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DID ABORIGINAL AUSTRALIANS RECORD A SIMULTANEOUS ECLIPSE AND AURORA IN THEIR ORAL TRADITIONS?

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Abstract: We investigate an Australian Aboriginal cultural story that seems to describe an extraordinary series of astronomical events occurring at the same time. We hypothesise that this was a witnessed natural event and explore natural phenomena that could account for the description. We select a thunderstorm, total solar eclipse, and strong *Aurora Australis* as the most likely candidates, then conclude a plausible date of 764 CE. We evaluate the different factors that would determine whether all these events could have been visible, include meteorological data, alternative total solar eclipse dates, solar activity cycles, aurorae appearances, and sky brightness during total solar eclipses. We conduct this study as a test-case for rigorously and systematically examining descriptions of rare natural phenomena in oral traditions, highlighting the difficulties and challenges with interpreting this type of hypothesis.

Keywords: Aboriginal Australians; oral traditions; cultural astronomy; geomythology; solar eclipse; *Aurora Australis*

Warning to Aboriginal Readers: This paper contains references to cultural subjects that may not be appropriate for the reader.

1 INTRODUCTION

The oral traditions of Aboriginal Australians are multi-layered and multi-faceted. Within these traditions are descriptions of natural events, both mundane (e.g. lunar phases) and rare (e.g. eclipses). These descriptions often are incurporated into a narrative, or storyline, which can include mythological elements. This serves as a mnemonic for remembering the information encoded in the story.

In this paper, we examine an oral tradition recorded by Peck (1933) from an Aboriginal person that appears to describe simultaneous rare natural events. There are several explanations for this oral tradition. The description could be based on a witnessed event. It could be purely 'mythological' in nature, serving a symbolic and/or mnemonic purpose. It is also possible that elements of the story could have utilised a degree of 'poetic license' by Peck. It is difficult to know the reasons, but some of them can be tested.

We hypothesise that the story reflects a living memory of simultaneous natural events that were witnessed and recorded in oral tradition. We test our hypothesis by exploring various natural phenomena that the tradition could be describing, then utilise historical records and scientific studies to test each one rigorously to identify the phenomena that best fit the narrative in the storyline.

This study serves as a test case for showing how the methods and frameworks of cultural astronomy and geomythology can be used rigorously to examine Aboriginal oral traditions for records of natural events. Our analysis is not conclusive, but rather highlights the various challenges and uncertainties researchers face when conducting this type of research.

Cultural astronomy is the study of the effect of astronomical knowledge or theories on ideologies or human behaviour (Campion, 2004), sometimes called the 'anthropology of astronomy' (Platt, 1991). It incorporates the sub-disciplines of archaeoastronomy (the study of past cultures, relying heavily on the archaeological record), ethnoastronomy (the study of contemporary cultures, relying heavily on the ethnographic record) and historical astronomy (the study of written records about astronomical objects and phenomena). A related field, geomythology, examines geological events described in oral and material traditions (Vitaliano, 1968). These disciplines are highly interdisciplinary, drawing from the social sciences, humanities, and natural sciences.

2 THE STORY

Aboriginal stories generally were collected and recorded by non-Aboriginal people. These individuals were often missionaries and 'explorers' in the early days of European colonisation, followed later by linguists, ethnographers and government-agents. In the early 1900s, a number of people published collections of Aboriginal stories as popular books. As part of a project exploring the Aboriginal astronomical traditions of the Sydney region, we identified an unusual story in one of these books that seems to describe simultaneous rare sky phenomena.

In 1925 Charles W. Peck published a book about Aboriginal stories titled *Australian Legends: Tales Handed Down from the Remotest Times by the Autochthonous Inhabitants of our Land*, which "… is by far the richest source of Illawarra Dreaming stories …" (Organ, 2014: 54), from the areas west and southwest of Sydney. Charles Peck (1875–1945) was born on the south coast of New South Wales, and was a schoolteacher from the age of 16, only breaking his career for two years to serve in the First World War. He travelled to areas around Sydney after 1920, including the Blue Mountains and the Burragorang Valley, to collect stories from Aboriginal people (Organ, 2014). At the time of the publication of the first edition of *Australian Legends* … in 1925 he was

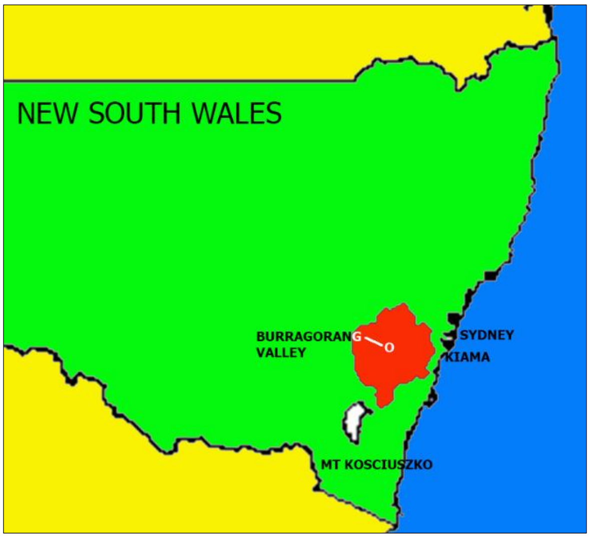

Figure 1: The location of Peck's story (Commonwealth of Australia, NNTT).[1]

one of only a handful of writers who treated Aboriginal cultural stories with the respect they deserved as often accurate depictions of natural events. His sources are not definitely known, but Michael Organ, who has written on Peck and *Aboriginal Legends* (ibid.), has confirmed that Peck's stories are faithful, and not embellished linguistically (Organ, pers. comm.). Although not an academic, Peck clearly understood the importance of the stories that he collected, and that they would be a valuable resource for future researchers.

This story is centred on the Burragorang Valley (Figure 1), however, Peck does not identify a specific Aboriginal community where he obtained the story, and it could have come from several different communities in that area.

The story, entitled "The First Kangaroo" (Peck, 1933: 85–86), tells how the first kangaroo was borne to Australia upon the "… greatest wind that ever blew." It was blowing across Australia from Perth (on the far western coast of the Australian continent) to the area of the story, where it was able to touch down. At the same time, an Aboriginal leader was searching for new country, and saw the following in the sky:

> The strangest mass of cloud he had ever seen was there. It was sepia coloured with black edges. It seethed and curled and split. It billowed and curled and broke – and frayed out. Long spirals of lighter colour worked wonderful patterns against the brown, but drawing out and contracting, waving like giant battle-plane streamers, now straight as spears, now bent over like millions of boomerangs, now detaching, then adhering; the awe-striking masses of vapour came on from the west. Big rocks were tumbling there. Hugh walls built up and tottered over and tumbled and crashed. Giant forests were born and waved in a giant storm and were felled. And with all that turmoil of vapour up aloft, the earth below was calm and serene. It faced an inevitable, and inevitable was a catastrophe.
>
> Suddenly it grew dark.
>
> A night in the daytime descended in a second, blotting out everything. But in the heavens a wondrous light appeared. Long streams of liquid fire started from the south, and shot sheer across the heavens from pole to pole. They waved from west to east. Red and yellow, purple and brown, pink and grey, golden and black, white and pale green. All these colours in long straight fingers stretched from pole to pole, waved and crossed, and passed away towards the east. The unfortunate black man had never seen such a sight.
>
> But he had heard of it.
>
> It seemed to him that perhaps once in a lifetime a man was privileged to see such a thing. He cowered before it. Then came the tornado. With the wind the lights waved out and the clouds passed, and the night (for it was really night then) showed starlight and clear.

The story goes on to describe the arrival of the first kangaroo, and the leader's further investigation of the new country. The story says Aboriginal people from a large area witnessed this event, ranging from Mt. Kosciusko in the south, the Nepean River in the north, Kiama to the east and Goulburn to the west, also including Mittagong, Currockbilly Mountain, Burragorang, and the Monaro District (Figure 2).

This remarkable description of multiple phenomena in the sky easily could be mistaken for a mythological story, which may be the case. But is it more than this? Could this story describe an actual event or events, as fantastic as it appears to be? We study this possibility.

3 METHODS

We examine a range of possible phenomena that could explain the three natural events:

Figure 2: Map of south-eastern New South Wales, the Australian Capital Territory, and north-eastern Victoria, featuring places mentioned in the oral tradition from where the event was visible. The story is centred on the Burragorang Valley (generated using Google Maps).

1. A large thunderstorm cell;
2. Something causing the day to turn to darkness very quickly; and
3. The appearance of multi-coloured streams of light stretching across the sky.

The approaching mass of cloud seems to be a clear description of a large thunderstorm cell, which are common in the Blue Mountains.

The sudden darkening of the sky could be attributed to cloud cover, but this seems an unlikely explanation given the description. Rather, an eclipse of the Sun seems to better fit the description in the story. The sky will only turn noticeably dark during a total solar eclipse. A partial eclipse can pass relatively undetected. A total solar eclipse would explain how the light display in the sky could be seen, which would not occur if the sky were over-cast. Partial eclipses largely are ignored, as Hughes (2000: 205) calculated that it is possible for a person to miss the change in sky brightness that would signal an eclipse when the Moon covers less than 93.7% of the Sun's disc.

As for the light display, we consider several atmospheric phenomena, including nacreous clouds, Sun pillars, parhelia, lightning sprites and the *Aurora Australis*. Nacreous clouds (Figure 3(A)) are very high-altitude clouds illuminated by the Sun that can exhibit a wide range of colours, including many of those mentioned in the story. These clouds can also exhibit long streams, but there are a number of behaviors in the story that nacreous clouds do not exhibit, including "… waving from west to east …" (they do move, but very slowly), and their location is normally from about 50º to 60º latitude (although they can be seen further from the poles).[2] Sun pillars (Figure 3(B)) are caused by low angle sunlight reflecting from horizontal ice crystals.[3] There is no reported evidence of Sun pillars moving rapidly in the sky. Parhelia, also known as sundogs (Figure 3(C)), are a similar phenomenon formed when sunlight reflects off ice crystals, creating a halo effect around the Sun.[4] Under certain conditions, smaller phantom Suns can be visible on either side of the Sun. Generally, they are seen when the Sun is near the horizon, and under the right conditions can produce a range of colours. Sundogs and parhelia are not associated with the movement of the lights described in the story. A solar eclipse would rule out Sun pillars, parhelia and possibly the nacreous clouds (except in areas near the edge of the path of totality). Given a description of an approaching storm cell, lightning sprites (Figure 3(D)) are another possibility. These transient luminous events are high altitude plasma discharges that can appear as large reddish flashes in the sky, similar to lightning (Füllekrug

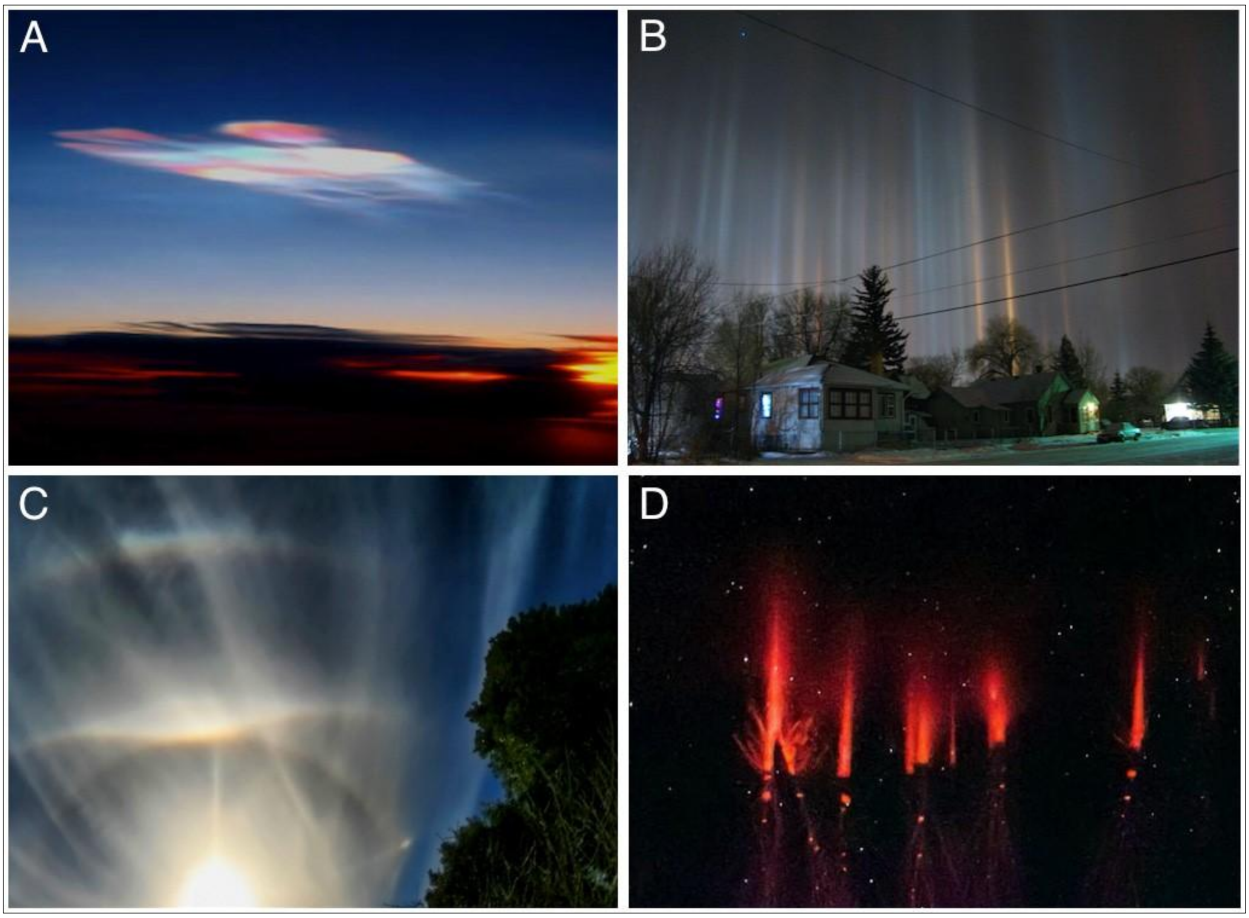

Figure 3: (A) Nacreous cloud (Wikipedia Commons: Foobaz); (B) Light pillars (Wikipedia Commons: Christoph Geisler); (C) Parhelia/solar halo phenomenon (Wikipedia Commons: Brocken Inaglory); (D) Lightning sprites (University of Alaska: Jason Arhens, Creative Commons).

et al., 2006). They occur on very short timescales (fraction of a second), but could certainly have been visible during the event in question given the approaching thunderstorm. However, sprites would not be able to produce the full display described in the story (Heavner, 2016).

Our final consideration is that the story describes an unusually bright display of the *Aurora Australis*. The *Aurora Australis* is recorded in Aboriginal traditions across the southern half of Australia (Hamacher, 2013) and as far north as southwestern Queensland and the Central Desert. Technically, aurorae can occur on any day of the year and in any year. They also can be seen far closer to the Equator, depending on the intensity of the event. For example, Willis et al. (1996) report on an aurora that was seen on 16 September 1770 by Cook and others on the *Endeavour* when it was at latitude 10º South and to the north of Australia. This aurora also was reported by Chinese and Japanese observers. Aurorae also were seen in Cuba and Hawaii during the Carrington Event in 1859 (Windridge, 2016). However, events seen at latitudes near the equator are rare and the frequency and intensity of aurorae are generally dependent on cyclic solar activity and the latitude of observers. Aurorae are more frequent within the auroral zones—a ring-shaped band stretching around the Earth's poles where auroral displays are the strongest and most frequent. While dynamic and changing, the northern edge of the southern auroral zone can extend to the far southern extremities of Australia, such as southern Victoria, South Australia, Western Australia, and all of Tasmania.

While uncommon, aurorae are visible from the Sydney region. Powerful geomagnetic storms resulting from a large solar coronal mass ejection (CME) can expand the range of visibility on the Earth and increase the intensity of the display. On the night of 1–2 September 1859, a CME led to a powerful auroral display that was visible from tropical latitudes such as Queensland, Australia, Cuba, Sub-Saharan Africa, Colombia, and Hawaii (Cárdenas et al., 2016; Green, 2005).

But do significant auroral displays exhibit the characteristics described in the story, and can they be seen during a total solar eclipse? The story describes "… long streams of liquid fire …" in "… red and yellow, purple and brown, pink and grey, golden and black, white and pale green." Several references (e.g. Douma, 2008, Tate, 2016, Trondsen, 1998: 86–88) describe the possible colours of aurorae to include all of those mentioned in the story, assuming brown could be

Figure 4: Strong displays of the *Aurora Borealis* over Norway. Displays like this could potentially be visible over the Sydney region during a powerful geomagnetic solar storm, such as the 1–2 September 1859 Carrington Event (Telegraph.co.uk: Tommy Eliassen).

a dark red, and purple could be a dark blue. Grey is an absence of colour due to low light intensity, and is seen in aurorae (Windridge, pers. comm., 13 October 2016). The description of streams of liquid fire waving from west to east is typical of aurorae bands following the Earth's geomagnetic lines and the colours "… in long straight fingers …" (Peck, 1933) are seen in curtain-like bands in aurorae (Windridge, 2016); Figure 4 (left image).

Critical to our hypothesis is whether an auroral display of this magnitude could be seen in the brief darkness of a total solar eclipse? Silverman and McMullen (1975) investigated the sky brightness during total solar eclipses in 1963, 1966 and 1970, and reported that it was not uncommon for observers to see 3rd magnitude stars during totality. They estimated that the sky brightness at totality was equivalent to approximately –5º to –7º of solar elevation during twilight, or the equivalent of 10^{-3} the brightness of the daytime sky. Können and Hinz (2008) also reported that +3.5 magnitude stars were visible during totality. More recently, Zainuddin et al. (2013) measured the sky brightness during a 2009 total eclipse at Hangzhou, China, using a Sky Quality Meter. At totality, they measured the sky brightness as 16.13 mag/arcsec^2 at the zenith. This enables us to compare the brightness of aurorae. The brightness measure for aurorae is based on the International Brightness Coefficient, Classes I, II, III and IV, which are expressed in kilo-Rayleighs. A Rayleigh is a unit of photon flux (see Hunten et al., 1956).

To compare auroral brightness to the sky brightness at totality requires finding equivalent (visual) mag/arcsec^2 values for the IBC Classes, which are not part of the IBC data. The brightness of the Milky Way, which is the equivalent of IBC Class I, is magnitude 21.4 (Crumley, 2014). The brightness of the full Moon (IBC Class IV) is magnitude –12.6 (Strobel, 2010). The sky brightness equivalents for Classes II and III are 21.1 and 18.0, respectively. We calculate these values by fitting the data to a linear (log) plot (Figure 5). The Class III value of 18.0 mag/ arcsec^2 is within the range of the *B*, *V*, and *R* bands (16.6 to 18.5) reported by Dempsey et al. (2005). This provides a first order approximation.

Using Zainuddin et al.'s (2013) measured sky brightness of 16 mag/arcsec^2 during the 2009 eclipse, we calculate that an auroral flux of approximately 185 kilo-Rayleighs is necessary for an aurora to equal this sky brightness, and a flux exceeding this value if it were to be visible during a total eclipse. Therefore, for an aurora to be visible during a total solar eclipse, it would need to have a brightness between Class III and IV (see Table 1).

We consider a significant display of the *Aurora Australis* to be the best description of the light display in the story, although lightning sprites could also have been visible given the approaching thunderstorm. Therefore, the best fit to the description in the story is an approaching large thunderstorm, a total eclipse of the Sun, and a simultaneous strong auroral display. Two of these (eclipse and aurora) are extremely rare events. The probability of them occurring simultaneously is very low, but we will demonstrate that this is possible under the right conditions.

If this is the case, can we use scientific studies and historical records to pinpoint when this event may have taken place?

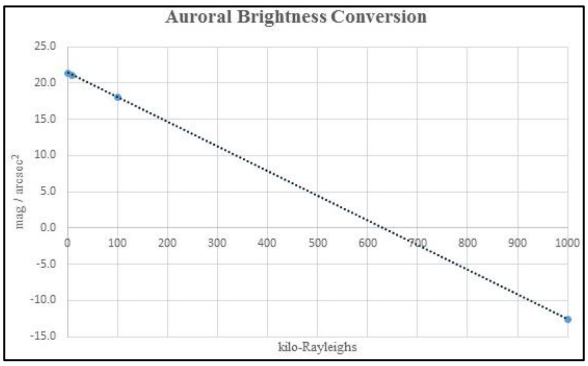

Figure 5: A linear plot fitting data of sky brightness (mag/arcsec^2) versus auroral photon flux (kilo-Rayleighs) using data from Crumley (2014) and Strobel (2010).

Table 1: International Brightness Coefficient (after Thomson, 2016).

AURORAL BRIGHTNESS			
IBC Class	kiloRayleigh	Description	mag/arcsec^2
I	1	Faint, brightness of Milky Way. No colour apparent.	21.4
II	10	Brightness of thin moonlit cirrus cloud.	21.1
III	100	Brightness of moonlit cumulus cloud.	18
IV	1000	Bright as the full Moon. Casts shadows.	-12.6

Table 2: Data for the five total eclipses visible from the Burragorang valley between 1500 BCE and CE 1900. Data include the year, time of maximum totality, the duration of totality and the altitude of the Sun at totality. We also show the maximum eclipse coverage (as a percentage of the Sun's disc) visible from Mt. Kosciusko, Kiama, Mt Currockbilly, Goulburn and the Nepean River. Values in red are those that fall below the 93.7% visibility threshold.

Year	Date	$T_{max\ tot.}$	D	Alt	Mt K.	Kiama	C'billy	G'burn	N. River
189 CE	27 October	15:04:53	1m 41s	40º	96.3	100	99.9	100	99.5
196 CE	14 June	08:31:04	2m 41s	15º	99.0	99.8	99.2	100	100
764 CE	28 November	13:43:14	2m 52s	63º	96.6	100	99.2	100	100
1033 CE	04 January	12:43:19	2m 04s	76º	93.3	98.9	96.6	99.2	100
1857 CE	25 March	10:47:15	1m 24s	8º	92.6	98.7	96.1	98.8	100

4 ANALYSIS

To identify the date of the event, we establish the following ranking criteria:

1. The solar eclipse should be total in the Burragorang Valley area, centring on the Valley, and should be visible as a total or high percentage-coverage partial eclipse (>93.7% of solar disc coverage) from all locations described in the story. We reject annular eclipses.
2. There should be a high probability of an *Aurora Australis* being visible in Southeast Australia during the year of the nominated solar eclipse or historical records of aurora in that year.
3. There should be a high likelihood of a thunderstorm occurring in the area of the event at the time of year and time of day the eclipse took place.

With respect to criterion #1, we used the Alcyone Eclipse Calculator[5] and the NASA Javascript Solar Eclipse Explorer[6] to search for total solar eclipses with the path of totality passing over the Burragorang Valley (33º 56′ S, 150º 24′ W). Our search was limited to the period between 1500 BCE and CE 1900 for this study so as to work within the limitations of eclipse calculating software. We acknowledge that the event may have occurred at an earlier date. We ignored the period CE 1900 to 1925, as this is the period that Peck may have been told the story, and there were no relevant eclipses in this period.

We identified five total solar eclipses visible from the Burragorang Valley in this time frame and calculated the visibility of this eclipse from the locations described in the story (Table 2). Any eclipses that fell below the 93.7% threshold were rejected. Of the five eclipses identified, two (CE 1033 and 1857) were rejected as they fell below the visibility threshold as seen from Mt Kosciusko. This left three candidate eclipses, which occurred in CE 189, 196 and 764 (Figure 6).

To address criterion #2, we searched for evidence of a major auroral event that would have occurred during the time of the CE 189, 196 and 764 eclipses. Attolini et al. (1988: 12,733) established an 11.4-year periodicity in the period CE 1180–1450 through the record of ^{10}Be deposits in polar ice (^{10}Berylium is a by-product of solar particle interaction with the upper atmosphere). Through historic reports of aurorae for the period 687 BCE to CE 1720, they also were able to establish a variable periodicity of aurorae in the range of 9.5 to 11.5 years.

Usoskin et al. (2013) reported a CE 774–776 SEP (solar energetic proton) event calculated at >30 MeV (the Carrington Event of 1859 was similarly assessed as >30 MeV). This CE 775 event was determined by ^{10}Be deposits in polar ice samples and ^{14}C measurement in trees. The CE 774 event is the strongest spike in the last 11,000 years of cosmogenic isotope records (Usoskin and Kovaltsov, 2014). Strong aurorae were recorded in a number of historical records in CE 770 and 776 (Yau et al., 1995).

Assuming that the CE 775 event took place at the maximum part of the Sun's periodic activity, then subtracting an average 11.4-year periodicity would mean that in CE 764 the Sun would only just be past its maximum peak. Švesta (1995) and Bai (2006) both suggest that the declining phase of a solar cycle often has energetic solar events, such as CMEs. The variable periodicity of aurorae for this time suggests that CE 764 could be consistent with the declining phase of a peak in solar activity, with ths possibility of a CME resulting in a aurorae.

We investigated whether the location of the South Magnetic Pole (SMP) (the Dip pole, where the lines of electromagnetic force are vertical) might have a bearing on the strength of the aurora at the Burragorang Valley. Historical records of the SMP exist from 1590 CE, and the National Oceanic and Atmospheric Administration (NOAA) publishes a historical declination map (Historical Magnetic Declination Viewer)[7] from that date. During that period, the SMP has been located along the coast of Antarctica, moving west from approximately 170º W longitude to 130º E at present, which is directly South of the Great Australian Bight. Extrapolating the movement back to CE 764, assuming that the movement has been west along the Antarctic coast, would put the SMP somewhere under South America, which is opposite Australia. If anything, this means that aurorae would have been centered further south of the Australian continent in CE 764, but any movement before CE 1590 is only conjecture.

Further evidence of a possible peak period coinciding in CE 764 was inconclusive. McCracken et al. (2001) examined the Gleissberg periodicity of sunspot activity (an 80-year cycle which has a peak in solar particle events in the middle of the cycle) between the years CE 1561 and 1994. Working backwards from the peak year CE 1620 of the CE 1580–1660 Gleissberg cycle (ibid.) in 80-year increments, the closest peak to CE 764 is CE 740, which means that CE 764 is on the 'shoulder' of the peak in that cycle. Steinhilber et al. (2009) used ^{10}Be records from polar ice to establish a Total Solar Irradiance (TSI) record for the Holocene over the last 9,300 years. This 40-year cycle (ibid.) does not show any peaks near CE 764. Rather, it shows a possible minimum around CE 700.

Using CE 775 as a peak in the various estimated solar cycles (11, 11.4, and 11.8-year cycles), we extrapolate backwards to CE 189 (586 years). None of the results shows the CE 189 eclipse as occurring near a peak in solar activity. Using the first solar maximum year reported (CE 1620), the CE 189 eclipse would have occurred on the shoulder period extrapolating back using the 80-year Gleissberg periodicity. From historical records, Chinese aurora accounts show activity on CE 24 November 195 (Yau et al., 1995: 2). This is pushing the data to its limits and is only a rough first-order estimate: there is little evidence for auroral activity in CE 189 or that this was a peak of any solar cycle maxima estimates.

As for criterion #3, Rasuly (1996) found that Katoomba, in the Blue Mountains 40 km from the centre of the Burragorang Valley, has the highest number of thunderstorm days, and the highest thunderstorm rainfall annually, in the entire Sydney Basin (which extends from Newcastle to Wollongong). Rasuly (1996: 199) also found that thunderstorm frequency is highest in the Spring and Summer (October to February) in the Sydney Basin, with a peak in November. Therefore, we reduce the ranking of eclipses occurring outside of this time frame. Thunderstorms are also more likely to occur in the afternoon and evening, as they tend to form at the warmest and most humid times of the day. Therefore, highest ranking will be given to eclipses that are visible at totality in the late afternoons or early evenings from October to February.

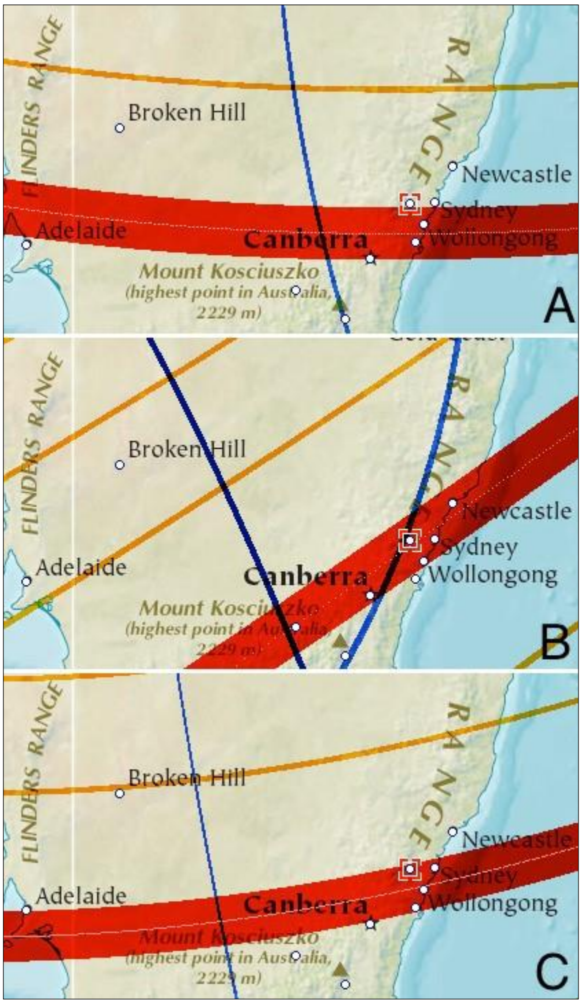

Figure 6: The paths of the three eclipses that meet the first criterion: (A) CE 189, (B) CE 196 and (C) CE 764. The box west of Sydney denotes the Burragorang Valley. The triangle in the bottom-centre denotes Mt Kosciusko (created with the Alcyone Eclipse Calculator).

Another line of evidence for the time of year the story may have taken place is in reference to the Aboriginal leader following a native bee (*Tetragonula carbonaria*) to its hive. Honey was a food source for Aboriginal people, and bees are most active from November to March (Dollin et al., 2000). This indicates the story may have occurred at a time between late spring and early autumn.

We developed a ranking system to estimate how well each candidate fitted these criteria (rejecting any that did not meet criterion #1). The points system was intended to reflect the probability of each category supporting the data. For example, auroral activity is difficult to determine, so a combination of historical accounts and the year being within the solar maxima attains a high rank, while those candidates not meeting these criteria were given a very low rank. The next two categories reflect the probability thunderstorms will occur at a particular time of the year and day. Since thunderstorms can occur at any time of the year or day, the point system is not as far removed between top and bottom ranking and therefore is worth less overall.

Auroral Activity:

- The eclipse coincided with a peak in the solar cycle in that year, and records of aurorae visible in that year could be identified. 5 points.
- The eclipse coincided with a peak in the solar cycle in that year, but it was not mentioned in the historical record. 3 points.
- The eclipse did not coincide with a peak in solar cycle in that year, or in the historical record. 1 point.

Time of Year:

- The eclipse occurred in November, coinciding with a peak in thunderstorm activity in the region. 4 points.
- The eclipse occurred in the period between October and February, but not November, coinciding with the period of more frequent thunderstorms (and bee activity). 3 points.
- The eclipse occurred in the period between March and September. 2 points.

Time of Day

- The eclipse occurred in the afternoon or early evening. 2 points.
- The eclipse occurred in the morning. 1 point.

Each candidate was ranked using the following guidelines:

- 10–11 points: Highly supported by the data
- 7–9 points: Moderately supported by the data
- 4–6 points: Poorly supported by the data

For each eclipse event, the combined scores are ranked as follows: CE 764 (9), 189 (6) and 196 (4). Note that none of the candidates received a top ranking of 'highly supported'. Of the three candidates, the CE 764 eclipse best fits the description in the story, but it is only moderately supported by the data.

5 DISCUSSION

We conclude that it is plausible that a thunderstorm, solar eclipse and auroral display could have occurred at the same time in the Burragorang Valley. Our best fit date to the description, assuming this event occurred within the 3,400-year time frame of this analysis, is on the afternoon of CE 26 October 189 or CE 28 November 764 (the latter achieving a higher ranking). We acknowledge that this is inconclusive and an aurora and eclipse happening simultaneously is highly improbable, but not impossible.

It is also possible that the Burragorang story is an amalgamation of two or even three events witnessed in the sky at different times. Certainly, a total solar eclipse and a strong aurora (at night) on different dates would be memorable (for example, the CE 764 eclipse and the CE 774–775 auroral event), and incorporating them into a single story featuring the more frequent appearance of a thunderstorm could add a dramatic element to serve a mnemonic function.

It is equally plausible that this is a description of a witnessed natural event that occurred much earlier than the time period of our study. With an Aboriginal presence in the Burragorang Valley stretching back at least 15,000 years (Attenbrow, 2010), the story could be much older. Aboriginal oral traditions are flowing and dynamic, not static in time. Oral traditions often incorporate new information and new events. The story reported by Peck may or may not be an example of this.

A key question often asked about Aboriginal oral traditions is how long they could be transmitted from generation to generation without loss of fidelity? Hamacher and Norris (2009), and Hamacher and Goldsmith (2013) have demonstrated that records of volcanic and meteoritic impact events in Aboriginal oral traditions extend back from 4,000 to >10,000 years ago. Meanwhile, Nunn and Reid (2015) reported Aboriginal oral traditions of sea level change around Australia's coastline dating back more than 7,000 years. Research by Kelly (2016: 29) may explain the mechanism whereby Aboriginal communities can use "… knowledge … passed down accurately within oral tradition for a thousand years." Kelly's research focused on the concept of a memory code created by using fixed objects such as landscape or night sky to encode memory over long periods of time. Thus, the idea that the memory of a rare natural event in CE 764 recorded in oral tradition surviving to 1925 is entirely plausible.

Upon reviewing the events mentioned in Peck's book and witnessed by the Aboriginal leader, the sequence at the very end initially was of concern *vis-a-vis* our hypothesis:

> Then came the tornado. With the wind the lights waved out and the clouds passed, and the night (for it was really night then) showed starlight and clear.

The time of totality of the CE 764 eclipse was in the early afternoon. Astronomical twilight (when the Sun is 18º below the horizon and the sky is

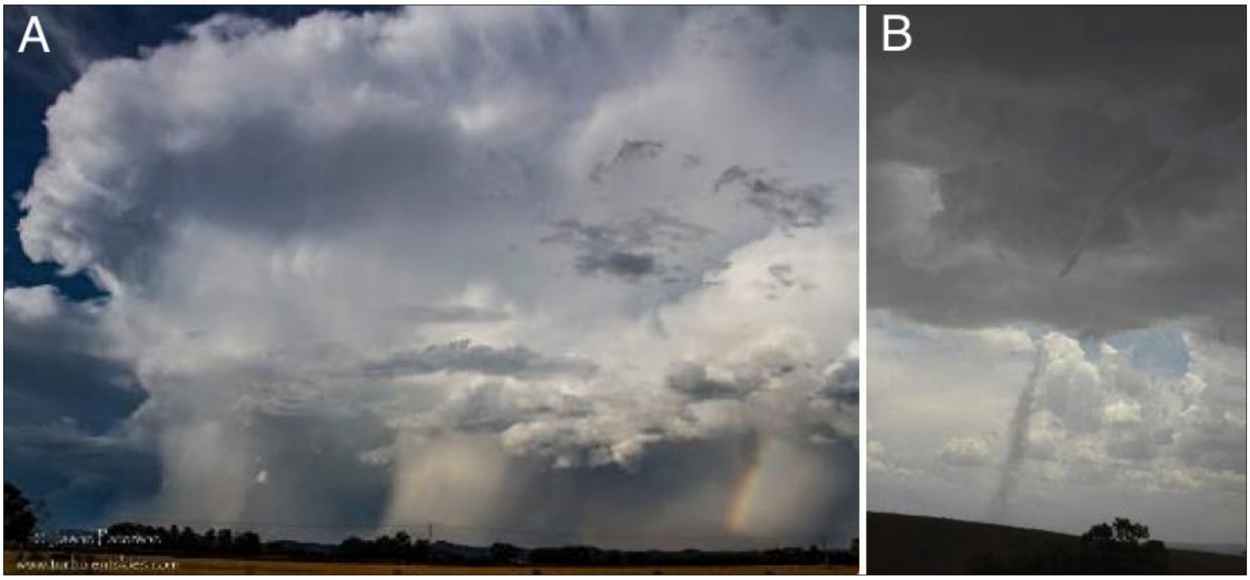

Figure 7: (A) Supercell thunderstorm. Lismore, NSW (Jason Paterson), (B) Tornado at Bathurst, NSW on 16 December 2015 (Ray Pickard).

effectively dark) was not until 19:54 on the evening of 28 November. What happened in the intervening time between totality and the sky becoming dark? We suggest one possibility is that the 'tornado' was the arrival of the thunderstorm (Figure 7A), which had been coming from the west but had not reached the Aboriginal person mentioned in the story. Thus, the person was able to see the sky during totality to observe the *Aurora Australis*. Before totality was over, the thunderstorm passed overhead, blocking off the view of the sky, and reducing the light level significantly. Thunderstorms in the Blue Mountains can be very large (Rasuly, 1996: 47) and take some time to clear to the East. Rasuly (1996: 49, their Figure 2.10) also shows that they start over higher terrain to the west of the Blue Mountains in the time 13:00 to 16:00, and move eastwards in the time 16:00 to 19:00 (while still being active in the Burragorang area). So, it is possible that it was nearly dark by the time the sky had cleared, and that the story, while not being detailed in terms of time, may have reflected the sequence of events. Night would have fallen six hours after the eclipse.

Another possibility is that the 'tornado' in question was actually a meteorological tornado (Figure 7B). On 20 November 1994, an estimated F0/F1 tornado struck Yellow Rock in the Blue Mountains, so tornadoes have occurred there.[8] As most tornadoes are concurrent with thunderstorm activity, both could have occurred on the day in question.

6 CONCLUSIONS

We determine that the Burragorang story recorded by Peck (1933) is a *plausible* description of the simultaneous occurrence of a thunderstorm, a total solar eclipse and an *aurora* observed by Aboriginal people in the Burragorang Valley and incorporated into their oral traditions. We determine that this could have occurred on CE 28 November 764, given the best fit to our analysis. However, there is no recorded documentation or scientific data that demonstrate an aurora was visible during that solar eclipse.

While there are many assumptions and variables in our analysis, it was a useful exercise in rigorously and systematically evaluating an Aboriginal oral tradition that includes a description of natural events. The analytical methods used in investigating this story show promise for future research into plausible descriptions of natural events in other Aboriginal oral traditions.

7 NOTES

1. After Commonwealth of Australia, National Native Title Tribunal, Creative Commons Attribution 3.0 Australia License.
2. Atmospheric Optics, *Nacreous Clouds (Type II Polar Stratospheric Clouds)* viewed 31 August 2016, http://www.atoptics.co.uk/highsky/nacr1.htm
3. Atmospheric Optics, *Sundogs*, *Parhelia, Mock Suns* viewed 31 August 2016, http://www.atoptics.co.uk/halo/parhelia.htm
4. Atmospheric Optics, *Pillar* viewed 31 August 2016, http://www.atoptics.co.uk/halo/pillar.htm
5. The Alcyone Eclipse Calculator uses data based on the Five Millennium Canon of Solar Eclipses –1999 to +3000, with eclipse predictions by Fred Espenak.
6. The NASA Javascript Solar Eclipse Explorer calculates eclipses from the time range 1500 BCE to 3000 CE. http://eclipse.gsfc.nasa.gov/JSEX/JSEX-AU.html
7. *NOAA Historical Magnetic Declination* (no

date), National Centers for Environmental Education, viewed 3 July 2016, https://maps.ngdc.noaa.gov/viewers/historical_declination
8. List of Southern Hemisphere tornadoes and tornado outbreaks, viewed 17 August 2016
9. https://en.wikipedia.org/wiki/List_of_Southern_Hemisphere_tornadoes_and_tornado_outbreaks>

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