

## **Scott's last expedition: the upper air observations**

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The British Antarctic Expedition (BAE) of 1910-1913 will be remembered for the heroic, ill-fated exploits of Captain Scott and his companions. The story of the preparation and final attempt at the pole is well documented (see, for example, Fiennes 2003; Solomon 2001) and so will not be repeated here. What is less well-known is the fact that much groundbreaking scientific work was conducted during this expedition. Scientists from many disciplines were engaged in a variety of studies throughout the expedition, including observations of magnetism, gravity, physiography, geology, zoology, and meteorology. The last included the release of recording meteorological balloons; making the BAE amongst the first (if not *the* first) major scientific field campaign to use weather balloons as part of their experimental effort\*. Although the attempt at the pole stirred the public imagination, the main goal of the expedition was the furtherance of knowledge. As Scott (always willing to engage with his academic staff) remarked: "Science, the rock foundation of all effort!!" (Scott 1927, diary entry for 9 May 1911.)

The purpose of this article is to summarise the first ever measurements of the troposphere of Antarctica, made by the BAE. The balloons used are described and the results of the expedition are presented and compared with more recent measurements.

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\*This was not the first recorded instance of a balloon flight in the Antarctic, however. In 1902 during the "Discovery" expedition, a large balloon was launched with Scott, suspended from it in a basket, rising to an impressive 240m - thus completing the first manned balloon flight in the Antarctic. The balloon was filled with Hydrogen (brought in cylinders for the purpose). For further details see Scott (1905), Chapter 5.

## The use of balloons during the expedition

The expedition's chief meteorologist was George Clarke Simpson. The first lecturer in meteorology appointed at any British university (Mathew and Harrison 2004), Simpson took up his position at Manchester in 1905, aged 27. Following a brief spell at the Indian Meteorological Office, he was asked by Captain Scott to join the BAE in 1909.

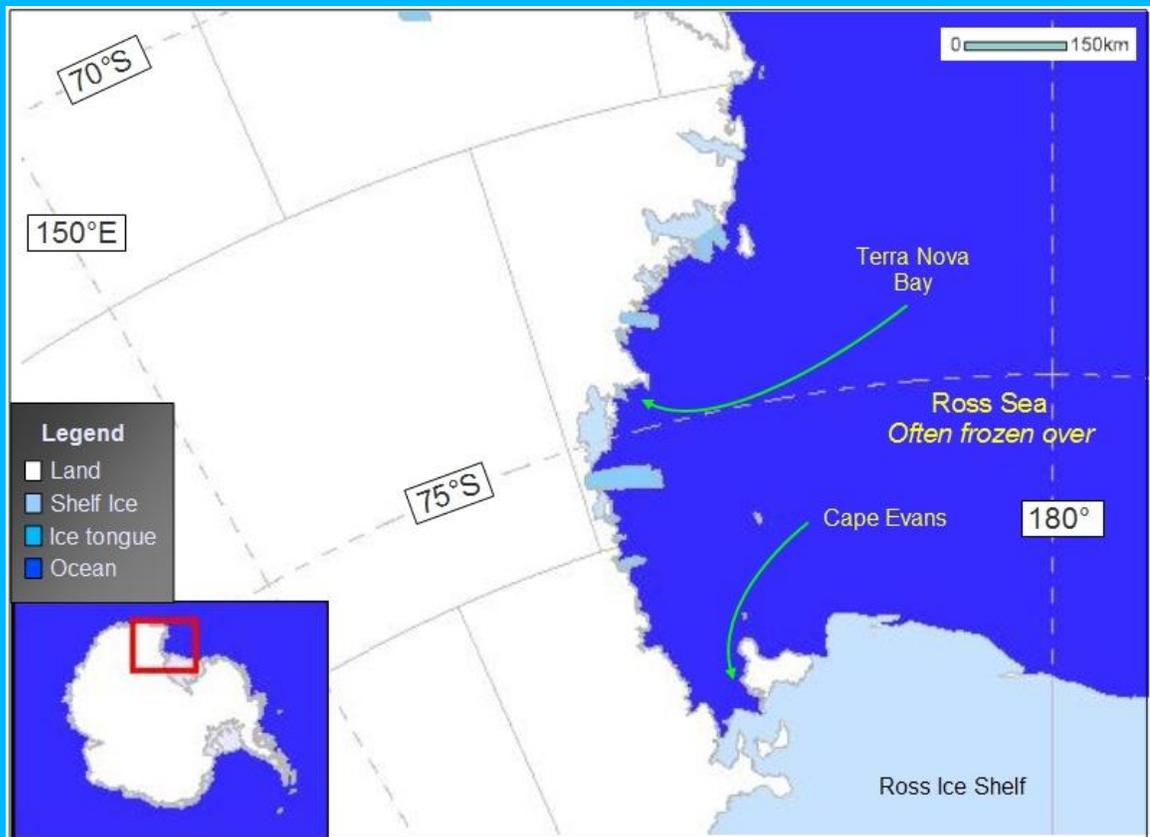


Fig. 1. The Ross sea coastal area showing the locations of Cape Evans and Terra Nova Bay. Graph derived from the USGS Atlas of Antarctic Research (USGS 2006)

The BAE base was situated at Cape Evans ( $77^{\circ} 38' S$ ,  $166^{\circ} 24' E$ ), in McMurdo Sound (see Fig. 1). Simpson - ably assisted by various members of the expedition - collected vast amounts of meteorological data. These were later written up as a three-volume work (Simpson 1919-1923). In particular, the expedition made the first ever measurements of the structure of the troposphere in Antarctica, via the use of balloons with recording instruments attached.

The balloons used during the BAE (see Fig. 2) weighed 226g and were made of Gutta-Percha (a type of latex). When inflated, they had a volume of approximately 1 cubic metre. Hydrogen was used to inflate the balloons; the gas liberated by the addition of calcium hydride to water. The recording instrument weighed 70g and was capable of measuring temperature and pressure. Both the

recording instruments and the gas production system were constructed by the pioneer of upper-air research, William H Dines. The instrument used fine steel points to scratch the pressure and temperature onto a silver plate; a full description of the Dines recording instrument, known as a “meteorograph”, can be found in Robinson (1968); the early history of radiosondes is described in Brettle and Galvin (2003).



**Figure 2. Simpson launching a meteorological balloon. The pipe attached to the balloon comes from the cylinder to the left, which contained a reservoir of water; calcium hydride was added, producing hydrogen. Photograph taken by Herbert Ponting. Copyright Royal Geographical Society; used with permission.**

In order to disengage the recording instrument once aloft, the meteorograph was attached to the hydrogen balloon via a device containing a “slow match” (i.e., a slow fuse); when the fuse reached the desired time (they were usually set for approximately 15 minutes) the recording instrument detached from the main balloon and fell to the ground (no parachute was used).



**Figure 3. Simpson and expedition member Bernard Day tracking a balloon by theodolite on “Wind Vane Hill”, a good spot for following the balloons (roughly 20m above the launch site). Photograph by Herbert Ponting. Copyright Royal Geographical Society; used with permission.**

The balloons were tracked by several methods, determined by the season. During the Antarctic summer months the balloons had a secondary red balloon, filled with air, attached to the recording instrument. When the fuse burnt, the recorder, together with the red balloon, detached from the hydrogen balloon and fell to the ground. The descent of the red balloon was tracked by theodolite (see Fig. 3) and a bearing to its landing place taken. In the winter months, however, the theodolite eyepieces suffered from frosting caused by the operator's breath. Thus some alternative method had to be employed. This consisted of attaching a very thin silk thread (weighing an incredibly light 115g per 8km, with a break strength of 560g (Scott 1927, entry for 24 April)) to the recording instrument. The bobbin containing many miles of thread would be secured at ground level and spun out as the balloon ascended. When the fuse burned, the meteorograph fell to the ground as before. The thread would then be followed, sometimes for many miles, hopefully to locate the recording instrument. Obviously the thread could snap (either in mid-air or against some obstacle while lying on the ground) and so the retrieval rate using this method was somewhat lower than the summer months. In all, Simpson launched 21 balloons, retrieving 14 meteorographs; two of the records were deemed unsatisfactory, giving a total of successful 12 balloon ascents. This success rate is quite impressive given the tracking

methods used, the harsh operating conditions, and the fact that balloon meteorology was in its infancy.

Note that balloons would only be launched when the state of the upper levels (judged by smoke ascending from nearby volcanic Mount Erebus) was calm. This may be due to logistics of launching a balloon in strong winds. Also, if the winds aloft were strong, it is likely that the recording instrument would be carried too far to make retrieval a possibility: typically, the meteorograph would be found 10km from the launch site.

### **Accuracy of the balloon measurements**

The accuracy of the BAE balloons will never be known. However, in 1919 Dines concluded (after studying data from approximately 600 balloon ascents) that the “probable error of a temperature observation at a definite height does not exceed 1 deg C” and the “probable error of pressure...to be 4mb” (as quoted in Robinson 1968). In the absence of any further data they represent the best estimate of the errors in the expedition balloons.

Compare this with the claimed error values for the latest generation of radiosondes: the Vaisala RS-92 which uses GPS to achieve a high degree of positional accuracy. The manufacturer (Vaisala 2006) claims a 0.5 deg C uncertainty in temperature and 1.5hPa uncertainty in the pressure\*. These days, of course, the tracking question is irrelevant due to the real-time transmission of data from radiosonde to ground station.

### **Results of the balloon ascents**

Table 1 shows the successful balloon ascents (i.e. those in which both the recording instrument was retrieved and the results deemed satisfactory) and the maximum heights attained; note the 25 December 1911 launch, which reached a very respectable 6743m.

Figure 4 shows average temperature profiles for the balloon launches of the BAE for winter and summer months. The winter profile is derived from 4 balloon ascents; the summer from 8 ascents. These data are reproduced verbatim from Simpson's report (Simpson 1919): no corrections have been applied. These averages were calculated by Simpson based on the mean temperature gradients derived from the balloon ascents.

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\*These are “cumulative uncertainties” and include factors such as repeatability, long-term stability and effects due to measuring conditions.

As can be seen, the profiles differ quite substantially. The main difference, other than the lower average temperatures, is the existence of a marked inversion in the lower levels during the winter months. Indeed, in winter the atmosphere does not fall to the surface temperature value until above 2km in height. This inversion, with colder temperatures at lower levels, is caused by the surface losing heat via radiation cooling associated with the lack of sunlight (Simpson 1919; Solomon 2001).

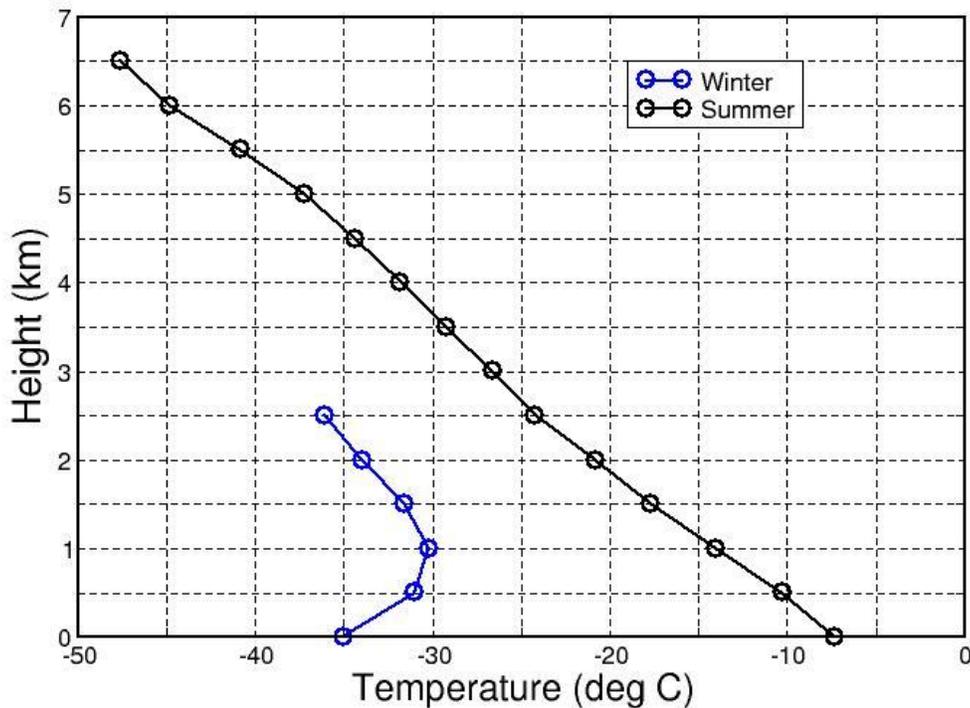
**Table 1. List of all successful balloon launches during winter and summer 1911.**

<i>Date</i>	<i>Season</i>	<i>Maximum height attained</i>
13 August 1911	Winter	3000m
16 August 1911	Winter	2000m
17 August 1911	Winter	2500m
30 August 1911	Winter	2210m
12 November 1911	Summer	3000m
15 November 1911	Summer	3000m
19 November 1911 (a)	Summer	4000m
19 November 1911 (b)	Summer	3040m
19 November 1911 (c)	Summer	4617m
29 November 1911	Summer	5000m
24 December 1911	Summer	4159m
25 December 1911 <sup>†</sup>	Summer	6743m

The existence of a low-level inversion had already been detected by Simpson and Scott, who noted that the temperature on Wind Vane Hill, 20m above the expedition hut, was several degrees higher than at the latter (Scott 1927, entry for 3 May 1911).

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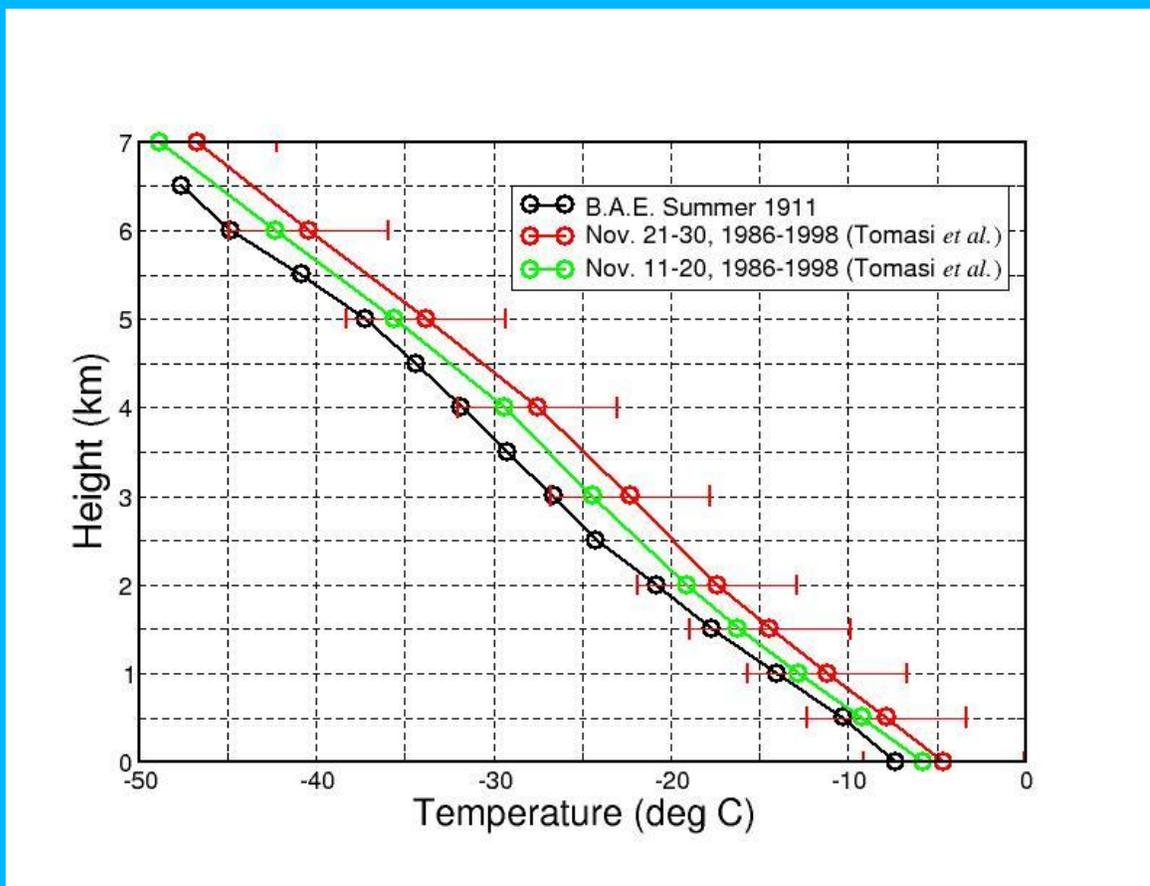
<sup>†</sup>While this balloon was being launched, Scott and his companions were on the final leg of the Polar attempt, having by this time reached the polar plateau. Unbeknown to the members of the BAE, Amundsen had already reached the South Pole.



**Fig. 4. Average temperature from the BAE balloon profiles, for the winter and summer months.**

The upper air over Antarctica is still a subject of much research; as well as providing profiles for use in forecast models, radiosondes provide the basis for calculations of radiative transfer, solar radiation absorption, and Rayleigh scattering coefficients (Tomasi *et al.* 2004). Thus, there are ongoing analyses of the thermal atmospheric structure over Antarctica, which can be compared with the results of the BAE. A recent study of radiosonde measurements over Antarctica is contained in Tomasi *et al.* (2004) In this paper, the authors analysed a significant amount of radiosonde data spanning the years 1986-1998, the data coming from the Italian research station at Terra Nova Bay ( $74^{\circ} 42' S$ ,  $164^{\circ} 07' E$ , 55m above sea level; see Fig. 1). A variety of sophisticated techniques were employed by the authors to eliminate sensor errors and they produced vertical profiles of temperature for numerous 10-day periods in the Antarctic summer months. In particular, data from 11 November – 20 November and 21 November – 30 November (which amounted to 224 radiosondes over the 12-year period) were analysed. These periods cover most of the dates on which balloons were launched during the BAE.

By the addition of measurements taken at sea level, Tomasi *et al.* (2004) constructed profiles spanning the atmosphere from sea-level to upper levels. The BAE balloons were launched at the Cape Evans base; the exact launch position does not appear to be mentioned in the literature, but is likely to have been near the expedition hut (situated on the gently sloping beach, less than 100m from the sea ice). Thus, it is acceptable to interpret the BAE results as being launched at sea level, and the results of the BAE and Tomasi *et al.* (2004) can be directly compared. Although the two launch sites used for comparison here are not co-located (the base at Terra Nova Bay is approximately 350km north of Cape Evans), both sites are situated in the Ross Sea coastal region.



**Fig. 5. Comparison between the results of the BAE and more modern measurements. The Nov. 11-20 and Nov. 21-30 data are from Tables 2 and 3 of Tomasi *et al.* (2004); horizontal bars (estimated from Fig. 3 of the same paper) give the standard deviations for the Nov. 21-30 measurements.**

As can be seen in Fig. 5, the BAE results generally fit within one standard deviation of the mean values of Tomasi *et al.* (2004) (sometimes skirting the standard deviation) and would represent an atmospheric profile whose temperature is colder than the modern mean, for the periods considered. Additionally, the trend is very similar for the two sets of results: temperature gradients for the BAE vary between  $-6.8 \text{ deg C/km}$  and  $-5.1 \text{ deg C/km}$ ; whereas

the more modern thermal gradients vary between -6.4deg C/km and -5.5deg C/km. The fact that the BAE profiles and the analyses of Tomasi *et al.* (2004) can be meaningfully compared at all is quite remarkable.

It has been suggested (by Simpson himself: see Cherry-Garrard 1921, Chapter 19; Solomon (1999) recently added much weight to the hypothesis) that March 1912 was colder than average on the Ross Ice Shelf, contributing to the conditions which led to the ultimate death of Scott and his companions. The present results appear to suggest that temperatures throughout the lowest 5 km of the atmosphere were lower than average during the preceding early summer months also (for the coastal region). Of course Simpson's measurements may well not have had as much post-processing as those of Tomasi *et al.* (2004), and the BAE launch sites and those used by the latter study are not identical. Additionally, the accuracy of the BAE balloon measurements are an unknown quantity, but even using the error estimates suggested by Dines (see above), the implication is still clear: these results suggest a 1911 Ross Sea coastal area troposphere which was colder than the modern average. The responsibility of global warming for this cannot be ruled out; the sparsity of observations makes any such statement rather speculative, however, and Solomon (1999) has argued that secular trends in temperature for this region – on the surface at least – are quite small.

Whether these below-average tropospheric temperatures were a precursor of, or can be linked in any way to, the abnormally low temperatures experienced by Scott's polar party, is impossible to say. However, it is satisfying to note that the BAE balloon results can still be meaningfully compared to more modern analyses. This latter is testament - in the words of one of its members (Evans 1921) - to this "merry band of sailor-adventurers and scientist-explorers" who undertook such pioneering work.

## Epilogue

Simpson did not take part in the final attempt at the pole himself, and was recalled to his old post at the Indian Meteorological Office in 1912. He was later director of the British Meteorological Office from 1920-1938 and was knighted for his contributions to meteorology in 1935. He died on 1 January 1965.

Currently there are 17 upper-air stations in the Antarctic (BADC 2006), operated by nine different countries.

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