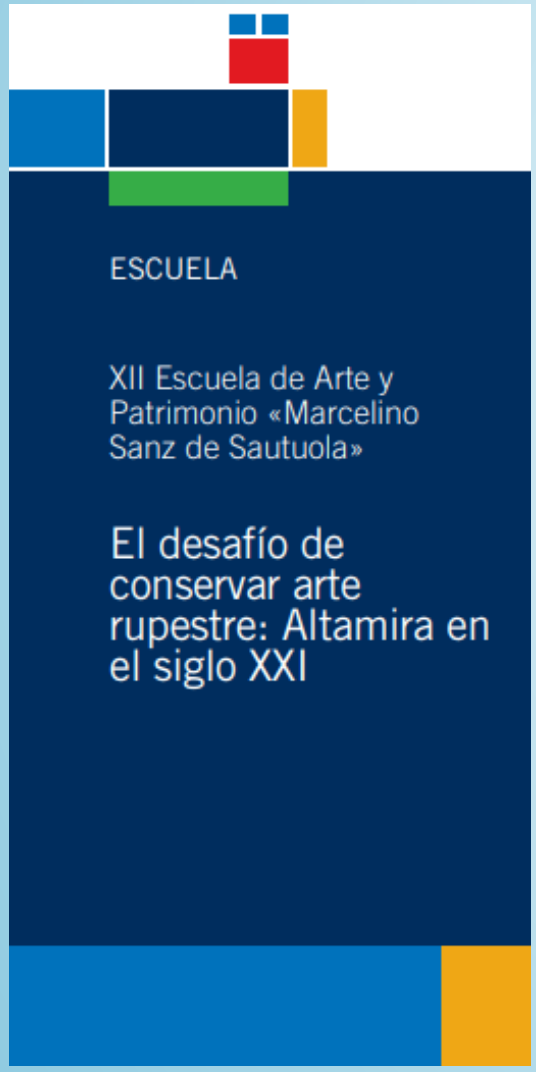
UIMP Universidad Internacional Menéndez Pelayo

Cursos de verano Santander 25



EL SEGUIMIENTO AMBIENTAL EN ALTAMIRA

Carlos Sainz Fernandez

Catedrático de la Universidad de Cantabria

UC UNIVERSIDAD DE CANTABRIA

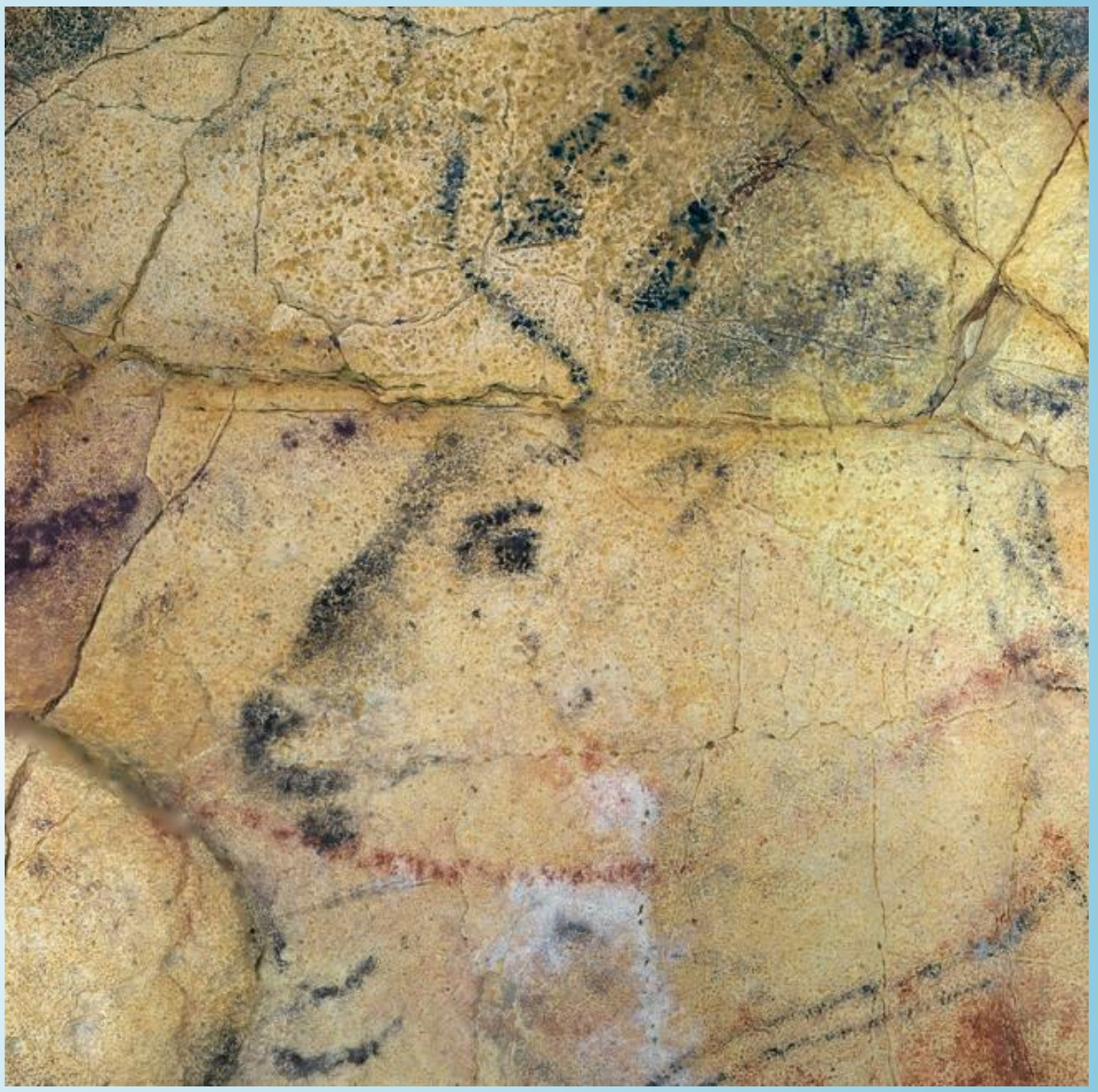
UC UNIVERSIDAD DE CANTABRIA LaRUC Laboratorio de Radiactividad Ambiental

Contexto físico de la cueva de Altamira

¿Qué es el seguimiento ambiental?

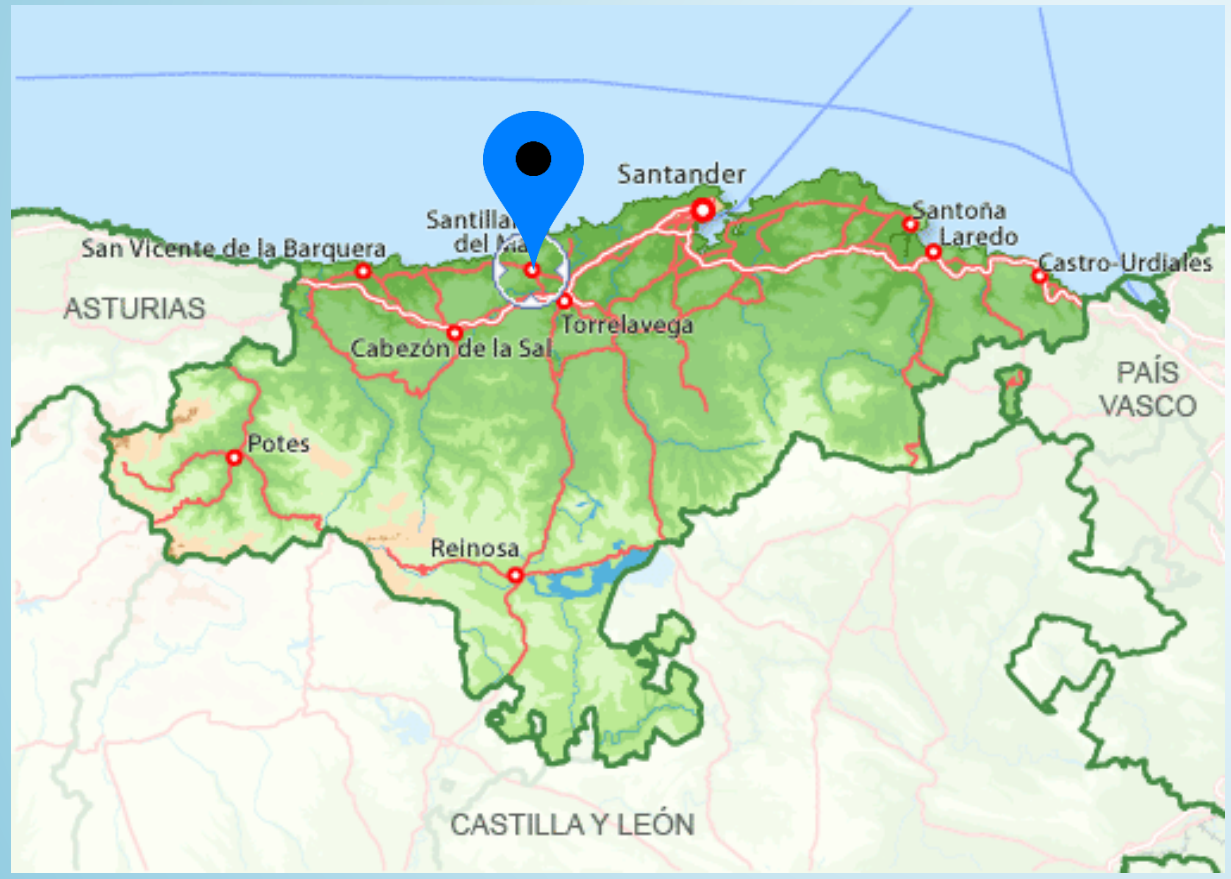
Resultados temperatura, agua, gases, influencia antrópica

Investigación

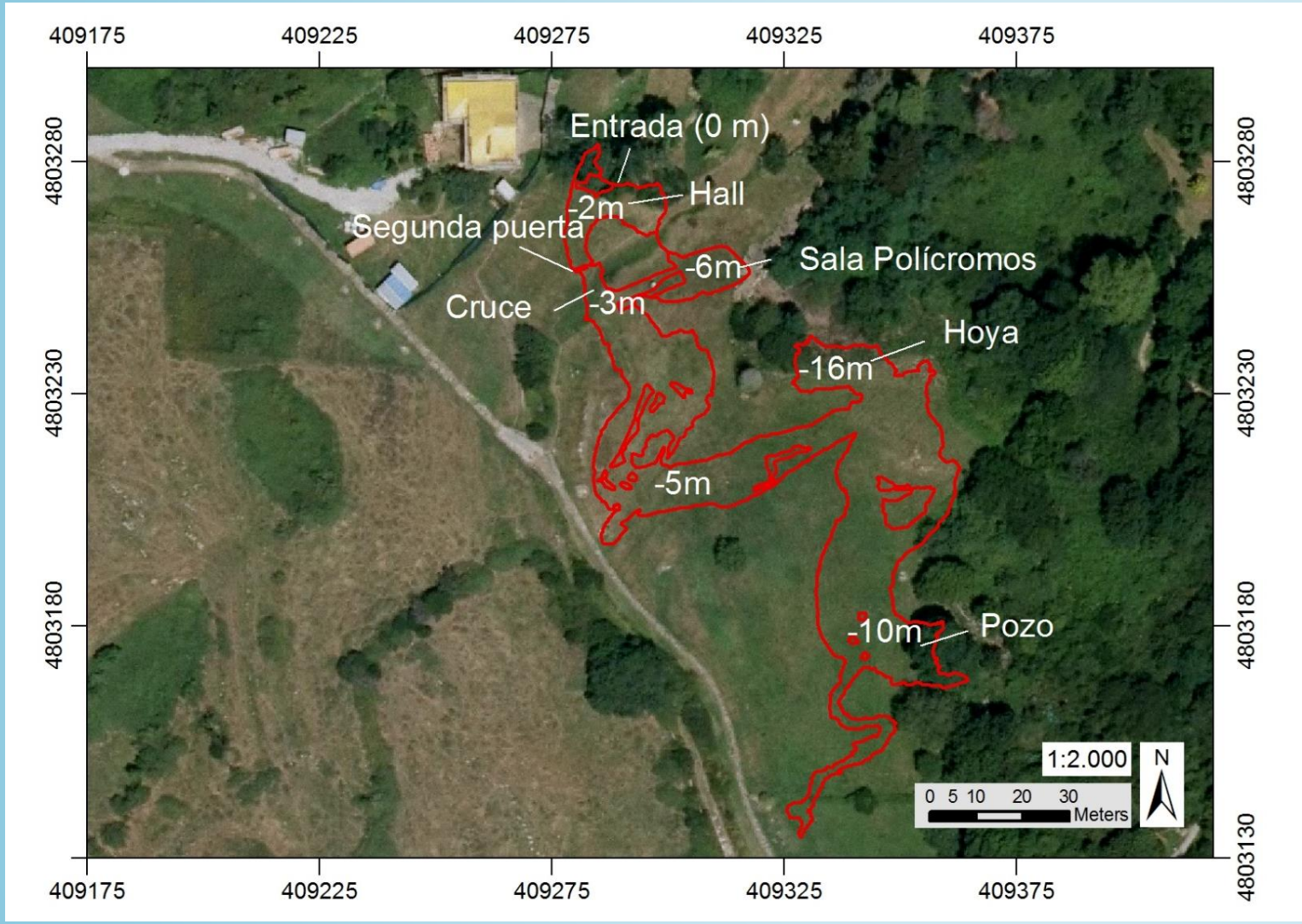


La Cueva de Altamira

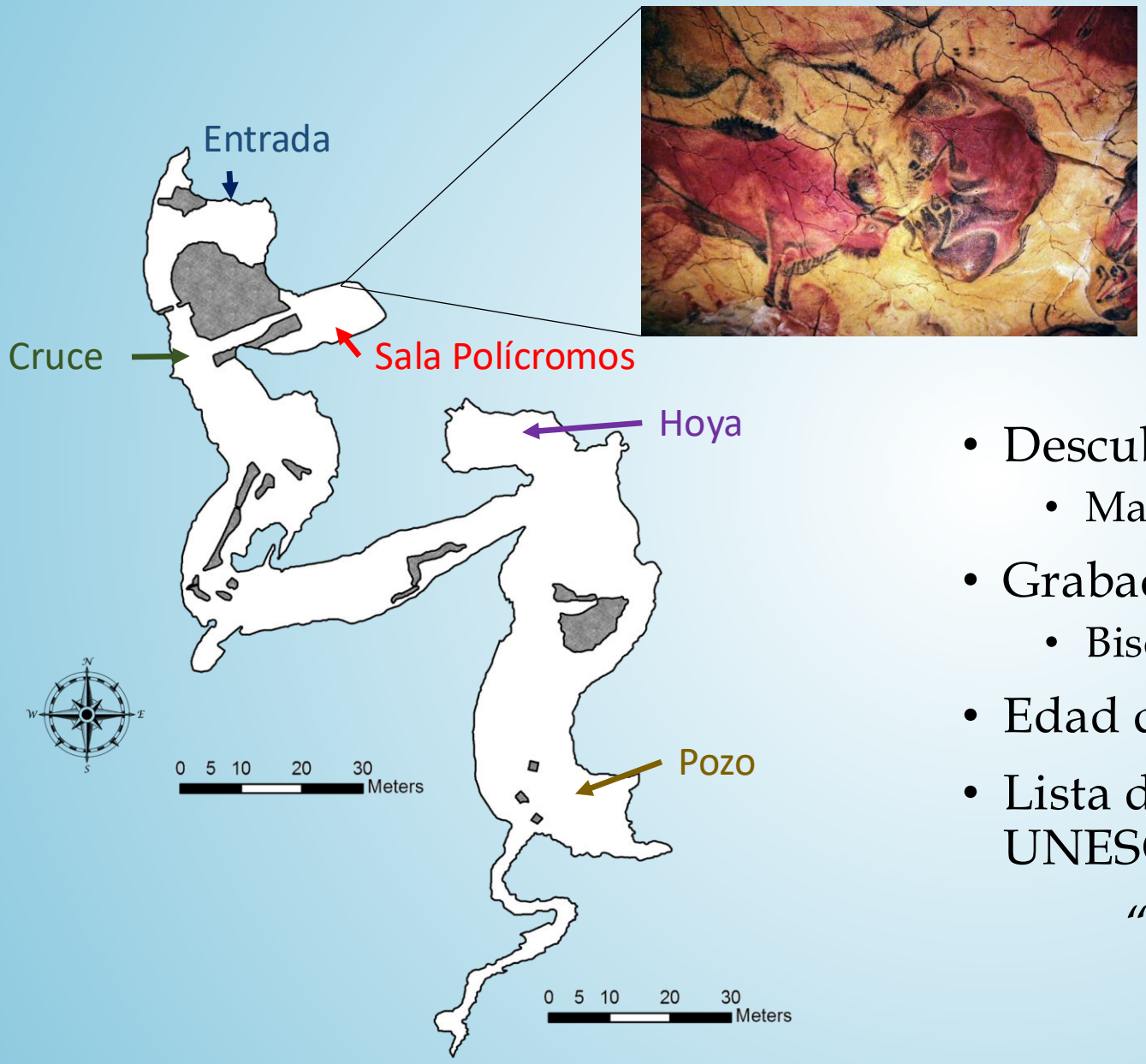
- Situación



- Santillana del Mar
- Sistema kárstico
- Cueva superficial
- Cota 152 m sobre nivel del mar
- 270 m de longitud


409175
409225
409275
409325
409375
4803280
4803230
4803180
4803130
Entrada (0 m)
Hall
-2m
Segunda puerta
-6m
Sala Polícromos
Cruce
-3m
Hoya
-16m
-5m
-10m
Pozo
1:2.000
N
0 5 10 20 30
Meters

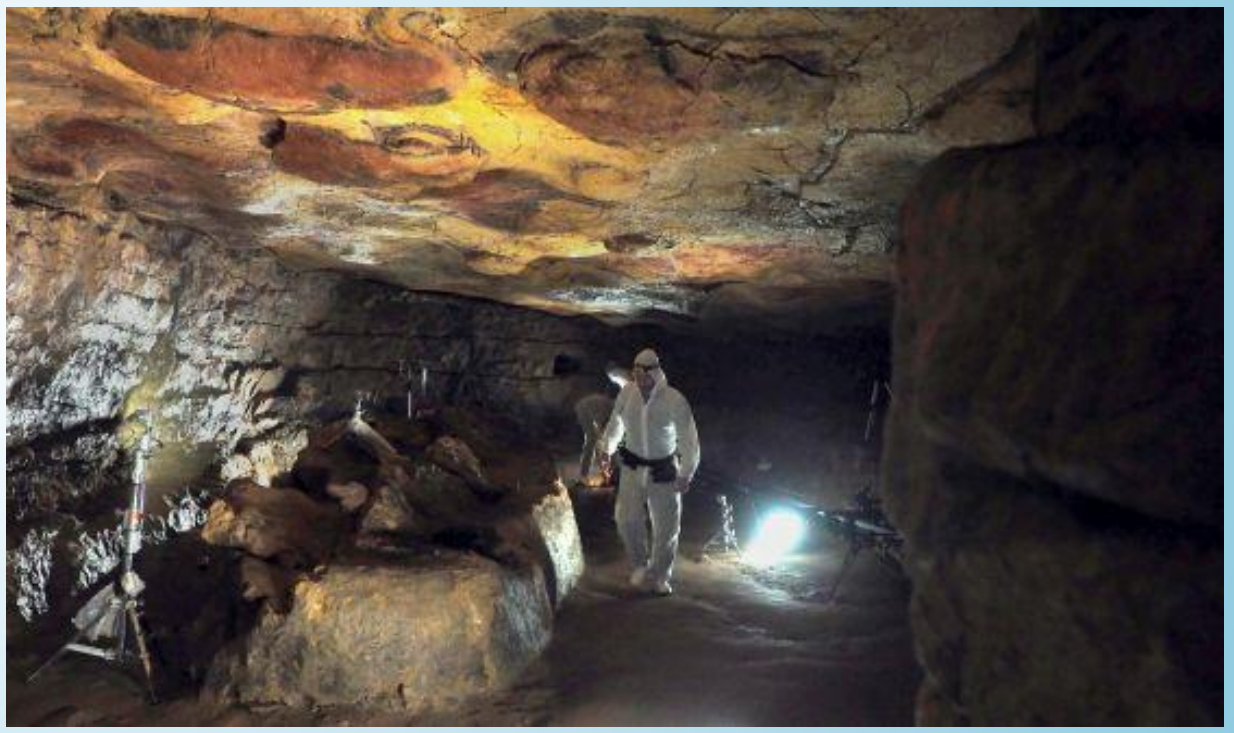
La Cueva de Altamira

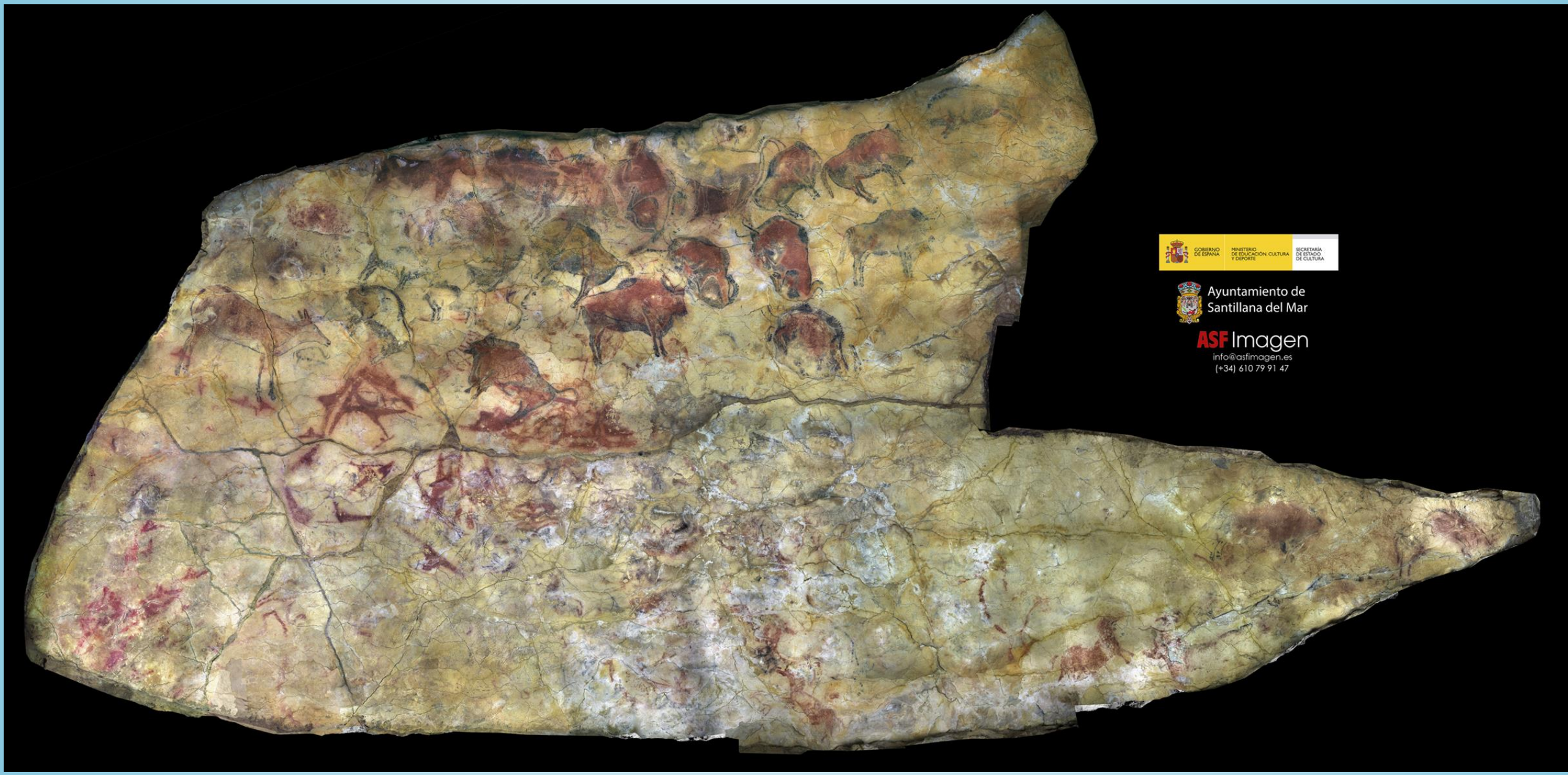


- Descubierta en 1868, Modesto Cubillas.
  - Marcelino Sanz de Sautuola 1875
- Grabados y pinturas por toda la cueva
  - Bisontes, ciervos, caballos y jabalíes
- Edad desde 13.000 hasta 35.600 años BP
- Lista de Patrimonio Mundial por la UNESCO desde 1985

"Valor universal excepcional"

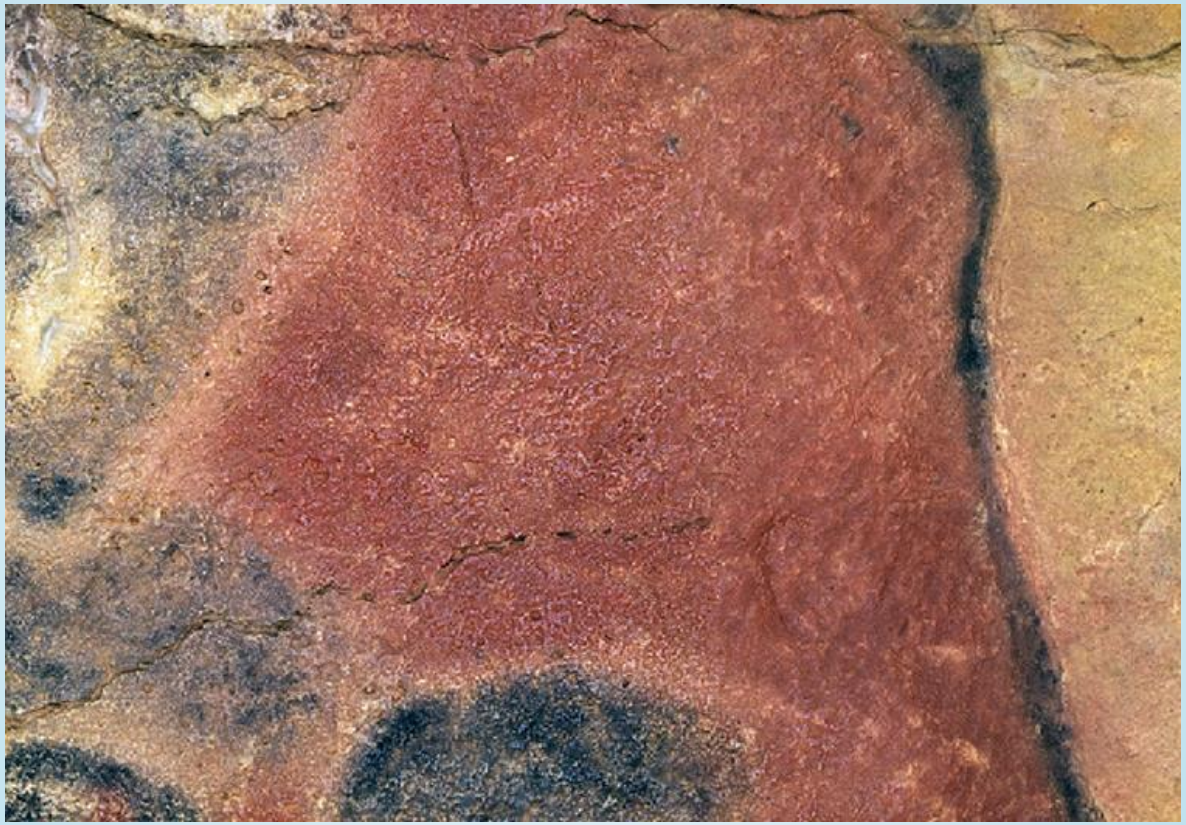
Sala de Polícromos




GOBIERNO DE ESPAÑA
MINISTERIO DE EDUCACIÓN, CULTURA Y DEPORTE
SECRETARÍA DE ESTADO DE CULTURA
Ayuntamiento de Santillana del Mar
ASF Imagen
info@asfimagen.es
(+34) 610 79 91 47

Estado de conservación tras 30000 años… Sistema de baja oscilación ambiental

¿Condiciones de equilibrio?



¿Cuál es el ambiente "natural"?

¿Cómo conservar el arte?

¿Influencia humana?

SEGUIMIENTO CIENTÍFICO Y OBSERVACIONAL

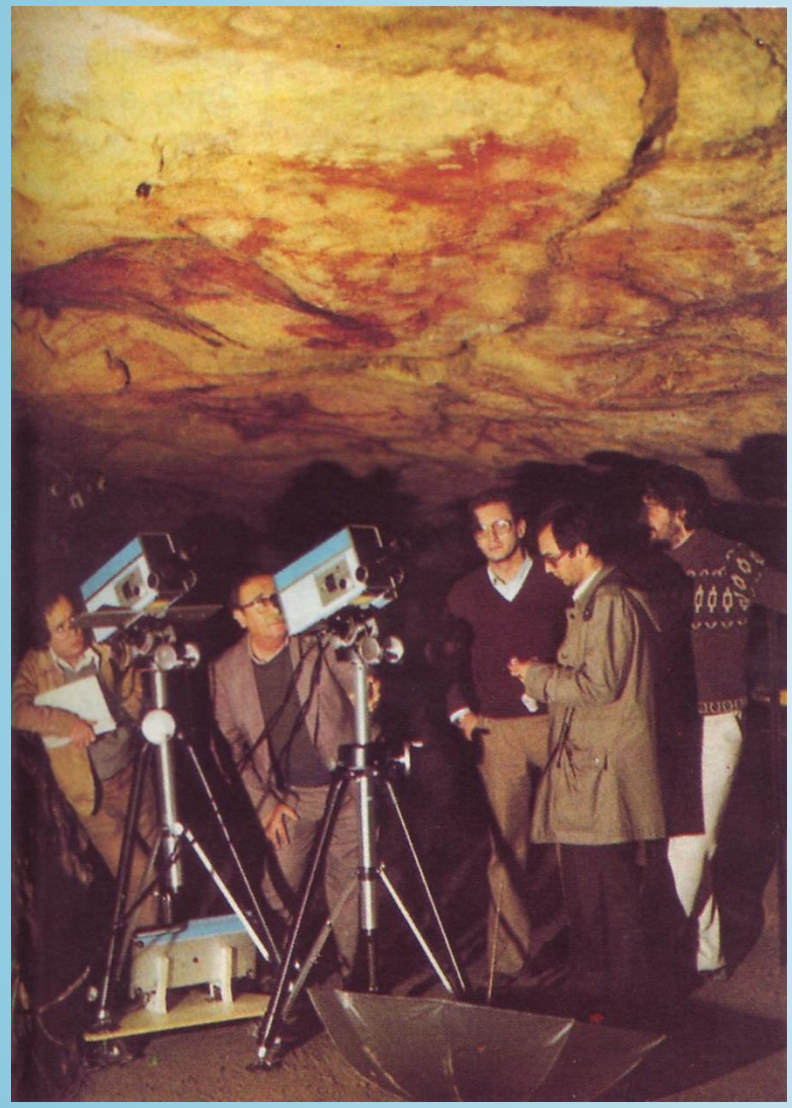
Observación estado (soporte, policromía)

Estabilidad geológica

Condiciones ambientales

Biodeterioro

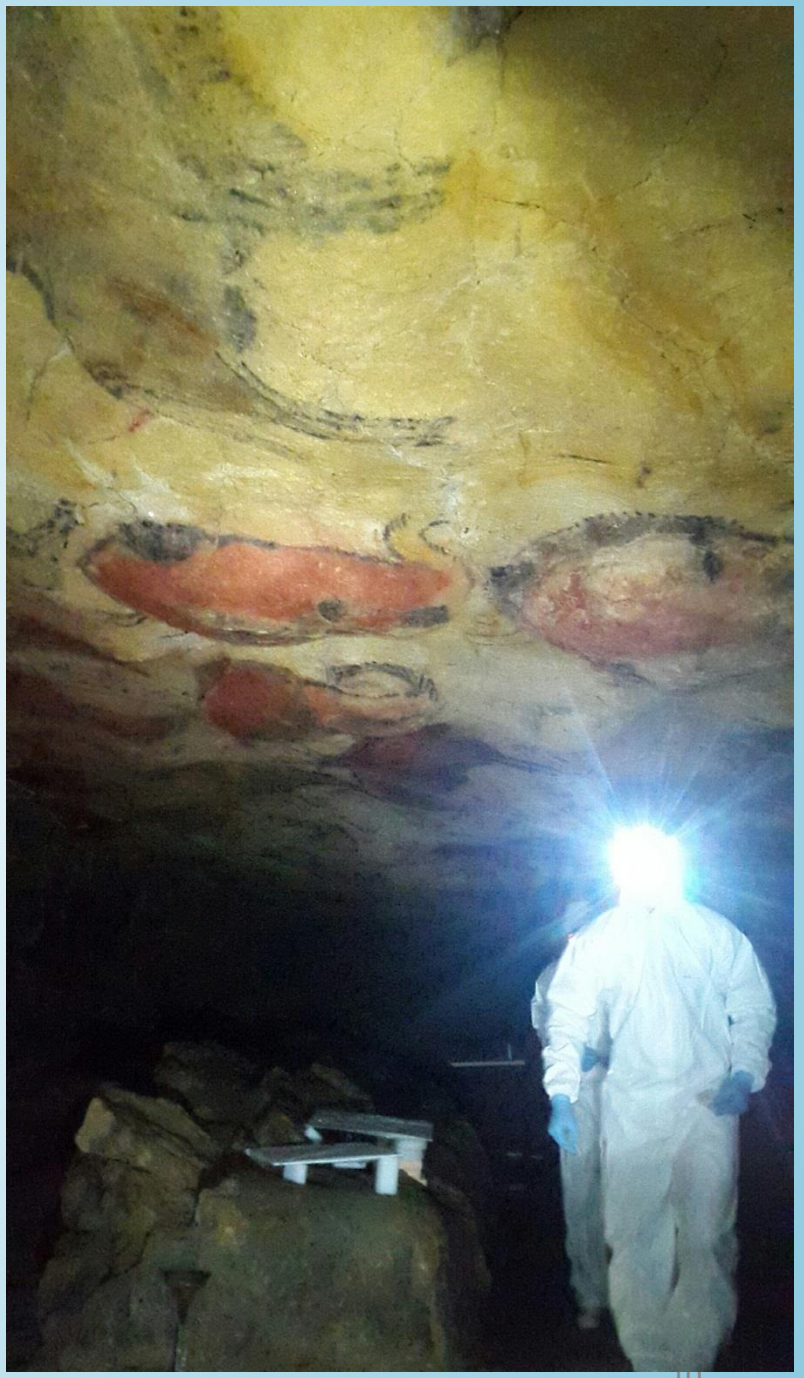
Accesibilidad



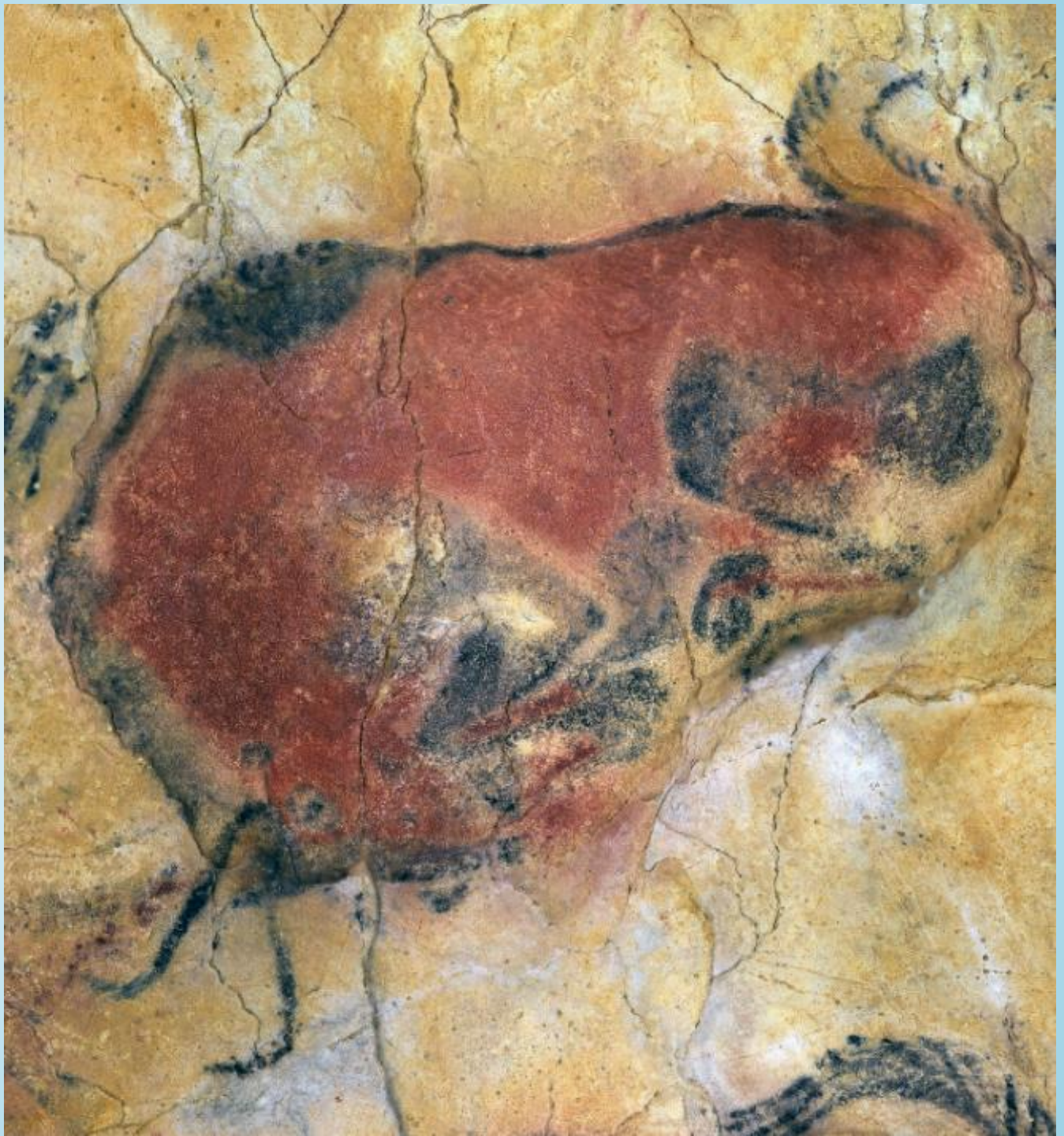
¿Qué es el SEGUIMIENTO AMBIENTAL?

VARIABLES Físico Químicas de interés para la conservación

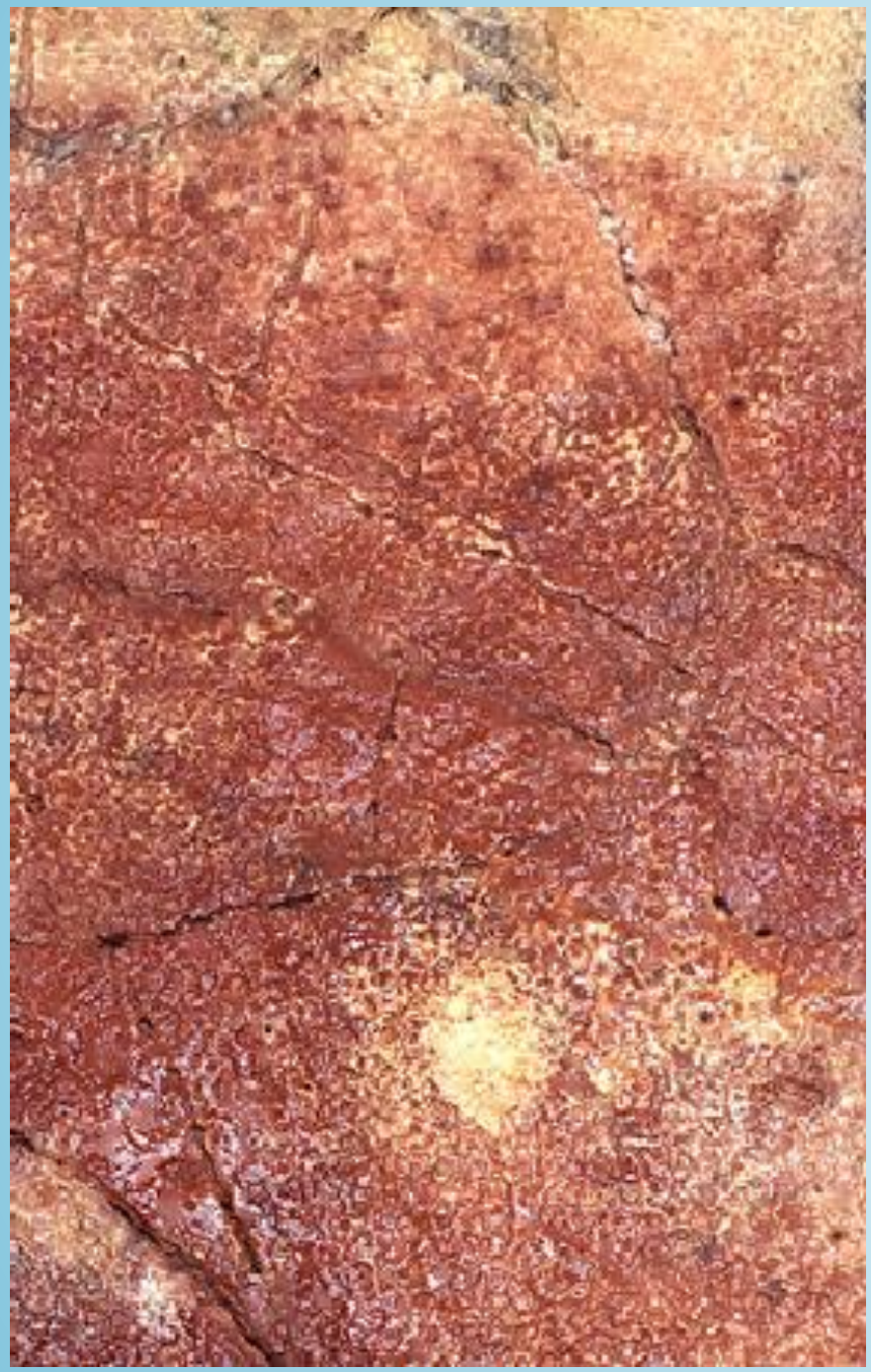
Control y minimización de RIESGOS



VARIABLES Físico Químicas de interés para la conservación



“More is different”
Philipp W. Anderson
Nobel 1977



CAUSAS DE DETERIORO

Desprendimiento del soporte (estabilidad mecánica)

Corrosión por contaminación química (poco probable, aislamiento)

Disolución y arrastre de pigmentos (lento, inexorable)

Descamación (disminución humedad, dilataciones/contracciones)

Precipitación de carbonatos (evaporación rápida, precipitación directa)

Destrucción por microorganismos

¿mas…?

Mecanismos de deterioro

- DESCAMACIÓN

- Disminución de propiedades adhesivas de los pigmentos/Dilataciones y contracciones de los materiales del techo
- Cambios relevantes de humedad
- Cambios bruscos de temperatura del techo

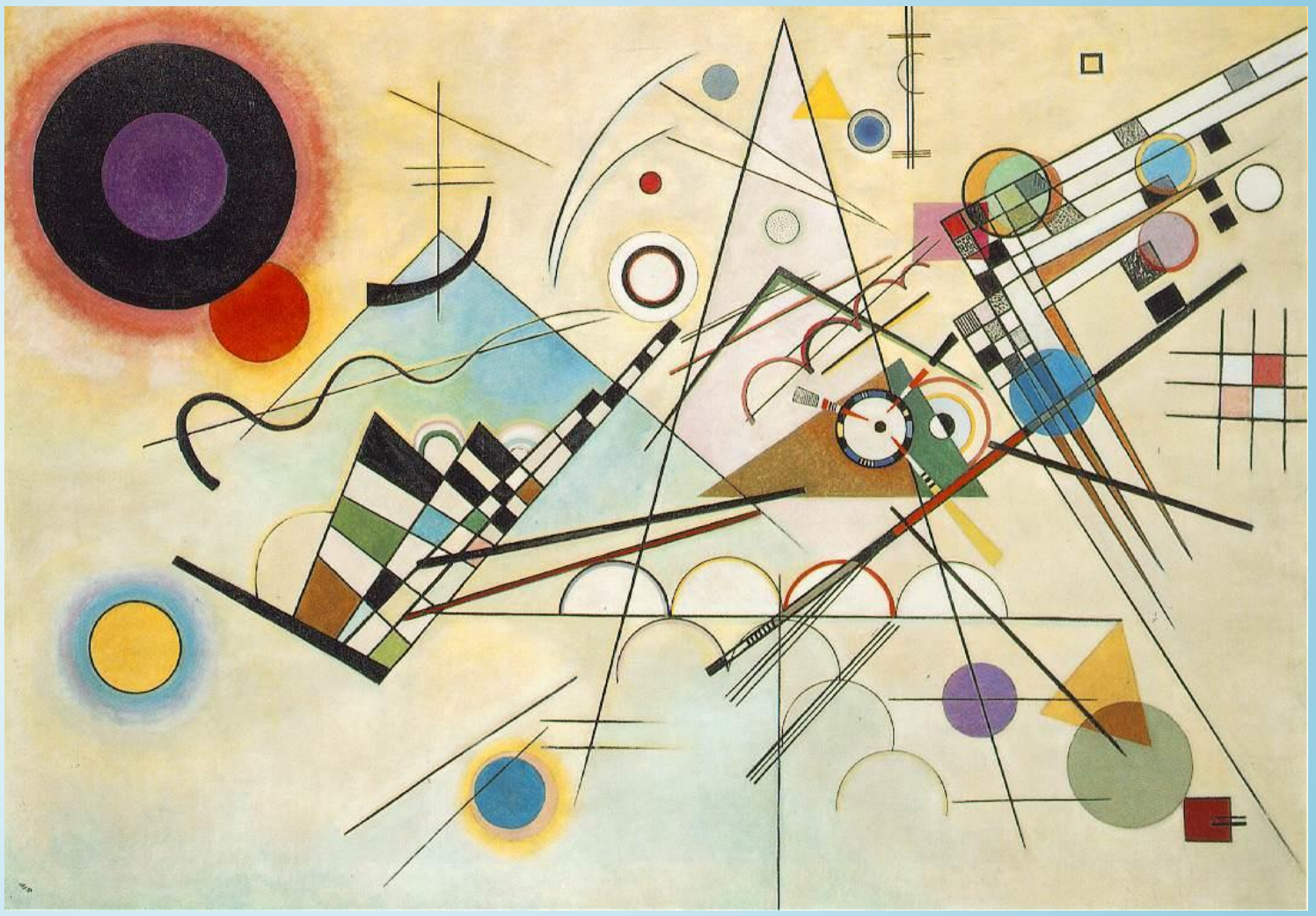
- DISOLUCIÓN DE SOPORTE Y ARRASTRE

- Proceso inexorable por el baño continuo del techo de Polícromos
- Carácter incrustante/agresivo del agua, CO2
- Pluviometría, vías y caudales de infiltración
- Ciclos de evaporación condensación

Ilustración:
Yolanda Gonzalez

- Campo de Temperaturas (aire, roca)
- Humedades:
  - Precipitaciones y caudal de infiltración
  - Análisis químicos del agua de infiltración
- Gases traza (Radon y CO_2)

¿Cómo se hace el seguimiento ambiental?



(Wassily Kandinsky, 1944)

¿Cómo se hace el seguimiento ambiental?

Equipamiento de precisión

Procedimientos rigurosos y validados

Equipo humano altamente cualificado

Gestión y análisis de datos

EXACTO Y REPRODUCIBLE

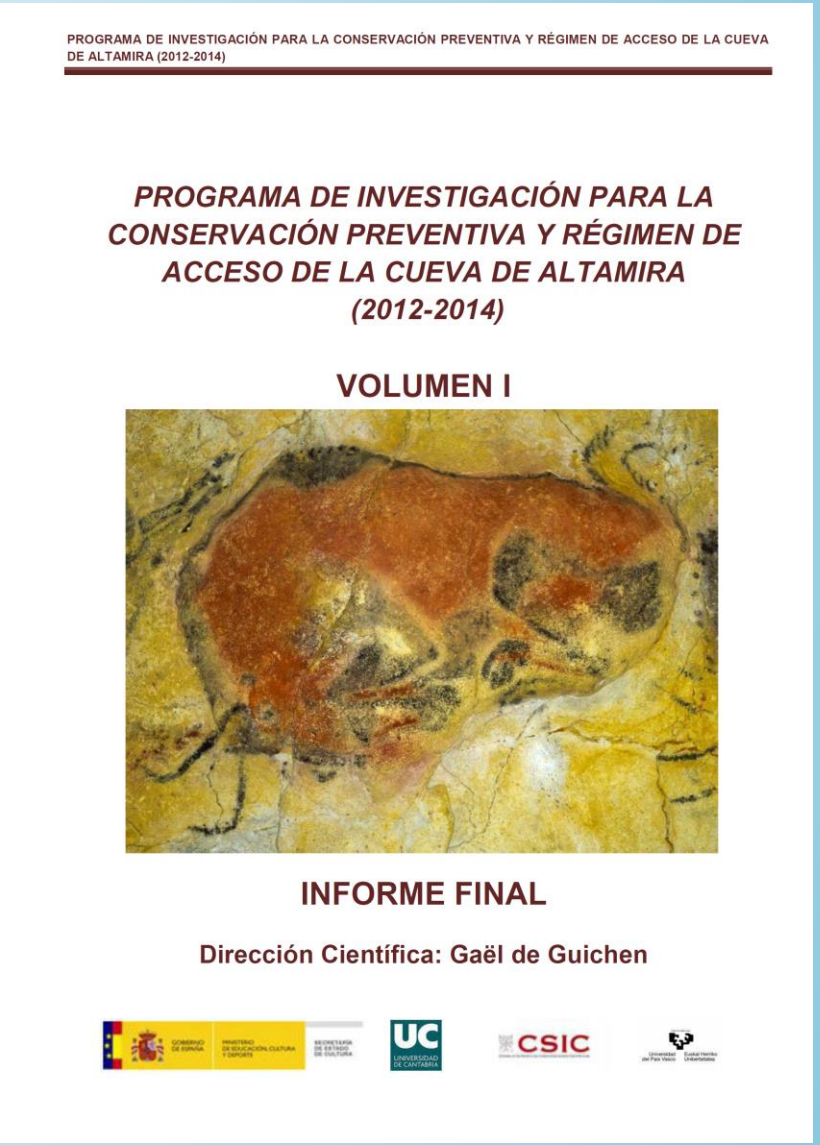
Seguimiento ambiental en Altamira, historia

Seguimiento Ambiental de Altamira, hoy

Programa de investigación para la Conservación Preventiva y de Régimen de acceso a la cueva de Altamira

2012 – 2014 :

- **Definición de métodos de trabajo SISTEMÁTICOS**
- **Definición de respuestas frente a riesgos para la conservación**



PROGRAMA DE INVESTIGACIÓN PARA LA CONSERVACIÓN PREVENTIVA Y RÉGIMEN DE ACCESO DE LA CUEVA DE ALTAMIRA (2012-2014)

PROGRAMA DE INVESTIGACIÓN PARA LA CONSERVACIÓN PREVENTIVA Y RÉGIMEN DE ACCESO DE LA CUEVA DE ALTAMIRA (2012-2014)

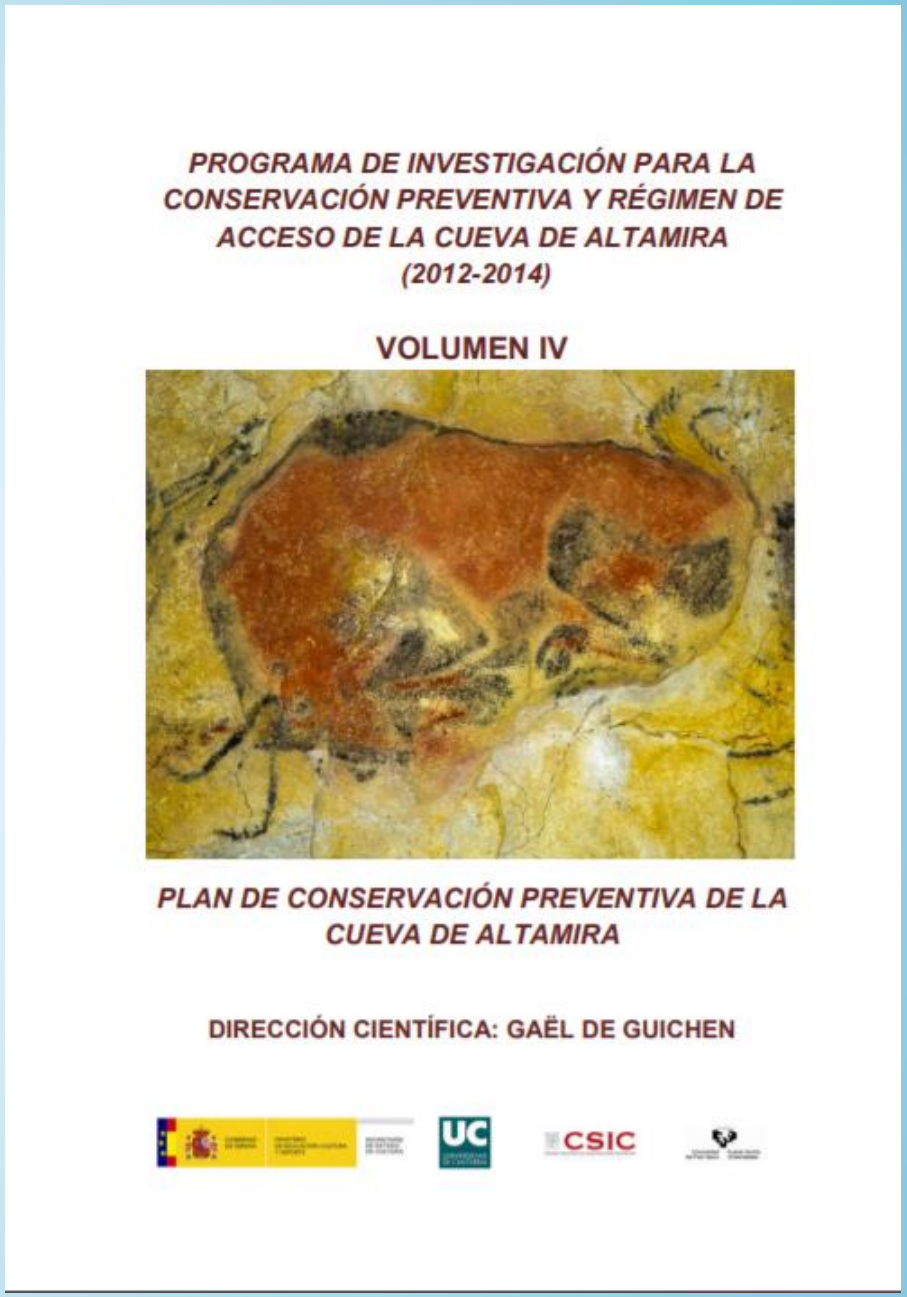
VOLUMEN I

INFORME FINAL

Dirección Científica: Gaël de Guichen

Plan de Conservación Preventiva (PCP)

- Fase 1
  - Análisis de documentación / modificaciones sufridas
  - Condiciones medioambientales cueva y entorno
  - Estado de conservación
- Fase 2
  - Identificación y valoración de los riesgos
- Fase 3
  - Establecer protocolos actuación

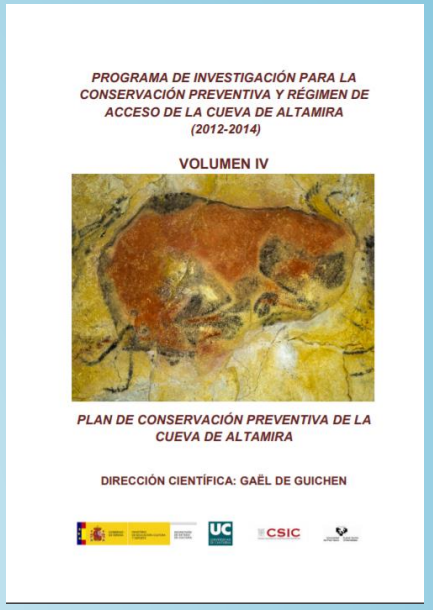

PROGRAMA DE INVESTIGACIÓN PARA LA CONSERVACIÓN PREVENTIVA Y RÉGIMEN DE ACCESO DE LA CUEVA DE ALTAMIRA (2012-2014)

VOLUMEN IV

PLAN DE CONSERVACIÓN PREVENTIVA DE LA CUEVA DE ALTAMIRA

DIRECCIÓN CIENTÍFICA: GAËL DE GUICHEN

Listado de protocolos

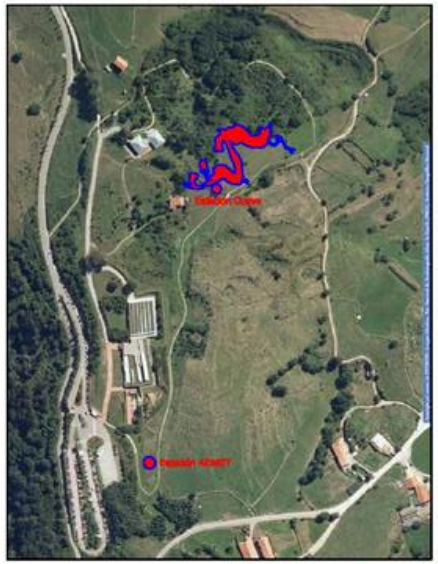

PROGRAMA DE INVESTIGACIÓN PARA LA CONSERVACIÓN PREVENTIVA Y RÉGIMEN DE ACCESO DE LA CUEVA DE ALTAMIRA (2012-2014)

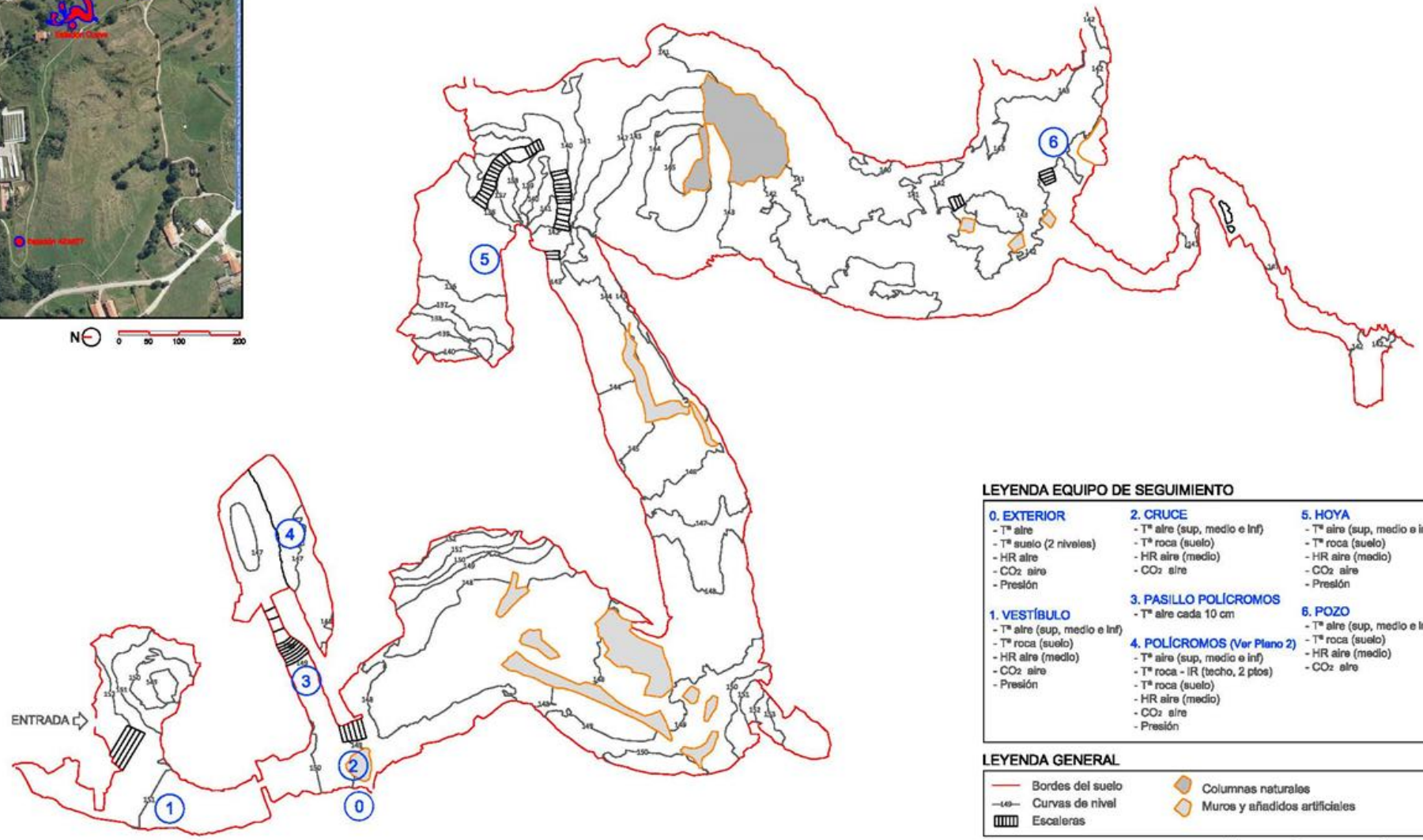
VOLUMEN IV

PLAN DE CONSERVACIÓN PREVENTIVA DE LA CUEVA DE ALTAMIRA

DIRECCIÓN CIENTÍFICA: GAËL DE GUICHEN

- P01- Normas de acceso
- P02- Control del biodeterioro
- P03- Seguimiento de la concentración de gas radón
- P04- Condiciones ambientales
- P05- Seguimiento de humedades y puntos de goteo
- P06- Seguimiento del estado de conservación
- P07- Estabilidad geológica-estructural
- P08- Control de las actividades en las superficie de la zona de influencia de la cueva





LEYENDA EQUIPO DE SEGUIMIENTO

0. EXTERIOR
- Tª aire
- Tª suelo (2 niveles)
- HR aire
- CO_2 aire
- Presión

1. VESTÍBULO
- Tª aire (sup, medio e inf)
- Tª roca (suelo)
- HR aire (medio)
- CO_2 aire
- Presión

2. CRUCE
- Tª aire (sup, medio e inf)
- Tª roca (suelo)
- HR aire (medio)
- CO_2 aire

3. PASILLO POLÍCROMOS
- Tª aire cada 10 cm

4. POLÍCROMOS (Ver Plano 2)
- Tª aire (sup, medio e inf)
- Tª roca - IR (techo, 2 ptos)
- Tª roca (suelo)
- HR aire (medio)
- CO_2 aire
- Presión

5. HOYA
- Tª aire (sup, medio e inf)
- Tª roca (suelo)
- HR aire (medio)
- CO_2 aire
- Presión

6. POZO
- Tª aire (sup, medio e inf)
- Tª roca (suelo)
- HR aire (medio)
- CO_2 aire

LEYENDA GENERAL

- Bordes del suelo
- Curvas de nivel
- Escaleras
- Columnas naturales
- Muros y añadidos artificiales

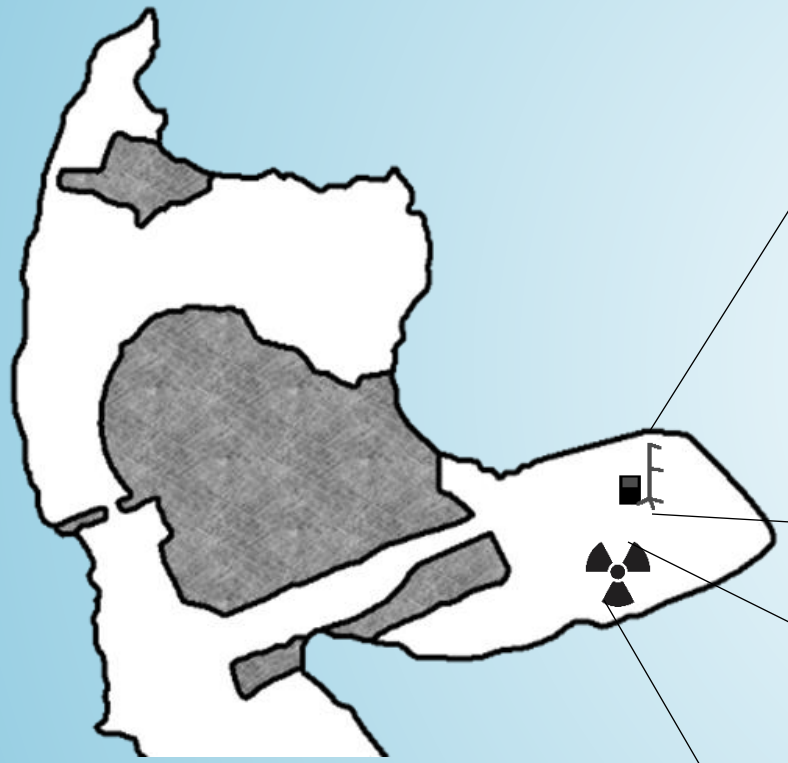
Programa ALTAMI+D

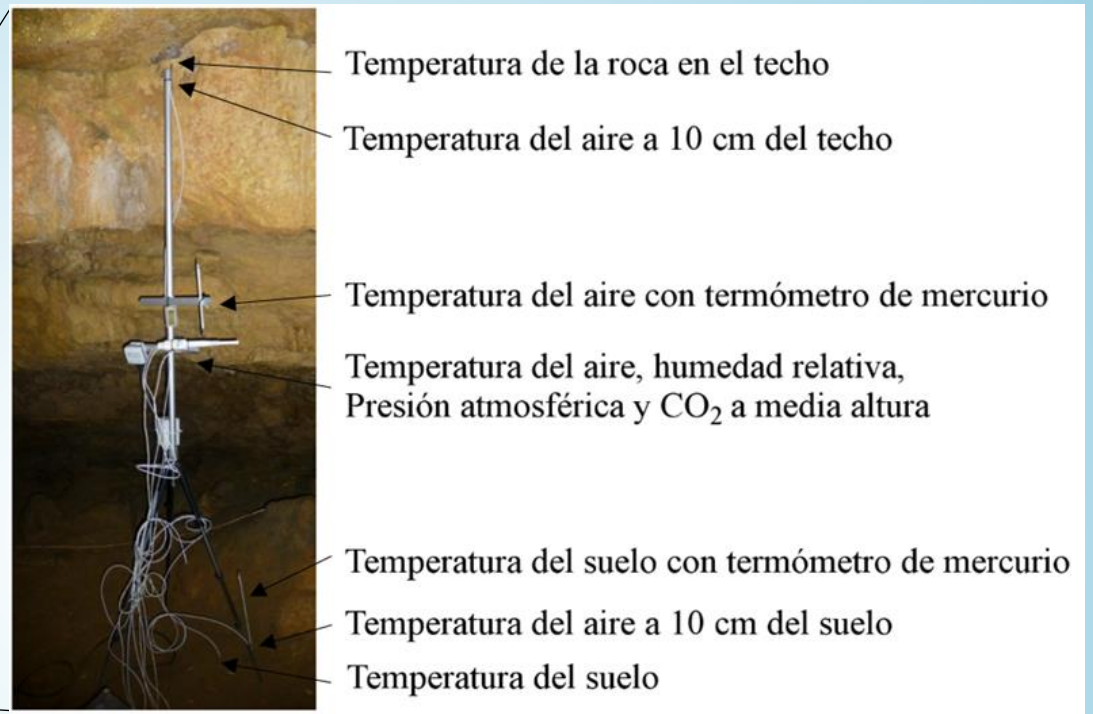
G2: Seguimiento Ambiental
Ubicación puntos de medición

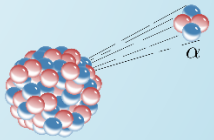
Orientación:	Fecha:	Nº Plano:
N	Rev: Febrero 2016	01

Escala gráfica (metros): 0 5 10 20

Seguimiento ambiental: Medios técnicos



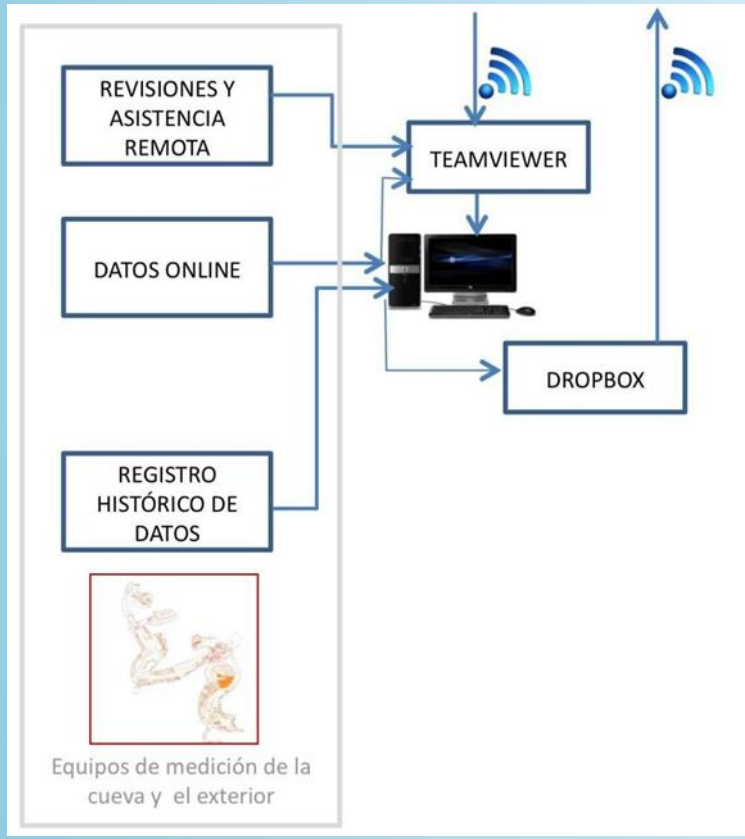




Radón

- Medidas en continuo
- Medidas integradas en el tiempo

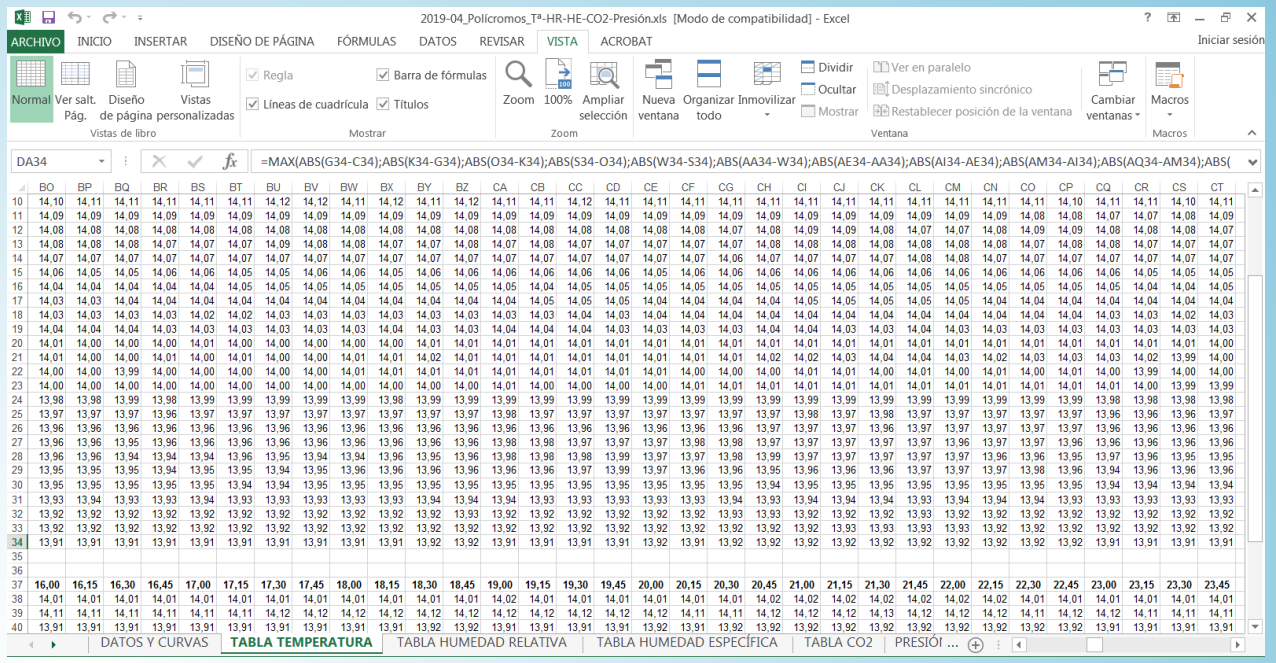
Seguimiento ambiental: Medios técnicos



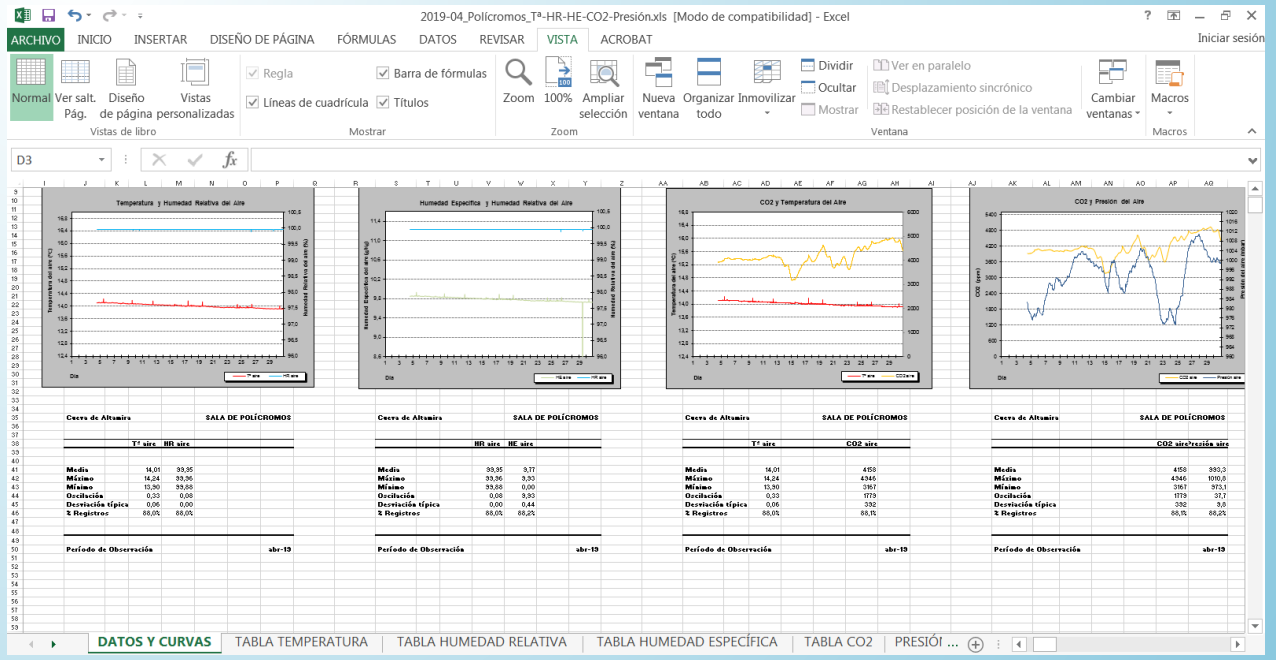
Sistema Remoto

Miles de datos monitorizados diariamente

Sensibilidad 0,01 ºC, 1 ppm

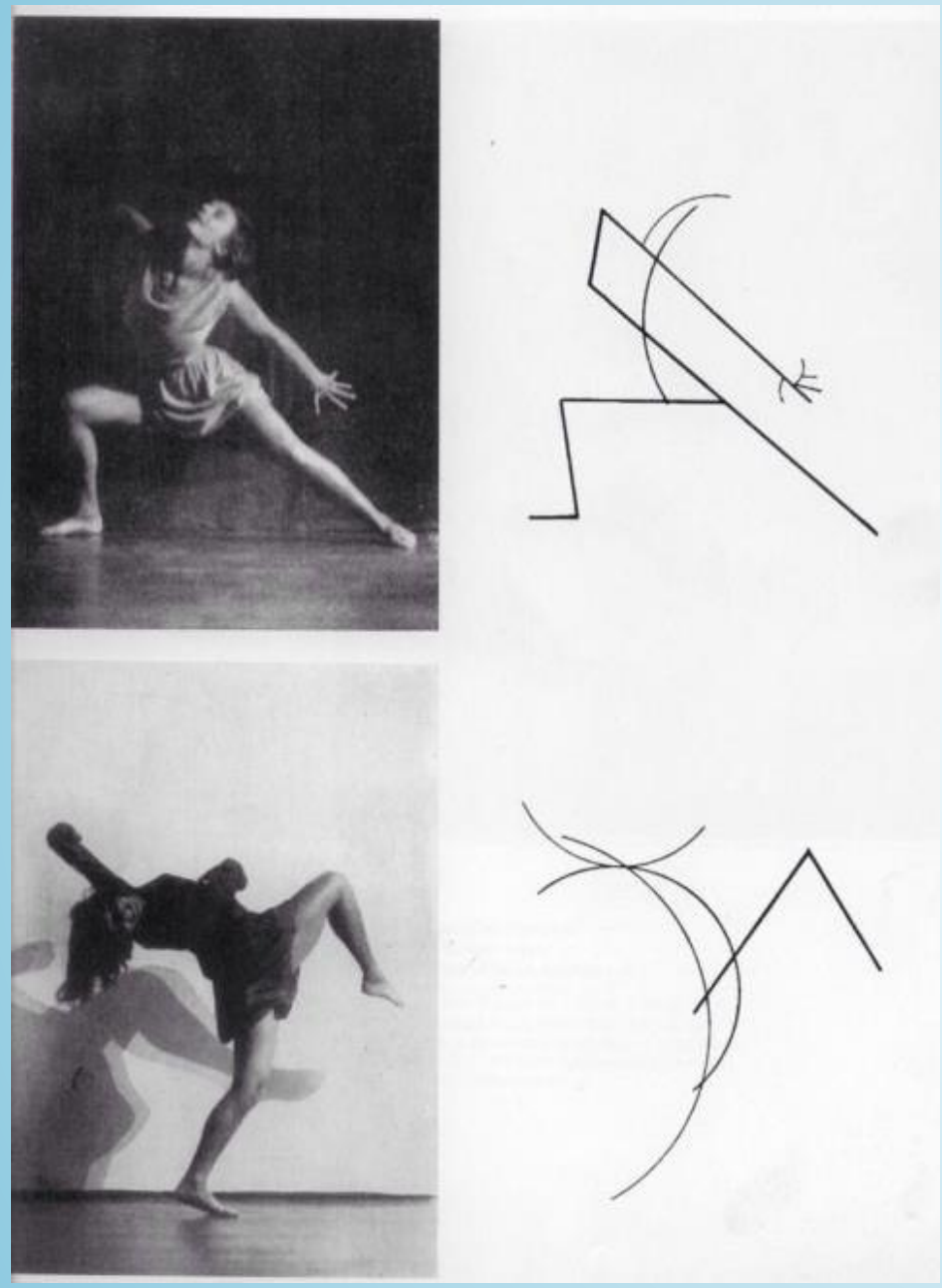


Datos en Sala de Polícromos cada minuto en tiempo real



Entradas de seguimiento (12 minutos)

- Seguimiento in situ para el control adicional de parámetros (quincenal)
  - Lectura de los termómetros Hg calibrados
  - Cambio de detectores de radón
  - Agua de infiltración
  - Humedad
  - CO2
  - Partículas
  - Medidas de conductividad y pH in situ
  - **VERIFICACIONES Y CALIBRACIONES**



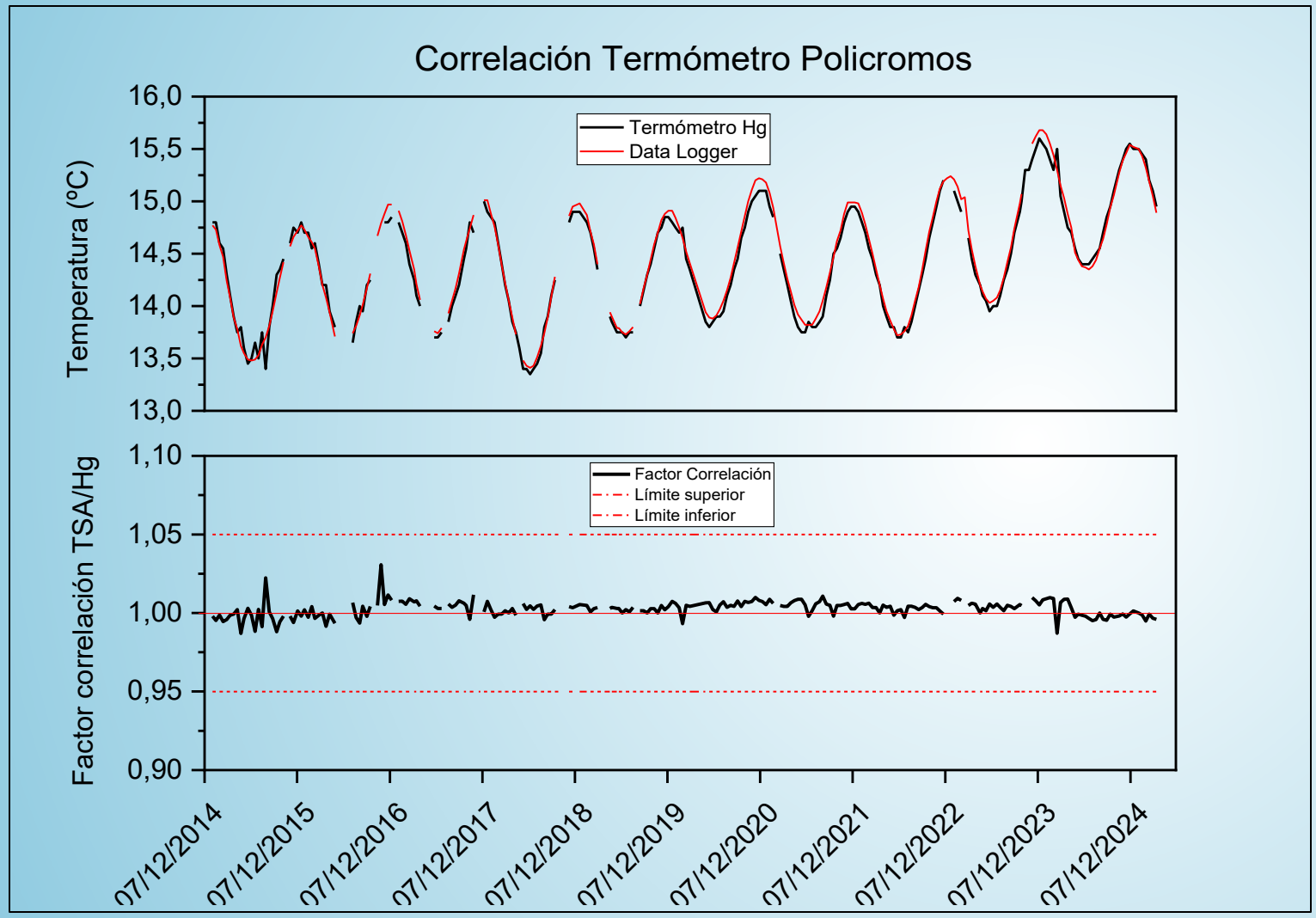
Kandinsky:. Dance Curves: On the Dances of Palucca (1926).

Campo de temperaturas

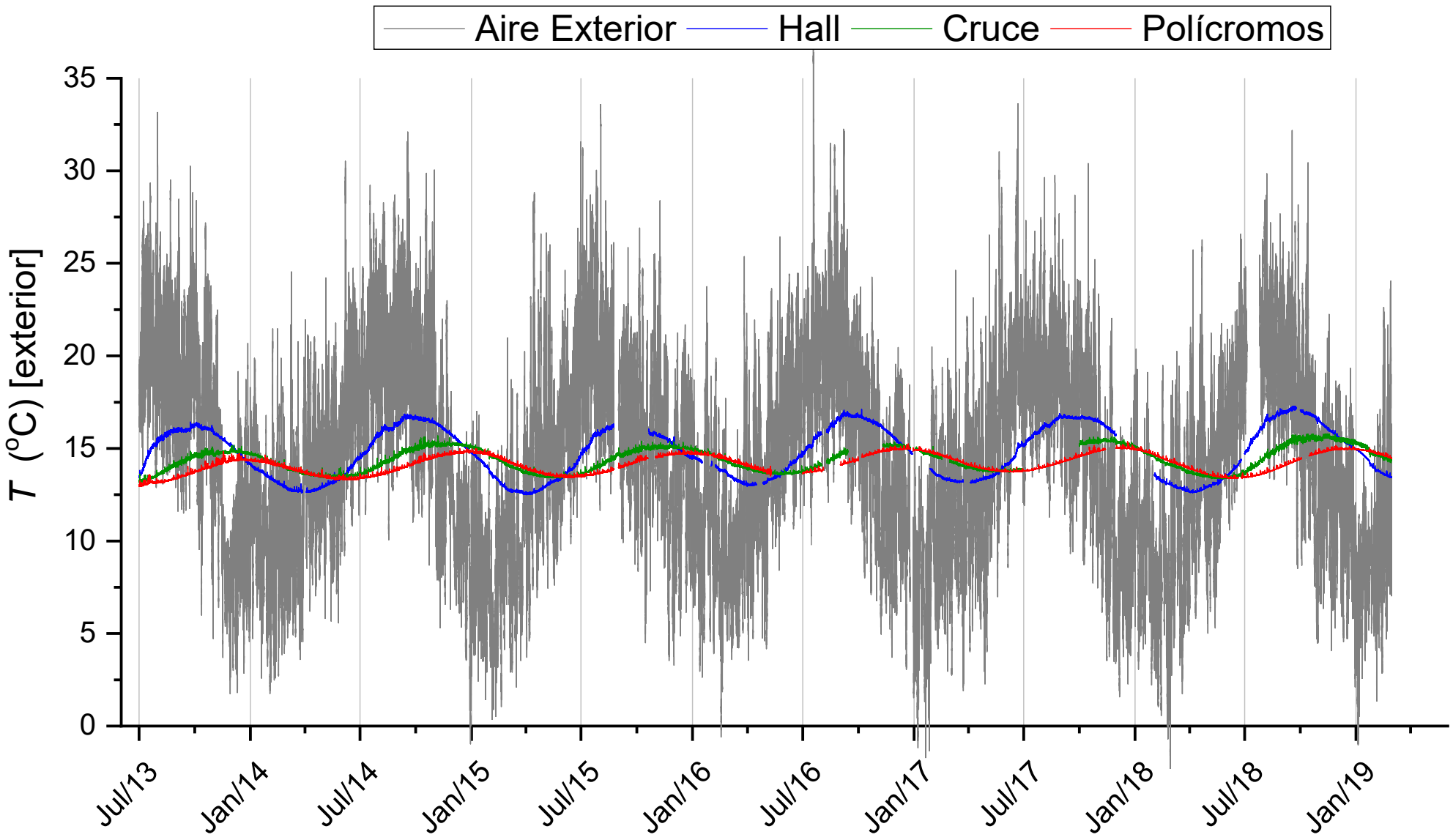
¿Cómo evoluciona el campo de temperaturas?

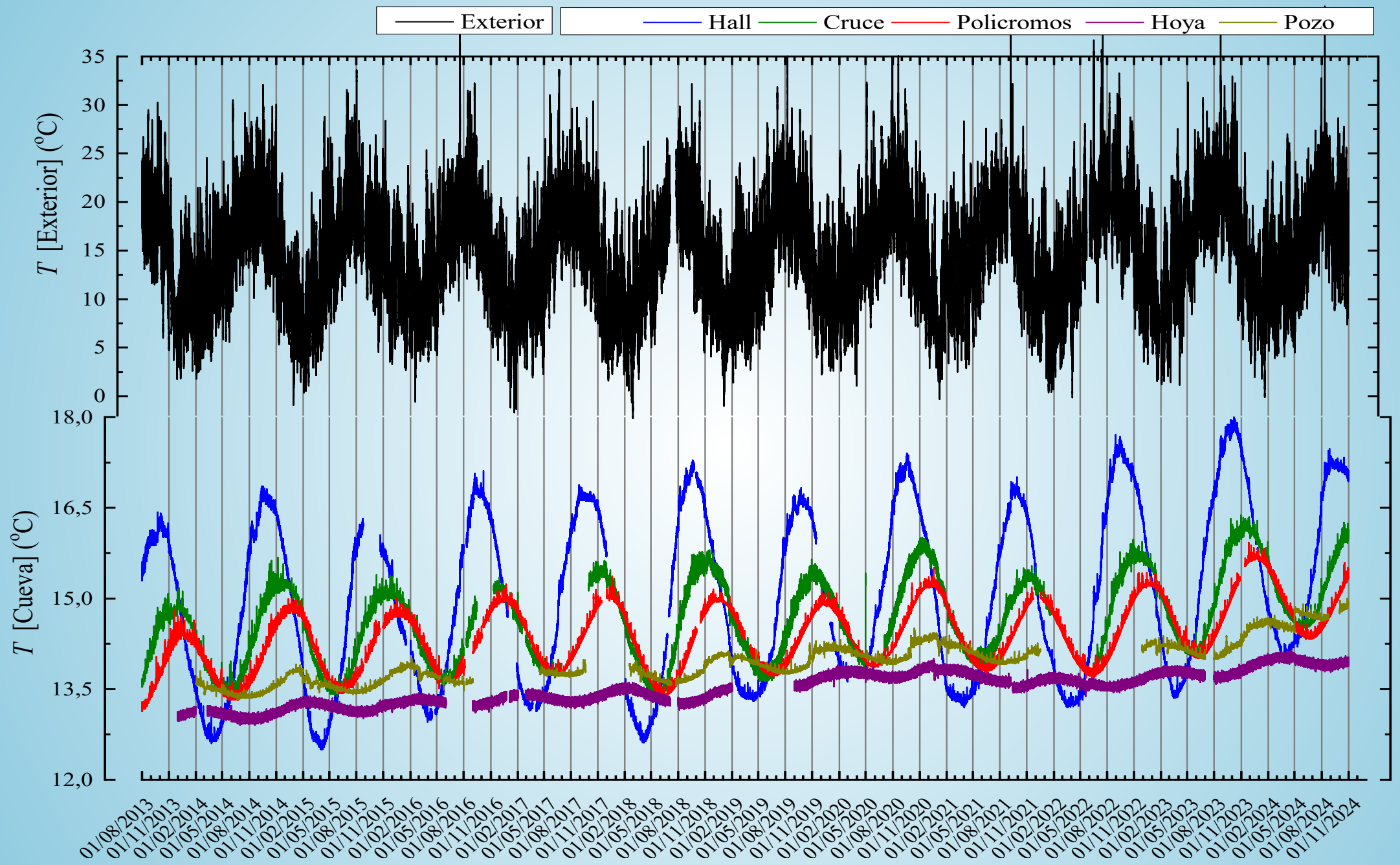
¿Por qué se pueden superar los límites de accesibilidad?

Temperaturas: Control de calidad



TEMPERATURAS




Exterior
Hall
Cruce
Policromos
Hoya
Pozo
T [Exterior] (°C)
35
30
25
20
15
10
5
0
T [Cueva] (°C)
18,0
16,5
15,0
13,5
12,0
01/08/2013
01/11/2013
01/02/2014
01/05/2014
01/08/2014
01/11/2014
01/02/2015
01/05/2015
01/08/2015
01/11/2015
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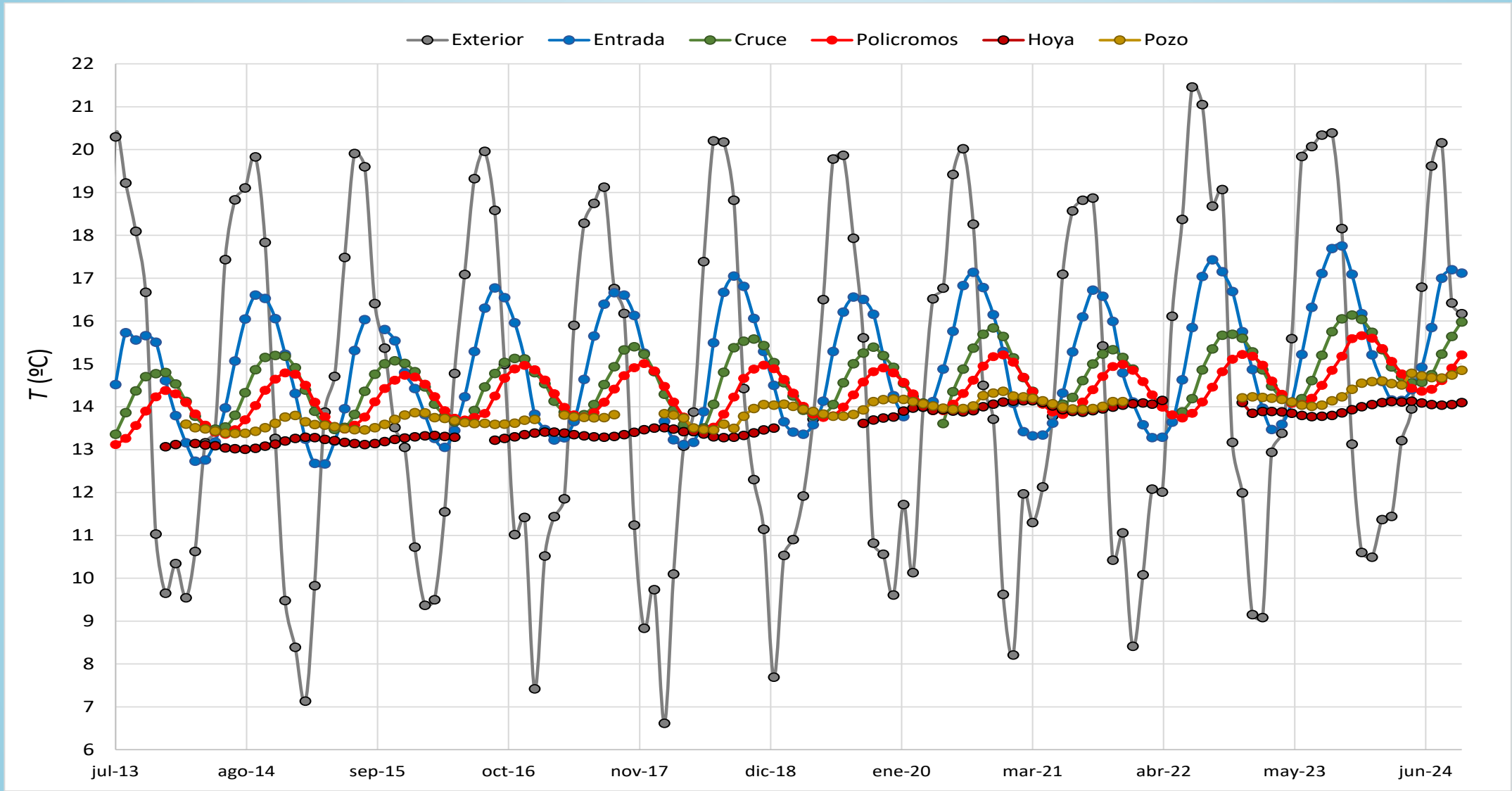
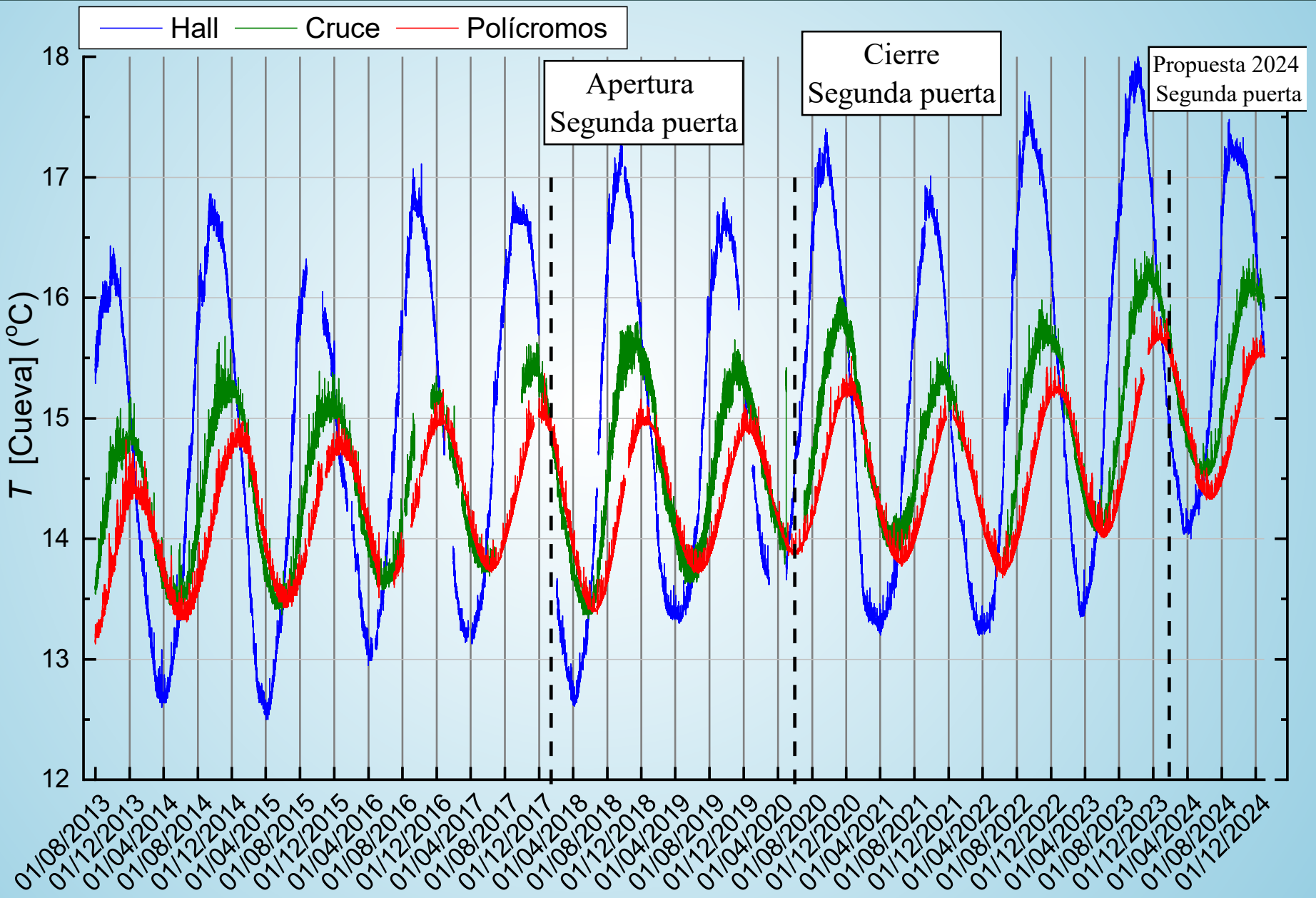
01/11/2024


Exterior
Entrada
Cruce
Policromos
Hoya
Pozo
T (ºC)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
jul-13
ago-14
sep-15
oct-16
nov-17
dic-18
ene-20
mar-21
abr-22
may-23
jun-24

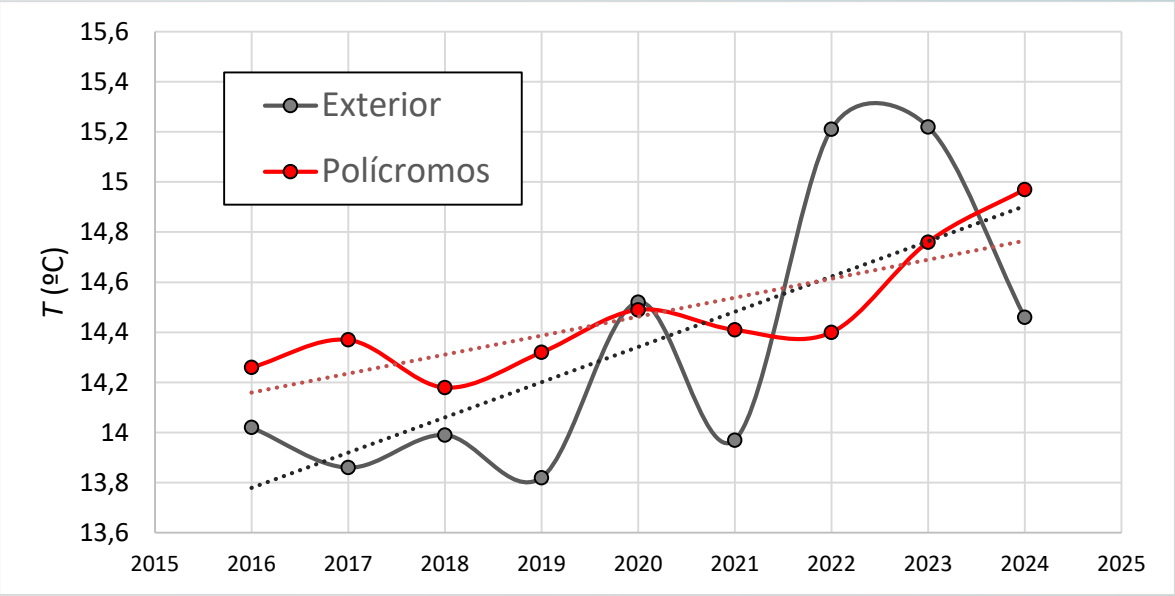
Temperaturas



Temperaturas

Medias anuales

Año	Exterior	Polícromos
2016	14,02	14,26
2017	13,86	14,37
2018	13,99	14,18
2019	13,82	14,32
2020	14,52	14,49
2021	13,97	14,41
2022	15,21	14,40
2023	15,22	14,76
2024	14,46	14,97

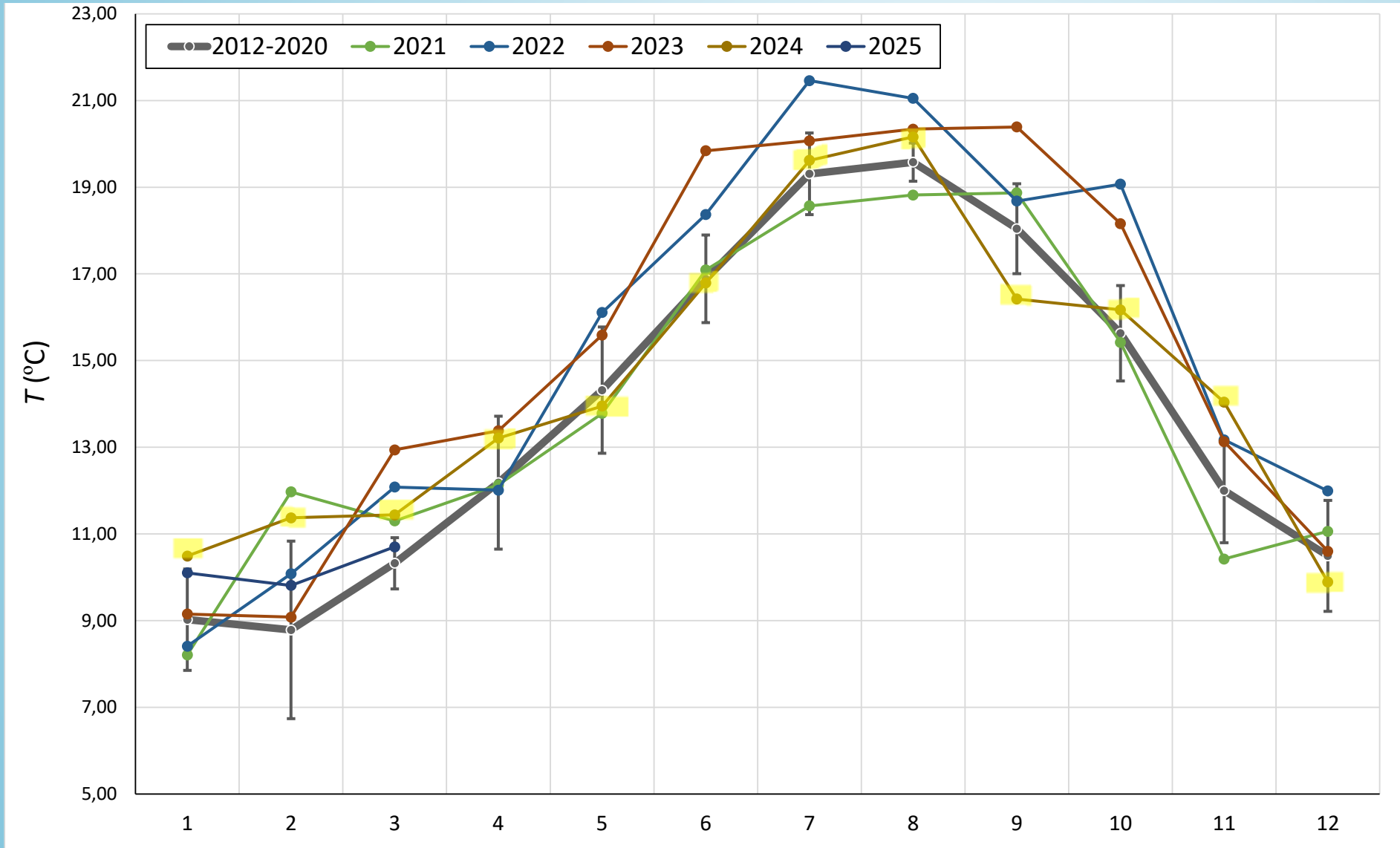


Exterior: 0,14 °C/año

Polícromos: 0,08 °C/año

Temperaturas

Evolución medida mensual Exterior



Calentamiento últimos 4 años

2021: febrero cálido/noviembre frío

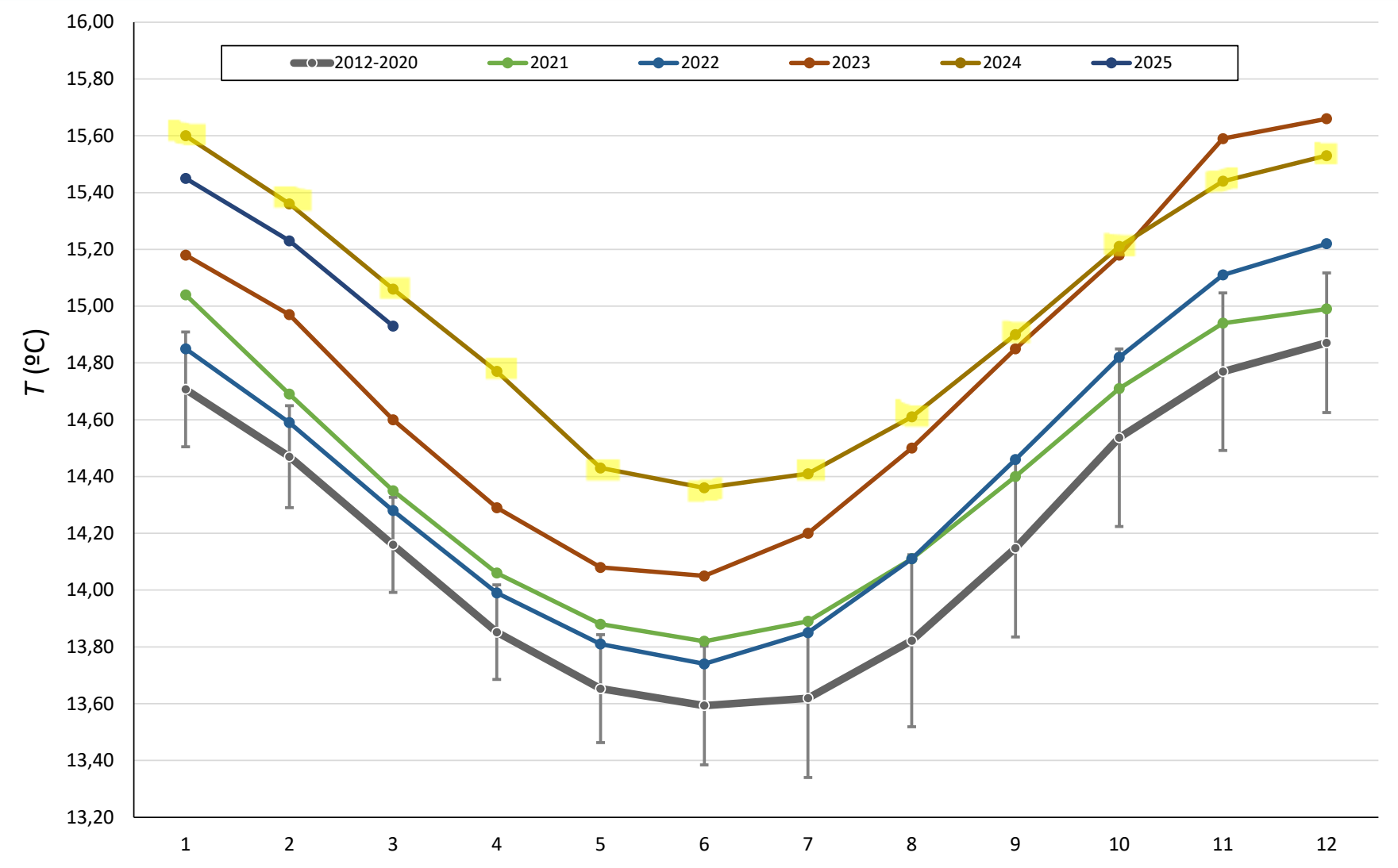
2022: Verano/octubre y diciembre máximos

2023: Primavera/junio septiembre máximos

2024:Mayo a Oct. Similar al histórico 2012-2020

Temperaturas

Evolución medida mensual Polícromos



Máximos históricos

Ene-Oct 2024

Oct-Dic 2023

Temperaturas: Propuesta nuevo límite

$$T_{acceso} = T_e + |T_{inicial} - T_{final}| + S$$

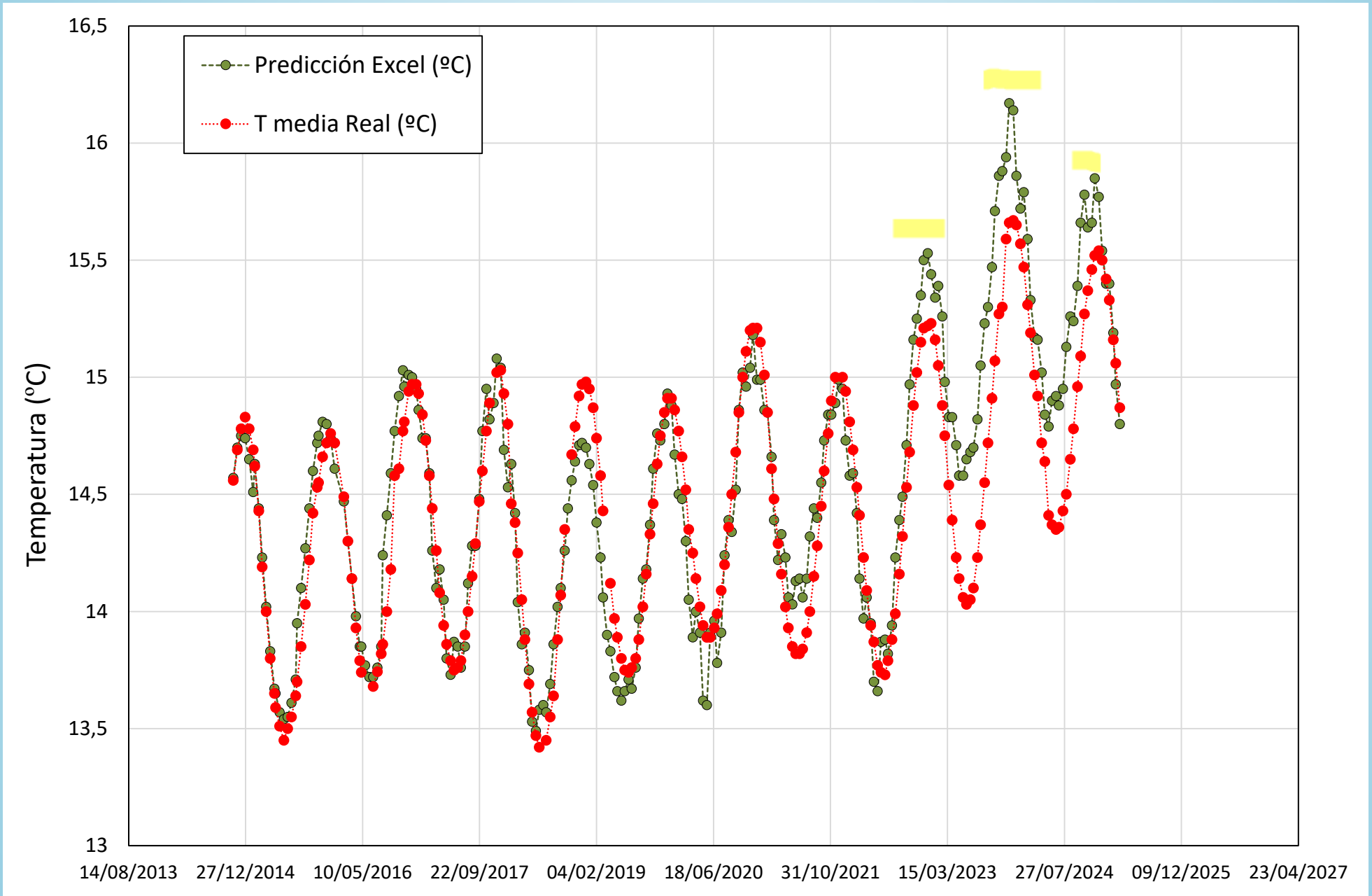
T_e = Temperatura predicha

$T_{inicial}$ del mes del año anterior

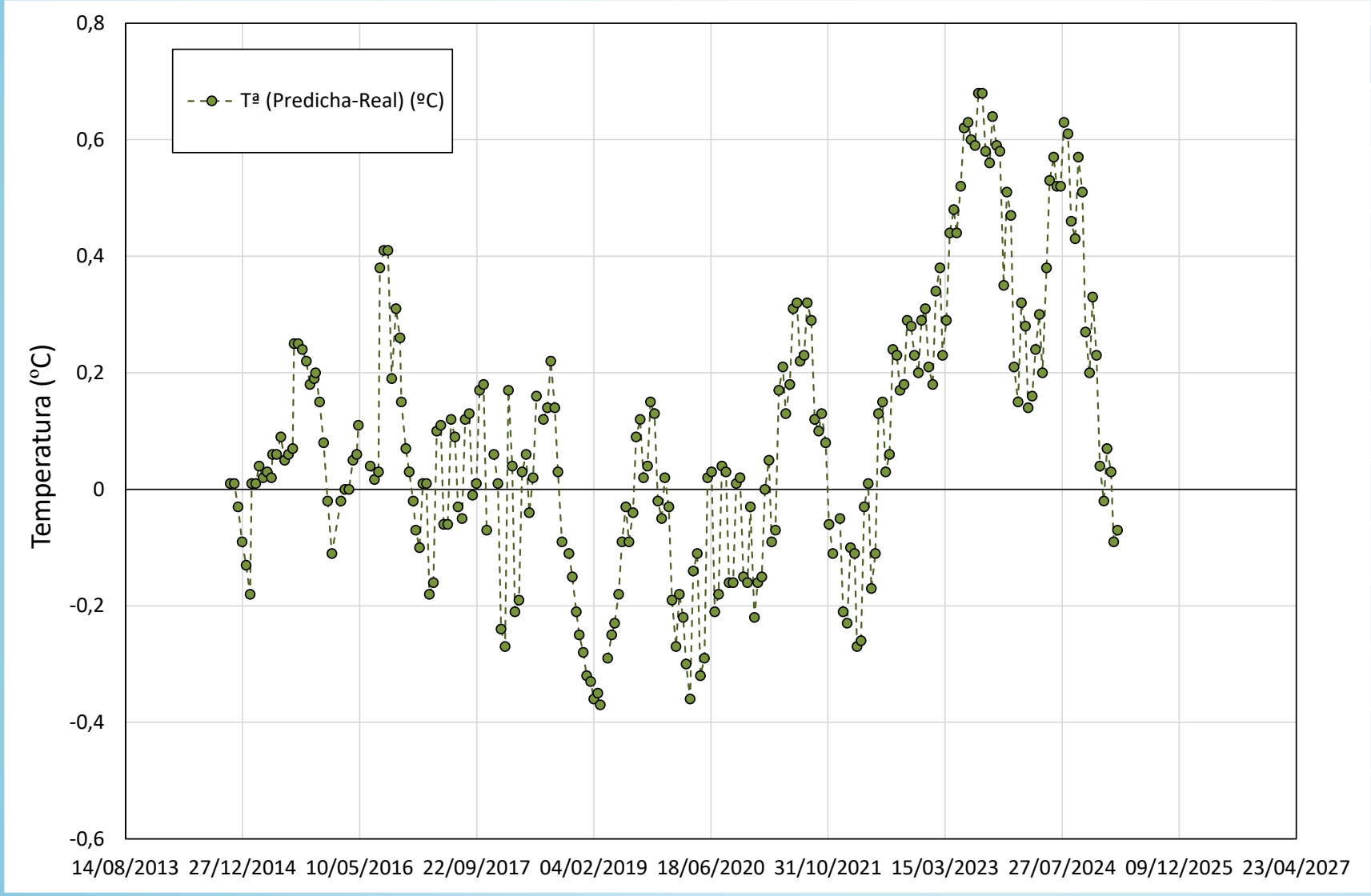
T_{final} del mes del año anterior

S: Sesgo promedio de los dos meses anteriores

Temperaturas



Temperaturas



Cálculo límite actual

Año	Promedio (Bias)
2015	0,09
2016	0,13
2017	0,02
2018	-0,03
2019	-0,11
2020	-0,15
2021	+0,09
2022	+0,06
2023	+0,48
2024	+0,37
2025*	-0,01

$$T_e + |T_{inicial} - T_{final}| - S$$

T_e= Temperatura estimada

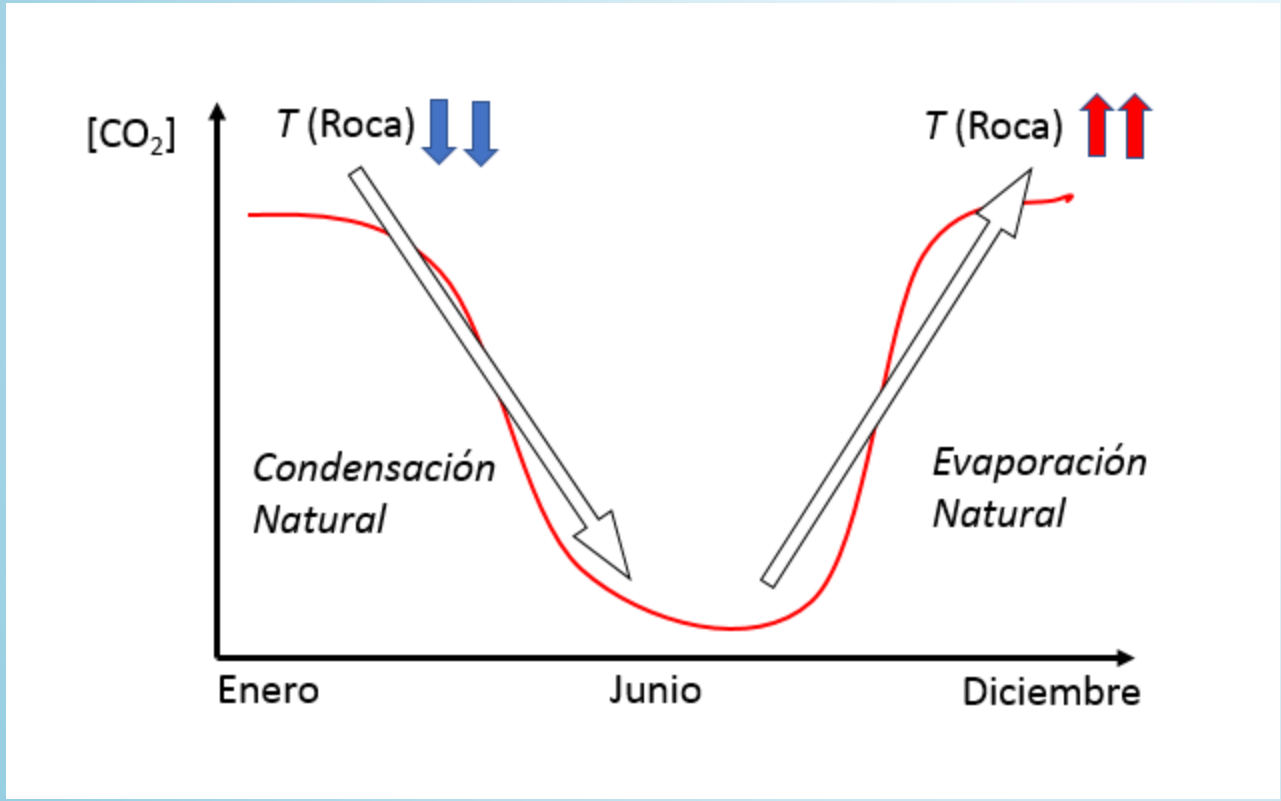
$T_{inicial}$ del mes del año anterior

T_{final} del mes del año anterior

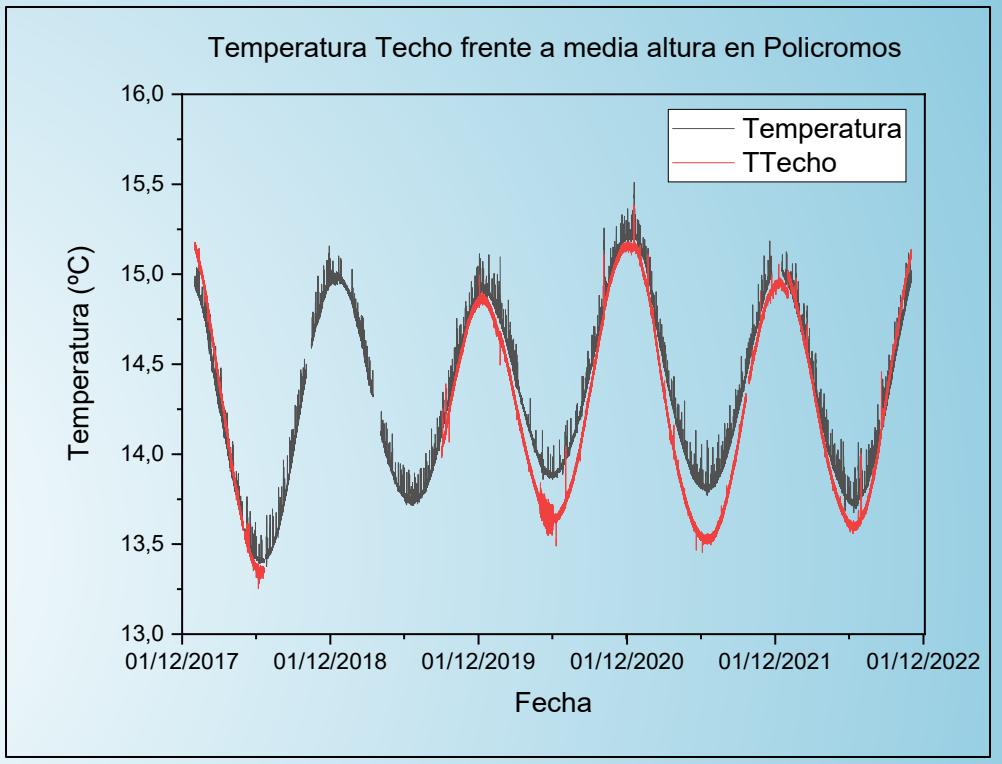
Caída de pigmento, Disolución y arrastre

- Influencia de la condensación

- Ciclos naturales



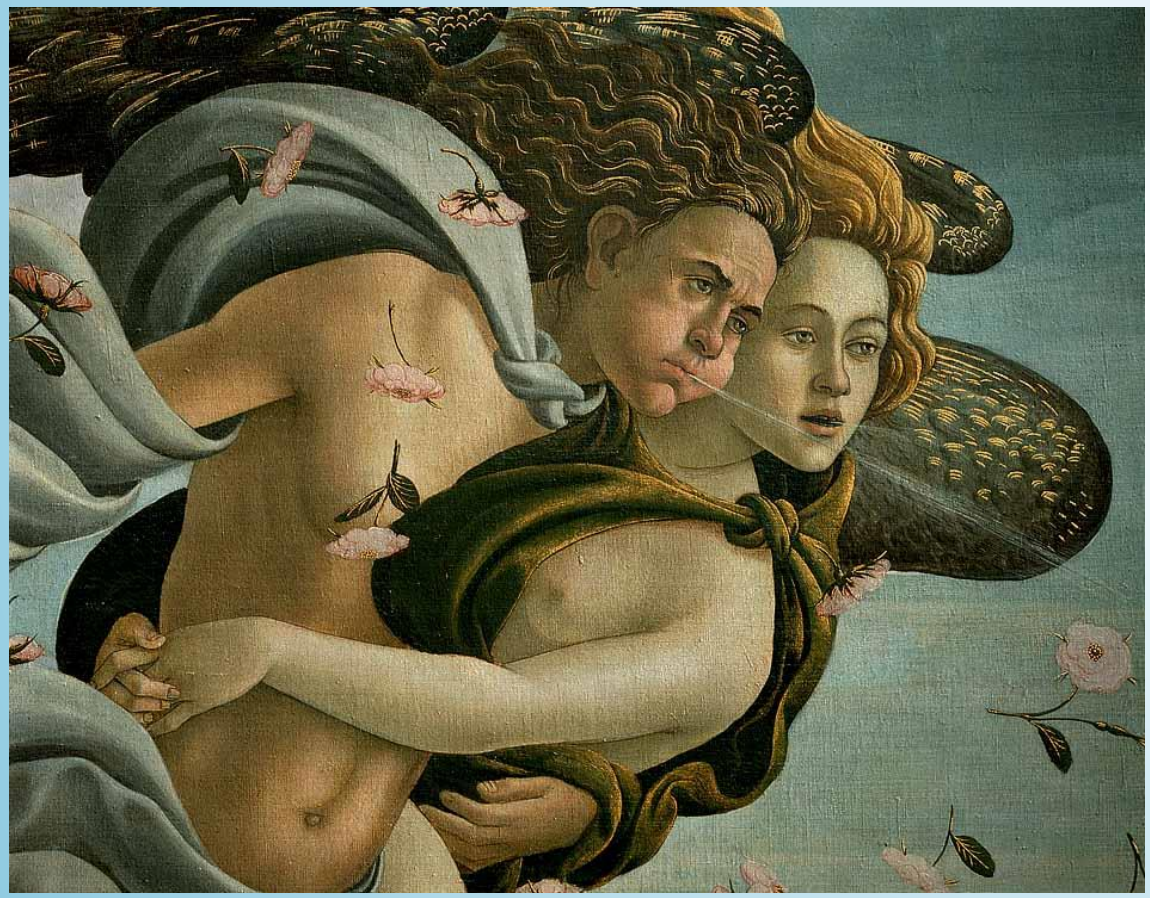
- **Gradiente techo/aire (condensación/evaporación)**

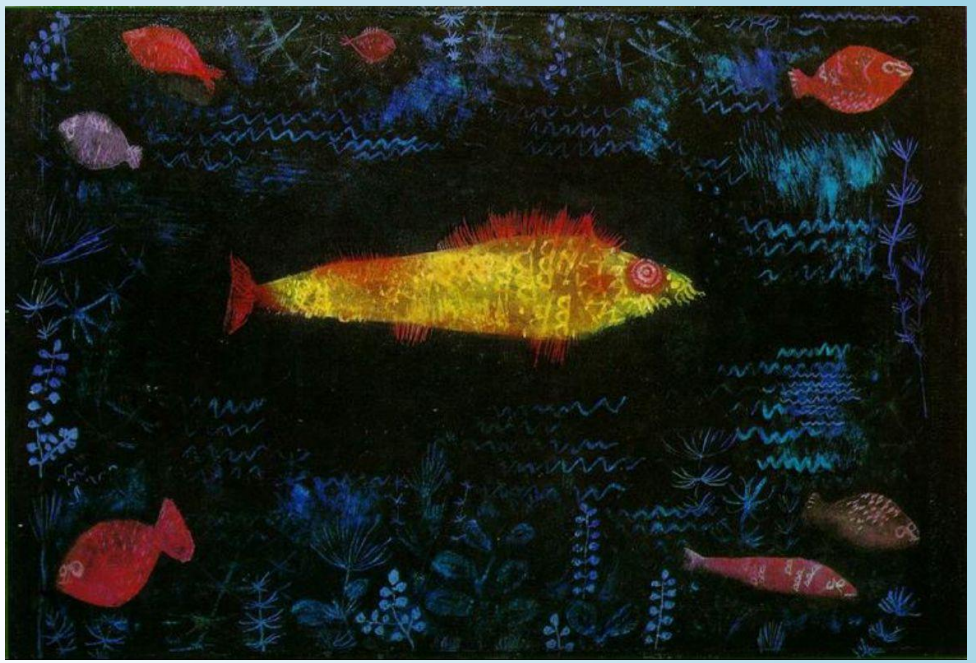


Equilibrio dinámico:

Condensación (Tt < Ta): dic – jun
Evaporación (Tt > Ta): jun - dic

GASES





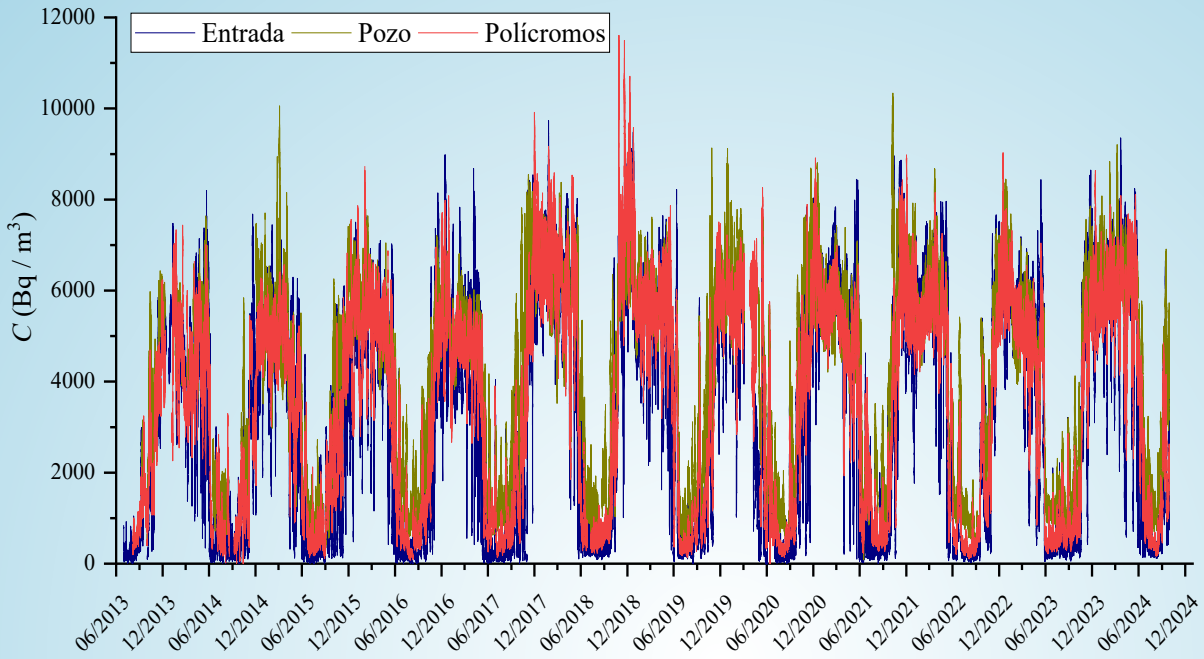
AGUA

Gases e hidrología

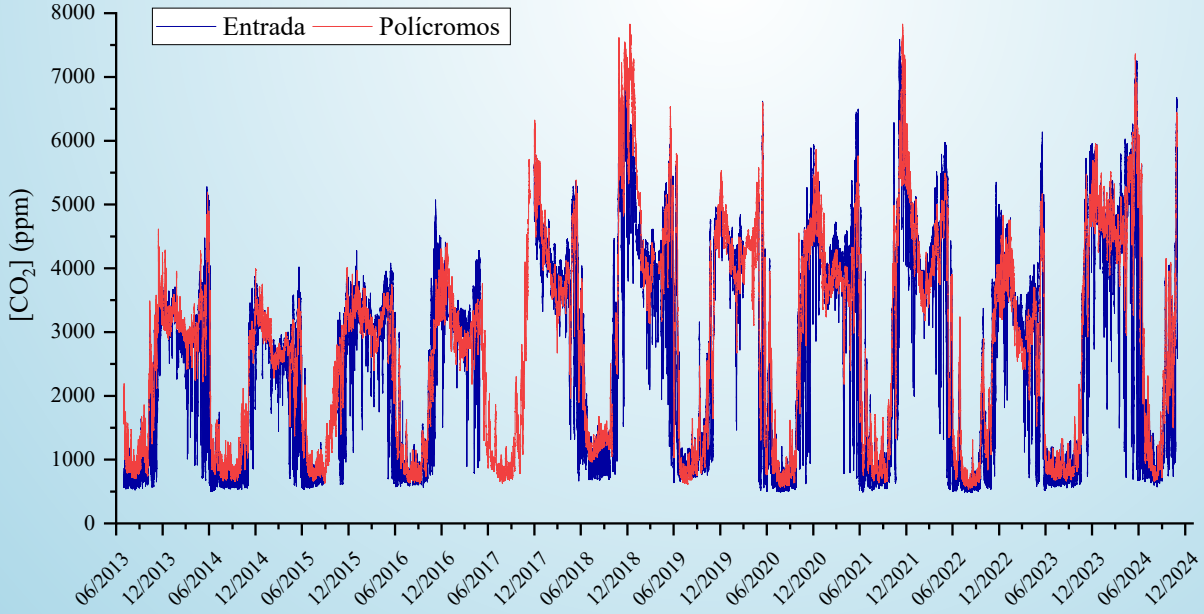
¿Cómo evolucionan las concentraciones de gases traza interiores?

¿Varía la cantidad de precipitación con respecto a años anteriores y/o los caudales de entrada de agua en Polícromos?

¿Varía la composición geoquímica del agua en los puntos de seguimiento?


Entrada
Pozo
Polícromos
C (Bq / m3)
12000
10000
8000
6000
4000
2000
0
06/2013
12/2013
06/2014
12/2014
06/2015
12/2015
06/2016
12/2016
06/2017
12/2017
06/2018
12/2018
06/2019
12/2019
06/2020
12/2020
06/2021
12/2021
06/2022
12/2022
06/2023
12/2023
06/2024
12/2024

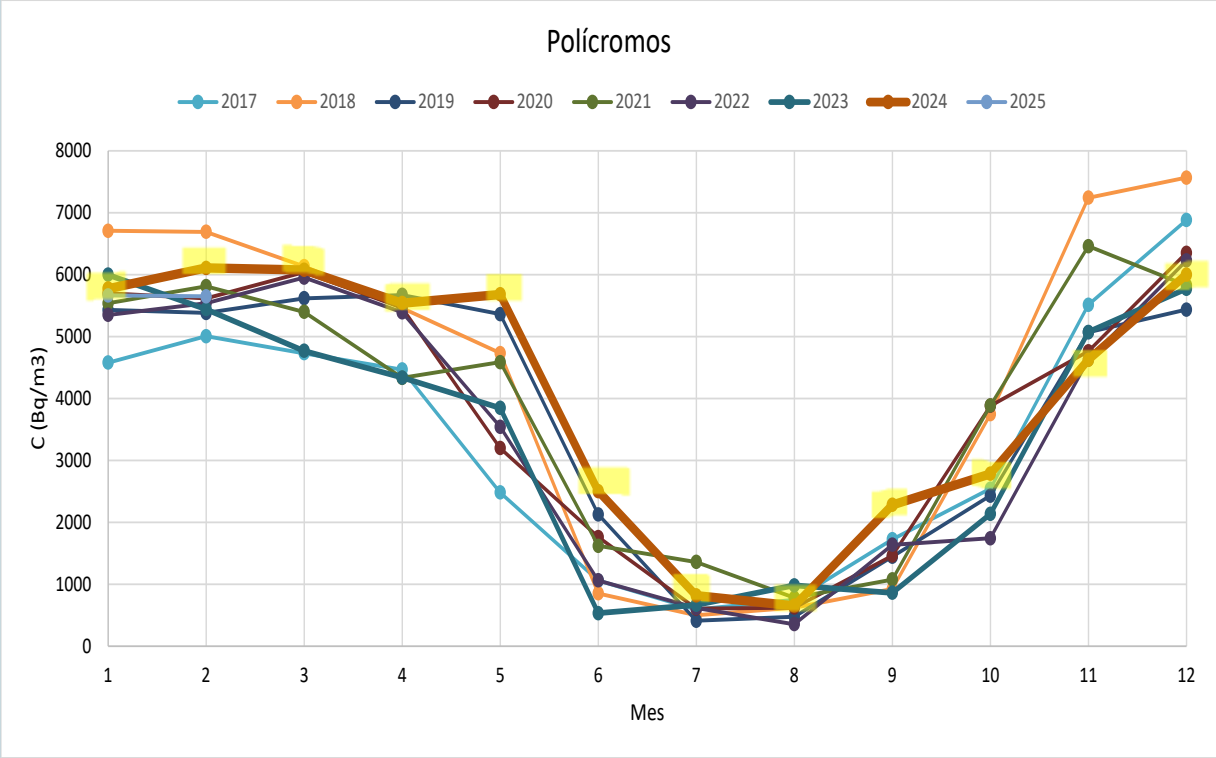
RADON


Entrada
Polícromos
[CO2] (ppm)
8000
7000
6000
5000
4000
3000
2000
1000
0
06/2013
12/2013
06/2014
12/2014
06/2015
12/2015
06/2016
12/2016
06/2017
12/2017
06/2018
12/2018
06/2019
12/2019
06/2020
12/2020
06/2021
12/2021
06/2022
12/2022
06/2023
12/2023
06/2024
12/2024

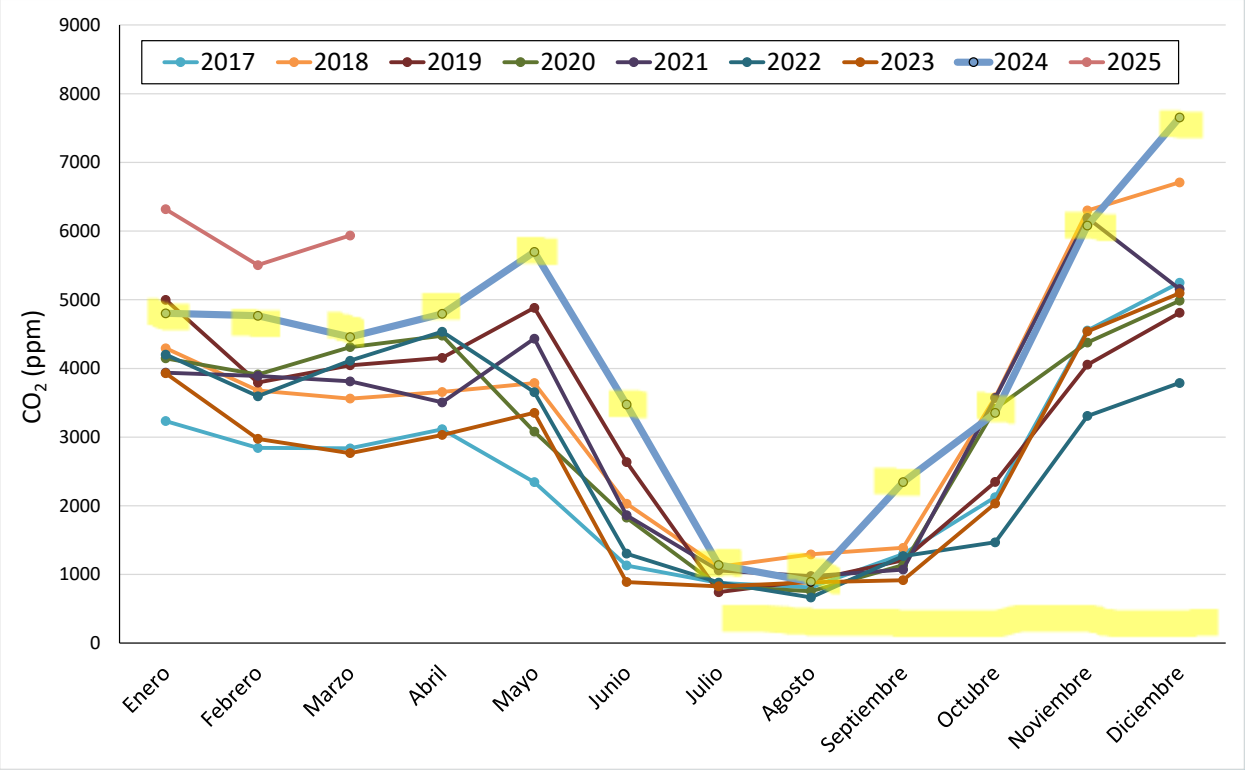
CO2

Radon y CO_2

Comparativa Polícromos datos mensuales 2016-2023



Máximos en 2018



Máximos en 2024-2025

Primer semestre: Similar nivel de confinamiento con respecto al histórico

Segundo semestre: Diferencia en tasa de producción de CO2

Dinámica de gases

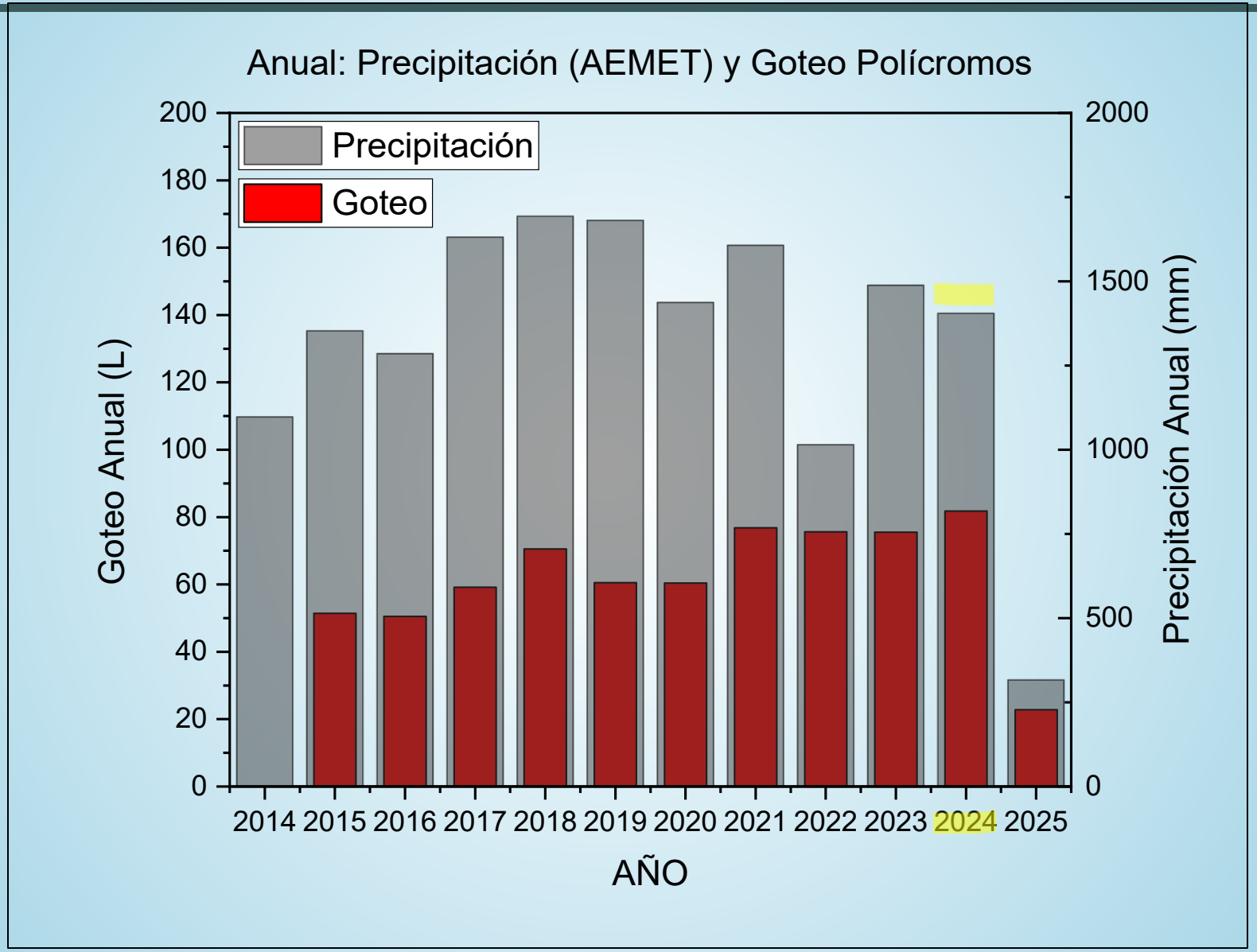
Periodos de Desgasificación-Recarga anual (*C* </> 2000 Bq/m^3)

	Desgasificación	Recarga	Nº días
2016	6 Junio	4 Noviembre	151
2017	1 Junio	9 Septiembre	100
2018	23 Mayo	15 Octubre	145
2019	2 Junio	25 Septiembre	115
2020	18 Junio	12 Noviembre	147
2021	8 junio	3 Octubre	117
2022	1 Junio	31 Octubre	152
2023	28 Mayo	19 noviembre	175
2024	21 Junio	10 noviembre	142

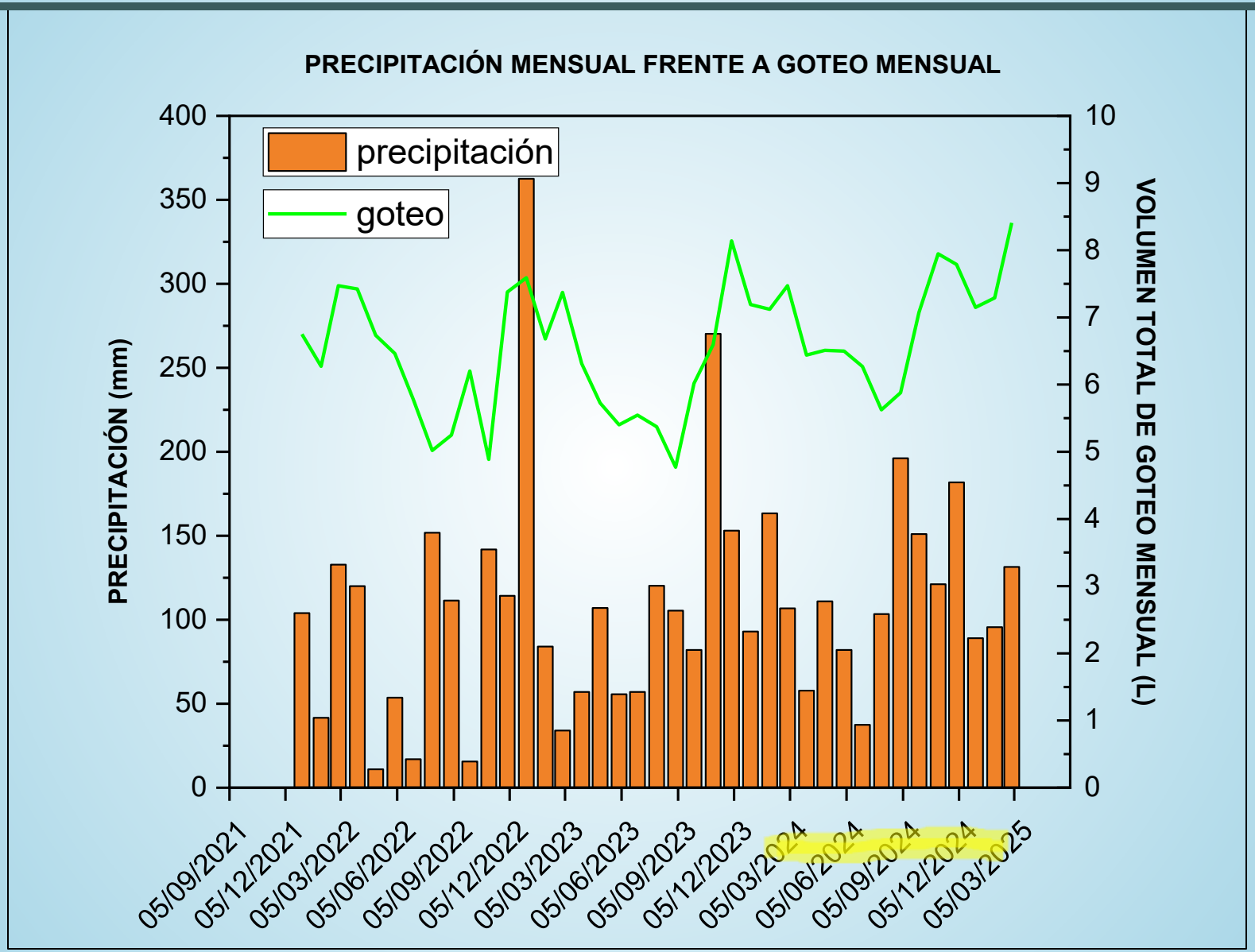
Variabilidad fechas de recarga (mes+) "Abrupto"

Variabilidad fechas desgasificación (días) "Progresivo"

Agua: Pluviosidad e Infiltración

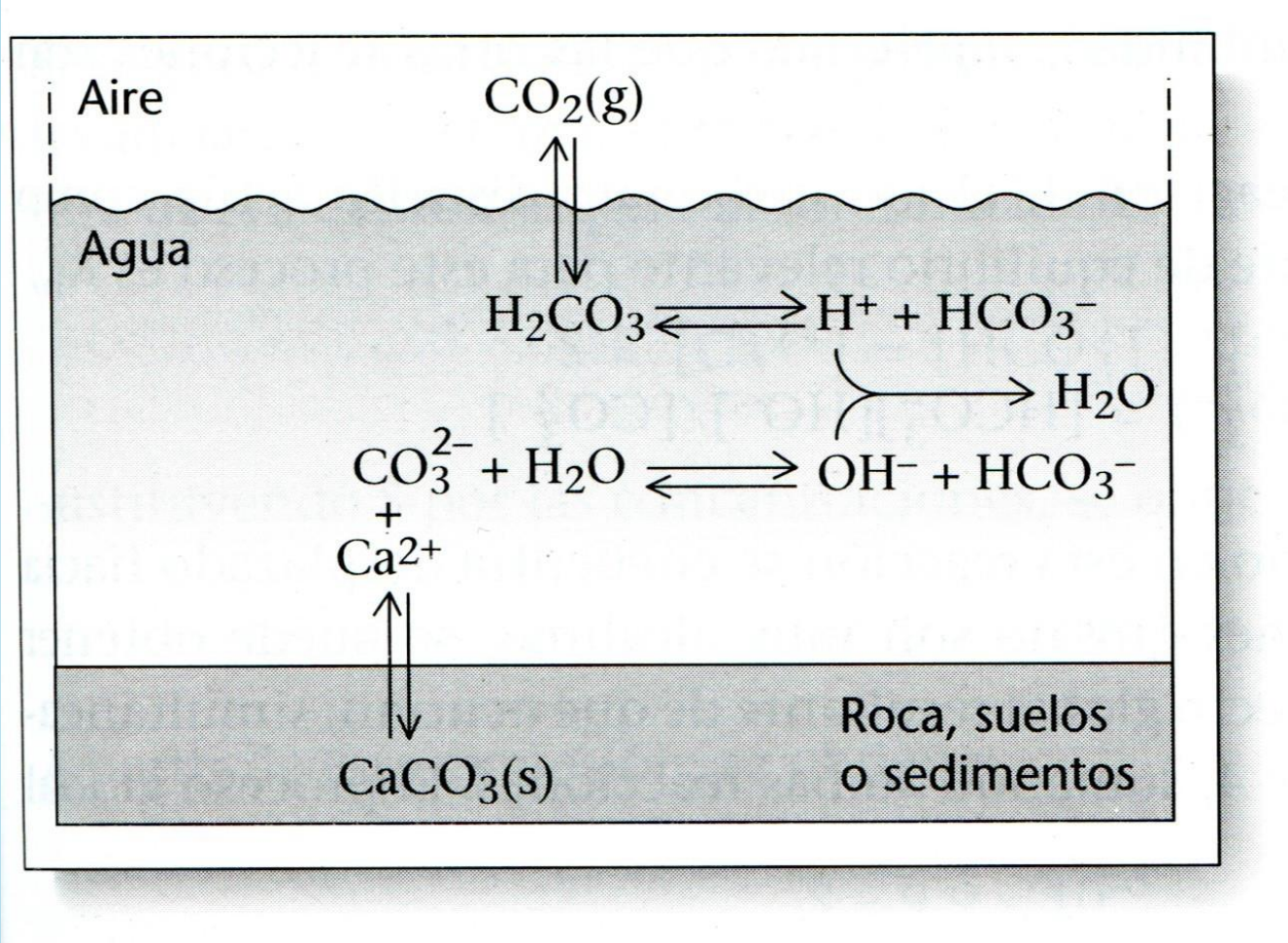


Agua: Pluviosidad e Infiltración



Agua: Composición química

Parámetro
pH
CO_3^{-2} (mg/l)
HCO_3^{-} (mg/l)
Cl^{-} (mg/l)
NO_2^{-} (mg/l)
NO_3^{-} (mg/l)
SO_4^{-2} (mg/l)
Na^{+} (mg/l)
K^{+} (mg/l)
Ca^{+2} (mg/l)
Mg^{+2}(mg/l)
TDS (mg/l)
Ca/Mg
COT (mg/l)

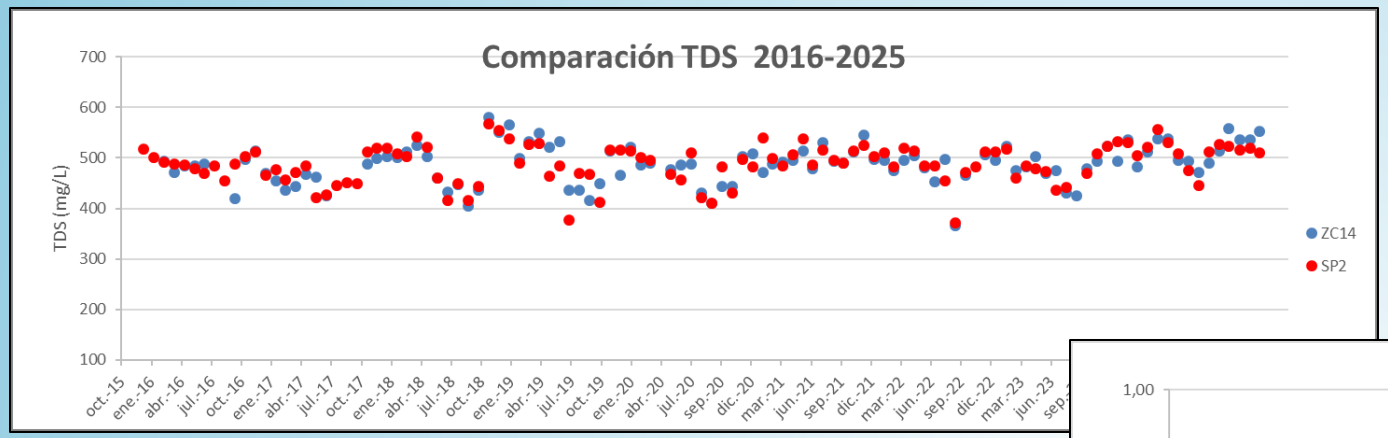


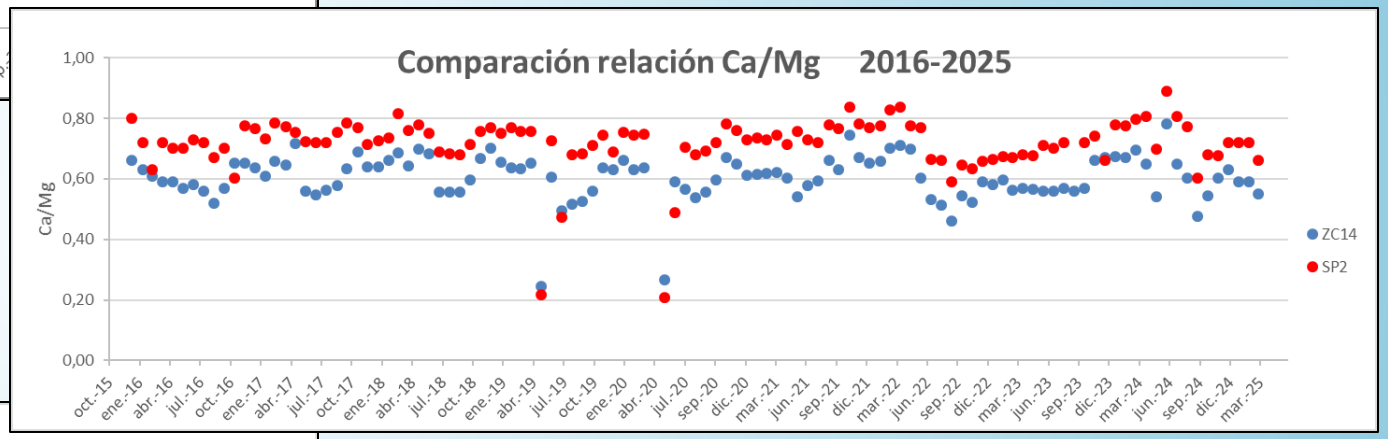
PUNTOS DE MUESTREO VS CONJUNTO

IS > 0

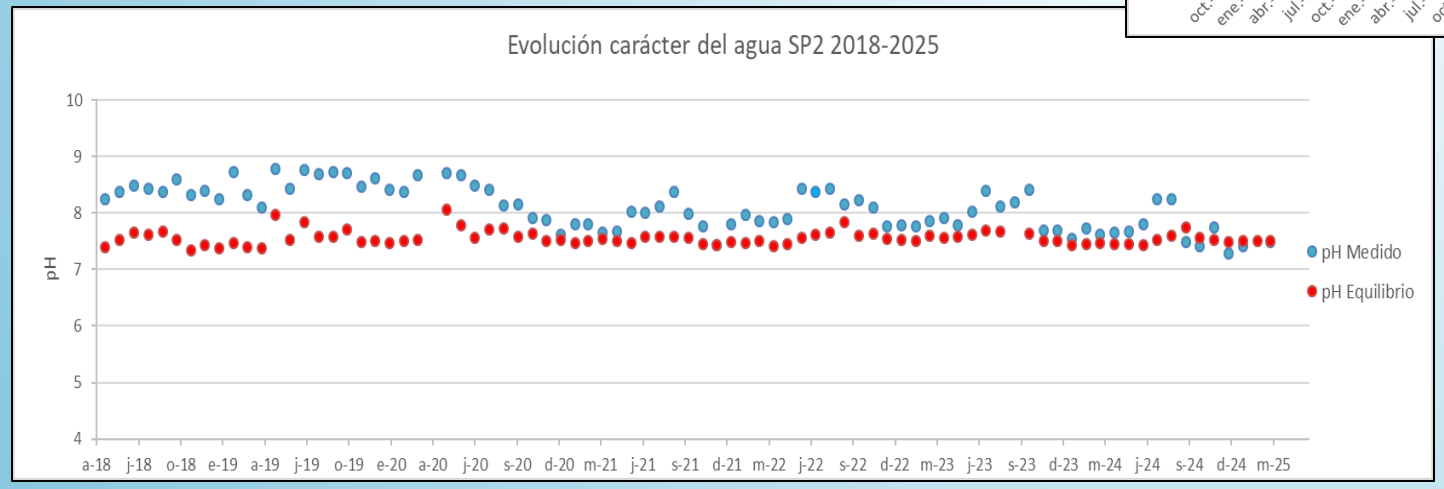
pH > pH (equilibrio)

Agua: Composición química

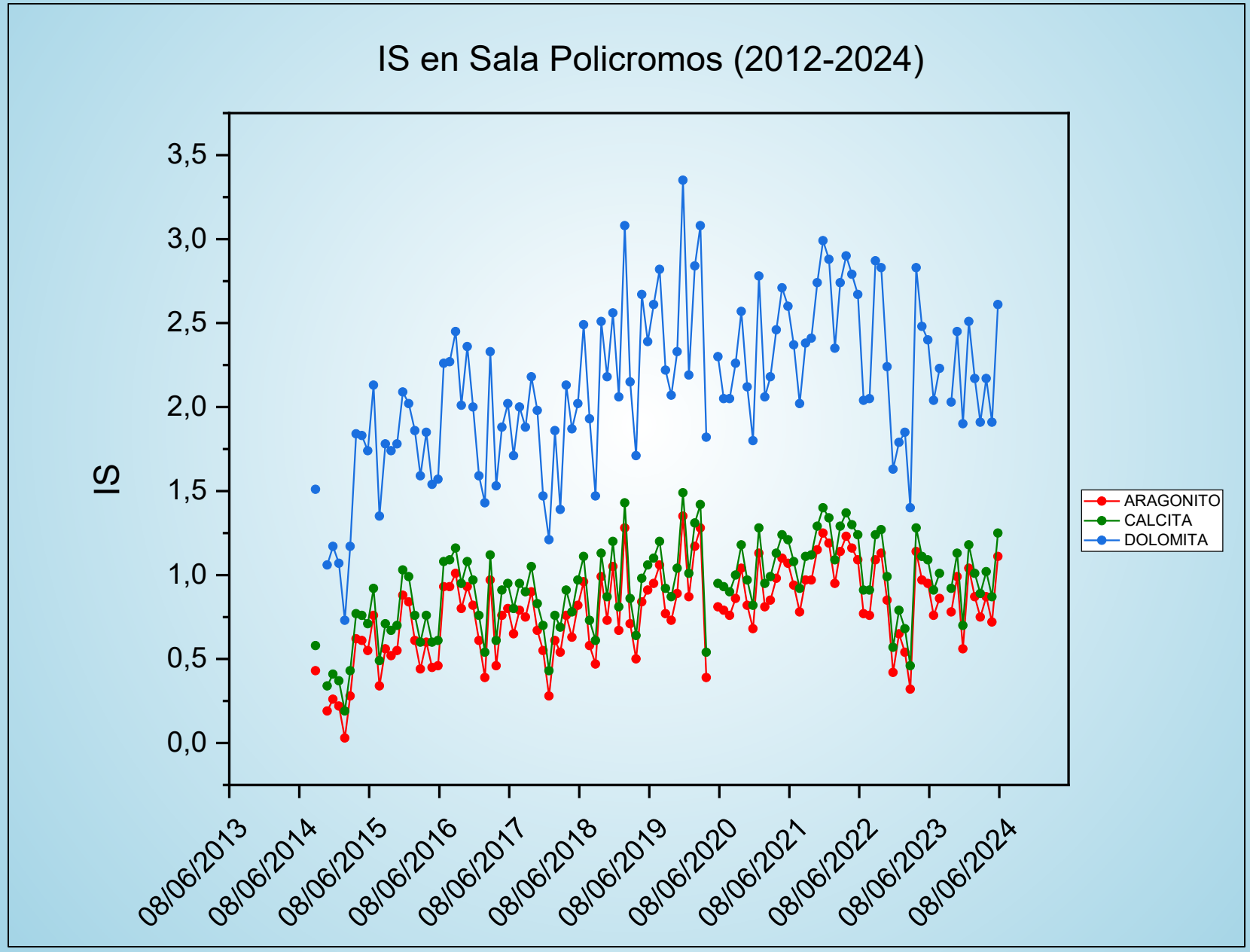




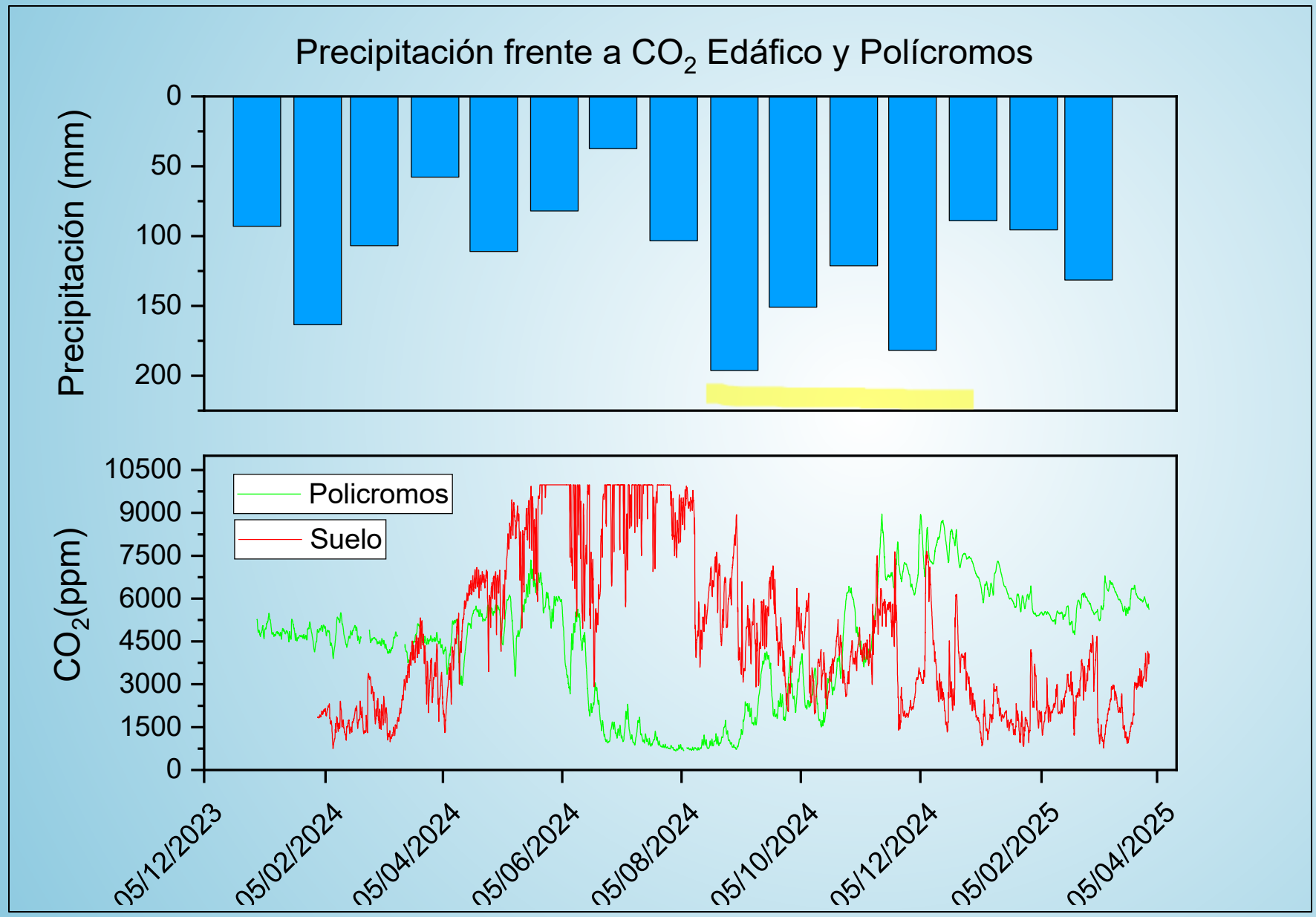
Comparación puntos 2 y ZC14



Agua: Composición química



Agua y CO2 edáfico

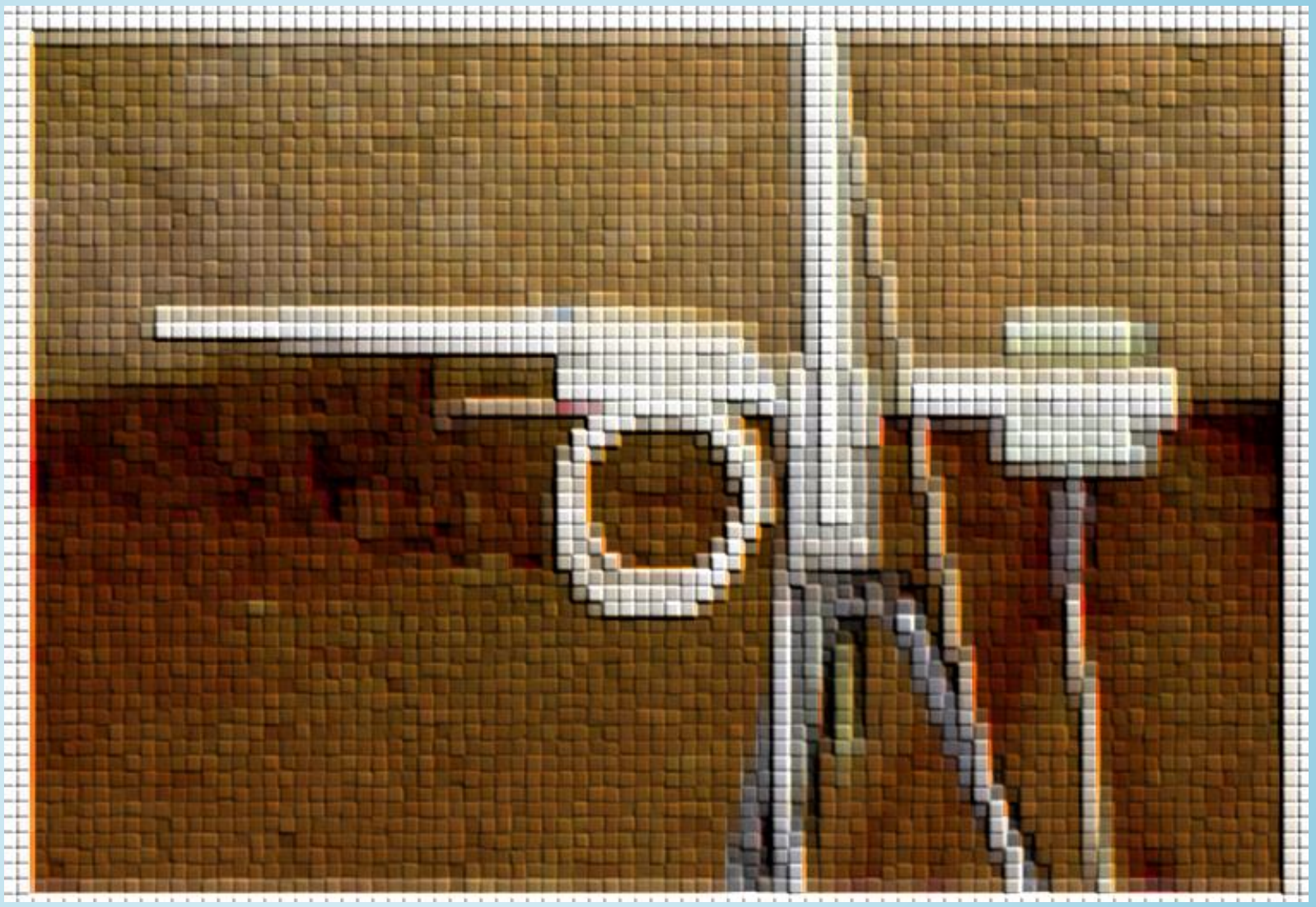


Lluvia y transporte de agua enriquecida en CO2 al final del periodo de desgasificación

¿Tiempo de residencia del agua?

Influencia antrópica

Accesibilidad y visitas experimentales/públicas



VISITA PÚBLICA

- 1967 – 1975: 150.000 personas / año
- 1977: 37.000 personas / año (máx 500 personas/día)
- 1977 – 1982: Cierre al público
- 1982 – 2002: 11.300 personas / año
- 2002 – 2014: Segundo cierre al público
- **2014 - … : Visitas experimentales/públicas**
  - **5 personas + 2 guias / semana**

Descontaminación
Monos desechables
Mascarillas
Calzado

(450+ visitas 2014-2024)

DEFINICIÓN DE LÍMITES

Basada en valores históricos
"Acceso" y "Alarma"

$$T_{acceso}=T_e + |T_{inicial}-T_{final}| + S$$

T_e= Temperatura estimada
$T_{inicial}$ del mes del año anterior
T_{final} del mes del año anterior
S: Sesgo promedio de los dos meses anteriores

$$H_{e,acceso}=\frac{37{,}95}{1013{,}25}\cdot X\cdot 10^{\left(\frac{7{,}5\cdot T_{accesibilidad}}{237+T_{accesibilidad}}\right)}$$

$T_{accesibilidad}$= Limite de acceso de temperatura ese mes
X= promedio histórico de H_R de ese mes.

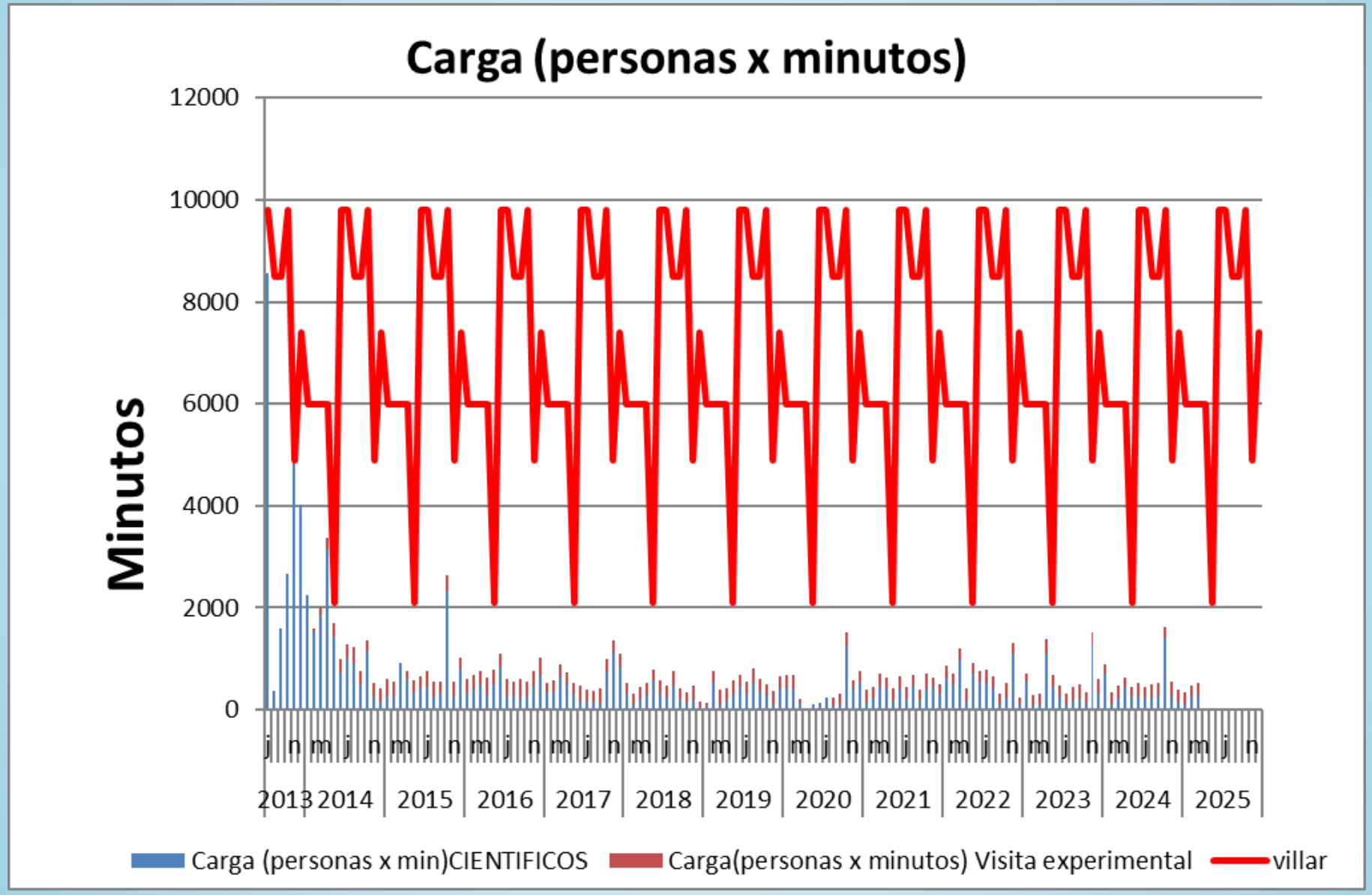
$$CO_{2,acceso}=\overline{CO_2}+|Med_{max}-Med_{min}|$$

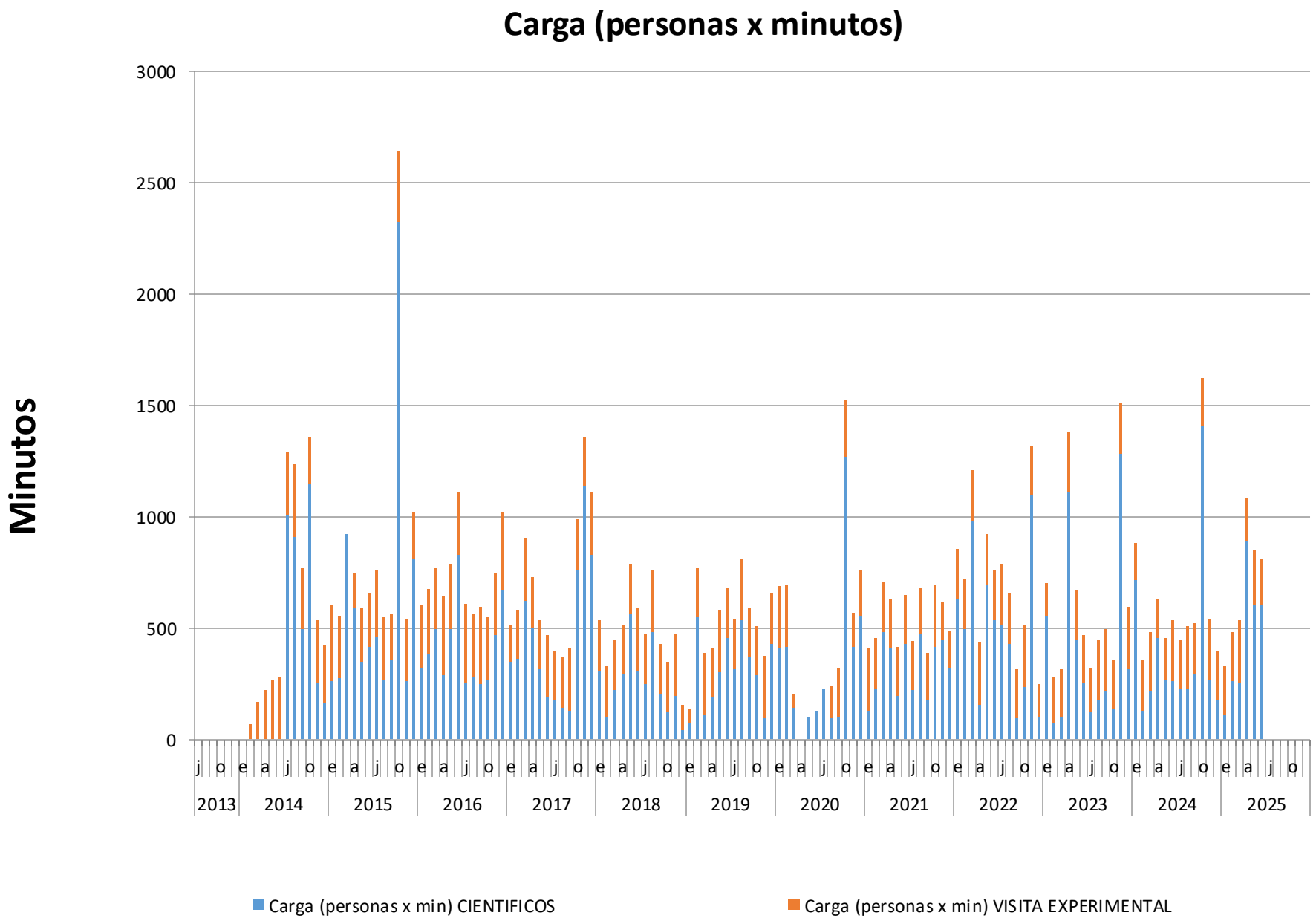
$\overline{CO_2}$= Promedio mes histórico
Med_{max} mediana 5 años valores máximos ese mes.
Med_{min} mediana 5 años valores mínimos ese mes.

¡IMPORTANTE!

Límites no definidos con relación a procesos de deterioro, sino con relación al ESTADO "NATURAL" de la Sala

CO2 y ocupación




Carga (personas x minutos)
Minutos
3000
2500
2000
1500
1000
500
0
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
Carga (personas x min) CIENTIFICOS
Carga (personas x min) VISITA EXPERIMENTAL

CO2 y ocupación

Estimación del aporte de CO2 por las visitas en la cueva de Altamira en el periodo Oct24 a Mar25 (ambos incluidos) para la Sala de Polícromos.

Se toma como referencia el incremento promedio experimentado en las visitas públicas:

$$\Delta[\mathrm{CO2}] = \frac{80\ \mathrm{ppm}}{7\ \mathrm{personas}\ \cdot\ 8\ \mathrm{min}} = 1.4\frac{\mathrm{ppm}}{\mathrm{persona}\cdot\mathrm{min}} = 1.4\frac{\mathrm{ppm}}{\mathrm{carga}}$$

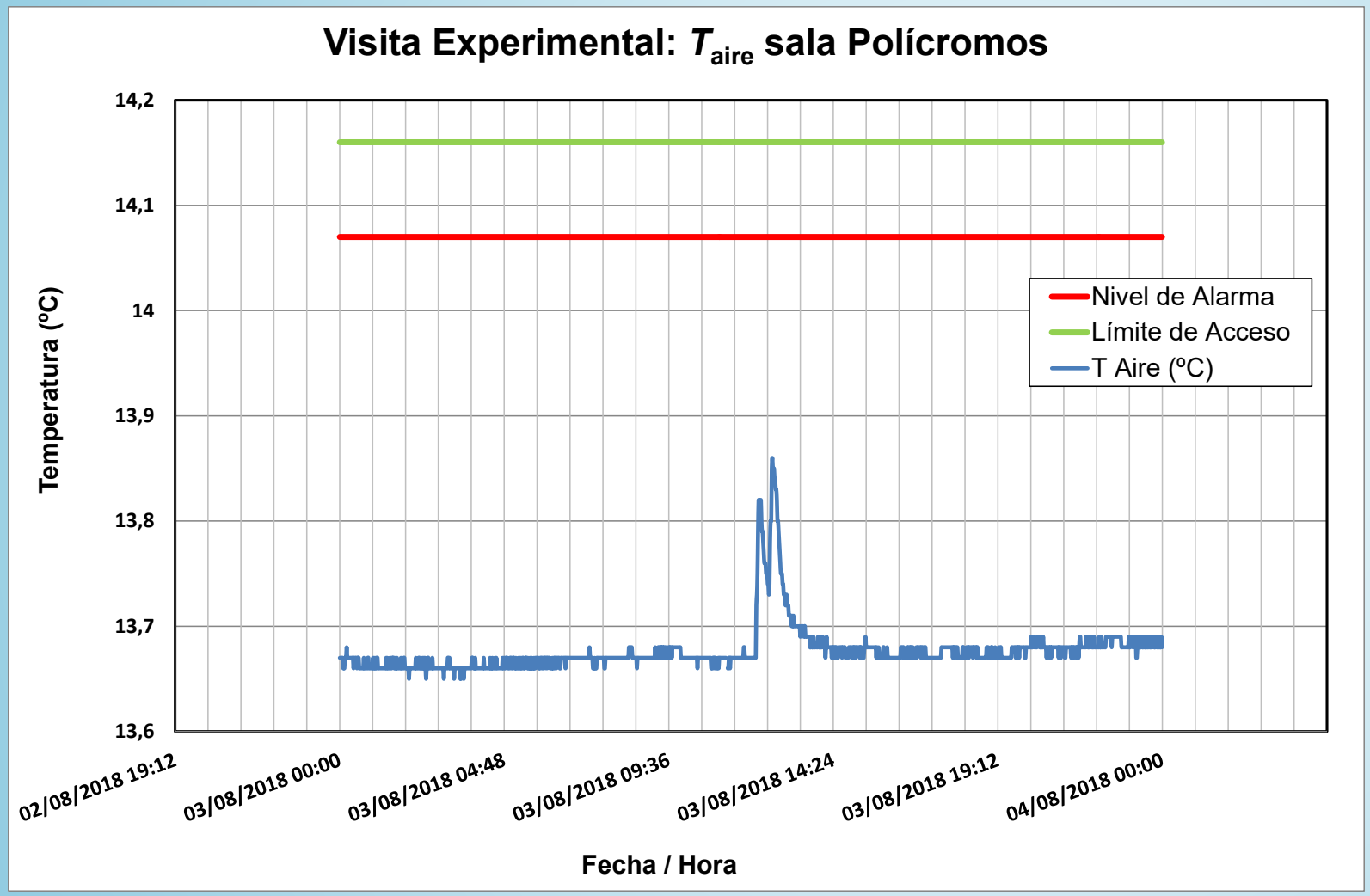
Mes	Carga total (Investigación + público) (personas · min)
Octubre 2024	1626
Noviembre 2024	543
Diciembre 2024	396
Enero 2025	330
Febrero 2025	483
Marzo 2025	537
Oct. 2024 a Marzo 2025	3915

Por lo tanto, el aporte de CO2 en el periodo mencionado es:

$$\delta[\mathrm{CO2}] = \Delta[\mathrm{CO2}]\cdot carga\ total = 1.4\frac{\mathrm{ppm}}{\mathrm{carga}}\cdot 3915\ \mathrm{carga} = 5872\ \mathrm{ppm}$$

Una parte del CO2 generado queda acumulado en la sala durante el periodo de confinamiento de gases

INFLUENCIA DE LAS VISITAS EXPERIMENTALES EN LA T



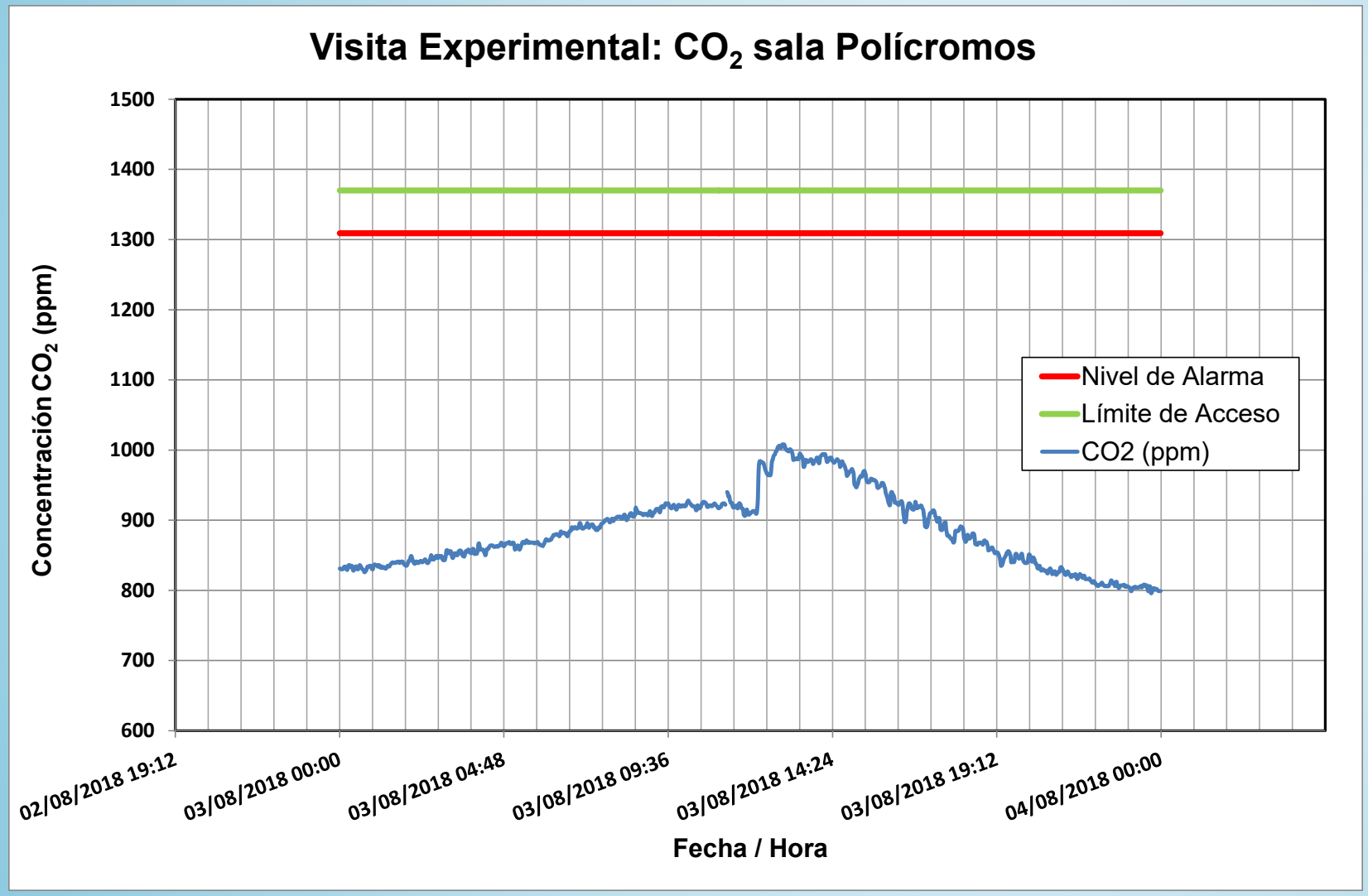
Límite Acceso:
Te + Variación año anterior

Nivel Alarma:
Inicial + 0,4 ºC

3+Guia /15 min/ 2+Guia

ΔT = 0,2 ºC

INFLUENCIA DE LAS VISITAS EXPERIMENTALES EN EL CO2

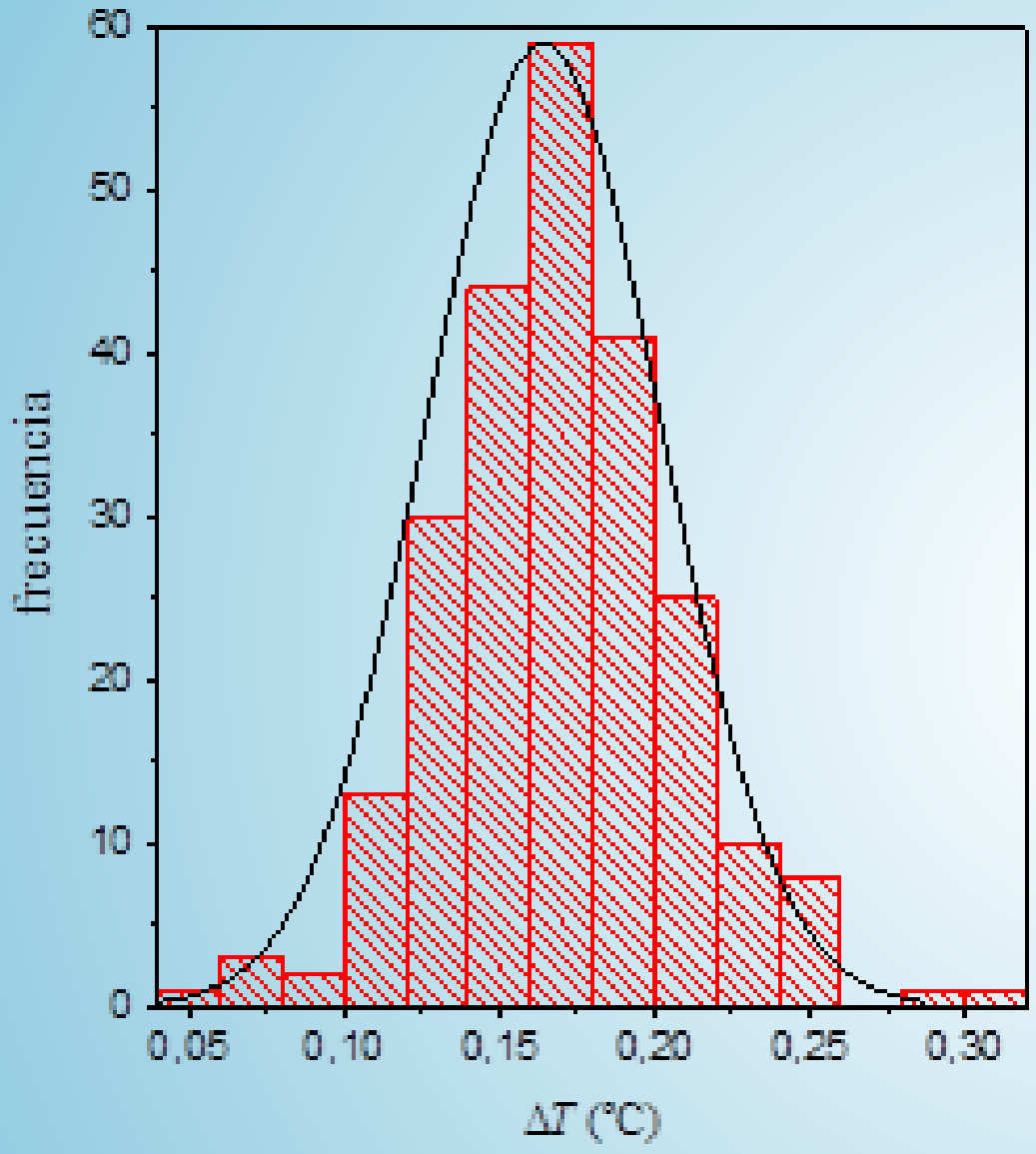


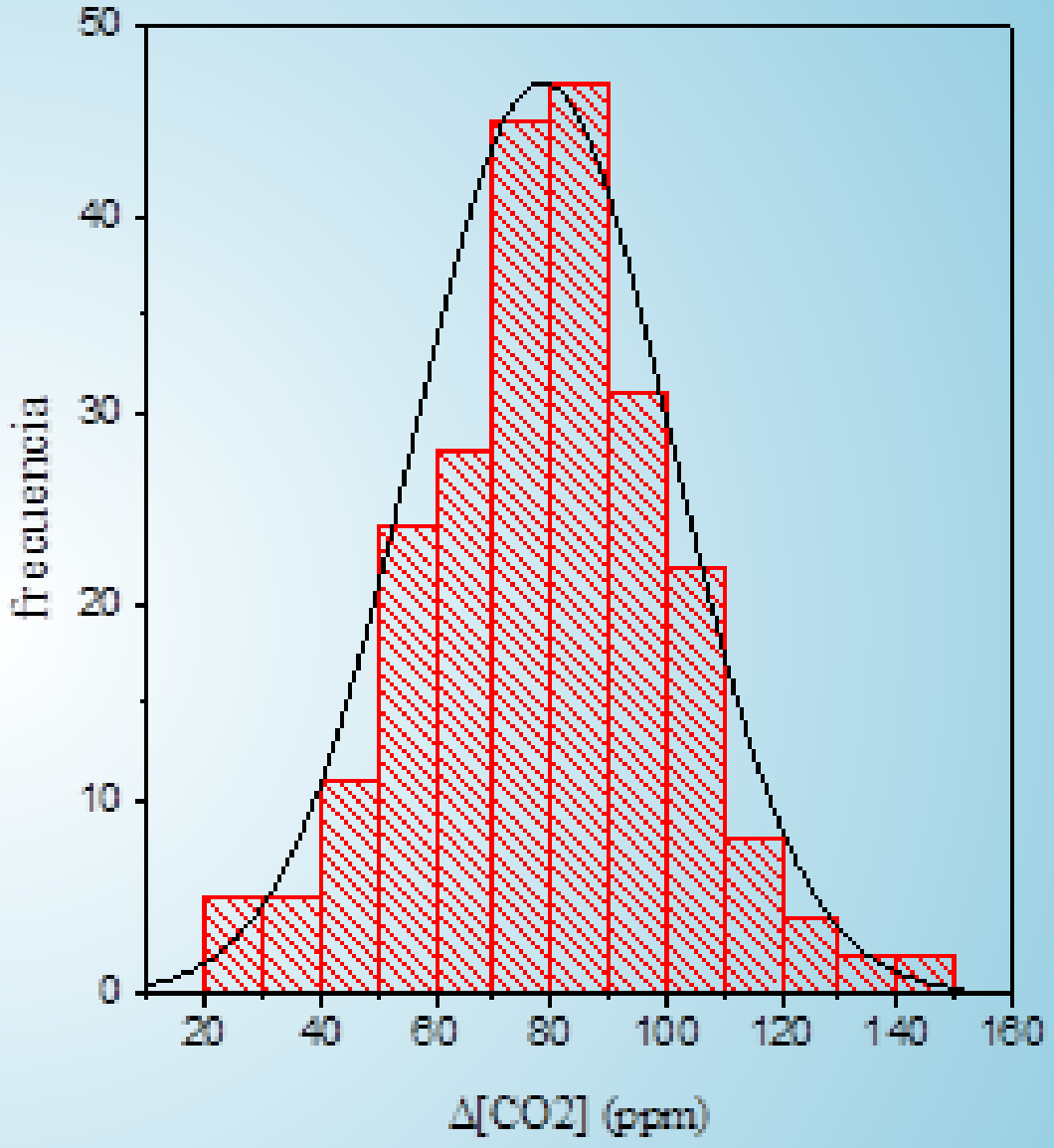
Límite Acceso:
CO2 histórico + Variación años anteriores

Nivel Alarma:
Inicial + 400 ppm

3+Guia /15 min/ 2+Guia

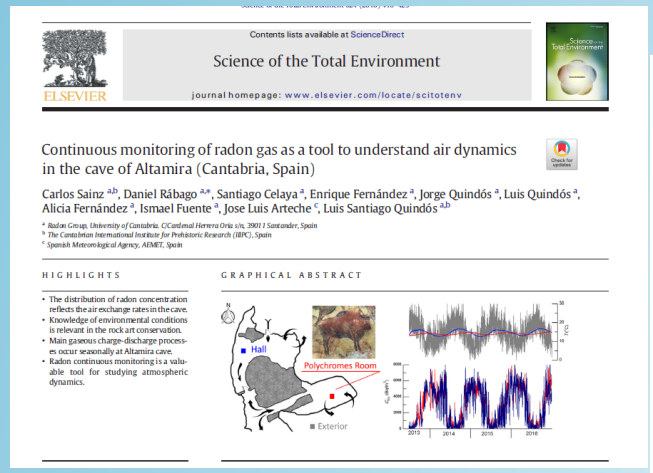
ΔCO2 = 100 ppm


frecuencia
0
10
20
30
40
50
60
0,05
0,10
0,15
0,20
0,25
0,30
ΔT (°C)


frecuencia
0
10
20
30
40
50
20
40
60
80
100
120
140
160
Δ[CO2] (ppm)

Dios creando el universo a través de principios geométricos. Frontispicio de la *Bible Moralisée*, 1215.

Investigación



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Continuous monitoring of radon gas as a tool to understand air dynamics in the cave of Altamira (Cantabria, Spain)

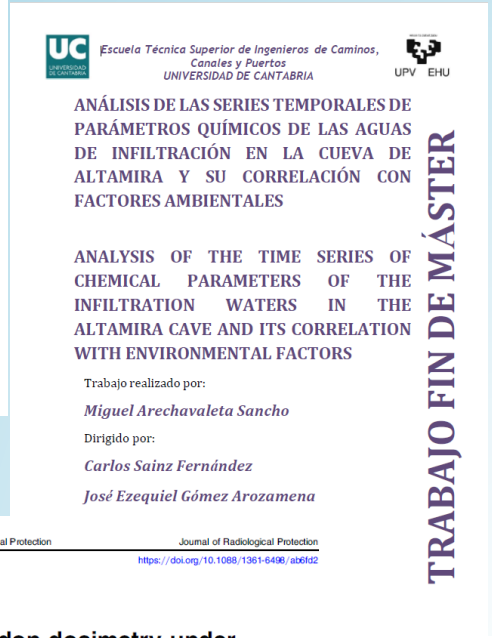
Carlos Sainz [a,b], Daniel Rábago [a,*], Santiago Celaya [a], Enrique Fernández [a], Jorge Quindós [a], Luis Quindós [a], Alicia Fernández [a], Ismael Fuente [a], Jose Luis Arteche [c], Luis Santiago Quindós [a,b]

[a] Radon Group, University of Cantabria, C/Cardenal Herrera Oria s/n, 39011 Santander, Spain
[b] The Cantabrian International Institute for Prehistoric Research (IIIPC), Spain
[c] Spanish Meteorological Agency, AEMET, Spain

HIGHLIGHTS

- The distribution of radon concentration reflects the air exchange rates in the cave.
- Knowledge of environmental conditions is relevant in the rock art conservation.
- Main gaseous charge-discharge processes occur seasonally at Altamira cave.
- Radon continuous monitoring is a valuable tool for studying atmospheric dynamics.

GRAPHICAL ABSTRACT



Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos
UNIVERSIDAD DE CANTABRIA

UPV EHU

ANÁLISIS DE LAS SERIES TEMPORALES DE PARÁMETROS QUÍMICOS DE LAS AGUAS DE INFILTRACIÓN EN LA CUEVA DE ALTAMIRA Y SU CORRELACIÓN CON FACTORES AMBIENTALES

ANALYSIS OF THE TIME SERIES OF CHEMICAL PARAMETERS OF THE INFILTRATION WATERS IN THE ALTAMIRA CAVE AND ITS CORRELATION WITH ENVIRONMENTAL FACTORS

Trabajo realizado por:

Miguel Arechavaleta Sancho

Dirigido por:

Carlos Sainz Fernández

José Ezequiel Gómez Arozamena

TRABAJO FIN DE MÁSTER

Facultad de Ciencias

ANÁLISIS DE SERIES TEMPORALES EN LAS TEMPERATURAS DE LA CUEVA DE ALTAMIRA: INFLUENCIA DEL AMBIENTE EXTERIOR

(Time series analysis of Altamira Cave temperatures: influence of external environment)

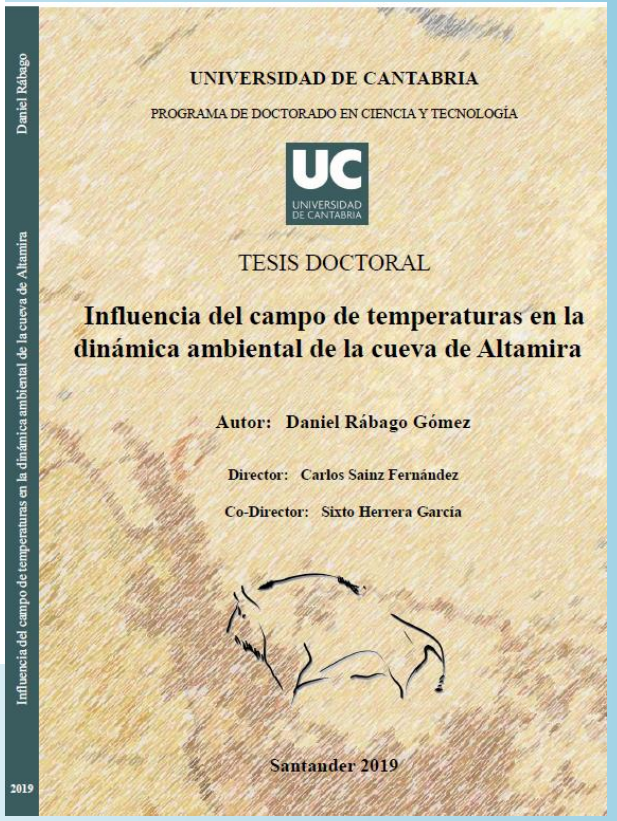
Trabajo de Fin de Máster para acceder al

MÁSTER EN FÍSICA, INTRUMENTACIÓN Y MEDIO AMBIENTE

Autor: Daniel Rábago Gómez

Director: Carlos Sainz Fernández
Co-Director: Sixto Herrera García

Octubre 2017



Daniel Rábago

Influencia del campo de temperaturas en la dinámica ambiental de la cueva de Altamira

UNIVERSIDAD DE CANTABRIA

PROGRAMA DE DOCTORADO EN CIENCIA Y TECNOLOGÍA

TESIS DOCTORAL

Influencia del campo de temperaturas en la dinámica ambiental de la cueva de Altamira

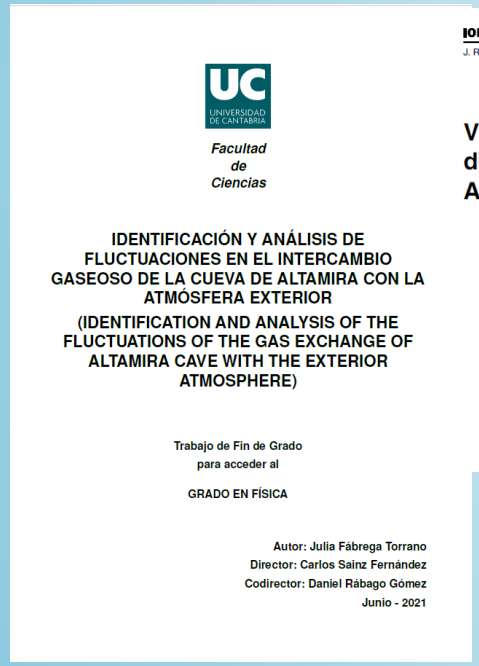
Autor: Daniel Rábago Gómez

Director: Carlos Sainz Fernández

Co-Director: Sixto Herrera García

Santander 2019

2019



Facultad de Ciencias

IDENTIFICACIÓN Y ANÁLISIS DE FLUCTUACIONES EN EL INTERCAMBIO GASEOSO DE LA CUEVA DE ALTAMIRA CON LA ATMÓSFERA EXTERIOR

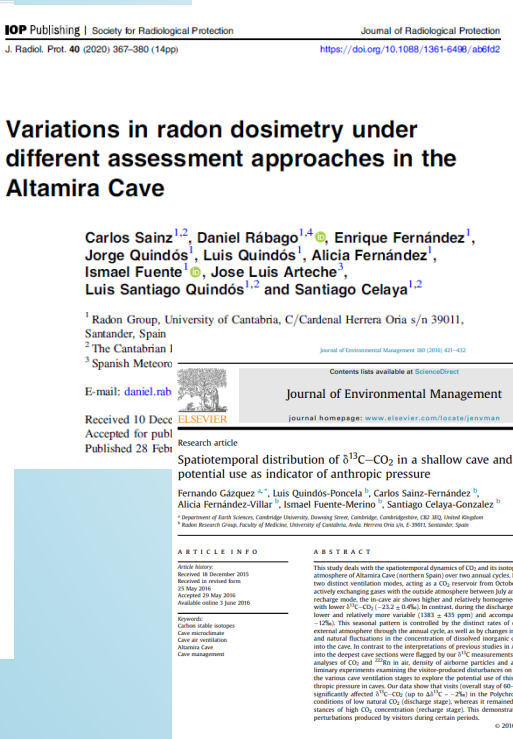
(IDENTIFICATION AND ANALYSIS OF THE FLUCTUATIONS OF THE GAS EXCHANGE OF ALTAMIRA CAVE WITH THE EXTERIOR ATMOSPHERE)

Trabajo de Fin de Grado para acceder al

GRADO EN FÍSICA

Autor: Julia Fábrega Torrano
Director: Carlos Sainz Fernández
Codirector: Daniel Rábago Gómez

Junio - 2021



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Variations in radon dosimetry under different assessment approaches in the Altamira Cave

Carlos Sainz[1,2], Daniel Rábago[1,4], Enrique Fernández[1], Jorge Quindós[1], Luis Quindós[1], Alicia Fernández[1], Ismael Fuente[1], Jose Luis Arteche[3], Luis Santiago Quindós[1,2] and Santiago Celaya[1,2]

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Research article

Spatiotemporal distribution of $\delta^{13}C-CO_2$ in a shallow cave and its potential use as indicator of anthropic pressure

Fernando Gázquez [a,*], Luis Quindós-Poncela [b], Carlos Sainz-Fernández [b], Alicia Fernández-Villar [b], Ismael Fuente-Merino [b], Santiago Celaya-Gonzalez [b]

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ABSTRACT

This study deals with the spatiotemporal dynamics of CO_2 and its isotopic composition ($\delta^{13}C-CO_2$) in the atmosphere of Altamira Cave (northern Spain) over two annual cycles. In general terms, the cavity shows two distinct ventilation modes, acting as a CO_2 reservoir from October to May (recharge stage), while actively exchanging gases with the outside atmosphere between July and September (discharge stage). In recharge mode, the in-cave air shows higher and relatively homogeneous CO_2 values (3332 ± 521 ppm) with lower $\delta^{13}C-CO_2$ (−23.2 ± 0.4‰). In contrast, during the discharge stage, the CO_2 concentrations are lower and relatively more variable (1383 ± 435 ppm) and accompanied by higher $\delta^{13}C-CO_2$ (up to −12‰). This seasonal pattern is controlled by the distinct rates of exchange of air masses with the external atmosphere through the annual cycle, as well as by changes in the production of CO_2 in the soil and natural fluctuations in the concentration of dissolved inorganic carbon transported by drip water into the cave. In contrast to the interpretations of previous studies in Altamira Cave, no local air intakes into the deepest cave sections were flagged by our $\delta^{13}C$ measurements. This finding is also supported by analyses of CO_2 and ^{222}Rn in air, density of airborne particles and air temperature. In addition, preliminary experiments examining the visitor-produced disturbances on $\delta^{13}C-CO_2$ were conducted during the various cave ventilation stages to explore the potential use of this parameter as an indicator of anthropic pressure in caves. Our data show that visits (overall stay of 60–85 min; *i.e.*, 4 people for 20 min) significantly affected $\delta^{13}C-CO_2$ (up to $\Delta\delta^{13}C$ = −2‰) in the Polychrome Hall of Altamira Cave under conditions of low natural CO_2 (discharge stage), whereas it remained almost unaltered under circumstances of high CO_2 concentration (recharge stage). This demonstrates that $\delta^{13}C-CO_2$ is sensitive to perturbations produced by visitors during certain periods.

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Research papers

The role of cave ventilation in the triple oxygen and hydrogen isotope composition of condensation waters in Altamira Cave, northern Spain

Fernando Gázquez [a,b,*], Luis Quindós [c,d], Daniel Rábago [c], Ismael Fuente [c], Santiago Celaya [c], Carlos Sainz [c,d]

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Keywords:
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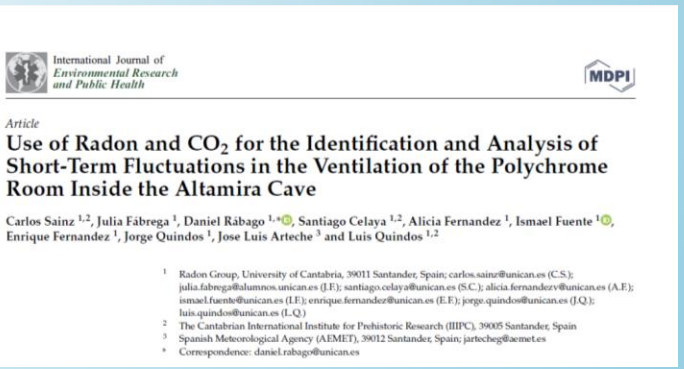
ABSTRACT

In cave environments, water vapor condensation occurs naturally when warmer/wet air masses flow close to colder cave surfaces. Artificial microclimate perturbations in show caves can enhance this process, leading to potential deterioration of rock art and degradation of speleothems. Here we investigate the triple oxygen and hydrogen isotopic compositions of condensation water in Altamira Cave (Cantabria, northern Spain) to evaluate the potential of stable isotopes in the study of condensation mechanisms in caves. We assess the role of cave ventilation in the spatiotemporal isotopic variability of condensation water in Altamira Cave. To this end, water drops that condense naturally on artificial supports in different parts of the cave were collected for 7 years and their isotopic compositions ($\delta^{17}O$, $\delta^{18}O$, δD and derived parameters ^{17}O-excess and d-excess) were compared to those of droplets with no apparent dripping taken from the cave ceiling (i.e. permanently condensation water) and fast dripping points (i.e. infiltration water) during the same period. Condensation waters in the outmost cave sectors, closer to the entrance, show higher $\delta^{17}O$, $\delta^{18}O$ and δD values during the cave ventilation period (June to October) compared to the rest of the year. This seasonal pattern can be explained by changes in the contributions of two moisture sources for condensation: advection of allochthonous water vapor from outside during the cave ventilation period and recycling of autochthonous vapor generated from cave dripwater during the stagnation period. In contrast, the isotopic values of condensation waters in the inner cave sectors are similar to those of infiltration water, with insignificant seasonal variability. This suggests that water condensation in the inner cave sectors is sourced by autochthonous vapor, with no significant contributions of external moisture, even during the cave ventilation period. We conclude that allochthonous water vapor condenses preferentially in the *Entrance Hall* and does not affect significantly the rest of the cave. These results are relevant for the management of Altamira Cave and for future investigations on condensation mechanisms in cavities elsewhere.



International Journal of Environmental Research and Public Health — MDPI

Article

Use of Radon and CO_2 for the Identification and Analysis of Short-Term Fluctuations in the Ventilation of the Polychrome Room Inside the Altamira Cave

Carlos Sainz [1,2], Julia Fábrega [1], Daniel Rábago [1,*], Santiago Celaya [1,2], Alicia Fernandez [1], Ismael Fuente [1], Enrique Fernandez [1], Jorge Quindos [1], Jose Luis Arteche [3] and Luis Quindos [1,2]

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Investigación

Isótopos estables

Uso de gases como trazadores de procesos de ventilación

Estimación de dosis por inhalación de radón interior

Caracterización de eventos de desgasificación/recarga de corto periodo

Origen del CO2

Caracterización de agua de condensación

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Fernando Gázquez [a,*], Luis Quindós-Poncela [b], Carlos Sainz-Fernández [b], Alicia Fernández-Villar [b], Ismael Fuente-Merino [b], Santiago Celaya-Gonzalez [b]

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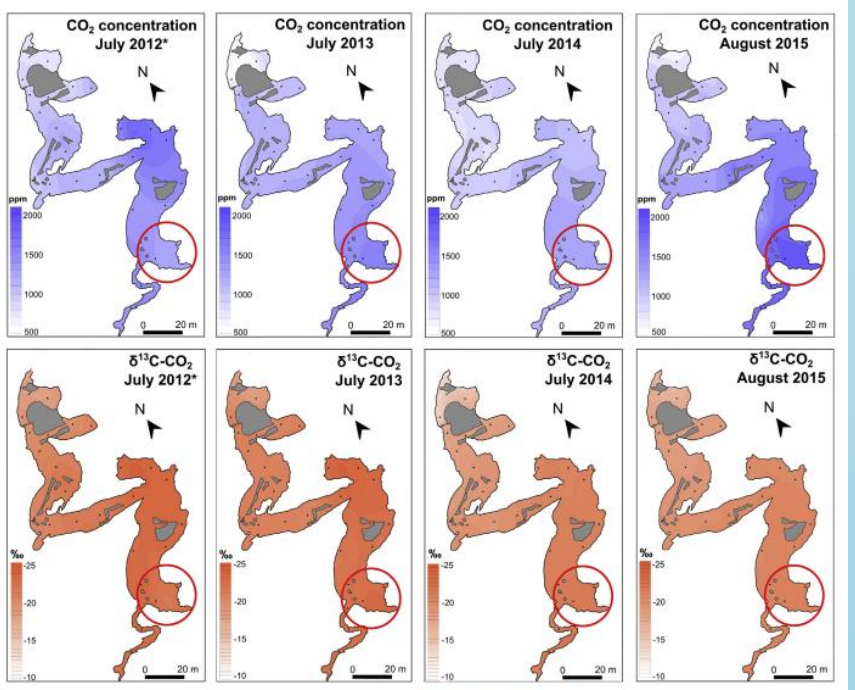

Fig. 5. Spatial distribution of CO_2 concentration and its $\delta^{13}C$ in Altamira Cave in July 2012 (García-Antón et al., 2013)*, July 2013, July 2014 and August 2015 (this study). Note that the small anomalies in CO_2 concentration and $\delta^{13}C$ observed in Well Hall (red circles) in 2012 were not repeated in 2013, 2014 or 2015. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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Research papers

The role of cave ventilation in the triple oxygen and hydrogen isotope composition of condensation waters in Altamira Cave, northern Spain

Fernando Gázquez [a,b,*], Luis Quindós [c,d], Daniel Rábago [c], Ismael Fuente [c], Santiago Celaya [c], Carlos Sainz [c,d]

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Keywords:
Cave management
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Condensation water
Stable isotopes
Oxygen-17
Triple oxygen isotopes

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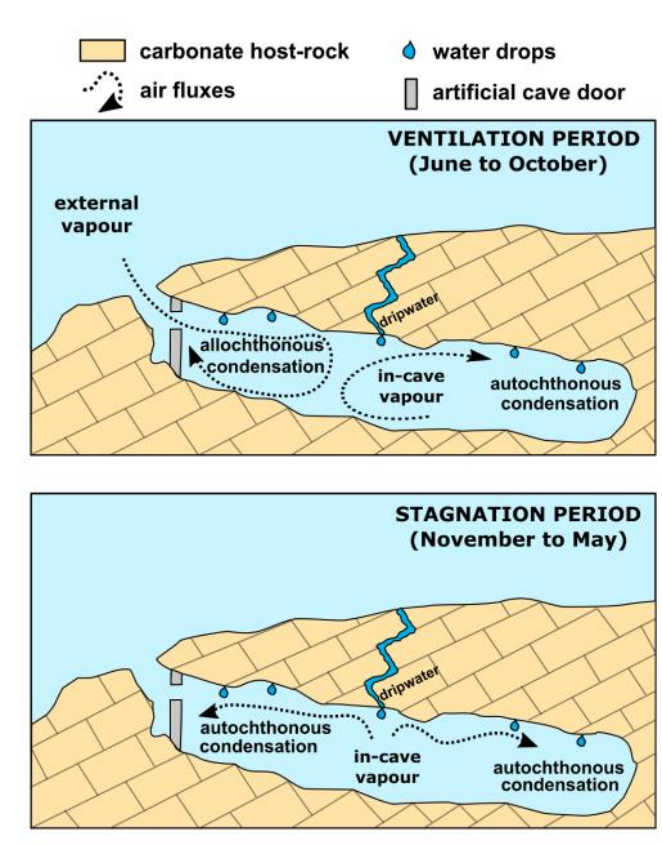

Caracterización isotópica y origen del agua de condensación en diferentes periodos del año

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Continuous monitoring of radon gas as a tool to understand air dynamics in the cave of Altamira (Cantabria, Spain)

Carlos Sainz [a,b], Daniel Rábago [a,*], Santiago Celaya [a], Enrique Fernández [a], Jorge Quindós [a], Luis Quindós [a], Alicia Fernández [a], Ismael Fuente [a], Jose Luis Arteche [c], Luis Santiago Quindós [a,b]

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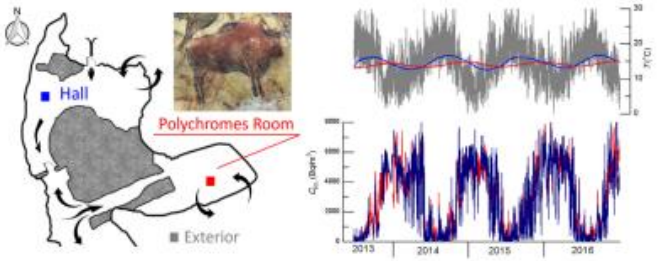
HIGHLIGHTS

- The distribution of radon concentration reflects the air exchange rates in the cave.
- Knowledge of environmental conditions is relevant in the rock art conservation.
- Main gaseous charge-discharge processes occur seasonally at Altamira cave.
- Radon continuous monitoring is a valuable tool for studying atmospheric dynamics.

GRAPHICAL ABSTRACT



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ABSTRACT

The use of radon as an atmospheric tracer in the Altamira Cave over the past 30 years has provided relevant information about gaseous exchanges between the Polychromes Room, the adjoining Chambers inside the cave, and the outside atmosphere. The relatively simple physico-chemical behaviour of radon gas provides a marked advantage over other tracer gases that are usually present in high concentrations in hypogeous environments, such as CO_2. Two types of continuous radon measurement were undertaken. The first involves active detectors located in the Hall and Polychromes Room, which provide radon concentration values at 1-hour intervals. In addition, nuclear solid track etched detectors (CR-39) are used in every chamber of the cave over 14-day exposure periods, providing average radon concentrations. In this paper we show some of the specific degassing and recharge events identified by anomalous variations in the concentration of radon gas in the Polychromes Room. In addition, we update knowledge regarding the degree of connection between chambers inside the cave and with the outside atmosphere. We verify that the connection between the Polychromes Room and the rest of the cave has been drastically reduced by the installation of the second closure in 2008. Except for point exchanges with the Crossing zone generated by a negative temperature gradient in that direction, the atmosphere of the Polychromes Room remains stable, or else it exchanges matter with the outside atmosphere through the karst interface. The role of radon as a tracer is demonstrated to be valid both to reflect seasonal cycles of degassing and recharge, and to analyse shorter (daily) period fluctuations.

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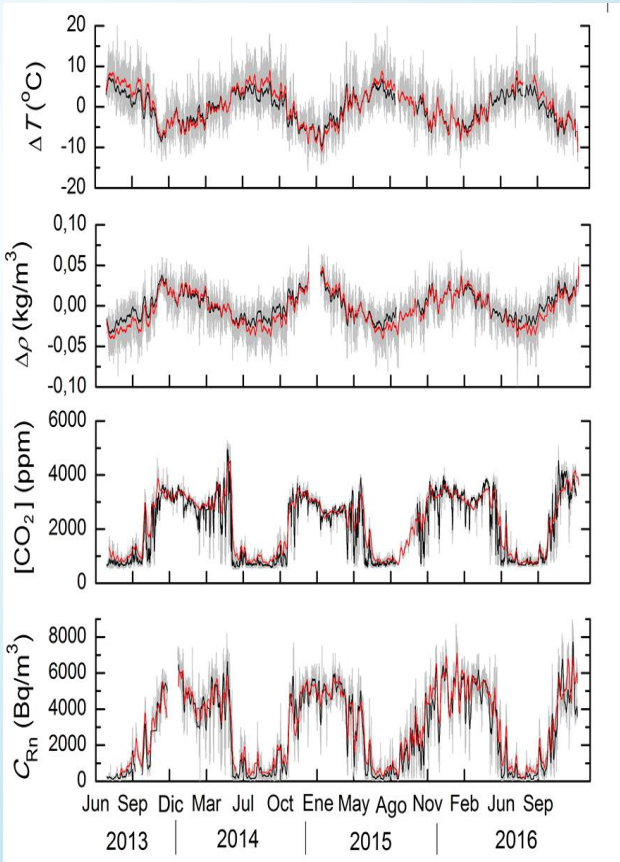

Uso del radón como trazador de dinámica atmosférica

Descripción de mecanismo principal de intercambio cueva exterior

International Journal of
Environmental Research and Public Health

MDPI

Article

Use of Radon and CO_2 for the Identification and Analysis of Short-Term Fluctuations in the Ventilation of the Polychrome Room Inside the Altamira Cave

Carlos Sainz [1,2], Julia Fábrega [1], Daniel Rábago [1,*], Santiago Celaya [1,2], Alicia Fernandez [1], Ismael Fuente [1], Enrique Fernandez [1], Jorge Quindos [1], Jose Luis Arteche [3] and Luis Quindos [1,2]

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Abstract: A study is presented on rapid episodes of air exchange in the Polychrome Room of the Altamira Cave (Cantabria, Spain) using continuous monitoring of radon and CO_2 tracer gases, as well as environmental parameters such as internal and external air temperature. For this, criteria have been developed to carry out an inventory of these types of events during the 2015–2020 period. Most of the degassing-recharging events occur over several hours or days, especially during spring and autumn. This means that the room can be significantly ventilated during these short periods of time, posing an exchange of energy and matter with potential impact in the preservation of the rock art present inside. In addition, the hypothesis that temperature gradients between the internal and external atmosphere is one of the main factors that induces degassing has been tested. To this end, correlation analysis has been carried out between the different magnitudes involved in this study, such as radon and CO_2 concentrations, and air temperature gradients. A total of 37 degassing-recharging events have been analyzed for the 5 year studied period. The distribution of the duration of the events have been described, as well as that of the correlations between the degassing and recharge stages of each event, showing significant values of r coefficients for the correlation with temperature gradients between the internal and external atmosphere.

Keywords: radon; CO_2; tracer; rock art; cave

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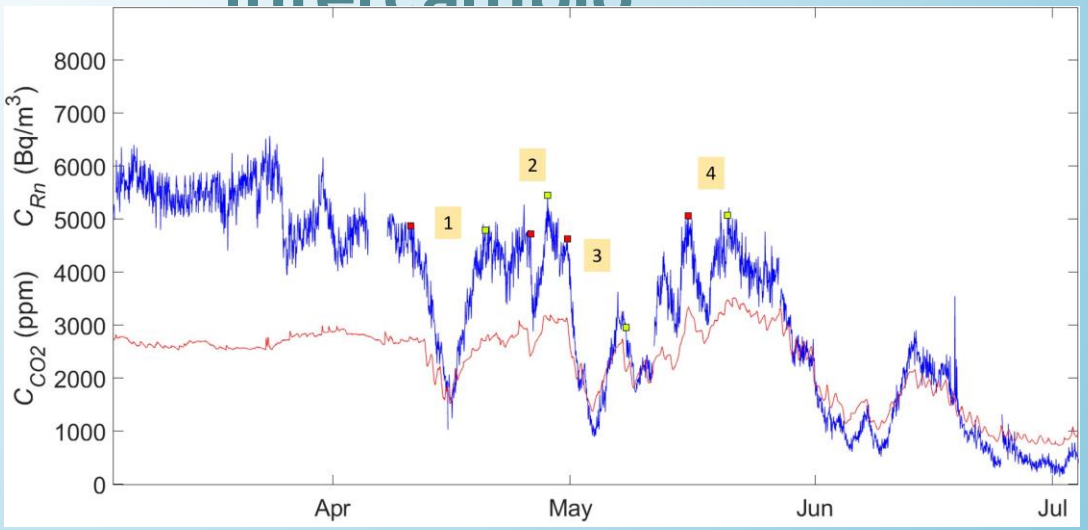
Uso del radón como trazador de dinámica atmosférica

Descripción de mecanismo principal de intercambio



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Variations in radon dosimetry under different assessment approaches in the Altamira Cave

Carlos Sainz[1,2], Daniel Rábago[1,4], Enrique Fernández[1], Jorge Quindós[1], Luis Quindós[1], Alicia Fernández[1], Ismael Fuente[1], Jose Luis Arteche[3], Luis Santiago Quindós[1,2] and Santiago Celaya[1,2]

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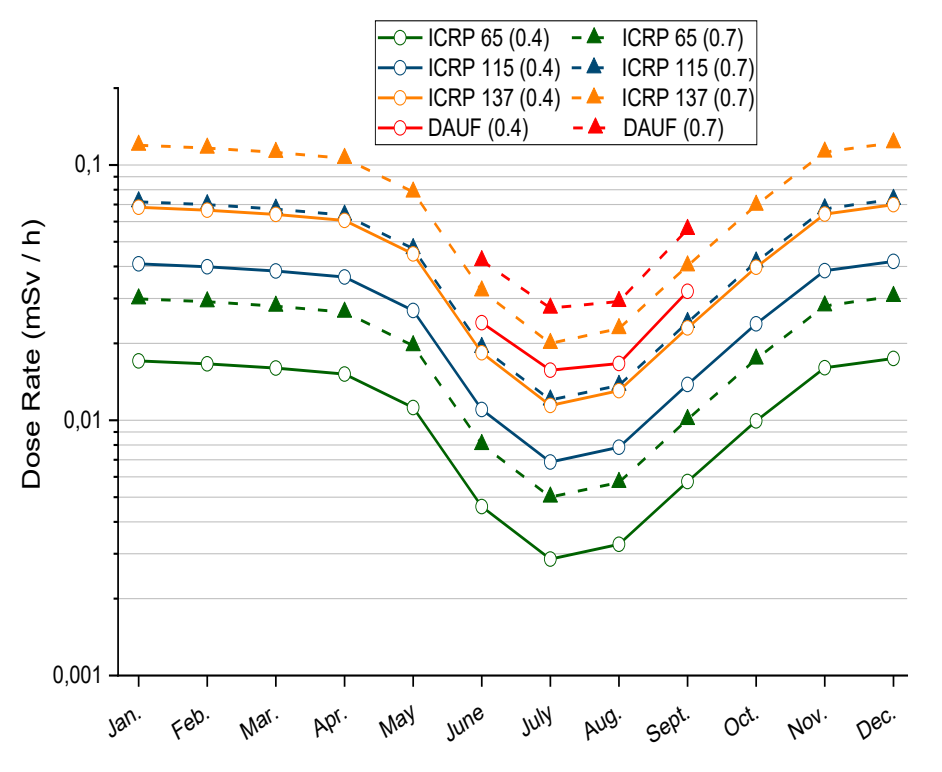
Abstract

The atmosphere of caves is a special environment where it is necessary to take into account some particular characteristics when assessing the radon dose. The equilibrium factor (F) between radon and its progeny, and especially its unattached fraction (f_p), is a key parameter in radon dose evaluation. In order to consider the specific features of the atmosphere in the Altamira Cave, the radon and particle concentrations have been measured. The mean annual radon concentration inside the cave over the period 2013–2019 is around 3500 Bq m^{-3} with a standard deviation of 1833 Bq m^{-3} and this exhibits seasonal variations. This value surpasses all international (WHO, IAEA, ICRP) upper action and reference levels (occupational and non-occupational). Dose rate levels expressed in μSv h^{-1} were estimated for four different equilibrium scenarios between radon and its progeny ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po. The most recent dose conversion factors have been used and the contribution made to the dose by the unattached fraction of radon progeny f_p has been also assessed from the particle concentration. The results suggest that the mean annual dose levels show variations of up to 500% due to the range of F and the f_p considered in this study. Given the high radon concentrations usually found in show caves, the best way to reduce this variability and its

Evaluación de tasas de dosis por inhalación de descendientes de radón



Relación Temperatura Cruce con Ramal

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Universidad de Cantabria

Facultad de Ciencias

ANÁLISIS DE FLUCTUACIONES TÉRMICAS NO ESTACIONALES EN LA ZONA DE CRUCE EN EL INTERIOR DE LA CUEVA DE ALTAMIRA
(No seasonal thermal fluctuations analysis in the Crossing zone inside Altamira's cave)

Trabajo de Fin de Grado
para acceder al

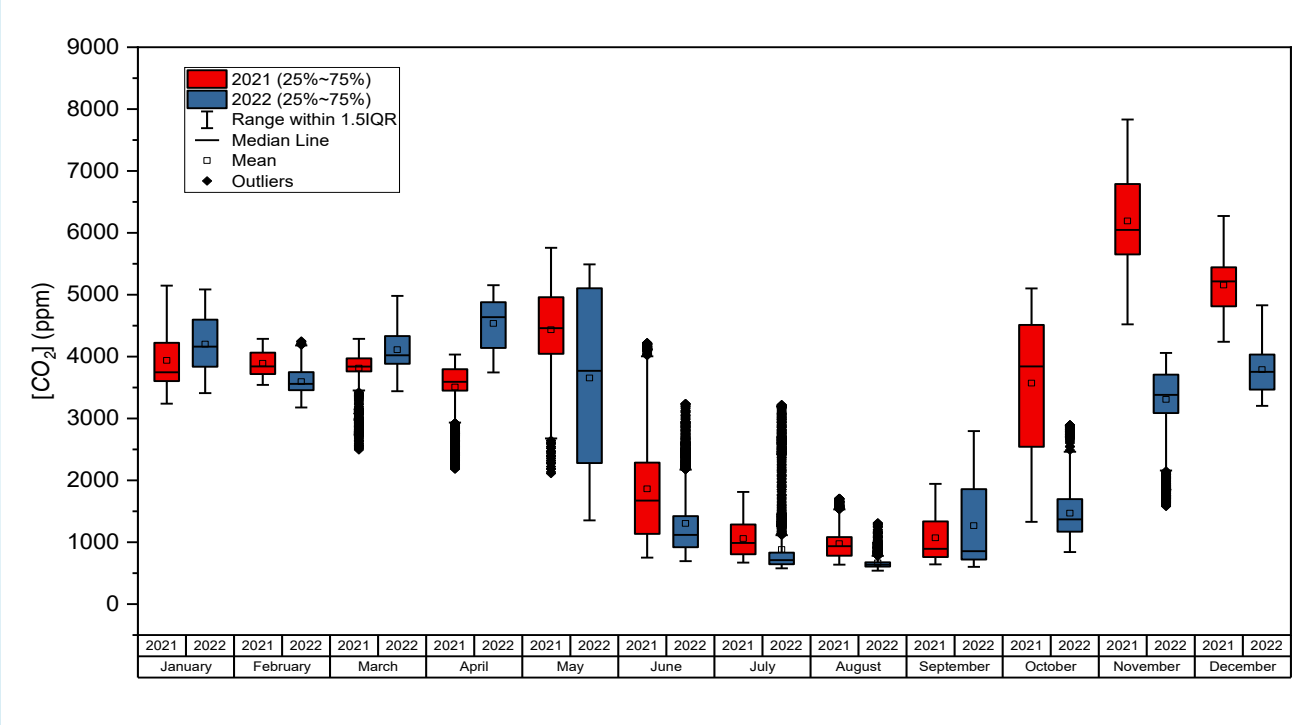
GRADO EN FÍSICA

Autor: Irene Morales Mena

Director: Carlos Sainz Fernández

Co-Director: Daniel Rábago Gómez

Septiembre - 2023



Implications of daily thermal variations in the ventilation and indoor CO2 levels in the Cave of Altamira (in press)

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Evaluation of commercial facemasks to reduce the radioactive dose of radon daughters

Isidoro Gutiérrez-Álvarez[1,2], Santiago Celaya González[1], Ismael Fuente Merino[1], Luis Santiago Quindós[1] and Carlos Saínz Fernández[1]

Abstract

Commercial facemasks have become a common tool during the COVID-19 pandemic. They are cheap, simple to use and some are capable of filtering out most particles in the air, protecting the user. These qualities are usually employed in relation to hurtful viruses or contaminants, but they could also be used to prevent the radioactive dose due to radon, which is the second leading cause of lung cancer worldwide. For that reason, the main goal of this study is to verify if facemasks could prevent radon decay products from entering the potential user's lungs. Since these decay products are the main source of radioactive dose, several commercial facemasks were tested by exposing them to radon and then measuring the presence of radon daughters by gamma spectroscopy. Reusable facemasks made from materials such as cotton, polyester or neoprene appeared to be inefficient with only 40% filtering efficiency, Polypropylene woven masks being the only exception, with 80% efficiency. Surgical masks presented filtering efficiencies between 90 and 98%. FFP3 and FFP2 proved to be the most reliable, almost completely filtering out radon daughters with filtering efficiencies up to 98%. Results prove that the use of

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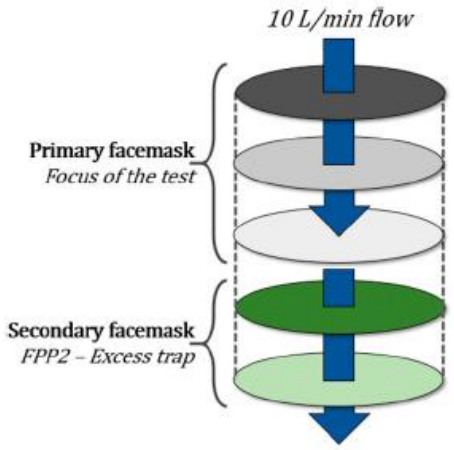
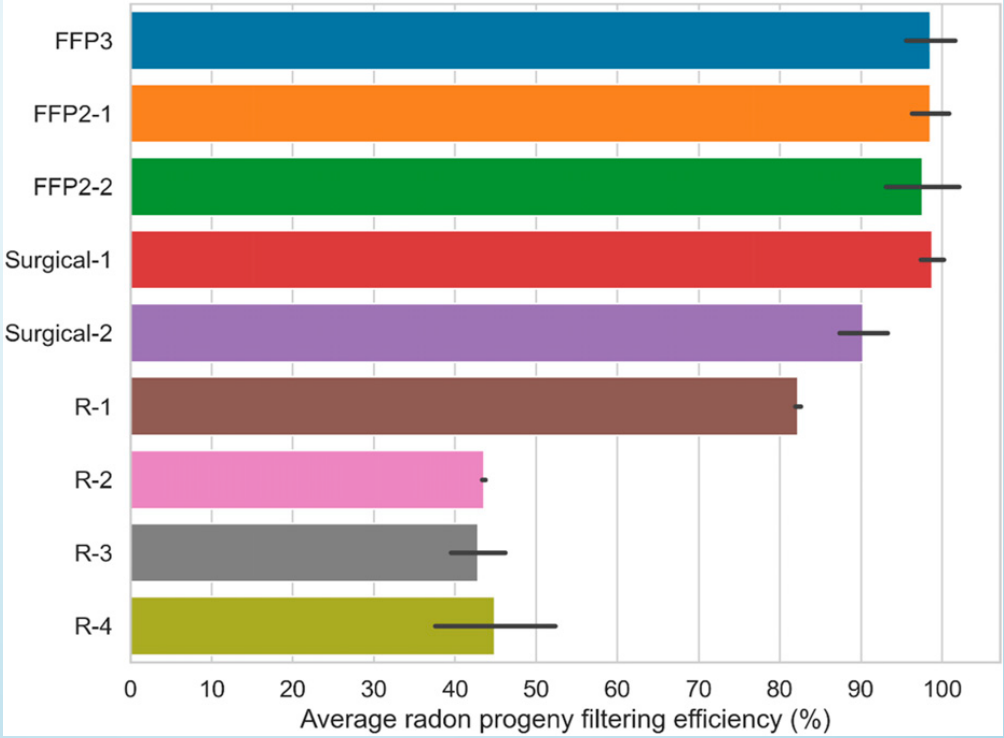


Figure 1. Idealized scheme of the placement of the primary and secondary facemaks during the samplings.



Lineas futuras…

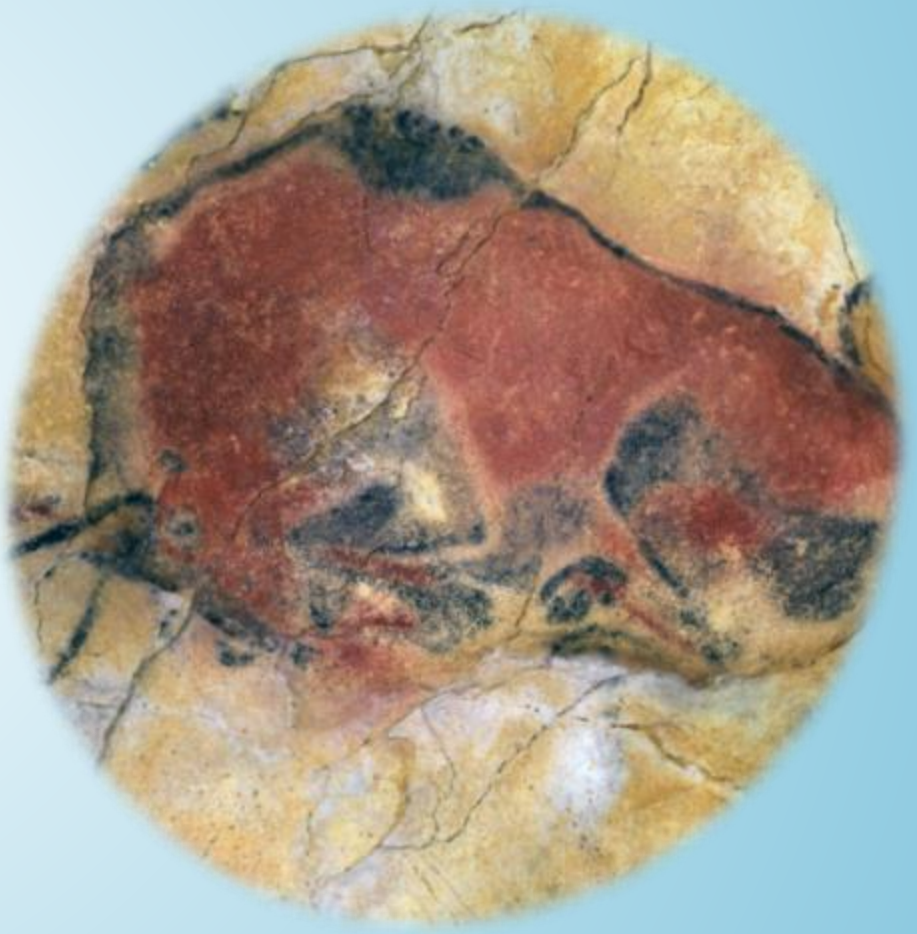
- Caracterización experimental del factor de equilibrio entre el radon y sus descendientes
- Estudio puntos caida de pigmento
- Evaluación ambiental del impacto antrópico
- Influencia calentamiento exterior
- Modelo ambiental integrado
- Etc…

A MODO DE CONCLUSIÓN…

- El seguimiento Ambiental es una herramienta esencial tanto para la gestión cultural como para la generación de conocimiento basado en la evidencia científica.

- La cantidad y, sobre todo, la calidad de la información acumulada tienen un valor fundamental para su uso y estudio futuros

- Altamira "respira" profundamente solo una vez cada año, y necesitamos ver como lo hace muchas veces para entenderla y conservarla mejor

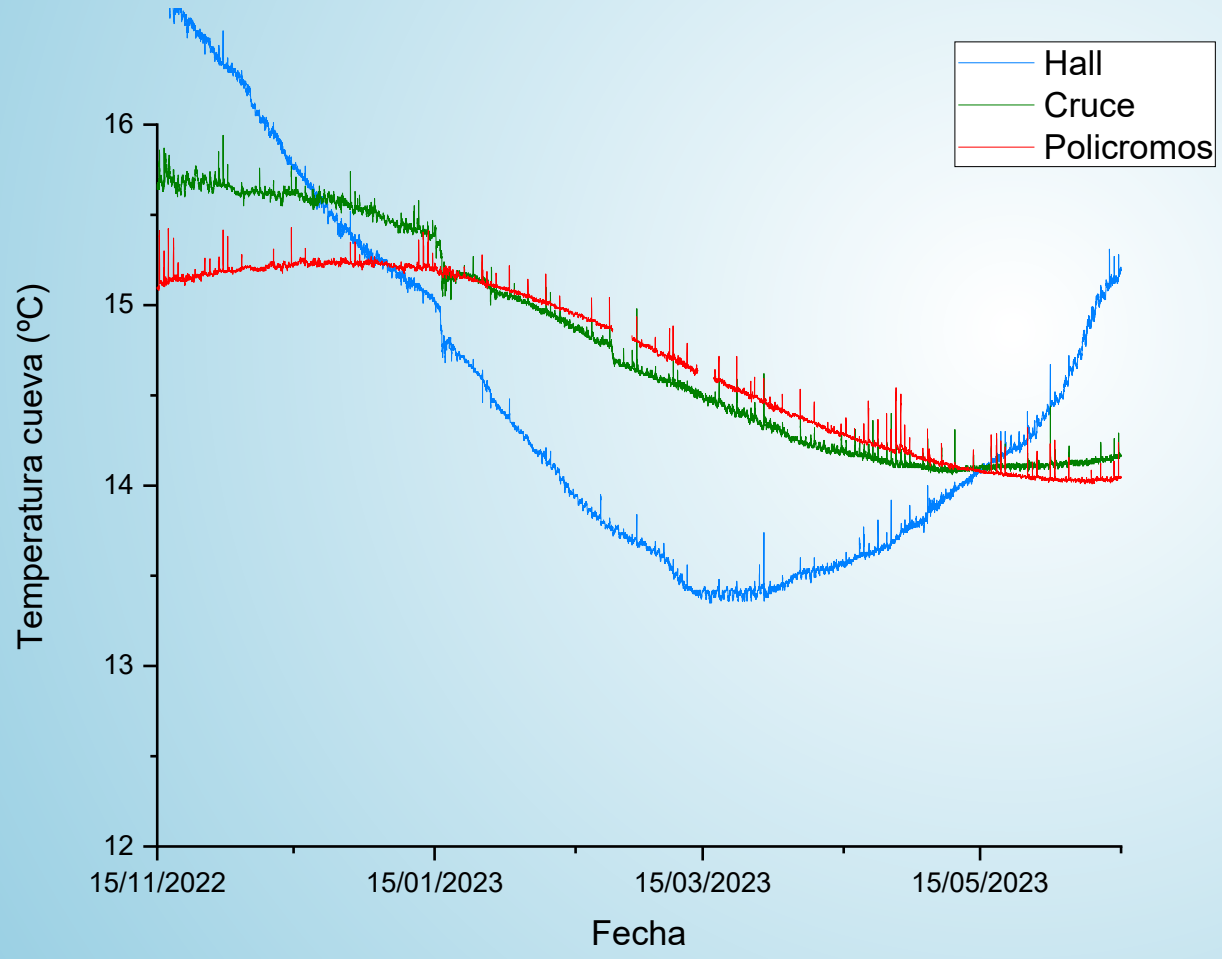


Muchas gracias por vuestra atención

Pictures Source: Altamira´s Museum
http://www.culturaydeporte.gob.es/mnaltamira/home.html

Cambios dinámica interna

“Situación 1”: t (Hall) < t (Cruce) < t (Policromos) // (diciembre-junio)



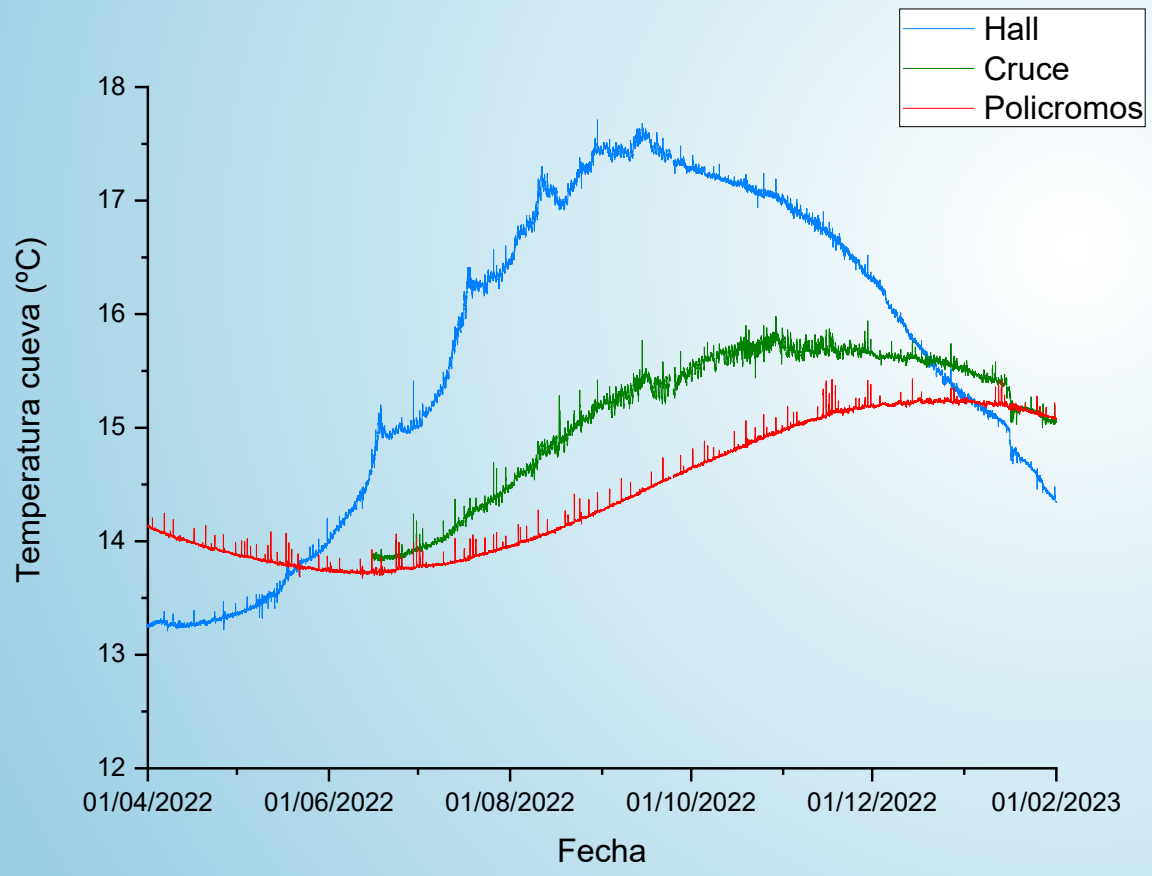
Intercambio Hall → Cruce

Enfriamiento Cruce

Transporte a Policromos (enfriamiento)

Cambios dinámica interna

“Situación 2”: t (Hall) > t (Cruce) > t (Policromos) // (junio-diciembre)



Intercambio Cruce → Hall

Calentamiento Cruce

“Aislamiento” Policromos

Radon y CO_2: Control de calidad

CO_2: Calibración realizada in-situ Nov. 2021

Radón: Detectores Pasivos CR-39 (Radosys RSKS)

Monitores en continuo: Radon Scout (SARAD GmbH)

ENAC
CALIBRACIÓN
ISO 17025
Nº279 / LC10.245

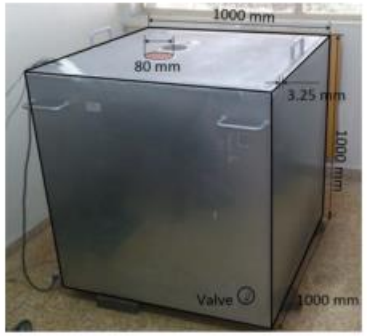
ENAC
ENSAYO
ISO 17025
Nº1204 / LE2219

LaRUC: Laboratorio acreditado para **Ensayos y Calibración** (ISO 17025)

Ejercicios de Intercomparación

Ensayos en paralelo entre técnicos

Determinación del factor de calibración en la cámara de radón



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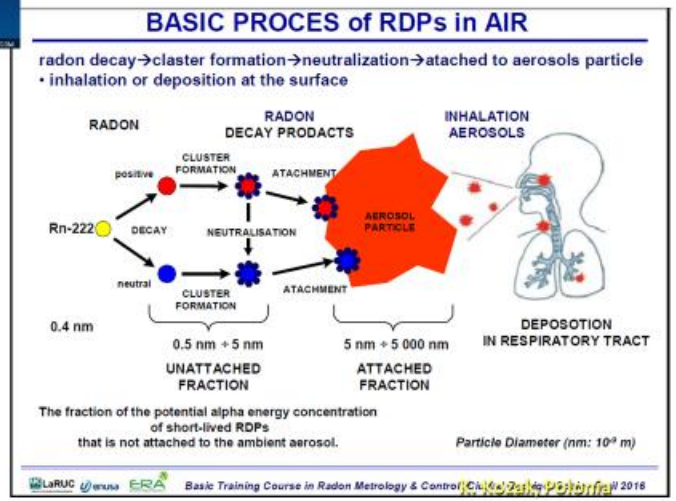
Radon : Dosimetría



Actualización marco legislativo

Posibilidad determinación factor de equilibrio por medida de descendientes.

Evaluación más precisa de dosis

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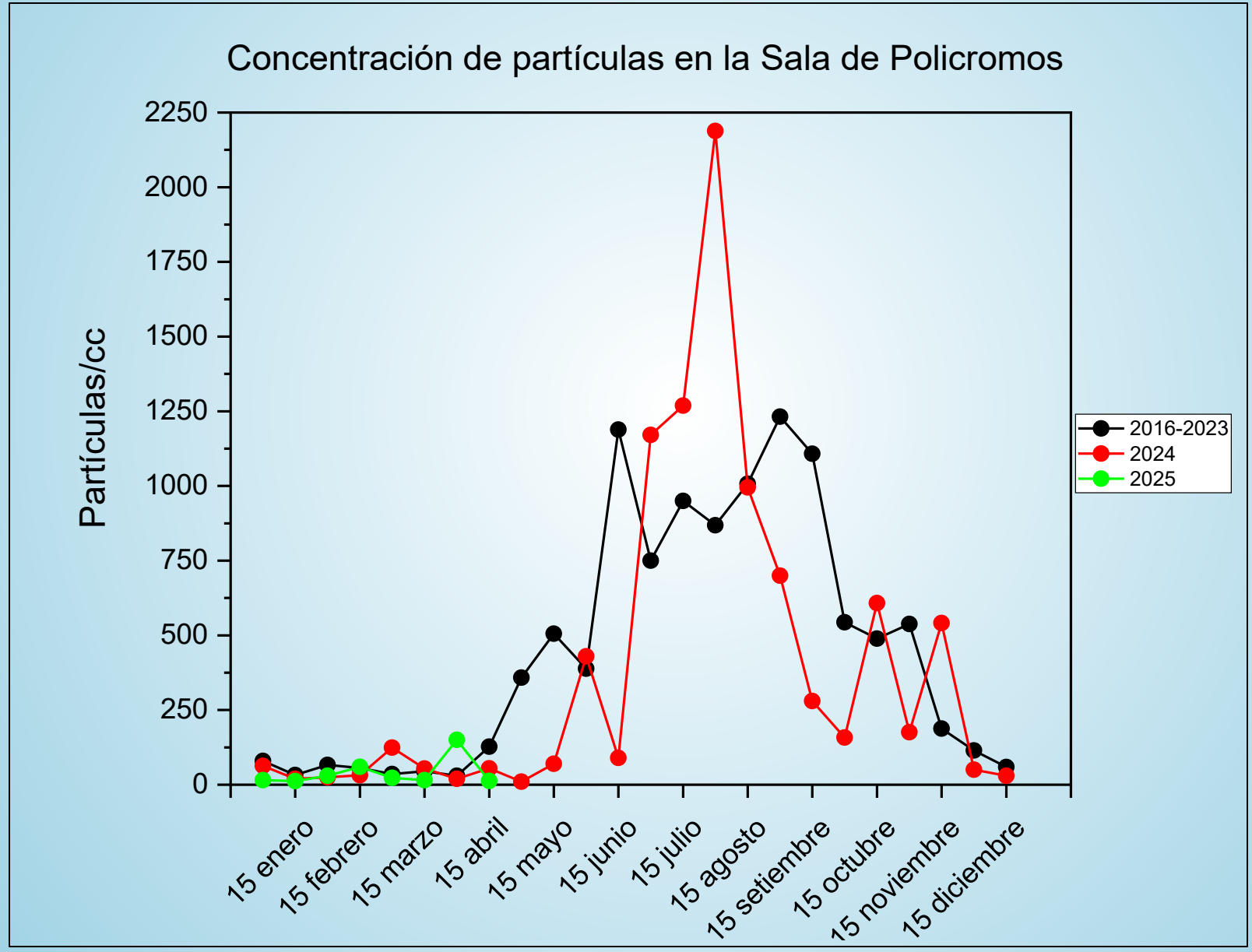
PROPUESTA 2º CIERRE

APERTURA DIC-ENE	VENTILACION
CIERRE INFERIOR FEB	VENTILACION ATENUADA
APERTURA MAR - ABR – MAY?	VENTILACION/REDUCCIÓN CO2
CIERRE JUN – JUL - AGO	PREVENCIÓN PARTÍCULAS
CIERRE SUPERIOR SEP - OCT- NOV	PREVENCIÓN NIEBLAS/HIDROAEROSOLES

Concentración de Partículas



~~Adquisición de equipo nuevo de iguales~~ características

Rango (0.01 – 1) µm

pH - Equipamiento

Thermo Scientific

Equipo: Orion Star A329

Sonda: 913600 Flat Surface

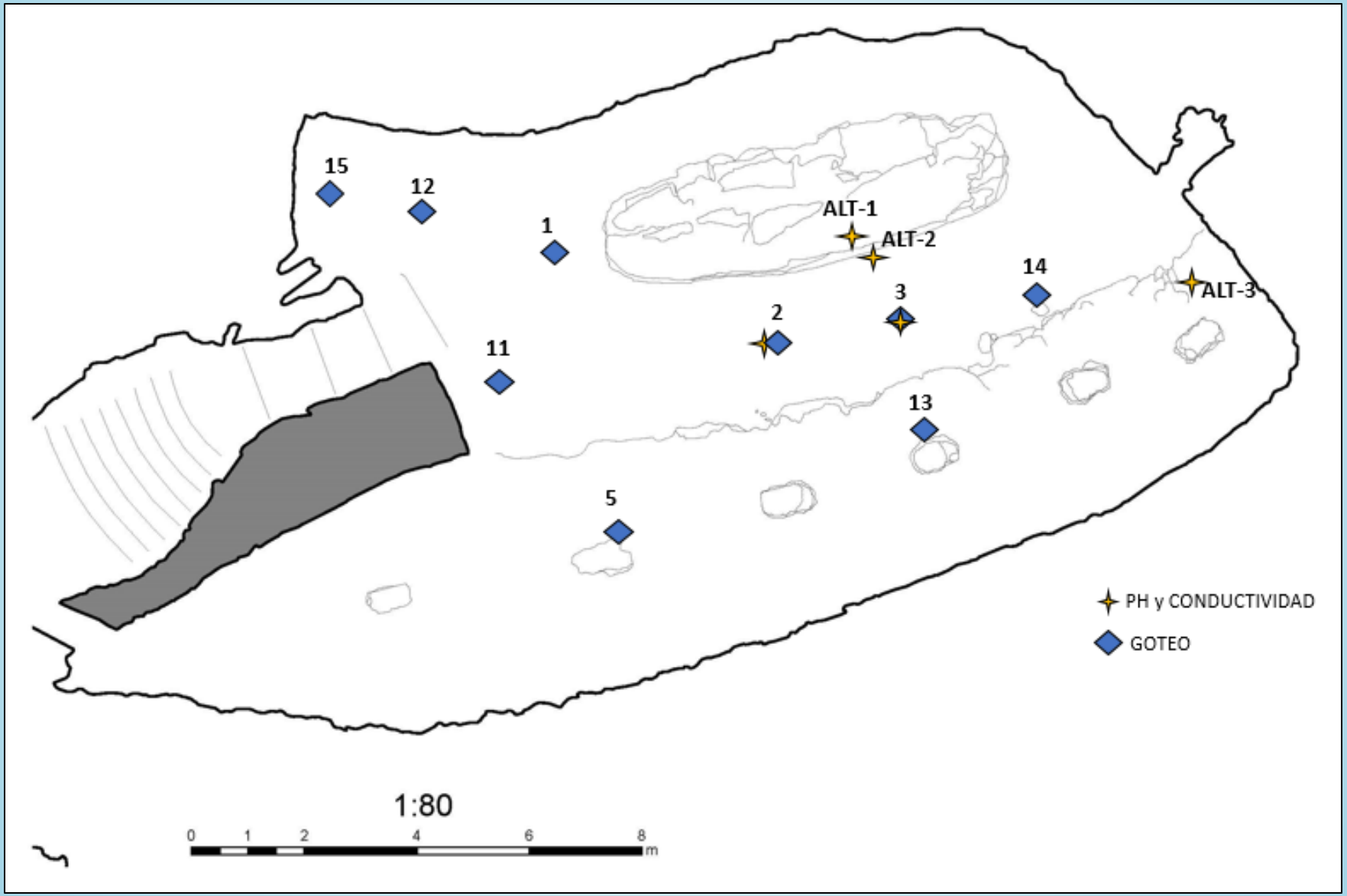
Toma de muestra superficial

Calibración disoluciones patrón:

pH= 4, 7, 9

SENSIBILIDAD ± 0.01 pH

pH – Puntos Estudio Policromos



Periodo	Estado puerta A: Lamas superiores B: Lamas inferiores	Acción sobre Polícromos
Noviembre-Enero	A: Abierta B: Abierta	Ventilación
Febrero	A: Abierta B: Cerrada	Ventilación atenuada
Marzo -hasta 15 Mayo	A: Abierta B: Abierta	Ventilación
15 de Mayo- Septiembre	A: Cerrada B: Cerrada	Prevención paso de partículas/hidroaerosoles
Octubre	A: Cerrada B: Abierta	Prevención paso hidroaerosoles