ANALYSIS OF SELECTED CLIMATOLOGICAL OBSERVATIONS OF TALUS & GORGE ICE CAVES IN NEW ENGLAND

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Abstract
Changing temperature regimes inside a field of debris with year-round ice blocks are the base of this study in northern New Hampshire. This unique ecosystem shows strong temperature anomalies in comparison to the surrounding area and ice, especially year-round ice, is not common below 700 m a.s.l. Yearly mean air temperatures can be strongly connected to the yearly ice level variations. Besides the analysis of the complete dataset of five years and a comparison of the impact of different seasons onto the ice considering precipitation, air temperature and special weather phenomena, the question about the use of talus & gorge ice caves as a climate indicator for a region has priority.

Keywords
ice cave, talus, gorge, climate change, climate indicator, subterranean ice, New Hampshire, Maine, New England, United States of America

Introduction
The White Mountains in the northern Appalachian Mountains of the USA are the study area of the Talus & Gorge Ice Cave monitoring network. The Talus & Gorge Ice Caves are also known as talus caves (with ice), because of the forming material, unsorted rocks. The hollow spaces in between the rocks can bury ice, also at altitudes far below the summer snowline, under special conditions. The hollow spaces also known as caves have different sizes depending on the sizes of the rocks.

In October 2008, we started to collect data in different Talus & Gorge Ice Caves of New Hampshire and Maine with the main goal to identify the climate of these unique ecosystems. We observe the air temperature above the talus and within the talus nearby the ice in connection with yearly and scattered semiannual ice level observations. After five years of collecting data, a first review about the past climate and its variations will be given. The temperature and ice level measurements of the study area with a comparison of the collected data of nearby reference stations result in important knowledge about the interaction of the climate between the talus & gorge caves and the external environment.

Since ice caves can be seen as a climate indicator for short- and long-term changes within the climate of their respective region, we will lead to a statement about the recent climate and its possible changes for New England especially northern New Hampshire and western Maine.

A final analysis of regional climate change indicators for New England like “length of ice cover on lakes”, “date of lake ice-out” or “days with snow on the ground” will introduce into a comparison of the results of our yearly ice level observations of the talus & gorge ice caves in that area. We will lead into a new representative idea of climate change observation for New England and discuss its advantages and disadvantages.

Site characteristics
The network of the Talus & Gorge Ice Cave monitoring consists three study sites in New Hampshire and Maine. The focus for this analysis is on the site with the longest datasets, the Ice Gulch in northern New Hampshire. Since 2008 we are measuring the air temperature of the Ice Gulch at different positions in the gulch and the ice level changes in regular intervals.

The Ice Gulch is situated in the White Mountains of New Hampshire, 50 km south of the Canadian border. The Ice Gulch is a small narrow Gorge with ~85 to 100 m high surrounding walls and a width of ~80 m. On the ground of the gulch huge rocks of a diameter up to 3 m form the cave-like hollow spaces, which contain year-round ice at some spots. The special characteristic of that gulch is that one can find ice in the talus right below the surface, at an elevation of approximately 650-690 m a.s.l. (Holmgren & Pflitsch, 2010). The Ice Gulch is far below the summer snowline. Mt. Washington (1,917 m a.s.l.), the highest mountain in the northeastern USA, in general is ice-free from May to September (Holmgren & Pflitsch, 2011). First obvious signs for an irregular climate are some plants within the Ice Gulch. Alpine plants, like the alpine blueberry, one can find in the Talus & Gorge Ice Caves are not common in this elevation in New England (Ice Gulch: Visiting New Hampshire's Biodiversity, 2009).

Methods

At the study site "Ice Gulch" five data loggers measure the air temperature. One at the vegetation line (compare Fig. 1, red box) and four at different spots within the talus 10 cm above the ice blocks (compare Fig. 1, blue box). The data loggers of the company "GeoPrecision" have sensors from the type PT1000 with a precision of+/-0.1 K at a temperature of 0 °C and a resolution of 0.01 °C (GeoPrecision, 2014). All five data loggers record the temperature in a 15 min interval. The ice level observations are done manually. The observations were observed yearly every potential ice level minimum.

For a data comparison of the Ice Gulch with the surrounding area, reference stations of the nearby Mount Washington Observatory are used. The Observatory at the summit of Mount Washington provides temperature, wind speed and wind direction data. The weather stations along the slopes, especially the 2,300 ft station at similar elevation and similar orientation like the Ice Gulch, provide important temperature data for a comparison.

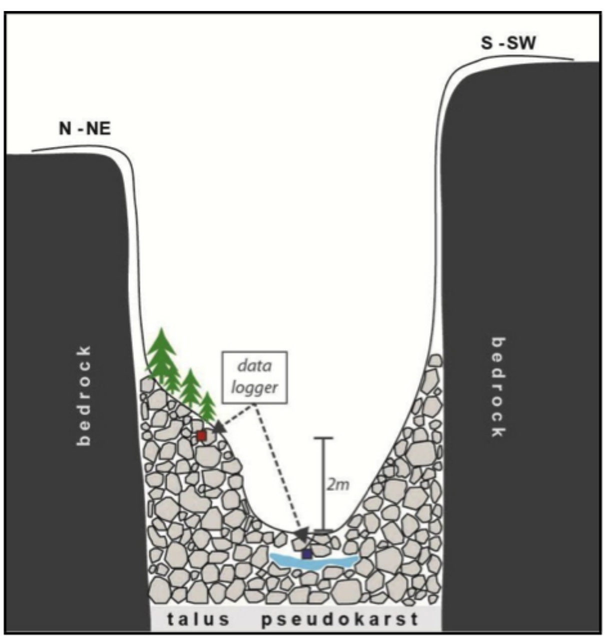

***Figure 1.** Schematic cross profile of the Ice Gulch and position of temperature sensors (adapted after Holmgren & Pflitsch, 2011).*

Procedure of data analysis

Temperature regimes of the last five years

A comparison of the last five years (Fig. 2) will give a first overview about the temperature features of the ecosystem Ice Gulch. The graphs in Figure 2 visualize the air temperature of two data loggers. One shows the temperature of the edge of the vegetation line (red) approx. 2 m above the floor of the gulch with one exemplary dataset from inside the talus close to an ice block (blue) (compare position in Fig. 1). The yearly returning cycles and the differences are in focus of that topic. Are there any changes or developments in the progress of the last five years of record? One of the most obvious developments in the past is the increasing period of temperature above freezing inside the talus year by year (Fig. 2 blue graph). The impact of the relatively warm air masses gets stronger and stronger due to the increasing mean summer temperatures of the surrounding area (and the varying mean winter temperatures). The result of this effect is a negative ice mass balance which leads to a less absorption of warm air during summer.

Another topic is the comparison of the yearly cave ice dynamics with the yearly temperature regime from November to October (ice minimum to ice minimum). We identified a strong comparison between the annual mean air temperatures and the yearly ice dynamics in Gorge Ice Caves with talus (like Ice Gulch), but not in Talus Ice Caves. Talus Ice Caves tend to be more sensitive and less

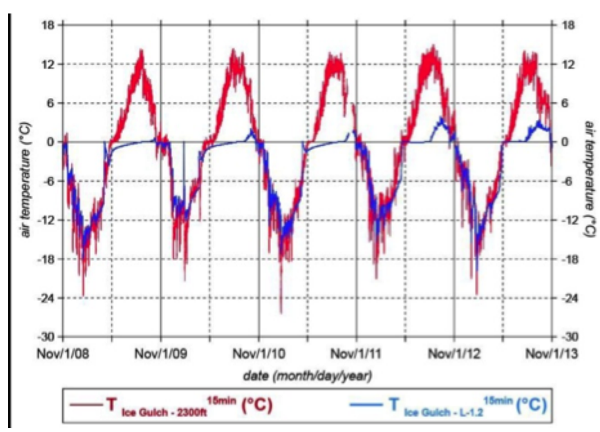

***Figure 2.** Temperature regimes of the Ice Gulch - above and within the talus (Nov/1/2008 – Oct/31/2013).*

protected for short-time weather phenomena especially in summer when former Hurricanes or tropical storms hit this area which influence the Talus Ice Caves much stronger. That's an enormous impact factor for a bigger ice loss in Talus Ice Caves (up to 2.2 m) than in Gorge Ice Caves (up to 0.25 m). Gorge Ice Caves, due to their surrounding walls, like you can find in the Ice Gulch, are much better protected against storms pushing air masses into the talus.

The impact of the seasons

For understanding the ice building and melting processes at these unique locations, the different seasons play an important role. The first question for us was, whether the typical known seasons, can find in the Ice Gulch as well? Or do we have a change in the typical cycle of seasons, affected by the specific conditions with a unique climate inside the Ice Gulch? This result will be important for the further view how the ice level measurements can be used as an indicator for a changing climate.

The seasons of the Ice Gulch are defined by a specific temperature behavior. Summer and winter are the seasons when the air temperature at the edge of the vegetation line stays continuously above or below the freezing point. Spring and fall are the seasons in between when the air temperature fluctuates around 0 °C.

First all of the seasons in the talus and gorge caves are different in length in comparison to the outer atmosphere. The mean length of the winter and summer seasons demonstrate the domination of these two seasons since our measurements began in October 2008.

Summer is the longest season with an average of 160 days, followed by the winter season which is a bit shorter than summer with a mean of 157 days. The shorter seasons are fall and spring. Fall has a mean length of 29 days, while spring has only a mean of 16 days.

Interesting are the developments in length of the seasons in the last 5 years. In 2009 fall began with a length of 51 days, a record year. From year to year fall got shorter and ended up with 13 days in 2013. Spring, the shortest climatological season in the Ice Gulch, has a minimum of 8 days and a maximum of 30 days, with a decreasing trend. The biggest development one can see is in winter, the length of winter has an increasing trend over the last five winters. The shortest winter was in 2009 with 129 days and the longest with 175 days below freezing in 2012. Summer with a minimum length of 153 and a maximum of 176 days shows a very light increasing trend of air temperatures above freezing. But an interpretation of the summer trend is very imprecise with this slightly increasing development and an observation period of only five years.

As you can see winter and summer seasons are the dominating seasons inside the talus. Fall and spring are short transition seasons and not very distinct. The climate and the ice blocks of the talus and gorge caves are very sensitive to the extreme temperatures and precipitation in summer and winter and that's one of the reasons why the first two mentioned seasons play besides their length an enormous role.

Ice caves as climate indicators for New England?

Besides the well known and observed climate elements of a weather station, we do have various climate indicators worldwide, like the extent of the arctic sea ice or the bird wintering ranges. For New England and especially the White Mountains in New Hampshire, the regional climate indicators, are for example the lilac bloom date or the Lake Winnipesaukee ice breakup.

An analysis will try to compare the existing long-term observations (partly since 1807 AD) of climate indicators of that region with the ice level variations at the yearly potential ice minimum of the Ice Gulch (since 2008 AD) (USGS, 2010; Lake Winnipesaukee New Hampshire, 2014). Finally, this analysis will result in a statement about the climate changes of that specific region. The validity of this new climate indicator was unknown before for New England. For other regions of the world, like the western European Alps or the ice caves of Lake Baikal in the south of the Russian region of Siberia (Luetscher et al., 2005; Trofimova, 2006), such analyses are already done.

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