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Mallory and Irvine on Mount Everest: Did extreme weather play a role in their disappearance?

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Introduction

The 1924 British Expedition represented the culmination of early attempts to climb Mount Everest (Norton, 1925; Venables, 2003). The expedition was notable for the two summit attempts that took place in early June of that year. On 4 June, Colonel Edward Norton climbed, without the use of supplementary oxygen, to an elevation of 8570 metres – just 280 metres below the summit. Four days later on the 8th, George Mallory and Andrew 'Sandy' Irvine were last seen around noon local time (0800 UTC) on Everest's Northeast Ridge (Figure 1) before vanishing into the clouds. In the ensuing years, a vigorous debate has taken place regarding their climb and over whether they were indeed successful in reaching the summit (Holzel and Salkeld, 1986; Hemmleb *et al.*, 1999). Curiously absent from this debate has been a quantitative discussion of the nature of the weather during their climb and the role it may have had in their disappearance. This absence is even more remarkable given that daily barometric pressure and temperature measurements were made from Base Camp at 5029 metres. Although these data were published as a table in 1926 (Somervell, 1926; Whipple, 1926), no attempt was made at the time or subsequently to interpret them so as to provide insight into the meteorological conditions associated with the expedition's activities.

In this paper, we will use the data collected during the expedition as well as a manually analysed sea-level pressure map from the period to show that this attempt occurred during a period in which there was a drop in barometric pressure and temperature on Mount Everest that was most likely the result of the passage of an upper-level trough known locally as a Western Disturbance (Dimri, 2004; Lang and Barros, 2004). We will argue that the passage of this disturbance most likely triggered an outbreak of convective activity that resulted in the blizzard that was observed to engulf the mountain during their summit attempt.

Figure 1. Mount Everest as seen from Base Camp during the 1924 Expedition. The Northeast Ridge, along which Mallory and Irvine climbed, can be seen extending from the left of the photograph towards the summit. (Photo by Bentley Beetham and reproduced courtesy of The Bentley Beetham 1924 Everest Trust.)

Overview of the 1924 Expedition

The 1924 Expedition arrived at Base Camp at 5029 metres on the north side of Everest (Figure 1) on 1 May 1924. The plan was to occupy a number of camps along the East Rongbuk Glacier, the North Col, the North Ridge and the Northeast Ridge in support of the summit attempt (Figures 2 and 3). This plan was thwarted by the passage of a number of weather systems that brought stormy weather to the Mount Everest region during May. For example, a storm that lasted from 8–10 May resulted in blizzard-like conditions with high winds and low temperatures that forced the team to return to Base Camp. The North Col camp, Camp IV, at 7100 metres was finally occupied on 21 May. Attempts to move higher up the mountain were rendered impossible by a heavy snowfall on the 22nd.

Near the end of May, a period of better weather allowed for another attempt on the mountain and on 2 June, Camp V at 7800 metres along the North Ridge was established. On the 3rd, Norton and Howard Somervell established Camp VI at 8200 metres. It was from this camp that they made their summit attempt on the 4th.

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Figure 2. This figure is not available in the online version of this article for licensing reasons

Figure 2. Schematic 'birds-eye' view of the route taken by the 1924 Expedition. The schematic was prepared for Captain John Noel, the expedition's photographer. Note that 'North Peak' is now usually referred to as 'Changtse'. (© John Noel Photographic Collection.)

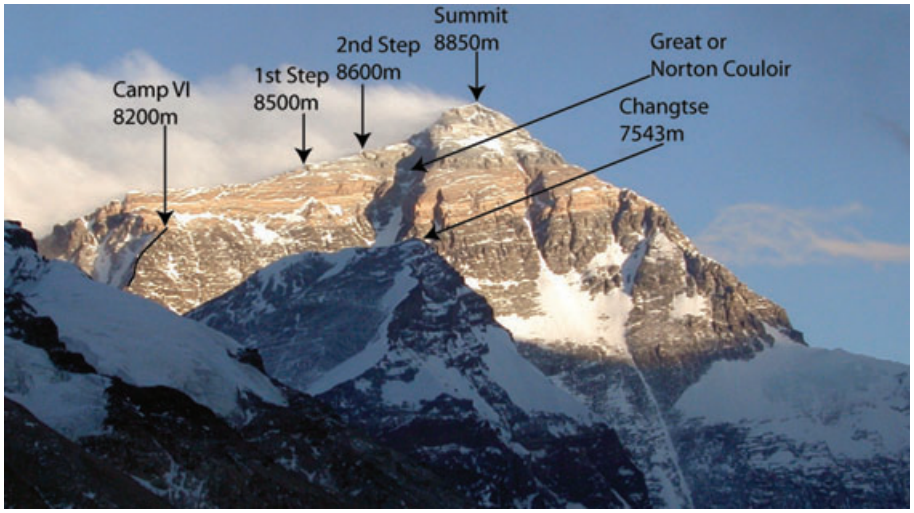

Figure 3. Photograph of Mount Everest's Northeast Ridge with the route up from the North Col (hidden by the mountain in the foreground) to Camp VI indicated. Above Camp VI, Mallory and Irvine's route towards the summit was along the ridge past the first and second steps, while Norton and Somervell traversed below the ridge along the linear feature known as the Yellow Band towards the Great or Norton Couloir. (© John Semple, May 2005.)

After the failure of the first party to reach the summit, Mallory and Irvine made a second attempt using supplementary oxygen. They departed Camp IV on 6 June and spent the night of the 7th at Camp VI with the intention of leaving for the summit on the morning of the 8th. Noel Odell was tasked with climbing in support of Mallory and Irvine and left Camp V on the morning of the 8th in anticipation of meeting the returning climbers at Camp VI that evening. Around noon (local time) while climbing toward Camp VI, there was a clearing of the clouds and Odell writes that he saw *the whole summit ridge and final peak of Everest unveiled* (Odell, 1924). Furthermore, he wrote that this clearing allowed him to see Mallory and Irvine climb over an obstacle along the ridge before the scene was again engulfed in clouds.

Odell remained for a time at or just above Camp VI looking for the climbers before returning to Camp IV. On the 9th he climbed back to Camp V and on the 10th returned to Camp VI. Finding no sign of the returning climbers, he reported to those below that Mallory and Irvine were lost (Norton, 1925). In the following years, a number of artefacts from Mallory and Irvine's climb have been recovered with the most significant being the discovery of Mallory's body in 1999 (Anker and Roberts, 1999). Despite these discoveries, much is still not known about their climb, including whether they were successful in their summit attempt.

Data collection activities

The 1924 Expedition was notable for collecting some of the earliest information on the meteorology, geology and natural history of the Mount Everest region. With respect to the meteorology, the focus was on temperature observations at various camps in order to calculate the environmental lapse rate (Somervell, 1926). Daily barometric pressure measurements were also made at Base Camp (Whipple, 1926).

Unfortunately, there is little information available on the methods used to carry out these measurements. It is, however, known that the air temperature at Base Camp and a number of higher camps was measured three times daily (0830h, 1200h, and 1600h local time) using a sling thermometer, with a daily pressure measurement being made at 0830h (Somervell, 1926; Whipple, 1926). With respect to the pressure measurements, there is no documentation available. The 1921 Everest Expedition report (Howard-Bury, 1922), however, provides some details on the barometers used during that expedition and it is safe to assume that similar devices and procedures were followed in 1924. In this regard, the 1921 Expedition employed aneroids that were calibrated before and after the expedition at the National Physical Laboratory. No significant change in their behaviour was noted as a result of time spent in the field (Howard-Bury, 1922).

Lapse rates were observed to be for the most part less than the dry adiabatic lapse rate indicating that the atmosphere was stably stratified (Whipple, 1926). Lapse rates tended to be higher at noon and during storm events suggesting that vertical mixing was more active in these circumstances (Whipple, 1926).

The weather during the Expedition

Figure 4 shows the barometric pressure and air temperature as measured at Base Camp for the duration of its occupation: 1 May to 13 June 1924. Both time series have positive trends that reflect the warming of the region and the resultant thickening of the atmosphere that occurs during the spring and early summer (Moore and Semple, 2004;

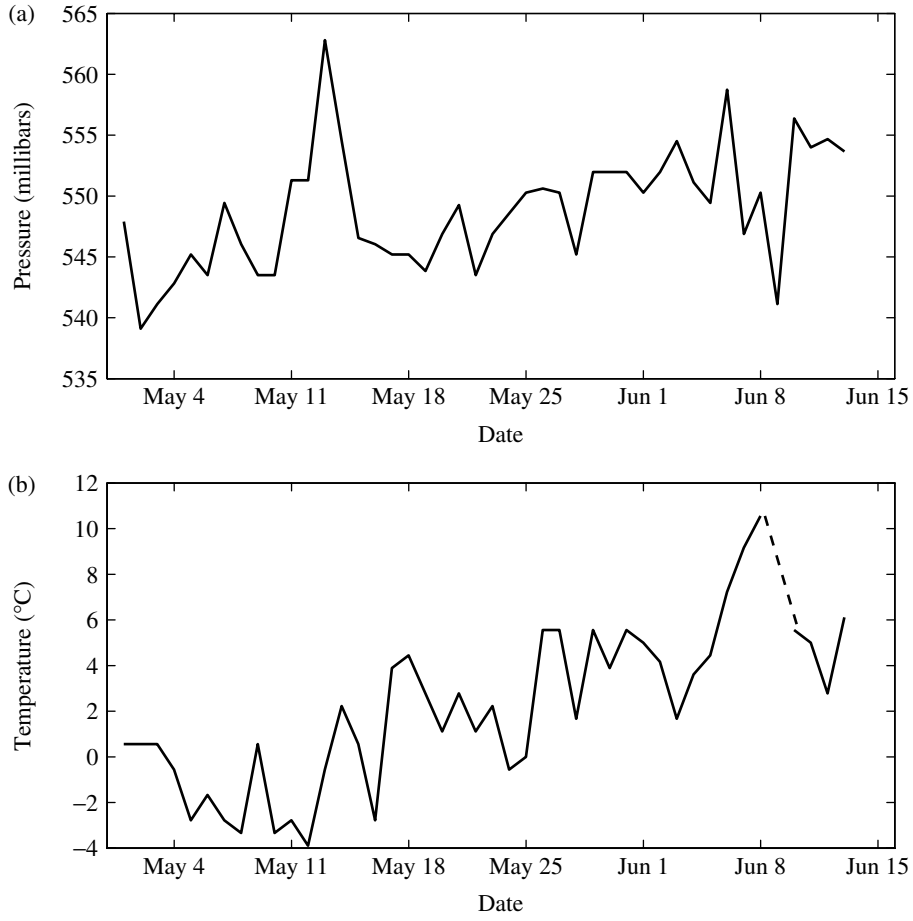

Figure 4. Time series of (a) barometric pressure (millibars) and (b) air temperature (°C) as collected at Base Camp on the north side of Mount Everest (5029 metres) during the 1924 Expedition. The dotted line in (b) represents missing data on 9 June.

2009). The pressure time series is in good agreement with the weather diary kept during the expedition. For example, the periods of low pressure on 2, 9, 10 and 22 May and 9 June correspond to days in which the weather was recorded to have been poor. During the first two weeks of June 1924 there was a warming from 1.5°C on the 3rd to 10.5°C on the 8th and a drop in barometric pressure from 559 millibars on the 6th to 541 millibars on the 9th. The barometric pressure measured on the 9th was the second lowest observed during the expedition, with the lowest reading of 539 millibars occurring five weeks earlier on 2 May.

These measurements are also in general agreement with the observations made by the various members of the expedition during the two summit attempts. For example, Norton describes 4 June as being *fine and nearly windless – a perfect day for our task – yet bitterly cold* (Norton, 1925). Mallory and Irvine left Camp IV (7100 metres) on 6 June for their summit attempt. In a note that day from Camp V (7800 metres), Mallory states that *there is no wind here and things look hopeful* (Norton, 1925). On the 7th, in his final note, Mallory describes conditions at Camp VI (8200 metres) as *perfect weather for the job* (Norton, 1925). Odell describes the morning of 8 June as *clear and not unduly cold* (Norton, 1925) with snow and strong winds beginning around 2pm that he described as being a *rather severe blizzard* (Odell, 1924). According to Odell, the blizzard lasted for about two hours and was severe enough as to have most likely forced the summit party to abandon its attempt (Norton, 1925). He climbed high on Everest on both 9 and 10 June looking for the climbers and mentions that strong winds persisted through the 10th before they started to relent (Norton, 1925).

To obtain additional information on the nature of the disturbance that gave rise to the dramatic pressure drop during Mallory and Irvine's summit attempt, the hand-drawn weather maps prepared on a daily basis by the Indian Meteorological Department were considered. Figure 5 shows the map for 9 June 1924. There was a region of low pressure over north central India with southerly flow ahead of the low that would have advected warmer air into the Mount Everest region – whilst up to 170 millimetres of precipitation fell in 24 hours in the vicinity.

Discussion

In this paper we have used measurements made during the 1924 British Expedition to Mount Everest to reconstruct the meteorological conditions during Mallory and Irvine's ill-fated summit attempt. We have shown that a drop in barometric pressure of 18 millibars was observed at Base Camp during this attempt (Figure 4). Once-daily pressure measurements make it difficult to fully resolve the temporal evolution of this drop but it is clear that the pressure was falling during their attempt. Given the synoptic-scale nature of the weather system that gave rise to this pressure drop, it is also probable that a pressure drop of a similar magnitude occurred on the mountain above Base Camp. Recent observations made on the South Col of Mount Everest (8000 metres) during May 1998 recorded a drop of seven millibars during an intense storm (Moore and Semple, 2004). During the *Into thin air* storm in May 1996, the magnitude of the pressure drop at the summit was estimated to be six millibars (Moore and Semple, 2006).

The surface expression of this drop was captured in the manually analysed weather maps produced at the time by the Indian Meteorological Department (Figure 5). The pressure data from Base Camp indicate there was most likely a coupled upper-level trough that was passing through the region during their attempt. Such a coupling between a surface low and an upper-level trough often occurs in the region during the pre-monsoon period and is referred to as a Western Disturbance. These systems are responsible for much of the cool-season severe weather in the region (Dimri, 2004; Lang and Barros, 2004). A composite analysis indicates that these systems have their largest amplitude around 500 millibars (Lang and Barros, 2004). The low-level southerly flow ahead of the surface feature would advect warm subtropical air into the region, a result that is consistent with the warming observed at Base Camp at the start of the summit attempt (Figure 4).

In the previously analysed 1996 and 1998 storms on Mount Everest, a similar weather pattern was identified (Moore and Semple, 2004; 2006). In both of these events, the surface and upper-level flow resulted in an environment conducive to organised convective activity in the form of thunderstorms (Doswell and Bosart, 2001). Indeed the role of Western Disturbances as producers of convective weather in northern India and Nepal has been known since the early period of synoptic meteorology in India (Blanford, 1884). We hypothesise that similar convective activity was responsible for the blizzard observed to engulf the mountain on 8 June 1924.

Additional support for this conjecture comes from the documented observations of heavy precipitation in the vicinity of Mount Everest on the 8th and 9th (Figure 5). There is another similarity with the 1996 *Into thin air* storm that is worth noting. In that

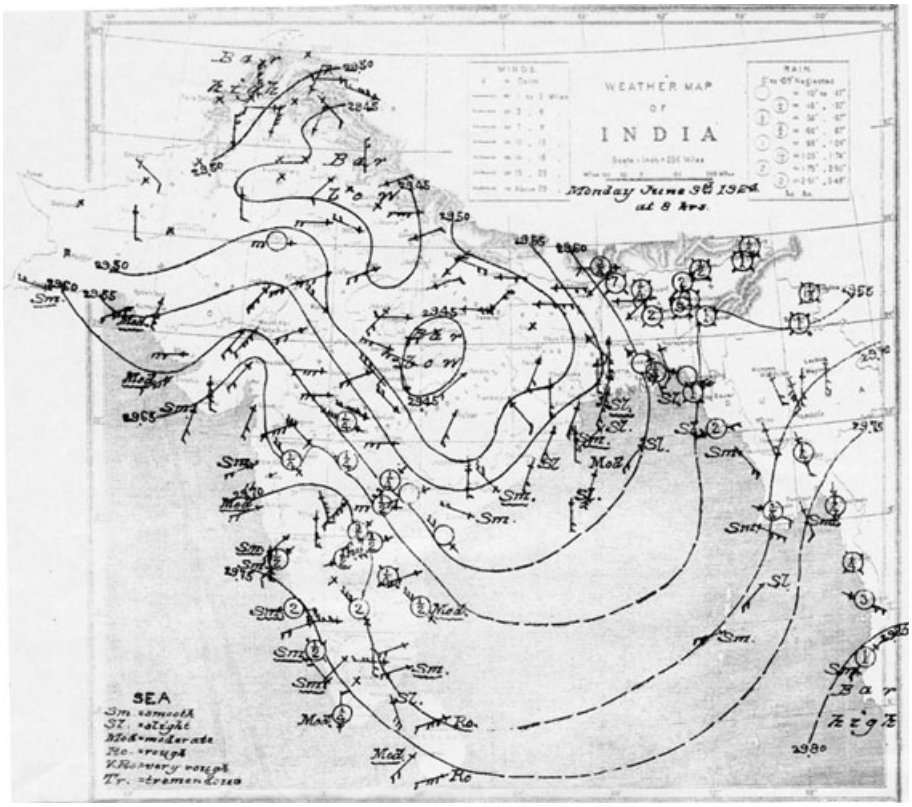

Figure 5. Manual analysis of the sea-level pressure (inches Hg) generated by the Indian Department of Meteorology at 0800h (local time) on 9 June 1924. The barbs indicate wind speed and direction while the circles indicate precipitation amount in the previous 24 hours. See the legend for details on wind speed and precipitation amount.

event, the stormy weather was of a short duration and the cessation of convection was followed by an extended period of high winds near the summit (Krakauer, 1999) that was shown to be associated with the presence of a jet streak (Moore and Semple, 2006). As discussed earlier, Odell mentions that the blizzard on the 8th lasted approximately two hours and that strong winds persisted through to the 10th before they started to relent.

As we have shown, Mallory and Irvine's summit attempt occurred during a period in which there was a very significant drop in barometric pressure. Mount Everest is so high that the low barometric pressure near its summit places humans extremely close to the tolerance limit for hypoxia; changes in pressure near the summit as small as four millibars have been argued to be of physiological relevance (West, 1983; West *et al.,* 2007). It is therefore likely that this drop in pressure would have resulted in an increase in their hypoxic state.

Compounded by the cumulative effects of hypoxia, fatigue, and extreme cold, Mallory and Irvine would have been at the limit of their endurance as they moved along the Northeast Ridge of Everest in the midst of a severe blizzard associated with the onset of convective activity. Their situation would have been aggravated by the fact that they most likely ran out of supplemental oxygen early on the afternoon of 8 June (Hemmleb *et al.,* 1999) resulting in an increase in their hypoxic state. Their route is now known to be a dangerous one on the mountain. Cognitive impairment during descent brought on by hypoxia is the most common cause of death on Mount Everest (Firth *et al.,* 2008). Although the details of what happened to Mallory and Irvine are still not fully known, we believe that there is compelling evidence, some of which was actually collected at the time of their disappearance, that the weather during their summit attempt may have been more severe than previously thought and that the decrease in barometric pressure that they experienced was an additional factor contributing to their demise.

Acknowledgements

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