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## ***Interactive comment on “Numerical simulation of formation and preservation of Ningwu ice cave, Shanxi, China” by S. Yang and Y. Shi***

**Anonymous Referee #1**

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Numerical simulation of formation and preservation of Ningwu ice cave, Shanxi, China  
S. Yang and Y. Shi

The authors use finite element methods to model heat exchanges in Ningwu ice cave, the largest of this kind in China. The study is motivated by the need of a better process-based understanding to assess the effect of climate/environmental changes on the cave ice mass balance. Eventually, results will enable a better scientific management of this show cave. The authors show that thermal convection during the winter season controls the heat exchange with the outside atmosphere whilst the latent heat of cave ice prevents a complete melting during the summer season. Based on their model, they conclude that the cave ice must be between  $-2.9$  and  $-3.9$  °C. This result is important as it would, for the first time, show that the cave and its surroundings are part of a

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[Interactive Discussion](#)

[Discussion Paper](#)



proper (sporadic) permafrost with implications on the karst hydrology and the age of the cave ice.

General comment: The model considers heat conduction in the cave host-rock as well as convective heat transfer through the cave entrance. Whilst phase changes are implemented in the model, mass conservation is implicitly assumed; i.e. there are no changes in the cave ice mass balance (but only seasonal freeze and melt). This hypothesis raises several questions which need to be addressed more thoroughly:

1) Qualitative analysis: a more detailed description of the cave ice would be required here. Is there really no interannual change (ablation or formation) in the cave ice volume? i.e. can you be sure that the cave ice is fossil and that no water infiltrates into the cave throughout the year? If so, where is the water from the catchment area above the cave being directed to? How do these water fluxes affect heat exchanges at the system's boundaries?

2) Ice build-up: the presence of cave ice supposes that, at least at the beginning, water infiltrated into the cave. However, water fluxes are not considered in the model. How would a change in the infiltration regime (i.e. timing and recharge) affect the ice build-up, resp. the preservation of the cave ice?

3) Implications: the presence of cold, fossil ice (i.e. ca.  $-3.5^{\circ}\text{C}$ ) suggests that the cave ice formed soon after collapse of the main cave entrance or that the (winter) climate deteriorated sufficiently to allow the formation and maintenance of the cave ice. Based on the sensitivity study, what would be the minimum climatic conditions required to form the ice cave?

Whilst the figures are of reasonable quality, the manuscript would benefit of some additional editing. Some suggestions are made below but a careful read by a native speaker is recommended.

Specific comments:

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2368 abstract: should be edited for language

2368 I.11 “etc” can you be more precise?

2368 I.18 an air temperature constantly “below 0°C” is not compulsory for the presence of ice

2368 I.19 specify what you mean by “cold zone”

2368 I.24 is among the largest ice caves. . . (no proper quantification/ranking available)

2369 I.6-8 off topic. This sentence refers to speleothem-based research and not to ice caves

2369 I.15 should be “performed” or “carried out” (instead of enabled)

2370 I.15 please specify. It is unclear to me what you call bowling-ball like. Do you mean spherical shape?

2370 I.18-21 edit or delete sentence as the formation of hoar frost (i.e. snow crystals) is not a process relevant to your system

2371 I.3-8 unclear; needs to be rephrased

2371 I.10 of “the” ice in “Ningwu” ice cave

2371 I.24 “in presence of” instead of “if when the”

2371 I.27 the temperature “gradient” can also be “reversed”

2371 I.25 “subduction zones”; Yes, but this is another scale which I wouldn’t refer to here

2372 I 1-4 delete

2372 I.5 cf discussion about temperature gradients in karst systems (Luetscher and Jeannin, 2004)

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2372 I.8 should be “In presence of a geothermal. . .“

2372 I.14 please rephrase: do you mean that cold air is trapped inside the cave and leads to a thermal stratification which is not affected by natural convection during summer?

2372 I.19 instead of “temperature rise” use rather the “heat transferred to the ice cave”. (the temperature change is buffered by the latent heat of ice not by the efficiency of the heat transfer)

2372 I.23 delete “underground and”

2372 I.24 replace “that” by “the heat” (?)

2372 I.26 delete “heat transfer”

2372 I.27 this assumes an equilibrated energy balance without considering any new formation or ablation of cave ice. Is this true (cf. also general comment)

2373 I.1-4 not necessary, I suggest to delete these lines

2373 I.4-17 the § could be edited for style

2373 I.4 please rephrase. the temperature doesn't rise if the heat is consumed by the melting ice. rather: during summer, much of the heat transferred to the cave is consumed...

2373 I.5 delete “action”

2373 I.7 delete “action”

2373 I.8 delete “action”

2373 I.25 what about the cave ice mass balance? is the formation/ablation strictly limited to the cave entrance zone (l. 10)? If so, does this mean the cave ice in the deeper cave is completely “fossil”? when would it have formed?

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2374 I.14-15 redundant; delete sentence

2374 I.17-18 please rephrase

2375 I.8-9 Eq. 3 and 4 are not necessary but Ts, Tl and T need to be better defined

2376 I.23 it might be recommended to use another symbol for the height to avoid confusion with the above mentioned enthalpy

2377 I.14 Eq (10). Please check! substitution of values in (9) gives me another value for Gr

2378 I. 7 a gradient of 2°C/100m would be surprisingly high for a mature karst system surrounding the ice cave. A gradient of ca. 0.5°C/100m would probably be more realistic; cf discussion in Luetscher and Jeannin (2004).

2379 I.11 “increasing rate” do you mean the “positive trend”?

2379 I.12 idem

2379 I.24 should be “of the ice cave. . .”

2380 I.26 “It is need to do” please rephrase

2381 I.2 should be “the thermal amplitude”

2381 I.3 should be “(respectively decreases) by 1.0°C, . . .” same further down

2381 I.3 shown instead of showed; same further down

2381 I.8 cal. Please use SI units

2381 I.11-13 needs to be edited

2381 I.16 should be “represents”

2383 I.8 Under this stable. . . please edit

Ref.: Luetscher M., Jeannin P.-Y., 2004. Temperature distribution in karst systems:

the role of air and water fluxes. *Terra Nova*, 16, 344-350. doi: 10.1111/j.1365-3121.2004.00572.x

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Interactive comment on *The Cryosphere Discuss.*, 9, 2367, 2015.

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9, C807–C812, 2015

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