

1 A pilot study about microplastics and mesoplastics in an Antarctic glacier:
2 the role of aeolian transport

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27
28 **Abstract**

29 Plastics have been found in several compartments in Antarctica. However, there is
30 currently no evidence of their presence in Antarctic glaciers. Our pilot study investigated
31 plastic occurrence on two ice surfaces (one area close to Uruguay lake and another one
32 close to Ionosferico lake) that constitute part of the ablation zone of Collins Glacier (King
33 George Island, Antarctica). Our results showed that expanded polystyrene (EPS) was
34 ubiquitous ranging from 0.17 to 0.33 items m⁻² whereas polyester was found only on the
35 ice surface close to Uruguay lake (0.25 items m⁻²). Furthermore, we evaluated the daily
36 changes in the presence of plastics in these areas in the absence of rainfall to clarify the
37 role of the wind in their transport. We registered an atmospheric dry deposition rate
38 between 0.08 items m⁻² day⁻¹ on the ice surface close to Uruguay lake and 0.17 items m⁻²
39 day⁻¹ on the ice surface close to Ionosferico lake. Our pilot study is the first report of
40 plastic pollution presence in an Antarctic glacier, possibly originated from local current
41 and past activities, and the first to assess the effect of wind in its transport.

46 **Introduction**

47 The cryosphere is the frozen water part of the Earth system that consists of areas in
48 which the temperatures are below 0°C for at least part of the year (NOAA, 2019). Most
49 of the cryosphere in terms of volume of ice is in Antarctica. Despite the increasing rate
50 of ice loss during last decades (Rignot et al., 2019), it has been estimated that the
51 Antarctic cryosphere holds around 90% of Earth's ice mass (Dirscherl et al., 2020).
52 Furthermore, the Antarctic cryosphere represents the majority of the world's
53 freshwater, representing the largest freshwater ecosystem on the planet (Shepherd et
54 al., 2018).

55

56 Plastics, especially microplastics (plastic items < 5 mm long; MPs), have been detected
57 in several specific locations of the cryosphere including mountain glaciers (Ambrosini et
58 al., 2019; Cabrera et al., 2020; Materić et al., 2020), snow (Bergmann et al., 2019;
59 Österlund et al., 2019) and sea ice (Geilfus et al., 2019; Kelly et al., 2020; La Daana et al.,
60 2020; Obbard et al., 2014; Peeken et al., 2018; von Friesen et al., 2020). The occurrence
61 of MPs in snow ranged from 0 to 1.5×10^5 MP L⁻¹ of melted snow (Bergmann et al., 2019),
62 although it should be noted that a part of this study was conducted near urban areas.
63 Regarding sea ice, concentrations of up to 1.2×10^4 MP L⁻¹ have been reported, although
64 there are large differences between studies even from the same region (Peeken et al.,
65 2018; von Friesen et al., 2020). The use of different units in reporting MP concentrations
66 in mountain glaciers such as the number of items per mass of ice weight (78.3 ± 30.2
67 MPs kg⁻¹ of sparse and fine supraglacial debris; Ambrosini et al., 2019) and mass of MPs
68 per volume (0 to 23.6 ± 3.0 ng of MPs mL⁻¹; Materić et al., 2020), makes comparisons
69 between studies difficult (101.2 items L⁻¹; Cabrera et al., 2020). Regarding the shape of
70 the MPs found in the cryosphere, fibers seem to be dominant in mountain glaciers (65
71 %) and sea ice (79 %), followed by fragments (Ambrosini et al., 2019; La Daana et al.,
72 2020). Concerning the size of MPs, it has been reported a broad size distribution in sea
73 ice, with 67 % of MPs in the 500-5000 µm range (La Daana et al., 2020). Other studies
74 found lower sizes, however, with significant amounts (up to 90 %) of MPs smaller than
75 100 µm in snow and sea ice (Ambrosini et al., 2019; Bergmann et al., 2019; Bergmann et
76 al., 2017; Kelly et al., 2020; Peeken et al., 2018). The differences between these studies
77 may be due to the different analytical methods used, particularly methodologies such
78 as micro Fourier transform infrared spectroscopy (µFTIR, which can identify smaller
79 sized MPs). In general, the presence of plastics > 5mm has not been reported in the
80 cryosphere, probably because they occur at lower concentrations and evade detection.
81 µFTIR revealed that polyethylene terephthalate (PET), polyamide (PA), polyester (PE),
82 varnish (acrylates/polyurethane), several synthetic rubbers, polypropylene (PP), and
83 polyurethane (PU) are the most common types of MPs in the cryosphere (Ambrosini et
84 al., 2019; Bergmann et al., 2019; Bergmann et al., 2017; La Daana et al., 2020; Materić
85 et al., 2020; Obbard et al., 2014; Peeken et al., 2018). The sources of MPs detected in the
86 cryosphere, however, remain poorly understood. It has been suggested that they could
87 be transported by the wind before being deposited by both wet and dry deposition in
88 remote areas such as polar regions (Halsband and Herzke, 2019). In fact, it has been
89 reported that air masses can transport MPs through the atmosphere over distances of

90 at least 100 km and that they can be released from the marine environment into the
91 atmosphere by sea-spray (Allen et al., 2020; Allen et al., 2019; González-Pleiter et al.,
92 2020a).

93

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

104

105 **Materials and Methods**

106 2.1 Study area

107 Collins Glacier is located on the northeast of Fildes Peninsula (King George Island,
108 Antarctica; Figure 1A) and has a total surface area of 15 km² (Simoes et al., 2015). Our
109 study was carried out on the ice surface of the glacier ablation areas **close to two lakes**
110 (Uruguay or Profound, and Ionosferico) in Maxwell Bay (Figure 1B). Uruguay lake (S 62°
111 11' 6.54", O 58° 54' 42.23") is located in the proximity of the Artigas Antarctic Scientific
112 Base and its access road (~300 m) is subjected to human transit (Figure 1B). The distance
113 from the shoreline to Uruguay lake is ~366 m. The lake is used for drinking and domestic
114 water supply. The glacier surface studied in this lake covered 1680 m². Ionosferico lake
115 (62° 11' 59.41", O 58° 57' 44.17") is located ~600 m from Artigas Base and has minimal
116 human activity. The distance from the shoreline to Ionosferico lake is ~694 m. **The glacier**
117 **surface studied in this lake covered 537 m² (Figure 1B).** It should be noted that there
118 were no visible footpaths through or nearby the glacier surfaces of both lakes during the
119 duration of our study (except our own footprints).

120

121 2.2 Experimental assessment of plastic concentration

122 To evaluate the concentration of plastics, twelve squares were marked on the ice
123 surface close to Uruguay lake (Figure 1C) and six squares on the ice surface close to
124 Ionosferico lake (Figure 1D), which constitute part of the ablation zone of Collins Glacier,
125 on 18/2/2020. The first square of **1m²** on the ice surface close to each lake was randomly
126 marked. After that, the rest of the squares of 1m² were distributed every ten meters
127 covering the entire ice surface **in each lake** (Figure 1E). All items visually resembling
128 plastic (suspected plastic) inside the squares were registered (Figure 1F). It should be
129 noted that our sampling strategy excluded the plastics non-detectable by the naked eye
130 (i.e. small plastics such as fibers). Thus, we probably underestimated the concentration
131 of small plastics on the ice surface.

132

133 2.3 Experimental assessment of atmospheric dry deposition of plastics

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

138

139 2.4 Characterization and identification of plastics

140 Every item visually resembling plastic detected in the squares was collected with
141 stainless-steel tweezers, placed into glass bottles, and stored at 4 °C until analysis. All
142 collected items were photographed, measured and their composition was identified by
143 ATR-FTIR using an Agilent Cary 630 FTIR spectrometer or by μ FTIR on a Perkin-Elmer
144 Spotlight 200 Spectrum Two apparatus equipped with a MCT detector (depending on
145 the size of the item). The spectra were taken using the following parameters in micro-
146 transmission mode: spot 50 μ m, 32 scans, and spectral range 550-4000 cm^{-1} with 8 cm^{-1}
147 resolution. The spectra were processed using Omnic software (Thermo Fisher). Items
148 with matching values > 60% were considered plastic materials. The results of
149 concentration and atmospheric dry deposition of plastics reported in this study include
150 only items positively identified as plastics according to the FTIR analysis and were
151 expressed as number of items per surface unit and items per surface unit and day
152 respectively.

153

154 2.5 Prevention of procedural contamination

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

163

164 **Results and discussion**

165 3.1 Characterization and identification of the plastics

166 In total, 45 items preliminarily identified as plastics were collected, of which 29 items
167 were confirmed as plastic by FTIR or μ FTIR analyses (matching > 60%). The size of
168 plastics ranged from 2292 to 12628 μ m length and from 501 to 11334 μ m width (Figure
169 2A). According to their size, 13 mesoplastic items (plastic items between 5-25 mm long;
170 MeP) and 3 MP items were found on the ice close to Uruguay lake, and 12 MeP items
171 and 1 MP item on the ice close to Ionosferico lake (Figure 2B). Meso and MPs
172 (hereinafter referred to as plastics) of expanded polystyrene (EPS) were found on the
173 ice close to both lakes: 8 plastic items on the ice close to Uruguay lake and 13 plastic
174 items on the ice close to Ionosferico lake (Figure 2B, C, and D). Polyester (n = 7 items;
175 Figure 2B, E, and F) and polyurethane (n = 1 item; Figure 2B, G and H) items were present
176 only on the ice close to Uruguay lake. It should be noted that spectra of the polyester

177 (Figure 2F) showed a high similarity with alkyd resin, a thermoplastic polyester widely
178 used in synthetic paints.

179

180 3.2 Plastic concentration

181 EPS items were ubiquitous on the ice with concentrations ranging from 0.17 items m⁻²
182 on the ice close to Uruguay lake to 0.33 items m⁻² on the ice close to Ionosferico lake
183 (Table S1). The concentration of polyester, which was found only on the ice close to
184 Uruguay lake, was 0.25 items m⁻² (Table S1). Polyurethane items were not observed in
185 Ionosferico lake (Table S1).

186

187

188 3.3 Atmospheric dry deposition of plastics

189 The dry deposition rate of EPS was 0.08 EPS items m⁻² day⁻¹ and 0.17 EPS items m⁻² day⁻¹
190 on the ice close to Uruguay and Ionosferico lakes, respectively (Table S2 and Figure 3).

191 Polyester was only deposited on the ice close to Uruguay lake at a rate of 0.08 items m⁻²
192 day⁻¹. Polyurethane items were not observed in Ionosferico lake during the duration
193 of the experiment (Table S2). The plastics deposited on the ice of Ionosferico lake during
194 the experiment were exclusively EPS (Table S2 and Figure 3).

195

196 Discussion

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

208

209 In this sense, winds (especially high-speed ones) appear to be a key element in the
210 transport of plastics to Antarctic glaciers. The prevailing winds in the study area (Figure
211 1B) blow predominantly from the west (Figure 4A). However, strong winds (Figure 4B),
212 wind gusts (Figure 4C), and strong wind gusts (Figure 4D) blow mainly from the east and
213 southeast directions, and could be responsible for the spreading of plastics from the
214 different origins to the surface of the glacier ablation areas. These strong winds would
215 explain the presence of MePs despite their size (Figure 2A). In fact, the low density of
216 the MePs found (mainly EPS; Figure 2B) would have allowed their easy dispersion by
217 wind.

218

219 Our results on the dry deposition of plastics support the hypothesis that the role of the
220 wind is essential for the transport of MPs and MePs in (and among) different areas of

221 Antarctica. The dry deposition of plastics (Table S2) was closely related to the wind
222 regimes during the study period (Figure S1). Based on information available on the
223 meteorological conditions during the study dates (18/02/2020 - 20/02/2020) in Villa Las
224 Estrellas (Figure S1A), which is located near the Artigas Beach (Figure S1B), the wind
225 blew from the northeast veering to the south with a speed between 10 and 30 km/h
226 (Figure S1A). These wind conditions suggest a possible link with marine environment,
227 which can act as a source of plastics (Allen et al., 2020), and potentially explain the
228 presence of plastics on the glacier ablation areas. However, considering the low intensity
229 of the winds recorded during those days (Figure S1A) and the presence of MePs, it is also
230 possible that the predominant high-speed winds transported MePs from other adjacent
231 areas of the Fildes Peninsula to the vicinity of the lakes, in the days prior to our study
232 (Figure 4B, C, and D) and then, the milder winds registered during the sampling days
233 (Figure S1A) deposited these MePs on the ice.

234

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

252

253 The role of the atmospheric dry deposition on the presence of plastics on glaciers is
254 supported by recent studies suggesting that MPs can be transported, up to hundreds of
255 kilometres, through the atmosphere before being deposited (González-Pleiter et al.,
256 2020a). Our results showed that the atmospheric deposition of plastics on glaciers is still
257 low, with figures between two and four orders of magnitude lower than values reported
258 in populated areas (Brahney et al., 2020; Cai et al., 2017; Dris et al., 2016; Klein and
259 Fischer, 2019; Roblin et al., 2020; Wright et al., 2020). Our results also show that plastic
260 pollution, even if only in small quantities, reaches remote areas with few human
261 settlements. The occurrence of plastic pollution in Antarctica represents the spreading
262 of anthropogenic pollutants in the last pristine environment on the **Earth**. Further
263 research is needed then to elucidate the occurrence, sources, fate, and impact of plastics
264 in such remote places.

265

266 Taken together, our research indicates that human activities in sensitive remote areas
267 such as Antarctica leave a footprint that includes plastic pollution. Since the early reports
268 of litter pollution on the seafloor (Dayton and Robilliard, 1971) and ,subsequently, on
269 beaches and seabirds of Antarctica (Convey et al., 2002; Creet et al., 1994; Fijn et al.,
270 2012; Lenihan et al., 1990; Sander et al., 2009) the handling of waste has been improved
271 by the implementation of the Antarctic Treaty System, Annex III 'Waste Disposal and
272 Waste Management'. The Treaty forces to remove all plastic from Antarctica, with the
273 only exception of plastics that can be incinerated without producing harmful emissions
274 (Antarctic Treaty Secretariat, 1998). However, once plastics are broken down into
275 smaller fractions and dispersed throughout the continent and nearby waters,
276 management measures become very difficult to address, as evidenced by our data.
277 Thus, a more rigorous management of plastics is essential for preserving a clean
278 environment within the Treaty Area (Zhang et al., 2020).

279

280

281 **Conclusion**

282 This is the first report of the presence of both MePs and MPs in an Antarctic glacier,
283 which were probably transported by wind from local sources such as beach areas. In
284 total, three types of plastics (EPS, PU and polyester) were found on two glacier surfaces
285 that constitute part of the ablation zone of Collins Glacier (King George Island,
286 Antarctica). EPS was ubiquitous in the two glacier surfaces studied. Our study showed
287 that the management of plastic contamination in Antarctica should be improved,
288 focusing on the waste generated by current and past anthropogenic activities that occur
289 in that area.

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291

292 **Author contribution**

293 **Miguel González-Pleiter:** identified the research question, formulated the hypothesis,
294 developed the experimental design, planned the experiments, performed the
295 experiments in the field, performed the experiments in the laboratory, compiled the
296 data sets, analyzed the data, discussed the results, prepared graphical material, wrote
297 the paper (original draft) and provided financial support. **Gissell Lacerot:** identified the
298 research question, formulated the hypothesis, developed the experimental design,
299 planned the experiments, checked the field data, discussed the results, wrote the paper
300 (final version). **Carlos Edo:** performed the experiments in the laboratory, compiled the
301 data sets, analyzed the data, discussed the results, prepared graphical material and
302 review final manuscript. **Juan Pablo Lozoya:** developed the experimental design,
303 checked the field data, discussed the results, review final manuscript and provided
304 financial support. **Francisco Leganés:** discussed the results, review final manuscript and
305 provided financial support. **Francisca Fernández-Piñas:** checked the field data, checked
306 the laboratory data, discussed the results, review final manuscript and provided
307 financial support. **Roberto Rosal:** checked the field data, checked the laboratory data,
308 discussed the results, review final manuscript and provided financial support. **Franco
309 Teixeira de Mello:** identified the research question, formulated the hypothesis,

310 developed the experimental design, planned the experiments, performed the
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312 the results, review final manuscript and provided financial support.

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327

328 **Declaration of competing interest**

329 The authors declare no conflict of interest.

330

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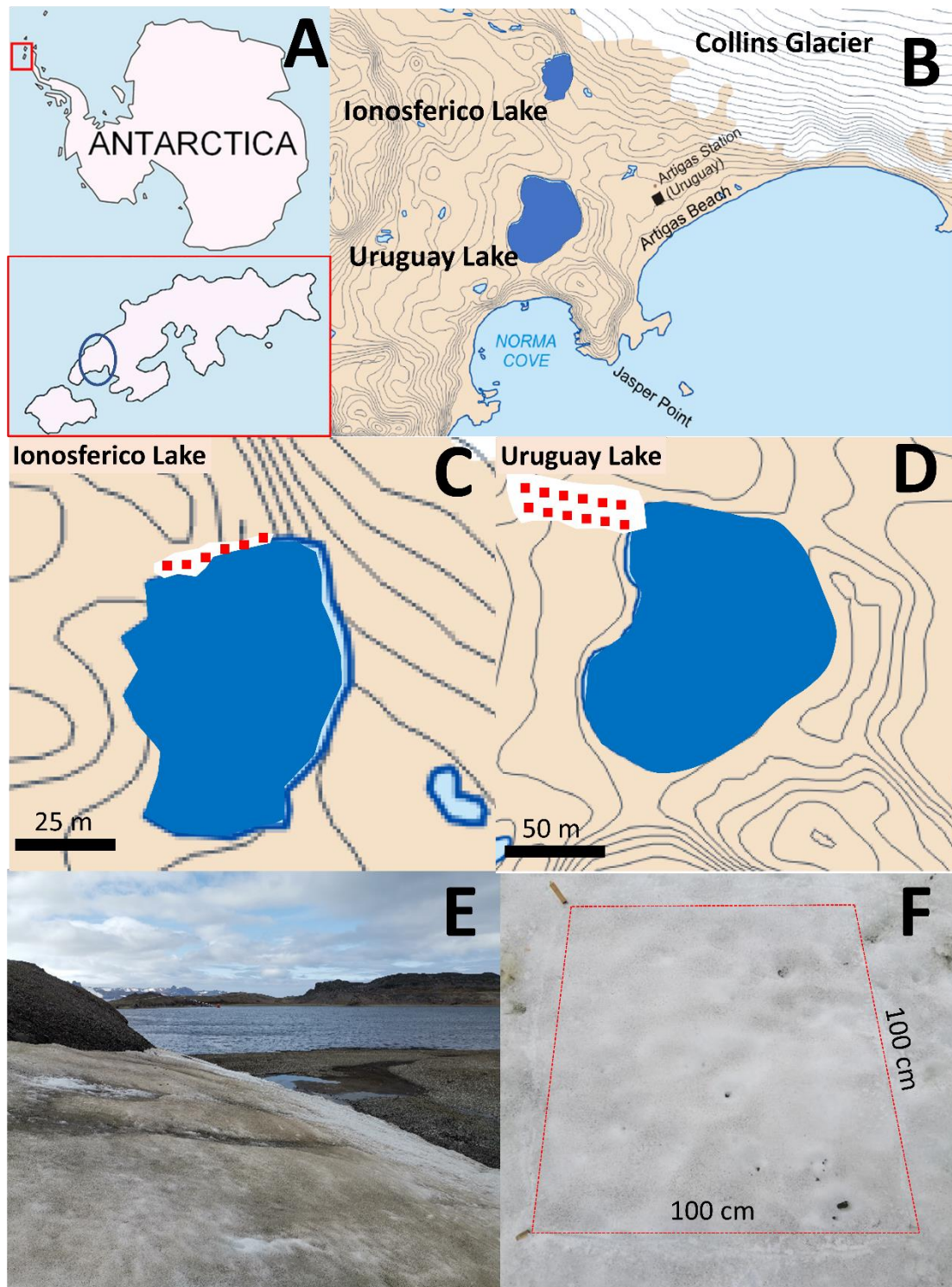
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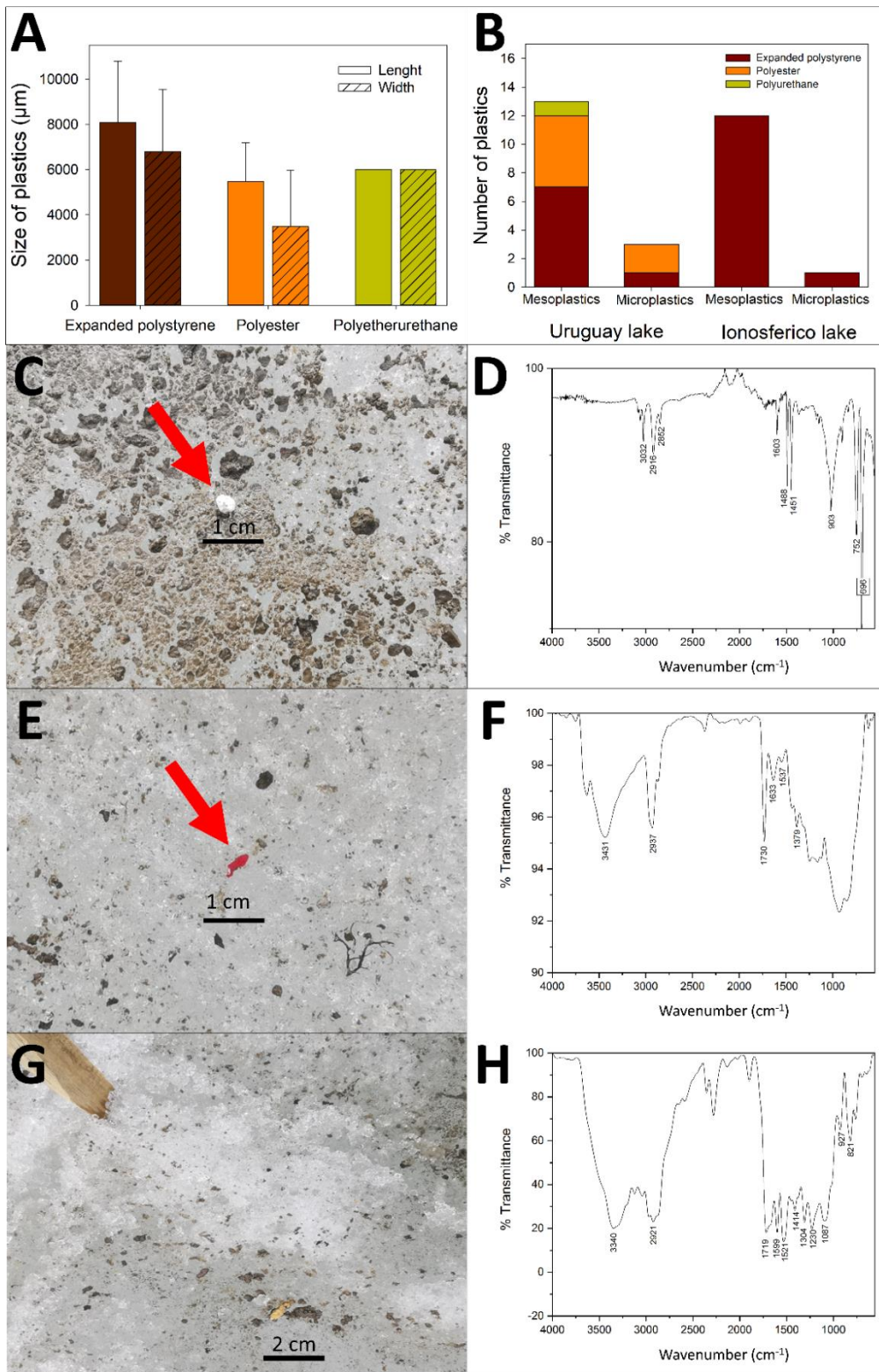
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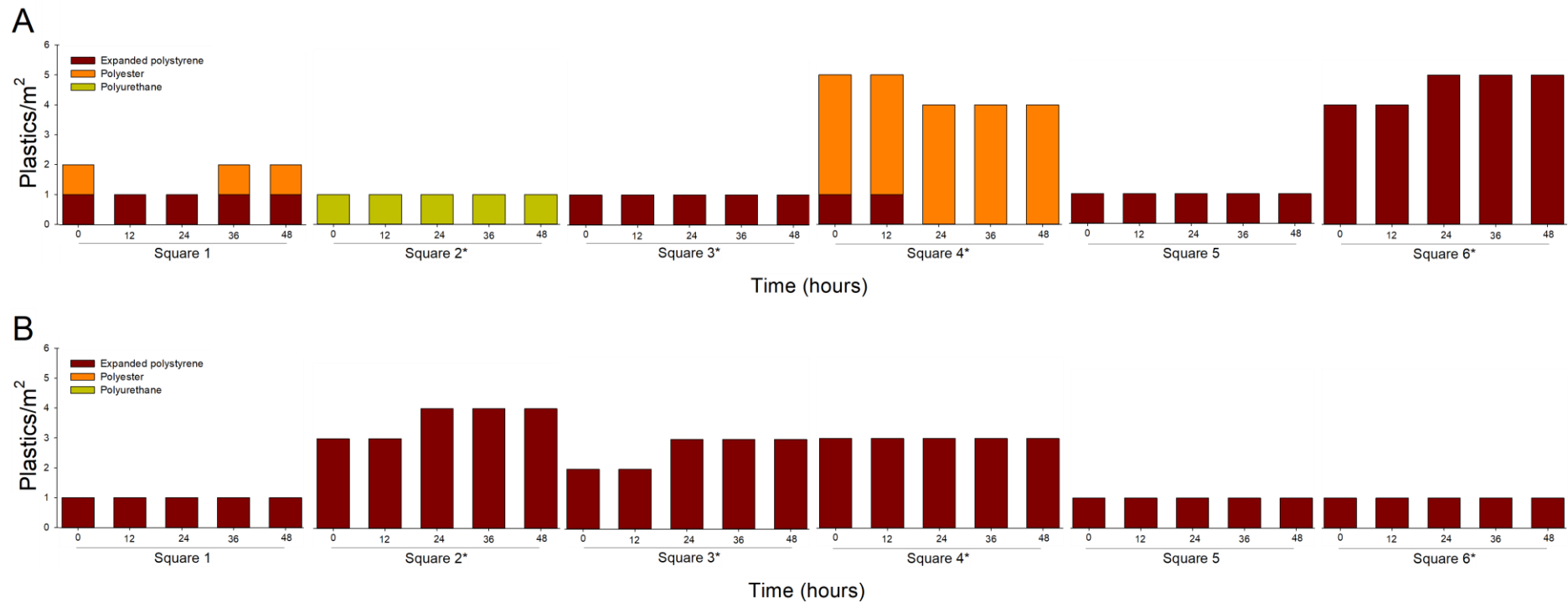
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 491 **Figure 1.** (A) General view of Antarctica and location of King George Island. The blue
 492 **circle** indicates the Fildes Peninsula. Collins Glacier is located on the northeast of Fildes
 493 Peninsula. (B) A detailed view of Ionosferico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

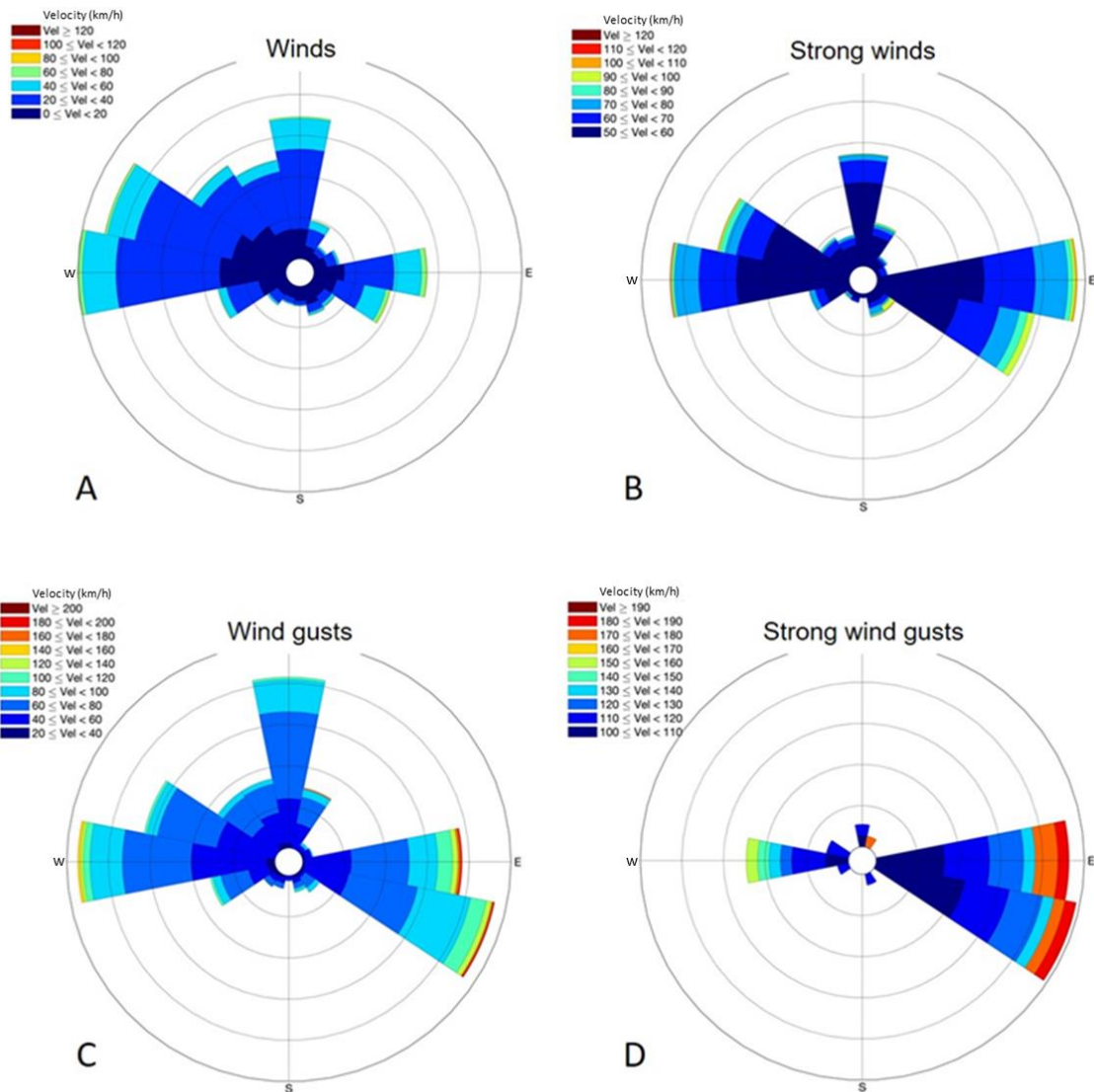


500 **Figure 2.** (A) Size of the plastics collected on the glacier surface. (B) Total number of the
 501 mesoplastics and microplastics found on the glacier surface close to Uruguay lake and
 502 Ionosferico. Representative photographs of expanded polystyrene (C), polyester (E) and
 503 polyurethane (G) found on the glacier surface. The red arrows indicate the plastics. FTIR
 504 representative spectra of expanded polystyrene (D), polyester (F) and polyurethane (H)
 505 found on the glacier surface.
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509 **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)
510 that constitute part of the ablation zone of Collins Glacier in Maxwell Bay in King George Island (Antarctica). Plastics were monitored every 12 hours
511 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
512 plastic concentration.



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

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