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Title: Simulation of a fire in a gallery of an archaeological cave (Chauvet-Pont d'Arc, France)

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Background

The Chauvet-Pont d'Arc cave is located in the South-East of France. This cave shelters paintings among the most ancient in the world, they have been dated between 32000 and 30000 BP. Archaeologists have observed numerous fire marks on its walls (spalling, rubefaction, soot deposits). Fireplaces have been rearranged, and it is difficult to find the position of the ones corresponding to the marks on the walls. Yet these information would be important to give interpretations of the function of the fires and to check which behaviours were possible near the fires. Unfortunately it is impossible to reproduce the fires in this environment. Starting from the 3D laser scan of the Megaceros gallery of the Chauvet-Pont-d'Arc cave we propose to simulate the burning of a fire in a volume like it to check whether it was possible or not to stay near the fire.

Methods

We use the LES (Large Eddy Simulation) code FDS (Fire Dynamics Simulation) to simulate the heat and smoke transport. FDS is an open source code developed by the National Institute of Standards and Technology (NIST) in the United States.
The methodology has been validated on an experimental fire in an underground quarry (LaScArBx IThEM program). The numerical data for the temperature on the wall of the fire, and for the carbon monoxide rates at the entrance of the quarry were compared to the experimental ones with a good agreement. The observations contributed also to the validation, as the smoke transport was video recorded during the experiment and matched with the simulations.

Results

Once the simulation has been validated on the data acquired during the experimentations in the monitored site, it is used to determine temperature, smoke, and toxic gases distributions near the fires in the Chauvet cave, and more specifically in the Megaceros gallery. We choose to simulate a fire in a zone of the Megaceros gallery close to fire marks in the upper parts of the walls and the ceiling. This gallery links 2 big volumes (Figure 1), the End Chamber (at the right of the figure) and the Hillaire Chamber (at the left) communicating with the rest of the cave. We considered an open condition in the Hillaire Chamber in order to take into account the huge volume of the cave, whereas the End Chamber is closed.
Temperatures at the ceiling above the fire exceed 250°C, i.e. the temperature of rubefaction of the limestone. This red colour is actually observed in the cave in these areas. Besides, simulation shows that smokes loaded with soots are concentrated in the upper parts of the domain. Observations by geoarchaeologists in the cave have located the soot deposits in the upper parts of the Megaceros gallery. Moreover, the highest concentrations of the toxic gases are also found numerically at the vaults of the gallery.

The Fractional Effective Dose is a parameter commonly used in toxicology. It evaluates the exposure time available to escape from a place in fire or to survive post exposure. It provides valuable data of the possible behaviours of people in the environment of a fire.
Figure 1 shows the circulation of the air. The hot air escapes the gallery towards the larger volume of the Hillaire Chamber, whereas colder air enters the Megaceros gallery from the rest of the cave. This convection current evacuates the heat and most of the toxic gases, providing a quite breathable area near the fire.

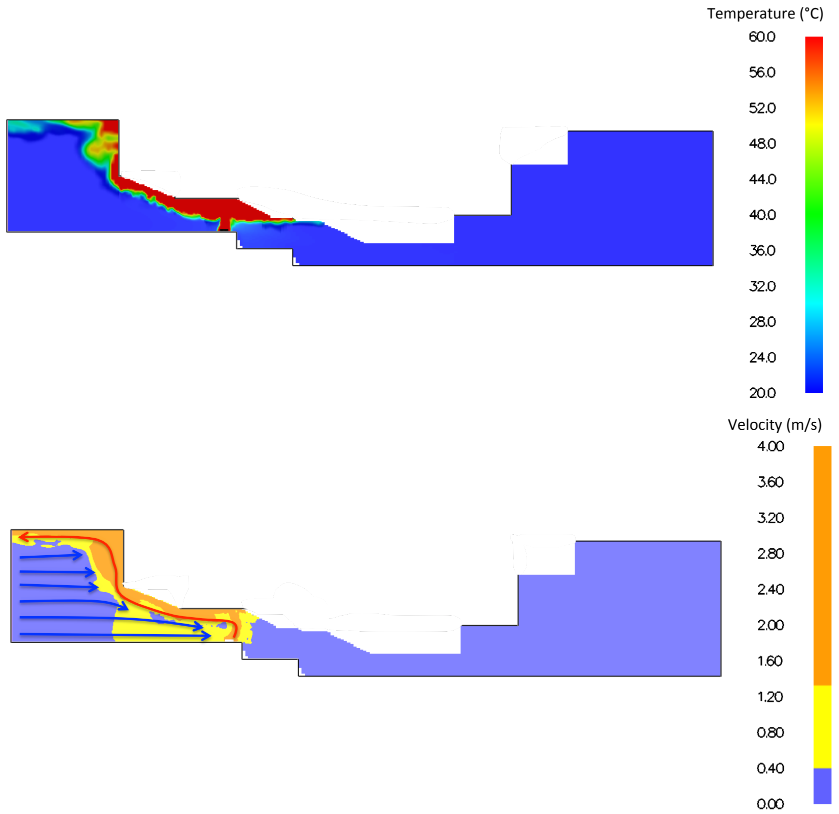

Figure 1: Temperature distribution (up) and air velocities (bottom) in a vertical slice of the gallery

The numerical results, corroborated with the observations in the Chauvet-Pont d'Arc cave, showed that it was possible to stay near a fire, in the lower parts of the gallery.

Conclusions

3D numerical simulations have shown that if there was a possibility for Palaeolithic men and women to put additional wood to the fire during the burning, and to circulate around it, it was in the lower parts of the galleries. The upper parts concentrate the heat and the toxic gases.
These first simulations on a simplified geometry have given valuable qualitative results. In order to go further with quantitative ones and to get more precise information, we will integrate the precise geometry of the cave, based on its 3D numerical modelling.
Furthermore, we will try several positions for the hearths, in order to identify which original position led to which mark on the walls.