Reply to reviewer 2 in blue

The manuscript as such is interesting in many ways. It deals with the *culturally extremely important* cave and presents an interesting, unusual and *valuable set of data*. As such I think authors should be motivated to revise the paper to a publishable version.

My criticism mainly goes to the clarity of the presentation, which makes the manuscript hard to read. Some important concepts and objectives should be clearly stated earlier in the paper to keep the reader interested. For example, the pressurization events are shown early on, but their essential role -- they are the reason for the long-term overpressurization of the cave (I guess do?) -- is not told.

We would like to thank the referee for the time spent reviewing the paper and for the valuable comments. We have carefully considered the feedback and believe the new information provided in this document, along with the point-by-point response, addresses the raised concerns.

The derivation of equations (albeit simple) is at some points not clear, therefore it is not possible to judge their correctness (see comments in the PDF).

The comments in the PDF mostly question the approximations required to derive equation (11) from Darcy's law:

$$\boldsymbol{q_n} = (P\ k_a)\mathbf{grad}(P) = (k_a)\mathbf{grad}\left(\frac{P^2}{2}\right)$$

There is no approximation involved in this equation as **grad**(P^2/2) = P.**grad** (P) is a formula resulting from the mathematical properties of the derivative. If needed, we may add reference in the manuscript to a textbook deriving this equation.

The conceptual model (Fig. 10) needs some reformulation and a clearer explanation. As such it is not very convincing, although it is hard to judge if the reason is only poor text or not well elaborated concept.

As the focus of the paper is on the permeability of the limestone massif, we did not anticipate that providing details on the pressurization process was useful. As pointed out by both referees, the pressurization of the cave is an intriguing phenomenon that requires some explanation. To clarify this point, additional information is provided to show that pressurization events occur when there are waves on the cliff and are not correlated to rain infiltration. To support our assumption of a causal relationship between high waves and pressurization events, the significant height of the waves in front of the cave (data provided by the French Naval Hydrographic and Oceanographic Service, SHOM) and the daily rainfall will be added to Figure 4 in the manuscript (Figure 1 in this reply). While storms are often associated with rainfall, events with high rainfall but no high waves occasionally occur (e.g. August 2018) and they do not cause pressure variations in the cave. On the other hand, some pressurization events are not associated with heavy rainfall, but they are systematically associated with waves. Ongoing statistical analysis suggests a wave height threshold of about 1 m, but this threshold also depends on other factors (sea level, wave direction…). This will hopefully be the subject of a separate publication.

As pointed out by both referees, we will add at the beginning of the paper, in section 2 (after line 99) more explanation about the several paths (or levels) of connection between the sea and the cave through the limestone massif. We will redraw Figure 2B to show that the upper pathway is below the sea-level at a deepest level (so not “placed at the sea-level” as reported by referee 1), and redraw in Figure 10 (conceptual model) the upper pathway at a shallow level (still below the sea-level of course). Given the existence of karst pathways at several levels at the beginning of the paper will help the reader to conceptualize that waves can generate bubbles and then force seawater and air to flow through the limestone massif. The detailed mechanism of how bubbles of air can flow inside the submerged karst is out of the scope of this paper.

Line by line responses:

l.41-42: This depends on the shape of the cave; downsloping cave would be active in winter, and vice versa.:

Modified sentence: “These flows are subject to seasonality, with generally stronger flows in winter and stratification of air masses in summer *for descending conduits and conversely for ascending conduits*”.

l.63-64: What kind of events ?

As pressurization events have not been addressed at this point, “events” is replaced by periods

l.93-94: I guess you mean intergranular porosity ?

Modified: “Neither macro nor micro porosity has been observed” (Lamarche et al., 2012).

l.101-103: It would be helpful to add another perspective of the cave. I guess this is a DMR of ground; why don't you add a side perspective to get a feeling of the volume. I guess that the scale on Figure 2a does not apply for Figure 2b.

You are right, scale only applies to Fig. 2A. Figure 2B is not based on a 3D model, it’s a drawing showing a cross-section of the Cosquer cave in its environment (sea, cliff). We believe Fig2B is more useful to understand the case study than a cross-section of the main rooms with archeological artwork (the totality of the cave is not yet available in 3D). We will had a vertical scale to Fig2B or a few elevation references to Figure 2B.

l.125: do you mean transmissivity and permeability of rock with respect to the air.

Absolutely

l.125: ms^-2:

Corrected

l.133-135: Since you are mentioning the phenomena and previous works, maybe mention what is the idea of mechanism behind it...:

Updated: “Data show that air pressure in the Cosquer cave is always higher than outside atmospheric pressure (Fig. 4). This very peculiar feature had already been shown by previous works (Vouvé et al., 1996; Arfib et al., 2018) and has now been confirmed on the timescale of several years of continuous survey (2014-2020). Air pressure in the cave and water level of the pools are correlated. *When the air pressure increases, the air is confined by the walls of the cave and pushes down the water table to balance the overpressure.* Conversely, between late spring…”

l.157: These events are highly interesting. I guess you should tell something about their origin already at this point.

As already mentioned in a previous comment, we will add more explanations about the mechanism that force the air to enter inside the cave: “Cave air pressure increases by the inflow of outside air, during periods with high waves on the cliff. Waves can produce and force air bubbles to propagate by submarine open fissures or karst conduits.” We will also update the Figure 4 with wave height and daily rainfall, to show the causal relationship between high waves and pressurization events. Furthermore, the absence of significant wave activity during summer months supports the observation of rising water levels during this period. This statement will be added to the section.

l.216: Cumulative ?

Corrected

l.242-243: Here you probably mean air filled volume.

Absolutely. We tried to define the volume of the cave l.226-227, but it may still unclear. "Air-filled volume" is a welcome clarification.

Updated line 226: "*V* the air-filled volume of the cave, defined as the volume of all the connected voids above the water level,"
Updated line 242: "Nevertheless, the variation of the air-filled volume of the cave due to tidal variations…"

l.263: if you write this in form 1/(1-palTah/pahTaL), equation 6 and 7 would be more obvious....

Corrected

l.282: Where do you get Qn from. Is it from dn(t)/dt from Eq. 9 ?

Absolutely yes, the equation will be added to the manuscript.

l.290: Explain P^2 in the right-hand side. It looks like that P from the left equation goes into the argument of grad.

It is a fundamental property of the gradient operator: $\mathrm{grad}(xy) = x\,\mathrm{grad}(y) + y\,\mathrm{grad}(x)$ or in the case $x = y : \mathrm{grad}(x^2) = 2x\,\mathrm{grad}(x)$ (Lang, 1999).

Formulation of Eq. 11 is also given by Lefebvre (2003) and Charbeneau (2006).

l.295: I don't get the meaning of "defining the percolation threshold".

This sentence was incorrect (incomplete), sorry. The last part has been deleted.

l.303: I cannot get the sense from this sentence. Please reformulate.

Corrected: "[…] it follows from Eq. (11) that the total flux depends linearly on the difference of the squared pressure between the boundary conditions."

l.306: Refer to my comment to Eq. 11.... I am not sure what approximations were used to derive this Equation...

To pass from Eq. 11 to Eq. 13, no approximation is required.

l.309-310: This sentence become clear only after one reads the next paragraphs and Fig. 8. Please reformulate... Initially tell clearly that you assume three different geometries shown on Fig. 8., so that the reader is not confused:

Reformulation: "The interpretation of the air effective transmissivity coefficient λ_a, which has dimension of m^3, can vary based on the geometrical configuration. Three geometries are considered: a porous rock volume (Fig. 8A), a single fracture (Fig. 8B) and a pipe (Fig. 8C)."

l.476-481: You have not directly shown what causes the pressurization events. Nevertheless, I miss this clear statements in the introductory part. What I can get is that you have multiple pressurization events in the cold season with relaxation of this overpressure through the summer season. Could you relate pressurization events to some other outside atmospheric or oceanographic data (observation of winds/waves).

See below.

l.489-491: see my previous comment... can you show some correlation between pressurization and external events.

See below.

l.502-506: Although this is somehow central for the manuscript, it is hard to understand what you want to say. How is the air "pushed" by the waves and why does this happen only in the upper conduit and not in the lower one. Event though this is said to be outside the scope of the paper, one would still need some concept that relates the waves with air inflow.

It must be clarified that both the upper karst and lower karst conduit ends in sumps. With a depth of -37 m, the lower conduit (the human entrance) is too deep to be the air intake point. The sump of the upper conduit is short and shallow as showed in Figure 2B and the water level in the pool on the cave side varies with waves outside. The conduits connecting this pool to the sea have not been fully surveyed yet, but it is very likely that large waves can push air through them. As previously replied in the first comments, we will introduce the mechanism that is supposed to force the air inside the cave at the beginning of the paper (a few words in the introduction, then in section 2 (case study) and then in section 3 (pressurization events)), so that the conceptual model presented in section 6.2 can be clearly understood. We will also slightly modify the figures 2B and 10.

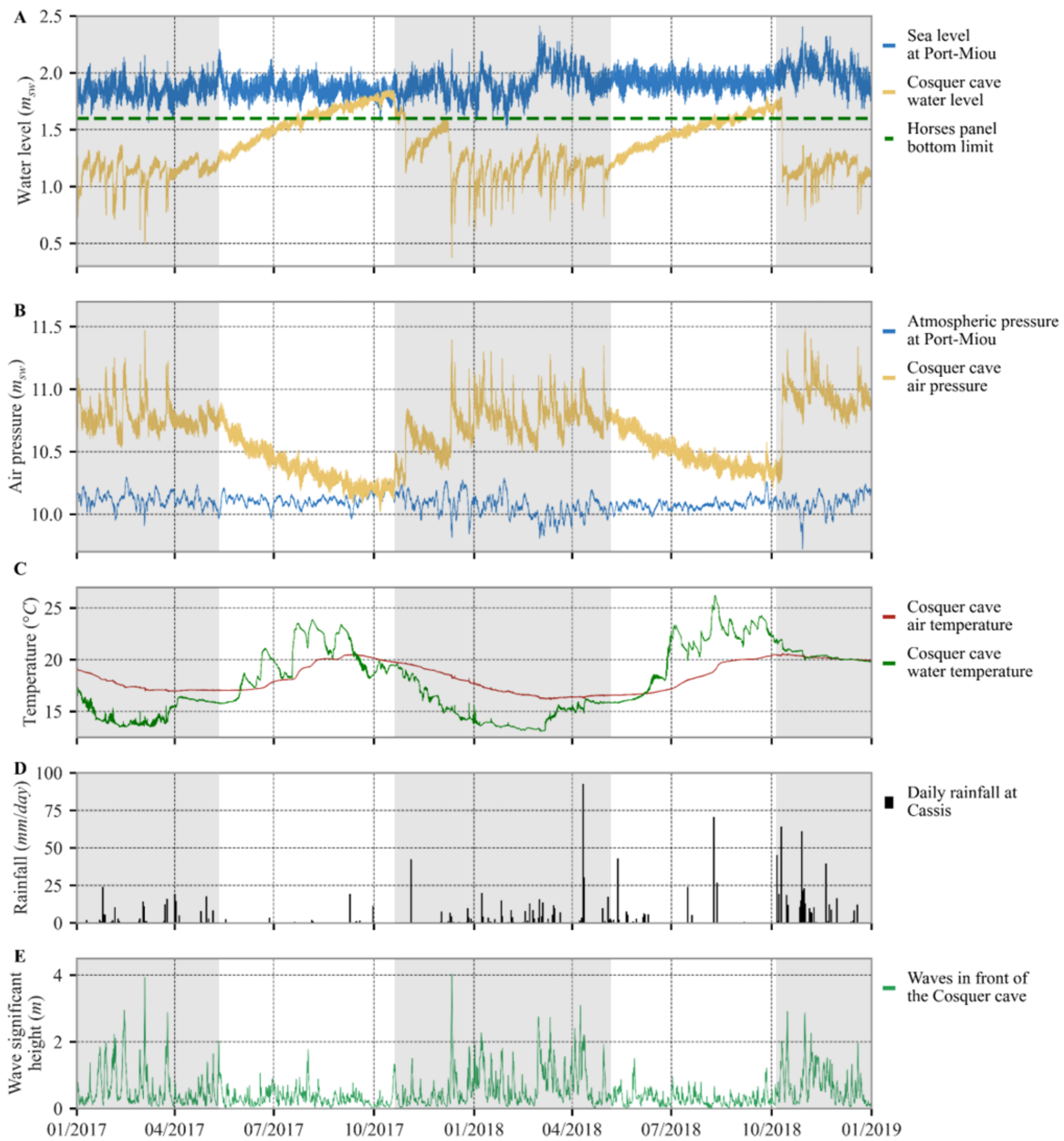

Figure 1: Pressure, water level and temperature time series recorded in the Cosquer cave and at the Port-Miou observatory for years 2017 and 2018: (A) Sea level at Port-Miou (h_s) and Cosquer cave water level (h_w), expressed in column of seawater (m_{sw}) above the probe with the same reference level. The green dashed line shows the bottom of the horses panel (paleolithic

decorated wall). (B) Atmospheric pressure (P_{atm}) outside the cave and cave air pressure (P_a). (C) cave air temperature (T_a) and cave water temperature in Room 1 (T_w). (D) daily rainfall and (E) waves significant height in front of the Cosquer cave. Pressurization events periods are highlighted in grey.

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