About the use of thermal imaging in cave micrometeorological studies

Andreas Pflitsch[1,2], Christiane Grebe[1], Martina Grudzielanek[1]

Introduction: Cave micrometeorological studies are so far mostly based on data resembling singular points or at best on data with linear character. What is missing, however, is the coverage of complete surfaces or three dimensional data, which would provide much more comprehensive information on the different measurement parameters. At least regarding the two dimensional measurement of the surface temperature of cave walls, ceilings and floors, thermal imaging is a method for a wide range of applications. Indirectly it allows conclusions about different processes and the cave air temperature and provides data for the study of several micrometeorological aspects such as the thermal differentiation of the cave, the influence of touristic use and infrastructure, the diagnosis of the air flow regime and the assessment of the impacts of air flow.

Keywords: infrared thermography, cave climatology, surface temperature, thermal differentiation, Jewel Cave, Wind Cave, Lechuguilla Cave, Carlsbad Cavern, Fort Stanton Cave, Schellenberger Ice Cave, Mauna Loa Ice Cave, Arsia Ice Cave

Infrared thermography

The human eye can only see the portion of the suns electromagnetic radiation lying in the range of the visible light. Other parts of the suns spectrum, such as infrared radiation, which are invisible to the eye, can nowadays be measured with adequate sensors. Over the last decades infrared thermography has become a highly advanced measuring technique for multiple purposes. With wavelengths in the range between 8 and 14 µm infrared radiation includes long-wave thermal radiation also called "thermal infrared" (VOLLMER & MÖLLMANN, 2010).

The surface temperatures of an object, which are derived from the measured infrared radiation, are useful information for many technical applications as well as in the physical science and medicine. For some time now thermal imaging has also been applied in speleology. The Caving Club Blaubeuren for example has been using infrared thermography for the detection of cave openings as well as for the identification of bats (HÖHLENVEREIN BLAUBEUREN e.V., 2012).

Several factors need to be taken into account when using infrared thermography for climatological studies. The surface temperature is calculated using a specific emission coefficient. This coefficient depends on the specific emissivity of a surface which is determined by its material, surface characteristics and viewing angle (VOLLMER & MÖLLMANN, 2010). These aspects are especially important in speleology, since cave surfaces vary in structure, colour, material, humidity and therefore have a varying emission coefficient. In addition to this, measurements in caves are affected by the high air humidity and the change in ambient air temperature when bringing a camera into a cave or even an ice cave. This must be considered in the setup of the measurement or corrected during data analysis. Other radiation sources in the observed area have to be avoided, because directed and diffuse reflection of thermal radiation from other objects would falsify the measurements (SCHUSTER & KOLOBRODOV, 2004).

The use of infrared thermography in caves

Modern thermal imaging systems can shoot picture series which makes it possible to analyze dynamic processes and apply statistical methods. We have been applying thermal imaging for the study of several different problems in speleology for a couple of years.

The identification of the best spots for temperature measurement is another important application of thermal imaging when preparing a long term micrometeorological measurement campaign in a cave.

So far we have used thermal imaging in the following studies:

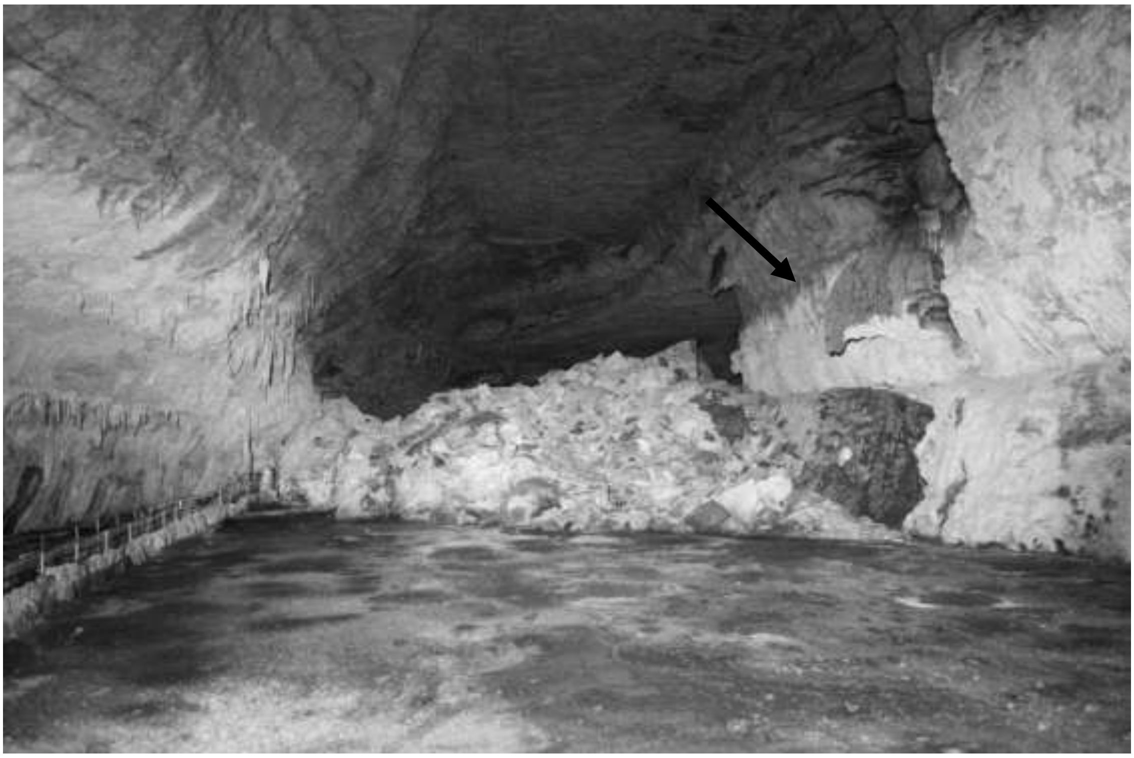
Caves with a barometric circulation

In the barometric caves Jewel Cave and Wind Cave in South Dakota as well as in Lechuguilla Cave in New Mexico it was possible to visualize the thermal effect of barometric airflow. The extreme cooling during winter as well as the strong warming could be very clearly localized spatially. Especially the differing characteristics of the vertical component showed impressing results in the course of the seasons. Also the reach of the inflowing cool air could be determined in different heights above ground.

[1] *Working Group Cave- & Subway-Climatology, Geography Department, Ruhr-University Bochum, 44780 Bochum, Germany*

[2] *andreas.pflitsch@rub.de*

Picture 1: Thermal image of the "Devils Spring" area in the twilight zone of the Carlsbad Caverns, New Mexico. The view direction is into the cave. The difference between the dark floor and the warmer ceiling is clearly visible. These two zones are divided by a line which is referred to as popcorn line (arrows). Below this line we do have the growth of popcorn speleothems, above the line we don't.



Picture 2: Image (visible wave length) of the "Devils Spring" area in the twilight zone of Carlsbad Caverns, New Mexico. The image represents more or less the area shown above in picture 1. This image is taken more in the middle, so the foreground is different, but the rock pile in the middle of both pictures and the ceiling are good comparable, as well as the popcorn line, marked by an arrow.

Changes in the climatological regime

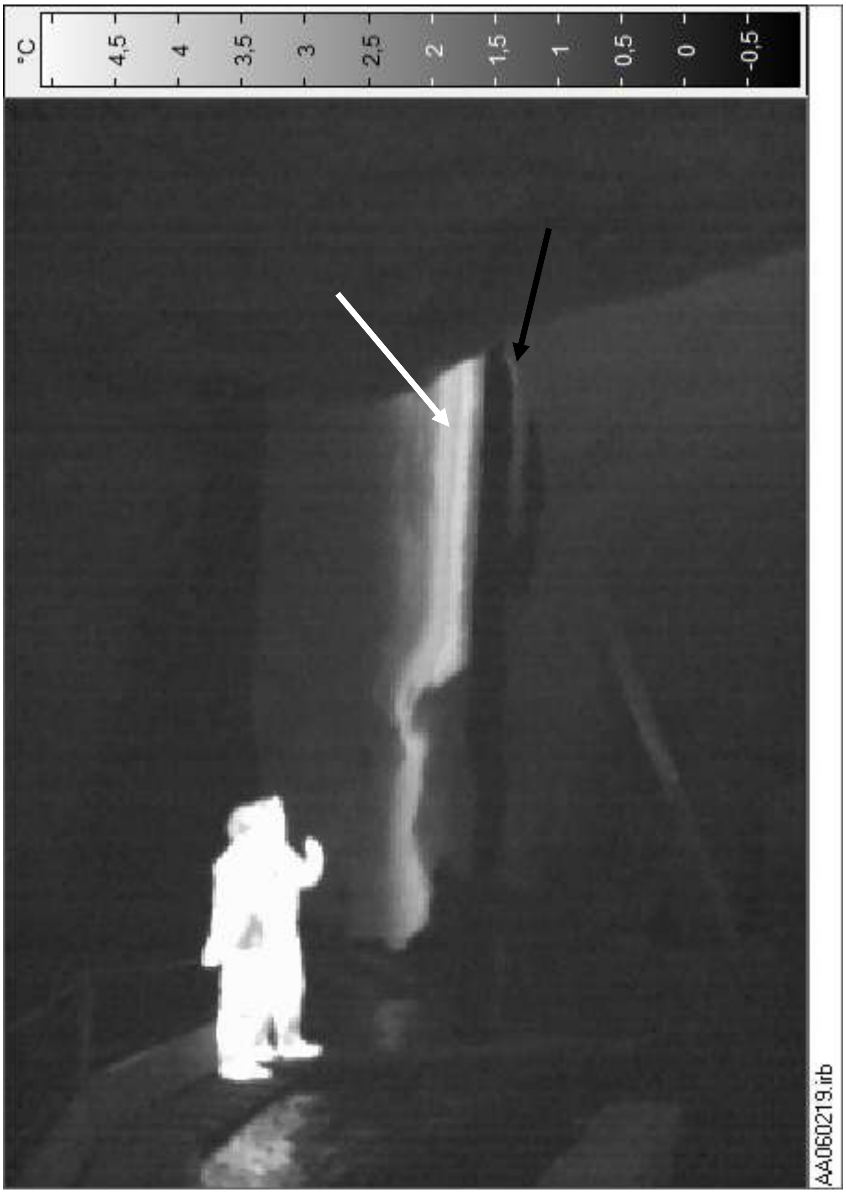
The analysis of the recorded images also provided valuable information on the effectivity of recent constructional changes in the touristic part of Wind Cave. There had been problems with frost weathering in the ceiling area in the past. Thermal imaging showed that after the constructional changes that the temperature in the ceiling area of the entrance tunnel does not drop below 0 °C anymore, even with inflowing cold air of -20 °C.

Caves with convective circulation

For Carlsbad Caverns in New Mexico, USA, a very stable circulation system with inflowing cold air close to the floor in periods with low outside temperatures and during night time and warm outflowing air close to the ceiling could be proven. Different thermal zones, so far deduced from the popcorn line (pic. 1 & 2) could be confirmed by the thermal images. Several picture series, each covering several hours of time, made it possible to visualize the dynamic range of in- and outflowing air masses.

Ice Caves

In Schellenberger Ice Cave, Germany, the effect of infiltrating melt water during spring on ice pillars built up by drip water during colder periods was studied. We found that the water, infiltrating after a long period of rain during May, entering the cave with a temperature between 4-5 °C lead to a rapid melting of the huge ice pillar (pic. 3).



Picture 3: Thermal image in the Angermayer Hall of Schellenberger Ice Cave, Germany. Two persons are looking to the melting ice column on the back wall. The melting ice column (black arrow), influenced by the melt water stream (white arrow), flowing down from the ceiling is clearly visible.

Other applications

Also the influence of the direct sunlight coming in through the large entrance opening of Schellenberger Ice Cave was analyzed. This showed the warming effect on the cave walls.

In Mauna Loa Ice Cave and Arsia Cave on Mauna Loa on Hawaii, USA, thermal imaging was used especially for the thermal analysis of the vertical climatic structure of the lava tunnels. For parts of the tunnels a clear thermal differentiation could be proven while other parts were uniformly tempered. A further analysis of the data is yet to be done. In Fort Stanton Cave, New Mexico, USA, a stationary thermal camera was used to monitor bats during hibernation in winter and to analyze their reaction on the disturbance caused by a count of the bats during hibernation.

Conclusions

Spatial analyses using single shots or panorama pictures as well as temporal analyses with picture sequences have given us valuable insights into short and long term processes of different caves. Especially the combination of infrared thermography and air temperature, air humidity and airflow measurements yielded important results for the understanding of the sensitive cave climate- and ecosystem.

Acknowledgement

Our thanks for all the support for our research go to:

- Schellenberger Eishöhle, D
- Wind Cave NP, South Dakota, USA
- Jewel Cave NM, South Dakota, USA
- Bureau of Land Management, New Mexico, USA
- Carlsbad Caverns NP, New Mexico, USA
- Division of Forestry and Wildlife, Hawaii, USA

References

HÖHLENVEREIN BLAUBEUREN e.V.: Thermographie, available at: http://www.hoehlenverein-blaubeuren.de/index.php?option=com_content&view=article&id=145&Itemid=43, accessed on May 21st 2012.

SCHUSTER N., KOLOBRODOV V. G. (2004): Infrarotthermographie. 2., überarb. und erw. Weinheim : WILEY-VCH.

VOLLMER M., MÖLLMANN K.-P. (2010): Infrared thermal imaging: Fundamentals, research and applications. Weinheim. WILEY-VCH.