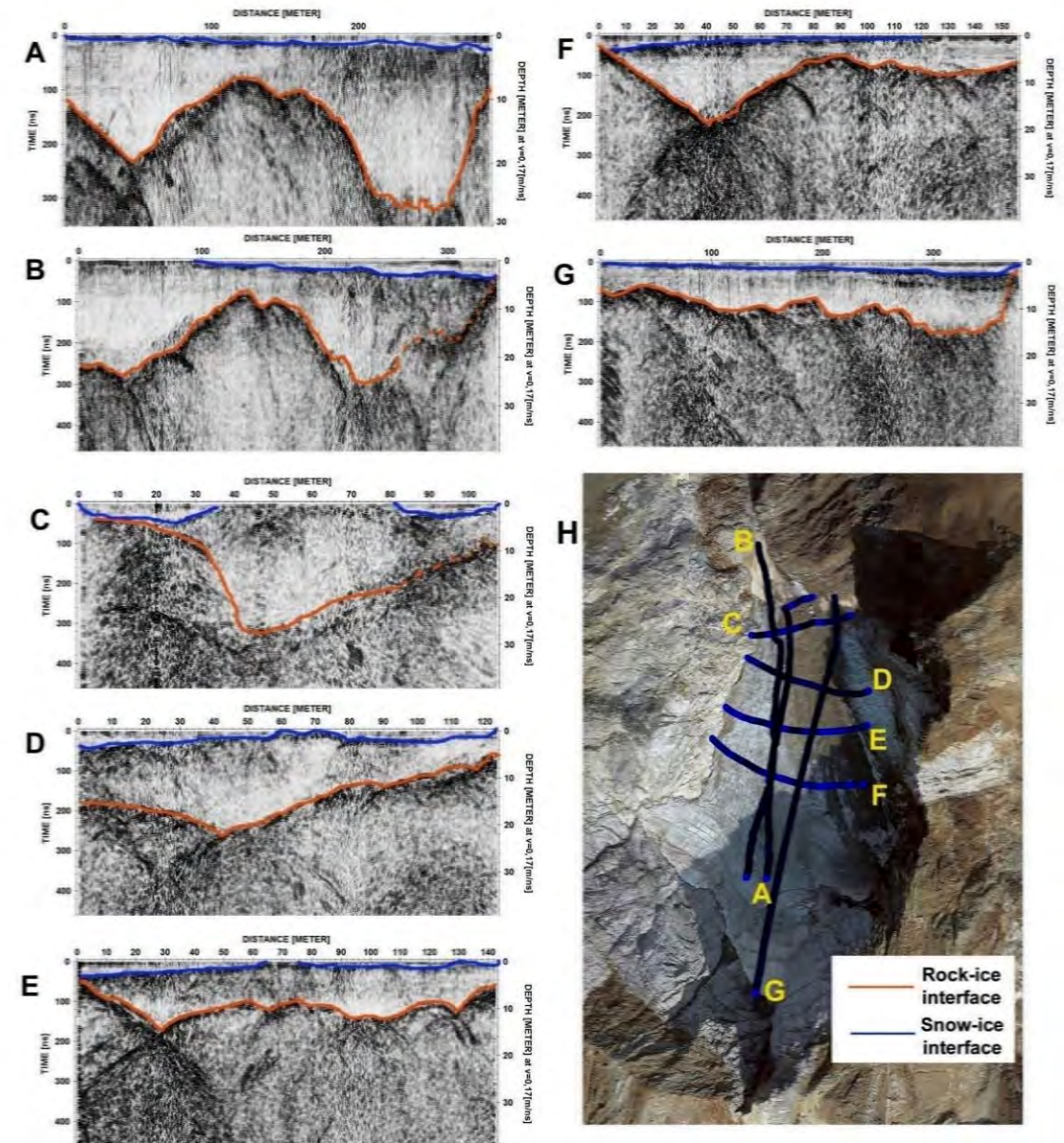
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How much ice remains?

Ground Penetrating Radar (GPR)

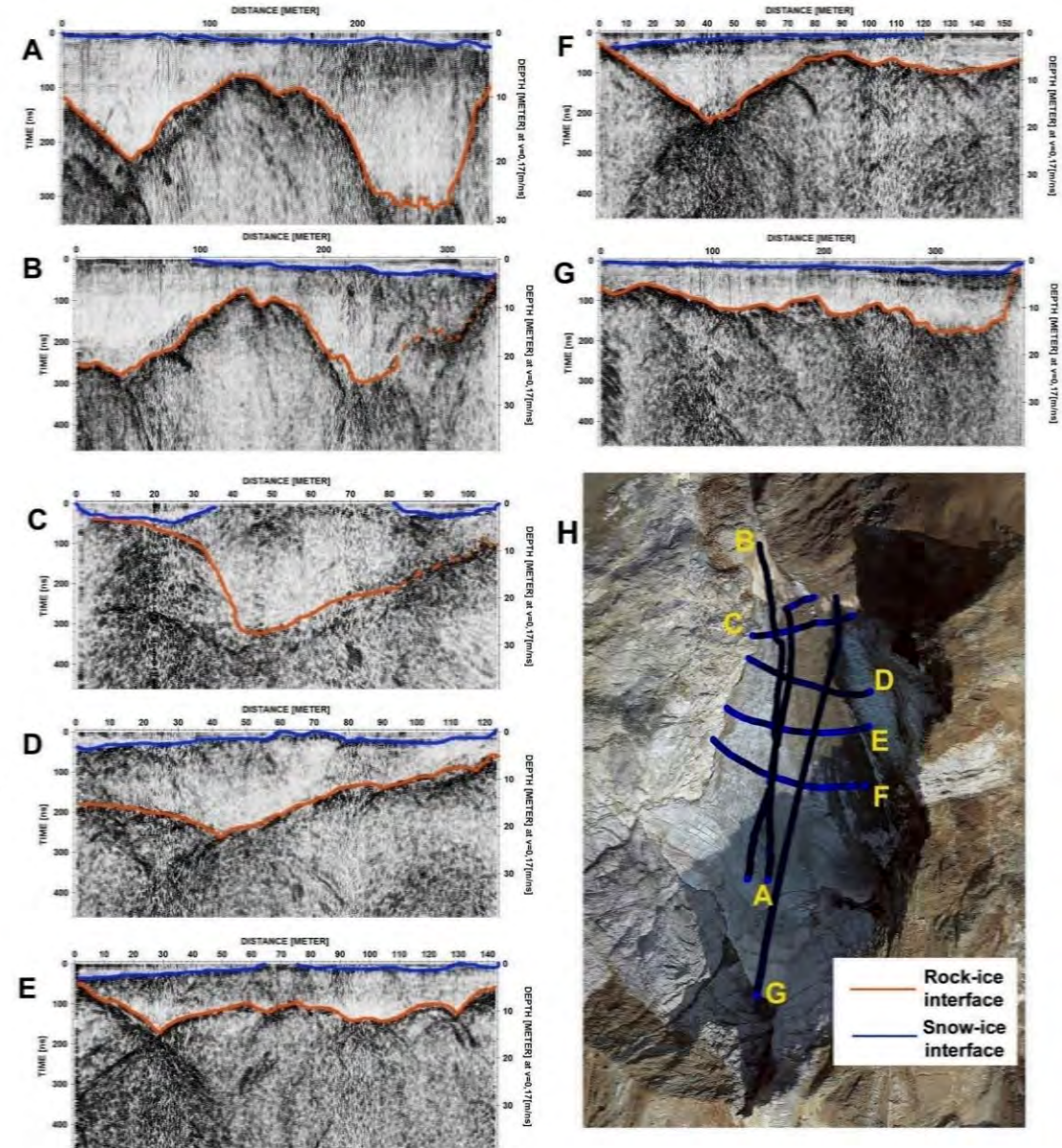
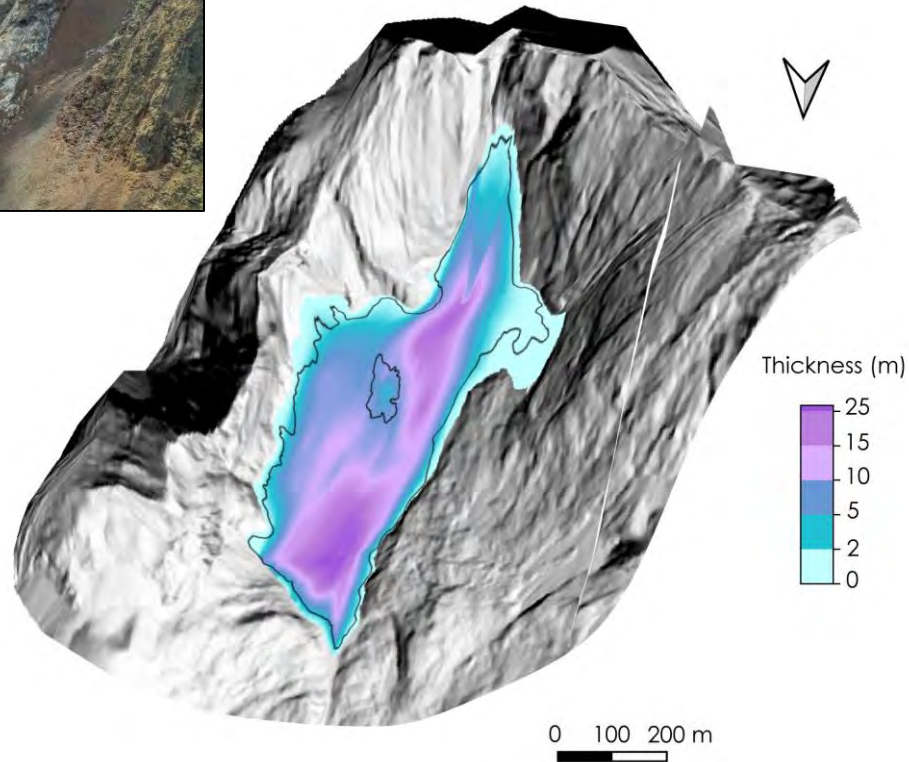
Example for Infiernos glacier in 2021



How much ice remains?

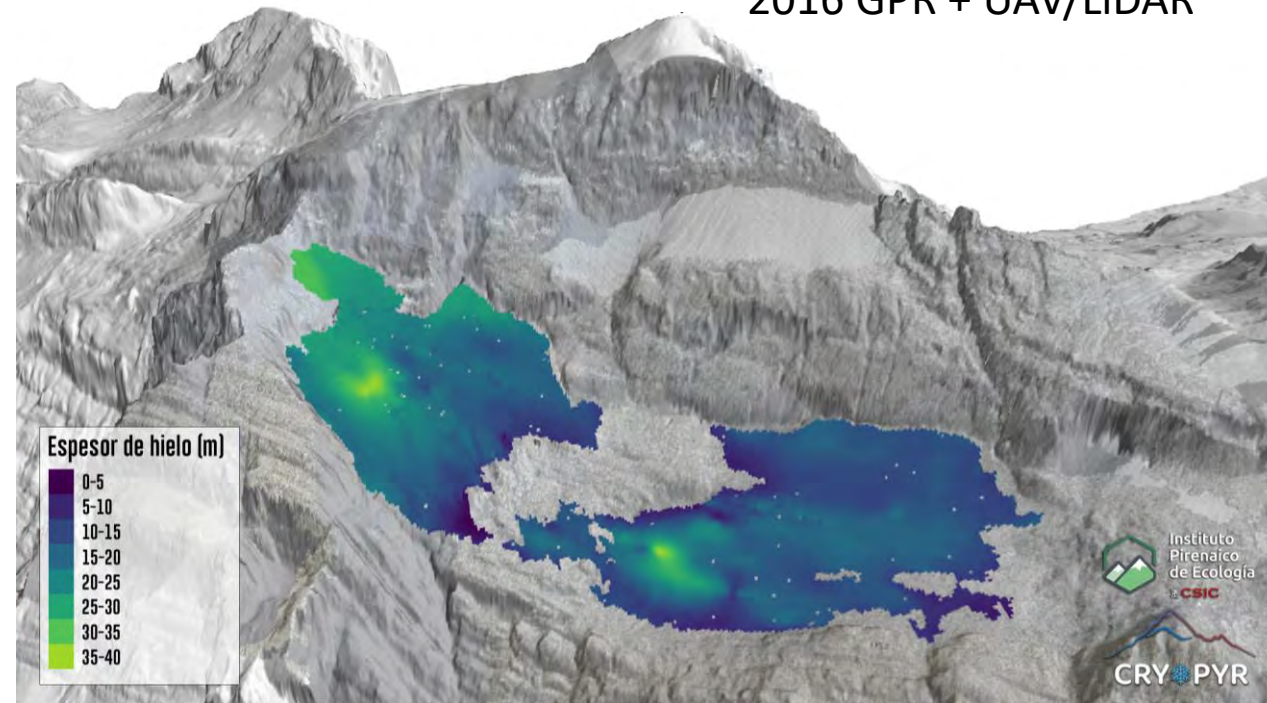
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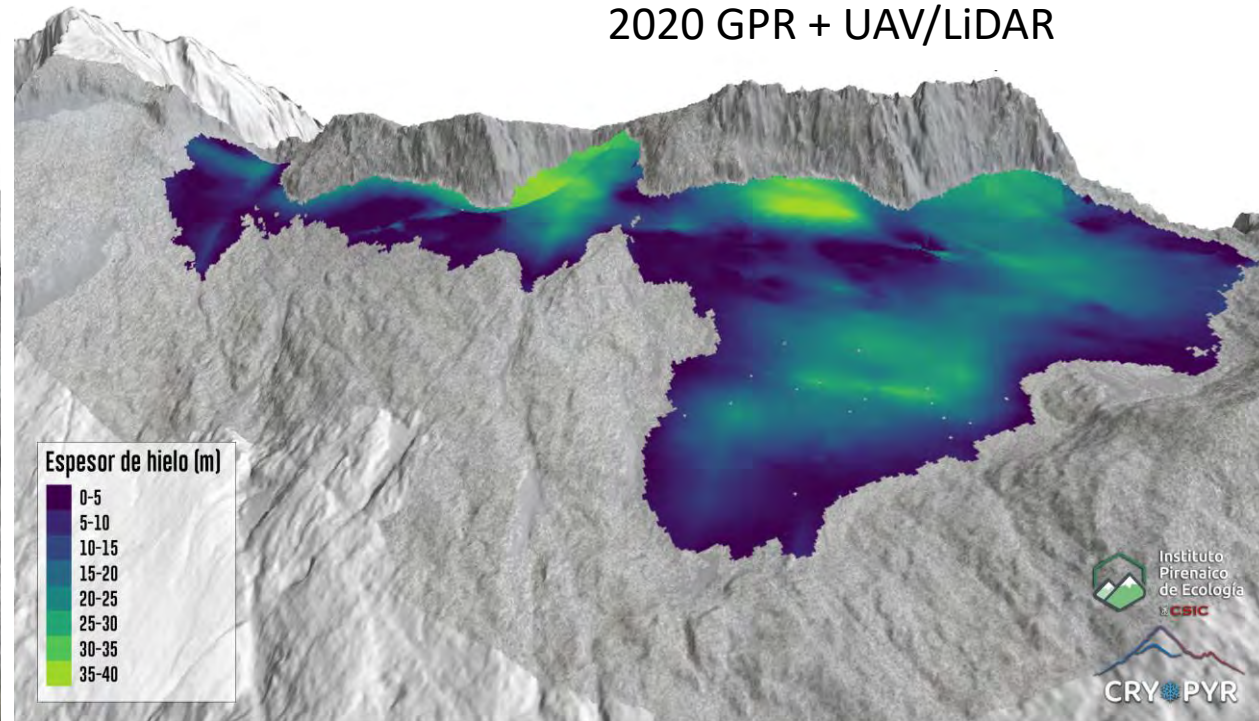


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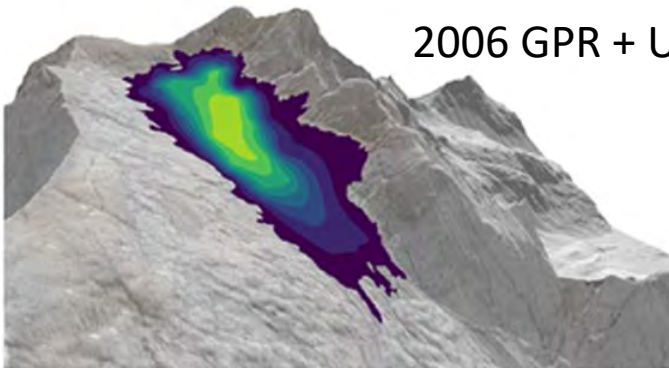
2024 Monte Perdido
2016 GPR + UAV/LiDAR



2024 Aneto
2020 GPR + UAV/LiDAR



2024 Ossoue
2006 GPR + UAV/LiDAR



Monte Perdido glacier

2011



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What can we expect in the future?

- Topographic control is is very complex.

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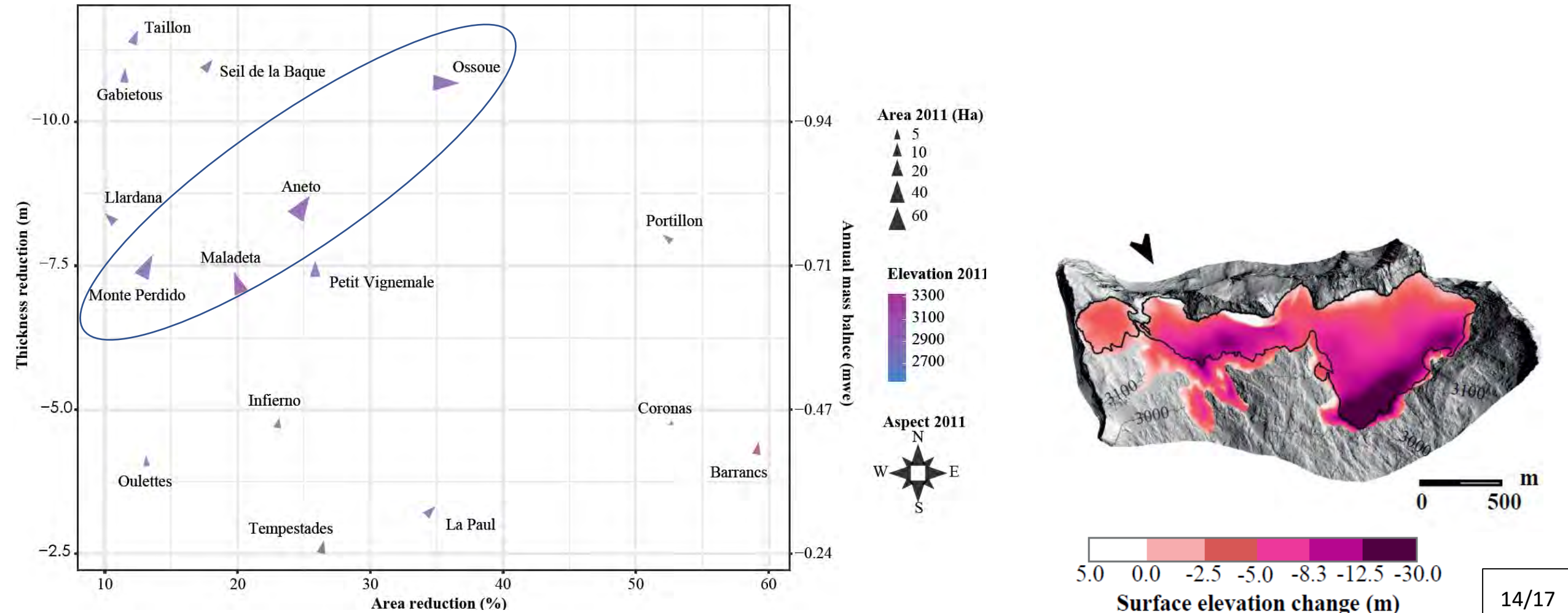
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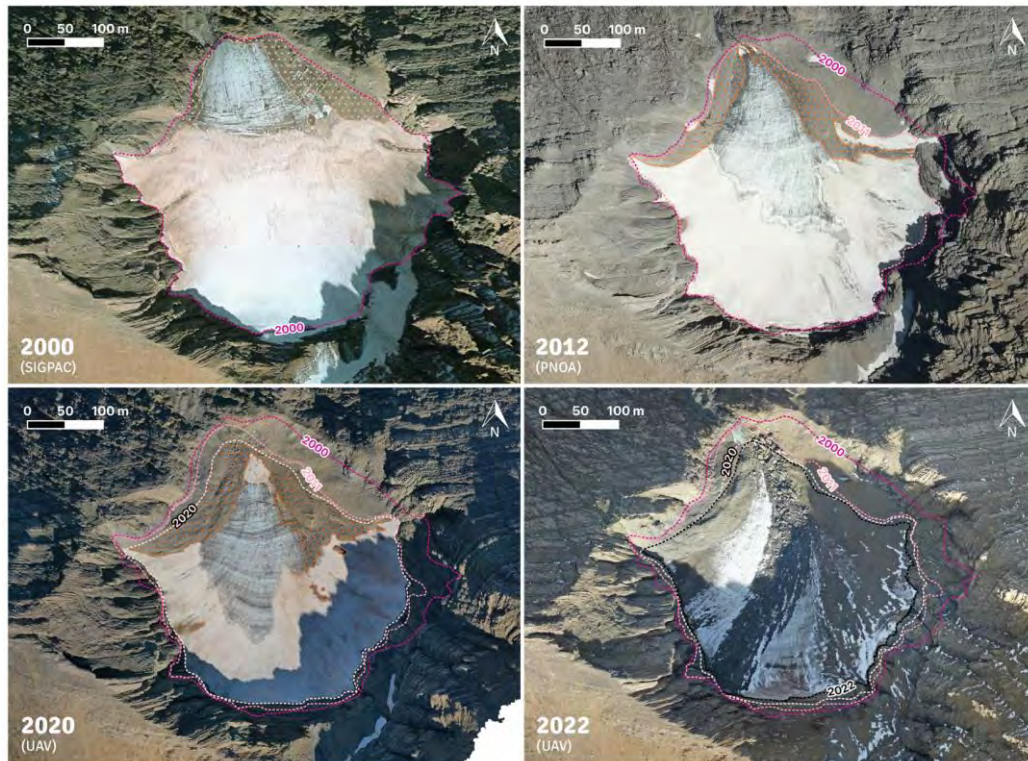
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What can we expect in the future?

- Topographic control is is very complex.
- Accumulation of debris on the surface.

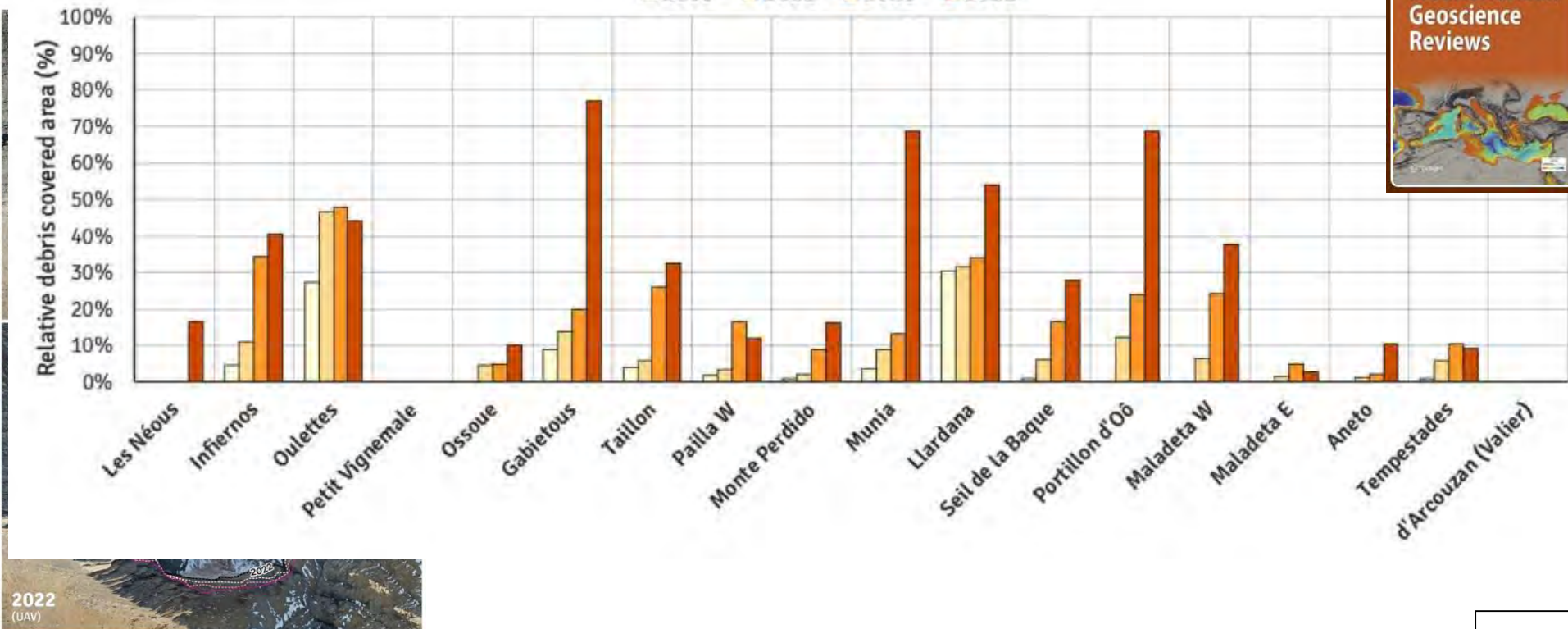
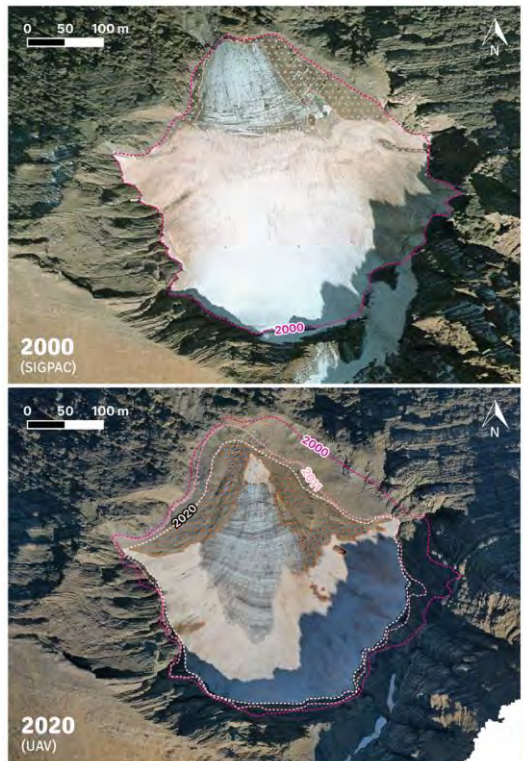
Gabietous glacier



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Gabietous glacier



Mediterranean Geoscience Reviews
<https://doi.org/10.1007/s42990-024-00149-z>

ORIGINAL PAPER

A variable increase of debris cover on Pyrenean glaciers from 2000 to 2022

Eñaut Izagirre^{1,2} · Ander Palacios³ · Ixeia Vidaller¹ · Enrique Serrano⁴ · Juan Ignacio López-Moreno¹ · Orbanje Ormaetxea² · Jesús Revuelto¹

Journal of Glaciology

Article

Cite this article: Revuelto J, Izaguirre E, Rico I, Río L, Serrano E, Vidaller I, Rojas-Heredia F, López-Moreno JI (2025) The last years of Infiernos Glacier and its transition to a new paraglacial stage. *Journal of Glaciology* **71**, e35, 1–13. <https://doi.org/10.1017/jog.2025.22>

The last years of Infiernos Glacier and its transition to a new paraglacial stage

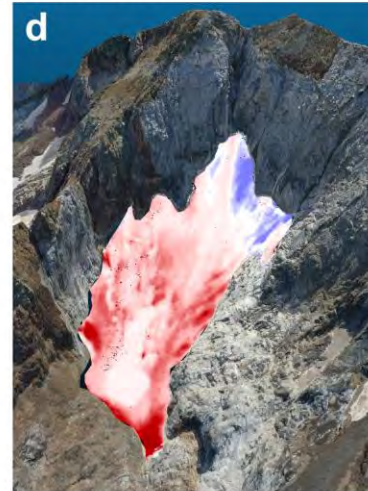
J. Revuelto¹ , E. Izaguirre^{1,2} , I. Rico² , L. Río³ , E. Serrano⁴ ,
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¹Consejo Superior de Investigaciones Científicas (IPE-CSIC), Instituto Pirenaico de Ecología, Zaragoza, Spain; ²Department of Geography, Prehistory and Archaeology, University of the Basque Country UPV/EHU, Vitoria-Gasteiz, Spain; ³Department of Applied Physics, Escuela Politécnica de Cáceres, University of Extremadura, Cáceres, Spain and ⁴Department of Geography, GIR PANGEA, University of Valladolid, Valladolid, Spain

Infiernos glacier



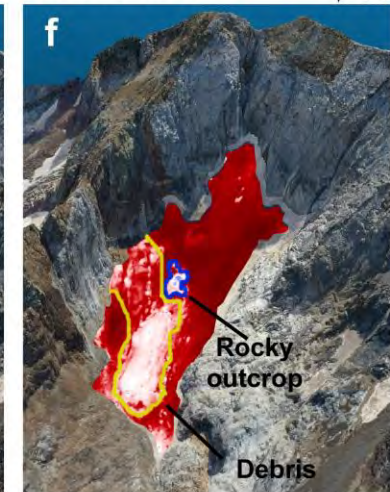
2020-2021



2021-2022



2022-2023



Surface
diff. [m]



Journal of Glaciology



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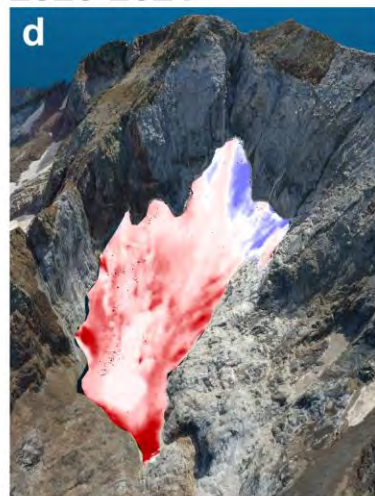
¹Consejo Superior de Investigaciones Científicas (IPE-CSIC), Instituto Pirenaico de Ecología, Zaragoza, Spain; ²Department of Geography, Prehistory and Archaeology, University of the Basque Country UPV/EHU, Vitoria-Gasteiz, Spain; ³Department of Applied Physics, Escuela Politécnica de Cáceres, University of Extremadura, Cáceres, Spain and ⁴Department of Geography, GIR PANGAEA, University of Valladolid, Valladolid, Spain

Infiernos glacier

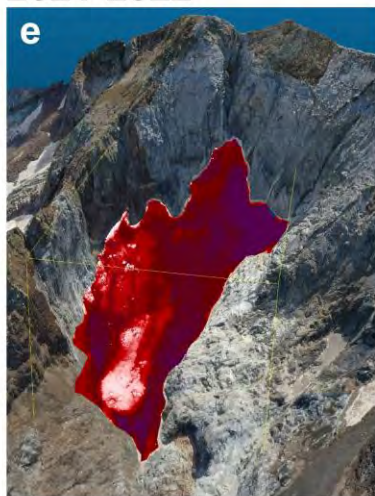


Period	Mean thickness change [m]	
	Full glacier extent	Debris covered area
2020-2021	-0.58	-0.41
2021-2022	-3.15	-1.73
2022-2023	-1.89	-0.76

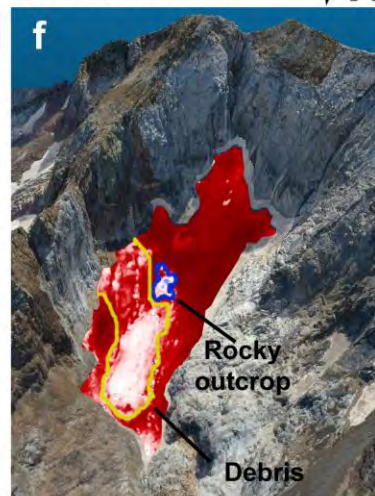
2020-2021



2021-2022



2022-2023



Journal of Glaciology

Article

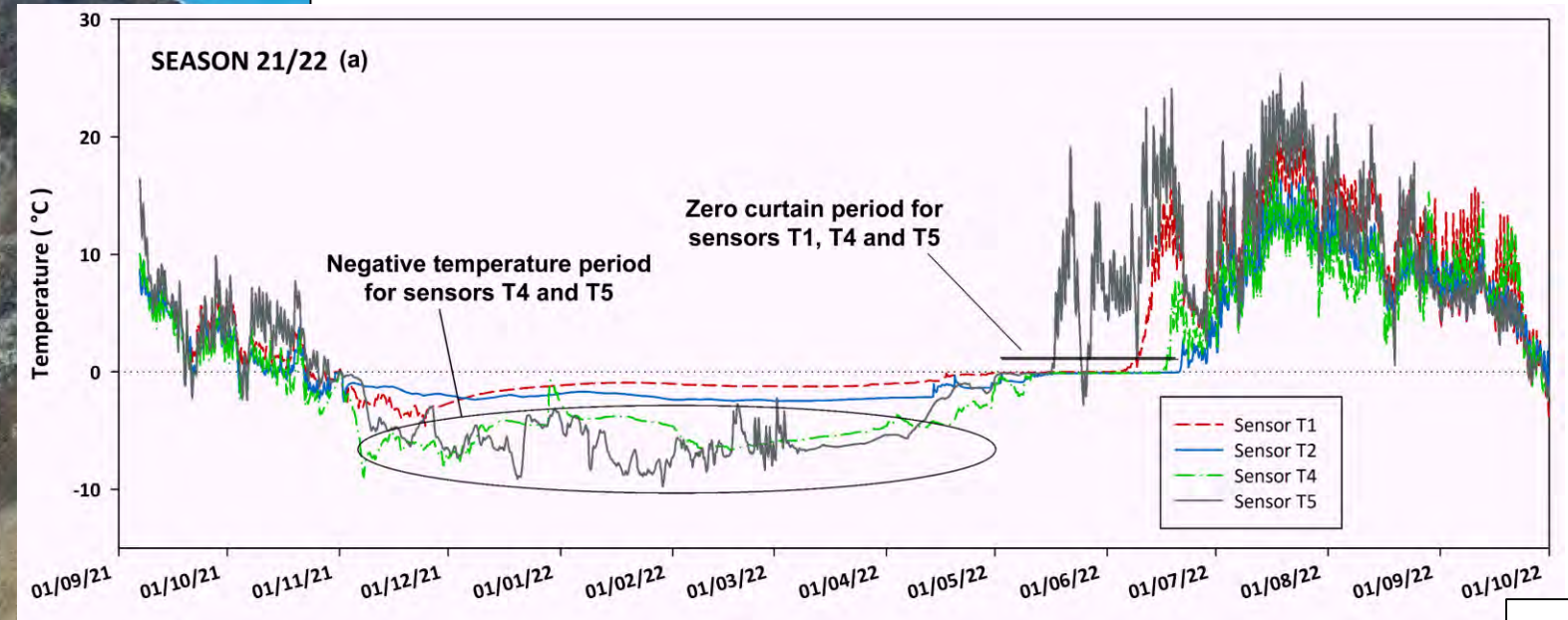
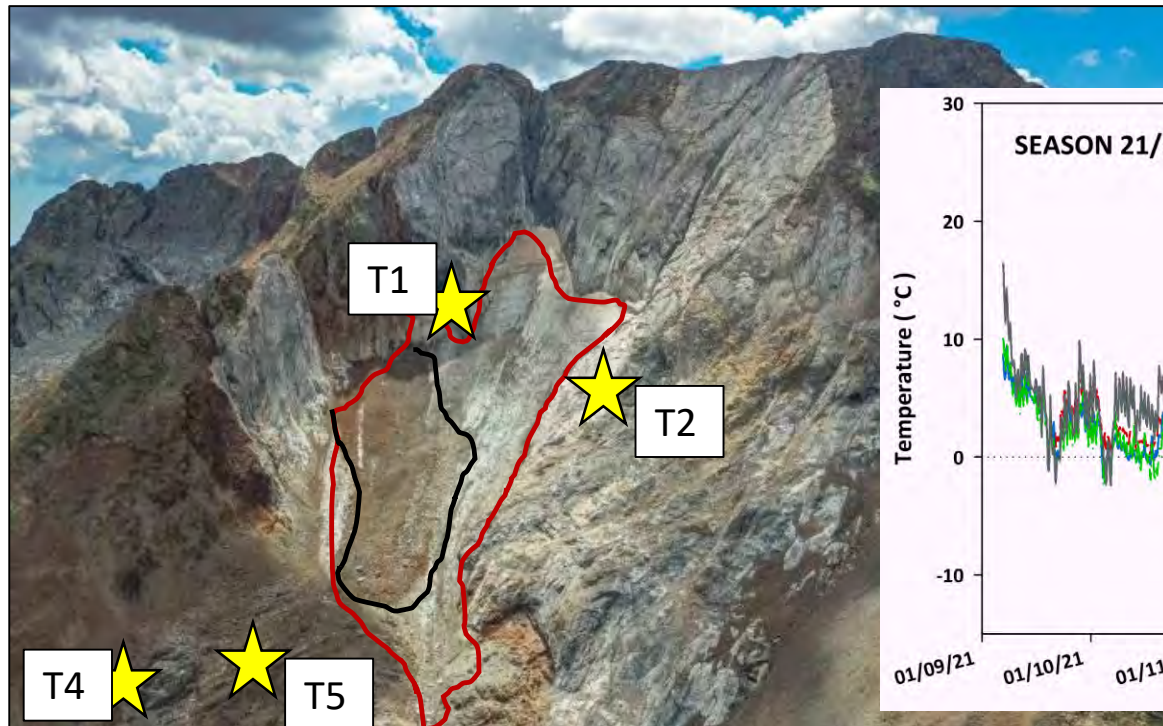
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Infiernos glacier



Journal of Glaciology

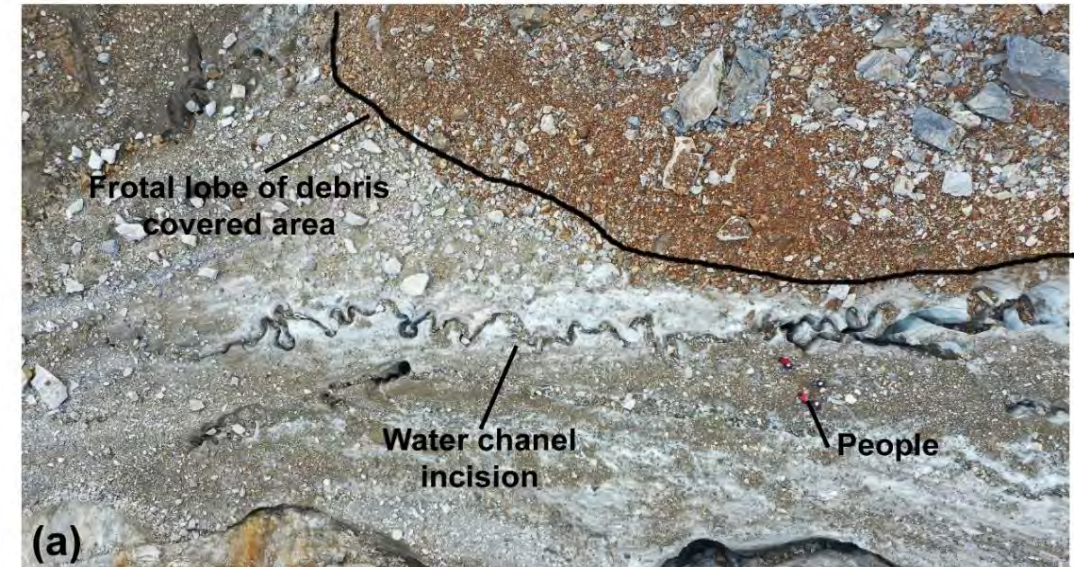
Article

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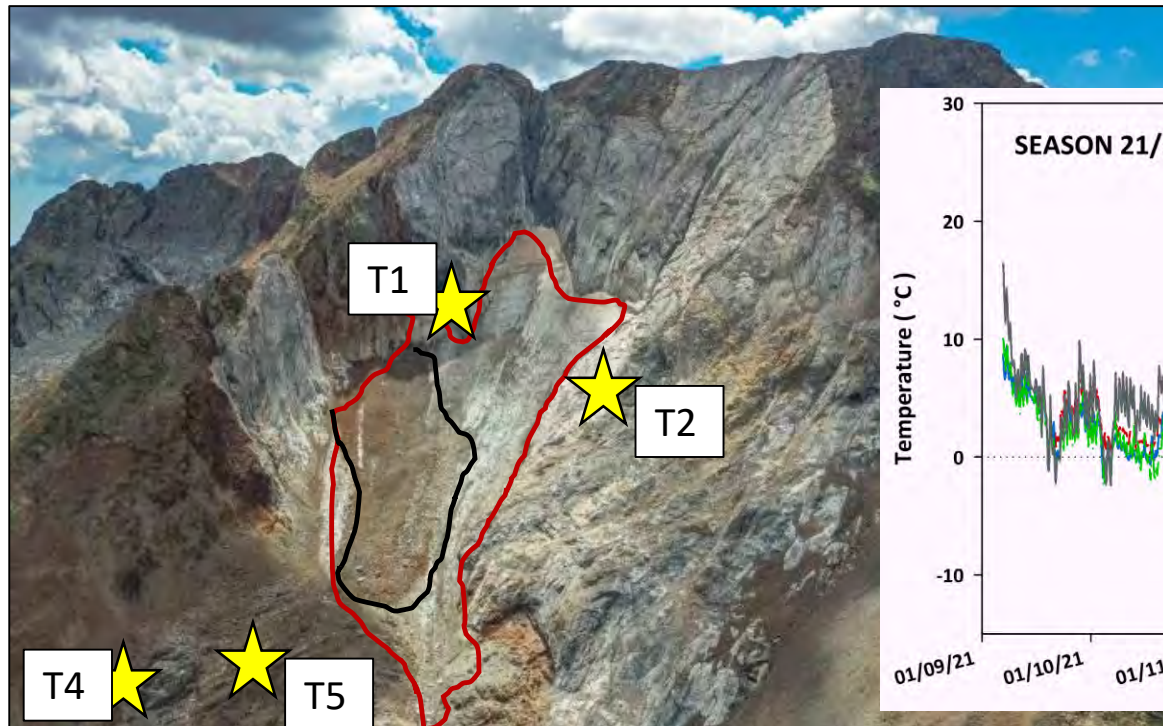
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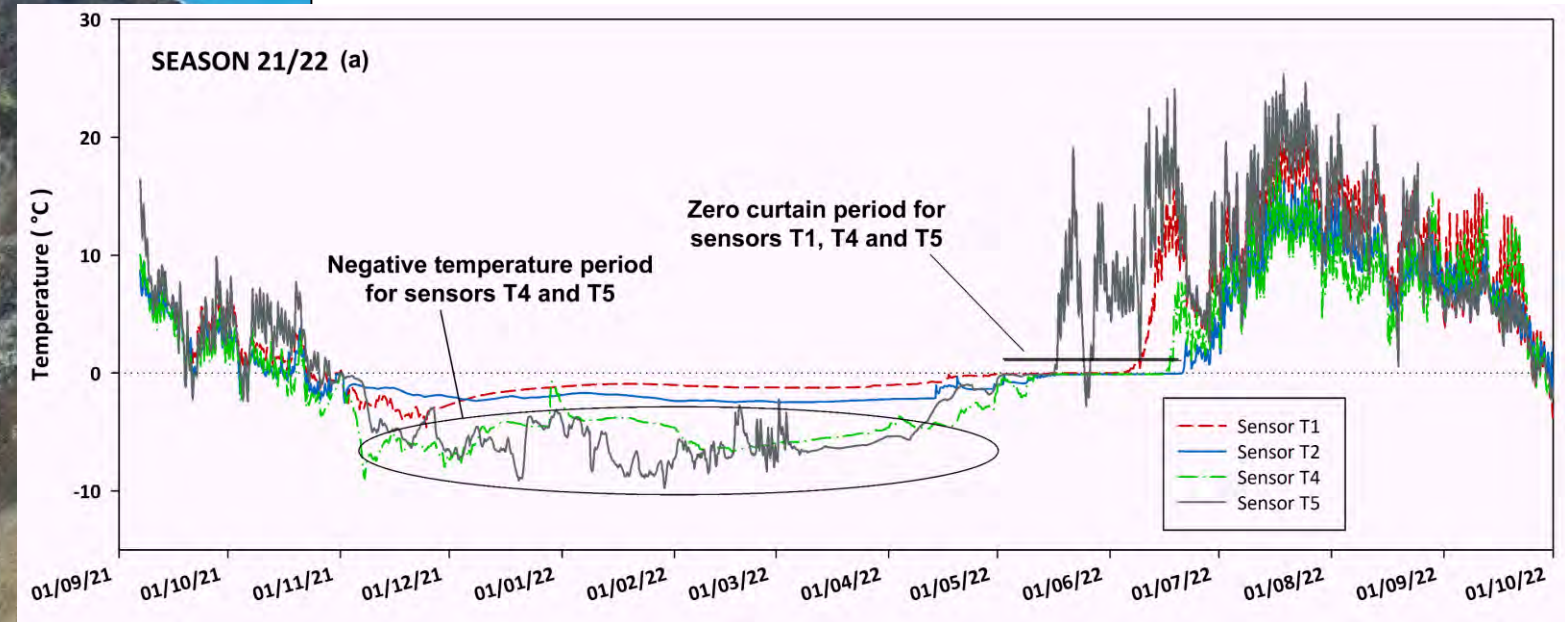
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Infiernos glacier



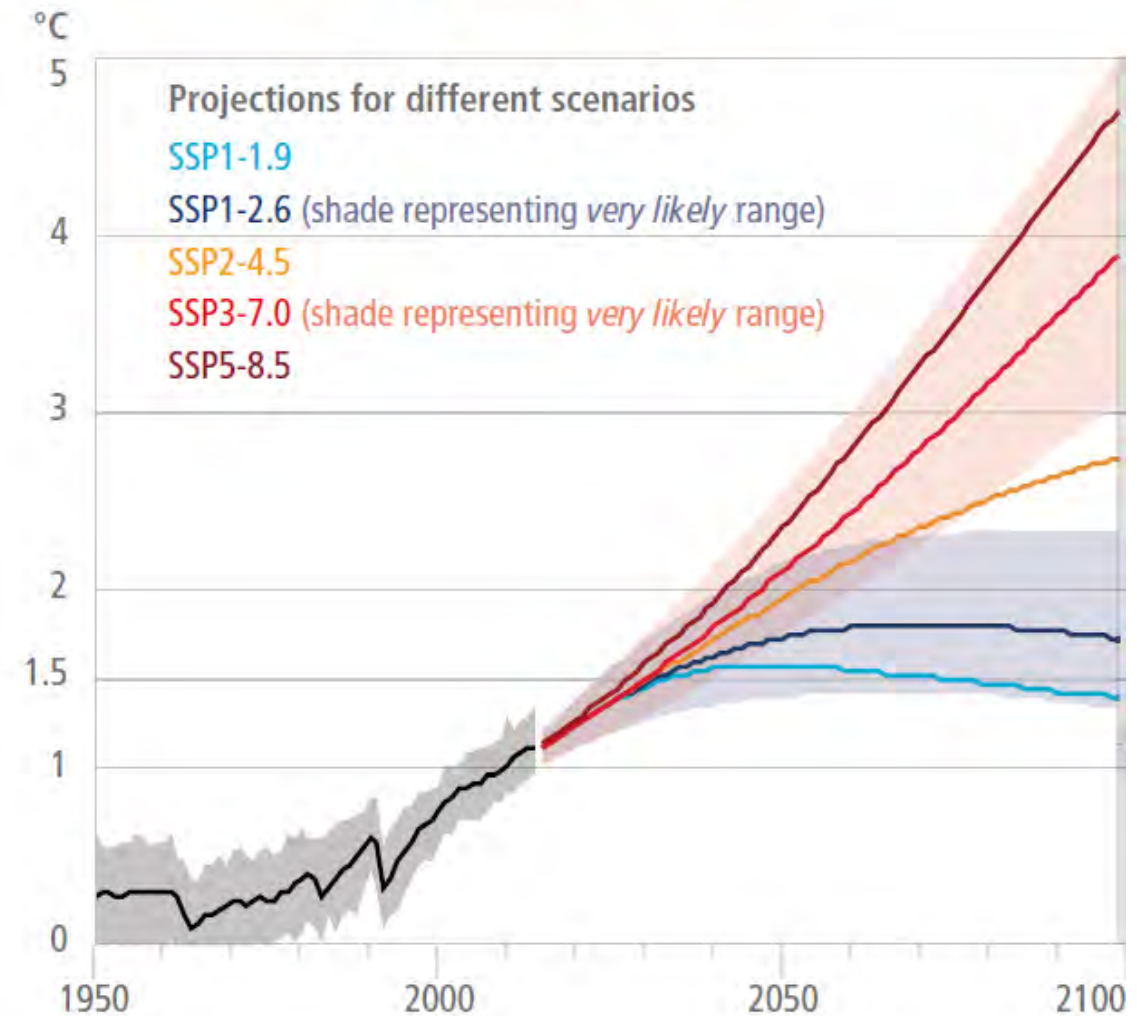
Not any more a glacier but an ice patch



What can we expect in the future?

- Topographic control is is very complex.
- Accumulation of debris on the surface.

(a) Global surface temperature change
Increase relative to the period 1850–1900



What can we expect in the future?

Annals of Glaciology



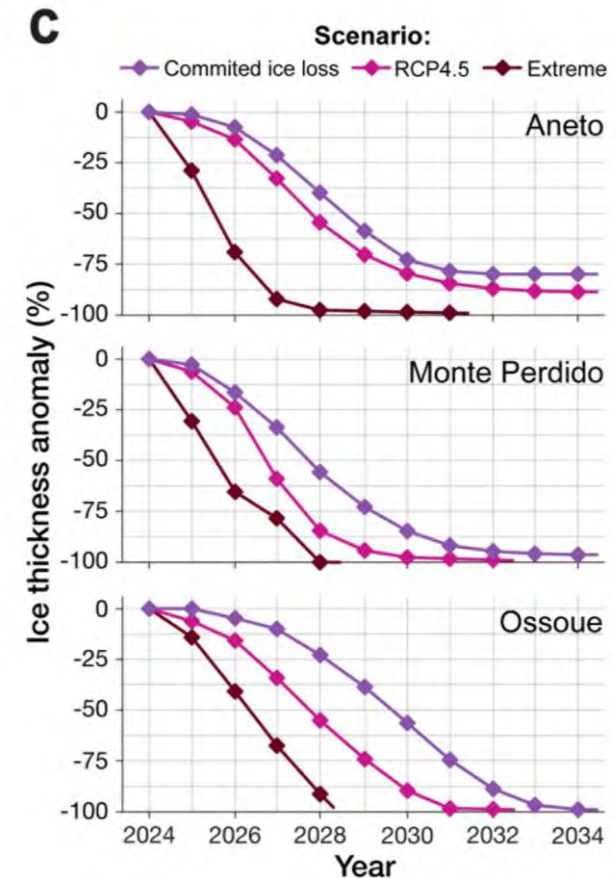
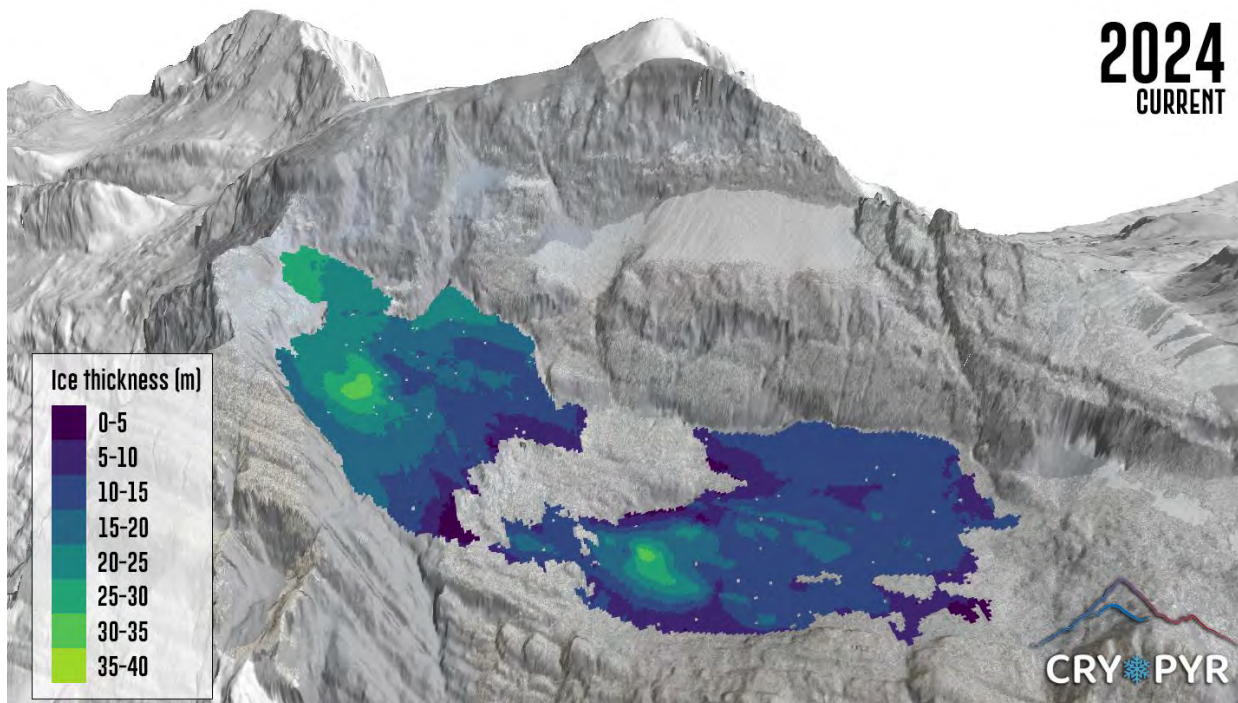
Letter

No hope for Pyrenean glaciers

Juan Ignacio López-Moreno¹, Jesús Revuelto¹, Eñaut Izagirre¹,
Esteban Alonso-González¹, Ixeia Vidaller¹ and Josep Bonsoms²

¹Geoenvironmental Processes and Global Change, Pyrenean Institute of Ecology, Spanish Research Council-CSIC, Zaragoza, Spain and ²Department of Geography, Universitat de Barcelona, Barcelona, Spain

IGM (Instructed Glacier Model)



What can we expect in the future?

Annals of Glaciology

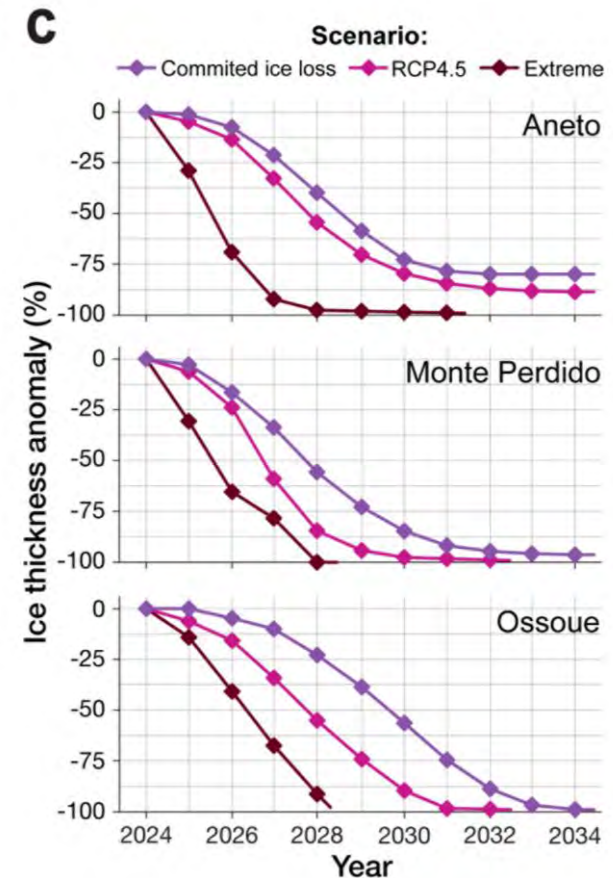
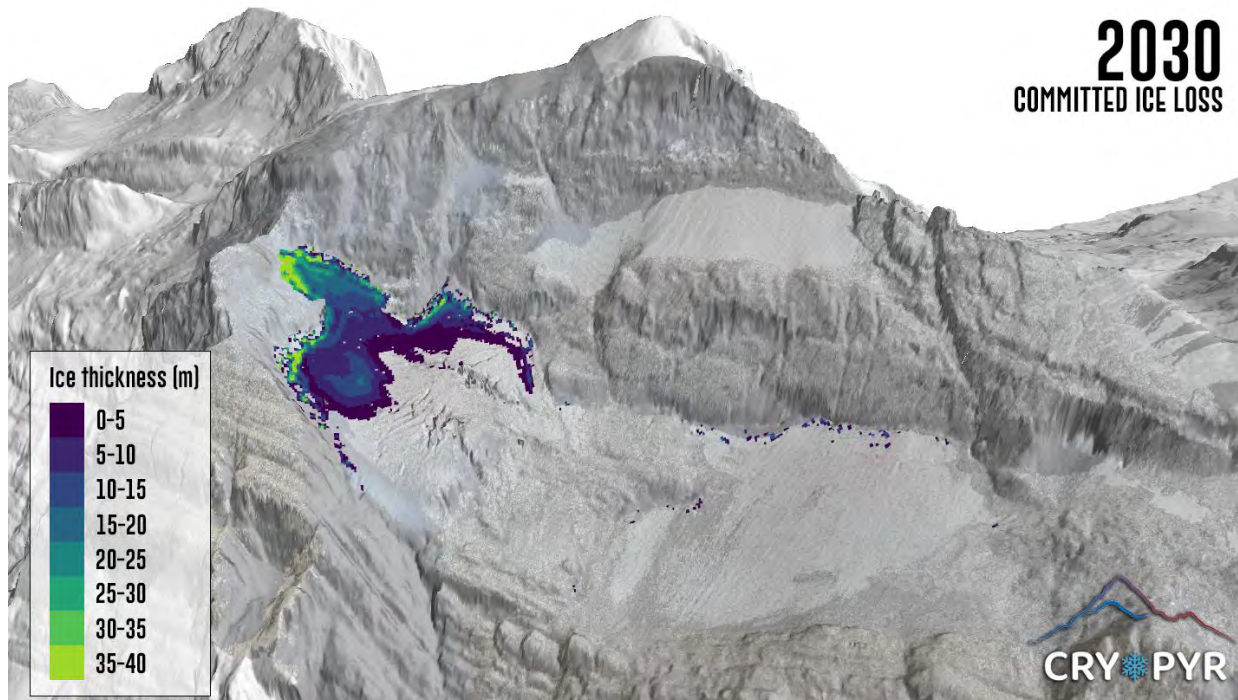


Letter

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What can we expect in the future?

Annals of Glaciology

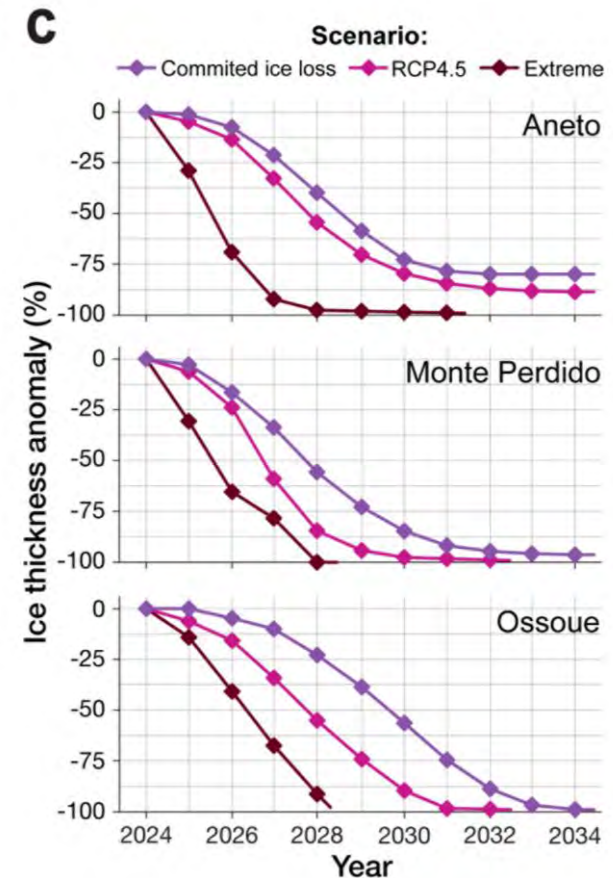
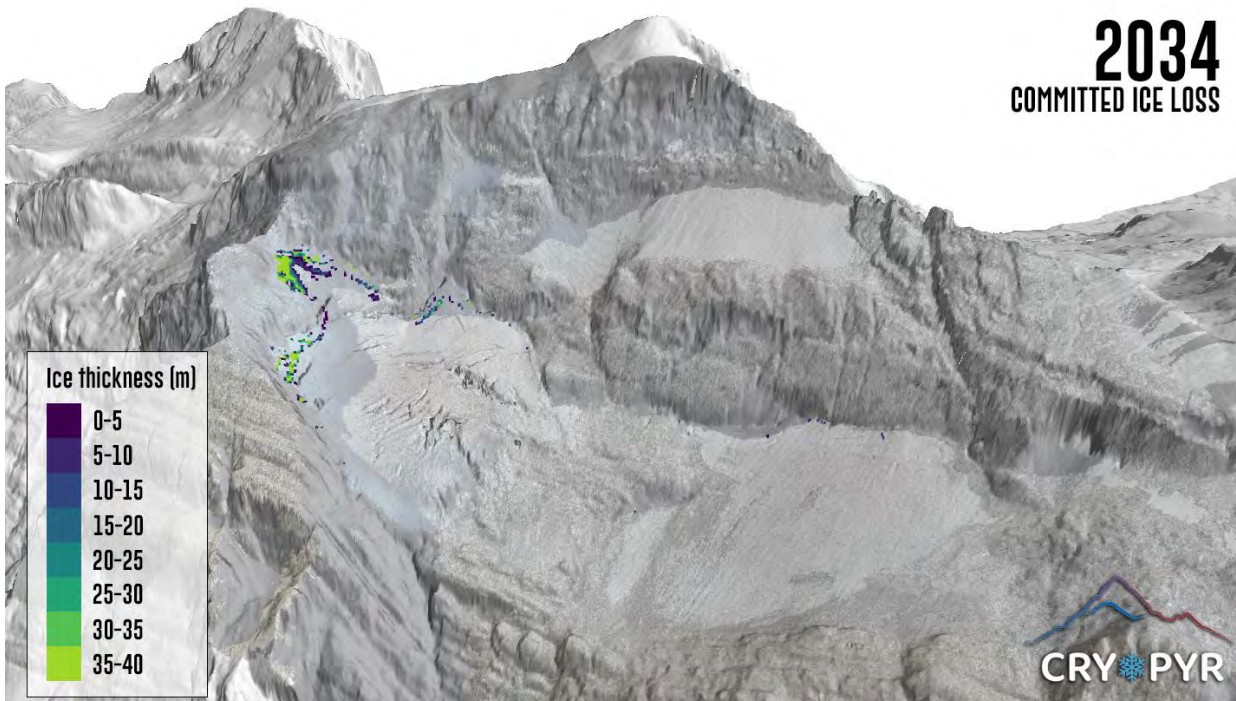


Letter

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New webcams: Aneto and Monte Perdido



New webcams: Aneto and Monte Perdido



<https://cryopyr.csic.es/>

New webcams: Aneto and Monte Perdido



<https://cryopyr.csic.es/>

New webcams: Aneto and Monte Perdido



<https://cryopyr.csic.es/>

Évolution récente des glaciers dans les Pyrénées

jrevuelto@ipe.csic.es
<https://cryopyr.csic.es/>

Jesús Revuelto
IPE-CSIC



Eñaut Izagirre
Francisco Rojas-Heredia
Ixeia Vidaller
Esteban Alonso-González
Cesar Deschamps-Berger
Pablo Domínguez
Javier Bandrés
Ibai Rico
Nacho López-Moreno

How much ice remains?

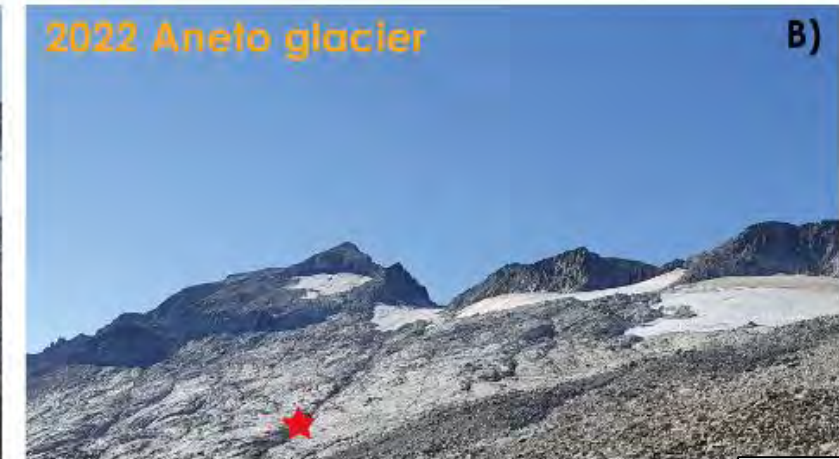
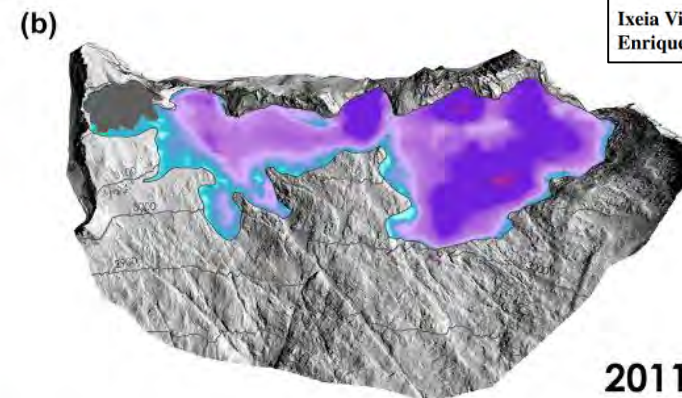
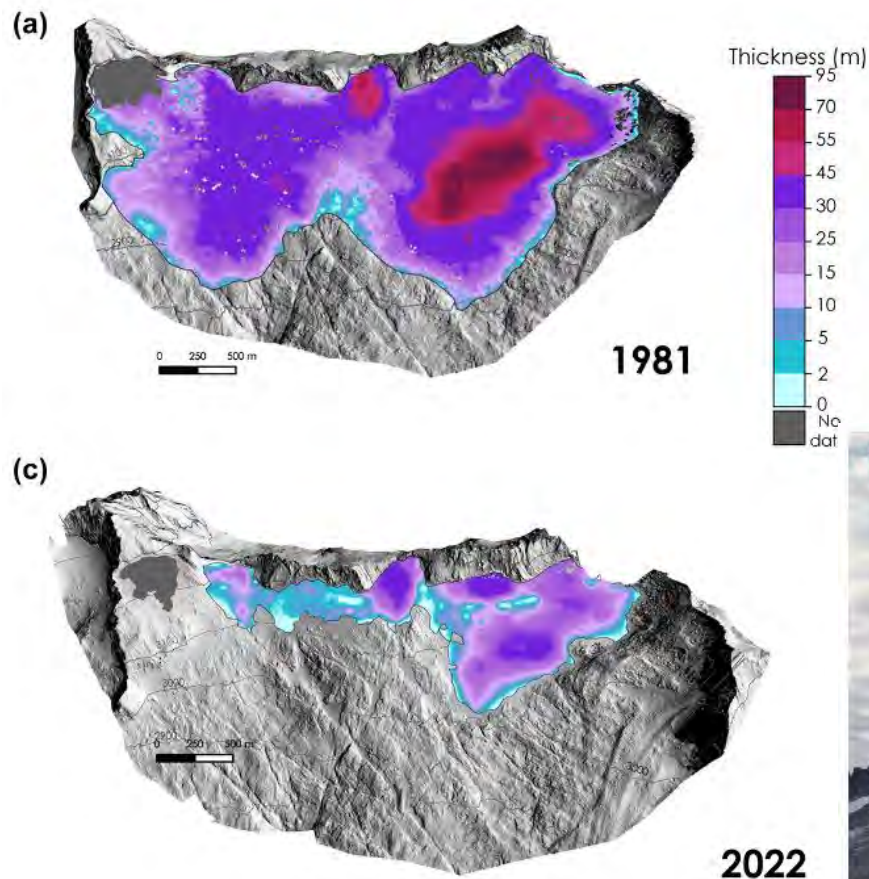
- Airborne imeages: SfM (1981)
- UAV: SfM (2022)
- Airborne LiDAR (2011)
- GPR (2020)

The Cryosphere, 17, 3177–3192, 2023
<https://doi.org/10.5194/tc-17-3177-2023>
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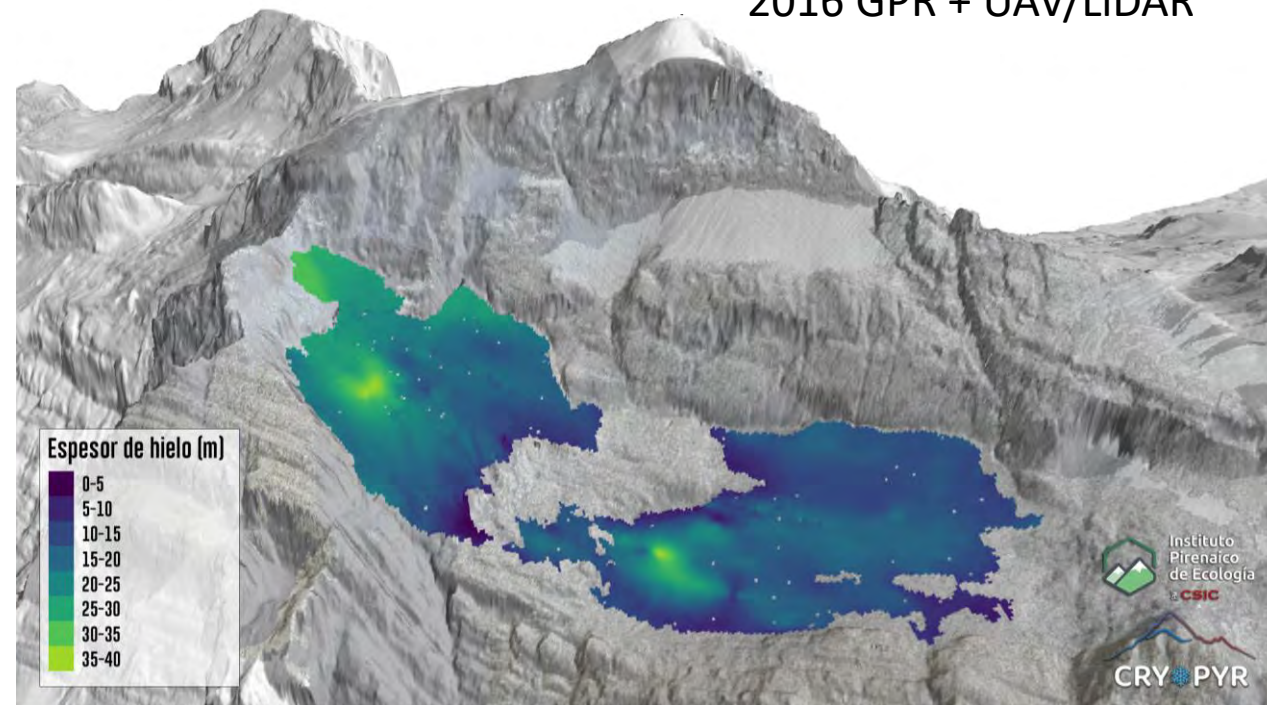
**The Aneto glacier's (Central Pyrenees) evolution from 1981 to 2022:
ice loss observed from historic aerial image photogrammetry and
remote sensing techniques**

Ixeia Vidaller¹, Eñaut Izagirre², Luis Mariano del Río³, Esteban Alonso-González⁴, Francisco Rojas-Heredia¹,
Enrique Serrano⁵, Ana Moreno¹, Juan Ignacio López-Moreno¹, and Jesús Revuelto¹

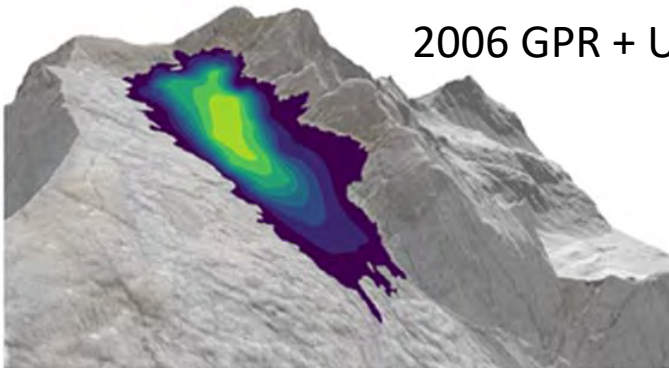


How much ice remains?

2024 Monte Perdido
2016 GPR + UAV/LiDAR



2024 Ossoue
2006 GPR + UAV/LiDAR

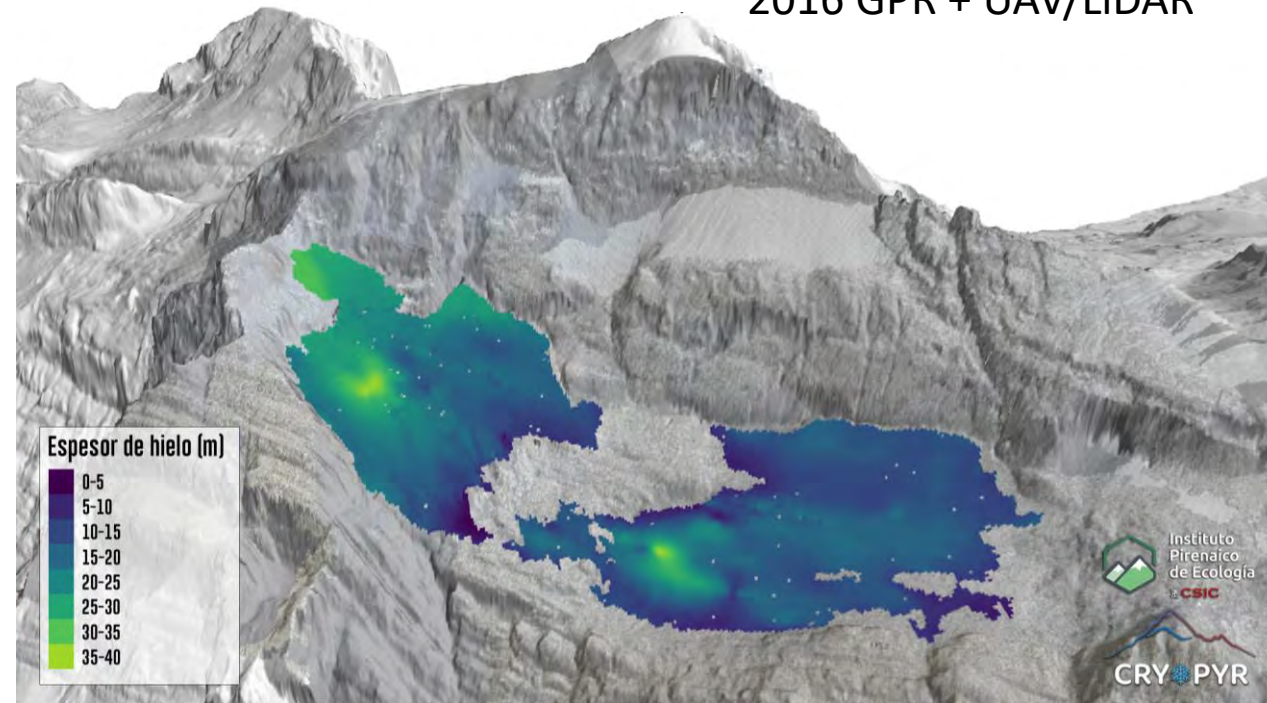


2025

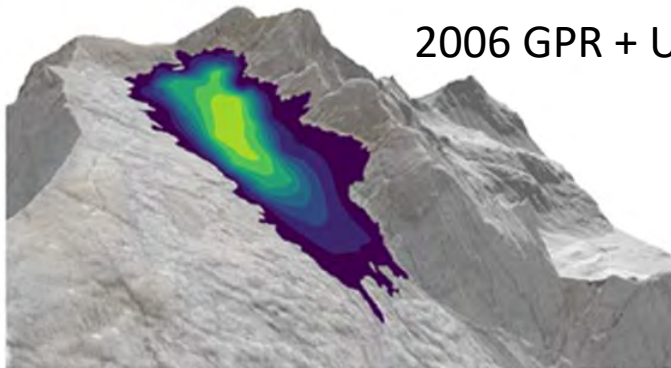


How much ice remains?

2024 Monte Perdido
2016 GPR + UAV/LiDAR



2024 Ossoue
2006 GPR + UAV/LiDAR



2025



Instalación de 9 estacas de ablación (2013)

- Posiciones GPS diferencial
- Movimiento hielo

Glaciar de Monte Perdido



En un año observadas diferencias de hasta 5m

Perdida espesor media 2,5 m
Distancia promedio: 3,5 m

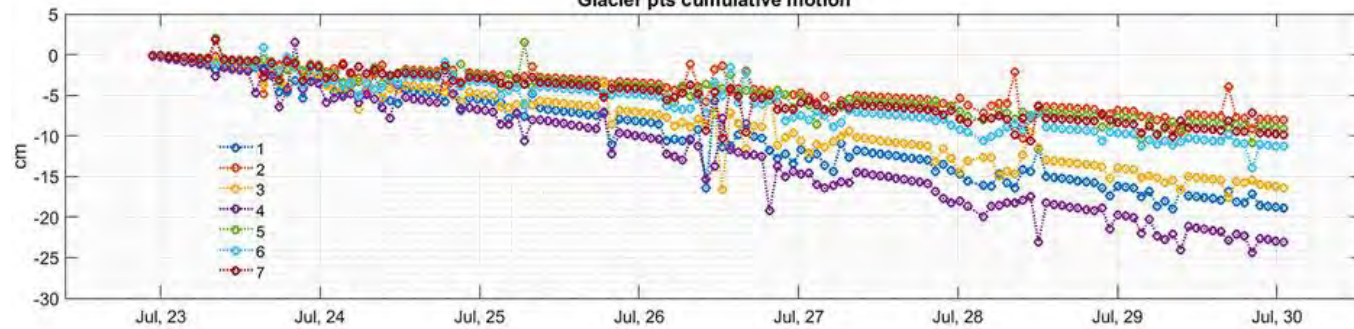


Observación GBSAR en verano 2015

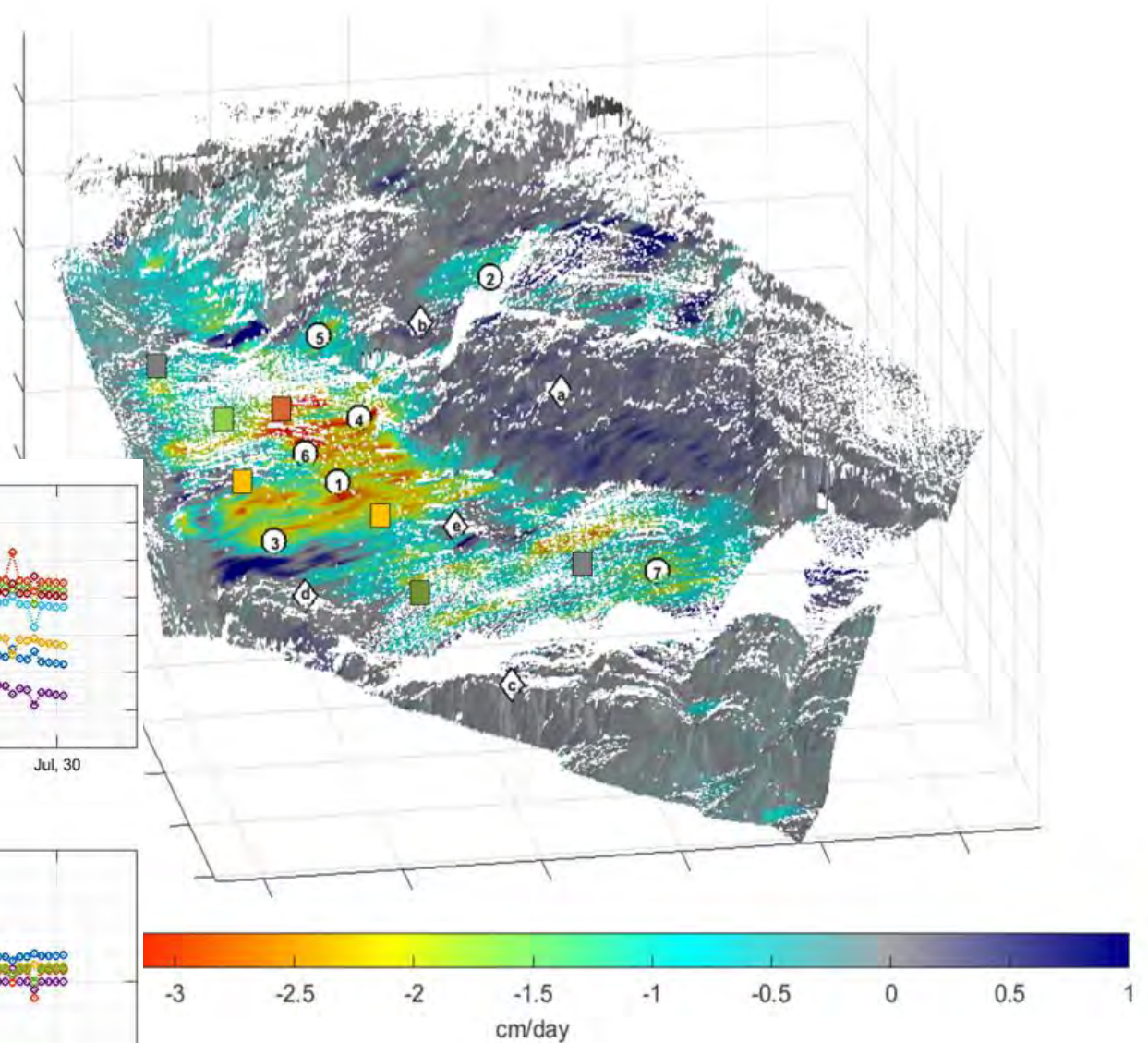
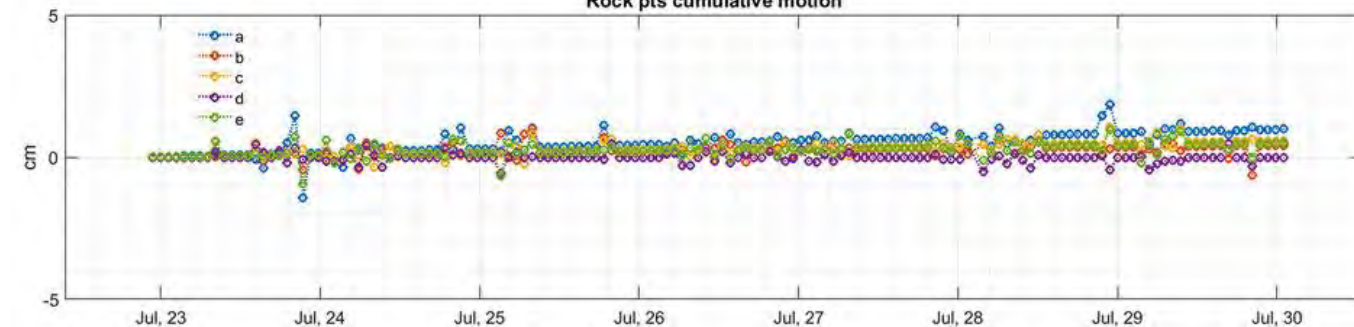
- Movimiento de hielo entre 1 y 4 cm diarios
- Zona central (donde mas “fluye” el glaciar 2,5- 3,5 cm /dia)



Glacier pts cumulative motion



Rock pts cumulative motion



Movimiento diario del Glaciar de Monte Perdido

Journal of Glaciology

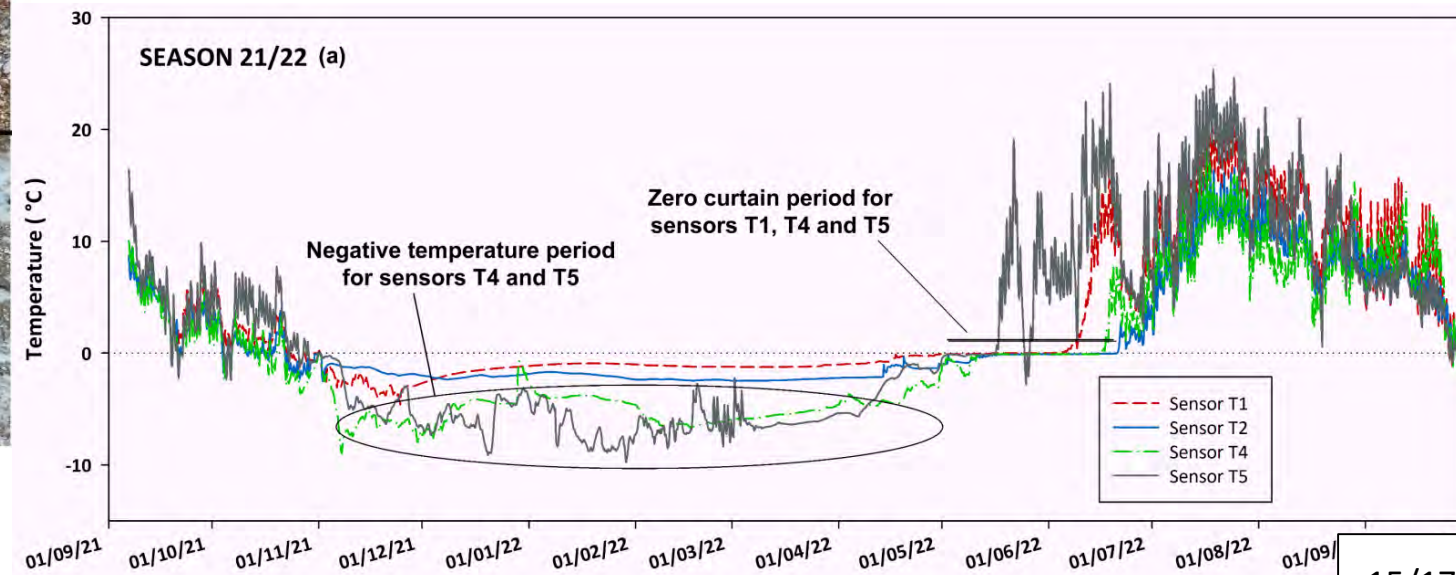
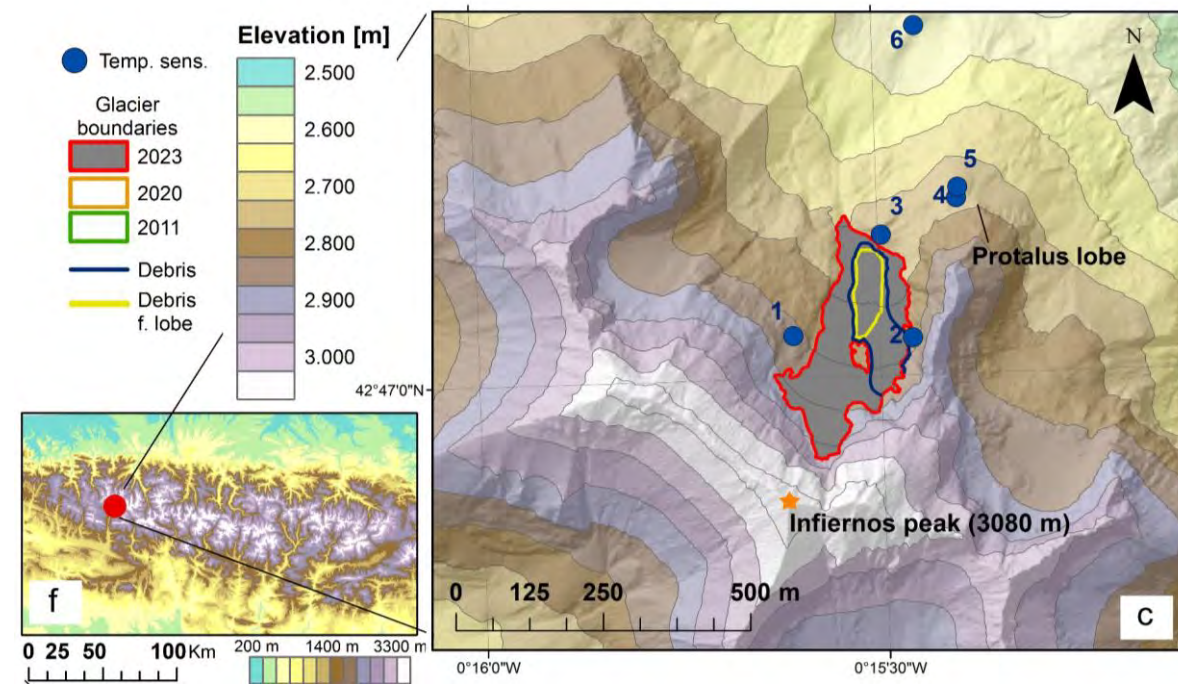
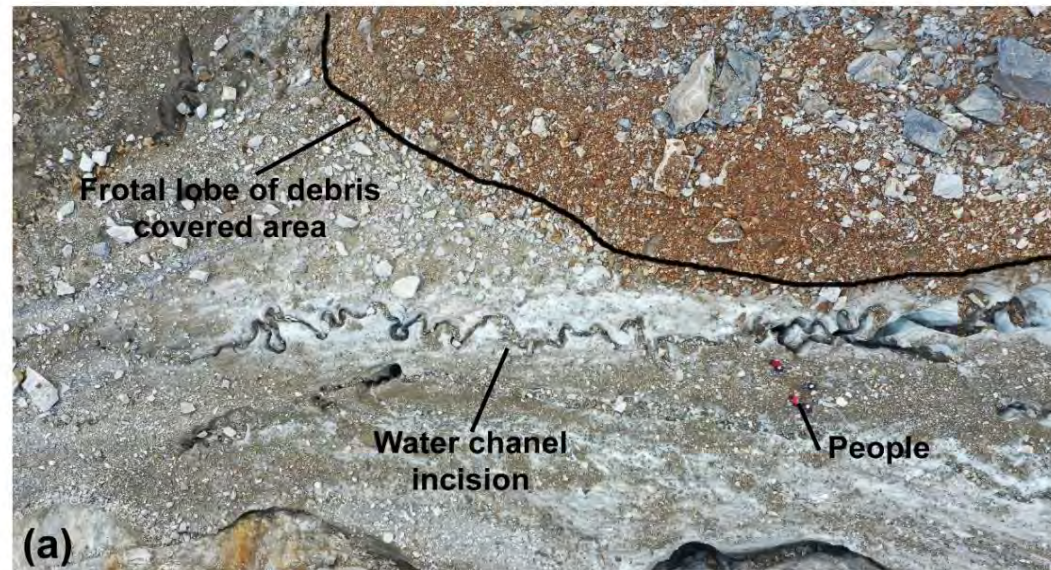
Article

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Registro de tiempo pasado ¿qué ha preservado el glaciar?

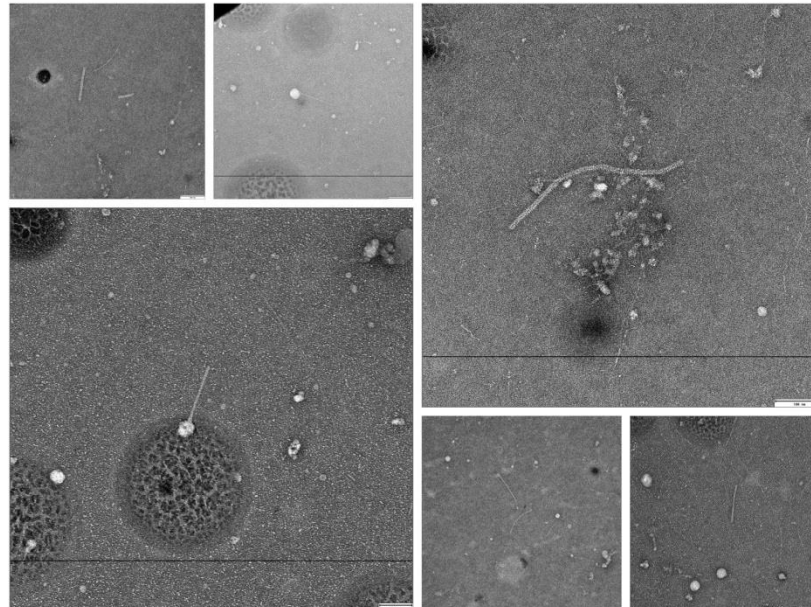
Estudiar el contenido del hielo como registro ambiental y biológico

Estudiar la composición microbiana y viral de muestras de agua del glaciar (y otras zonas)

Metagenómica de bacterias, virus, hongos, algas...

¿Para?

Comparar la microbiota actual y pasada de estos ecosistemas con la que puede aparecer en el futuro



Transición de nuevos ecosistemas en zonas deglaciadas



Lago ignominato (3110 m s.n.m.) a los pies del glaciar del aneto, se formó hace 9-10 años...

Estudio de suelos y vegetación en zonas recientemente deglaciadas. Collado Maldito 3255 m s.n.m.



Science of the Total Environment 967 (2025) 178740

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Incipient soils: New habitats in proglacial areas of the Maladeta massif (Central Pyrenees)

Ixeia Vidaller^{a,*}, Xosé Luis Otero^b, José Mariano Igual^c, Gabriel Nuto Nobrega^d,
Tiago Osorio Ferreira^e, Ana Moreno^a, Juan Ignacio López-Moreno^a



Estudio de procesos erosivos en entornos deglaciados

Mejorar la comprensión de los procesos que rigen la evolución del hielo/nieve

Estudio de procesos erosivos en entornos recientemente deglaciados

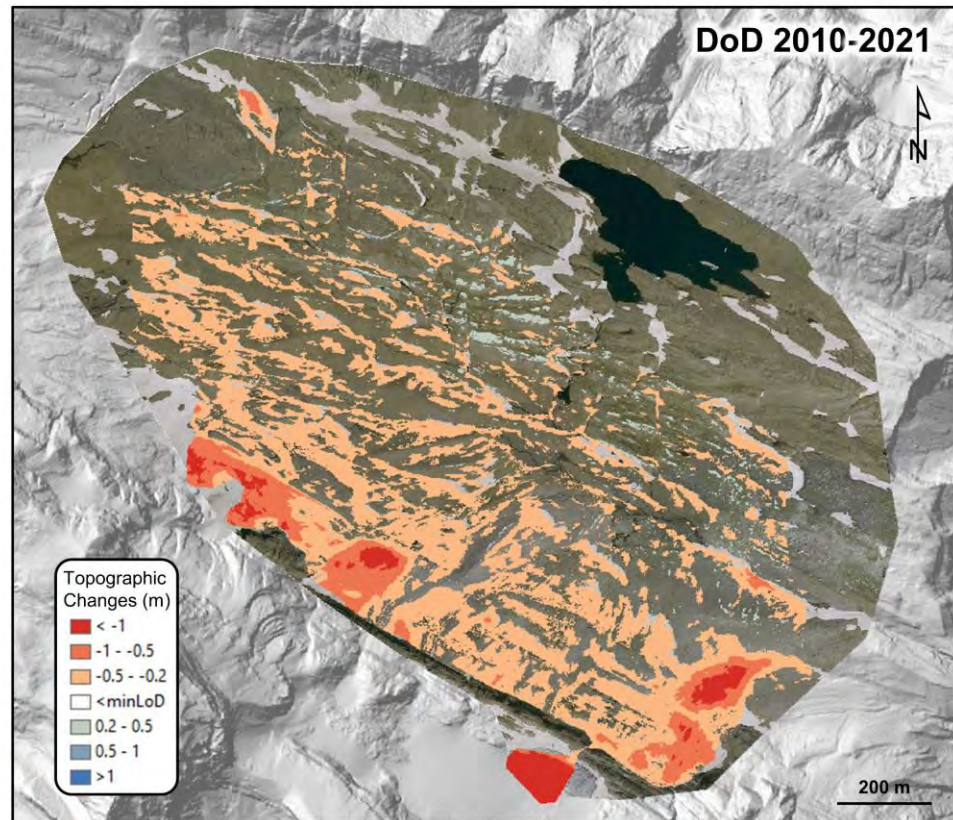
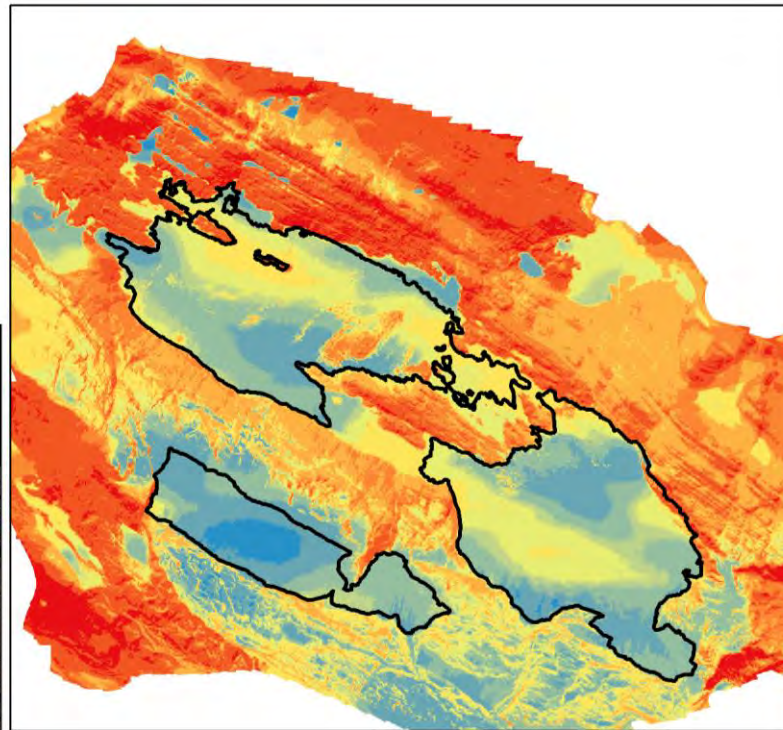
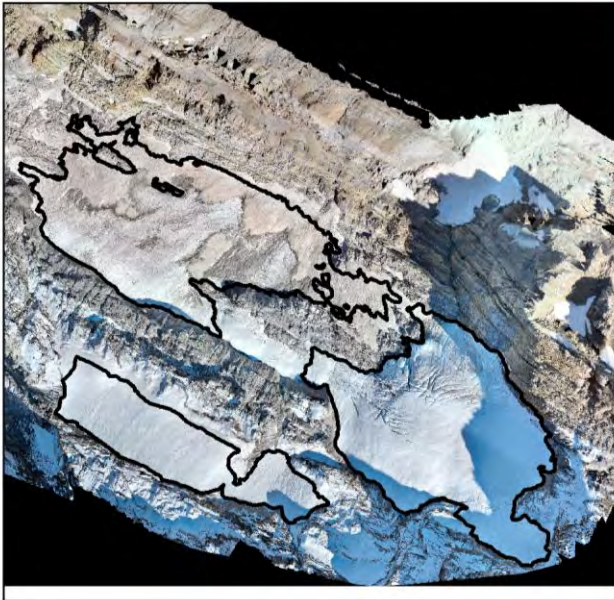
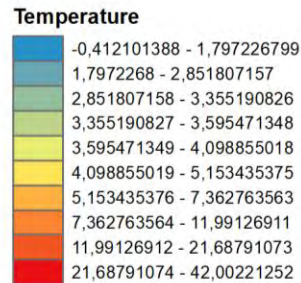


Fig1

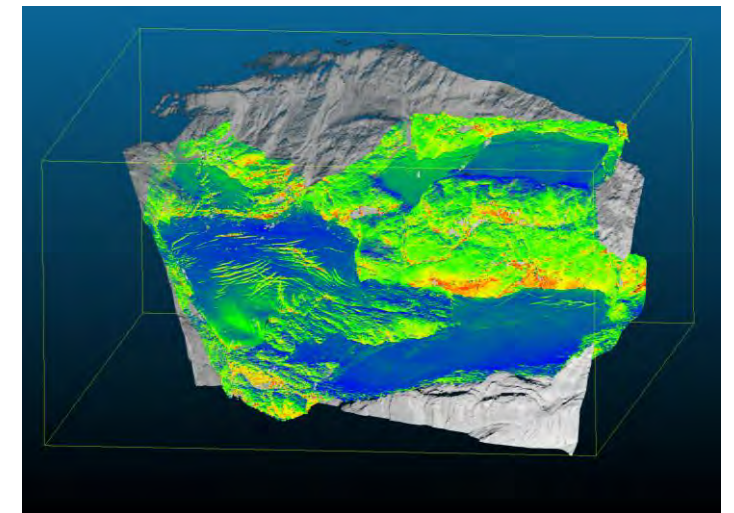
¿Qué se puede esperar en las próximas décadas?

Glaciares Pirenaicos

- Control de la topografía en su evolución futura muy complejo. ¿Control topoclimático?



13:20 del 1 de Septiembre de 2024



	Feature	Observed processes	Glaciological significance
1	Absence of crevasses	Ice lacks traction or extension crevasses, proving the absence of internal flow. The ice body behaves like a rigid block.	This is the most important feature, especially when studying the evolution of the ice mass from the presence of crevasses to their absence.
2	Melting processes leading to collapse	Melting processes occur inside the ice mass due to air currents and lack of flow. The ice body hollows out and cavities form with a thinning of the roof, which then collapses and causes a sudden retreat of the glacier front.	It is usually present, although it is often not visible on the surface, but only at the bottom. If they have already formed, they can be detected by aerial photography or UAVs.
3	Water incisions in the ice, rectilinear or meandering, with water circulation through the substrate	Water flowing over the ice mass creates incisions in the ice that extend to and circulate through the substrate or ground moraine. In this way, the ice masses are separated from each other and do not deform or eliminate these incisions in the absence of flow continuity.	This is very common, but when water circulates on ice or substrate. In unfavourable years, it is also visible on the upper part of the glacier.
4	Disconnection of the accumulation area	The ice mass is separated from the accumulation area, stopping the supply and transformation processes of snow into snow and ice, as well as deformation and flow.	This is not only the case with ice patches. There are glaciers that split but remain as fragmented glaciers, usually by mass or slope transfer, or by input from another (regenerated) glacier.
5	No false bergschrund or fracture in the upper part in contact with the wall	The false bergschrund, that is, the gap between the ice and the wall over the upper part, is not present, so that the ice rests directly on the wall. If landslides or rockfalls occur, the pressure of the ice during the rotational movement on the wall causes fractures.	This is a clear indicator, but it does not always occur, and there are ice patches as well as snowfields that can have false bergschrunds.
6	Covering debris by falling rocks or moraine sediments	The ice is gradually covered with debris, partly by melt leaving englacial debris on the surface, and partly by falling rocks of moraine sediments surrounding the glacier. There are no contributions from the ice (shear crevasses, folds or fractures).	The distinction between a debris cover on the glacier and an ice-patch is tricky. The important point is that this debris cover mostly favours the preservation of the ice-patch.
7	Fragmentation in relict ice bodies	Ice mass fragments into smaller bodies between cirques, walls, or thresholds, loses its dynamic connection (thrust, flow, deformation), and eventually become independent ice masses.	This is very obvious in the smallest glaciers and ice-patches, but in larger glaciers their fragmentation does not mean that they become ice-patches.

Degradación glaciar a helero

