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Save the Arctic from Greening

Abstract:

The Arctic has been experiencing the fastest warming under climate change. One of the consequences of Arctic warming is “Arctic Greening”, which is termed as shrub expansion and increased plant productivity in the Arctic. Some research findings suggest that this process might disturb the soil carbon storage and thus give a positive feedback to climate change. The feedback could be massive because the Arctic stores the largest amount of soil carbon on earth. However, there is still lack of understanding of Arctic greening and its influence on soil carbon storage. Herein, this project idea is to integrate the above-ground biomass (i.e., plant biomass) monitored by satellite missions, the below-ground biomass (i.e., microbial biomass) estimated by a network of empirical studies and the measurements of carbon emissions, to better understand the Arctic Greening, to evaluate the severity of its effect on carbon fluxes, and to promote future climate action.

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1. Introduction

1.1 Arctic greening and carbon storage

Due to the harsh climate, the Arctic used to be described as an ecosystem where the aboveground is covered by tree-less, low-growing vegetation. Activities of organisms living belowground are also constrained by the environmental conditions. However, this has been strongly influenced by the global warming. A phenomenon that has come to gain attention is “Arctic greening”, where shrubs such like birch and willow have gradually expanded to the territory of tundra plants such like moss, forb, and sedge, which has led to an increase of plant productivity in the Arctic [1]. A study found that 37% of the Arctic tundra has gradually become greener since 1985 (Fig. 1) [2]. The National Oceanic and Atmospheric Administration has also recorded exceptionally high plant productivity across tundra occurring in 2020 (Fig.1) [3].

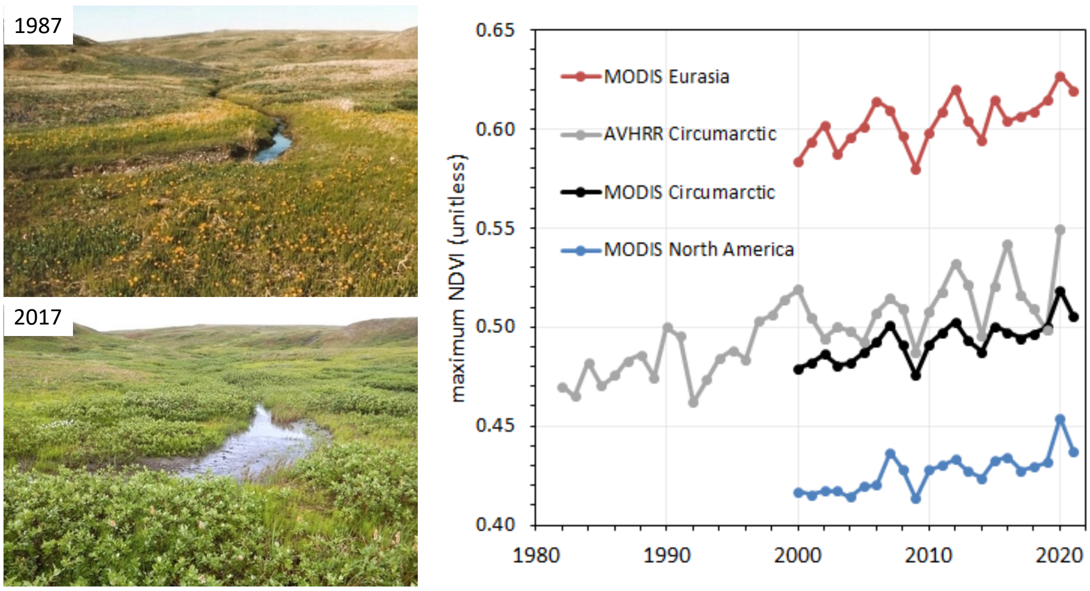

Figure 1. Left: Change in vegetation at the Yukon’s Qikiqtaruk-Herschel Island Territorial Park (Canada) between 1987 and 2017. Credits: Isla Myers-Smith/University of Edinburgh [4]. Right: Time series of changes in plant productivity, shown as maxNDVI (Maximum Normalized Difference Vegetation Index) [3].

The increased plant productivity has been traditionally associated with a positive contribution of carbon (C) sequestration in the ecosystem because it withdraws the atmospheric CO_2 through photosynthesis. However, increasing research indicates that Arctic greening might result in net emissions of C to the atmosphere, since the changes in vegetation could stimulate the soil microbial respiration due to more plant-derived supply to microbial decomposition [5-7] (Fig. 2). Given that Arctic soil is the largest terrestrial C pool [8], there is a big concern that the Arctic greening might contribute to rising CO_2 levels, rather than mitigating it.

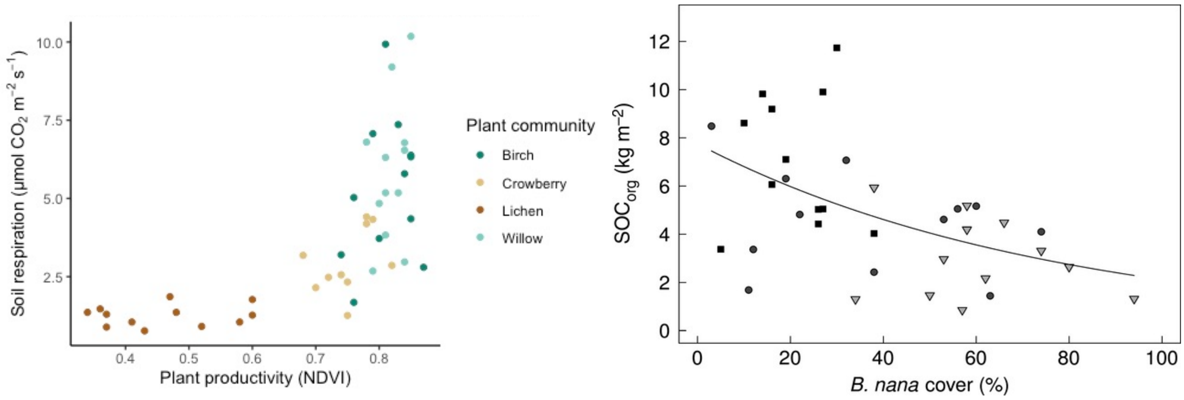

Figure 2. Left: The positive correlation between plant productivity soil respiration among different plant communities in Abisko, Sweden. Data from Azevedo (2021): Abisko soil respiration dataset. Right: A negative relationship between cover of birch (*Betula nana*) and soil organic carbon (SOC) in tundra-health (squares), shrub-heath (circles) and shrub-dominated area (triangles) in Abisko and Vassijaure, Sweden [7].

1.2 An integrated evaluation system

The concern of the relation between Arctic greening and C storage arises a question: **How severe C loss the Arctic will face during Arctic greening?** This project idea proposes an integrated evaluation system to answer to this question, by disentangling the correlation between C emission, plants and soil microbes (Fig. 3). According to different roles of plants and soil microbes in the scenario of Arctic greening, four parameters are selected: 1) above-ground biomass, as the indicator of plant productivity; 2) structure of vegetation, as the indicator of changes in vegetation composition; 3) below-ground biomass, as the indicator of soil microbial activity; 4) emission of CO_2 (and CH_4), as the indicator of the C emission in the ecosystem.

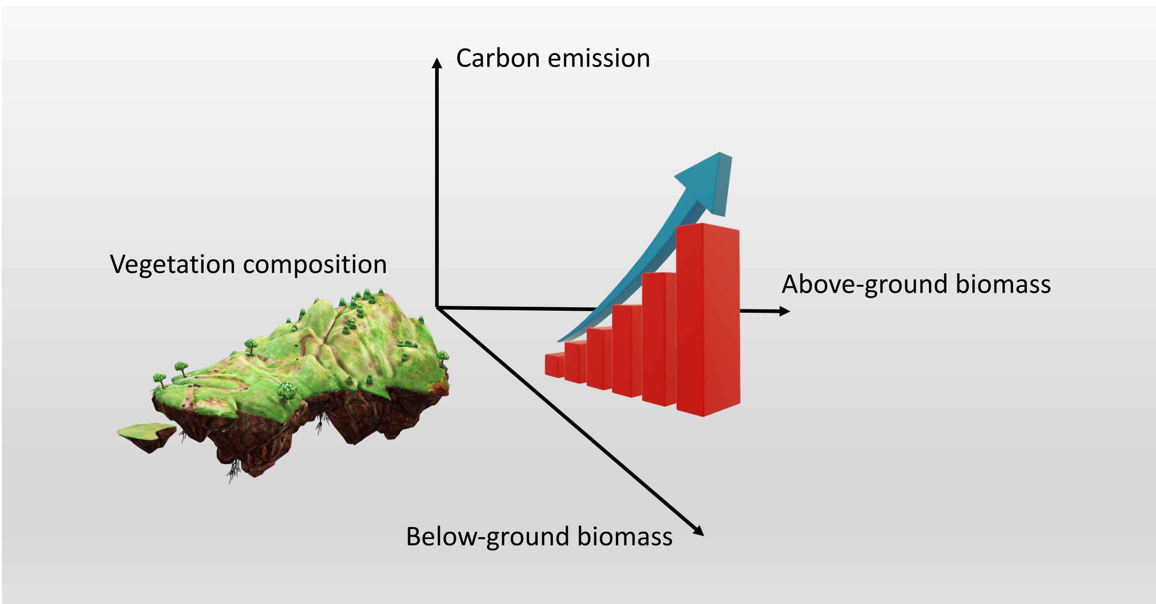

Figure 3. An integrated evaluation system of C loss during Arctic greening.

In this report, the techniques used to monitor these four parameters will be elucidated in Chapter 2, the project idea's links to the Sustainability Development Goals (SDGs) will be discussed in Chapter 3, and the feasibility of the project idea will be assessed by a SWOT analysis in Chapter 4.

2. State of the art

2.1. From space

Synthetic aperture radar (SAR) is a type of data collection in remote sensing, which has been well-applied in the global forest observation. The forest biomass information is estimated by the amount of emitted energy returns back from the surface of leaves (after some energy is captured by chlorophyll), also the size, shape and water content of the left can affect how the signal scattered by the surface [9]. Among all employed bands in SAR, P-band is the longest wavelength available in the earth observation so far, which can penetrate the canopy so that has great capacity to show the structure of forest (Fig. 4). P-band SAR has been used in the European Space Agency (ESA) biomass emission, which includes different data acquisitions: SAR polarimetry uses the intensity of the reflect-back signal to provide information on plant biomass, and Polarimetric SAR interferometry makes at least two observations to access plant height (Fig. 4). Then, the vertical structure of forest can be completed using additional geometric information (Fig. 4) [10, 11].

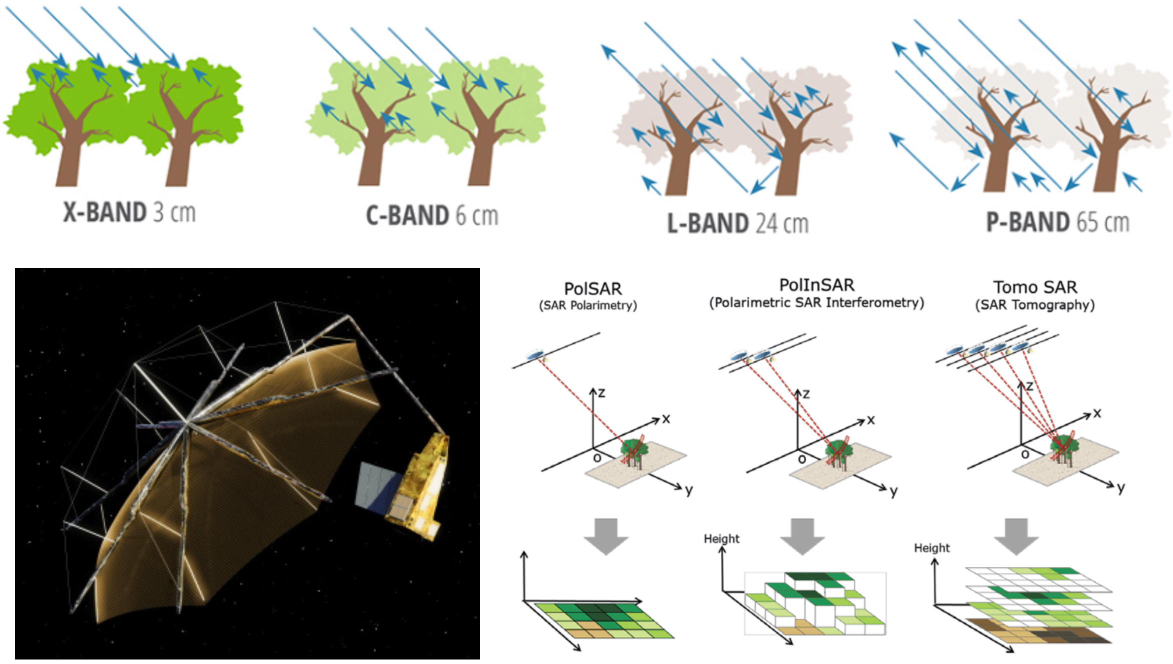

Figure 4. Top: Penetration of SAR measurements into the canopy in different wavelength [9]. Bottom-left: the satellite of ESA biomass emission (will be launched in 2023). Credit: ESA. Bottom-right: Data acquisitions of ESA biomass emission [10].

During Arctic greening, the changes in vegetation composition, e.g., from grass-dominant to shrub-dominant, could result in changes in the structure of vegetation. Indeed, the height of canopy has been observed to increase along with the increase of shrub cover in two northern high-latitude tundra [6, 7] (Fig. 5). P-band SAR has a great potential to detect this change in structure of vegetation, which thus can provide information of changes in above-ground biomass and in the vegetation composition simultaneously.

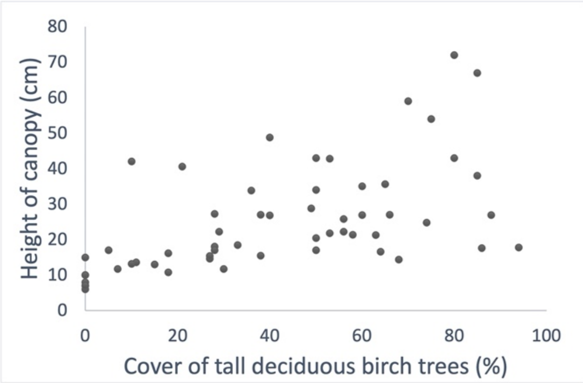

Figure 5. A positive relationship between cover of birch and height of canopy in Abisko, Sweden and in Kobbefjord, Greenland. Data from Parker et al., (2021) [7].

2.2 On earth

The below-ground biomass i.e., soil microbial biomass, can be directly estimated in the laboratory and subsequently assessed on the large scale by using modelling tools. A classical way to estimate soil microbial biomass in the laboratory is by using the substrate-induced respiration technique, which is based on the high correlation between substrate-induced microbial respiratory rate and microbial biomass-C. This technique was used, for instance, when mapping the microbial biomass across the European Union (Fig. 6) [12].

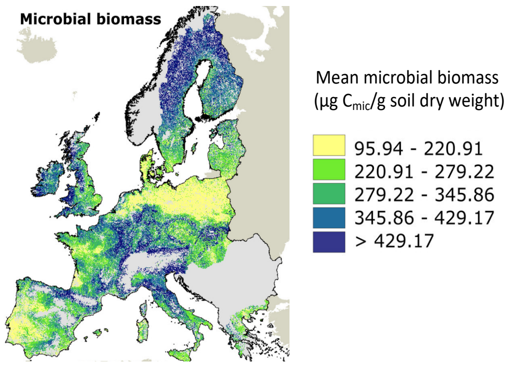

Figure 6. Estimated mean of below-ground biomass (i.e., microbial biomass) across EU [12].

Concerning the binary effects of microbial activities on soil C storage, that an increased below-ground biomass not only reflects the microbial activity, but also reflects the microbial growth, the latter resulting in a potentially persistence C storage, C emission is also an essential proxy in this case. C emission of the ecosystem can be measured by gas analysers, and can be monitored in a large scale via network using standardised gas measurements, e.g., Integrated Carbon Observation System (ICOS) [13].

Currently, there is no on-going network of research focusing on monitoring dynamics of below-ground biomass and C emission in the Arctic [14]. However, this investigation is worth to establish, and should take the consideration that how the collected data can be compatible with the above-ground biomass data collected from satellite observation.

3. Links to the Sustainable Development Goals

3.1 Climate action

The integrated evaluation system proposed in this project could provide valuable information for the possible future climate actions. As mentioned in the introduction, birch trees are both the pioneer and the dominant species in the process of Arctic greening, which has also been linked to the C loss from soil (Fig. 2). Some local residents have already started seeking professional help to cut down birch trees to protect the ecosystem (due to cultural reasons, see Section 3.2) [15]. If it is a realistic solution to Arctic greening? Or any action we can take an initiative to prevent the C loss due to Arctic greening? I would say we are still far behind to take an ecosystem-level action in this issue. However, the integrated evaluation system can be capitalised to evaluate the future large-scale practices for slowing down Arctic greening. For example, the ideal outcome would be that the practice can balance the above-ground biomass and below-ground biomass, without any change in C emission, or with a decline of C emission in the ecosystem.

3.2 Life on land

Arctic greening does not only disturb the soil C storage in the ecosystem, but also challenge its biodiversity. For instance, it has been noticed to cause a decrease on lichen abundance [16]. Changes in vegetation could also affect the habitat and food supplies for animals, especially herbivores. That thickets developed by the birches does hamper the reindeer to walk or dig through, and therefore affects the reindeer herbivory [15].

It is noteworthy that the impact on reindeer community can be directly linked to the life of residents in the north. The Sámi people, the aforementioned local residents who are expecting solution of Arctic greening [15]. The reindeer herding has economic and cultural significance to their livelihood, which now is under threat due to the Arctic greening.

3.3 Partnership for the goals

This project idea will promote multidisciplinary collaboration e.g., across biology, ecology, geology, and policy making. A scientific network is required to improve the understanding of the ecological complexity during Arctic greening and complete the feedback loops to climate change [17]. Governments could integrate the scientific information from the observation to the pilot practices and then to the final climate action [18, 19].

4. the SWOT analysis

4.1 Strength

The P-band SAR is a very efficient way to monitoring both the changes in biomass and in the vegetation composition at the same time. The repeated measurements carried by satellite remote sensing have power to unravel the effect of altered growth season on aboveground biomass. As for the monitoring of below-ground biomass, all current methods are well-tested and widely-used, in other words, there is no technical limitation when establishing a network for measuring below-ground biomass and C emission in a large scale.

4.2 Weakness

In this project, the observations of below-ground biomass and above-ground biomass are conducted in different scales, it is required a solution to convert the data from different observations compatible with the needs of evaluating the C emission. Apart from this, the data collection of belowground biomass can be expensive since it requires extensive fieldworks across less accessible regions and intensive laboratory measurements dealing with thousands of samples.

4.3 Opportunity

This project idea has a great possibility to collaborate with relevant projects existing interactions with Arctic greening. For instance, research related to permafrost has been tightly linked with vegetation and C dynamics in the Arctic. Data collected from this project idea could be compatible with data from the ongoing or upcoming satellite missions focusing on the C emission from permafrost [20]. In addition, this integrated evaluation system can also be applied in other similar situations, like Antarctica greening [21].

4.4 Threat

Unpredictable extreme climate events may have disproportionately large effects on the accuracy of observation. Likewise, extreme weather can also hamper the evaluation *per se*. For instance, a summer heatwave or a sudden warm period in the middle of winter can kill plants and therefore damage the capacity of ecosystem uptake of CO_2, which might rephrase the interpretation of correlation between C emission and plant biomass.

Conclusion

Arctic soils has been called as “a ticking climate time bomb” [22] because it has great potential to add C to the atmosphere when the climate conditions change, and this can further exacerbate climate warming. Arctic Greening has gained attention for several years, but its influence on Arctic soils remains obscure. The implementation of this project is expected to shed some light on this phenomenon and its influences on C stored in Arctic soils. To do so, the P-band SAR satellite will be used to monitor the vegetation changes including productivity and composition, and a network following standardised measurements is suggested herein to make the data of below-ground biomass and ecosystem C emission compatible with the large-scale observation of above-ground biomass. Furthermore, this project can be used as a base for developing climate actions to guard the C storage in the Arctic.

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