On the role of the weather in the deaths of R. F. Scott and his companions

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Robert Falcon Scott and his companions reached the South Pole in January of 1912, only to die on their return journey at a remote site on the Ross Ice Shelf, about 170 miles from their base camp on the coast. Numerous contributing causes for their deaths have been proposed, but it has been assumed that the cold temperatures they reported encountering on the Ross Ice Shelf, near 82–80°S during their northward trek toward safety, were not unusual. The weather in the region where they perished on their unassisted trek by foot from the Pole remained undocumented for more than half a century, but it has now been monitored by multiple automated weather stations for more than a decade. The data recorded by Scott and his men from late February to March 19, 1912, display daily temperature minima that were on average 10 to 20°F below those obtained in the same region and season since routine modern observations began in 1985. Only 1 year in the available 15 years of measurements from the location where Scott and his men perished displays persistent cold temperatures at this time of year close to those reported in 1912. These remarkably cold temperatures likely contributed substantially to the exhaustion and frostbite Scott and his companions endured, and their deaths were therefore due, at least in part, to the unusual weather conditions they endured during their cold march across the Ross Ice Shelf of Antarctica.

In November of 1911, Captain Robert Falcon Scott led a team of men south from their base at Cape Evans on McMurdo Sound, striving to be the first to arrive at the South Pole and to claim this historic achievement in exploration for Britain. They marched and skied over the Ross Ice Shelf, up the Beardmore Glacier, and across the south Polar Plateau for more than 900 miles (see Fig. 1), reaching the Pole in January, 1912. There they found what they had feared—the flag of Norway, which had been planted by Roald Amundsen and his team almost a month earlier. Scott and two remaining companions ended their terrible trek of more than 1,600 miles near the end of March, 1912, in a tent at roughly 79.6°S, 170°E, about 170 miles from the safety of their base, after completing an epic journey wholly by foot in the most inhospitable place in the world (ref. 1; ref. 2, p. xxxviii).

As they marched to their deaths, some of the men kept journals. On February 27, 1912, E. A. Wilson ended his very last diary entry with the stark words "Turned in at −37 (°F)" (ref. 3, p. 245). Scott continued writing, and on March 10, 1912, he wrote that "the weather conditions are awful" (ref. 1, p. 588). In his last days, Scott also penned numerous farewell letters. Among these was a "Message to the Public," in which he presented his view of the problems that had plagued their expedition (such as the loss in the previous summer of several of the ponies that were used to pull their supplies part of the way). But he stressed that "all the facts above enumerated were as nothing to the surprise which awaited us on the Barrier . . . our wreck is certainly due to this sudden advent of severe weather, which does not seem to have any satisfactory cause" (ref. 1, p. 606).

The meteorologist of Scott's expedition was George C. Simpson, who left Antarctica before Scott's body was found. In 1919, Simpson published a three-volume treatise reporting his pioneering studies of polar meteorology; in that work he concluded that "Captain Scott experienced unusually low temperatures on his return from the pole" (ref. 4, p. 32). Simpson is quoted by another surviving member of the expedition as stating that the polar party would have survived in 9 of 10 years, but struck the 10th unlucky one (ref. 2, p. 594).

History at first lionized Scott as a hero, but later studies raised questions about his leadership. Some factors that are often suggested as contributing to the lethal end of his trek include the general health of his ponies when purchased, the reliance primarily on man-hauling and on ponies (rather than sled dogs) to transport supplies, the lack of experience with skis, and the decision to include five men in the polar party rather than the original plan of four (ref. 2, pp. 565–566). Vitamin deficiencies such as scurvy or pellagra (attributable to poor diet) have frequently been advanced as the primary cause of his demise (5, 6). A blizzard that struck the team near 83°S while en route to the pole in December, 1911, also added to the expedition's difficulties by laying down a deep layer of soft snow that impeded their progress (7). Remarkably, Scott's and Simpson's statements regarding the temperatures in March of 1912 have been largely ignored. A few authors explicitly dismissed suggestions of severe weather (8), perhaps because such conditions were assumed to be typical for the harsh climate of Antarctica.

It is not our goal to evaluate the relative contributions of each of the many factors that could have played some role in the fatal outcome of Scott's polar journey. Rather, we focus in this paper only on the question of whether the temperatures encountered in the last month of the lives of Scott and his companions posed an unusual challenge in the final stages of their struggle for survival. We will show that observations made possible only by modern meteorological instruments that began recording data more than half a century after Scott's death indeed demonstrate that he and his men perished following a battle with conditions far colder than average for this region of the Ross Ice Shelf.

Meteorological Data: Historical and Modern

Temperatures have been routinely measured at a handful of manned Antarctic stations since about the 1950s, but most of these are located near the coast. The inland temperatures of the region of the Ross Ice Shelf where Scott and his men ended their march (see Fig. 1) have remained largely undocumented until about the past two decades. Even today, accurate and representative measurements of surface temperature can only be made by local methods, because the steep inversions, low-level clouds, and ice fog that frequently prevail in the Antarctic render

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Abbreviation: ENSO, El Niño Southern Oscillation.

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§The views presented in this paper are those of the authors and not an agency position on the part of the National Oceanic and Atmospheric Administration.

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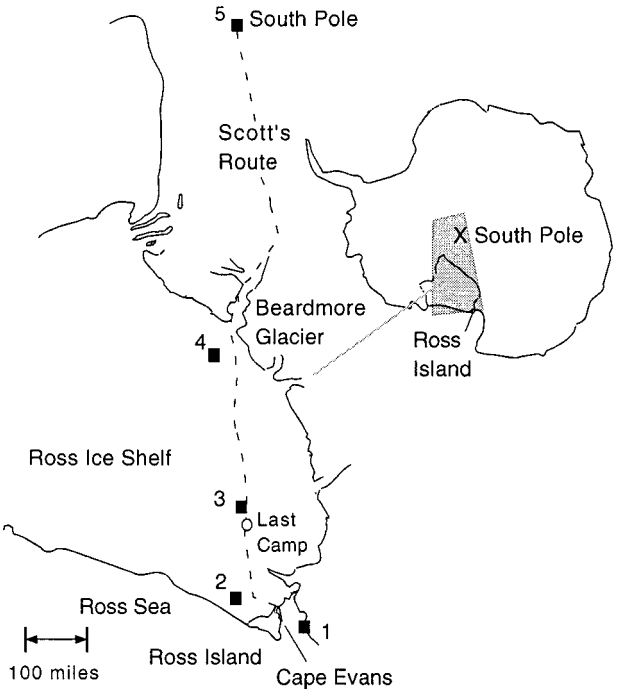

Fig. 1. Map of the Antarctic, with expanded view of the Ross Ice Shelf across which Scott and his men marched. Their base camp was located at Cape Evans on Ross Island, and they traveled south near the 170°E meridian to the South Pole. Contemporary automated weather station sites near their route are numbered 1 through 5.

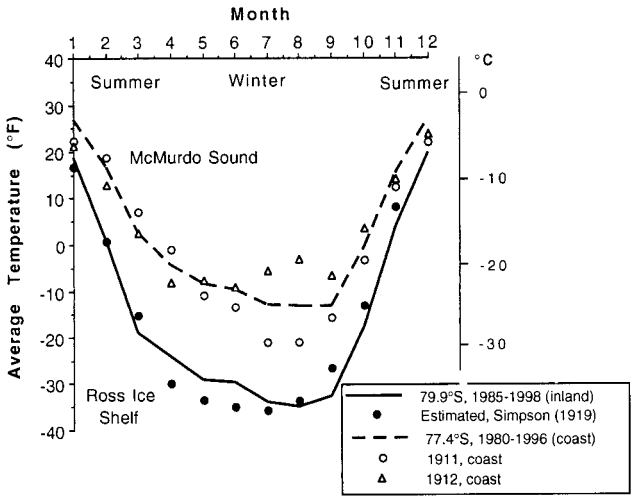

Fig. 2. Averaged monthly temperature climatologies from the automated weather stations (see Fig. 1) at McMurdo Sound (dashed line, Marble Point data for 1980–1996) and for the Ross Ice Shelf at 79.9°S (solid line, station 3 of Fig. 1, for 1985–1998). The open symbols show meteorological data taken at Cape Evans on McMurdo Sound during Scott's expedition in 1911 and 1912 (ref. 4, p. 11), which agree well with the nearby Marble Point data. The closed symbols show Simpson's estimate of the likely annual cycle of temperature on the ice shelf (see text).

satellite techniques of limited use in detecting the temperature at the ground. Beginning in the early 1980s, a network of automated weather stations was installed at remote sites around the continent, allowing for routine measurements of surface temperature, pressure, wind, and humidity (see ref. 9 for details of the instrument design and data quality checks). Data are reported every 10 minutes and are transmitted in real-time. Temperatures are measured by solid platinum wire resistance thermometers and are calibrated and read out to an accuracy of better than ±0.5°C; the precision is mainly limited by the digitization currently employed. Consistent observations from adjacent but independent stations provide support for the overall accuracy of these unattended measurements. A primary purpose of these automated measurements is to improve aviation safety, and their locations near the U.S. base at McMurdo Sound on Ross Island and at a few remote places between McMurdo and South Pole stations reflect this objective. The meridian near 170°E also served as Scott's "*via dolorosa*," along which he and his men marched to the South Pole and nearly all the way back. Fig. 1 shows the locations of the automated weather stations to be considered here, along with the route traversed by Scott and his companions in 1912.

Scott's expedition had dual goals of exploration and science. The meteorological instruments used were of high quality for their time and were carefully calibrated against standards at Kew Observatory in London to an estimated accuracy of better than ±0.5°F (ref. 4, pp. 16–17). Hourly measurements were made throughout 1911 and 1912 at the expedition's base at Cape Evans (see Fig. 1) with multiple instruments. During journeys away from the base, temperature was measured by using alcohol- or toluene-based sling thermometers, because mercury could freeze at the temperatures encountered. All of the temperatures henceforth will be given in degrees Fahrenheit (°F) to maintain consistency with the historical documents.

The monthly averaged observations made at Cape Evans during 1911 and 1912 (ref. 4, p. 11) are compared with the long-term average provided by 17 years of automated weather station data that are now available from the site at Marble Point on McMurdo Sound (station 1 in Fig. 1) in Fig. 2. This comparison broadly supports the accuracy of Simpson's calibration standards.

The rapid onset of Antarctic winter cooling after the summer solstice was expected by Scott and his meteorologist, based largely on observations carried out during Scott's previous south polar expedition of 1902–1904 (ref. 4, pp. 85–91). Simpson also recognized that the climate in the region of McMurdo Sound is moderated in part by the relative warmth of the nearby ocean (ref. 4, p. 93), so that the surface temperatures of the continental interior would be considerably colder than those on the coast, even at sea level. More recent studies also show that the blocking effects of surrounding surface topography further moderate the climate on Ross Island (10). The large temperature differences between the averaged monthly data for the coastal automated weather station at Marble Point, located at 77.44°S, and that inland on the Ross Ice Shelf, at 79.9°S (station 2 in Fig. 1), are illustrated in Fig. 2.

Simpson (ref. 4, pp. 21–33) carefully examined the temperature data gathered on a very limited number of exploratory treks away from the coast to derive the typical temperature differences expected to occur between Cape Evans and the "Great Barrier" (now known as the Ross Ice Shelf). He combined these temperature differences with the 2-year record of hourly data at Cape Evans to deduce the annual cycle of temperature that would normally be expected in the nearly unexplored inland regions. His estimate of the likely annual cycle of mean Barrier temperatures agrees remarkably well with the climatology that has now been established by multiple years of continuous data via the automated weather station data as shown in Fig. 2.

The Cold March of 1912

Scott and his four companions began their long march back to the coast from the South Pole on January 19, 1912. At an elevation of over 10,000 feet, the average temperatures of the

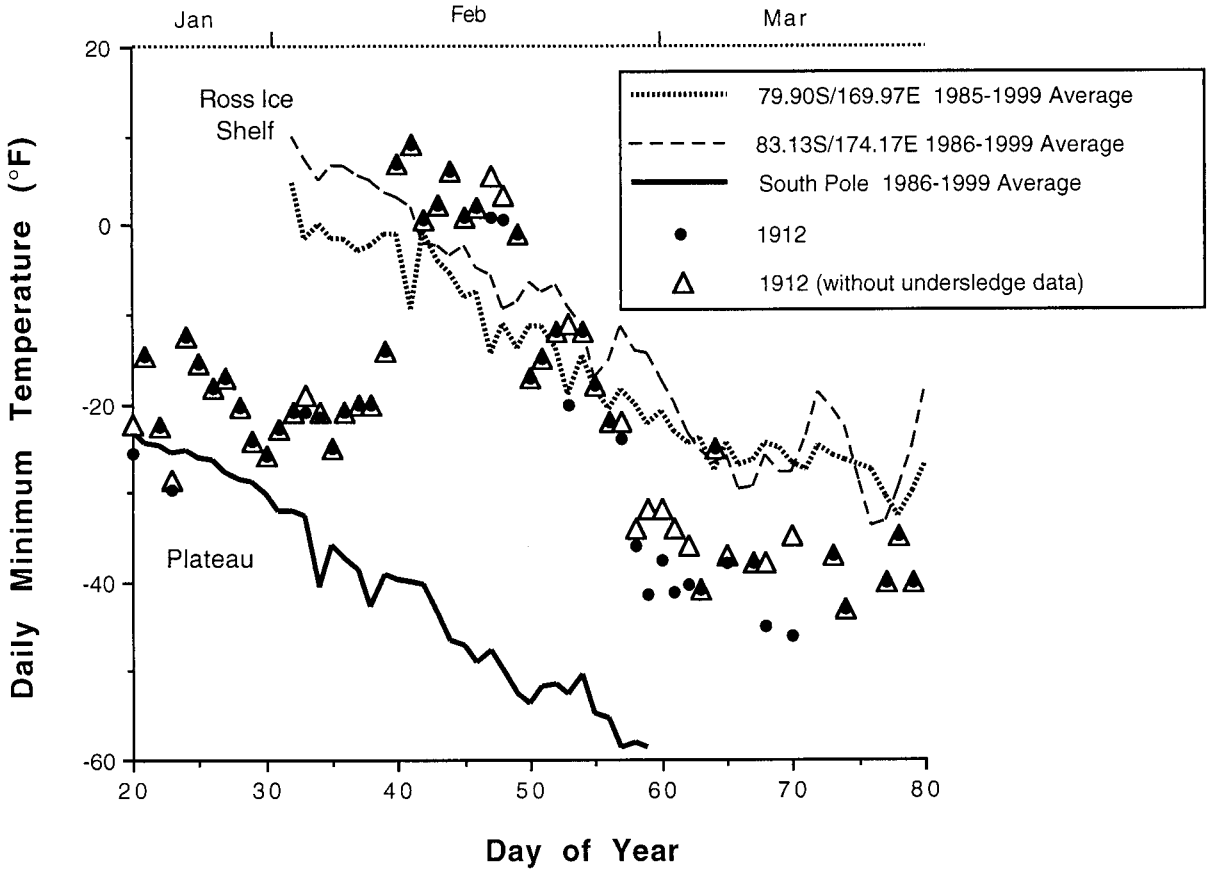

Fig. 3. Observations of daily minimum south polar temperatures. Open triangles show the 1912 ventilated data only, whereas filled circles display minima considering available under-sledge daily measurements (11), beginning near the South Pole on January 20 (day number 20), descending to the Ross Ice Shelf near February 1–14 (days 32–45), and continuing until March 19. The rapid warming between days 40 and 45 is caused by the descent from the high plateau at about 10,000 feet elevation to near sea level. The heavy black line shows the average daily minimum at the South Pole (station 5) from automated weather station data, while the two broken lines show the observations from stations at 79.9°S and 83.13°S (stations 3 and 4 in Fig. 1).

south polar plateau remain below freezing even at the height of austral summer. The sling thermometer was typically used to record the 1912 temperature three times per day: just before the daily march, during the lunch halt, and while the evening meal was prepared (11). Fewer observations were taken on many days, probably because of observer fatigue. The precise daily averaged temperatures experienced by Scott and his men are uncertain because three observations, at most, were made each day (ref. 4, pp. 17–20). Rather than attempting to construct an average from these sparse measurements, in this paper we examine the daily minimum temperatures that can be derived from the data obtained by Scott and his companions in 1912, and compare these with modern observations. At night, the sling thermometer was sometimes placed under one of the wooden sledges (a type of sled that carried supplies) to shield it from the sun and to estimate the nightly minimum temperature. Although such observations may be biased low by up to 2° because of the pooling of cold air (ref. 4, p. 19), the ventilated data taken while swinging the thermometer only a few times per day are likely to be warmer than the actual daily minimum. It is therefore probable that the true 1912 minima lie between the ventilated and under-sledge data; both will be shown here where available.

The minimum daily temperatures played a large role in the physical discomforts reported by Scott and his companions. The men sometimes complained of the wind, but even under very cold conditions the strenuous labor of the march while hauling their equipment was usually sufficient to make even rather windy days more comfortable than the nights (ref. 2, pp. 242–244, 248, 291, 302). The men's concerns were generally less focused on wind chill than on the air temperature. Cold nighttime temperatures were particularly dreaded, as these rendered their sleeping bags frozen and uncomfortable, making "life at night a clammy misery" (12).

Simpson (ref. 4, pp. 19–21) demonstrated that three independent sledge thermometers used by different parties involved in the first stage of the polar trek, during November 1911, agreed with one another to within a few degrees, supporting the measurement precision. Only one group continued to the South Pole, carrying one of these three instruments. Scott and his team were within 1° of latitude of the geographic South Pole from January 13 to 23, 1912. The average of the daily minimum temperatures recorded by them during these dates is −23°F, considering only the ventilated measurements, and −24.1°F, when the available under-sledge data are also included in the mean (11). The intense solar illumination at the South Pole in summer renders the temperatures relatively consistent there from year to year in this period. The average of the daily minima for January 13–23, recorded annually by the automated weather station at the Pole since 1986, is −22.6°F, with a SD of 3.7°F, which is in good quantitative agreement with Scott's 1912 data and thus further supports the measurement accuracy.

Fig. 3 shows the daily minimum temperatures encountered by Scott's party as they struggled to return from the Pole in 1912 (11). The 1912 data are compared with the average daily minima from automated weather station data at the South Pole, at 83.13°S, and at 79.9°S (stations 5, 4, and 3 in Fig. 1) obtained over

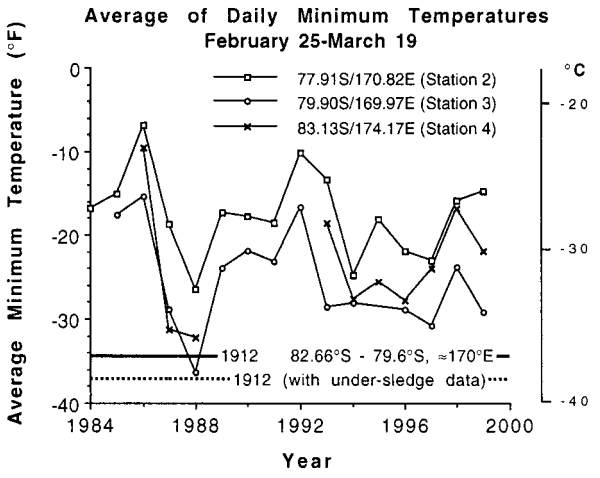

Fig. 4. Average of daily minimum temperatures for February 25–March 20 on the Ross Ice Shelf. Data for 1912 both with and without the inclusion of under-sledge nighttime minima (see text) are compared with measurements made by the automated weather stations at 77.91°S, 79.9°S, and 83.13°S (stations 2, 3, and 4 in Fig. 1).

many years since the mid-1980s. As Scott's party descended from the cold of the high plateau to near sea level (around days 32–45, or February 1–14, 1912), the temperatures they experienced increased accordingly, as they had anticipated. By February 9, 1912, Scott wrote that "tonight it is wonderfully calm and warm" (ref. 1, p. 565); Wilson similarly reported that "we are all thoroughly enjoying temps of +10°F" (ref. 3, p. 241). Nevertheless, on February 17, one member of the party (Seaman Evans) died. This first death may have been related to a brain injury caused by a fall in a crevasse (ref. 1, p. 573), but complicating factors could have included scurvy, extreme hunger, frostbite, and a cut on the hand (ref. 2, pp. 531–532, 572; ref. 13).

Fig. 3 reveals that the minimum daily temperatures experienced by Scott and his men from about February 10 through 25, 1912, while on the southern end of the Ross Ice Shelf were comparable to the climatological average. But near the end of February (day 57), minimum temperatures fell below −30°F, well below the average values in this region based on modern data. Persistently low daily minimum temperatures were recorded from this point through at least March 12, when the sling thermometer broke. Scott made a few more observations up to March 19, 1912, with his personal thermometer. These were recorded in his journal and are also shown in Fig. 3. With one exception (March 4, 1912), every day of available measurement from February 27 through March 19, 1912, was characterized by daily minimum temperatures below −30°F, as much as 20°F colder than the long-term average daily minima for this region based on automated weather station data for 14 and 15 years (respectively) at two nearby sites as shown. Further, the persistence of the cold temperatures observed in 1912 is unusual. In an average year at station 3 in the modern record, only nine days between February 25 and March 19 display minimum temperatures below −30°F, whereas about 5 days are characterized by much warmer temperatures above −15°F; not one such warm day occurred in 1912. Only 1 of the 15 years of modern data (1988) displays a nearly uninterrupted period of cold daily minima, similar to 1912.

Fig. 4 compares the data of 1912 to the average of daily minimum temperatures for February 25 through March 19 from 1985 to 1999, as recorded by the automated weather stations at 77.91°S, 79.9°S, and 83.13°S (stations 2, 3, and 4, respectively, in Fig. 1); missing data reflect occasional instrument failures. The automated measurements generally track one another well. The more northerly station at 77.91°S is located near the coast and tends to be the warmest of the three locations, whereas the station at 79.9°S frequently displays the coldest conditions; local winds play a major role in controlling temperatures at stations on the Ross Ice Shelf (9). Fig. 4 demonstrates that the period from February 25 to March 19 of 1912 was as cold as or perhaps was the coldest yet recorded near 80°S, 170°E, although it must be acknowledged that the present record is limited to only 16 years. The average minimum temperatures for this time of year in 1912 are about 10°F colder than the average of all of the years of available data from the automated weather station sites at 79.9°S and 83.13°S. Only 1 year in the modern record seems to rival the severity of the temperatures measured in 1912, broadly consistent with Simpson's conclusions that conditions would likely have been milder in roughly 9 out of 10 years. The meteorological data shown in Figs. 3 and 4 therefore reveal that Scott was correct rather than petulant when in his final message to the public he wrote, "... no one in the world would have expected the temperatures . . . which we encountered at this time of year" (ref. 1, p. 606).

Although Fig. 4 demonstrates that there is large interannual variability (a range of ±15°F) in the temperatures near the location where Scott died, secular trends in the same region are quite small (<0.02°F per decade since the late 1950s, see refs. 14 and 15), so that possible long-term climatic changes such as global warming are not the cause of the cold March of 1912. Temperatures at a few Antarctic sites have also been measured for longer periods. Continuous measurements have been carried out since 1903 on the Palmer Peninsula, and sporadic data are available from about 1900 at five more sites, including two on the edges of the Ross Ice Shelf. These observations suggest long-term trends in annually averaged Antarctic temperatures during the 20th century of <2°C, probably closer to 1°C (16). Scott and his party were particularly vulnerable to the large variability of the weather in a specific time of year—late February and March—rather than to the average climatological state and its modest trends.

Among the factors that may contribute to global weather variability in any given year is the El Niño Southern Oscillation (ENSO) that modulates sea surface temperatures in the tropical Pacific region with a periodicity of about 4 years (17). Possible teleconnections between these tropical processes and weather at higher latitudes have been the subject of considerable research (17, 18). Connections between ENSO and Antarctic conditions are speculative because of the relatively short records, and the physical mechanisms for such a link have yet to be firmly established. However, evidence for an ENSO-like (i.e., quasi-quadrennial) signal in the seasonal extent of the sea ice that surrounds Antarctica has been documented in several studies (19–21). One mechanism that has been advanced to couple El Niño to Antarctic sea ice and surface temperature is that of the transfer of heat via the ocean circulation (21). Other authors have stressed the role of katabatic drainage flows from the Antarctic continent in affecting the atmospheric wave structure in the New Zealand sector and, hence, perhaps also the climate on broader scales (22–24). Although a longer record will be needed to ascertain the linkages, if any, of the quasiquadrennial variability in Antarctic weather to ENSO, the evidence suggests that some process does modulate Antarctic climatic variables on a time scale of about 4 years. Observations of the difference in surface pressure measured at Tahiti from that at Darwin, Australia, provide a means of estimating the strength of El Niño. Such data extend back to the latter part of the 19th century and are made publicly available by the Australian Bureau of Metereology. A statistical study of temperatures on the land surface at Antarctic stations also points toward a quasiquadrennial modulation, with minimum Antarctic surface temperatures of-

ten occurring in the Ross Ice Shelf sector near the El Niño phase of the ENSO cycle (22). It is intriguing to note that 1912 was an El Niño year (25).

The impact of the extreme temperatures shown in Figs. 3 and 4 on Scott and his men in their final month are documented primarily by Scott's own journal, because his companions had ceased writing their diaries by this point (although a few parting letters to family were found). One man (Oates) had been suffering from frostbite throughout much of the return journey (ref. 3, pp. 238–240), and the prolonged cold temperatures of 1912 (as shown in Fig. 3) exacerbated his condition. On March 2, 1912 (day 62), Oates "disclosed his feet, the toes showing very bad indeed, evidently bitten by the late temperatures" (ref. 1, p. 583); Fig. 3 shows that those temperatures were about 20°F colder than average for this location and time of year. His pain and debilitation ultimately drove him out to the snow to die about 2 weeks later, leaving his comrades with the poignant statement: "I am just going outside and may be some time" (ref. 1, p. 592).

In addition to frostbite and lack of rest during nights so cold that sleep in ice-filled reindeer bags was precluded, the cold conditions greatly altered the texture of the snow across which Scott and his party had to drag the sledge that carried their tent, food, and other critical supplies. The low temperatures produced "a thin layer of woolly crystals" and ". . . impossible friction on the runners" (ref. 1, p. 584). The increased drag of the cold snow surface on the sledges therefore also contributed to reducing Scott's northward progress to a crawl. Between March 5 and 14, for example, the team covered only 6–8 miles per day in a region where about 15 miles per day had been achieved on the outbound journey in November 1911 (ref. 1, p. 632). A blizzard began on March 20 (ref. 1, pp. 594–595). This storm ended the attempt to continue marching at a site about 11 geographic miles (12.66 statute miles) from the next depot containing food and fuel (ref. 2, pp. 495–498). Scott's diary is not specific as to the wind speeds during this period, but he emphasized that windy conditions persisted until his final diary entry on March 29. Peak daily winds in excess of 30 km/hour for 7 or more consecutive days have occurred in March during half of the years of available observations (from 1986–1999) by the automated weather station at 79.9°S, with as many as 10 such days being recorded in 3 years. Hence, windy conditions do not appear to be highly unusual for this location and time of year. It is likely that the increased wind raised the temperatures, but Scott ceased recording temperature data when the blizzard began.

The diaries and farewell letters of Scott and his men were recovered from their last camp, at about 79.6°S, along with their meteorological log about 8 months after they died (ref. 2, pp. 495–498).

Concluding Remarks

The observations of the extremely cold temperatures reported by Scott and his companions in March of 1912 do not imply that these frigid conditions alone caused their deaths. Indeed, one man perished before these challenges were encountered and another was already suffering from frostbite, as has been noted. But the unusually cold temperatures that prevailed over an extended period of several weeks substantially contributed to the tribulations faced by Scott and his team during the final stages of their battle for survival. In spite of their plight, the party continued to record the scientific data that provide key information regarding their fate. Those measurements show that they endured minimum temperatures more than 10°F lower than the average that can now be derived from multiple years of automated measurements for the period from February 25 to March 19 near 80°S on the Ross Ice Shelf. On some particular days in March, the daily minimum temperatures in 1912 were more than 20°F colder than the climatological average. These conditions likely contributed to frostbite and extreme fatigue in the men, as well as to the friction of the very cold snow surface that amplified the physical demands of the strenuous task of man-hauling their supplies by sledge, and thereby slowed their progress. Scott and his last two companions died near the 29th of the month (ref. 1, p. 632), after enduring what might be dubbed "the coldest march."

The efforts of many dedicated students, scientists, and support personnel are required to keep the automated weather station network operating in the Antarctic and its results routinely available at uwamrc.ssec.wisc.edu/aws/awsproj.html. The financial support of the National Science Foundation for this network is gratefully acknowledged. Helpful comments by the reviewers of this paper are also appreciated.

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