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1 **An Exceptional Summer during the South Pole Race of 1911-1912**

2
3 Ryan L. Fogt¹, Megan E. Jones¹, Susan Solomon², Julie M. Jones³, and Chad A. Goergens¹

4
5 ¹Department of Geography and Scalia Laboratory for Atmospheric Analysis, Ohio University,
6 Athens, OH, USA

7 ²Department of Earth, Atmospheric, and Planetary Science, Massachusetts Institute of
8 Technology, Cambridge, MA, USA

9 ³Department of Geography, University of Sheffield, Sheffield, UK

10
11 **Corresponding author address:** Ryan L. Fogt, 122 Clippinger Laboratories, Department of
12 Geography, Ohio University, Athens, OH, 45701. Email: fogtr@ohio.edu

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20 **Capsule Summary**

21

22 The race for the South Pole during the summer of 1911-1912 was marked by exceptionally high
23 temperature and pressure anomalies experienced by both Amundsen and Scott.

24

25 **Abstract.**

26 The meteorological conditions during the Amundsen and Scott South Pole expeditions in
27 1911-1912 are examined using a combination of observations collected during the expeditions as
28 well as modern reanalysis and reconstructed pressure datasets. It is found that over much of this
29 austral summer, pressures were exceptionally high (more than two standard deviations above the
30 climatological mean) at both main bases, as well as along the sledging journeys, especially in
31 December 1911. In conjunction with the anomalously high pressures, Amundsen and his crew
32 experienced temperatures that peaked above -16°C on the polar plateau on December 6 1911,
33 which is extremely warm for this region. While Scott also encountered unusually warm
34 conditions at this time, the above average temperatures were accompanied by a wet snowstorm
35 that slowed his progress across the Ross Ice Shelf. Although January 1912 was marked with
36 slightly below average temperatures and pressure, high temperatures and good conditions were
37 observed in early February 1912, when Scott and his companions were at the top of the
38 Beardmore Glacier. When compared to the anomalously cold temperatures experienced by the
39 Scott polar party in late February and March of 1912, the temperature change is in the top 3%
40 based on more than 35 years of reanalysis data. Scott and his companions therefore faced an
41 exceptional decrease in temperature when transiting to the Ross Ice Shelf in February/March
42 1912, which likely made the persistent cold spell they experienced on the Ross Ice Shelf be
43 perceived as even more intense by comparison.

44

45

46 **1. Introduction**

47 The Norwegian and the British Antarctic Expeditions to the South Pole are often
48 regarded as the height of the heroic age of Antarctic exploration. Using a team of five men and
49 primarily relying on dog sledges, Roald Amundsen first reached the geographic South Pole on
50 December 14, 1911. Just over a month later, a team of five men led by Captain Robert Falcon
51 Scott reached the South Pole on January 17, 1912, only to find a tent left by Amundsen. While
52 Amundsen and the remaining crew at the main Norwegian base at Framheim were able to safely
53 leave the Antarctic continent in late February 1912, Scott and his four companions, who
54 primarily man-hauled their sledges and supplies, unfortunately perished on their return journey
55 to their main base of Cape Evans on Ross Island. Figure 1 shows the routes of each polar
56 expedition, as well as the location of their main bases.

57 The stories of these heroic journeys have been documented in several books, but are also
58 recorded in journals kept by many of the members of both polar parties. Both teams kept
59 meteorological logs of the weather conditions at their main bases and at least daily measurements
60 made by various sledging parties, containing primarily pressure and temperature data. In
61 particular, the extensive analysis of the observations by British meteorologist George Simpson
62 provides substantial insight into the conditions faced by the teams. Using this data in
63 comparison with contemporary automatic weather station data on the Ross Ice Shelf (called the
64 ‘Barrier’ by both polar parties), Solomon and Stearns (1999) and Solomon (2001) concluded that
65 the weather in March of 1912, when Scott and his two remaining companions perished, was
66 much colder and persistent than average, and was a primary cause of their tragic end. Here it is
67 demonstrated that the atmospheric pressure and associated temperature conditions throughout
68 much of early December 1911 and late February – March 1912 were also exceptional across the

69 location of the South Pole race, and likely across much of Antarctica. In the context of the
70 colder than average conditions in March 1912 experienced by Scott and his polar party, this
71 places an even more dramatic change in the weather coming down from the south polar plateau
72 to the Ross Ice shelf, and therefore might have also made these cold spells be perceived as more
73 intense by comparison. It is not our intent to contrast the leadership styles or other factors that
74 led to the vastly different outcomes between the Norwegian and British Antarctic South Pole
75 expeditions as done by Huntford (1985), but to rather demonstrate that the pressure and
76 temperature conditions during the journey to the pole in December for both polar parties and
77 back in February / March for Scott were unique in many aspects.

78 **2. Data and Methods**

79 The primary source of data for the British Antarctic expedition comes from atmospheric
80 temperature and pressure data analyzed by Simpson, who first published the records and other
81 aspects of the Antarctic meteorology in a three-volume set in 1919 (Simpson 1919, 1923). The
82 third book provides numerical tables of observations at Cape Evans and all the field party
83 observations. For the field party observations, latitude and longitude are given when they were
84 determined by theodolite or sextant. Observations at Cape Evans were generally taken every
85 hour, while up to three data points were typically taken by the field parties (often morning, lunch
86 time, and evening). Rather than focusing on daily minimum temperatures as done in Solomon
87 and Stearns (1999), this study uses daily means for both temperature and pressure, averaging all
88 available well-exposed sling thermometer observations for each day that they were recorded.
89 Exposure to the free airstream is critical for accurate measurements of atmospheric temperature,
90 and both expeditions used sling thermometers that were twirled to ensure this (Simpson (1919),
91 pp. 17-18; Moen (1915), pp. 49-50). Minimum thermometer data recorded underneath the

92 sledges reported by the Scott expedition are not used because they can display a cold bias due to
93 pooling of cold air beneath the sledges, impeding the airflow needed for accurate temperature
94 measurements (Simpson 1919, p. 19). Similar results for the sling thermometer data along the
95 sledging journeys are obtained using daily maximum and minimum temperatures, or by
96 averaging the measured maximum and minimum temperatures rather than all available
97 observations (Fig. S1), despite some of the differences discussed between these values in
98 Simpson (1919). In addition to the meteorological observations from the main polar party led by
99 Scott, we also make use of data from shorter duration sledging parties in support of the main
100 British polar party (such as the Dog Sledge party, the Motor Sledge party, and the First Relief
101 party), available in Simpson (1923).

102 For the Norwegian expedition, meteorological observations were published in 1915,
103 which similarly includes observations at their main base of Framheim and observations during
104 the dog sledging journey to the South Pole and back (Mohn 1915). For the Framheim
105 observations, the three-times daily pressure and temperature observations from April 1911 -
106 January 1912 are used. On the main polar journey, there are often three observations per day
107 from 19 October 1911 through 26 January 1912; daily mean temperature and pressure are used,
108 averaging over all available observations each day.

109 To place the observations in a climatological context, pressure and temperature
110 measurements at McMurdo, the main U.S. Antarctic base situated on the southern tip of Ross
111 Island in very close proximity to the British base of Cape Evans (Fig. 1), are employed, although
112 sea ice conditions at the two stations often differ, which can affect climate. Hourly observations
113 from 1957-2016 are analyzed, obtained from the British Antarctic Survey. During the summer,
114 pressures at McMurdo are similar to those across the Ross Ice Shelf / Barrier (Costanza et al.

115 2016), and this single point with the longest continuous record therefore provides an estimate of
116 pressure across the entire Ross Ice Shelf, as will be demonstrated later. Further, the seasonal
117 pressure reconstructions at McMurdo presented in Fogt et al. (2016a) are examined, which
118 extend the seasonal mean pressure at this location back to 1905. Further information on the
119 pressure reconstruction techniques can be obtained in Fogt et al. (2016a,b), but during summer
120 (December - February, DJF), the pressure reconstruction at McMurdo correlates at $r=0.872$ with
121 observations during the period of overlap; it is therefore deemed that this pressure reconstruction
122 is the best available estimate of pressure variability at McMurdo over the early 20th century.
123 While pressures can be considered fairly uniform, local temperatures are well known to be
124 highly variable around Ross Island and on parts of the Ross Ice Shelf, due for example to
125 katabatic and foehn winds, and variations in sea ice cover (e.g., Bromwich, 1989, Spiers et al.,
126 2012; Costanza et al. 2016).

127 To estimate the long-term climatological context of the meteorological conditions along
128 the sledge journeys for both Amundsen and Scott, daily mean temperature and pressure from the
129 European Centre for Medium Range Weather Forecasts (ECMWF) Interim Reanalysis (ERA-Int)
130 are used. This reanalysis is available at $0.75^\circ \times 0.75^\circ$ latitude / longitude resolution, and
131 compares well to surface observations of Antarctic climate (Bracegirdle and Marshall 2012).
132 The climatological aspects of near-surface temperature on the Ross Ice Shelf and surrounding
133 polar plateau in ERA-Interim (Fig. S2) agree well with temperature maps from interpolated
134 AWS data discussed in Costanza et al. (2016), including the relatively colder temperatures
135 extending westward from Roosevelt Island toward the Transantarctic mountains and the
136 relatively warmer air on the Ross Ice Shelf near many of the major glacial valleys in the
137 Transantarctic mountains. However, in places of steep terrain, especially within the

138 Transantarctic mountains when the journeys ascended glaciers (the Axel-Heiberg for Amundsen
139 and the Beardmore for Scott, Fig. 1) to reach the polar plateau, there are differences in the
140 surface elevation between ERA-Int and the real-world reflected in the observations collected on
141 both sledge journeys. To account for this, the model elevations in ERA-Int (determined from the
142 invariant variable geopotential, Fig. S3) were corrected to a best estimate taken along each
143 sledging journey track in Fig. 1 from Google Earth. For temperature, a standard atmospheric
144 environmental lapse rate of 6.5°C per km was used to adjust ERA-Int temperatures to the actual
145 elevation; despite large differences in the ERA-Int elevations within the Transantarctic
146 mountains, the corrected temperature climatology from ERA-Int agrees well with observations
147 by Amundsen and Scott (Fig. S4). Further, 85% of the elevations from Google Earth are within
148 50 m of the 1-km Bedmap2 surface elevation data (Fretwell et al. 2013), implying less than
149 0.4°C difference after correction using the environmental lapse rate. This uncertainty is small
150 compared to the $>5^{\circ}\text{C}$ anomalies focused on here. Elevation-corrected pressure data are not used
151 in this study, as only pressure measurements taken on the Barrier are investigated. For all these
152 locations, the reported elevations by both Scott and Amundsen were below 100m, and the
153 differences between the ERA-Int model's surface elevation and those from Google Earth were
154 less than 50m, therefore having negligible impact on our interpretation of the pressure
155 climatology.

156 ERA-Int provides a daily location-dependent climatological (1981-2010) average and
157 standard deviation and daily maximum and minimum (1979-2015) elevation-corrected
158 temperature along the tracks of both parties. This allows us to approximate how unusual the
159 daily measured conditions were for each party along their routes. For pressure comparisons,
160 three century-length gridded reanalyses / pressure datasets are also briefly examined, namely the

161 ECMWF 20th century reanalysis (ERA-20C), the Hadley Centre gridded mean sea level pressure
162 version 2 (HadSLP2; Allan and Ansell 2006), and the National Oceanic and Atmospheric
163 Administration – Cooperative Institute for Research in Environmental Studies (NOAA-CIRES)
164 20th century reanalysis, version 2c (20CR, Compo et al. 2011). In all cases, austral summer is
165 defined as the December-February (DJF) average.

166 **3. Results**

167 While recent research has discussed the negative summer pressure trends across much of
168 Antarctica associated with the trend toward the positive polarity of the Southern Annular Mode
169 (SAM; Turner et al. 2005; Fogt et al. 2016b; Jones et al. 2016), there is not much known about
170 Antarctic pressure variability prior to 1957. The seasonal pressure reconstructions of Fogt et al.
171 (2016a,b) provide additional detail on this, and the pressure reconstruction for McMurdo is
172 presented in Fig. 2a. Notably, there is a large positive spike during summer 1911/12, when
173 seasonal mean pressures rise above 1000 hPa. The reconstruction pre-1957 shows only one
174 other summer with pressures above 1000 hPa, in 1925/26, as discussed in Fogt et al. (2016b),
175 while the direct observations display one summer in 1976/77 when they exceed 1000 hPa. This
176 ranks the McMurdo pressure during the summer of the South Pole races in the top three highest
177 over the last 110 years, highlighting its exceptional character; similar conclusions are reached
178 when examining the pressure reconstruction at Amundsen-Scott South Pole station (Fig. S5). In
179 comparison with the seasonal mean pressures recorded during 1911/12 at Framheim and Cape
180 Evans in Fig. 2b, as well as three gridded pressure datasets (20CR, ERA-20C, and HadSLP2), it
181 is clear that the DJF 1911/12 pressure is much higher in magnitude than the other seasons during
182 these two years (and above the summer McMurdo climatological average of 992.03 hPa), with
183 all six datasets agreeing with this anomaly.. Remarkably, the summer averaged observed

184 pressure values at Framheim (December-January only) and Cape Evans are within 0.8 hPa of the
185 reconstructed value (which is based solely on Southern Hemisphere midlatitude pressure data,
186 Fogt et al. 2016a), indicating that pressures were fairly uniform across the Ross Ice Shelf in
187 summer, and that the McMurdo pressure reconstruction performs near perfectly when compared
188 with the Cape Evans observations. Looking across the entire Antarctic continent in DJF 1911/12
189 using the 20CR reanalysis (Fig. 2c), which assimilated the surface pressure data at both
190 Framheim and Cape Evans, both the reanalysis anomalies (contoured / shaded) and the
191 observations (equatorward of 60°S) and reconstruction (poleward of 60°S, except for Orcadas,
192 near the Antarctic Peninsula at 60.7°S, 44.7°W, which has observations back until 1903, Zazulie
193 et al. 2010) pressure anomalies (circles) indicate that this summer was exceptional across all of
194 the high southern latitudes. The station-based pressure reconstruction anomalies are strongly
195 positive over Antarctica, in agreement with 20CR, with the standardized anomaly almost always
196 greater than 2 standard deviations from the 1981-2010 mean, and some of the
197 observed/reconstructed anomalies at the stations > 6.0 hPa. The overall pattern in Fig. 2c is
198 consistent with a very strong negative SAM index year, and both ERA-20C and HadSLP2
199 similarly show this structure, although with differing magnitudes of the anomalies over
200 Antarctica (Fig. S6). SAM index reconstructions in Jones et al. (2009) for DJF 1911/12 were
201 strongly negative, with the Fogt SAM index reconstruction showing a value of -3.867 in this
202 year, the second most negative since 1850, only slightly weaker than in 1964. Thus, there is a
203 larger body of supporting evidence that not only were pressures well above average across the
204 Ross Ice Shelf in DJF 1911/12, but also across the entire Antarctic continent in conjunction with
205 a strong negative SAM index year.

206 To further investigate the exceptional nature of this summer, daily mean pressure and
207 temperature observations at Cape Evans and Framheim Bases, as well as from the sledging
208 records when Scott and Amundsen were on the Barrier (defined here as elevations below 100 m)
209 are investigated in Fig. 3. The 1911/12 observed pressures are compared to the daily McMurdo
210 climatological mean (1981-2010) and ± 2 standard deviation envelope (black line and shading,
211 respectively, in Fig. 3a) to provide a climatological context. All observations, including sledging
212 data from both Amundsen and Scott, indicate pressures frequently above 1000 hPa, more than
213 two standard deviations above the McMurdo daily climatological means, from late November
214 through December 1911. During summer, pressure anomalies are fairly uniform across the
215 Antarctic continent (Fogt et al. 2016b), especially across the Ross Ice Shelf (Fig. S7; Costanza et
216 al. 2016), allowing for a comparison of the sledging pressure data while the parties were on the
217 Barrier along with their pressure observations at each base. From the Cape Evans observations,
218 daily mean pressures are again anomalously high during early February 1912, and return to
219 within the 2 standard deviation range of McMurdo daily mean observations in mid-February,
220 remaining within this envelope throughout March 1912. Many of these daily mean pressure
221 observations would be records in comparison to the 60+ years of McMurdo observations (not
222 shown), which is most comparable to the pressure at Cape Evans, about 15 miles from McMurdo
223 and at the same elevation (near sea level; Fig. 1).

224 Temperatures during the period in December 1911 when pressures were particularly high
225 are examined in Fig. 3b, plotted as daily anomalies from the ERA-Int climatology at each
226 location and day, since temperature varies much more than pressure across the Ross Ice Shelf
227 (Costanza et al. 2016). Using seasonal mean data, Marshall (2007) demonstrated that warmer
228 temperatures are common during SAM negative years in Antarctica (outside of the Antarctic

229 Peninsula), when the pressure is above average poleward of 60°S. However, from ERA-Int data,
230 the relationship between pressure and temperature across Antarctica is much weaker in monthly
231 data, and much stronger on the Antarctic plateau than the Ross Ice Shelf, with the latter only
232 showing statistically significant ($p < 0.05$) pressure / temperature correlations in November and
233 February (Fig. S8). It is therefore not surprising to see a strong positive temperature anomaly for
234 the Norwegian polar party temperatures in early December (Fig. 3a), when Amundsen was
235 already on the polar plateau above the Axel Heiberg glacier and approaching the South Pole (Fig.
236 1). At their peak on 6 December 1911, the temperatures measured by Amundsen exceeded -
237 16°C, which represents an anomaly relative to our estimate from ERA-Int climatology of more
238 than 10°C (note, elevation corrections to ERA-Int daily mean temperatures account for very little
239 of this large positive anomaly; elevation differences average only 3 meters for the period 1-10
240 December between ERA-Int and Google Earth along Amundsen's route). Amundsen's sledging
241 temperature measurements during this time are much warmer than the hourly and daily mean
242 observations collected at the South Pole station since 1957, even when accounting for the
243 average differences in temperature between Amundsen's location and the South Pole, which is
244 often colder than nearby areas due to pooling of cold air in the slightly lower elevation (Comiso
245 2000). The daily mean temperature measured at the South Pole on December 7, 2015 of -19.8°C
246 (max hourly temperature of -18.2°C) is the only comparable warm day before December 11th,
247 otherwise observed South Pole daily mean temperatures have never exceeded -20°C in this
248 portion of early summer. Using the closest ten-minute quality controlled data at the Henry
249 automatic weather station (-89.0°S, -0.39W; also corrected for warm temperature bias at low
250 wind speeds following Genthon et al. 2011), daily maximum temperatures above -20°C occurred
251 for two consecutive days in 2015 and 2012, but these are quite warm exceptions to the normal

252 conditions (Fig. S9). In contrast, Amundsen experienced four continuous days with daily mean
253 temperatures exceeding -19.0°C and temperature anomalies from the ERA-Int climatology
254 greater than 10°C . At the onset of this warm weather on December 5, 1911, Amundsen noted
255 that ‘...there was a gale from the north, and once more the whole plain was a mass of drifting
256 snow. In addition to this there was thick falling snow, which blinded us and made things worse,
257 but a feeling of security had come over us and helped us to advance rapidly and without
258 hesitation, although we could see nothing.’ (Amundsen 1913, p. 107). The blizzard like warm
259 weather continued on through December 8th, when it finally gave way to clearer and calmer
260 conditions. At this time, Amundsen reflects on the warmer conditions, writing ‘*The weather had*
261 *improved, and kept on improving all the time. It was now almost perfectly calm, radiantly clear,*
262 *and, under the circumstances, quite summer-like: -0.4°F [-17.5°C]. Inside the tent it was quite*
263 *sultry. This was more than we expected’* (Amundsen 1913, p. 115). Later, on that same day, he
264 further noted ‘*The warmth of the past few days seemed to have matured our frost-sores, and we*
265 *presented an awful appearance.*’ (Amundsen 1913, p. 116). Little did he and his companions
266 know that these ‘summer-like’ conditions in early December 1911 were exceptionally warm,
267 even though this region frequently experiences warm air intrusions from the Ross Ice Shelf
268 (Hogan 1997).

269 Although not as exceptional, Scott’s party also experienced warm conditions in excess of
270 5°C above the ERA-Int climatological mean during 5-8 December 1911 (Fig. 3b), when he and
271 his team were on the Ross Ice Shelf. As for the Amundsen polar party, the warm conditions
272 experienced by the British expedition at this same time were also accompanied with a blizzard
273 on the Ross Ice Shelf, which kept them immobile during the Dec 5-8 1911 period. In contrast to
274 the relative dryness of the high Plateau, conditions on the Ross Ice Shelf can be wet when flow

275 conditions allow an influx of relatively warmer marine air. During this time, Edward Wilson, the
276 doctor on the British polar party, frequently mentions in his journal the warm, wet conditions,
277 with heavy wet snow, as noted on December 8, 1911: ‘*We woke up to the same blizzard blowing*
278 *from the S. and S.E. with warm wet snow +33 (°F) [0.56°C]. All three days frightfully deep and*
279 *wet...It has been a phenomenal warm wet blizzard different to, and longer than, any I have seen*
280 *before with excessive snowfall.*’ (King 1972, p. 212).

281 Despite the warm conditions experienced by both parties in early December on the Ross
282 Ice Shelf and polar plateau, temperature anomalies at the northern end of the Ross Ice Shelf
283 recorded at Cape Evans and Framheim were slightly negative throughout December (Fig. 3b).
284 The negative temperature anomalies at these locations are consistent with the fact that the SAM
285 influence is much weaker on the perimeter of the continent, especially at McMurdo, compared to
286 the interior (Marshall 2007). Additionally, local conditions such as the extent of sea ice cover,
287 likely influenced temperatures differently at these sites than poleward along the sledging tracks,
288 in agreement with the overall weak and insignificant pressure - temperature correlations on the
289 northern Ross Ice Shelf throughout much of October – March (Fig. S8).

290 To gain further insight on the temperatures experienced by the polar parties throughout
291 their entire sledging journey, the temperature anomalies along the tracks of both Amundsen and
292 Scott are compared to the ERA-Int climatological (1981-2010) and maximum / minimum daily
293 mean (1979-2015) temperature anomalies (for each day and location along the tracks in Fig. 1) in
294 Fig. 4. Amundsen’s temperature anomalies are almost entirely positive until January, with some
295 values in early December when pressures were the highest (Fig. 3) being well above the
296 maximum anomaly in ERA-Int (Fig 4a); these temperature anomalies are consistent with the
297 above-average pressure anomalies at Framheim throughout all of December and the stronger

298 positive pressure-temperature correlations on the polar plateau (Fig. S8), where Amundsen spent
299 much of the month of December. Temperature anomalies along Scott's track are also available
300 from the first and second return parties (Fig. 4b), which were sent back to Cape Evans from near
301 the bottom of and the top of the Beardmore Glacier, respectively; temperature data collected in
302 these sledging records indicate a warm December, especially in early December when a few high
303 temperature records were observed compared to ERA-Int values, consistent with the negative
304 SAM influence in summer (Fig. 2), and the stronger temperature – pressure correlations during
305 December along the Transantarctic mountains (Fig. S8) near Scott's route (Fig. 1).

306 Even though both polar parties spent some time on the polar plateau in January 1912,
307 where temperature-pressure relationships are stronger (Fig. S8), due to the much smaller pressure
308 anomalies at this time at Cape Evans and Framheim, it is not too surprising to see both parties
309 observe colder than average temperatures (Figs. 4a,b). Because of the reduced temperature
310 variability in January (indicated by the gray shading in Figs. 4a,b), these below average
311 temperature anomalies rarely are lower than -5°C , and are generally smaller than the positive
312 anomalies in early December 1911. Further, while a few of the colder temperature
313 measurements for each party in January 1912 may have fallen below two standard deviations
314 from the ERA-Int climatological mean (for that location / day), the two parties never
315 simultaneously observed persistent strong cold spells, unlike the warm spell in early December
316 discussed previously (Fig. 4c).

317 When the pressure measurements at Cape Evans become exceptionally high again in
318 early February 1912 (Fig. 3a), conditions change for Scott's party, and persistent above average
319 temperature anomalies were recorded again on the polar plateau (Fig. 4b). Similar to the blizzard
320 conditions in early December he encountered on the Ross Ice Shelf, Scott makes frequent note of

321 these warm conditions at the top of the Beardmore Glacier, providing further evidence that they
322 were exceptionally warm and not an artifact of elevation adjustments to the ERA-Int data. When
323 the daily mean temperature anomalies were the highest on February 9th and 10th 1912, more than
324 8°C and 10°C above the ERA-Int climatological average (Fig. 4b), respectively, Scott writes:
325 *‘Very warm on march and we are all pretty tired. To-night it is wonderfully calm and warm,*
326 *though it has been overcast all the afternoon’* (Huxley 1913, p.389) on February 9, and *‘...snow*
327 *drove in our faces with northerly wind-very warm and impossible to steer, so camped...The ice*
328 *crystals that first fell this afternoon were very large. Now the sky is clearer overhead, the*
329 *temperature has fallen slightly, and the crystals are minute’* (Huxley 1913, p. 390). Although
330 the temperatures fell slightly on the evening of the 10th, they remained warm, with anomalies
331 from the ERA-Int climatology generally at or above 5°C until February 14th. Notably, Scott
332 makes no further mention of the warmer weather, and instead writes more on the crevassed
333 conditions, finding the next depot, and the failing health of seaman Evans. However, during
334 these unusually warm days, Scott’s team slowed their pace, spending time collecting geologic
335 specimens. They failed to reach a key life-saving supply depot by only about 12 miles when
336 Scott’s party died a few weeks later, and it is plausible that they may have survived if they had
337 not slowed down on these days. The unusual warmth of early February, consistent with the
338 timing of exceptionally high pressures at Cape Evans and Framheim (Fig. 3a), may have
339 contributed to that choice.

340 These much warmer-than-average temperatures in early February were followed by
341 unusually cold conditions in late February and March 1912, as shown in Figs. 4b-c and discussed
342 in Solomon and Stearns (1999). It should be noted that the sling thermometer used by Bowers,
343 who collected the meteorological observations for the Scott polar party, broke on March 10; the

344 instrument and method used for later data noted by Scott in his diary are unknown and those data
345 are not examined here. Examining all available sling thermometer temperature anomalies from
346 the various sledging parties (Fig. 4c), including the Dog Sledge party, the Motor Sledge party,
347 and the First Relief party (who were sent to find and attempt to rescue Scott and his companions
348 if needed in March 1912), the general pattern of a warmer-than-average December 1911 emerges
349 (especially early December), and the warmer-than-average conditions experienced by Scott in
350 early February also stand out as exceptional; these temperature anomalies are overall consistent
351 with the exceptionally high pressure anomalies throughout December and again in early
352 February recorded at Cape Evans. Importantly, temperature anomalies are plotted in Fig. 4, and
353 therefore these warm conditions, particularly in early February experienced by Scott's crew,
354 exceed the climatologically averaged locally warmer temperatures on the Beardmore Glacier
355 compared to nearby places in the Transantarctic mountains (Fig. S2). Similarly, the colder
356 temperatures experienced by Scott and his companions in early March are below the
357 climatologically averaged (1981-2010) locally colder temperatures in the central and western
358 Ross Ice Shelf, where they were located at this time (Costanza et al. 2016; Fig. S2).

359 The cold spell experienced by Scott in late February and March 1912 has been discussed
360 as an element that led to the weakening of several of the Scott polar party and played a role in
361 their fate (Solomon and Stearns, 1999). Consistent with the findings of Solomon (2001), the
362 present analysis suggests that although the daily averaged temperatures at this time were unusual,
363 they were not record cold, and they do not fall below the 2 standard deviation threshold based on
364 the ERA-Int climatology. Despite Scott writing that '*...no one in the world would have expected*
365 *the temperatures and surfaces which we encountered at this time of year*' (Huxley 1913, p. 416)
366 in his letter to the public, it was likely not the cold temperatures per se, but rather their

367 persistence, that played a role in their demise, as argued by Solomon (2001). However, the
368 change in temperature anomalies from early to late February, associated with the tail end of the
369 exceptionally high pressures at Cape Evans (Fig. 3a), is nonetheless exceptional. As discussed
370 earlier, Scott and his companions were at the top of the Beardmore Glacier in early February
371 1912, and because there are larger differences here in the elevation of the ERA-Int model and the
372 real world (Fig. S3), a portion of the temperature anomalies at this time may be due to an
373 underestimation of the climatological temperature when correcting for the elevation difference in
374 ERA-Int. To provide the most conservative estimate, ERA-Int temperatures were also corrected
375 using the dry adiabatic lapse rate of $9.8^{\circ}\text{C km}^{-1}$ rather than the environmental lapse rate of 6.5°C
376 km^{-1} used in all of our previous analyses. Following this adjustment, the warm spell during
377 February 9-15 is then contrasted with the cold spell from February 27 – March 5, using
378 histograms of the ERA-Int corrected temperature difference between these two periods at the
379 respective locations on Scott's route in Fig. 5, plotted as both a raw difference and anomalies
380 (which removes the seasonal cycle). Scott's absolute difference of 19.58°C and anomaly
381 difference of 12.58°C clearly stand out as unique: in only one year during 1979-2015 was there a
382 similar large swing in temperatures on these days (and in ERA-Int these are still smaller than that
383 observed by Scott, although it just falls in the same 2-degree wide histogram bin). Such a
384 difference, based on the approximate normal distribution of the data in Fig. 5, has a probability
385 of $p < 0.001$ occurring in any given year, highlighting that the change from a warm early February
386 to a cold late February was exceptionally rare. Notably, the temperature change remains in the
387 top 3% of the data distribution when using various window lengths (from 4 – 15 days) for both
388 the warm and cold spells (Fig. S10), and is therefore not sensitive to the specific range of dates
389 chosen. As such, this unique and dramatic change would have undoubtedly made the colder

390 temperatures experienced soon after on the Barrier be perceived as even colder, perhaps
391 justifying the surprise that Scott conveyed in his letter to the public about these cold conditions.

392 **4. Conclusions**

393 While several studies have focused on the unusually cold conditions Scott and his
394 companions experienced in March 1912 (Solomon and Stearns 1999; Solomon 2001), new
395 analysis presented here highlights that for both expeditions, many aspects of the summer of
396 1911/12 were also exceptional in terms of the meteorological conditions. Most impressive was
397 the prolonged period of anomalously high pressures recorded during December 1911 at the bases
398 of Cape Evans and Framheim, as well as by the sledging parties while on the Ross Ice Shelf.
399 Associated with these pressure values that frequently and persistently exceeded two standard
400 deviations from the climatological average at McMurdo were warmer-than-average conditions in
401 the interior of the Ross Ice Shelf, near the Transantarctic mountains, and on the polar plateau, in
402 wet and dry blizzard conditions, respectively. In particular, Amundsen's polar party observed
403 temperature anomalies in excess of 10°C (an absolute daily mean temperature of -15.5°C) on the
404 plateau in their approach to the South Pole; comparable warmth has only once been observed in
405 over 60 years of temperature measurements during December 1- 10 at the Amundsen-Scott
406 South Pole station. At the same time, Scott experienced warmer-than-average temperatures as
407 well while on the Barrier, with warm wet snow that delayed their journey several days. While
408 both temperature and pressure remained below to near average in January 1912, Scott
409 experienced much warmer-than-average conditions on the descent down the Beardmore Glacier
410 in early February, followed by much colder-than-average temperatures on the Ross Ice Shelf in
411 early March. The period of warmth, consistent with another period of exceptionally high
412 pressures at Cape Evans, may have lulled Scott's party into slowing down, and it is possible that

413 they would have reached their key next depot if they had not done so. Although temperatures
414 naturally turn colder at this time of year with the onset of winter, over 30 years of ERA-Int data
415 indicate that during 1979-2015, the temperatures rarely ($p < 0.05$) changed as sharply as Scott and
416 his men experienced. Reconstructions of the pressure at individual stations across Antarctica, as
417 well as early SAM index reconstructions, further indicate that the summer of 1911/12 was
418 marked by one of the strongest negative SAM years since 1850. Notably, the summer of
419 1911/12 was also marked with El Niño conditions in the tropical Pacific (reflected to some
420 extent by the Southern Oscillation pattern in Fig. 2c), and other research suggests that the
421 combination of El Niño events with negative SAM phases act to amplify the atmospheric
422 response across the Pacific sector of Antarctica (L'Heureux and Thompson 2006; Fogt et al.
423 2011). It was therefore likely that the combination of these two climate patterns gave rise to the
424 overall exceptional summer during the South Pole race, which makes this incredible story even
425 more of a legend.

426

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433 Laboratory for the 20th Century Reanalysis data
434 (http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2c.html), and the UK Hadley
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437 [finder.htm](https://www.freemaptools.com/elevation-finder.htm)), and Dr. Stephen Livingstone of the University of Sheffield is thanked for comparing
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439 our manuscript and their comments, which helped to clarify our main points.

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502

503 **Figure Captions**

504 **Figure 1.** Map showing the routes of Scott and Amundsen, along with key locations. The return
505 journey for Scott is only depicted for when meteorological observations were collected up until
506 March 10, 1912.

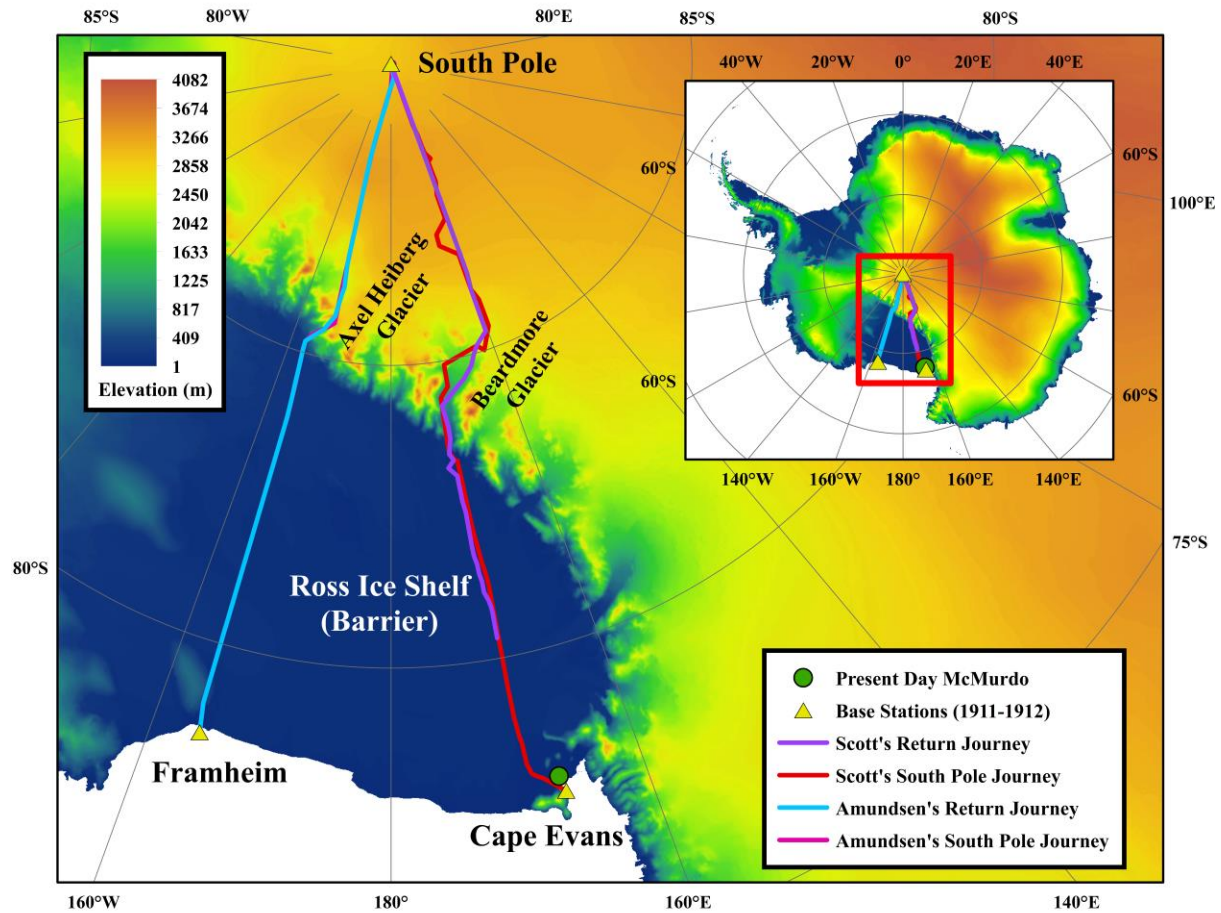
507 **Figure 2.** a) Summer mean pressure observations (black) and reconstructions with 95%
508 confidence intervals (gray band) for McMurdo station (see Fig. 1 for location). b) Comparison
509 of seasonal mean pressures from observations, gridded pressure datasets, and reconstructions
510 (and their 95% confidence intervals, gray shading) during 1911-1912. c) 20CR pressure
511 anomalies and standard deviations (contoured and shaded, respectively), along with circles
512 indicating observed midlatitude pressure anomalies (equatorward of 60°S) and Antarctic pressure
513 reconstruction anomalies (poleward of 60°S), with anomaly magnitude given by the legend.
514 Anomalies are relative to the 1981-2010 climatological mean.

515 **Figure 3.** a) October 1911 – March 1912 daily mean pressure data from the British and
516 Norwegian bases, and along the sledging routes on the Barrier/ Ross Ice Shelf when the
517 elevations are <100 m. The McMurdo daily mean climatological pressure and 95% confidence
518 interval (± 2 standard deviations, gray shading) are given for reference. b) Daily mean
519 temperature anomalies, calculated from the 1981-2010 ERA-Int climatology for day / location,
520 during December 1911.

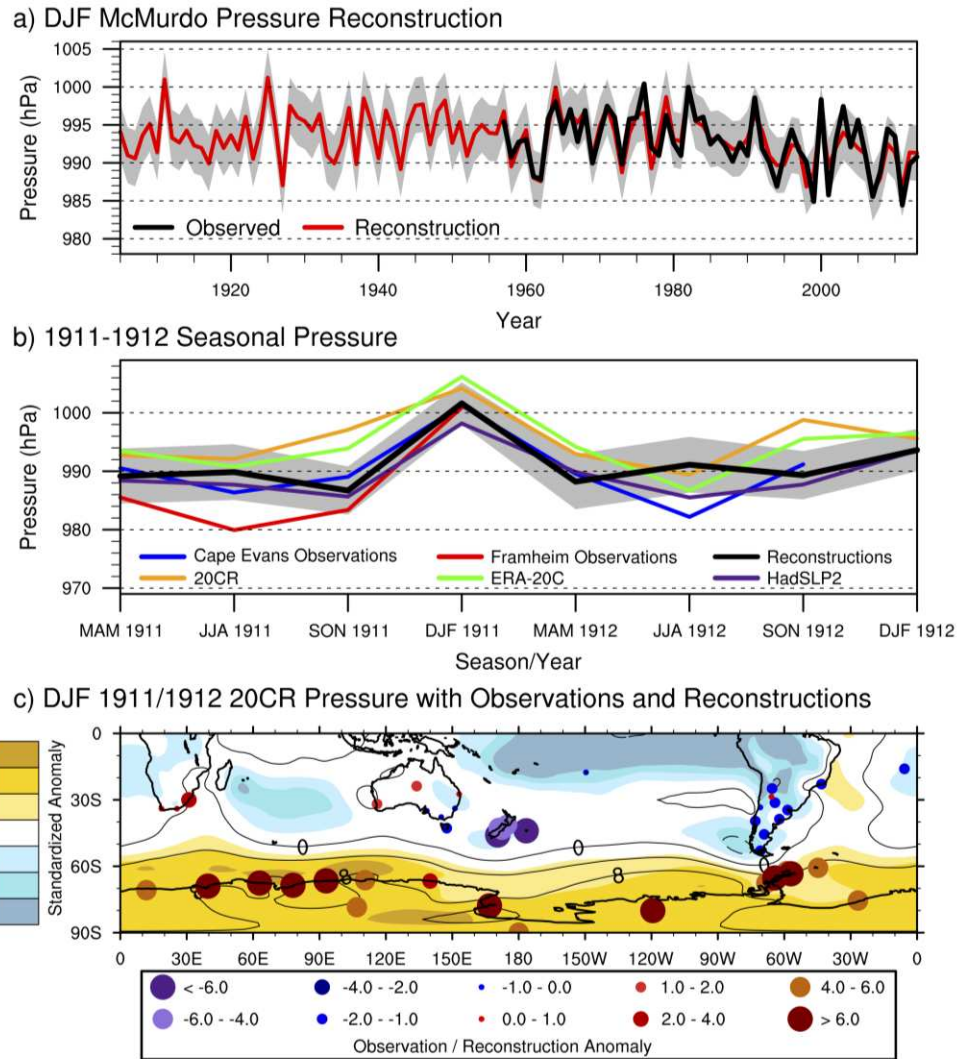
521 **Figure 4.** a) Along track temperature anomaly for Amundsen, as well as the ± 2 standard
522 deviation envelope and maximum and minimum along-track temperature anomaly. Anomalies
523 are calculated with reference to the ERA-Int 1981-2010 daily climatology for each day/ location,
524 corrected to elevation using a lapse rate of $6.5^{\circ}\text{C km}^{-1}$. b) As in a), but for sledging
525 measurements along the Scott route. The thin purple lines represent the maximum and minimum
526 temperature anomalies for the second return party. c) Combined plot of all available sledging
527 temperature anomalies during 1911-1912.

528
529 **Figure 5.** Temperature difference histograms for the a) absolute and b) anomaly temperature
530 difference from ERA-Int during 1979-2015 for February 9-15 minus February 27-March 5, 1912.
531 The x-axis is binned in 2°C increments. The differences as recorded by the Scott polar party are
532 indicated with a red outline. To provide the most conservative estimate, ERA-Int temperatures
533 were corrected for elevation differences using the dry adiabatic lapse rate of $9.8^{\circ}\text{C km}^{-1}$.

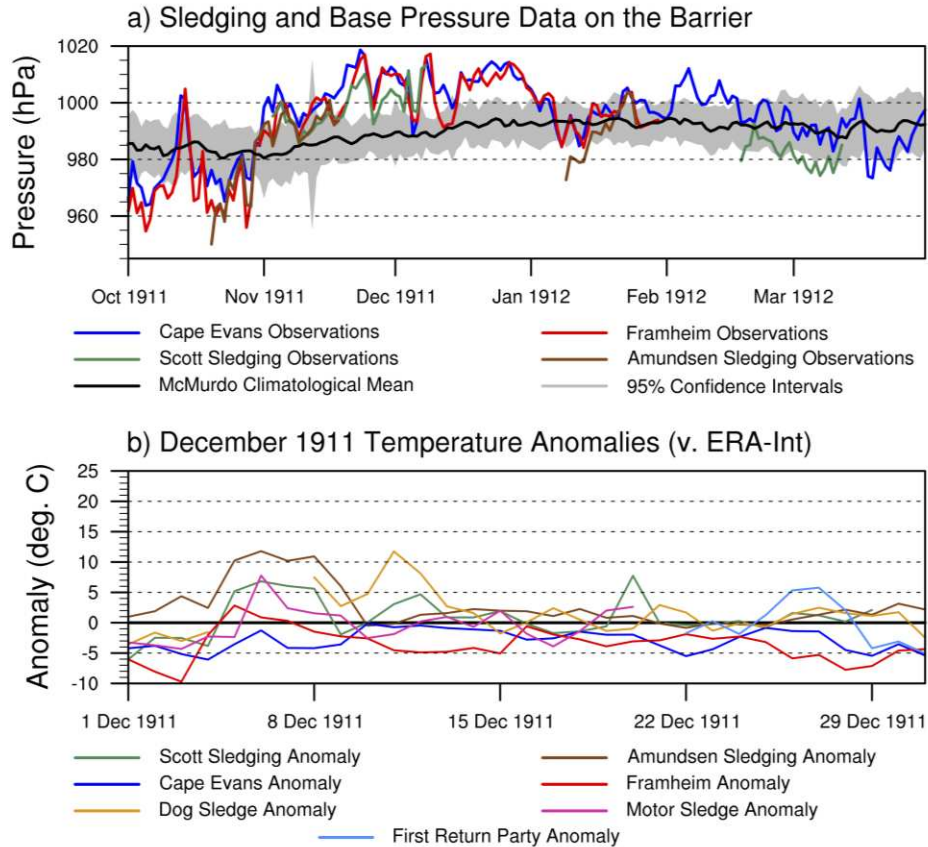
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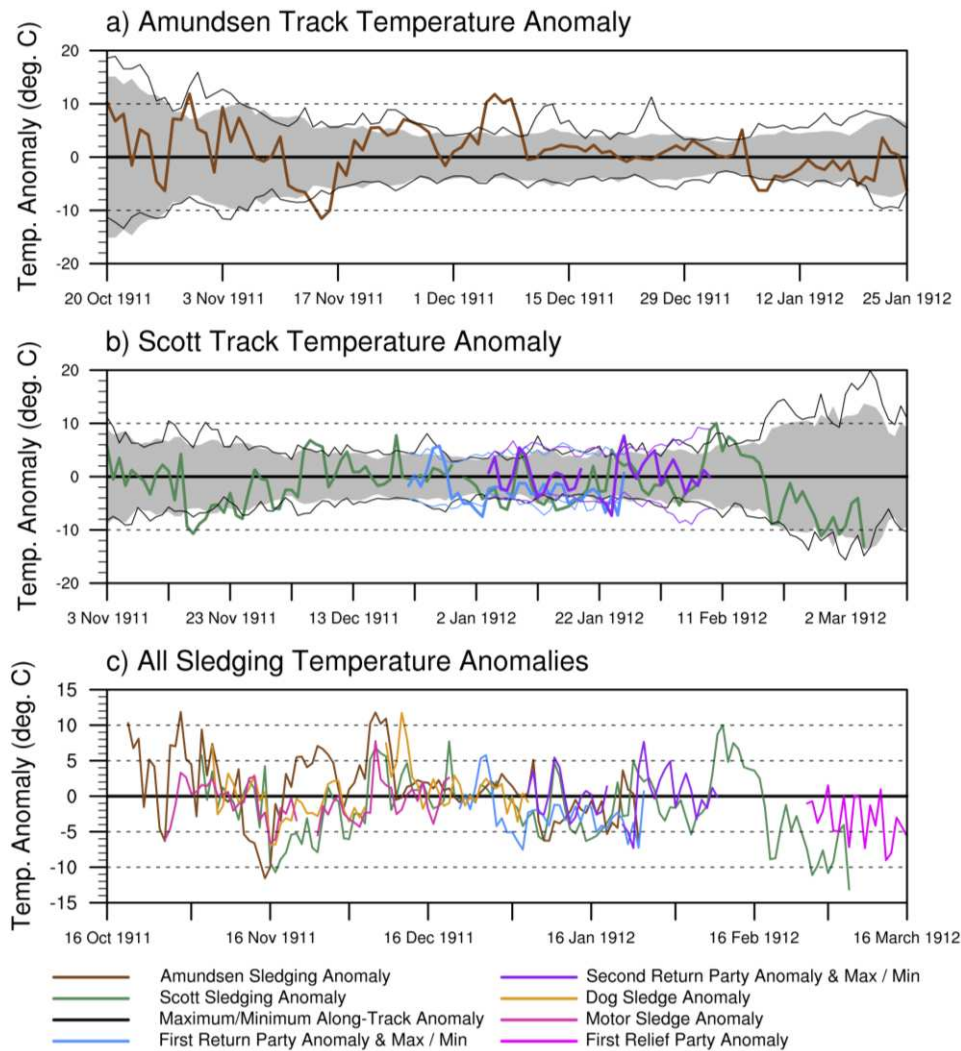
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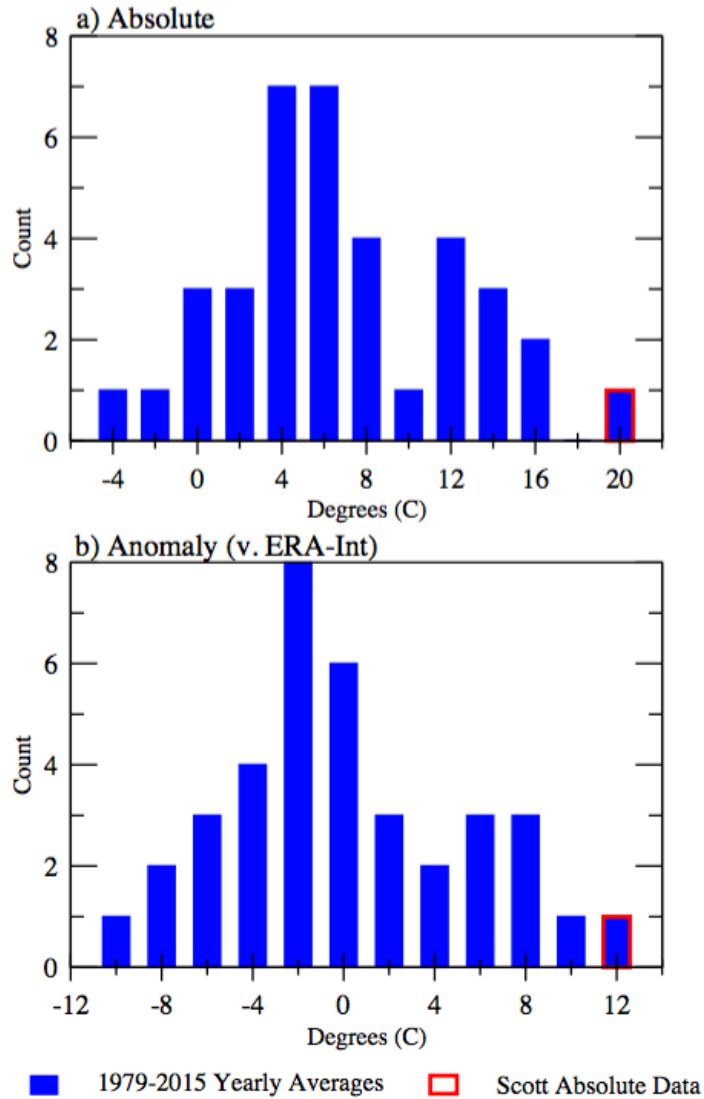
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