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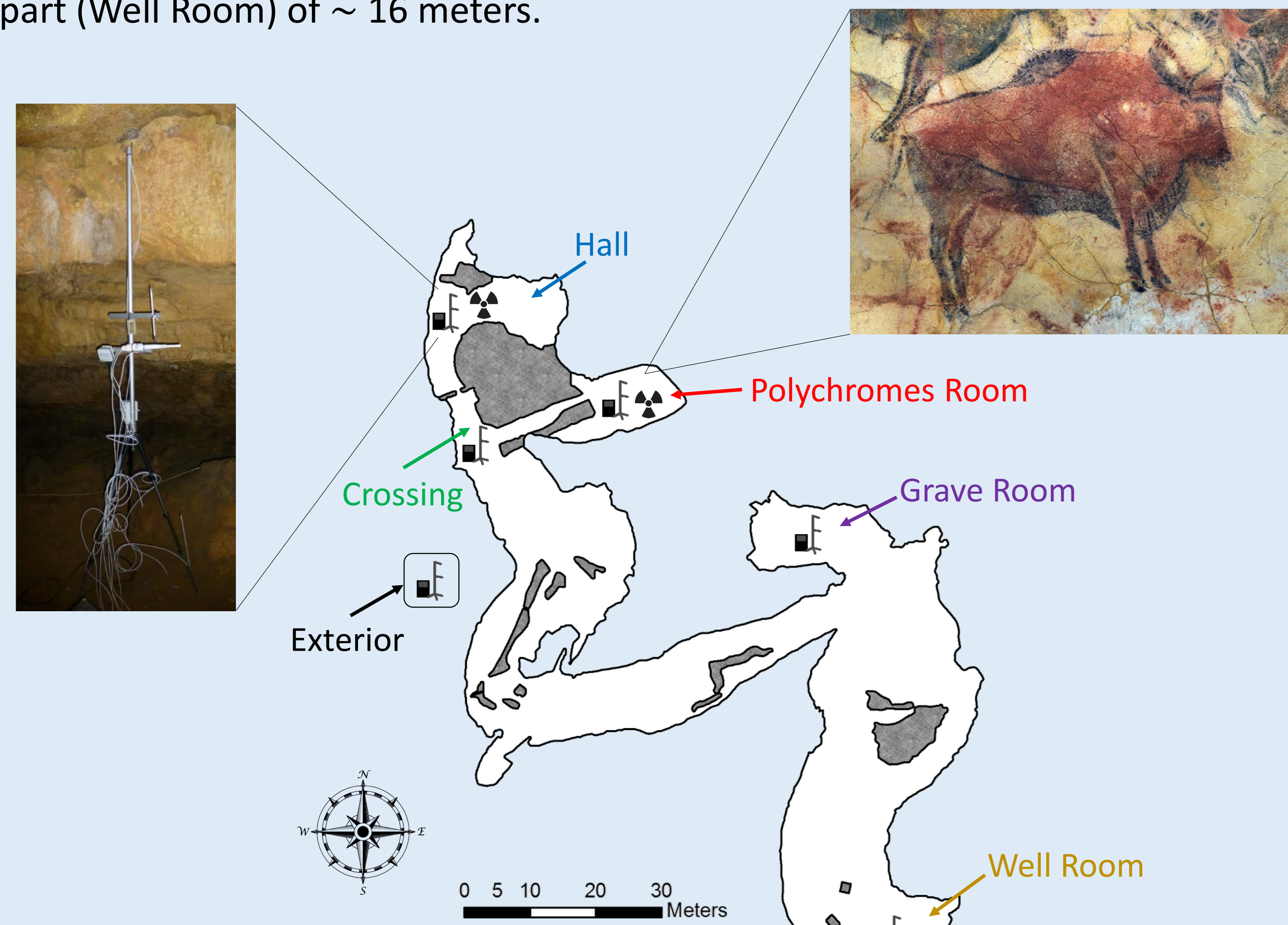
² The Cantabrian International Institute for Prehistoric Research (IIIPC)

³ Spanish Meteorological Agency, AEMET

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I Altamira Cave

- » Located in Santillana del Mar, Cantabria, northern Spain
- » Main Ancient rock art dating back about 15,000 years
- » World Heritage site by UNESCO (1985, list no. 310)
- » Shallow cave with an absolute height difference between entrance and deepest part (Well Room) of ~ 16 meters.



Continuous and integrated radon monitoring

- Track etch detectors CR-39
- Radon Scout monitor (Sarad GmbH)

Station of environmental parameters

- Air temperature: Pt100 probes – Mercury in glass thermometer
- CO₂ concentration: EE82 Series instrument
- Air pressure: Pressure sensor Delta OHM HD 9408



II Methodology

» Exchange rate Q calculated from simplified model of Wilkening: Radon concentration in a chamber varies according to the quantity emitted through the surface of the rocks, the quantity that disappears by disintegration, and the variations produced by exchange with air masses containing different concentrations from other chambers and/or the outside atmosphere.

$$Q = \lambda \cdot V \frac{C_{\max} - C}{C - C'} \quad (1)$$

- λ : radon disintegration constant (0.0076 h⁻¹)
- V : volume of Polychromes Room (~ 340 m³)
- C : radon concentration
- C' : radon concentration in chamber which it exchanges (Outside $C' \approx 0$)
- C_{\max} : maximum annual radon concentration in the room

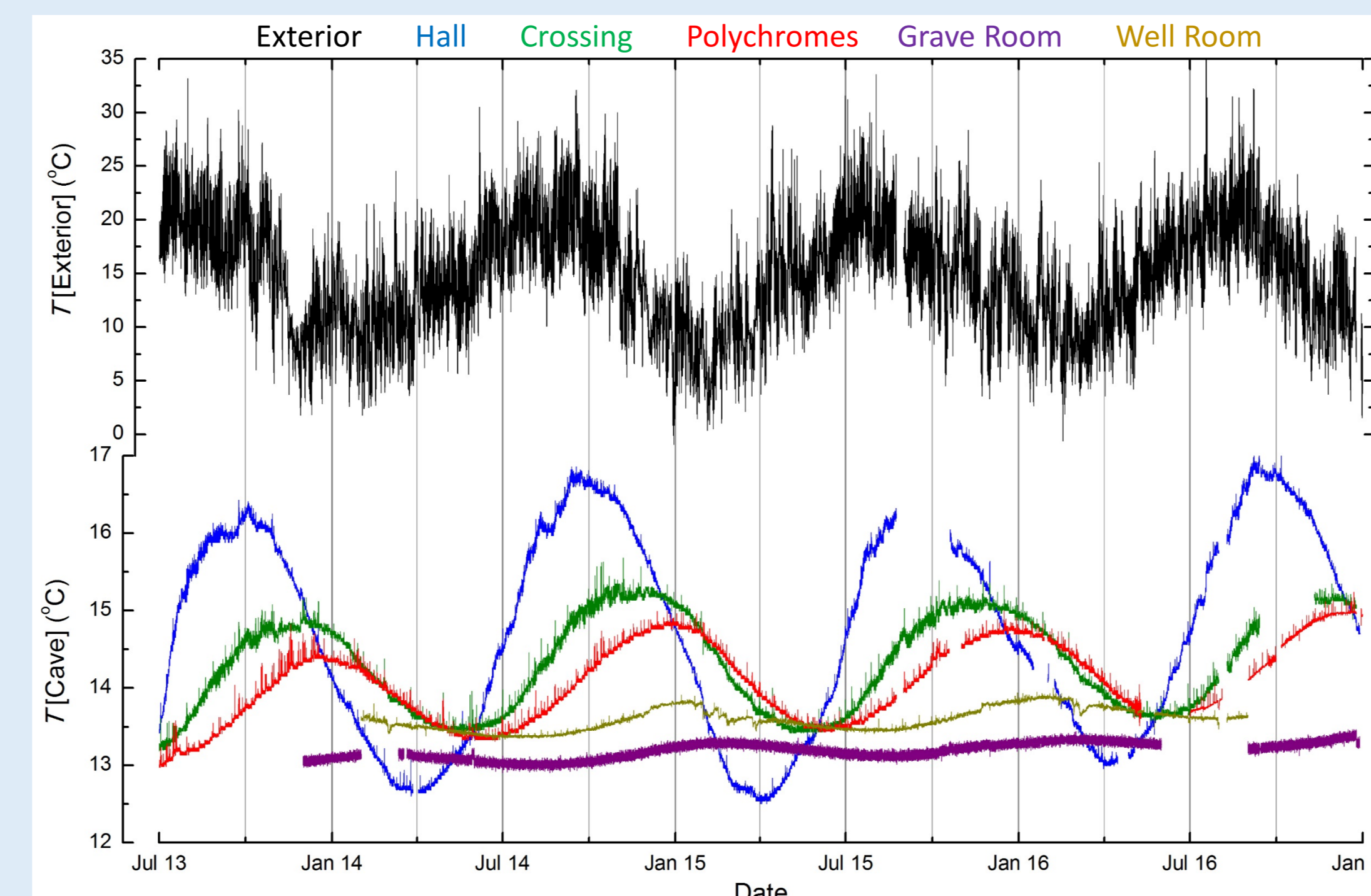
IV Conclusions

- » The distribution of radon concentration reflects the air exchange rates in the cave
- » Main gaseous charge-discharge processes occur seasonally at Altamira cave
- » High correlation found between seasonally, short term gases variation and Δp
- » Rn and CO₂ continuous monitoring is a key tool for studying atmospheric dynamics
- » Radon presents simpler mechanisms as tracer than CO₂

V References

- Fernandez et al. 1986. Natural ventilation of the paintings room in the Altamira cave
- Quindós et al. 1991. National survey on indoor radon in Spain
- Sainz et al. 2018. Continuous monitoring of radon gas as a tool to understand air dynamics in the cave of Altamira (Cantabria, Spain)
- Sánchez-Moral et al. 2009. Estudio integral del estado de conservación de la Cueva de Altamira y sus representaciones artísticas paleolíticas

III Results

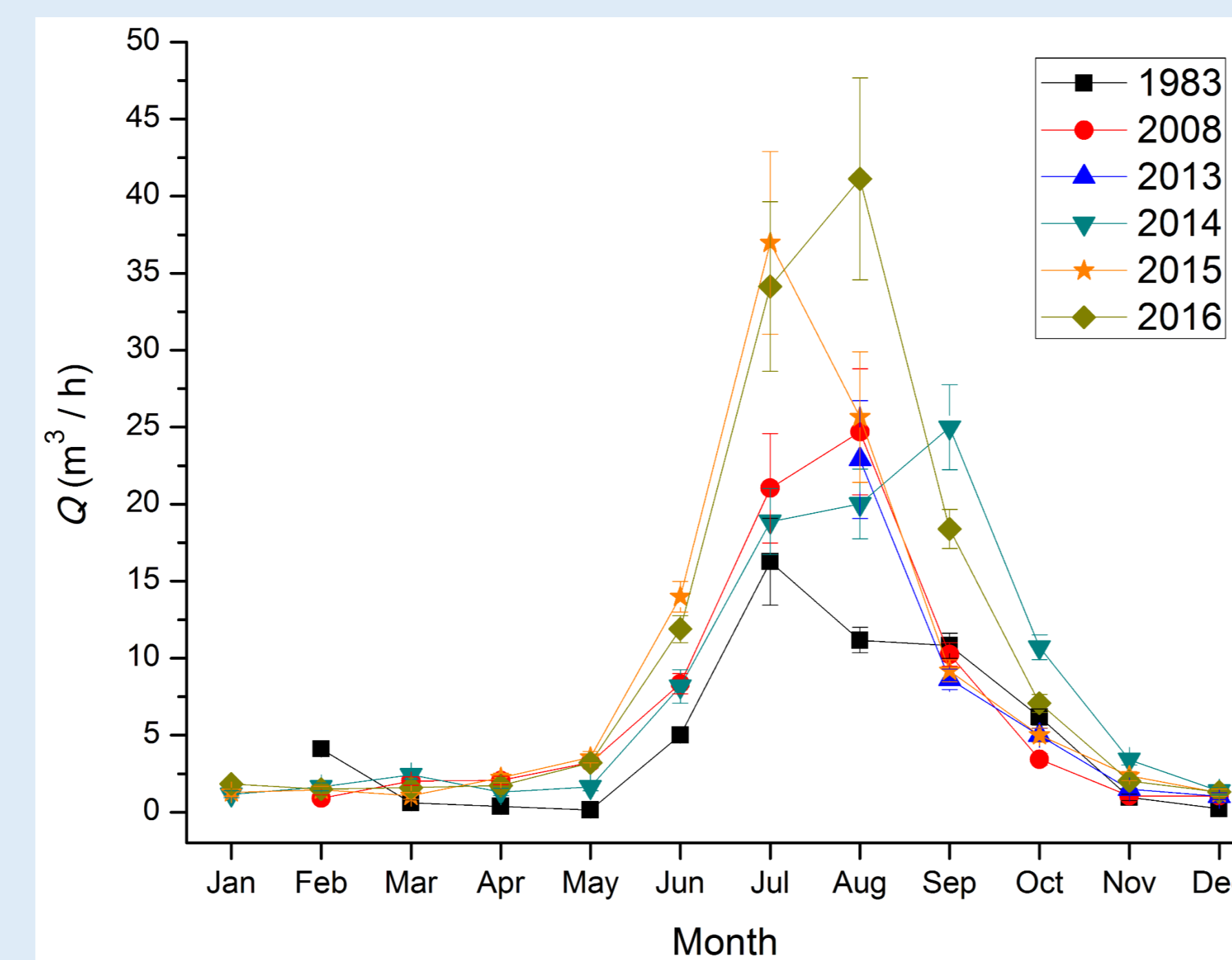


Air temperature at half height inside and outside the cave

- » Cave temperature is result of thermal wave propagation through the rock
- » Amplitude attenuation
- » Delay with respect to the outer wave

Linear correlation coefficient

	[CO ₂] (ppm)	C _{Rn} (Bq/m ³)
ΔP (Ext.-Hall)	-0.28	-0.34
$\Delta \rho$ (Ext.-Hall)	0.77	0.75
ΔT (Ext.-Hall)	-0.79	-0.76
ΔP (Ext.-Poly.)	-0.53	-0.51
$\Delta \rho$ (Ext.-Poly.)	0.80	0.82
ΔT (Ext.-Poly.)	-0.81	-0.82

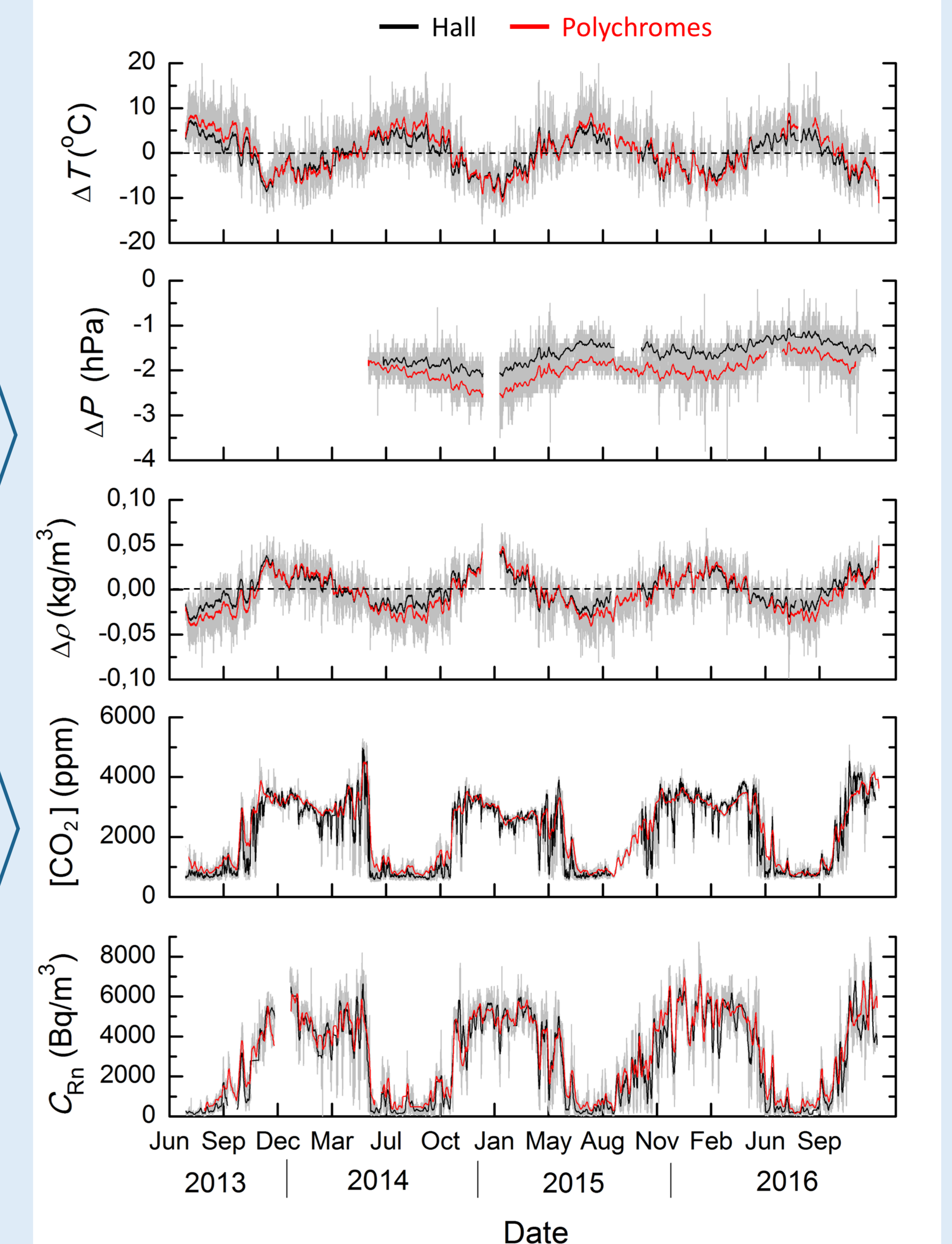
 Pressure P (hPa); Air density ρ (kg/m³); Temperature T (°C)

 Ventilation rate Q (m³/h) between Polychromes Room and the outside

- » Seasonal gases variation: Degasification in summer
- » High correlation between air temperature and air density differences between rooms and outside

$$\rho_{\text{ext}} < \rho_{\text{cave}} \rightarrow \text{Degasification}$$

$$\rho_{\text{ext}} > \rho_{\text{cave}} \rightarrow \text{Recharge}$$

- » Greater ventilation rate in summer due to high air density differences between exterior and cave
- » Degasification: Denser air inside the cave tends to descend to lower levels through the pores and cracks of the karst
- » Recharge: Denser air outside along with the moisture increment in soil block outputs and air exchange


 Differences in T , P and ρ of the air between the Exterior and the Hall and Exterior and Polychromes Room. CO₂ and Rn concentration in the Hall and Polychromes