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The Cryosphere Discussions

Brief communication:

Atmospheric dry deposition of microplastics and mesoplastics in an Antarctic glacier: The case of the expanded polystyrene.

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Abstract

Plastics have been found in marine water and sediments, sea ice, marine invertebrates, and penguins in Antarctica; however, there is no evidence of their presence in Antarctic glaciers. Our pilot study investigated plastic occurrence on two ice surfaces that constitute part of the ablation zone of Collins Glacier (King George Island, Antarctica). Our results showed concentrations of expanded polystyrene (EPS) in the 0.17-0.33 items m^{-2} range. We registered an atmospheric dry deposition between 0.08 and 0.17 items m^{-2} day^{-1} (February 2019). This is the first report of plastic presence in an Antarctic glacier, which was probably transported by wind.

https://doi.org/10.5194/tc-2020-261
Preprint. Discussion started: 30 October 2020

Introduction

The cryosphere is the frozen water part of the Earth system that consists of areas in which the temperatures are below 0°C for at least part of the year (NOAA, 2019). Most of the cryosphere in terms of volume is in Antarctica. Despite that its rate of ice has increased in the last decades (Rignot et al 2019), it is estimated that the Antarctic cryosphere holds around 90% of Earth's ice mass (Dirscherl et al 2020) covering its cap of ice up to 6% of the planet during the austral winter (Shepherd et al 2018). Furthermore, Antarctic cryosphere represents the majority of the world's freshwater (Shepherd et al 2018) being, probably, the largest freshwater ecosystem in the planet.

Plastics, especially microplastics (plastics items < 5 mm long; MP), have been detected in several compartments of the cryosphere including alpine glaciers (Ambrosini et al., 2019; Materić et al., 2020), snow (Bergmann et al., 2017; Österlund et al., 2019) and sea ice (Obbard et al., 2014; Peeken et al., 2018; Kelly et al., 2020; La Daana et al., 2020; Von Friesen et al., 2020). The occurrence of MP in snow is generally higher (0 to 1.5 x 10^5 MP L^{-1} of melted snow) near urban areas (Bergmann et al., 2017), than in sea ice (up to 12000 MP L^{-1} of melted ice), although there are large differences between studies even from the same region (Peeken et al., 2018; Von Friesen et al., 2020). The use of different units in reporting MPs concentration in alpine glaciers such as number of items per mass of sediment weight (78.3 ± 30.2 MPs Kg^{-1} of sediments; Ambrosini et al., 2019) and mass of MPs per volume (0 to 23.6 ± 3.0 ng of MPs mL^{-1}; Materić et al., 2020), makes comparisons between studies difficult. Regarding the shape of the MP found in the cryosphere, fibers seem to be dominant in alpine glaciers (65 %) and sea ice (79 %) followed by fragments (Ambrosini et al., 2019; La Daana et al., 2020). Concerning the size of MP, La Daana et al. (2020) reported a broad size distribution in sea ice, with 67% of MP in the 500-5000 µm range. Other studies found lower sizes, however, with significant amounts (around 90%) of MPs smaller than 100 µm in snow and sea ice (Bergmann et al., 2017; Peeken et al., 2018; Ambrosini et al., 2019; Kelly et al., 2020). In general, the presence of plastics > 5mm are not reported in compartments of the cryosphere, probably due to the difficulty of large plastic items to reach the remote areas where these are located. MP identification using micro-Fourier transform-infrared spectroscopy (µFTIR) revealed that polyethylene terephthalate (PET), polyamide (PA), polyester (PE), varnish (acrylates/polyurethane), nitrile rubber, ethylene-propylene-diene monomer (EPDM) rubber, polypropylene (PP), varnish, rayon and polyurethane (PU) are the most common types of MPs found (Obbard et al., 2014; Bergmann et al., 2017; Peeken et al., 2018; Ambrosini et al., 2019; Kelly et al., 2020; La Daana et al., 2020; Materić et al., 2020). On the other hand, sources for these MP detected in the cryosphere remain poorly understood. It has been suggested that they could be transported by wind before being deposited by both wet and dry deposition in remote areas such as polar regions (Halsband and Herzke, 2019). In fact, it has been reported that air masses can transport MPs through the atmosphere over distances of at least 100 km, and that they can be released from the marine environment into the atmosphere by sea-spray (Allen et al., 2019; Allen et al., 2020).

https://doi.org/10.5194/tc-2020-261
Preprint. Discussion started: 30 October 2020

So far, studies on plastics have been conducted on three compartments of the cryosphere (alpine glacier, snow and sea ice); however, there is no evidence about their presence in freshwater glaciers in Antarctica. In this sense, our hypothesis is that plastics have reached these glaciers and that the dry deposition is crucial in this process. Therefore, we carried out a pilot study to investigate the presence of plastics on the surfaces of two freshwater glaciers that constitute part of the ablation zone of Collins Glacier in Maxwell Bay in the King George Island (Antarctica) as well as the occurrence dynamics of the MPs in the absence of rainfall.

Materials and Methods

2.1 Study area

Collins Glacier is located on the northeast of Fildes Peninsula (King George Island, Antarctica; Figure 1A) and has a total surface area of 15 km^2 (Simoes et al., 2015). Our study was carried out on the ice surface of the glacier ablation areas around two lakes (Uruguay or Profound, and Ionosferico) in Maxwell Bay (Figure 1B). Uruguay lake (-62.18515, -58.91173) is located in the proximity of the Artigas Antarctic Scientific Base and its access road (~300 m) is subjected to intense human transit (Figure 1B). The lake is used for drinking and domestic water supply. The glacier surface studied in this lake covered 1680 m^2. Ionosferico lake (-62.17987, -58.91070) is located ~600 m from Artigas Base and has minimal human transit. The glacier surface studied in this lake covered 537 m^2 (Figure 1B). It should be noted that there were no visible footpaths through or nearby the glacier surfaces of both lakes during the duration of our study.

2.2 Sampling and identification of plastics

To evaluate the concentration of plastics, twelve squares were marked on the ice around Uruguay lake (Figure 1C) and six squares on Ionosferico lake (Figure 1D) on the 18/2/2020. Squares of 1m^2 were randomly distributed every ten meters covering the entire ice surface on the margin of Uruguay (Figure 1E) and Ionosferico lakes. All items visually resembling plastic (suspected plastic) inside the squares were collected (Figure 1F) and registered.

Right after evaluating the concentration of plastics, on 18/02/2020, we started the study of the dry atmospheric deposition of plastics on ice. For this purpose, we monitored six squares on the ice around each lake. For that, we used the squares where suspected plastics had already been observed (squares 1U and 5U in Uruguay lake, and squares 1I and 5I in Ionosferico lake; see details in Table 1) and we marked other new squares up to a total of six squares in each lake around where, at least, one suspected plastics were observed. All squares were visually monitored every 12 hours for 2 days (18/02/2020 and 20/02/2020). Every item visually resembling plastic detected in the squares at the end of the experiment was collected with stainless steel tweezers, placed into 100 mL ISO reagent bottles, and stored at 4°C until analysis. No rainfall occurred during the duration of the experiment.

All collected items were photographed, measured and their composition was identified by FTIR using an Agilent Cary 630 FTIR spectrometer or by µFTIR using a Perkin-Elmer Spotlight 200 Spectrum Two apparatus equipped with a MCT detector (depending on the size of the item). Their spectra were taken using the following parameters in micro-transmission mode: spot 50 µm, 32 scans and spectral range 550-4000 cm^{-1} with 8 cm^{-1} resolution. The spectra were analysed by Omnic software (Thermo Fisher). Items with matching values > 60% were considered plastic materials. The results of concentration and atmospheric dry deposition of plastics reported in this study are only of those items positively identified as plastics, according to the FTIR analysis, per the total surface of sampled squares.

Results and discussion

In total, 45 items visually resembling plastics were collected, of which 29 items were confirmed as plastic by FTIR or µFTIR analysis. The size of plastics found ranged in length from 2292 to 12628 µm and in width from 3 to 11334 µm (Figure 2A). According to their size, 13 mesoplastic items (plastic items between 5-25 mm long; MeP) and 3 MP items were obtained on the ice around Uruguay lake and 12 MeP items and 1 MP item on the ice around Ionosferico lake (Figure 2B). Meso and microplastics (hereinafter referred to as plastics) of expanded polystyrene (EPS) were found on the ice around both lakes: 8 plastic items on the ice around Uruguay lake and 13 plastic items on the ice around Ionosferico lake (Figure 2 B, C and D). Polyester (n = 7 items; Figure 2B, E and F) and polyetherurethane (n = 1 item; Figure 2B, G and H) items were present only on the ice around Uruguay lake. It should be noted that spectra of the polyester (Figure 2F) showed a high similarity with alkyd resin (polyester modified by the addition of other components), which are widely used in many synthetic paints.

EPS items were ubiquitous on the ice with concentrations ranging from 0.17 EPS items m^{-2} on the ice around Uruguay lake to 0.33 EPS items m^{-2} on the ice around Ionosferico lake. The concentration of polyester, which was found only on the ice around Uruguay lake, was 0.25 Polyester items m^{-2}. Polyetherurethane items were not observed in Ionosferico lake during the evaluation of plastics concentration.

Regarding atmospheric transport experiment, a dry deposition of 0.08 EPS items m^{-2} day^{-1} and 0.17 EPS items m^{-2} day^{-1} was observed on the ice around Uruguay and Ionosferico lakes, respectively (Table 1). Polyester showed a deposition rate of 0.08 polyester items m^{-2} day^{-1} on the ice around Uruguay lake (Table 1), probably due to its proximity to the Artigas Base. Items deposited on the ice in Ionosférico lake during the experiment were exclusively EPS (Table 1).

The presence of plastics have been reported in different places in Antarctica such as marine surface waters (Cincinelli et al. 2017), zooplankton samples of ocean water (Absher et al., 2019), marine sediments (Munari et al., 2017; Reed et al., 2018), marine benthic invertebrates (Sfriso et al., 2020) and penguins (Bessa et al., 2019). However, there was only one study about the presence of plastics in the Antarctic cryosphere that

https://doi.org/10.5194/tc-2020-261
Preprint. Discussion started: 30 October 2020

was carried out in Antarctic sea ice (Kelly et al. 2020). Thus, this is the first report of the presence of plastics in the freshwater cryosphere of Antarctica, namely in Antarctic freshwater glaciers.

The concentration of plastics found on the surfaces of two freshwater glaciers that constitute part of the ablation zone of Collins Glacier in Maxwell Bay are similar to those found in nearby Antarctic marine environments (Cincinelli et al., 2017; Munari et al., 2017; Reed et al., 2018) supporting the notion that freshwaters could play a role in the life cycle of plastics in this region. In our study wind was probably the transportation mode of plastics to the ice from the anthropogenic activities that occur around these lakes, and differences in the concentration of plastics (higher in Uruguay lake) a consequence of its proximity to these anthropogenic activities. Notably, EPS is widely used as insulation material of old buildings in the area, and alkyd resins find use as external coatings. Besides, a growing number of tourists poses an increasing pressure on the area. The transport of plastics by wind would be supported by studies evidencing the transport of soil and propagules of terrestrial and marine invertebrates and grasses, mosses and algae (Nkem et al., 2006).

The Antarctic Treaty System is the agreed mechanism for governance within the Antarctic Treaty area. In fact, Annex III 'Waste Disposal and Waste Management' of the treaty states that all plastic shall be removed from Antarctica, with the only exception being those plastics that can be incinerated without producing harmful emissions (Antarctic Treaty Secretariat, 1998). However, once plastics are broken down into small fractions and dispersed throughout the continent and nearby waters, management measures become very difficult to address. A more rigorous management of macro-plastics is essential for preserving the integrity of sensitive polar environments.

Conclusion

This is the first report of the presence of both MeP and MP in an Antarctic glacier, which was probably transported by wind. In total, three types of plastics were found on two glacier surfaces that constitute part of the ablation zone of Collins Glacier (King George Island, Antarctica) being EPS ubiquitous on the ice. Our study shows that the management of plastic contamination in Antarctica should focus strongly on the waste generated by anthropogenic activities that occur in this place.

Author contribution

Miguel González-Pleiter: identified the research question, formulated the hypothesis, developed the experimental design, planned the experiments, performed the experiments in the field, performed the experiments in the laboratory, compiled the data sets, analyzed the data, discussed the results, prepared graphical material, wrote the paper (original draft) and provided financial support. **Gissell Lacerot**: identified the research question, formulated the hypothesis, developed the experimental design, planned the experiments, checked the field data, discussed the results, wrote the paper (final version). **Carlos Edo**: performed the experiments in the laboratory, compiled the

https://doi.org/10.5194/tc-2020-261
Preprint. Discussion started: 30 October 2020

data sets, analyzed the data, discussed the results, prepared graphical material and review final manuscript. **Juan Pablo Lozoya**: developed the experimental design, checked the field data, discussed the results, review final manuscript and provided financial support. **Francisco Leganés:** discussed the results, review final manuscript and provided financial support. **Francisca Fernández-Piñas**: checked the field data, checked the laboratory data, discussed the results, review final manuscript and provided financial support. **Roberto Rosal**: checked the field data, checked the laboratory data, discussed the results, review final manuscript and provided financial support. **Franco Teixeira de Mello**: identified the research question, formulated the hypothesis, developed the experimental design, planned the experiments, performed the experiments in the field, checked the field data, prepared graphical material and provided financial support.

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Declaration of competing interest
The authors declare no conflict of interest.

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Preprint. Discussion started: 30 October 2020

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https://doi.org/10.5194/tc-2020-261
Preprint. Discussion started: 30 October 2020

The Cryosphere Discussions
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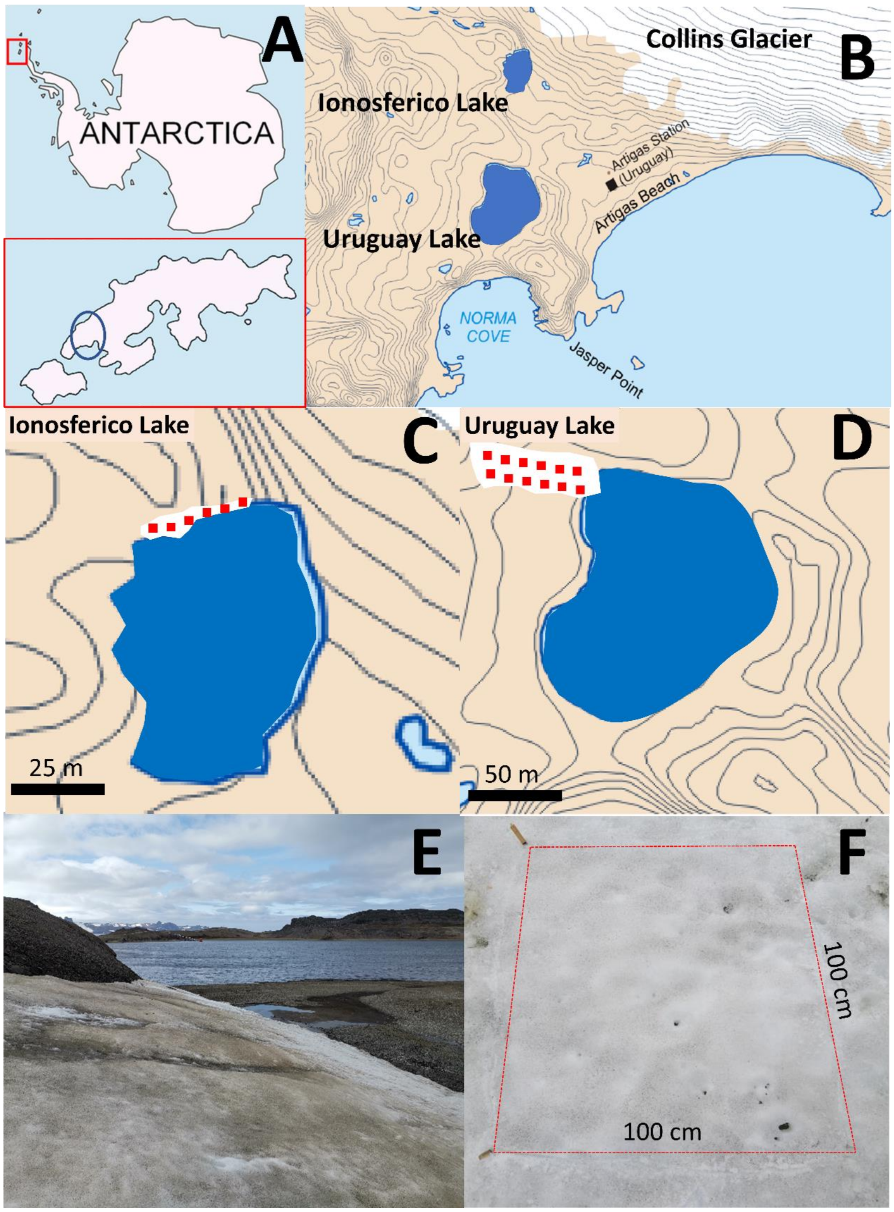

Figure 1. (A) General view of Antarctica and location of King George Island. The blue circle indicates the Fildes Peninsula. Collins Glacier is located on the northeast of Fildes Peninsula. (B) A detailed view of Ionosferico lake, Uruguay lake, Artigas Research Station and Collins Glaciers in the Fildes Peninsula. (C) and (D) ablation zone of Collins Glacier around Ionosferico lake and Uruguay lake, respectively. (E) Photograph of the glacier surface around Uruguay lake that constitute part of the ablation zone of Collins Glacier taken on 18/02/2020. (F) A representative square on the glacier surface used in this study.

https://doi.org/10.5194/tc-2020-261
Preprint. Discussion started: 30 October 2020

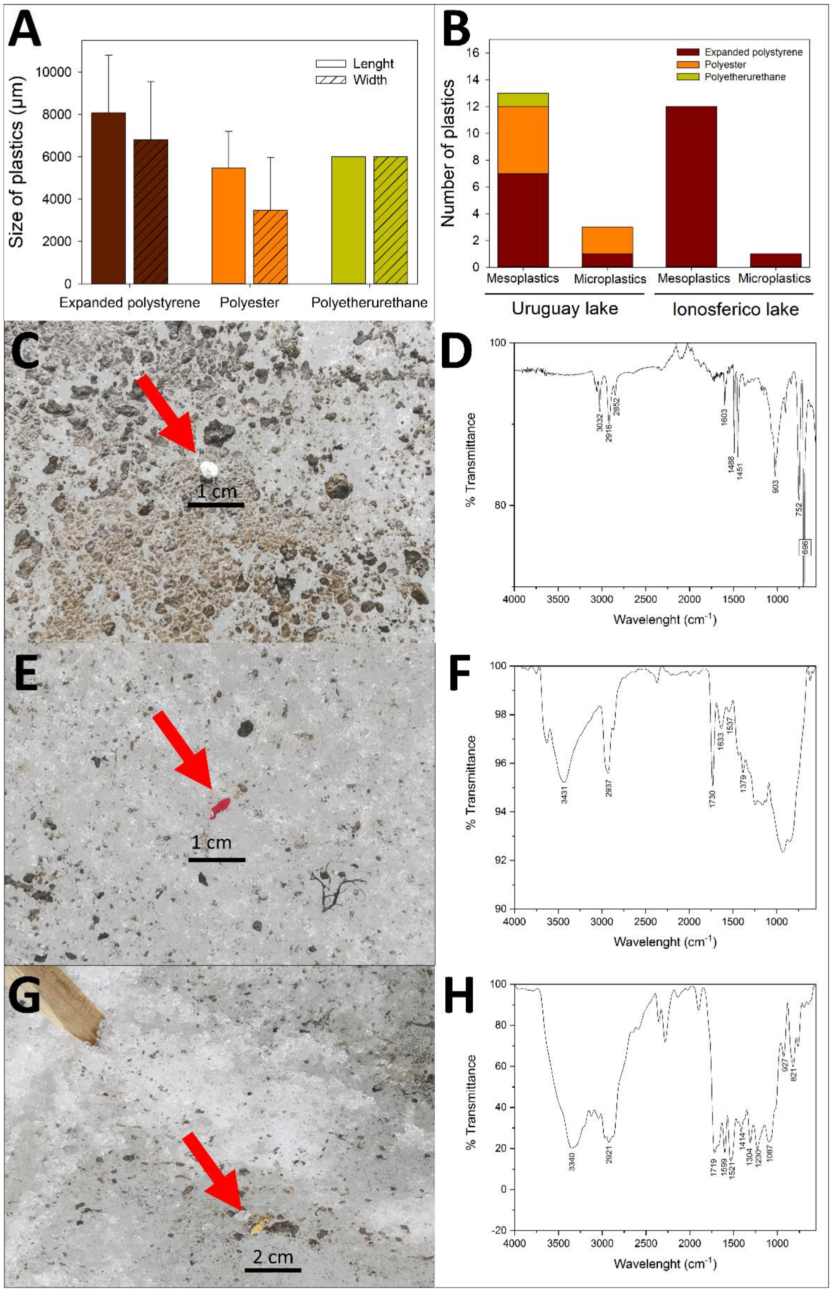

Figure 2. (A) Size of the plastics collected on the glacier surface. (B) Total number of the mesoplastics and microplastics found on the glacier surface around Uruguay lake and Ionosferico. Representative photographs of expanded polystyrene (B), polyester (D) and polyetherurethane (F) found on the glacier surface. The red arrows indicate the plastics. FTIR representative spectra of expanded polystyrene (C), polyester (E) and polyetherurethane (G) found on the glacier surface.

https://doi.org/10.5194/tc-2020-261
Preprint. Discussion started: 30 October 2020

Table 1. Concentration of plastics found in each square on 18/02/2020 and dry atmospheric deposition of plastics monitored every 12 hours for 2 days (18/2/2020 and 20/2/2020). The asterisks indicate squares where suspected plastics had already been observed when we evaluated their concentration.

Concentration of plastics

Uruguay lake														
Squares	1U	2U	3U	4U	5U	6U	7U	8U	9U	10U	11U	12U	Plastics m^{-2}	Total plastics confirmed by FTIR
EPS	1	0	0	0	1	0	0	0	0	0	0	0	0.17	2
Polyester	1	1	0	0	0	0	0	0	0	0	0	1	0.25	3
Polyetherurethane	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ionosferico lake														
Squares	1I	2 I	3 I	4 I	5 I	6 I							Plastics m^{-2}	Total plastics confirmed by FTIR
EPS	1	0	0	0	1	0							0.33	2
Polyester	0	0	0	0	0	0							0	0
Polyetherurethane	0	0	0	0	0	0							0	0

Atmospheric dry deposition experiment

Uruguay lake																																
Squares	1U					2U*					3U*					4U*					5U					6U*					Total plastics confirmed by FTIR	Plastics m^{-2} day^{-1}
Time (h)	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48		
EPS	1										1					1		-1			1					4		1			8	0.08
Polyester	1	-1		+1												4															5	0.08
Polyetherurethane						1																									1	0
Ionosferico lake																																
Squares	1 I					2 I *w					3 I *					4 I *					5 I *					6 I *					Total plastics confirmed by FTIR	Plastics m^{-2} day^{-1}
Time (h)	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48		
EPS	1					3		1			2		1			3					1					1					13	0.17
Polyester																															0	0
Polyetherurethane																															0	0