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Extreme precipitation event at the Ross Ice Shelf during the 1911–1912 South Pole run

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Abstract: In March 1912, Captain Robert Falcon Scott and his companions perished on their return journey from the South Pole. The Final Blizzard delivered a terminal blow. However, it was only a part of this story of endurance and tragedy. In December 1911, en route to the South Pole, the men had been tent-bound for 4 days due to an exceptionally warm, wet blizzard. This article compares the meteorological situation that the polar party encountered in December 1911 to a similar situation in the modern time and suggests a possible climatology behind the 1911 event.

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Introduction

The South Pole Race of 1911–1912 probably makes one of the most dramatic stories of the heroic age of exploration of Antarctica. The British expedition, led by Captain Robert Falcon Scott, and the Norwegian expedition, led by Roald Amundsen, both aimed to reach the South Pole in parallel routes with no way of learning about the progress of each other before they reached the South Pole. Scott's party reached the South Pole on 17 January 1912, only to discover that Amundsen had put the Norwegian flag there 1 month earlier, on 14 December 1911. While Amundsen and his party safely made it back to their home base, Scott and his men perished on their return journey. The human factor of the tragedy of the British expedition is fascinating, and so is the weather, which played an enormous role in the catastrophic outcome. The most notable, fateful weather events were the December 1911 4 day blizzard and the March 1912 10 day Final Blizzard. Schwerdtfeger (1984: 153–156) wrote about the December 1911 blizzard: 'It is a fair guess that without … intervention of this extraordinary weather phenomenon, Scott and his men would have made it home.' Several papers and books have been written regarding the weather during the 1911–1912 South Pole run (Solomon & Stearns 1999, Solomon 2002: 305, Fogt *et al.* 2017). However, none has discussed the climatology behind the rare blizzard that both parties experienced on 5–6 December 1911, and that Scott's party also experienced for 2 more days. At that time, Amundsen was at the Polar Plateau and Scott was 12 miles north of the Beardmore Glacier (Fig. 1). Solomon (2002: 178) calls this blizzard 'truly unusual', and unusual it was. Even before the 4 day blizzard started, on 3 December 1911, Scott (1913: 332) noted: 'The changes of conditions are inconceivably rapid, perfectly bewildering', and that 'the whole weather conditions seem thoroughly disturbed'. On 4 December 1911, Scott (1913: 332) writes in his journal: 'The barometer rose from 29.4 [99 560 pa] to 29.9 [101 253.0 pa] last night, a phenomenal rise. Evidently there is very great disturbance of atmospheric conditions.'

At Scott's camp, this blizzard was accompanied by tremendous wind (up to 80 miles/h or 35.8 m/s; Solomon 2002: 178). However, even more unusual was the enormous amount of wet snow that fell on Scott's camp between 5 and 8 December 1911. Amundsen experienced snowfall on the Plateau for more than 2 days, but he and his group were able to continue on their journey south. This blizzard was probably the first ever extreme precipitation event (EPE) witnessed by humans on both the Ross Ice Shelf (RIS) and the Plateau.

This study uses the modern data associated with similar weather conditions that occurred at the RIS in early January 2005 to suggest a possible climatology of the December 1911 event.

Data and methods

For historical data, Scott's (1913), Cherry-Garrard's (1922) and Amundsen's (1913) accounts are used, as well as Simpson's (1923) tables with meteorological diaries. The Twentieth Century Reanalysis by National Oceanic and Atmospheric Administration (NOAA), Cooperative Institute for Research in Environmental Sciences (CIRES) and the US Department of Energy (DOE; NOAA-CIRES-DOE 20CR version 3; 20CRv3) and the ERA5 reanalysis are used to create the synoptic plots for 1911 and 2005, respectively. Satellite images from NASA are also used for the 2005 EPE.

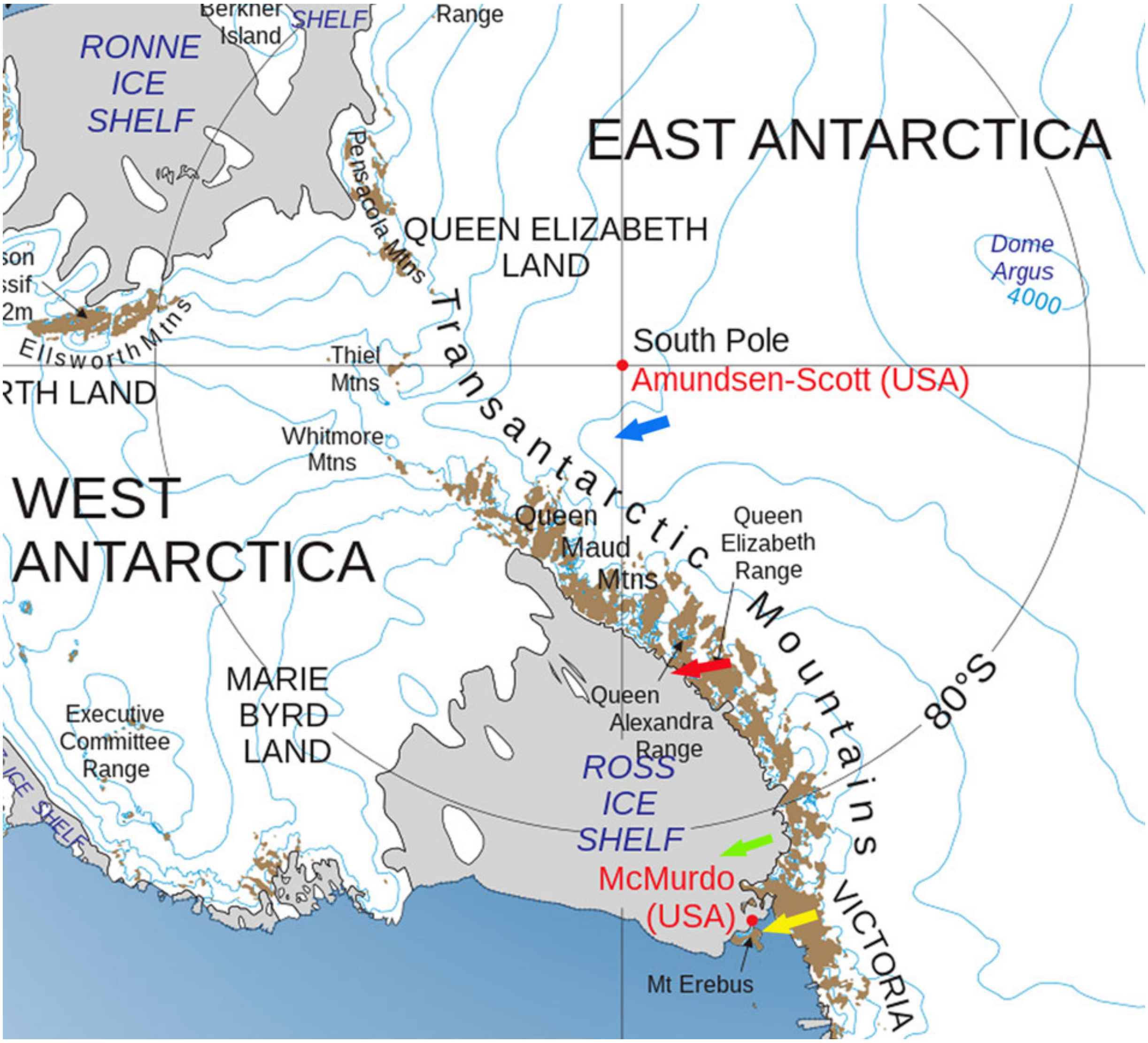

Figure 1. Map of Antarctica. An approximate position 88°3' S, 170° W of Amundsen for 5 December 1911 is marked with the blue arrow; the position of Scott's party (83°20' S) on 5 December 1911 is marked with the red arrow; the position of the motor party is marked with the green arrow; the position of Cape Evans is marked with the yellow arrow.

Results

The accounts of the eyewitnesses

The blizzard that stopped Scott's party at the RIS started on 5 December 1911, when Scott's party was ~12 miles from Beardmore Glacier (83°20' S; Fig. 1) on their way south. However, the bad weather began earlier, on 2 December 1911. At that time, the challenging conditions were variable, and the party was still able to march south. Below are the descriptions of the weather conditions that the explorers from different parties encountered from 2 to 5 December 1911.

2 December 1911

The stratus spreading over from the S.E. last night meant mischief, and all day we marched in falling snow with a horrible light. (Scott 1913: 332)

[…]

It was so warm when we camped that the snow melted as it fell, and everything got sopping wet. (Scott 1913: 331)

3 December 1911

[…] *thick and snowy* (Scott 1913: 332)

4 December 1911

[…] *a glance outside was sufficient to show a regular white floury blizzard.* (Scott 1913: 333)

Late evening on 5 December 1911

It has blown hard all day with quite the greatest snowfall I remember. The drifts about the tents are simply huge. The temperature was +27° this forenoon, and rose to +31° in the afternoon, at which time the snow melted as it fell on anything but the snow, and, as a consequence, there are pools of water on everything, the tents are wet through, also the wind clothes, night

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boots, &c.; water drips from the tent poles and door, lies on the floorcloth, soaks the sleeping-bags, and makes everything pretty wretched. (Scott 1913: 335)

Keohane's rhyme!

The snow is all melting and everything's afloat, If this goes on much longer we shall have to turn the tent upside down and use it as a boat. (Scott 1913: 336)

[…] *snow in large flakes* (Simpson 1923: 637)

Noon on 6 December 1911

[…] *everything in the tent is soaking. People returning from the outside look exactly as though they had been in a heavy shower of rain. The snow is steadily climbing higher about walls, ponies, tents, and sledges* (Scott 1913: 336)

Very much like sleet in wetness (Simpson 1923: 637)

7 December 1911

Phenomenal snowfall, large, soft, wet flakes like sleet (Simpson 1923: 637)

[…] *snow sticks to shovels as plaster but falling on one's clothing runs down as rain* (Simpson 1923: 637)

This day was just as warm, and wetter - much wetter. The temperature was +35.5°, and our bags were like sponges (Cherry-Garrard 1922: 346)

8 December 1911

[…] *snow and wind as usual* (Scott 1913: 336)

[…] *wind and snow were monotonously the same. The temperature rose to +34.3°* (Cherry-Garrard 1922: 346)

Snowfall round the camp tremendous, drifts 6 ft. high, consisting of soft, squashy snow. (Simpson 1923: 625)

During a.m. blowing fresh from SSE with much snowfall (Simpson 1923: 637)

9 December 1911

The tremendous snowfall of the late storm had made the surface intolerably soft, and after the first hour there was no glide. (Scott 1913: 338)

At the same time the Polar Party was experiencing the blizzard, another part of the British expedition (the Motor Party) was located at 79.31 S, 169.22 E (Fig. 1). Their weather observations are provided in Simpson (1923: 661):

6 December 1911

[…] *This morning everything is wet and the surface is sticky.*

7 December 1911

Minimum temperature 32 F. every dark object - i.e. sledge, shovel, ski boards all wet.

8 December 1911

Water still lying on all dark objects; surface very soft.

9 December 1911

Water still lying on all dark objects; surface very soft; water running off sledges (Scott 1913: 338)

On 5 December 1911, the Norwegian party was at the Polar Plateau at ~88° S (and later 88°9' S, 170° W). Amundsen (1913: 107) wrote in his journal:

5 December 1911

[…] *there was a gale from the north, and once more the whole plain was a mass of drifting snow. In addition to this there was thick falling snow, which blinded us and made things worse* […]

6 December 1911

[…] *the same weather: thick snow, sky and plain all one, nothing to be seen.*

7 December 1911

December 7 began like the 6th, with absolutely thick weather […]

On 6 December 1911, Amundsen recorded the temperature to be > -16°C (~3°F), 'which represents an anomaly relative to our estimate from ERA-Interim climatology of more than 10° C' (Fogt *et al.* 2017).

By 9 December 1911, 18–24 inches (457–610 mm) of snow was recorded at Cape Evans (Fig. 1; Simpson 1923: 306). Was this blizzard an EPE? Turner *et al.* (2019) define an EPE as an event in which daily precipitation exceeds a percentile value of the 1979–2016 distribution (the 90th percentile in their study) for 1 or more days. The 90th percentile (mm) for the RIS is 1.16 mm (Turner *et al.* 2019). Thus, the snowfall the Polar Party endured on the RIS from 2 to 8 December 1911 was definitely an EPE, as evident from the weather conditions described by the eyewitnesses.

Did some parts of the RIS and the Transantarctic Mountains melt and refreeze in December 1911?

Several accounts by Scott (1913) appear to suggest that melting of some parts of the RIS and the Transantarctic Mountains did occur. After the storm subsided, the Polar Party entered the glacier's valley in the Transantarctic Mountains. Day after day, they continued to encounter very soft snow, in which 'the sledges themselves sank to the crossbars in soft spots' (Scott 1913: 341). On 16 December 1911, Scott (1913: 348) wrote that 'the snow had become wet and sticky'. The air temperature on that day was +15°F. On 19 December 1911, at a height of ~5800 feet (1768 m), Scott (1913: 351) fell in one of the 'very annoying criss-cross cracks'. A few times Scott used the word 'neve' to describe the surface:

- 15 December 1911: 'patches of ice and hard neve are showing through in places'.
- 19 December 1911: 'The last mile, neve predominating'.
- 23 December 1911: 'we got on the most extraordinary surface - narrow crevasses ran in all directions. They were quite invisible, being covered with a thin crust of

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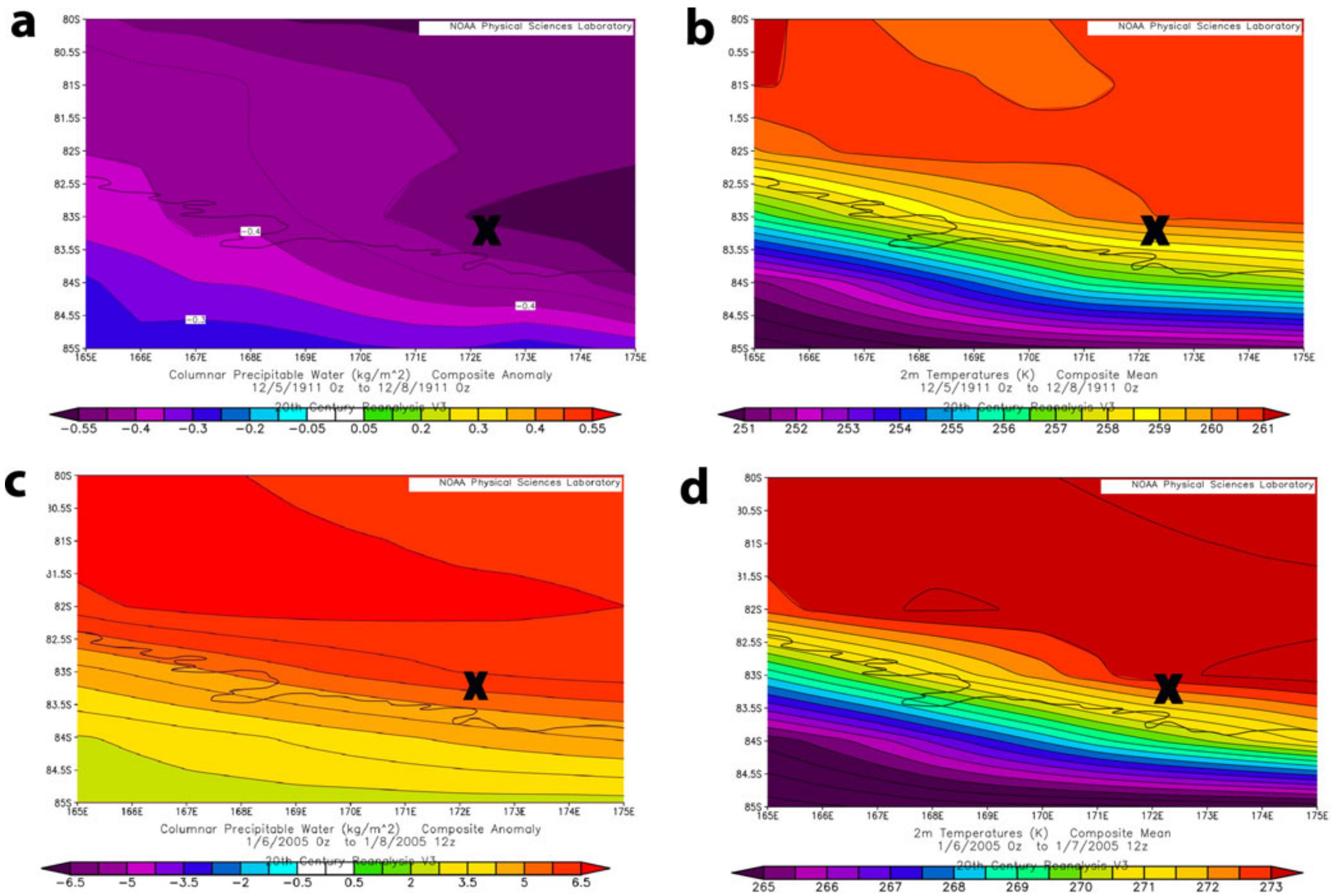

Figure 2. The plots created with the Twentieth Century Reanalysis. **a.** Anomaly of columnar precipitable water from 5 to 8 December 1911. **b.** The 2 m mean air temperature from 5 to 8 December 1911. **c.** Anomaly of columnar precipitable water from 6 to 8 January 2005. **d.** The 2 m mean air temperature from 6 to 8 January 2005. The position of Scott's Party is marked with the black 'X'.

hardened neve without a sign of a crack in it.' According to dead reckoning, the party was located at 85°22'1" S., 159°31' E. Their elevation was 7750 feet (2362 m; Scott 1913: 355).

- 25 December 1911: 'to our annoyance found ourselves amongst crevasses once more - very hard, smooth neve between high ridges'. Dead reckoning was 85°50' S, 159°8'2" E (Scott 1913: 357).

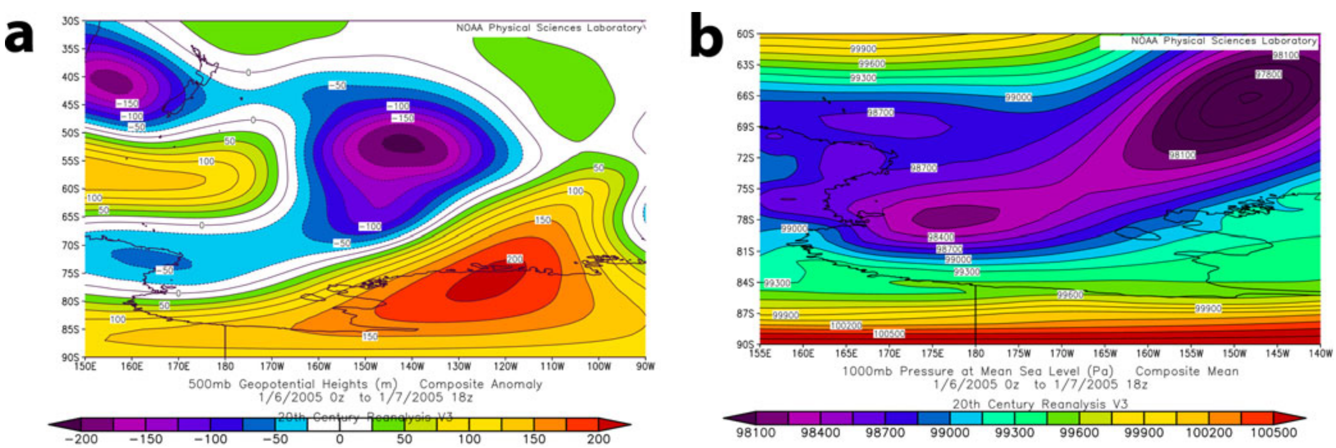

Figure 3. a. 500 mb geopotential height anomaly shows a blocking high over Marie Byrd Land (Fig. 1). **b.** Pressure at mean sea level shows a synoptic-scale cyclone affecting the Ross Ice Shelf.

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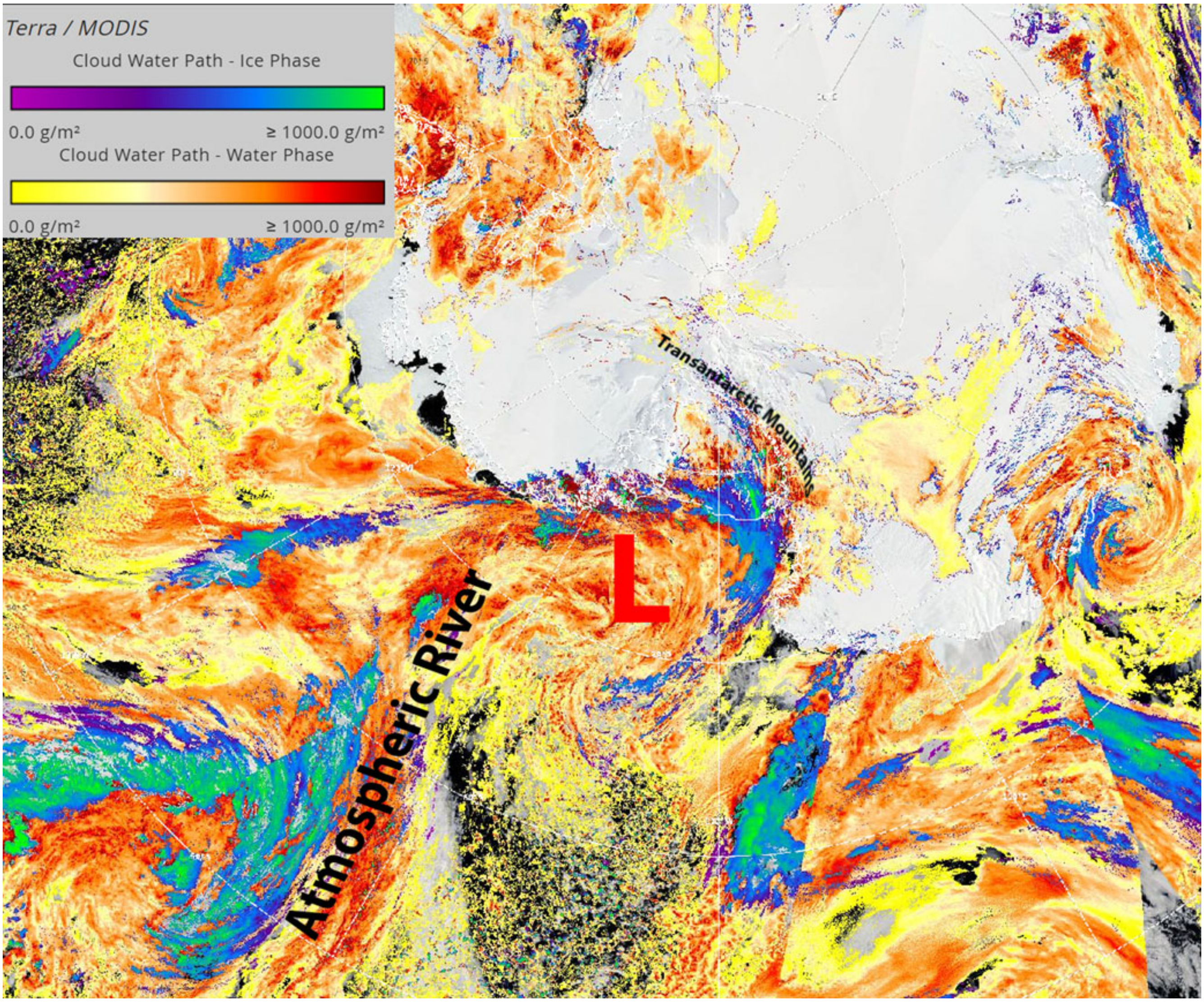

Figure 4. A Moderate Resolution Imaging Spectroradiometer (MODIS) satellite image of the Antarctic and sub-Antarctic Oceans for 3–4 January 2005. The MODIS Cloud Water Path indicates the amount of water in the atmosphere above a unit surface area of the Earth. The image reveals an atmospheric river, which transported moisture from the mid- to high latitudes, where it embedded itself into the extratropical cyclone (marked with the red 'L') in the Ross Sea. Notice that the moisture advanced into the Ross Ice Shelf alongside the Transantarctic Mountains, to the same places, in which the members of the Terra Nova expedition endured the December 1911 4 day blizzard. Credit: NASA.

Miller (1952: 150) talked to several French and Swiss glaciologists (because *névé* is a French word) and they 'consider that *névé* is a more or less dense and settled, although permeable, aggregate of medium to large individual grains formed and welded together by frequent alternations of melting and freezing on original snow crystals'.

Some melting and refreezing affected the RIS as well. On 27 February 1912, while going north over the RIS, Scott (1913: 401) encountered '[v]ery curious surface - soft recent sastrugi which sink underfoot, and between, a sort of flaky crust with large crystals beneath'. The author of this article asked a retired NASA scientist, Dr James L. Foster (who has published multiple papers on snowmelt), what he makes of Scott's description. Dr Foster responded: 'Yes, to me, the mention of flaky crust seems to indicate some sort of melt and refreeze.'

The Twentieth Century Reanalysis

The Twentieth Century Reanalysis cannot be used to analyse the climatology of the December 1911 EPE. The key synoptic parameters (the anomaly of columnar precipitable water and 2 m mean air temperature) plotted

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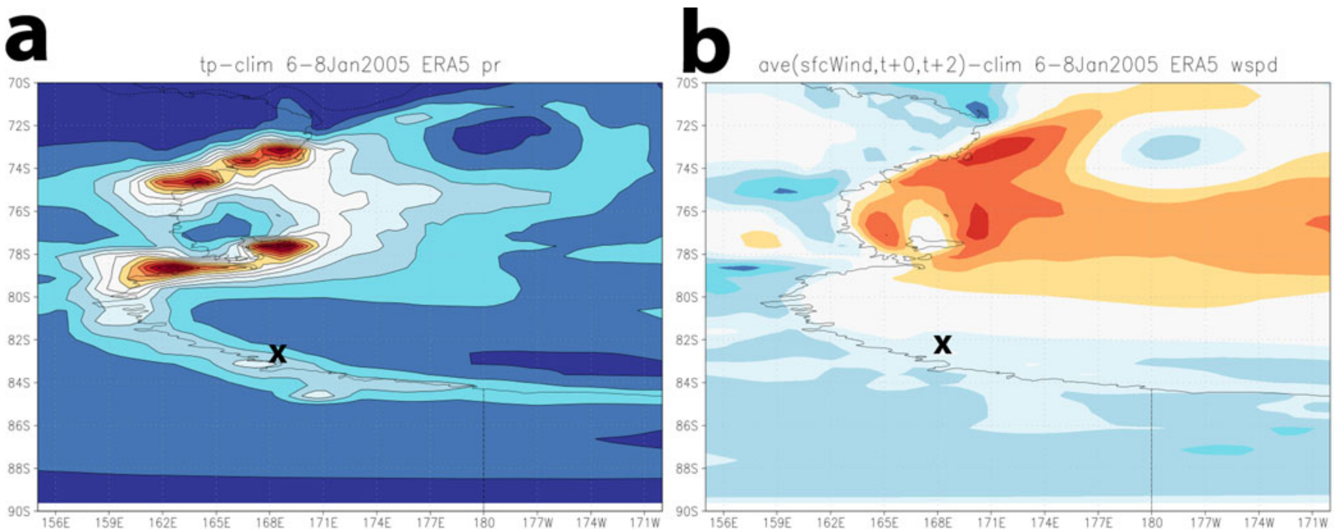

Figure 5. The reanalysis plots created with ERA5 reveal the anomalies in **a.** precipitation and **b.** wind speed from 6 to 8 January 2005. The position of Scott's party is marked with the black 'X'.

with the Twentieth Century Reanalysis for the key days in December 1911 (Fig. 2a,b) do not agree with the descriptions provided by the members of the Terra Nova expeditions. The anomaly of columnar precipitable water (Fig. 2a) is negative, and the 2 m mean air temperature of 260 K (8°F) is much lower than that reported by Scott's party. This confirms Bromwich *et al.*'s (2007) findings that early Antarctic reanalysis is unreliable and cannot be used to determine the climatology of the December 1911 EPE.

On the other hand, the synoptic parameters of a similar event that occurred in January 2005 (Fig. 2c,d) mostly agree with the conditions of the December 1911 EPE. Is it possible to use reanalysis plots and satellite images of the January 2005 event to better understand the climatology of the December 1911 event?

January 2005 event

Fogt (2005) describes 'a persistent low pressure and snow' from 4 to 11 January 2005. The storm 'disrupted all of the north-south flights during its stay, and many of the intercontinental operations'. Some of the roads at Scott's Base (New Zealand research station at Ross Island) were at condition 1, the worst weather condition possible, whereas McMurdo Station (the US research station at Ross Island; Fig. 1) was at condition 2 and sometimes, during a 'several windows of good weather', at condition 3. The storm was a synoptic-scale cyclone that 'remained in this location for several days due to ridging [a blocking high] over Marie Byrd Land'. Figure 3a (500 mb geopotential height anomaly) shows a blocking high that kept a synoptic-scale cyclone (Fig. 3b) in place in January 2005.

Zou *et al.* (2021) identified January 2005 as a year with a 'powerful moisture transport (~100 $kg \cdot m^{-1} \cdot s^{-1}$) from the Amundsen/Ross Sea region' to the RIS, which expanded towards the Transantarctic Mountains. In 2005, moisture flux occurred from 3 to 7 January (Zou *et al.* 2021). Two atmospheric rivers (ARs) made landfall at the RIS on 4 January (Fig. 4) and 6 January (Wille *et al.* 2019). The Glossary of Meteorology defines an AR as a 'long, narrow, and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone'. A satellite image of the AR that made landfall on the RIS on 3–4 January 2005 is presented in Fig. 4. The AR originated over mid-latitudes and transported moisture to Antarctica, embedded in the warm conveyor belt of an extratropical cyclone over the Ross Sea.

The January 2005 event resulted in above-normal air temperatures (Fig. 2d) and above-normal precipitation (Fig. 5a). According to the ERA5 plot (Fig. 5b), the winds along the Transantarctic Mountains were not affected, which probably means that the event of December 1911 was stronger.

Not only can ARs cause EPEs, they also can cause severe melting over the RIS (Zou *et al.* 2021) that can last for weeks (Scott *et al.* 2019). The meltwater can penetrate beneath the surface, and then, when the air temperature drops, this meltwater turns into ice. In January 2005, the surface melting on the RIS was captured by NASA satellites (Fig. 6), and the mechanisms of the melting were described by Wille *et al.* (2019) and Zou *et al.* (2021). The 2005 melting event was rather unusual because it affected high elevations in the Transantarctic Mountains. Tedesco *et al.* (2007) write: 'Also, first-time [for the study years 1987–2006]

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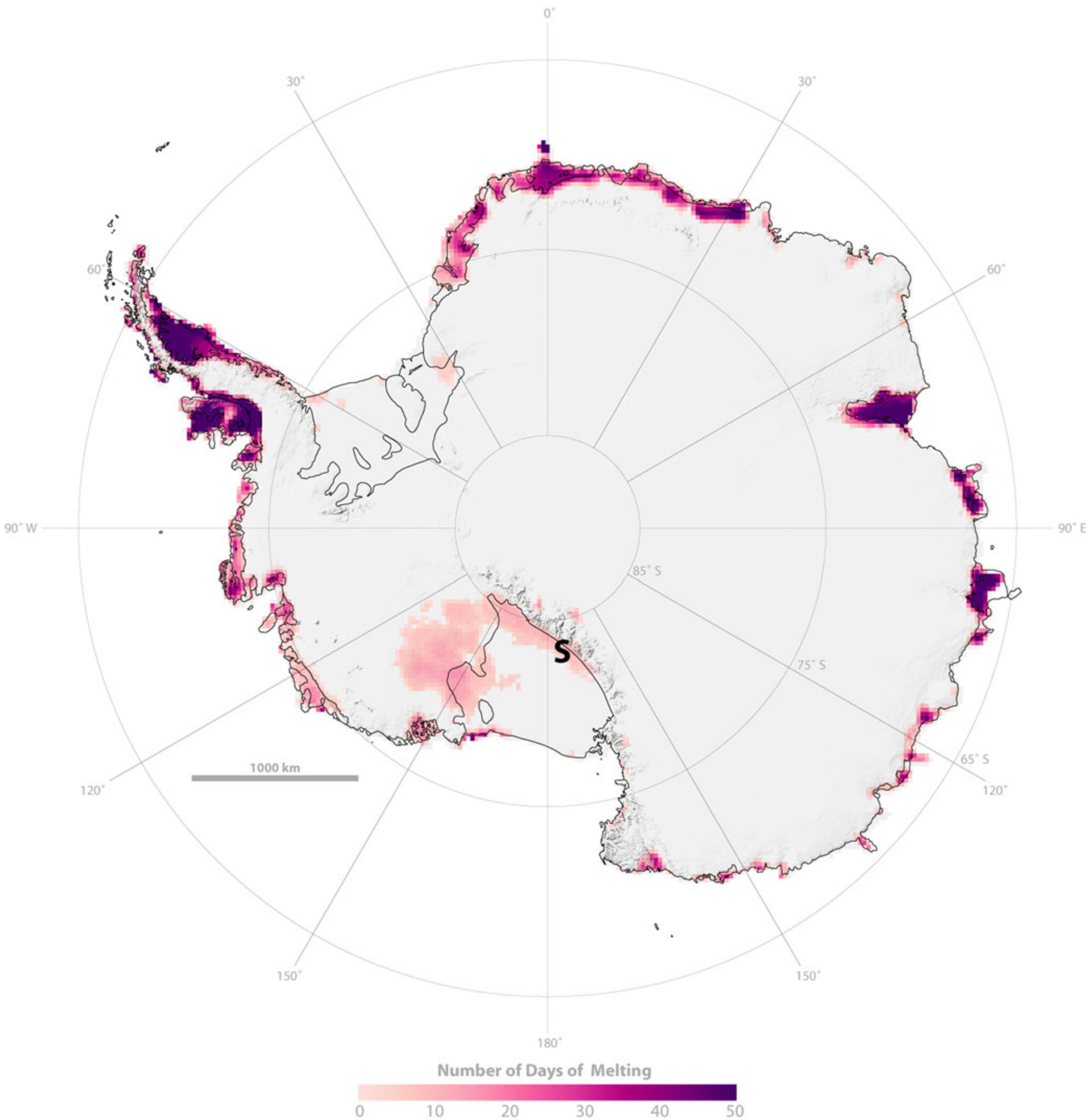

Figure 6. Satellite imagery shows the number of Antarctic melting days for the 2004–2005 season. Areas where melting occurred for a greater number of days are indicated in increasingly dark purple shading. Note the melting patches at > 85°S. An approximate location of Scott's party is marked with the black 'S'. Credit: NASA/Rob Simmon.

extensive melting occurred over the Transantarctic Mountains and on the edge of the Ross Ice Shelf for the week between January 6–12, 2005, with melting reaching areas located 875 km inland and 2000 m above sea level.' Wille *et al.* (2019) attribute 'nearly 100%' of the melting events at the higher elevations in the Marie Byrd Land (Fig. 1) to the ARs. Although the authors do not mention the higher elevations in the Transantarctic Mountains, it is reasonable to assume that the tendency at the higher elevations in Marie Byrd Land and at the higher elevations in the Transantarctic Mountains would be approximately the same.

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Are there some similarities between the December 1911 event and the January 2005 event?

We have already proven that the December 1911 event was an EPE. Adusumilli *et al.* (2021) established that 63% of the EPEs over the West Antarctic Ice Sheet were associated with ARs. Wille *et al.* (2021) concluded that '70% of the highest 1% of precipitation events can be attributed to ARs across East Antarctica'. As we discussed earlier, the Norwegian party experienced an EPE on the Polar Plateau (East Antarctica) for > 2 days and a 10°C positive air temperature anomaly for 4 days (Fogt *et al.* 2017), which both suggest the intrusion of warm marine air.

Was the December 1911 EPE caused by the ARs? A few factors suggest that it was:

1) The apparent melting over some parts of the western RIS and most importantly in the higher elevations in the Transantarctic Mountains as described by Scott (1913).
2) The Southern Annular Mode (SAM) index for December 1911 was strongly negative (-3.867; Fogt *et al.* 2017). Negative SAM favours ARs affecting Marie Byrd Land and the RIS (Fig. 1; Wille *et al.* 2019).
3) The duration of the event from 2 to 8 December 1911 strongly indicates the presence of a blocking high, and as Wille *et al.* (2019) write: 'AR landfalls are most likely when the circumpolar jet is highly amplified during blocking conditions in the Southern Ocean.'
4) The significant increase in the air temperatures, not only on the RIS but also on the high Plateau, is consistent with intrusion of very warm marine air.
5) Figure 3 reveals that the locations where the observations were made in December 1911, which are located in a very close proximity to the path that the ARs took in January 2005. In addition, the apparent refreezing that Scott (1913) observed in the Transantarctic Mountains at 85°22'1" S., 159°31' E is located alongside the melting-refreezing site of January 2005 (Fig. 6).

Conclusion

The early December 1911 snowfall was experienced by multiple parties of explorers over an area of > 1000 km from Cape Evans at Ross Island to the Polar Plateau (Fig. 1) and over a wide range of elevations from just a few hundred metres above sea level to ~3000 m above sea level. The snowfall lasted for a few days and was described as 'phenomenal' and 'tremendous'. It was accompanied by a 'very great disturbance of atmospheric conditions' (Scott 1913: 332). Therefore, this event was certainly an EPE.

The plots created with the Twentieth Century Reanalysis (Fig. 2a,b) do not agree with the accounts provided by Scott (1913) and Simpson (1923). On the other hand, the December 1911 accounts provided by the explorers do agree with the synoptic situations in January 2005 presented by the Twentieth Century Reanalysis plots (Fig. 2c,d). The extent of the melting-refreezing in January 2005 (Fig. 6) also agrees with Scott's (1913) account of December 1911. Thus, it is reasonable to assume that, in December 1911, there was probably a blocking high in the position similar to that of January 2005 (Fig. 3). An AR probably made landfall on the RIS, and its path was similar to that of January 2005 (Fig. 4).

The accounts of the December 1911 EPE probably represent the only case in which observations of such a rare event were made by humans from multiple locations and over multiple days, and as such they are of significant scientific value.

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Author contributions

Mila Zinkova - 100%.

Competing interests

The author declares none.

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