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High resolution pCO_2 monitoring reveals ventilation of Bunker Cave (NW Germany) and its impact on speleothem growth

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Understanding the environmental processes that influence geochemical proxies archived in speleothems depends critically on detailed cave monitoring. Cave air pCO_2 is one of the most important factors controlling speleothem growth. The pCO_2 concentration of cave air depends on (i) the productivity of its source(s), (ii) CO_2-transport dynamics through the epikarst and (iii) cave ventilation processes. We monitored the pCO_2 concentration ca. 100 m from the lower entrance of the Bunker-Emst-Cave system (NW Germany) with a CORA CO_2-logger at a two-hourly resolution between April 2012 and February 2014. Near-atmospheric minimum pCO_2 concentrations of 408 ppm are observed in winter, while higher values up to 811 ppm are recorded in summer. Higher summer concentrations are due to increased plant and soil microbial activity, resulting in elevated CO_2 in the soil, which is transferred to the cave with infiltrating water. Generally, the front passages of Bunker Cave are well ventilated. Besides the seasonal pattern, pCO_2 concentrations vary at diurnal scale. Correlations of pCO_2 with the temperature difference between surface and cave air are positive during summer and negative in winter, with no clear pattern for spring and autumn months. Thus, Bunker Cave ventilation is driven by temperature and density differences between cave and surface air, with two entrances at different elevations allowing dynamic ventilation. During summer, relatively cooler cave air flows from the upper to the lower entrance, while in winter this pattern is reversed due to ascending warm cave air. The situation is further complicated by preferential south/southwestern winds that point directly on the cave entrances. Thus, cave ventilation is frequently disturbed, especially during periods of higher wind speed. Modern ventilation systematics only developed when the two cave entrances were artificially opened (1863 and 1926). Before that, ventilation was restricted and cave pCO_2 concentrations were presumably higher under natural conditions. Thus, the present-day ventilation system of Bunker Cave is not a direct analogue for natural ventilation conditions. pCO_2 concentrations are relatively low compared to other caves, and because the difference between summer and winter pCO_2 is relatively low (max. 400 ppm), a significant effect on seasonal speleothem growth rate is unlikely. In case of Bunker Cave, it is rather a combination of the availability of water, and thus of calcium and carbonate ions and pCO_2 concentrations that allow higher carbonate precipitation during winter than summer. Holocene speleothems from Bunker Cave display relatively slow growth rates. We suggest that – with absence of major entrances to the cave system during the Holocene – ventilation was minimal and pCO_2 concentrations significantly higher, making winterly water supply the governing factor regulating speleothem growth. Thus, stalagmites from Bunker Cave are likely to record a climatic signal biased towards the winter season.