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How do snow algae and microbial life affect glacial systems?

Abstract:

Glacial systems and ice caps are melting in response to global warming and climate change. The physical causes and its relation to glacial melting have been studied extensively, but the icy environments are thought to be less biological diverse and the role of biological processes that takes place on the surface of glaciers and ice has been neglected in the radiative forcing balance models. In recent years field observations and lab experiments have shown how large bio-cover (termed as supraglacial environment) can be and their role in changing surface reflectivity which ultimately contributes to melting, hence starting a positive feedback loop. Furthermore, cyanobacteria and algae capture CO2 in this environment and convert it into organic matter, when they die they are broken down by microbes in the form of carbonic acid and other biomolecules and are flushed by water during melting season causing increased weathering. Here in this paper, the correlation between algal abundance and reduction of albedo has been analyzed graphically from the data based on the recent research.

The Extent of Bio-Cover(Snow algae)

The Superaglacial environment or biological growth covers about 800,000km^2 of the area and it is seen to be growing with time **[5]**. Global warming is accelerating the cover and is more profoundly be seen in the regions where the glacial environment meets the non-icy regions. These bio-covers are mainly composed of several algals (*Mesotaenium berggrenii* and *Ancylonema nordenskioldi*i) and bacterial species, having different colors depending on algal species, mostly the covers are of green, reddish-pink, and violet. The dark pigments help them to survive in harsh environments by absorbing UV light thus protecting the cells from damage.

Role of Bio-cover in Reducing Local Albedo

The glacial and ice systems contribute significantly in reflecting back the incoming solar radiations hence maintaining the global energy fluxes. But a huge part of glacial and icy systems suffers from reduced reflectivity, both physical and biological factor are the causes of it. Physical cause being deposition of atmospheric black soot and dust particles and biological factor being agal cover. In the regions where there is an abundance of both soot particles and algal cover, small circular clumps of soot is observed, they are called Cryoconites.
It has been suggested that they might be the reason for cryoconite formation because of the fact that bacterias living together with the algae secrete some kind of glue termed as 'extracellular polymeric surface' that aggregates the particulate matter together and forms dark clumps**[5]**. The cryoconite and algal snow cover reduces local albedo significantly hence causes accelerated melting of ice and snow.

Recently, combined ground sampling, radiative transfer modeling, and satellite imagery showed that algal blooms specifically can cover at least 78% of the ice in the dark zone, generating at least 6 %–9% additional ice melt in the south-west dark zone of Greenland during the dark year of 2016 compared to the year of 2017**[4]**.

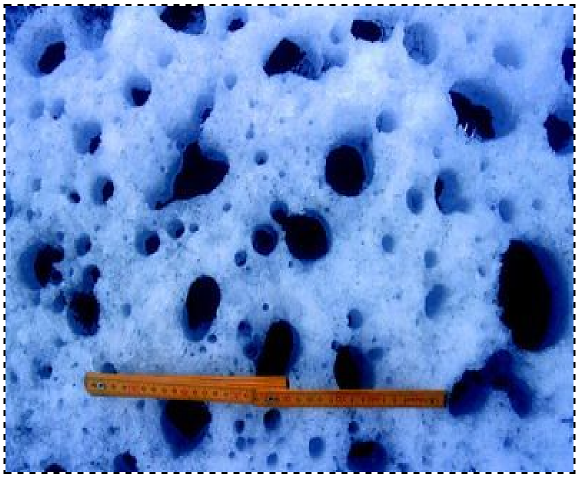

Figure 1: Cryoconites holes in Greenland, Showing reduction of albedo on a local scale.[web]

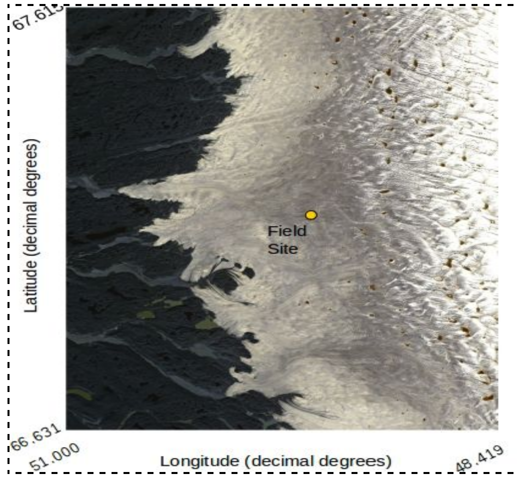

Figure 2: Darkening of ice sheet due to soot deposition and algal growth on a big scale.[1]

The bare ice algae act as an albedo reducing agents, causing a positive feedback system that triggers more melt causing more algal boom. Also, these algal life supports the bacterial microbiome, bacterias decomposes the dead algae and breaks down the organic carbon to CO2. The biological layer as a whole can act as either carbon dioxide source or sink, if the biological layer is more than 3mm thick then it acts as a carbon sink, and if less than 3mm it acts as a carbon source(releasing CO2 back to the atmosphere). This bio-cover includes many algae species and bacterial species, they also do nitrogen fixation[3], and are part of many biogeochemical cycles in such desert environments.

Methods :

Here based on two data sets obtained from the references **[1,2]** which were obtained from the field study in Black and Bloom Project field site Greenland, Sweden, and Svalbard, I analyze the data in a more of graphical and qualitative way. The data from Sweden and Svalbard is on red-pigmented algae whereas data from Greenland is on purple pigmented algae. Both show that algal bloom reduces the local albedo significantly. The purple pigment absorbs more radiation than the red color pigment but both types of algae cause an easily observable change in reflectivity.

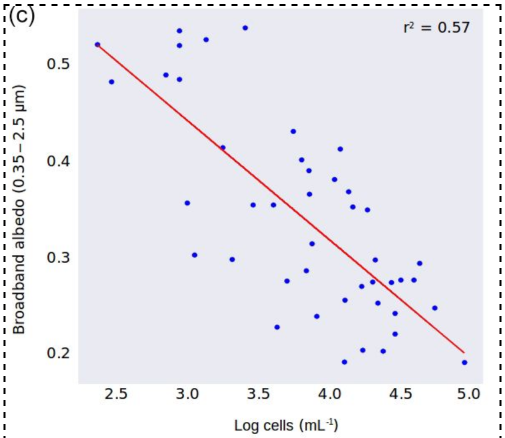

Figure 3: Broadband albedo against log of cell abundance.[1]

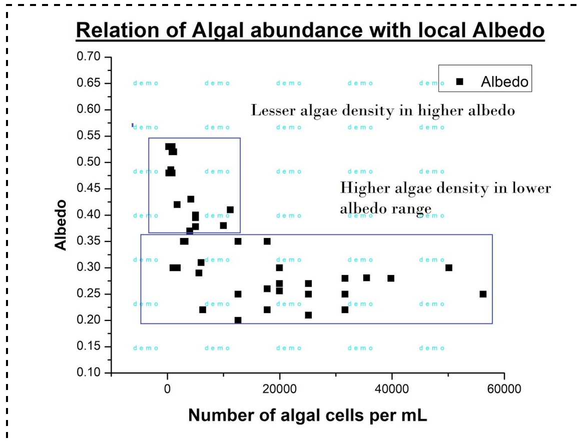

Figure 4: Broadband albedo vs Number of cells per ml

Figure 3 is a plot of broadband albedo (0.35-2.5μm) against the natural logarithm of algae cell abundance showing a negative correlation but this graph doesn't show the real distribution as the horizontal axis is in natural log scale. I have plotted the data from this graph and have converted the log scale to the number of cells per mL. This plot [figure 4] clearly shows a large number of algal cells distributed in the lower albedo region (points marked in the lower box, number of datapoints=24) and low algal distribution in the higher albedo region(points marked in the upper box, number of datapoints=11).

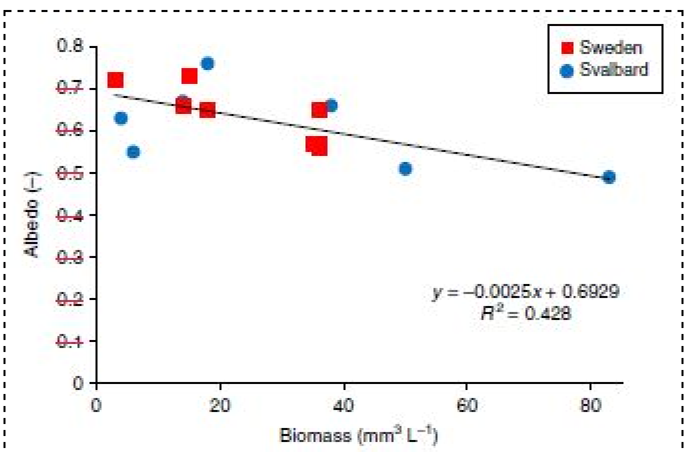

Figure 5: Albedo against Algal Biomass [2]

Figure 5 also shows the negative slope at two different places Sweden and Svalbard which supports the fact that albedo reduces due to algal bloom (higher biomass in lower albedo region), it should be noted that this has very less datapoint compared to the Greenland algae plot.

Results:

The analyzed graph (figure 4) shows two distinct regions clearly separated within the box showing the relationship between a high abundance of algae and lower albedo. It can be inferred without hesitation that algal growth is the cause of lowering albedo observed in the glacial systems which in turn acting as a positive feedback loop resulting in increased absorption of thermal energy implying more melting.

Conclusion

The biological activities seem to have both cause and effect on increased algal growth and melting of ice and glacial systems, This is in line with the positive feedback loop suggesting that increased algal growth causes increased melting and more melting supports algal bloom and vice versa. But the more extensive field study at different locations and research is needed in this field to have a better understanding of the role of biological processes in large scale processes like climate change.

References used in this draft :

1)Joseph M. Cook. "Glacier algae accelerate melt rates on the south-western Greenland ice sheet". The Cryosphere (2020).

2)Stefanie Lutz, Alexandre M. Anesio, Liane G. Benning. "The biogeography of red snow microbiomes and their role in melting arctic glaciers". Nature Geoscience (2012)

3) Jeff R.Haviga.Trinity L.Hamilton. "Snow algae drive productivity and weathering at volcanic rock-hosted glaciers". Science Direct (2019)

4) Andrew J. Tedstone, Joseph M. Cook, Christopher J. Williamson, Stefan Hofer, Jenine McCutcheon, Tristram Irvine-Fynn, Thomas Gribbin, and Martyn Tranter. "Algal growth and weathering crust state drive variability in western Greenland Ice Sheet ice-albedo" The Cryosphere (2019)

5) Marek Stibal, Marie Šabacká & Jakub Žárský. "Biological processes on glacier and ice sheet surfaces" Nature Geoscience. (2012)