

# CO<sub>2</sub> EVOLUTION IN CAVE ATMOSPHERES: NEW INSIGHTS, CONCERNS AND MITIGATION STRATEGIES.

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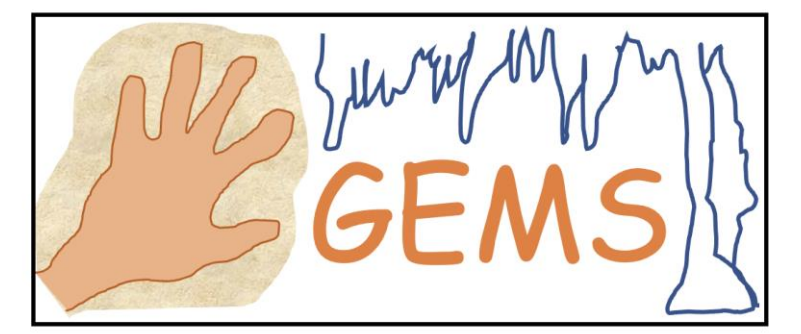
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This work is carried out by a research group : GIS-GEMS "Groupe d'Etudes du Milieu Souterrain"

## Motivation

CO<sub>2</sub> concentration upward drifts in cave atmospheres induce

- worrying levels of CO<sub>2</sub> concentration for human safety
- questioning about underground patrimony preservation

## Study Sites

The **Chauvet Cave** has preserved a 360 centuries old rock art karstic massif of the French Massif Central. The cave atmosphere is divided in two compartments with contrasted compositions on average (2.2% CO<sub>2</sub> Vol. in the main volume (C1) and 3.4% in the rear room (C2) all are subject to smooth, 1.6 to 2% in amplitude, annual sinusoidal variations.

The **Aven d'Orgnac** located at 7 km is a tourist-cave with outstanding underground landscapes and speleothems. Atmosphere composition variations are controlled by ventilation regimes. During the hot season, air is drained from the karst porosity (2.5 to 3 %Vol. CO<sub>2</sub> in the visited rooms, and 3 to 5% in remote networks). During the cold season, ventilation switches to a density driven regime: mixing with outside air falling from the upper entrance and dilutes the CO<sub>2</sub> concentration (<0.5 %).

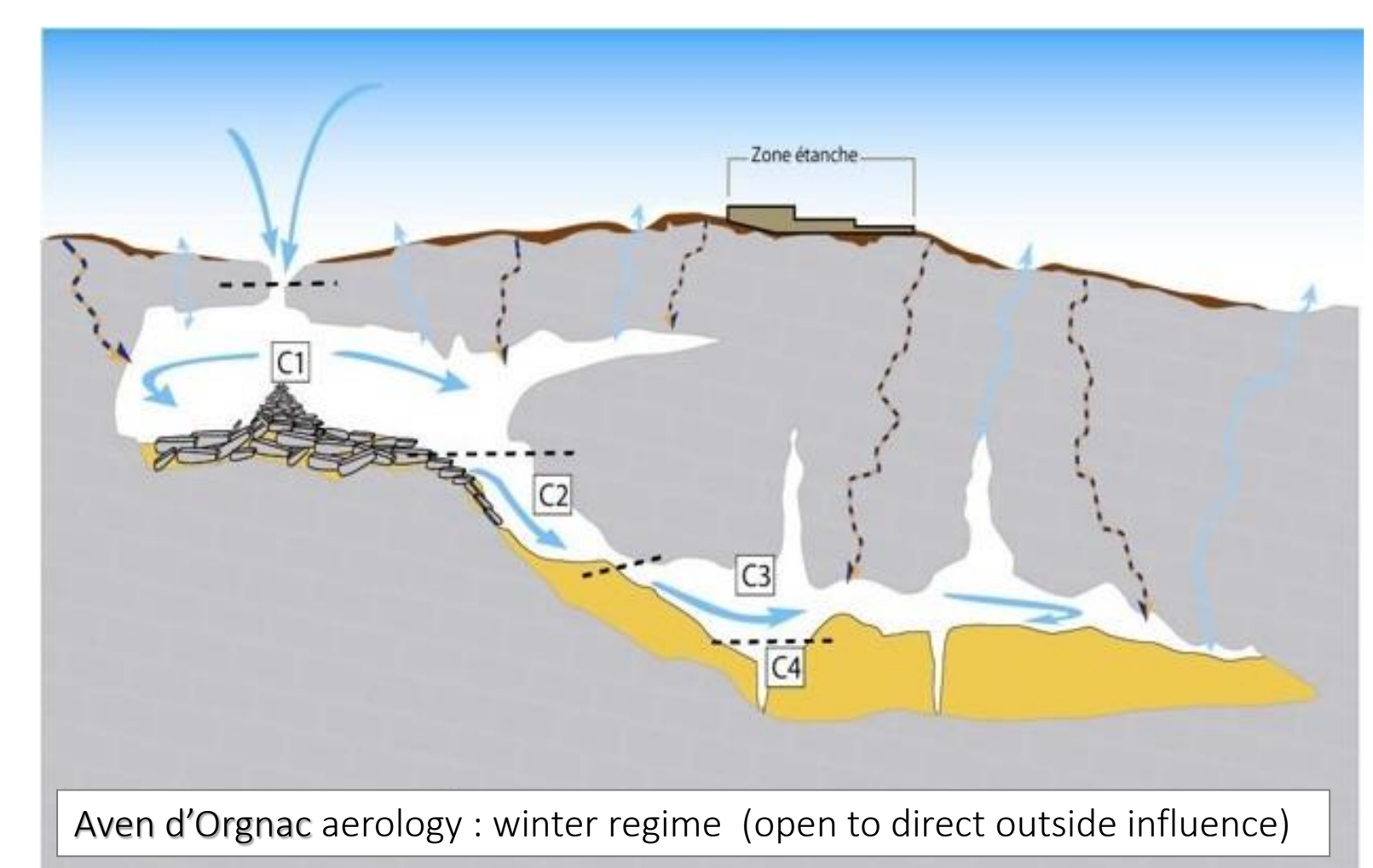
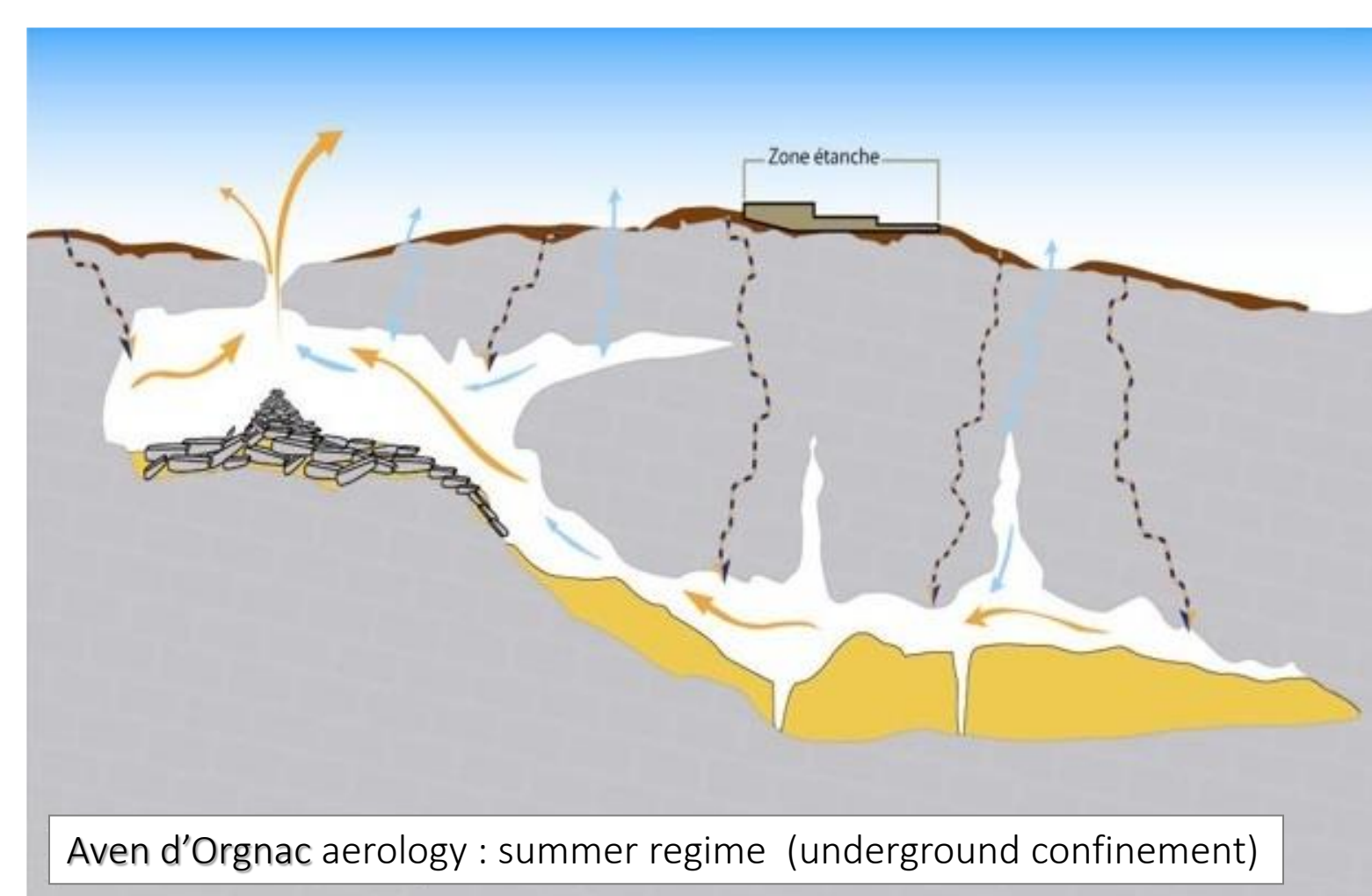
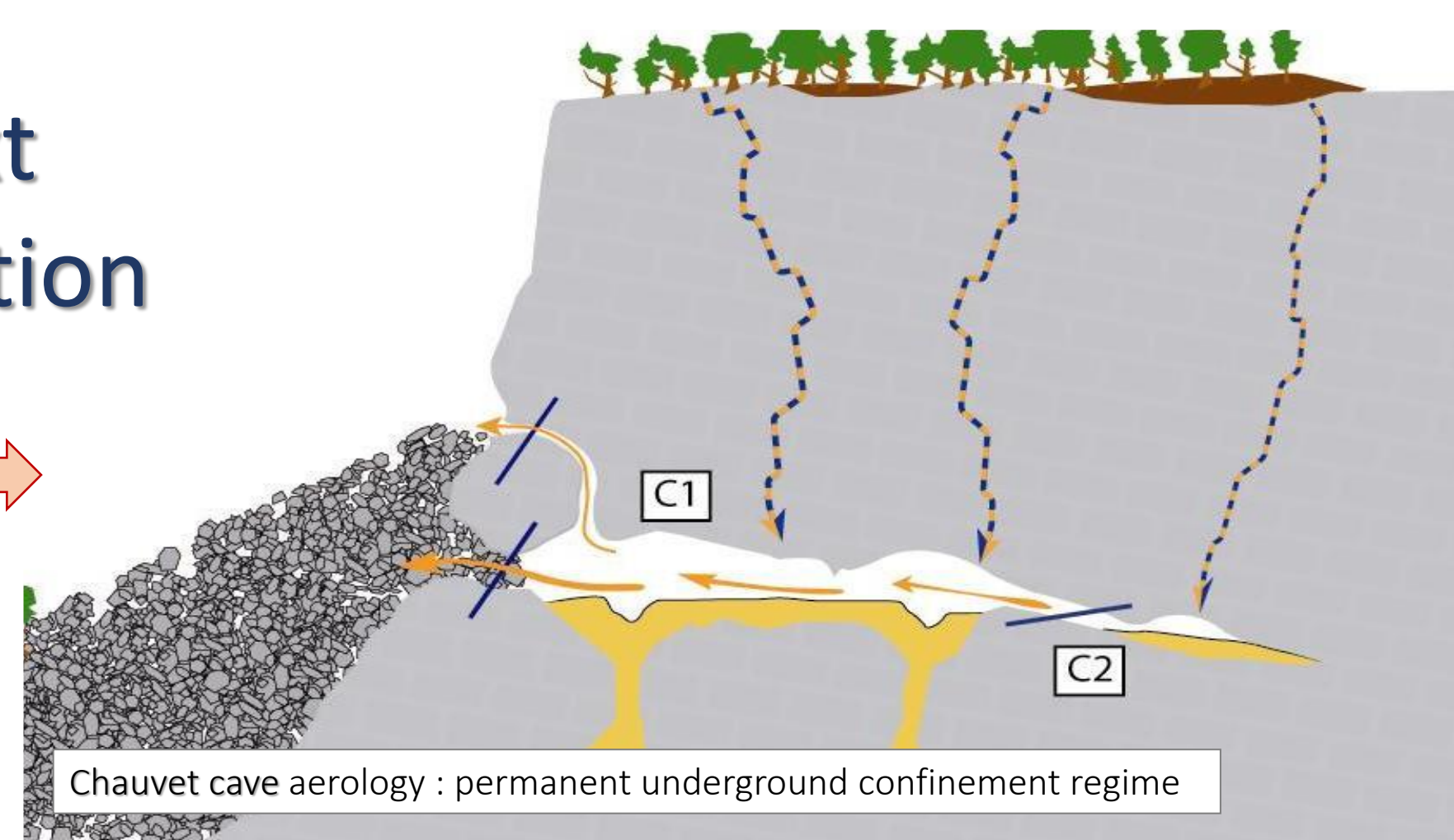


## Methods

Long term multiparameter monitoring (since 1997) with continuous measurements and synchronized acquisition (15 mn time lag) were installed in the two caves and outside.

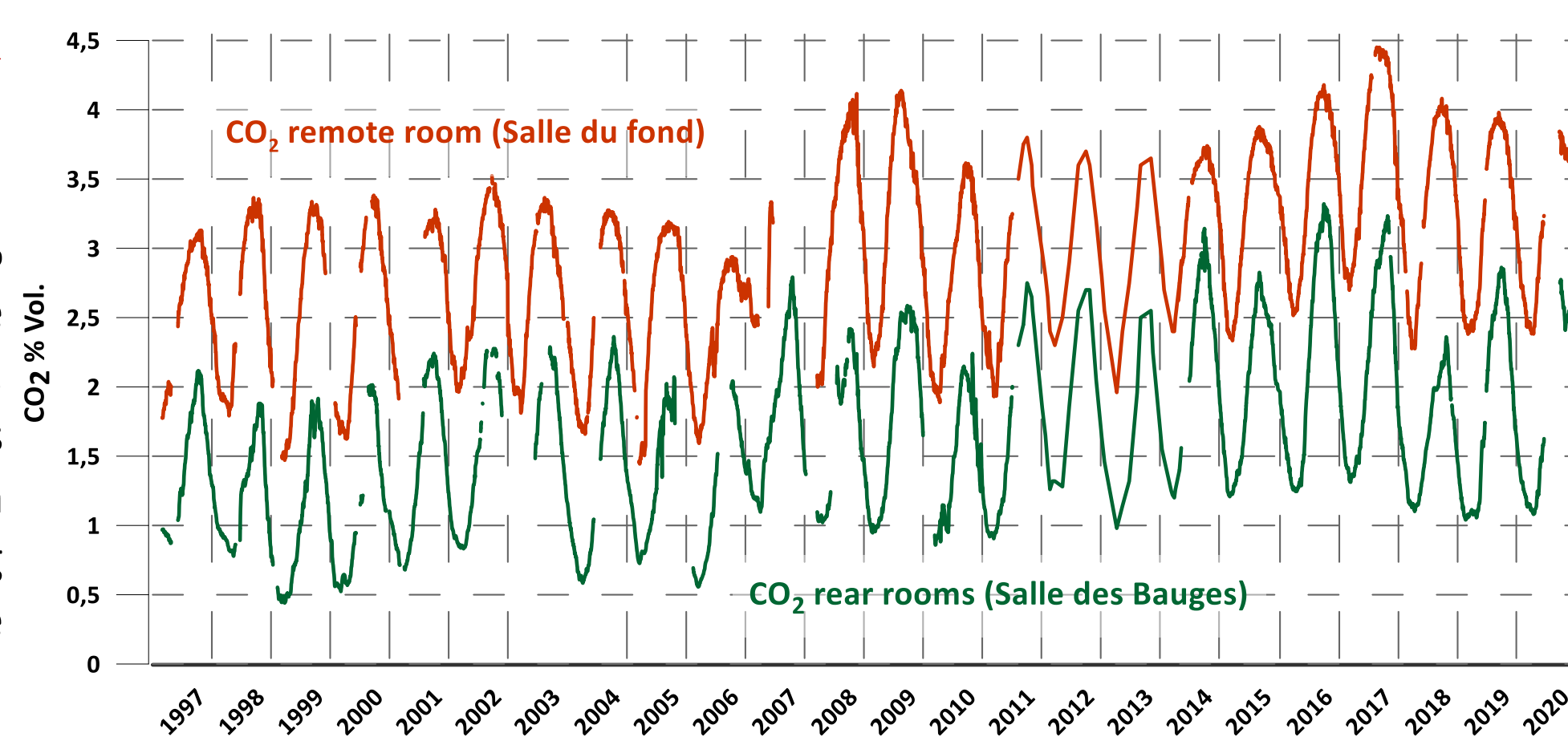
## Natural context and CO<sub>2</sub> evolution

Caves cross sections and ventilation patterns.

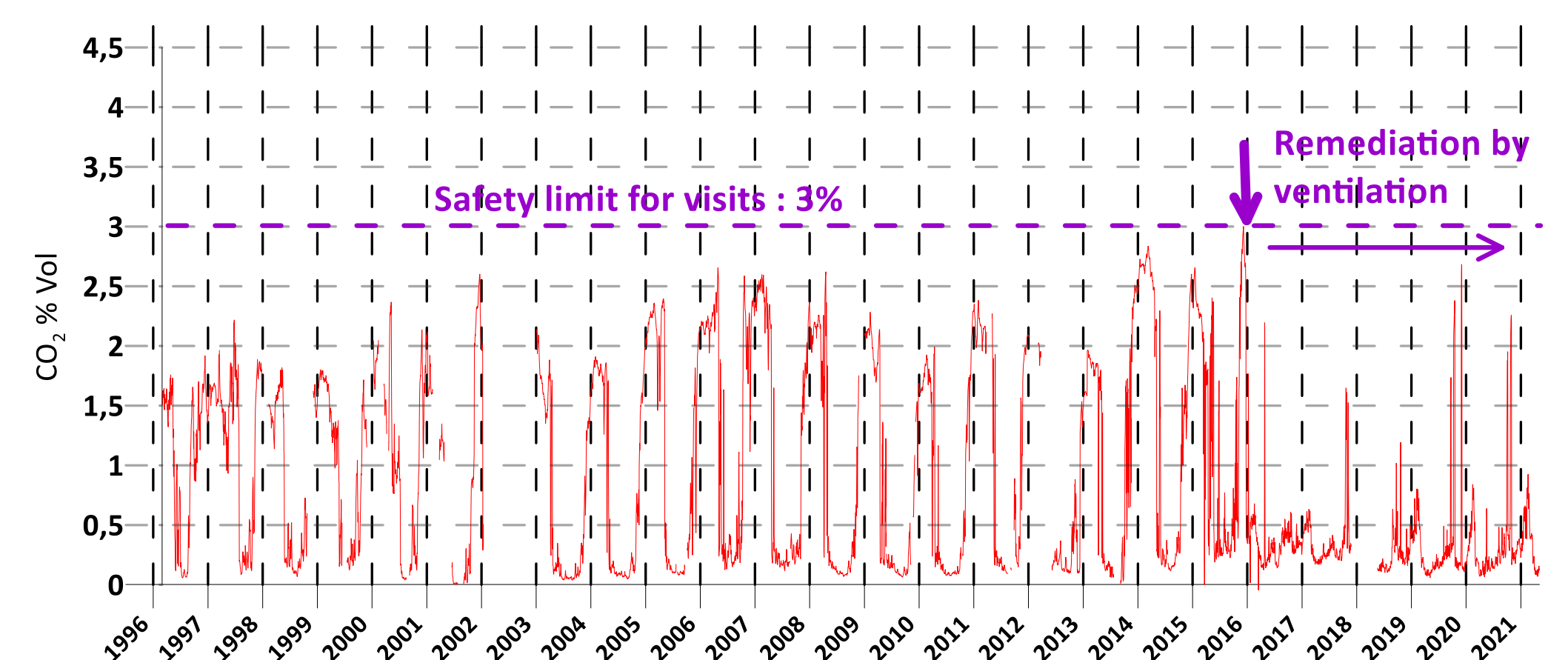


CO<sub>2</sub> long term evolutions

**Chauvet Cave** : a drift of + 0,5 % Vol. CO<sub>2</sub> is recorded in the confined Chauvet cave. Atmosphere in the cave is increasingly incompatible with human presence. Diverging climate situation can put the paintings at risk.



**Aven d'Orgnac** : The safety limit of 3% Vol. CO<sub>2</sub> for visitors has been reached in 2016. Since then, forced ventilation is now necessary each year.

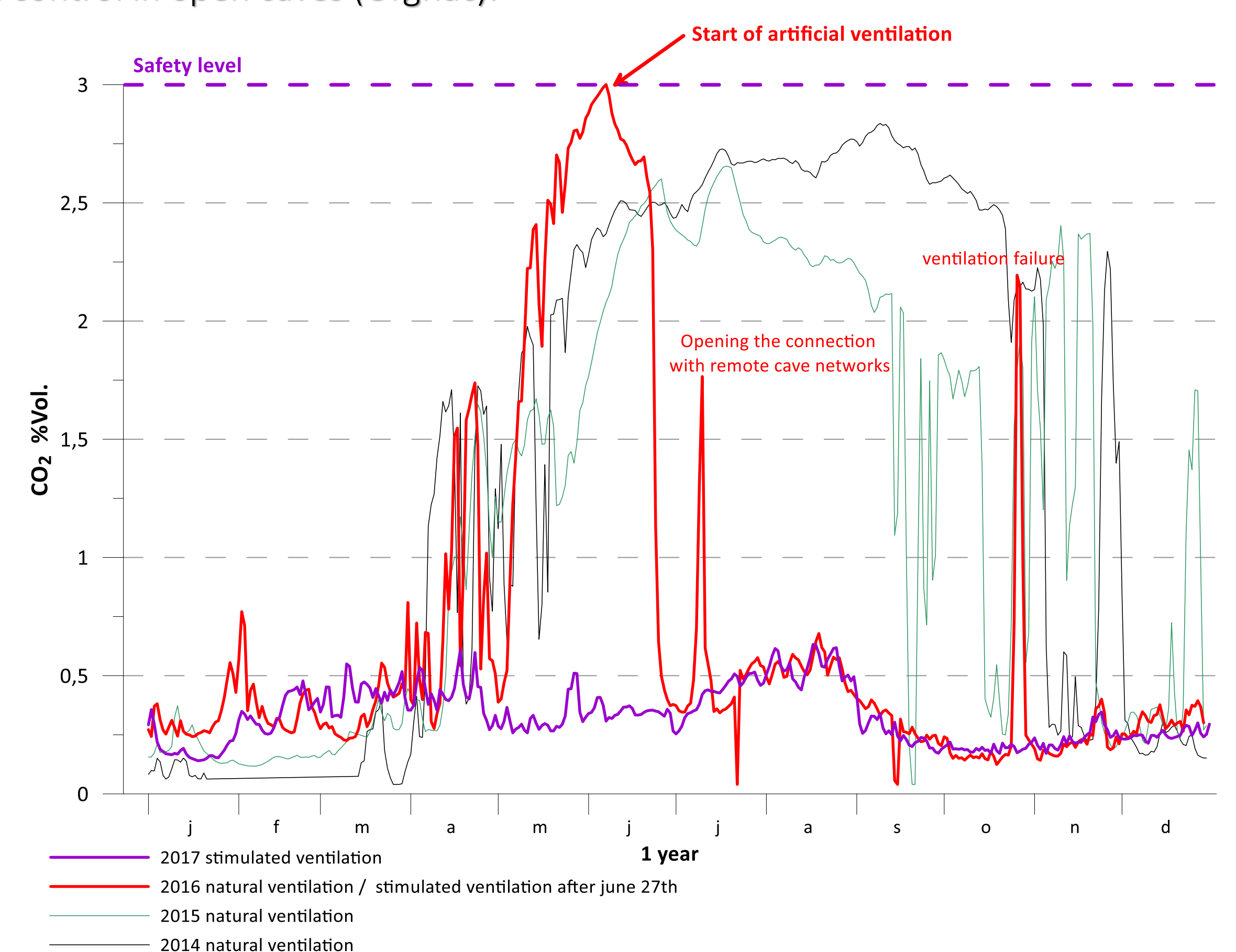
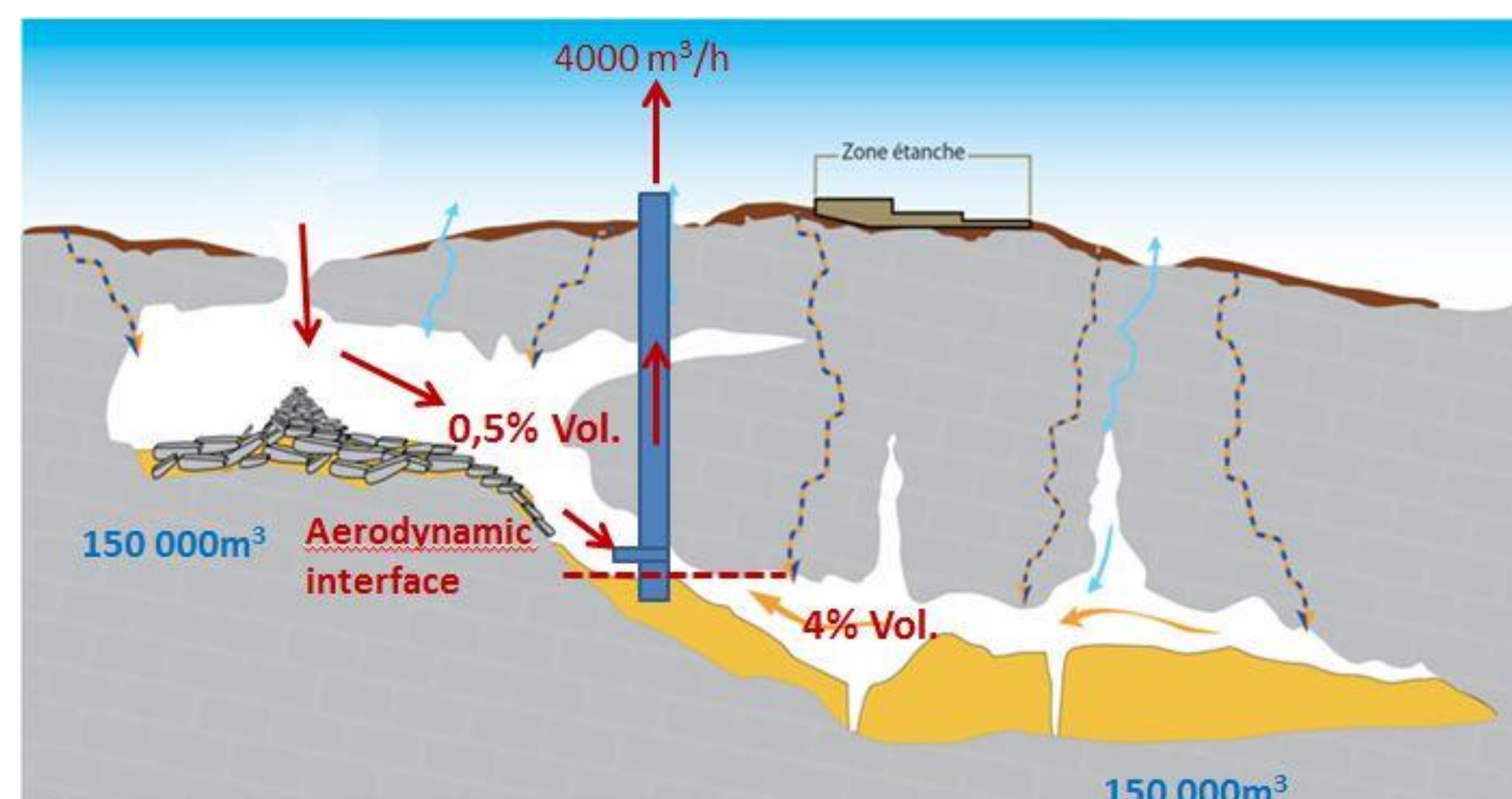


- Long term drifts of CO<sub>2</sub> in cave atmospheres can be attributed to a source effect : increase of vegetation density identified in most french karsts since 50 years.
- Seasonal and pluriannual variations are attributed to a transfert effect mostly influenced by : 1) rainfall and subsequent infiltration in confined caves (Chauvet), 2) aerodynamics exchanges under thermal control in open caves (Orgnac).

## Remediation in the Aven d'Orgnac

Stimulated ventilation that mimics the natural winter regime is operated in the visited part of the cave since 2016 safety alert.

Air pumping by the existing lift shaft is optimized to dilute CO<sub>2</sub> and radon and to keep characteristics of a subterranean atmosphere due to natural air input flux from the porosity of the karst volume.



## Lessons

- The atmosphere composition of many caves evolves significantly (+ 5 000 ppm in 23 years at Chauvet) due to constraints of the local environment and climate change consequences.
- In touristic caves as in l'Aven d'Orgnac, stimulated ventilation is used to dilute CO<sub>2</sub> thus mimicking a natural regime and keeping the characteristic features of the cave atmosphere.
- In fragile painted caves, direct action on cave aerology is not recommended and only actions on the CO<sub>2</sub> source driver (vegetation cover) appears to be possible.

## References

- Hydrogeological control on carbon dioxide input into the atmosphere of the Chauvet-Pont d'Arc cave. F. Bourges, D. Genty F. Perrier, B. Lartiges, É. Régnier, A. François, J. Leplat, S. Touron, F. Bousta, M. Massault, M. Delmotte, J.-P. Dumoulin, F. Girault. M. Ramonet, Ch. Chauveau, P. Rodrigues, Science of The Total Environment, Vol. 716, 10 May 2020.
- Conservation of prehistoric caves and stability of their inner climate: lessons from Chauvet and other French caves. Bourges F., Genthon P., Genty D., Lorblanchet M., Mauduit E., D'Hulst D. Science of the Total Environment. Vol. 493, 15 Sept. 2014, p. 79-91 DOI:10.1016/j.scitotenv.2014.05.137
- Microclimates of l'Aven d'Orgnac and other French limestone caves (Chauvet, Esparros, Marsoulas). BOURGES François, GENTHON Pierre, MANGIN Alain and D'HULST Dominique. International Journal of Climatology, 2006, 26 (12), p. 1651-1670. Wiley InterScience.