Anonymous Referee #1

Thank you very much for your comment. You are right, the goal of this manuscript was to report the first evidence of plastic contamination on an Antarctic glacier, in the format of a brief communication. We think our findings are a significant advance for scientific investigations about plastics since no such studies have been conducted in Antarctic glaciers, a remote, and supposedly pristine area. We used an adequate methodology according to our goal, and the current scientific literature. Of course, further research is necessary to elucidate the extent of this contamination in Antarctic glaciers (especially of the small fraction that were probably overlooked in this study due to the methodology used), their sources, and their impacts. Before all this, the first step was to demonstrate that plastics are there and, in this study, we have been able to show it.

Anonymous Referee #1

Thank you very much for your comments.

- Line 49, we have written: "*Despite the increasing rate of ice loss during last decades* […]" instead of "*Despite that its rate of ice has increased* […].

- Line 51 - 52, we have written: "[…] *it has been estimated that the Antarctic cryosphere holds around 90% of Earth's ice mass* […]" instead of "[…] *the Antarctic cryosphere… (Dirscherl et al., 2020) covering its cap of ice up to* […] "

Rachel Obbard (Referee)

Thank you very much for your comments. It is a pleasure to discuss these issues with you. Following your suggestions, we have revised and improved the English, and we have discussed the issues that are affecting the scientific quality of our study. As you know, brief communications have a maximum of 3 figures and/or tables, a maximum of 20 references, a maximum of 4 pages, and no supplementary material; therefore, the space was very limited. For this reason, we have changed the article category to a research article, and we have included additional information to further clarify your comments.

<u>Major issue:</u>

Firstly, we have added the compass points in Figure 1 as an essential element in any map. Furthermore, we have included more information about the local meteorological conditions including prevailing winds (Figure 4) and daily wind patterns during the experiment (Figure S1). As you mentioned, the predominant winds in that area are from west. Historical data of the Uruguayan National Institute of Meteorology from BCAA (January 1998 - May 2016; 24,698 records) confirm that (Figure 4A), but also show that the strongest winds (i.e. gusts and strong gusts >150km/h) are mainly from east - southeast with some events from west (Figure 4B, C and D).

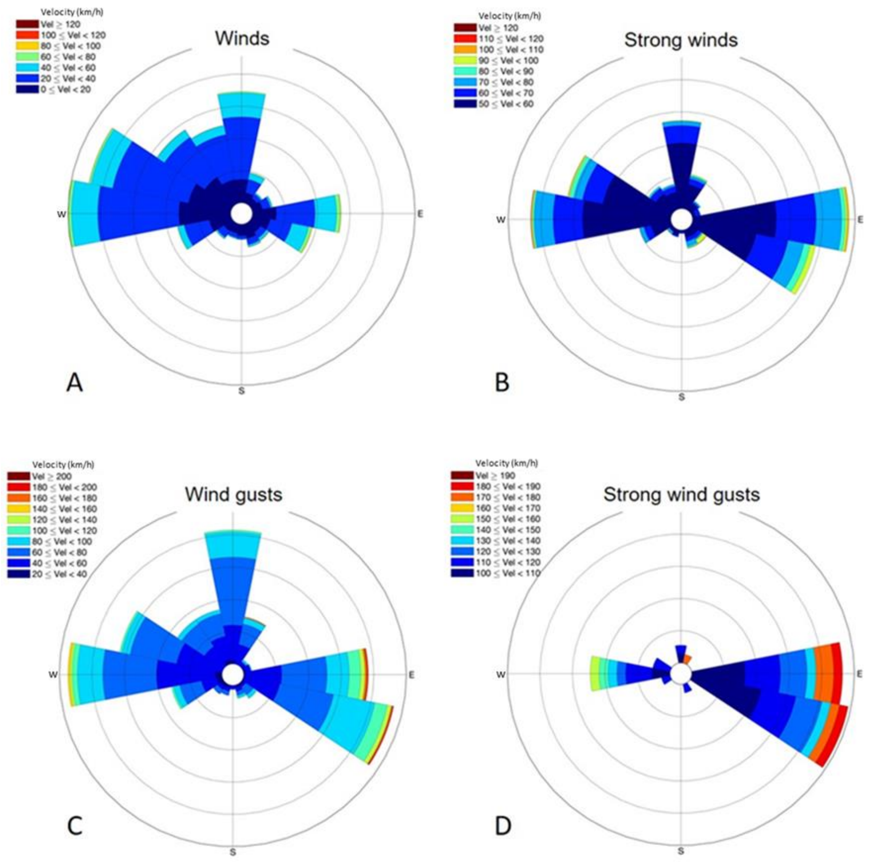


Figure 4. Wind Roses obtained for the area of BCAA based on historical data of the Uruguayan National Institute of Meteorology (January 1998 - May 2016; 24,698 records). Based on the speed of winds considered (A) and (B) refer to *Winds* and *Strong winds*, and (C) and (D) to *Wind Gusts* and *Strong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

Considering the used experimental strategy (i.e., checking the presence and removing 'new' plastics on a daily basis), the presence of plastics should be more related to the wind regimes that occurred on the days the study was conducted. Based on the available information we had access (i.e. *Villa de la Estrellas, Fildes Peninsula* climatological information, which is located near the Artigas Beach as shown in Figure S2A), during the study period (18/02/2020 - 20/02/2020) the wind was from northeast (45°) rotating to south (180°), with a speed between 10 and 30 km/h (Figure 2A). These wind conditions seem to suggest a possible link between Artigas Beach activities (BCAA and, especially, tourism) and wind-mediated aerial deposition of plastics.

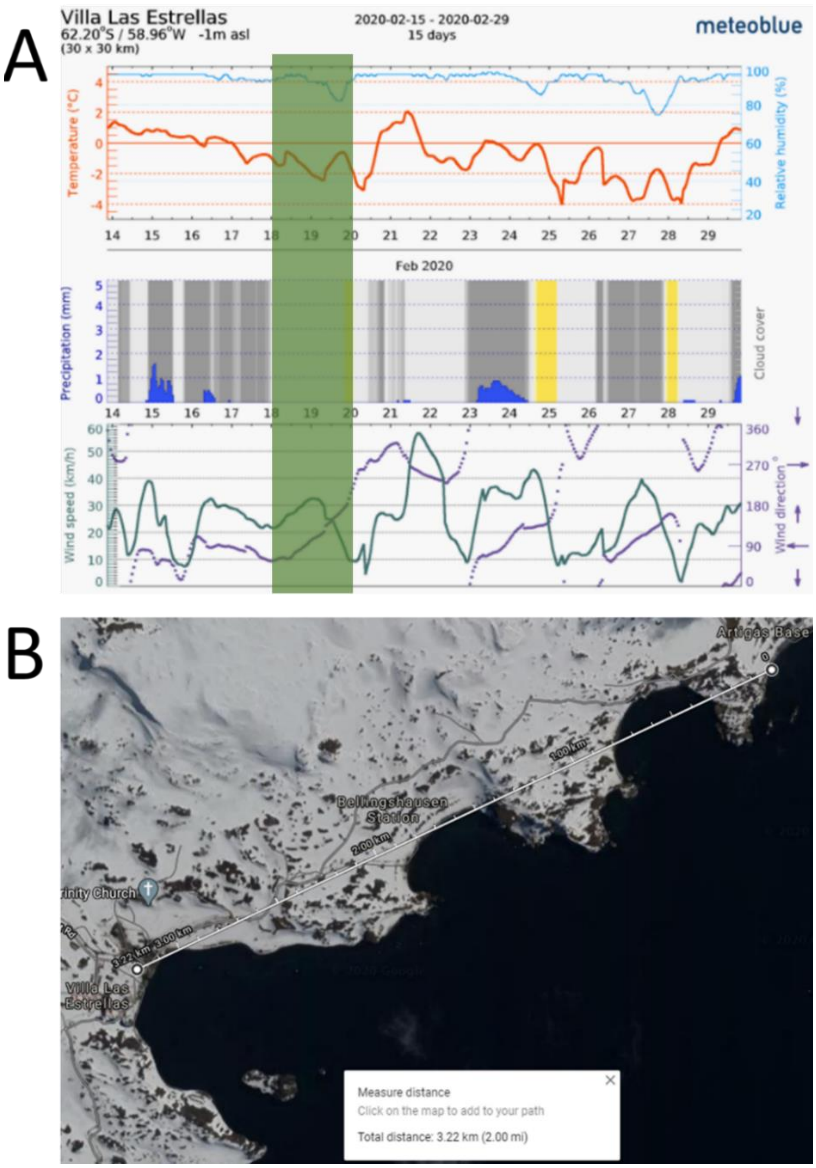


Figure S1. Weather conditions in *Villa Las Estrellas*, during February 2020 based on the available information we had access to (i.e. *La Villa de la Estrellas, Fildes Peninsula* climatological information) (A), green rectangle indicates the study period (18/02/2020 and 20/02/2020), and (B) the distance between *Villa Las Estrellas* and Artigas Beach.

In general, the presence of microplastics and ,especially, mesoplastics on the surface of these Antarctic glacier could be explained by the prevailing winds (i.e., strong winds, wind gusts and strong wind gusts), which could transport plastics from the Artigas Beach to the ice around both Uruguay and Ionosferico lakes. Atmospheric dry deposition of plastics could be the result of daily wind patterns was from northeast (45°) rotating to south (180°) during the collection period, which could have also transported plastics from the Artigas Beach. Therefore, plastic wastes present on the Artiga Beach, which are probably released from marine environments, and the human activities (e.g.: tourisms) could be the source of the plastics reaching glacier and atmospheric dry deposition could play a key role in their transport. Regarding mesoplastics found, they had very low density (e.g. EPS and PU), which probably eased their transport.

Regarding the alternative explanation ("that the particles were transported from ships on the far side"), it does not seem too likely considering the wind direction on the days of the experiment (Figure S1A). Considering only the predominant winds this could be, but the strongest winds, which could move the mesoplastics long distances, come predominantly from the E-SE.

It should be notes that this is a first step which pretends to show that meso and microplastics are present in Antarctic glaciers, and undoubtedly further researches are necessary to elucidate their distribution, their sources, pathways and trajectories (e.g. using HYSPLIT, LAGRANTO, FLEXPART), and of course their possible impacts. Based on the wind information we were able to collect; we have modified our discussion as follows: "*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.*"

Minor issues:

Lines: 121 - 131. Regarding the sample contamination, all the materials used (metal, steel and glass) were previously cleaned with MilliQ water, wrapped in aluminum foil and heated up to 300 ºC for 4 hours in order to remove all possible rests of organic matter. The use of any plastic material was avoided. Furthermore, possible contamination due to clothing was controlled throughout the whole process by comparing clothes fibres and fragments with our samples. Moreover, it should be noted that the types of plastics found in our study are not typically associated with clothing, or any of our sampling tools. In fact, some of them (e.g. EPS) are not even allowed currently in the scientific bases and were not part of any of our sampling gear. Given their size, plastics found in this study were detected by the naked eye and their traceability was easily maintained during quantification and identification of the samples. We have incorporated this in our manuscript, as follows (lines: 153 -161): "*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.*"

Line 145: Regarding the identification of the particles, 16 items were not confirmed as plastic by FTIR or µFTIR analysis. These items were not considered plastic materials because they were not identified as a known material with matching values > 60%. Some of these spectra could show some similarities with alkyd resin (polyester modified by the addition of other components), which are widely used in many synthetic paints. However, none of them resembled soot. Regarding plastics identified, the types found (Figure 2B) are related to human activities carried out in the Artigas area. For instance, EPS are widely used in packaging and (together with the PU) as insulation material in old buildings in this area and alkyd resins found are used as external coatings. We have incorporated this in our manuscript, as follows (lines: 233 - 249): "*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).*"

Lines 49-52, we have written: "*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)*."

Line 52 and 54, we have revised and corrected all references.

Line 57. We have removed "compartments".

Line 68: We have included (line: 71) a comma after (79%)

Line 237: We have written: "*EPs was ubiquitous in the two glacier surfaces studied*"

Melanie Bergmann (Referee)

Thank you very much for your comments, and the opportunity to discuss our study with you. As you know, brief communications have a maximum of 3 figures and/or tables, a maximum of 20 references, a maximum of 4 pages, and no supplementary material; therefore, the space is very limited. For this reason, we have changed the article category to a research article, and we have included additional information to further clarify your comments.

Regarding the sample contamination, all the materials used (metal, steel and glass) were previously cleaned with MilliQ water, wrapped in aluminum foil and heated up to 300 ºC for 4 hours in order to remove all possible rests of organic matter. The use of any plastic material was avoided. Furthermore, possible contamination due to clothing was controlled throughout the whole process by comparing clothes fibres and fragments with our samples. Moreover, it should be noted that the types of plastics found in our study are not typically associated with clothing, or any of our sampling tools. In fact, some of them (e.g. EPS) are not even allowed in the scientific bases and were not part of any of our sampling gear. Given their size, plastics found in this study were detected by the naked eye and their traceability was easily maintained during quantification and identification of the samples. We have incorporated this in our manuscript, as follows (lines: 153 -161): "*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.*"

About the hypothesis of our research. Given the fact that plastics have already been found in other parts of the cryosphere (alpine glaciers, snow and sea ice) and in Antarctica (seawater, freshwater, sediments and organisms), our research question was: could plastic be found on Antarctic glaciers? and, does dry deposition (i.e. by wind) play a role in its transport from areas with human activities?. Following these research questions, the hypothesis in our original manuscript was *"Our hypothesis is that plastics have also reached freshwater glaciers in Antarctica and that the dry deposition could be playing a crucial role in this process"*. To assess this, we chose two ice surfaces areas (an area around Uruguay lake and another around Ionosferico lake) that constitute part of the ablation zone of Collins Glacier (King George Island, Antarctica). The reason for this choice is that we could easily access from BCAA to both areas on foot as often as the experiment required. Uruguay lake is located ~300 m from Antarctic Scientific Base and Ionosferico lake is located ~600 m from Artigas Base (see section 2.1 in material and methods). These relative differences in human pressure and distance from Artigas Beach could be evaluated in future studies to test the effect of distance to human plastic source in their atmospheric dry deposition of plastics in Antarctica. However, our goal in this pilot study was not to test this. In fact, plastics collected in our study are not enough to perform a robust statistical test in order to test this. Furthermore, we believe that other factors such as topography and a more detailed sampling gradient would have been necessary if that was our goal. Therefore, we have written: "*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.*"

According your request, we have added another graph showing the temporal trend over the 48 hours in each squares of both ice surface (an area around Uruguay lake and another around Ionosferico lake) that constitute part of the ablation zone of Collins Glacier in Maxwell Bay in King George Island (Antarctica).

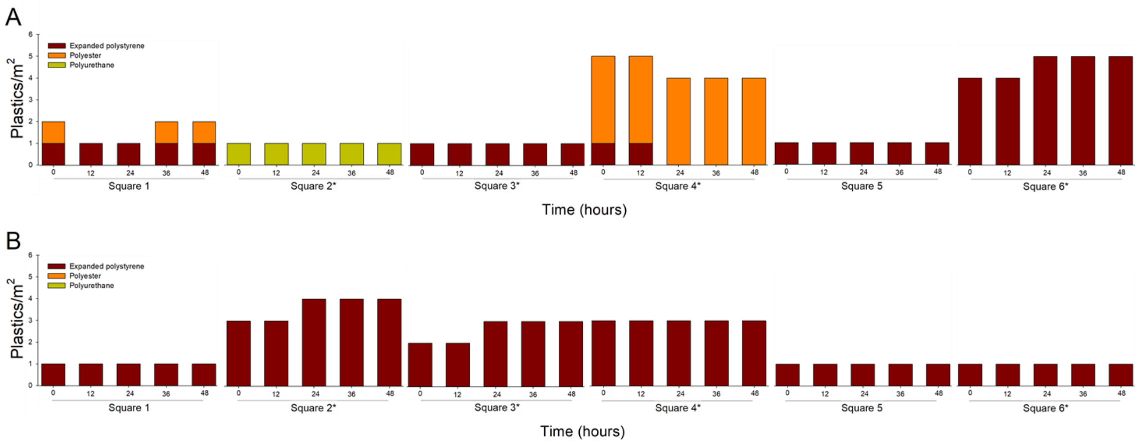


Figure 3. Changes in the presence of plastics into the squares marked on ice surface close to Uruguay lake (A) and close to Ionosferico lake (B) that constitute part of the ablation zone of Collins Glacier in Maxwell Bay in King George Island (Antarctica). Plastics were monitored every 12 hours for two 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.

Following your request, we have structured the MS including in the results and material and methods new subtitles.

Besides, we agree with the reviewer about the importance of showing data as per m^2. In this sense, all data have been also presented as plastics per m^2 throughout the MS (.

In fact, we have included two tables to clarify the results of both experiments (the assessment of plastic concentration and the assessment of atmospheric dry deposition of plastics). Furthermore, we considered relevant to include the total number of items identify as plastics with respect the total items collected as well as their characterization (see section 3.1 Characterization and identification of the plastics) in order to show the importance of the item identification using appropriate techniques (e.g. FTIR, RAMAN, HPLC-MS/MS).

Table S1. Characteristics of plastics found into the squares used for the assessment of plastic concentration on ice surface close to Uruguay lake and close to Ionosferico lake that constitute part of the ablation zone of Collins Glacier in Maxwell Bay in King George Island (Antarctica).

Area	ID Square	Polymer	Color	Size 1 (µm)	Size 2 (µm)	Type
Uruguay	1	EPS	White	4100	4022	Microplastic
Uruguay	1	Polyester	Red	4822	2544	Microplastic
Uruguay	2	Polyester	Red	6662	3747	Macroplastic
Uruguay	3	not detected	-	-	-	-
Uruguay	4	not detected	-	-	-	-
Uruguay	5	EPS	White	12628	11334	Macroplastic
Uruguay	6	not detected	-	-	-	-
Uruguay	7	not detected	-	-	-	-
Uruguay	8	not detected	-	-	-	-
Uruguay	9	not detected	-	-	-	-
Uruguay	10	not detected	-	-	-	-
Uruguay	11	not detected	-	-	-	-
Uruguay	12	Polyester	Red	2292	1356	Microplastic
Uruguay	Mean	0.17 EPS/m^2 and 0.25 Polyester/m^2				
Ionosferico	1	EPS	White	7583	5591	Macroplastic
Ionosferico	2	not detected	-	-	-	-
Ionosferico	3	not detected	-	-	-	-
Ionosferico	4	not detected	-	-	-	-
Ionosferico	5	EPS	White	3817	3318	Microplastic
Ionosferico	6	not detected	-	-	-	-
Ionosferico	Mean	0.33 EPS/m^2				

Table S2. Characteristics of plastics found at the end of the experiment into the squares used for the assessment of atmospheric dry deposition of plastics on ice surfaces that constitute part of the ablation zone of Collins Glacier (King George Island, Antarctica).

Area	ID Square	Polymer	Color	Size 1 (µm)	Size 2 (µm)	Type
Uruguay	1	EPS	White	4100	4022	Microplastic
Uruguay	1	Polyester	Red	4822	2544	Microplastic
Uruguay	2*	Polyurethane	Brown	> 5000	> 5000	Macroplastic
Uruguay	3*	EPS	White	9301	8265	Macroplastic
Uruguay	4*	Polyester	Red	6989	6834	Macroplastic
Uruguay	4*	Polyester	Red	6168	5891	Macroplastic
Uruguay	4*	Polyester	Red	5909	501	Macroplastic
Uruguay	4*	Polyester	White	> 5000	> 5000	Macroplastic
Uruguay	5	EPS	White	12628	11334	Macroplastic
Uruguay	6*	EPS	White	9720	7963	Macroplastic
Uruguay	6*	EPS	White	6292	5567	Macroplastic
Uruguay	6*	EPS	White	9192	9023	Macroplastic
Uruguay	6*	EPS	White	5595	4574	Macroplastic
Uruguay	6*	EPS	White	7847	3640	Macroplastic
Ionosferico	1	EPS	White	7583	5591	Macroplastic
Ionosferico	2*	EPS	White	6437	5220	Macroplastic
Ionosferico	2*	EPS	White	10932	7572	Macroplastic
Ionosferico	2*	EPS	White	5278	4726	Macroplastic
Ionosferico	2*	EPS	White	9363	9186	Macroplastic
Ionosferico	3*	EPS	White	9209	7932	Macroplastic
Ionosferico	3*	EPS	White	7946	3834	Macroplastic
Ionosferico	3*	EPS	White	13155	7925	Macroplastic
Ionosferico	4*	EPS	White	7007	6905	Macroplastic
Ionosferico	4*	EPS	White	7094	5112	Macroplastic
Ionosferico	4*	EPS	White	16737	16085	Macroplastic
Ionosferico	5	EPS	White	3817	3318	Microplastic
Ionosferico	6*	EPS	White	11576	11105	Macroplastic

Asterisks indicate squares different from those used for the assessment of plastic concentration.

It should be noted that in our new version of the manuscript we have also added more information and further discussed the role of wind intensity and direction in the area, in order to give more insight into the possible influence of this environmental variable.

Specific points

Line 31 (lines: 29 - 41): Thank you for your comment, we have included the most important data in the 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.*"

Line 60: We have written (lines: 60 – 65): "*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).*"

Line 65: Ambrosini et al 2019 reported the occurrence of plastics as "items kg^{-1} of sediment (dry weight)". Checking section *2.2. Sample collection* of their article we found the following description: "*collected two cryoconite samples and four samples of sparse and fine (<2 mm) supraglacial debris from the ablation area of Forni Glacier*". We have modified our manuscript to reflect this as: We have written (lines: 66 – 67): "*[…] of ice weight (78.3 ± 30.2 MPs Kg^{-1} of sparse and fine supraglacial debris; Ambrosini et al., 2019) and mass […]*" instead of "[…] of sediment weight (78.3 ± 30.2 MPs Kg^{-1} of sediments; Ambrosini et al., 2019) and mass […]"

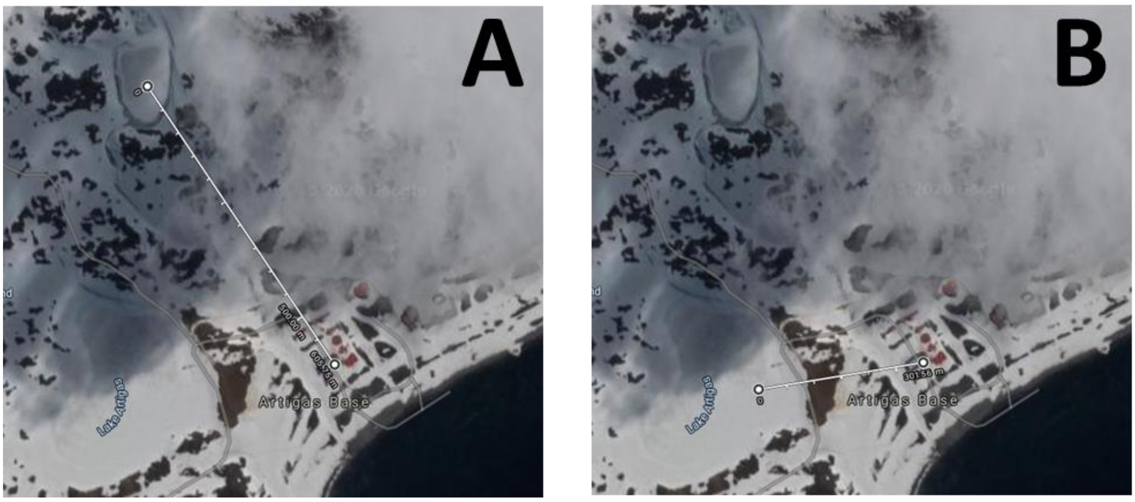
Line 73: We have written: "*The differences between these studies may be due to the different analytical methods used, particularly methodologies such as micro Fourier transform infrared spectroscopy (µFTIR, which can identify smaller sized MPs).*"

Line 74: We have written (line 76 – 79): "*In general, the presence of plastics > 5mm are not reported in discrete parts of the cryosphere, probably because they occur at lower concentrations and therefore often evade our detection*" inside of "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."

Line 96: Please, see lines: 94 -103.

In general, we excluded fibers from our study, since they were non detectable with the naked eye, and would have required ice extraction, melting and posterior water analysis, impacting our sampling strategy (i.e ice extraction from sampling squares). We have now added this information in the materials and methods section 2.2 (lines: 127 - 130): "*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.*"

Regarding the distance of each lake to the Artigas Scientific Base, we have now added this information in the new version of the manuscript (lines: 112 – 115).



Distance between Artigas Scientific base and Ionosferico lake ~600 m (A). Distance between Artigas station and Uruguay lake ~300 m (B).

Line 104: Following your request, we have modified geographical positions as follows: "*(S 62° 11' 6.54'', O 58° 54' 42.23'')*" and "*(62° 11' 59.41'', O 58° 57' 44.17'')*"

According our request, we have added a paragraph on data analysis (see section 2.4)

Following your request, we have structured the MS including in the results and material and methods new subtitles.

Line 145-157: To clarify, we have added Figure 3 and a new Table S2 showing the temporal trend over the 48 hours in each squares of both ice surface (an area around Uruguay lake and another around Ionosferico lake) that constitute part of the ablation zone of Collins Glacier in Maxwell Bay in King George Island (Antarctica).

Lines 182: Following your request, we have compared our results in m^{-2} with the papers that we cited (lines: 251 -262)

Line 184: We have deleted this.

Line 187: These relative differences in human pressure and distance from Artigas Beach could be evaluated in future studies to test the effect of distance to human plastic source in their atmospheric dry deposition of plastics in Antarctica. However, our goal in this pilot study was not to test this. In fact, plastics collected in our study are not enough to perform a robust statistical test to test this.

Line 190: We have incorporated this in our manuscript (see discussion).

Line 193: Here, we have mentioned: "*Our results show that the atmospheric deposition of plastics on glaciers is very low being between two and four orders of magnitude lower than what is generally found in the rest of the continents (Dris et al. 2016; Cai et al 2017; Klein and Fischer, 2019; Brahney et al 2020). This could be due to the fact that we have used a different methodology that those used in previous studies and that probably underestimated the concentration of plastics, especially small fractions. Nevertheless, further research is necessary to elucidate the distribution, sources, pathways and trajectories, and impacts on this ecosystem of the plastics*".

Line 195: We have modified our discussion

Figure 2 and Table 1: To clarify , we have added a new Figure 3 and a new Table S2 showing the temporal trend over the 48 hours in each squares of both ice surface (an area around Uruguay lake and another around Ionosferico lake) that constitute part of the ablation zone of Collins Glacier in Maxwell Bay in King George Island (Antarctica).