Air Impurities Affecting the Melting of Icebergs and the Possibility of Airborne Microplastics Influence on Icebergs

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Abstract. The glaciers and icebergs are important not only for the hydrology but also the ecosystem of earth. The melting of glaciers will release the stored organic carbon and further accelerate the melting rate, thus affecting the global climate. Previous explorations have demonstrated that an important factor in the glacier retreat is human emissions. Carbon particles are major components, which could further be divided in to two categories by existing forms: light-absorbing aerosols (LAAs) and light-absorbing impurities (LAIs). Nowadays, microplastic particles (MP) have been discovered as a new form of pollutants in the environment. By comparing and analyzing the data of radiative forcing (RF) as well as optical characteristics, MPs have a great potential to accelerate the melting of glaciers and an impact on the ecosystem. Therefore, further research on the MPs are necessary to be completed.

Keywords: Microplastic Particles, Glacier, Light-absorbing Aerosols, Radiative Forcing, Black Carbon

1. Introduction

Glaciers and icebergs are an important part of the Earth. To be more specific, glaciers play a significant role on hydrology. Snow melt from glaciers that sinks into the ocean can drive an overturning circulation and change the heat flux of the ocean. Taking the Greenlandic glacier as an example, over 95% of heat were used to melt the submarine iceberg in Sermilik Fjord and increasing the net up-fjord heat flow by around 10% [1]. Meanwhile, the shrinking glaciers would confluence into rivers and influence the surrounding ecosystems. The melting icebergs carrying distinctive thermal states can affect the stability of the river and water temperature. With the original solutes and sediments in the iceberg flowing into rivers, the environment for river organisms such as microorganisms, algae and fish will be drastically altered, thus affecting the localized ecological balance. On the Red List of Algae of Germany, 19 (about 22%) taxa have been identified as being in danger, endangered, rare, or declining [2]. Among these 19 taxa, 6 taxa were located in rivers with glacier cover ≤ 28%, which means the they need to be placed in protected status in the list because they are threatened by the melting of the glaciers [2]. Such a change in the reorganization of the ecosystem would influence biodiversity and related ecosystems, thus threatening the global ecological balance and affecting the human habitat. Therefore, Glaciers play a crucial part in the both of the Earth's climate and the stability of development of human society.

Glaciers have been proven to be the important indicator reflecting the global climate and are mutually reinforcing with climate change. Ice cores extracted from glaciers contain information about historical changes in the Earth's climate. This is very important in the analysis and prediction of the Earth's climate, both in the past and in the future. On the other hand, glaciers store large amounts of organic carbon formed in ancient times [3]. The melting glaciers would increase the density of carbon fluxes circulating in the Earth's climate and further accelerate glacier melting through a positive feedback effect, thus damaging the ecological balance of the earth [3]. Nowadays, glaciers are melting rapidly. By studying the recorded information in the ice core and comparing the locations (whether there are the nearby anthropogenic sources), it shows that elements like the change of Earth’s climate and glaciological factors are not sufficient to support glacier retreat. In other words, there is an automatic link between anthropogenic air pollutants and glacier recession rates.

Anthropogenic emissions that accelerate the rate of glacier melt can be largely divided into two categories: light-absorbing aerosols (LAAs) and light-absorbing impurities (LAIs). Light-absorbing aerosols (LAAs) are formed by tiny particle collected in the air, which has the ability to absorb radiations. Black carbon (BC), dust, and organic carbon are among the resources of LAAs, which substances increase the radiative forcing (RF) of aerosols and have a substantial influence on climate change due to their high absorption capacity [4]. On the other hand, when these light-absorbing impurities (LAIs) adhere to the surface of the cryosphere with precipitation, they can dramatically lower the albedo of ice, thus hastening the melting of snow and ice. [4]. The sources of LAIs are mainly organic carbon (OC) and black carbon (BC). Additional divisions include water-soluble organic carbon (WSOC), water-insoluble organic carbon (WIOC), and BC (WSOC). Therefore, studying and analysing the impact of the airborne particles on the glaciers is meaningful and important.

A large number of plastic wastes have been deposited in landfills and dispersed throughout the environment ever since 1950 [5]. As counted by Revell et al. (2021), the amount has risen to about 500 million tonnes by 2014. Microplastics (MPs) are classified by size, which is known to be in the range between 1-5000 micrometres (μm) [6]. MPs can be further divided into fibres, fragments and films by the shape. In the atmosphere, MPs are usually with a small size and a low density, which allows them to be easily carried by the wind and distributed around the globe [5]. Similar to the aerosols formed by BC and OC, the atmospheric aerosols formed by MPs can absorb and scatter the radiations, thus influencing the local climate [5]. Moreover, MPs are not only prominent in the atmosphere but also identified as a pollutant in both terrestrial and aquatic habitats [5]. The article by Zhang et al. (2022) claims that, artic can be the particular receptor region for MPs due to its sensitivity. Therefore, the emergence of MPs may play a role in glacial melting as BC and OC.

2. Light-absorbing Aerosol Sampling Method

Physical, optical and radiative properties of light-absorbing aerosols are very important when analyzing their impact on glaciers. These effects can be quantified with radiative forcing (RF) by analyzing the collected data on the optical properties of particles [5]. The following sections introduced how the information of the particles be collected.

2.1. Carbon & Dust Particles

Observation and numerical model are the most common and widely used techniques. The basic features like aerosol optical depth (AOD), aerosol concentrations, particle size, index of particle light scattering and chemical features of LAAs can be measured by network observations that are ongoing and time-integrated at typical stations [4]. For LAIs, the field tests primarily focus on the concentration of LAIs, alteration in the albedo, RF of glacier surfaces and so on [4]. Moreover, remote sensing model achieved by satellites and reanalysis data [4]. Numerical models like CAM4, RegCM, WRF-Chem can also measure the spatial distribution of both LAIs and LAAs and thus the impacts on climate [4].

2.2. Microplastic Particles

Two methods of taking samples of airborne microplastics (LAA) are using active pumping samplers and passive atmospheric deposition. For passive atmospheric deposition, microplastics suspended in the air can fall to the ground due to gravity or weather, so the level of microplastics in the collected total atmospheric sediment (wet and dry fallouts) can be used to measure the concentration of microplastics in the atmosphere [6]. This method is suitable for unpowered sampling in remote areas and continuous sampling conditions [6]. For a longer sampling period, recording the data of weather at the sampling site is necessary for later analysis [6]. The active pumped samplers are also widely used in sampling process providing data for the study of airborne aerosols [6]. The particles in the pumped air will be filtered by the filter in the machine to achieve the purpose of sampling. In combination with sample processing methods, such instruments have been developed for the detection of microplastics [6]. This sampling method is characterized by high efficiency and that the pumped air flux can be adjusted according to the purpose of the experiment, but electricity is necessary [7]. On the other hand, using the unique optical characteristics of MPs (due to chemical composition and structure), microplastics in water and ice (LAIs) can be detected by near-infrared (NIR) radiation [8]. The responses of polymers to radiations are recognizable in the wavelengths due to their chemical composition. Combining the identifiable absorption bands of water and ice in the infrared spectrum, the concentration of MPs can be divided. Furthermore, the wavelength region used for this detection method is recommended to be set at 750-1000 nm since the peak wavelength of water and ice would shift with a temperature change but the change is relatively small in this region [8].

3. Glacier Melting Impact Factor Analysis

In this section, the data of radiative forcing of the carbon particles and microplastic particles would be presented and compared to discuss whether the microplastics would have an impact on the melting of glaciers.

3.1. Carbon & Dust Particles

The BC can affect both the regional and the global climate by lowering localized radiation and heating the atmosphere [4]. These impacts can further cause the influences on convection intensity, latent heat fluxes, evaporation, atmospheric stability, vertical temperature profile of climate and alteration of large-scale circulation [4].

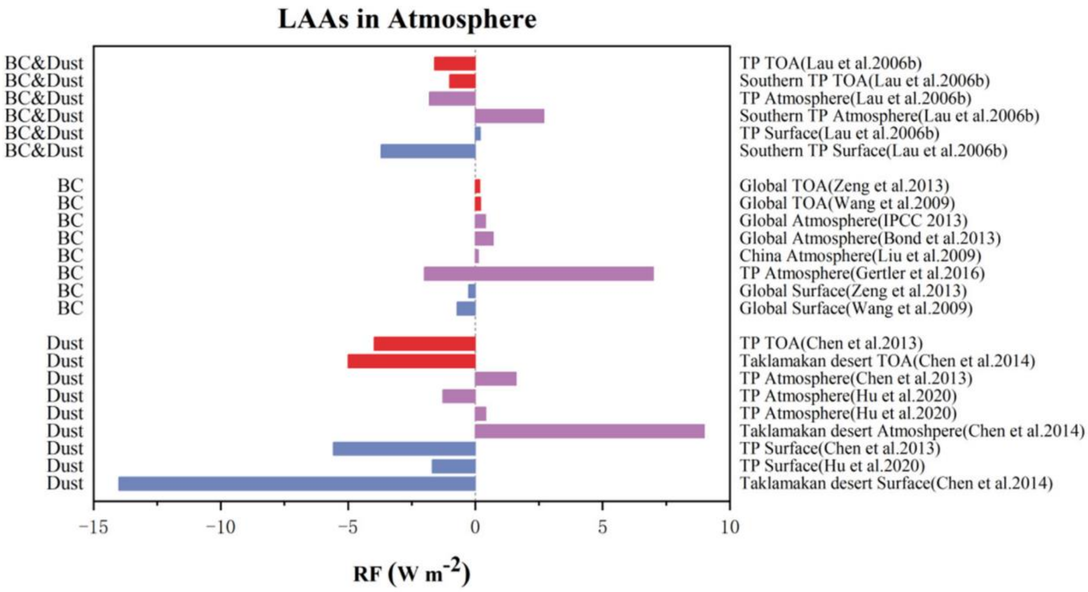

Figure 1. The data of radiative forcing of LAAs in the air over Tibetan Plateau (TP). The colors of bars represent the location of LAAs as correspondence as follows: red for the top of atmosphere, purple for the atmosphere and blue for the earth surface [4].

Figure 1 shows the calculated RF of LAAs over Tibetan Plateau (TP), where is a typical symbol of glacier that sensitive to the global climate change [4]. Based on the calculation by IPCC (2013), the RF of black carbon in the atmosphere is 0.4 Wm-2, which takes a non-negligible part of the total aerosol direct RF. Similarly, the RF of BC at the top of atmosphere is calculated to be 0.18 Wm-2 and -0.26 for in the atmosphere [4]. In the past 40 years until 2009, the average annual RF since of BC in China is 0.13 Wm-2 [4]. However, the values of direct RF reported by Chen et al. (2022) are in the range from -2 Wm-2 to 7 Wm-2. Therefore, the uncertainty is still large in the value of RF induced by BC. The biggest contribution to this undertainty is the complex origin and drastic temporal and geographical fluctuations of the BC [4], even it has been suggested to have a non-negligible impact on the melting of glaciers.

In addition, dust LAAs also has a large impact on the climate [4]. According to Chen et al. (2022), from 2010 to 2015, the values of dust RF over TP are calculated to be -1.27, 0.41 and -1.69 Wm-2 above, in and bottom of the atmosphere respectively. Although these values are relatively smaller compared to BC's, dust LAAs would still cause an impact on the atmosphere. The heating rate of atmosphere caused by dust can be up to 0.11 K/day at 7 km above TP [4]. Moreover, the concentration of both BC and dust LAAs fluctuates with the seasons [4], while the atmospheric dust would have a major impact on the South Asian summer monsoon in July and August [4].

On the other hand, LAIs also play an integral role in the warming effect. Chen et al. (2022) reported that the effects caused by LAIs are higher than that of CO2 and other anthropogenic factors.

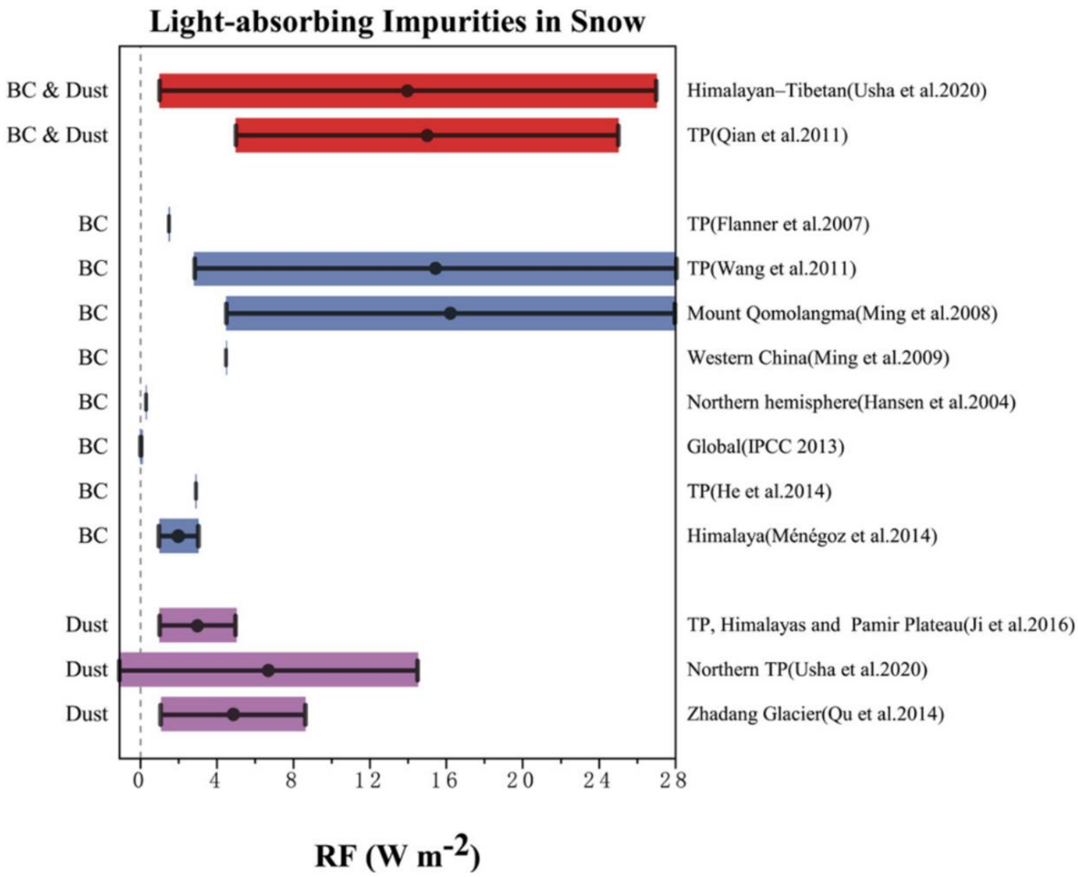

Figure 2. The RF values of LAIs at snow surface plotted. The colors of bars represent the location of LAAs as correspondence as follows: red for the Mixture of BC and Dust, purple for BC and blue for Dust [4].

As can be observed from Figure 2, the RF of LAIs still has a great range of uncertainty, which may be caused by components, uncertainty in microphysical characteristics and regional differences of LAIs [4]. According to Usha et al. (2020), under the influence of the deposition of LAAs, the snow albedo can be reduced by 0.15 ± 0.13 in Himalayan-TP region before the monsoon period. In spring and winter, at the Mera Glacier, BC LAI can decrease the albedo by 6-10 % [4]. In the global context, LAIs may have triggered a decline of in albedo of snow and ice by approximately 0.4% and contributed to the global warming by about 0.06 K/decade [9-11]. The LAIs are significantly influence the albedo of snow and accelerating the melting rate of glaciers [4]. The decease of the albedo of snow and ice would further influence the thermal structure of the glacier regions and cause additional carbon emissions, forming a positive feedback effect and acceleration the global warming [4].

3.2. Microplastic Particles

Microplastics are the plastic particles with the size of 1-5000 μm and have now been recognized distributing in the atmosphere globally. Similar to the BC and dust aerosols, the MP aerosols can also influence the climate by absorbing and reflecting radiations.

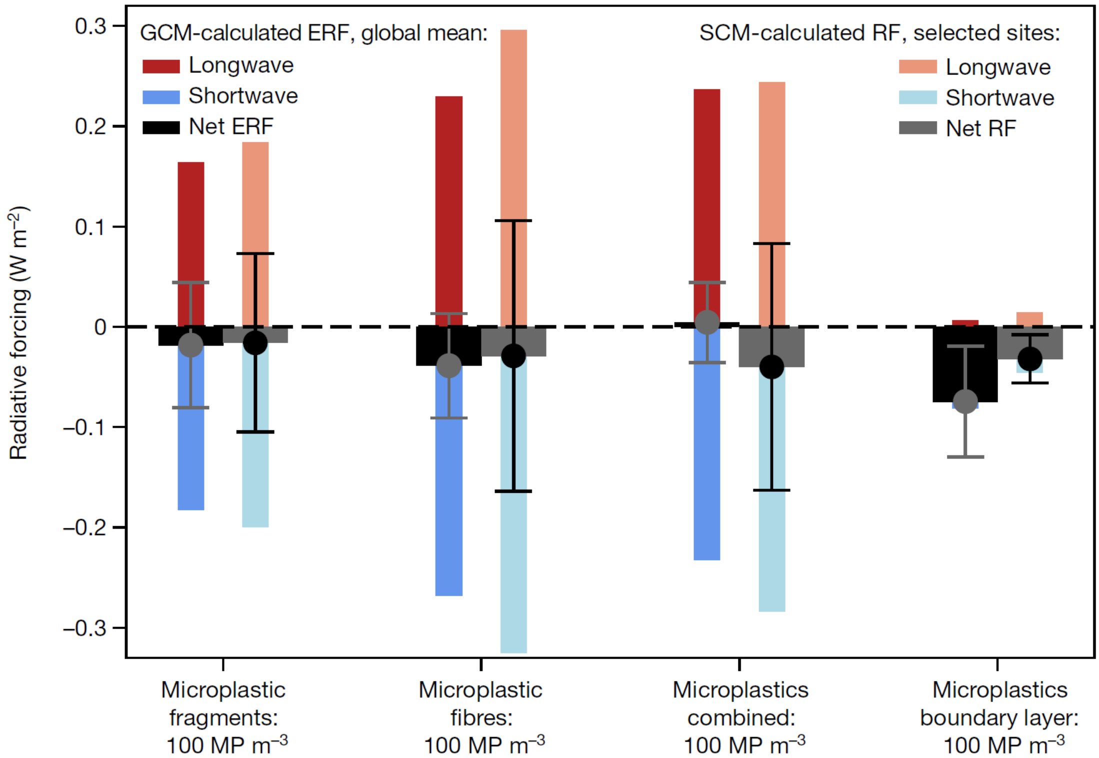

Figure 3. The calculated radiative forcing (RF) and effective radiative forcing (ERF) of different microplastic particles (MP) aerosols (fragments, fibres and fragment & fibre combined aerosols) under a certain density (100 MP/m3). The models used for simulation are General Circulation Model (GCM) and Single-Column Model (SCM) [5].

Figure 3 demonstrates the data of calculated RF and ERF. The two most prevalent forms of microplastics are fragments and fibres, occupying 52.2% and 30.4% of the total MPs in the atmosphere respectively [5]. The combined MP aerosol is assumed to be 50% for both fragments and fibres in the simulations [5]. As the figure above shows, the MPs are able to absorb radiations from longwave. The measured results of ERF are 0.164 ± 0.086 and 0.229 ± 0.110 W/m2 for fragments and fibres respectively in the longwave range [5]. Similar to the BC LAAs, the calculated RF values are consistent in order of magnitude with positive sign. This shows that MP LAAs is potentially heating up the climate, even the both calculated Net RFs are negative in two models. Moreover, based on GCM and SCM, the ERF values are calculated to be 0.004 ± 0.078 W/m2 and −0.040 ± 0.123 W/m2 separately with the assumption of combined MP aerosols [5]. These results show that the global warming potential of MP aerosols may be higher than its regional warming potential.

In addition, another factor, that may influence the impact of MP LAAs on the climate, is the distribution altitude of microplastic aerosols [5]. According to González-Pleiter et al. (2020), the concentration of microplastic aerosols varies between 13.9 MP/m3 above urban regions and 1.5 MP/m3 above rural areas, with the average distribution height of these aerosols being 3.5 km above sea level. In the simulation experiments by Revell et al (2021), the net ERF is computed to be 0.746 ± 0.553 mW/m2 to investigate the impact of height on the ERFs (Simulation conditions for this value are altitude of 2 km and density of 1 MP/m3 for MP aerosols in GCM). This value is smaller than 0.044 ± 0.399 mW/m2, which is calculated under another simulation condition that altitude of 10 km and density of 1 MP/m3 for MP aerosols in GCM [5]. The decline of radiation flux from longwave with distance may be the leading cause for this result. This comparison experiment also reveals the sensitivity of MP aerosols to long waves since, with a drop in height, the longwave radiation flux would reduce.

The MP LAAs have shown that they may have the impact on climate as BC LAAs. The study of MP LAIs seems to be particularly important for glacier melting. Zhang et al, (2022) found a high level of microplastics in sea ice, especially in Arctic Sea ice. Similarly, a range of polystyrene (EPS) between 0.17 and 0.33 items/m2 was discovered on the surface of the Collis glacier at King George Island [7]. In the remote cryosphere areas, the main route of microplastic pollution is atmospheric transport [7]. However, although we already discovered the main modes of transport of microplastics and have obtained some data showing that they have started to accumulate in glaciers [7], there is no paper has demonstrated its actual impact on glacier changes due to the lack of data and the uncertainty of the available data.

4. Discussion

The calculated RF of LAAs in the article by Revell et al. (2021) have shown that the MP aerosols have a great potential to increase the Earth's climate, thus accelerating the melting of glaciers. The optical properties of fragment and fibre MPs also show the similar trend, which has been shown in the Figure 4 below.

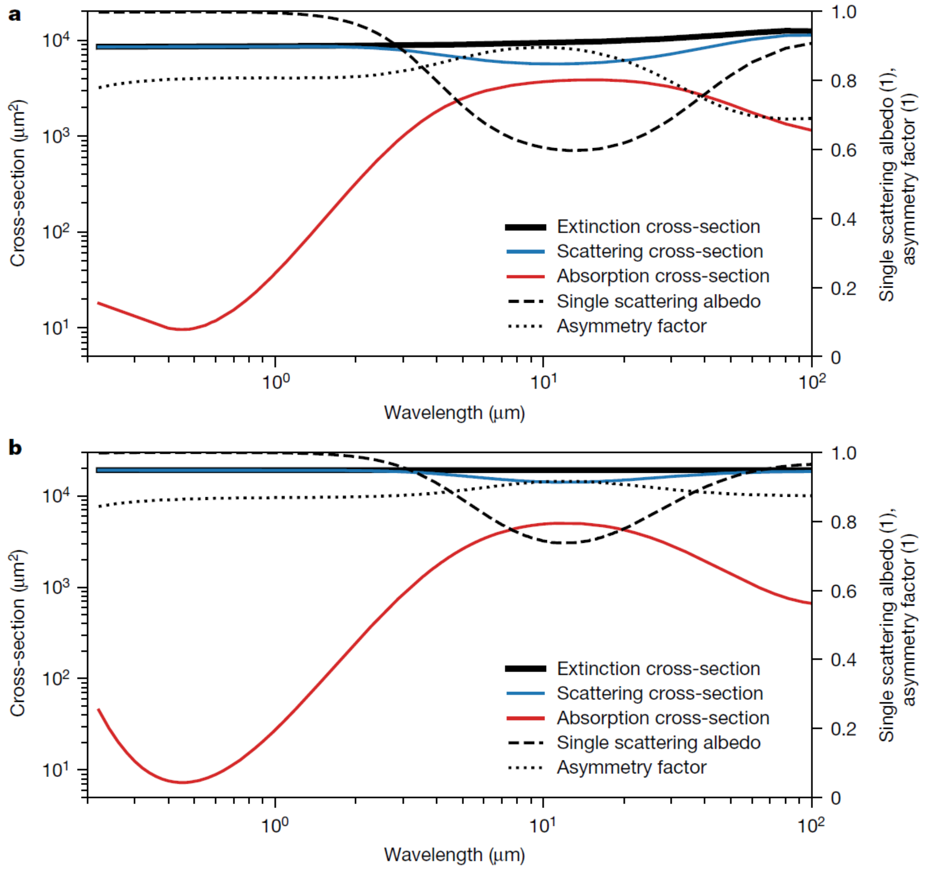

Figure 4. The optical properties of fragments and fibres (a and b) respectively [5].

As can be observed from the figure above, the MP LAAs demonstrate a characteristic particularly similar to BC LAAs, that they both exhibit a strong absorption ability in NIR range. This characteristic can be a significant threat to climate change since the energy of the radiation waves would be absorbed and held in the atmosphere. Furthermore, the photochemical dissolution of MPs in ocean system would influence dissolved organic carbon [13], which may further influence the climate. Also, Lin et al. (2022) presented potential threats to ocean carbon sequestration caused by MPs.

However, the direct impact of MP LAAs on the atmosphere needs to be further investigated. To begin with, the simulation conditions create uncertainty about the veracity of estimated ERFs for MP

LAAs. The data presented in the 3.2 above by Revell et al. (2021) is calculated under a certain simulation in both GCM and SCM. Even simulation conditions for both SCM and GCM are the same (concentration of 100 MP/m3 and evenly distributed at an altitude of 10 km), the computed values based on these two models are still not enough to reflect the real impact caused by MP LAAs. The available data of concentration of the MP LAAs is still little, that the method and equipment of sample collection in remote iceberg areas needs to be developed and updated. In addition, the colours of MP LAAs are also under the simulation that all MPs in aerosols are transparent, which is not in a real situation. The optical characteristics of airborne microplastics will vary depending on colour [5]. To be more specific, the absorption and scattering coefficients of the microplastic aerosols would alter as a result of the application of colour additives and other possible additives, such as optical brighteners, which would modify their contribution to Earth's climate and have an impact on global warming [5]. Therefore, the results show two completely different effects on climate under two models (positive for GCM and negative for SCM) in the article by Revell et al. (2021).

As mentioned above, BC precipitates exhibit a strong absorption for NIR. Similarly, Bond and Bergstrom (2006) found that WSOC (discovered in surface snow and granular ice with amount of $11.62 \pm 12.07\%$ and $8.40 \pm 10.37\%$ relative to that of BC respectively [15]) can reduce the albedo of snow and ice surface, thus increasing the warming of snow and ice, like BC. The MP particles are also been discovered on the Vatnajökull ice cap in Iceland. However, the impact of MP on glaciers remains unproven. Snow sampling from remote glaciers is generally an anthropogenic process (collected with stainless steel spoons by staff in cotton uniforms) [7]. Therefore, more advanced sampling methods should be introduced to microplastic sampling to obtain more accurate and reliable data. Moreover, degradation of microplastics can be significantly influenced by degradation enzymes and selectively affected by microorganisms [14]. However, we still lack research on the degradability of microplastics in glaciated areas. This may allow the accumulation of microplastic on the surface of glaciers and icebergs with seasonal changes. Moreover, further researches on how the impact of microplastics on the carbon cycle in the aquatic environment [14] would be further caused to the climate need to be completed and integrated.

5. Conclusion

That anthropogenic emissions play an integral role in the glacier retreat is an indisputable fact. Anthropogenic carbon particles affect the rate of glacier melting by forming aerosols or settling on snow and ice surfaces, thereby accelerating the radiation absorption capacity of the regional atmosphere and reducing the radiation albedo of snow and ice surfaces. The calculated RFs of aerosols of Dust and BC and the mixture of them demonstrate a relatively large fluctuation, which could be caused by the drastic temporal and geographical fluctuations. Similar to that, the BC LAIs also show a great range of uncertainty due to the microphysical characteristics and regional differences. For the microplastics, even the calculated RFs are based on the simulations, the values of both aerial and ground-bound MP aerosols are in the same magnitude range as BC aerosols. The MP LAIs have also been detected in glacial regions. Overall, the influence exhibited by MP is similar to BC’s, accelerating the melting rate of the glaciers. Combining the optical characteristics, MPs have a great potential to have an impact on glaciers. Therefore, the further studies on both BC and MP are necessary. For BC, the experiments about how the seasonal and regional factors would influence the calculated RFs are necessary for reducing the range of uncertainty. On the other hand, to eliminate testing mistakes, procedures and practises should be standardised for MPs. To fully understand the impact of airborne microplastics, additional characteristics such as colours, cloud duration, and albedo of microplastic aerosols and sediments should be taken into account.

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