A pilot study about microplastics and mesoplastics in an Antarctic glacier: the role of atmospheric dry deposition

~~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 several compartments in Antarctica. However, there is currently no evidence of their presence in Antarctic glaciers. Our pilot study investigated plastic occurrence on two ice surfaces (one area close to Uruguay lake and another one close to Ionosferico lake) that constitute part of the ablation zone of Collins Glacier (King George Island, Antarctica). Our results showed that expanded polystyrene (EPS) was ubiquitous ranging from 0.17 to 0.33 items m^{-2} whereas polyester was found only on the ice surface close to Uruguay lake (0.25 items m^{-2}). Furthermore, we evaluated the daily

changes in the presence of plastics in these areas in the absence of rainfall to clarify the role of the wind in their transport. We registered an atmospheric dry deposition rate between 0.08 items m^{-2} day^{-1} on the ice surface close to Uruguay lake and 0.17 items m^{-2} day^{-1} on the ice surface close to Ionosferico lake. Our pilot study is the first report of plastic pollution presence in an Antarctic glacier, possibly originated from local current and past activities, and the first to assess the effect of wind in its transport.

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.

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 of ice is in Antarctica. Despite the increasing rate of ice loss during last decades (Rignot et al., 2019), it has been estimated that the Antarctic cryosphere holds around 90% of Earth's ice mass (Dirscherl et al., 2020). Furthermore, the Antarctic cryosphere represents the majority of the world's freshwater, representing the largest freshwater ecosystem on the planet (Shepherd et al., 2018).

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 (plastic items < 5 mm long; MPs), have been detected in several specific locations of the cryosphere including mountain glaciers (Ambrosini et al., 2019; Cabrera et al., 2020; Materić et al., 2020), snow (Bergmann et al., 2019; Österlund et al., 2019) and sea ice (Geilfus et al., 2019; Kelly et al., 2020; La Daana et al., 2020; Obbard et al., 2014; Peeken et al., 2018; von Friesen et al., 2020). The occurrence of MPs in snow ranged from 0 to 1.5 x 10^5 MP L^{-1} of melted snow (Bergmann et al., 2019), although it should be noted that a part of this study was conducted near urban areas. Regarding sea ice, concentrations of up to 1.2 x 10^4 MP L^{-1} have been reported, 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 MP concentrations in mountain glaciers such as the number of items per mass of ice weight (78.3 ± 30.2 MPs kg^{-1} of sparse and fine supraglacial debris; 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 (101.2 items L^{-1}; Cabrera et al., 2020). Regarding the shape of the MPs found in the cryosphere, fibers seem to be dominant in mountain glaciers (65 %) and sea ice (79 %), followed by fragments (Ambrosini et al., 2019; La Daana et al., 2020). Concerning the size of MPs, it has been reported a broad size distribution in sea ice, with 67 % of MPs in the 500-5000 µm range (La Daana et al., 2020). Other studies found lower sizes, however, with significant amounts (up to 90 %) of MPs smaller than 100 µm in snow and sea ice (Ambrosini et al., 2019; Bergmann et al., 2019; Bergmann et al., 2017; Kelly et al., 2020; Peeken et al., 2018). The differences between these studies may be due to the different analytical methods used, particularly methodologies such as micro Fourier transform infrared spectroscopy (µFTIR, which can identify smaller sized MPs). In general, the presence of plastics > 5mm has not been reported in the cryosphere, probably because they occur at lower concentrations and evade detection. µFTIR revealed that polyethylene terephthalate (PET), polyamide (PA), polyester (PE), varnish (acrylates/polyurethane), several synthetic rubbers, polypropylene (PP), and polyurethane (PU) are the most common types of MPs in the cryosphere (Ambrosini et al., 2019; Bergmann et al., 2019; Bergmann et al., 2017; La Daana et al., 2020; Materić et al., 2020; Obbard et al., 2014; Peeken et al., 2018). The sources of MPs detected in the cryosphere, however, remain poorly understood. It has been suggested that they could be transported by the 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., 2020; Allen et al., 2019; González-Pleiter et al., 2020a).

~~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).

So far, plastics have been found in specific parts of the cryosphere (mountain glacier, snow, and sea ice) and Antarctica (seawater, freshwater, sediments, and organisms). We hypothesize that plastics have also reached freshwater glaciers in Antarctica and that atmospheric dry deposition plays a crucial role in this process. To test this hypothesis, we carried out a pilot study to investigate the presence of plastics on two ice surfaces (one area close to Uruguay lake and another one close to Ionosferico lake) that constitute part of the ablation zone of Collins Glacier in Maxwell Bay in King George Island (Antarctica). Furthermore, the daily changes in the presence of plastics in these ice surfaces was evaluated in the absence of rainfall, to clarify the role of wind in their transport.

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 close to two lakes (Uruguay or Profound, and Ionosferico) in Maxwell Bay (Figure 1B). Uruguay lake (S 62° 11' 6.54'', O 58° 54' 42.23'') is located in the proximity of the Artigas Antarctic Scientific Base and its access road (~300 m) is subjected to 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° 11' 59.41'', O 58° 57' 44.17'') is located ~600 m from Artigas Base and has minimal human activity. 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 (except our own footprints).

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2.2 Experimental assessment of plastic concentration

To evaluate the concentration of plastics, twelve squares were marked on the ice surface close to Uruguay lake (Figure 1C) and six squares on the ice surface close to Ionosferico lake (Figure 1D), which constitute part of the ablation zone of Collins Glacier, on 18/2/2020. The first square of 1m^2 on the ice surface close to each lake was randomly marked. After that, the rest of the squares of 1m^2 were distributed every ten meters covering the entire ice surface in each lake (Figure 1E). All items visually resembling plastic (suspected plastic) inside the squares were registered (Figure 1F). It should be noted that our sampling strategy excluded the plastics non-detectable by the naked eye (i.e. small plastics such as fibers). Thus, we probably underestimated the concentration of small plastics on the ice surface.

~~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.~~

2.3 Experimental assessment of atmospheric dry deposition of plastics

After the initial sampling, we selected six squares on the ice close to each lake for subsequent daily monitoring. Additional sampling was performed every twelve hours for two days (18/02/2020 and 20/02/2020) after the initial sampling. No rainfall occurred during the duration of the experiment.

2.4 Characterization and identification of plastics

Every item visually resembling plastic detected in the squares was collected with stainless-steel tweezers, placed into 100 mL ISO reagent bottles, and stored at 4 °C until analysis. All collected items were photographed, measured and their composition was identified by ATR-FTIR using an Agilent Cary 630 FTIR spectrometer or by µFTIR on a Perkin-Elmer Spotlight 200 Spectrum Two apparatus equipped with a MCT detector (depending on the size of the item). The 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 processed using 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 include only items positively identified as plastics according to the FTIR analysis and were expressed as number of items per surface unit and items per surface unit and day respectively.

2.5 Prevention of procedural contamination

To avoid sample contamination, all materials used were previously cleaned with MilliQ water, wrapped in aluminum foil, and heated to 300 °C for 4 h to remove organic matter. The use of any plastic material during sampling was avoided. Furthermore, possible contamination from our clothes was controlled throughout the sampling, by checking fibers and fragments extracted from the clothes against the MPs and MePs found in the samples, and by positioning us against the wind during sampling. Given their size, plastics found in this study were detected by the naked eye and their traceability could be easily maintained during quantification and identification of the samples.

~~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

3.1 Characterization and identification of the plastics

In total, 45 items preliminarily identified as plastics were collected, of which 29 items were confirmed as plastic by FTIR or µFTIR analyses (matching > 60%). The size of plastics ranged from 2292 to 12628 µm length and from 501 to 11334 µm width (Figure 2A). According to their size, 13 mesoplastic items (plastic items between 5-25 mm long; MeP) and 3 MP items were found on the ice close to Uruguay lake, and 12 MeP items and 1 MP item on the ice close to Ionosferico lake (Figure 2B). Meso and MPs (hereinafter referred to as plastics) of expanded polystyrene (EPS) were found on the ice close to both lakes: 8 plastic items on the ice close to Uruguay lake and 13 plastic items on the ice close to Ionosferico lake (Figure 2 B, C, and D). Polyester (n = 7 items; Figure 2B, E, and F) and polyurethane (n = 1 item; Figure 2B, G and H) items were present only on the ice close to Uruguay lake. It should be noted that spectra of the polyester (Figure 2F) showed a high similarity with alkyd resin, a thermoplastic polyester widely used in synthetic paints.

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.

3.2 Plastic concentration

EPS items were ubiquitous on the ice with concentrations ranging from 0.17 items m^{-2} on the ice close to Uruguay lake to 0.33 items m^{-2} on the ice close to Ionosferico lake (Table S1). The concentration of polyester, which was found only on the ice close to Uruguay lake, was 0.25 items m^{-2} (Table S1). Polyurethane items were not observed in Ionosferico lake (Table S1).

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.

3.3 Atmospheric dry deposition of plastics

The dry deposition rate of EPS was 0.08 EPS items m^{-2} day^{-1} and 0.17 EPS items m^{-2} day^{-1} on the ice close to Uruguay and Ionosferico lakes, respectively (Table S2 and Figure 3). Polyester was only deposited on the ice close to Uruguay lake at a rate of 0.08 items m^{-2} day^{-1}. Polyurethane items were not observed in Ionosferico lake during the duration of the experiment (Table S2). The plastics deposited on the ice of Ionosferico lake during the experiment were exclusively EPS (Table S2 and Figure 3).

~~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).~~

Discussion

The presence of plastics has been documented in different places in Antarctica: marine surface waters (Cincinelli et al., 2017; Isobe et al., 2017; Jones-Williams et al., 2020; Lacerda et al., 2019; Suaria et al., 2020), marine sediments (Cunningham et al., 2020; Munari et al., 2017; Reed et al., 2018), zooplankton samples from ocean water (Absher et al., 2019), marine benthic invertebrates (Sfriso et al., 2020), Antarctic Collembola (Bergami et al., 2020b), penguins (Bessa et al., 2019), seabirds (Ibañez et al., 2020) and freshwater (González-Pleiter et al., 2020b). However, there was only one study showing the occurrence of plastics in the Antarctic cryosphere, which was carried out on sea ice (Kelly et al., 2020). Thus, this is the first report on the presence of MPs and MePs in Antarctic freshwater glaciers. Furthermore, our findings provide an insight into the role of wind in the transport of this material.

~~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 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.~~

In this sense, winds (especially high-speed ones) appear to be a key element in the transport of plastics to Antarctic glaciers. The prevailing winds in the study area (Figure 1B) blow predominantly from the west (Figure 4A). However, strong winds (Figure 4B), wind gusts (Figure 4C), and strong wind gusts (Figure 4D) blow mainly from the east and southeast directions, and could be responsible for the spreading of plastics from the different origins to the surface of the glacier ablation areas. These strong winds would explain the presence of MePs despite their size (Figure 2A). In fact, the low density of the MePs found (mainly EPS; Figure 2B) would have allowed their easy dispersion by wind.

Our results on the dry deposition of plastics support the hypothesis that the role of the wind is essential for the transport of MPs and MePs in (and among) different areas of Antarctica. The dry deposition of plastics (Table S2) was closely related to the wind regimes during the study period (Figure S1). Based on information available on the meteorological conditions during the study dates (18/02/2020 - 20/02/2020) in La Villa de la Estrellas (Figure S1A), which is located near the Artigas Beach (Figure S2B), the wind blew from the northeast veering to the south with a speed between 10 and 30 km/h (Figure S1A). These wind conditions suggest a possible link with marine environment, which can act as a source of plastics (Allen et al., 2020), and potentially explain the presence of plastics on the glacier ablation areas. However, considering the low intensity of the winds recorded during those days (Figure S1A) and the presence of MePs, it is also possible that the predominant high-speed winds transported MePs from other adjacent areas of the Fildes Peninsula to the vicinity of the lakes, in the days prior to our study (Figure 4B, C, and D) and then, the milder winds registered during the sampling days (Figure S1A) deposited these MePs on the ice.

The chemical composition of the plastics found (Figure 2D, F, and H) supports the fact that the source of the plastics could be of marine and/or land-based origin. The types of plastics found (Figure 2B) are related to human activities in the Fildes Peninsula that could generate plastic debris such as tourism, leaks in waste management at scientific bases or the presence of abandoned infrastructures. Considering the location of Collins Glacier and the main human activities on the Fildes Peninsula (e.g. airfield, scientific bases), the prevailing winds from the west could have transported small and lightweight plastics to the study area. In fact, EPS is widely used in packaging and as insulation material in old buildings in this area and polyester is also a component of old buildings paints. In the same way, some of these plastics could be released from the marine environment to Artigas beach area and, then, be transported by the wind to the glaciers. In this sense, polyurethane MePs (which are similar to those found in this work) have already been reported in sea surface waters in the Antarctic (Jones-Williams et al., 2020) and EPS MePs have been found on Artigas beach (Laganà et al., 2019). These findings highlight a potential threat to the fragile Antarctic ecosystem, since the presence of these plastics (e.g. polystyrene particles) has been shown to affect Antarctic biota (Bergami et al., 2019; Bergami et al., 2020a).

The role of the atmospheric dry deposition on the presence of plastics on glaciers is supported by recent studies suggesting that MPs can be transported, up to hundreds of kilometres, through the atmosphere before being deposited (González-Pleiter et al., 2020a). Our results showed that the atmospheric deposition of plastics on glaciers is still low, with figures between two and four orders of magnitude lower than values reported in populated areas (Brahney et al., 2020; Cai et al., 2017; Dris et al., 2016; Klein and Fischer, 2019; Roblin et al., 2020; Wright et al., 2020). Our results also show that plastic pollution, even if only in small quantities, reaches remote areas with few human settlements. The occurrence of plastic pollution in Antarctica represents the spreading of anthropogenic pollutants in the last pristine environment on the Earth. Further research is needed then to elucidate the occurrence, sources, fate, and impact of plastics in such remote places.

Taken together, our research indicates that human activities in sensitive remote areas such as Antarctica leave a footprint that includes plastic pollution. Since the early reports of litter pollution on the seafloor (Dayton and Robilliard, 1971) and ,subsequently, on beaches and seabirds of Antarctica (Convey et al., 2002; Creet et al., 1994; Fijn et al., 2012; Lenihan et al., 1990; Sander et al., 2009) the handling of waste has been improved by the implementation of the Antarctic Treaty System, Annex III 'Waste Disposal and Waste Management'. The Treaty forces to remove all plastic from Antarctica, with the only exception of plastics that can be incinerated without producing harmful emissions (Antarctic Treaty Secretariat, 1998). However, once plastics are broken down into smaller fractions and dispersed throughout the continent and nearby waters, management measures become very difficult to address, as evidenced by our data. Thus, a more rigorous management of plastics is essential for preserving a clean environment within the Treaty Area (Zhang et al., 2020).
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 MePs and MPs in an Antarctic glacier, which were probably transported by wind from local sources such as beach areas. In total, three types of plastics (EPS, PU and polyester) were found on two glacier surfaces that constitute part of the ablation zone of Collins Glacier (King George Island, Antarctica). EPS was ubiquitous in the two glacier surfaces studied. Our study showed that the management of plastic contamination in Antarctica should be improved, focusing on the waste generated by current and past anthropogenic activities that occur in that area.

~~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 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, discussed the results, review final manuscript and provided financial support.~~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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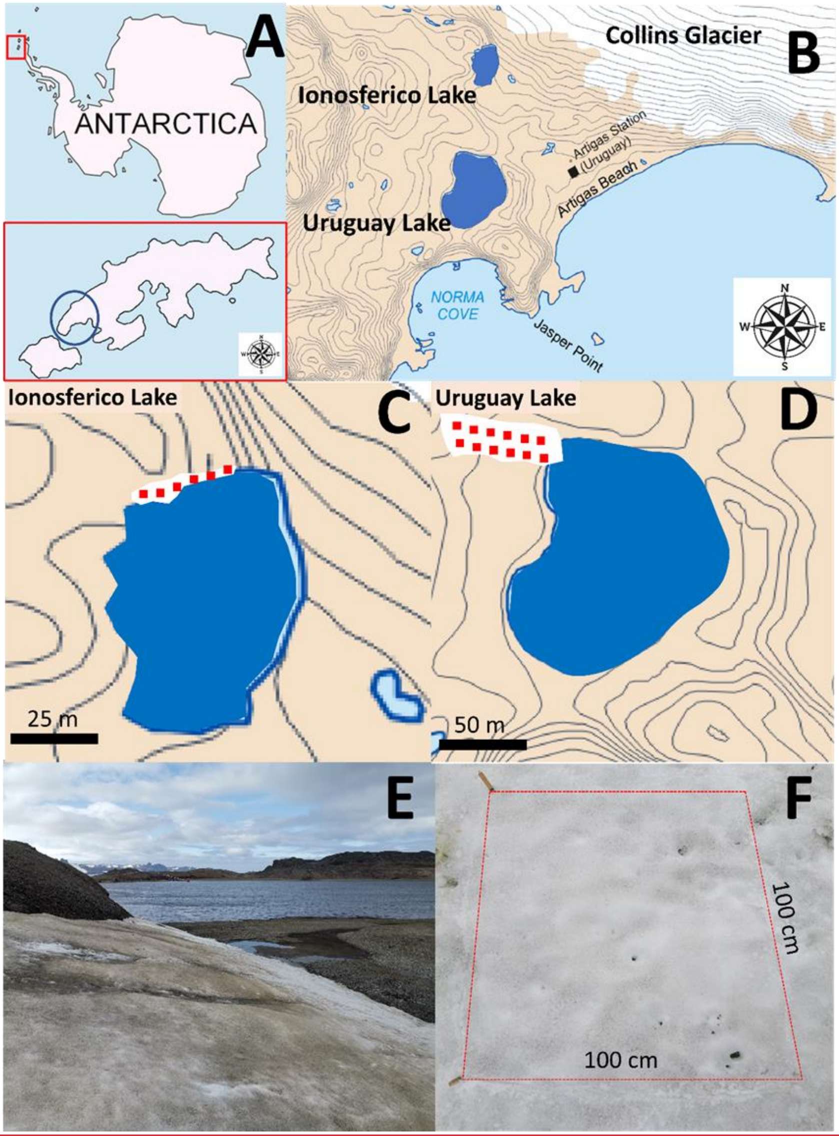
732 
A
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B
Collins Glacier
Ionosferico Lake
Artigas Station (Uruguay)
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Uruguay Lake
NORMA COVE
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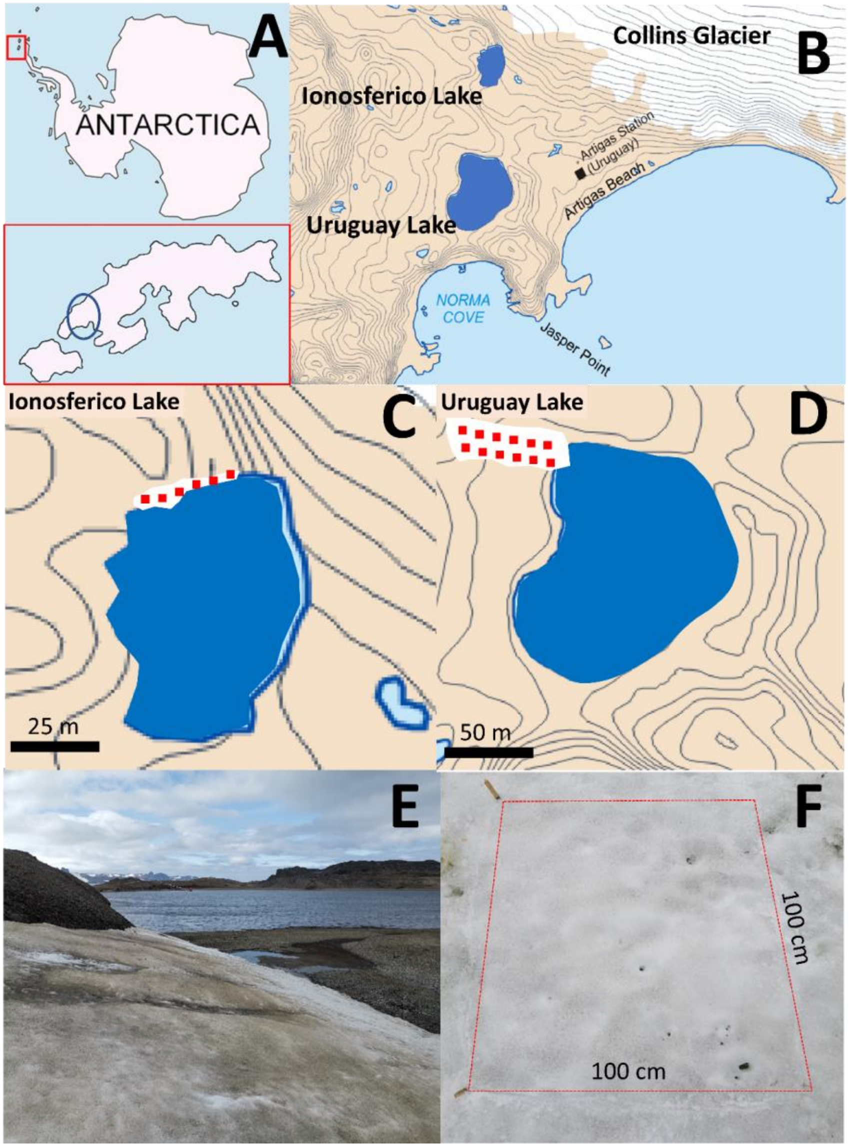

Figure 1. (A) General view of Antarctica and location of King George Island. The blue circle indicates the Fildes Peninsula. Collins Glacier is located on the northeast of Fildes Peninsula. (B) A detailed view of Ionosferico lake, Uruguay lake, Artigas Research Station and Collins Glaciers in the Fildes Peninsula. (C) and (D) ablation zone of Collins Glacier close to Ionosferico lake and Uruguay lake, respectively. (E) Photograph of the glacier surface close to 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.~~(A) General view of Antarctica and location of King George Island. The blue circle~~

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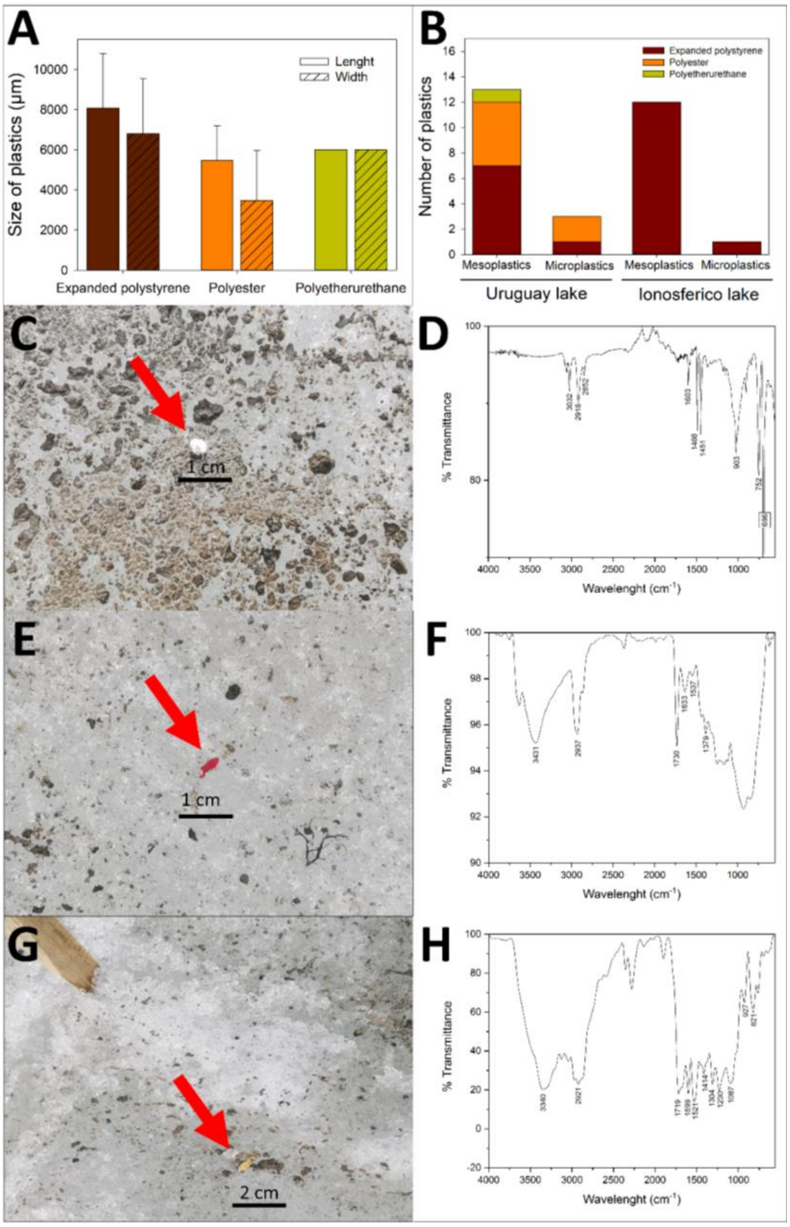

Figure 2. (A) Size of the plastics collected on the glacier surface. (B) Total number of the mesoplastics and microplastics found on the glacier surface close to Uruguay lake and Ionosferico. Representative photographs of expanded polystyrene (C), polyester (E) and polyurethane (G) found on the glacier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

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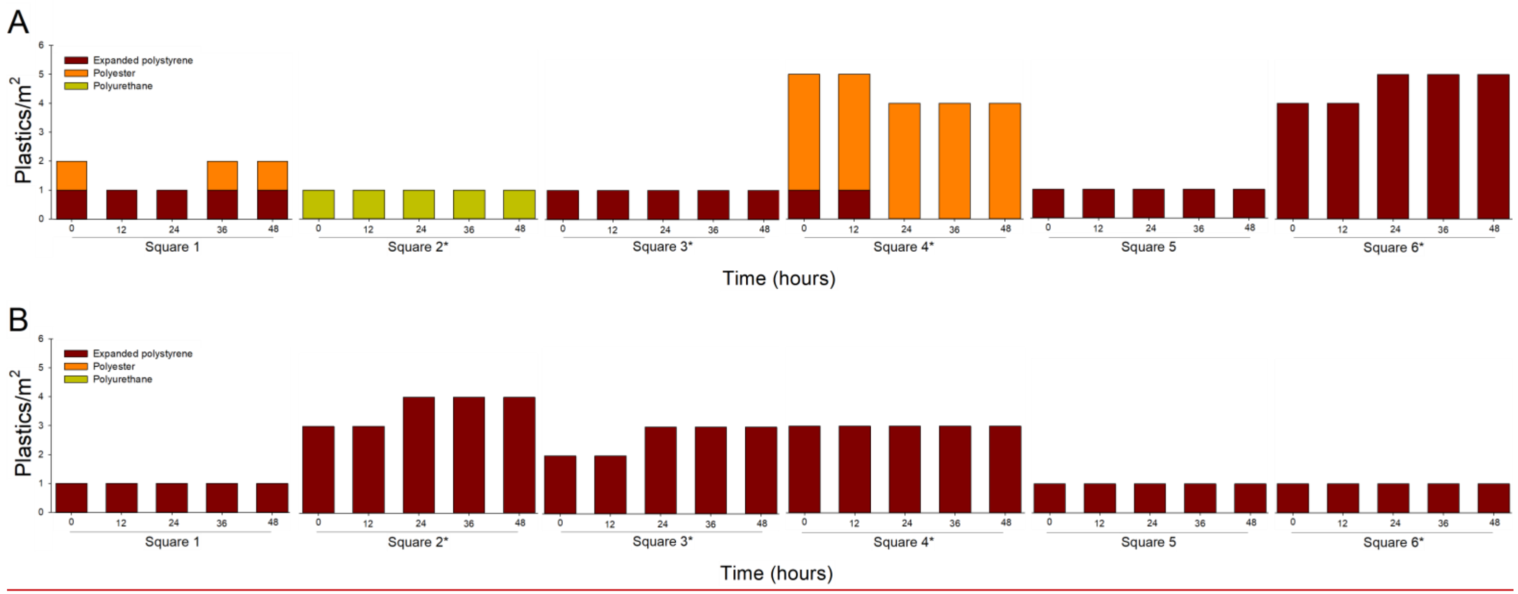

Figure 3. Changes in the presence of plastics into the squares marked on ice surface close to Uruguay lake (A) and close to Ionosferico lake (B) that constitute part of the ablation zone of Collins Glacier in Maxwell Bay in King George Island (Antarctica). Plastics were monitored every 12 hours for two days (18/2/2020 and 20/2/2020) in the absence of rainfall. Asterisks indicate squares different from those used to the assessment of plastic concentration.

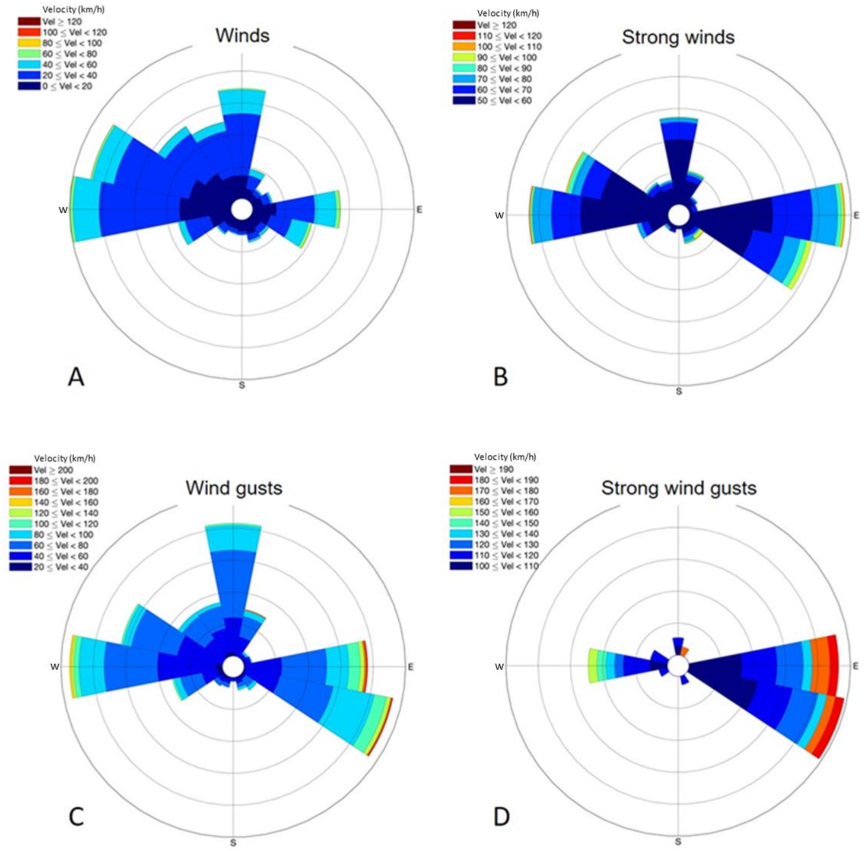

Figure 4. Wind Roses obtained for the area of BCAA based on historical data of the Uruguayan National Institute of Meteorology (January 1998 - May 2016; 24,698 records). Based on the speed of winds considered (A) and (B) refer to *Winds* and *Strong winds*, and (C) and (D) to *Wind Gusts* and *Strong wind gusts*, respectively.

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