LIFE IN ICE AND SNOW

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ABSTRACT: Snow and ice surfaces were long considered as sterile environments and hence neglected as a research topic in a biological context. Today, the presence of active life in the cryosphere is evident and key strategies for survival under extreme conditions on ice and snow surfaces have been explored. Here we present microbially dominated communities in the cryosphere and demonstrate how these organisms actively decrease the reflectivity of ice and snow surfaces and hence alter the physical properties of snow and ice. Further, we highlight challenges of sample acquisition and how these hurdles can be minimized by using a novel portable laser prototype for the non-invasive in-situ detection of supraglacial biota. Ultimately, we discuss the impact of anthropogenic footprints on glaciers and ice sheets in context with global warming.

KEYWORDS: Glacial Ice, Snow Pack, Cryoconite Holes, Cryobiosphere, Microbes, Bioalbedo, Laser-Induced Fluorescence Emission

1. BACKGROUND

Snow and ice are part of the cryosphere and constitute about 70% of the global fresh water reserves which cover about 11% of the Earth (Boyd et al., 2010). Research dealing with this solid form of water is often linked with modelling of avalanche forecasts and glacier mass balances, resulting in valuable knowledge for many applications. From a biological perspective, these snow and ice surfaces were long considered as sterile environments being too harsh for any living organism to survive. Today, glaciers and ice sheets are recognized as a biome, hosting life in many different habitats (Anesio & Johanna Laybourn-Parry, 2012).

2. CRYO*BIO*SPHERE

The presence of diverse organisms on several trophic levels emphasize the important role of cold ecosystems. Communities thriving in ice and snow are mainly dominated by microbes. Bacteria, viruses, algae, fungi, protozoa and sometimes even metazoans are present in supraglacial zones which can be divided in three main habitats: Bare ice surfaces, snow covers and cryoconite holes. The latter is a typical feature of glaciers and ice sheets which cover up to 10% of glacial ablation zones (Anesio et al., 2009). These mini-lakes form when deposited organic and inorganic particles at the ice surface melt the ice due to solar radiation, creating little basins with sediment in the bottom and liquid water on top. Despite extreme environmental conditions, microbial communities in cryoconite holes photosynthesize and respire at rates rather known from temperate soils (Anesio et al., 2009). Despite the research focus was set on cryoconite holes for a long time, bare ice surfaces and snow covers increasingly attract attention as important habitats, too.

Environmental conditions in high altitudes or latitudes require efficient survival strategies to cope with low temperatures, high irradiance, desiccation, osmotic stress, low nutrient availability and freeze-thaw cycles. For example, anti-freeze proteins in psychrotropic and psychrophilic organisms prevent the formation of damaging ice needles and hence enable an active metabolism even at subzero temperatures. These microbes also survive within the ice matrix either in brine channels or in small veins between ice crystals which are characterized by elevated salt concentrations, lowering the freezing point of water which is crucial for any active metabolism (Boetius et al., 2015). Among metazoans, tardigrades constitute another example of successful survival specialists. They withstand not only the cold but also heat, desiccation, vacuum and even radioactive radiation. These remarkable features qualify them as a model organism for astrobiology.

3. BIOLOGICAL DARKENING OF SNOW AND ICE SURFACES

On glacier surfaces organic or inorganic particles lower the reflectivity (albedo) and absorb solar radiation. Consequently, increasing surface temperature induce melt processes if the energy transfer is high enough enhancing microbial activity due to the availability of liquid water. Additionally, cells on ice and snow surfaces are equipped with dark pigments, not only protecting them against harmful UV-radiation but also lowering the albedo. Hence, the presence of organisms on glaciers and ice sheets accelerate surface melt and consequently stimulate the growth of

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microbial communities, resulting in a positive feedback loop. This biologically induced albedo-effect is known as “bioalbedo” which has not been considered in climate models yet (Hamilton & Havig, 2018).

3. DETECTION OF L.I.F.E. LASER -INDUCED FLUORESCENCE EMISSION

Modelling and predicting biological activity in melting snow and ice is challenging and requires high resolution data due to the patchy distribution. However, manifold constraints in extreme environments often hamper sufficient data resolution and therefore inevitably lead to conclusions based on spatially limited sample points or data being up-scaled to a global perspective. Moreover, sample handling such as melting ice cores manipulate sensitive organisms already before being analyzed. As a consequence, measurements in the laboratory will not capture the in-situ situation. This dilemma could be avoided by the use of non-invasive in-situ techniques which are not commercially available yet.

Here we present a portable prototype that detects laser-induced (405nm and 532nm) fluorescence patterns emitted from porphyrin derivatives in bacterial and algae communities. This method enables non-destructive in-situ assessment of terrestrial and ice ecosystems, delivering data with high spatial and temporal resolution and no manipulation. Using such a single-shot in-situ laser beam measurement makes sampling, transport and subsequent hands-on analysis obsolete. By exchanging lasers with different wavelengths, many other target molecules may be quantified. Here, the L.I.F.E. prototype is used as a powerful tool to monitor rapidly changing environments in context with global change.

4. ANTROPOGENIC FOOTPRINTS

Ongoing climate change and further darkening of ice and snow surfaces lead to increased ablation rates on a global scale. Consequently, anthropogenic radionuclides that have been deposited and buried in the ice during atomic bomb tests and nuclear power plant accidents are now being released into melt waters in relatively high concentrations (Tieber et al., 2009).

Glaciers are also a crucial economic factor. Skiing slopes increasingly destabilize due to melt. To prevent high ablation rates, hectares of polypropylene covers are used to limit melt processes during the summer months. These fabrics contain a lubricant – a water soluble chemical substance that is hazardous to water. Further, these fleece covers are comprised of microplastic fibers that partly disintegrate and hence remain in the ice after the fabrics are retrieved before the upcoming winter season. Using this approach is ethically and ecologically questionable and leads to the conclusion that for sustaining economic values we take a pollution of our waters into account.

5. CONCLUSION

Today, glaciers and ice sheets are known to harbor microbially dominated life that is well adapted to extreme environmental conditions. Their presence leads to a biological darkening of ice and snow surfaces and consequently enhances melt rates. Because there is no data and no long-term monitoring system available, it is crucial to address the bio-albedo effect in future studies. Further, ablation in ski resorts forces stakeholders to cover vast areas of the skiing slopes with a plastic cover that prevents high ablation rates. Since this cover has negative side effects for the environment, we suggest reconsidering the choice of materials by establishing collaborations among biologists, material scientists and stakeholders in ski resorts. Our L.I.F.E. prototype may be used as an innovative tool for further studies in this field.

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