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# The Min Min light and the *Fata Morgana*

## An optical account of a mysterious Australian phenomenon

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**Background**: Despite intense interest in this mysterious Australian phenomenon, the Min Min light has never been explained in a satisfactory way.

**Methods and Results**: An optical explanation of the Min Min light phenomenon is offered, based on a number of direct observations of the phenomenon, as well as a field demonstration, in the Channel Country of Western Queensland. This explanation is based on the inverted mirage or *Fata Morgana*, where light is refracted long distances over the horizon by the refractive index gradient that occurs in the layers of air during a temperature inversion. Both natural and man-made light sources can be involved, with the isolated light source making it difficult to recognise the features of the *Fata Morgana* that are obvious in daylight and with its unsuspected great distance contributing to the mystery of its origins.

**Conclusion**: Many of the strange properties of the Min Min light are explicable in terms of the unusual optical conditions of the *Fata Morgana*, if account is also taken of the human factors that operate under these highly-reduced stimulus conditions involving a single isolated light source without reference landmarks.

Key words: Channel Country, *Fata Morgana*, inverted mirage, Min Min light, temperature inversion

Accounts of the Min Min light are a colourful and inextricable part of Australian outback folklore that seem to have resisted many attempts at their explanation. In the Channel Country of western Queensland where the majority of sightings of the Min Min have taken place, the town of Boulia has linked its public image to the phenomenon and thereby tried to improve its attractiveness as a tourist destination. The following notice is found in the town:

'*Min Min light, this unsolved mystery is a light that at times follows travellers for long distances—it has been approached but never identified.*'

Maureen Kozicka[1] spent two years researching Min Mins before her untimely death and produced the only book devoted to the phenomenon. Although she interviewed many who had seen the light and spent much time in the Channel Country, Kozicka[1] never saw the phenomenon herself and was not able to reach any firm conclusions about it. I was lucky enough to witness the phenomenon on a number of occasions while on field trips to study the nocturnal activities of the letter winged kite, *Elanus scriptus*, in classical Channel country; namely, the upper reaches of the Diamantina and Georgina rivers in Western Queensland. The present accounts of Min Min lights and my optical explanation of them are based on those experiences and on some investigations and an experiment designed to reproduce the phenomenon under field conditions.

I will begin with a brief description of the Min Min light phenomenon, summarising the key observations of others, with an emphasis on the 'notorious' features that excite so much emotion in virtually all those who have witnessed it. Next, I will describe my own encounters with the phenomenon, including some field measurements of its distance from the observer, as well as an experiment on the plains that successfully reproduced the major features of the phenomenon. Finally, I will discuss the findings in the light of the hypothesis that the Min Min is a refractive phenomenon, in the same class as the inverted mirage, or *Fata Morgana,* except that it occurs at night. This explanation may have been overlooked largely because the nocturnal Min Min phenomenon involves an isolated light source and the relationship of it to other visual landmarks cannot be determined, as can more readily occur with a daytime *Fata Morgana.* Such a single small light source, at night, without any reference points, may not readily reveal the diagnostic features of this kind of mirage in the way that would make it easily recognisable in a landscape during daylight. I also discuss the subjective aspects of this phenomenon in the light of work on how visual perception deals with ambiguous or incomplete information. These internal, subjective aspects vary with the individual observer and assume greater importance for unfamiliar visual events where there are few supporting visual clues, as occurs with the Min Min.

## DESCRIPTION OF THE MIN MIN LIGHT

The following summary is based loosely on the many descriptions collected by Kozicka[1] and my own experience with five separate sightings. These are meant to be an introduction to this varied phenomenon, rather than a rigorous account, so that the reader can have a background for the specific accounts that follow.

### Angular size, shape and position

Viewed through binoculars, the light is often seen to be a fuzzy, roughly circular disc, a fraction of a degree of arc in diameter (that is, usually seen to be smaller than the diameter of a full moon, which is 0.52 degrees of arc), rather than a point source of light like a star. The fuzzy edges are usually in rapid motion, like a swarm of bees. While there are rare reports of Min Min lights high overhead for short times, especially when the terrain has hollows, the majority of accounts describe the light as if it were floating not far above the horizon.

### Brightness and colour

Brightness varies greatly in different reports, from dim lights similar to a second magnitude star, to brilliant sources that are able to illuminate objects in the landscape and to cast bright shadows of the observer onto building walls. Most reports involve white light but changing colour is not unusual, with gradual changes through the spectrum from red to green and back again. Blue Min Mins are rare compared with green, yellow and red ones.

### Animation

The light seems to have a mind of its own, approaching closely at times and retreating to the distance at other times. This aspect of the behaviour of the Min Min light is literally hair-raising and the source of considerable emotion that may inhibit observers from telling their experiences to a stranger. Even hardened residents of the Outback—if interviewers are fortunate to be able to overcome the residents' reluctance to talk about Min Mins—usually admit to being terrified by these apparent movements of the light, which seems to dance erratically in all three axes and can sometimes move smoothly and swiftly over very large distances. On occasions, a single Min Min light has been observed to split into two independent lights. In many stories, the light moves suddenly just as the emotion of the observer peaks or the observers themselves make a move. Some have reported a sudden disappearance when a rifle shot was fired at the light.

### Velocity

A favourite response to sightings of a Min Min in the Outback is to give it a speed-test, whether by horse or motor vehicle. Min Mins always pass these tests with flying colours, apparently keeping up effortlessly even when the observer attains speeds up to 120 kilometres per hour. However, note that these measurements make a presumption that the light is located relatively nearby, an assumption tested below. If the light were situated at a great distance, its ability to keep up with a high-speed vehicle is not so surprising. For example, the moon seen behind trees would also appear to pass such a test to anyone unfamiliar with the concept of parallax and with the moon's great distance. Nevertheless, even when the observer is stationary, it is clear that the Min Min can sometimes change its apparent location very quickly. Some of these rapid changes seem to be linked to the observer's own actions but clear examples are known where the movements of the light rapidly illuminate different features of the landscape in succession, an effect that can be explained only if the light source itself is changing.

### Distance

Reports vary widely concerning the distance at which the Min Min light is perceived. Changes in the apparent distance of the light are the source of the most unnerving aspect of the light, which can appear to approach within a metre or two, only to recede rapidly to what appears to be many hundreds of metres, sometimes linked to the observer's own movements or thoughts. As the light is usually a single source without any nearby reference landmarks, estimates of its distance are difficult and subject to error, particularly by observers not familiar with the concepts of parallax and angular subtense. Like the moon illusion, where the same angular subtense is attributed to a larger physical size when the moon is perceived to be further away (for example, when seen in relation to adjacent buildings or trees on the horizon), the disorienting aspects of Min Min lights may often result from a misperception of its distance.

### Sound

Virtually all reports of the Min Min light indicate that it is silent, unaccompanied by any sound.

### When and where of sightings

The open plains of the Channel Country are the legendary best site for encountering Min Min lights but reports have been filed from virtually every part of Australia, including seashores and over water. In the Channel Country, sightings are distributed all year round but peak noticeably in midwinter, which favours stable air conditions and a cold ground layer (temperature inversion). Sightings usually take place when the weather is fine with no more than a slight breeze but some of the spectacular reports of large fast movements of the light came from clear but windy nights. Of the 140 sightings investigated by Kozicka,[1] not one was associated with stormy weather.

### Past history

Although Min Mins have an Aboriginal name and were certainly present before the coming of Western civilisation, indigenes to whom I have talked consider that Min Mins have increased in number in modern times. Pre-existing legends about Min Mins include using the fear of them to help control children. I have not found any Aborigines in the Channel Country who regard Min Mins in a positive way. By the same token, there is no report of Min Min lights causing any harm. Unlike Arctic cultures, which have specific words to describe the *Fata Morgana* and related refractive atmospheric effects, I was not able to find any Aboriginal references to, or awareness of, such refractive phenomena in the Channel Country.

## EXPLANATIONS PREVIOUSLY OFFERED FOR MIN MIN LIGHTS

### Luminous micro-organisms associated with flying insects or a bird

While bioluminescent fungi are known from a variety of sites around Australia and could theoretically contaminate a flying bird or insect, no-one has ever caught or even observed the proposed insect or bird. This explanation is also incompatible with the great brilliance of the Min Min, which on occasions can illuminate the landscape and cast bright shadows, a feat not observed with even the brightest bioluminescence. The theory of the cloud of flying luminous insects has an initial appeal, because most accounts of the Min Min include a description of a bright ball with dynamic fuzzy edges. The problem with this explanation, apart from the issue of brightness and the absence of any descriptions of such luminous flying things in contrast to the repeated observations of the Min Min, is that one would not expect a cloud of flying insects always to maintain a roughly circular outline, as Min Mins almost always do. There is one vivid description of a luminous bird in Kozicka,[1] but this has not been replicated, in contrast to the many hundreds of verified accounts of Min Mins that defy this explanation.

### Burning marsh gas

'The will o' the wisp' is a well-known phenomenon that has some similarities to the Min Min but lacks its brilliance and its height above the ground. Moreover, this explanation fails to account for the Min Min's widespread occurrence far from sources of marsh gas and its great mobility at times. The flame-like appearance of will o' the wisps is also different from the circumscribed, usually disc-shaped Min Min.

### Light associated with magnetic anomalies/artesian basin/ionosphere

All of these possibilities are associated with the emission of light but they are largely theoretical, being put forward on the basis that these unusual geophysical phenomena could account for the preferred location of Min Mins over the Great Artesian Basin. There are no direct observations of light that can be attributed to these phenomena, apart from the fact that they would be expected to produce diffuse light effects (for example, the aurora) that are distinct from the circumscribed Min Min. Moreover, Min Mins have been described from every location in Australia, not just the locations where these geophysical phenomena are localised.

### Refractive phenomena

The proposal on which the present paper rests is not new, as landowner Colin McKinnon had already suggested that the refractive effects of an atmospheric temperature inversion could explain the Min Min light (quoted in Kozicka[1]). I have elaborated this suggestion in an attempt to show how refractive atmospheric phenomena, in combination with a light source, either natural (for example, planet or star) or man-made (for example, lamp or quartz-halogen headlight), along with human factors, could account for the diverse puzzling aspects of the Min Min light.

## DIRECT OBSERVATIONS AND MEASUREMENTS OF THE MIN MIN LIGHT

### Observation 1

Teriboah Creek in the Diamantina-Georgina watershed, Coorabulka Station, 140 deg 8 min E 23 deg 47 min S, 11 July 1992: 2153 hours; weather fine and clear with a slight breeze; bright moonlight from three-quarter moon; driving across ashy-downs plains observing the behaviour of letter winged kites (*Elanus scriptus*).

We noticed what we thought was eye shine from a cat or a fox, although oddly it was less-coloured than either predator's tapetal reflex. We estimated that it was located about 100 metres ahead of the vehicle. We were surprised that the bright spot of light was still there when we turned off the headlights. We got out of the vehicle for a better look and an emotional argument ensued concerning the nature of the light, as the three observers, (two scientists and one grazier with more than 20 years of experience of the Channel Country) disagreed violently about its nature. The arguments concerned the amount of movement and the distance of the light, as well as the possibility that it was responding to us.

We all agreed that the light appeared to be floating above the horizon. In the field of view of 10X binoculars, it was about 0.5 to one degree above the horizon; this estimation was difficult to make because the horizon was indistinct in the dark. Through binoculars, the light was a fuzzy disc, about 0.1 to 0.2 degree in diameter, with an outline that gave the impression of dynamic activity, as if it were a ball of bright swarming insects that could not be resolved. The light was variable in brightness, from around the brightness of a first magnitude star to perhaps five times brighter than that, changing unpredictably but gently over seconds. The light had an eerie quality, apparently moving closer or further away, as well as bobbing around, up and down and from side to side. As these movements were one major source of disagreement among the three observers, I suspected that they might be connected with the observers' own head and eye movements and suggested that we get back in the vehicle. There, we could observe the light against the reference frame of the vehicle (there were no trees or other reference objects visible on the horizon), with a head-rest to stabilise head movements. When we did this, most of the apparent movements of the light ceased (as did the heated argument). The variations in brightness could still give the impression that the light was approaching and receding, but the stability provided by viewing from a headrest reduced some of the uncanny aspects of the light and made the variation in intensity the likely key feature that was making it appear to approach and recede.

By carefully manoeuvring the vehicle it was possible to take a bearing on the light, using the magnetic compass mounted above the dash, in combination with the sharp vertical contour provided by the VHF radio antenna attached to the bull bar. By making repeated measurements, we were able to achieve an accuracy of around one degree for the bearing of the light. The bearing of the light was 130 degrees true (120 degrees magnetic). We then drove the vehicle across the plain, orthogonal to the direction of the light (a relatively simple proposition in the plains country where the only obstacles are occasional small channels that can be driven across, with care). After a distance of about one kilometre, we could not detect any change in the bearing of the light. This was reassuring confirmation about the stability of the light's location but was disconcerting in that it implied a great distance. Even though our compass limited the accuracy of bearings to around one degree, the light would have to be more than 60 km away to have an undetectable shift in bearing with a one-kilometre change in the sighting location. We drove a further four kilometres to put a base on the triangle of five kilometres. The bearing at five kilometres was now 129 degrees true. Within

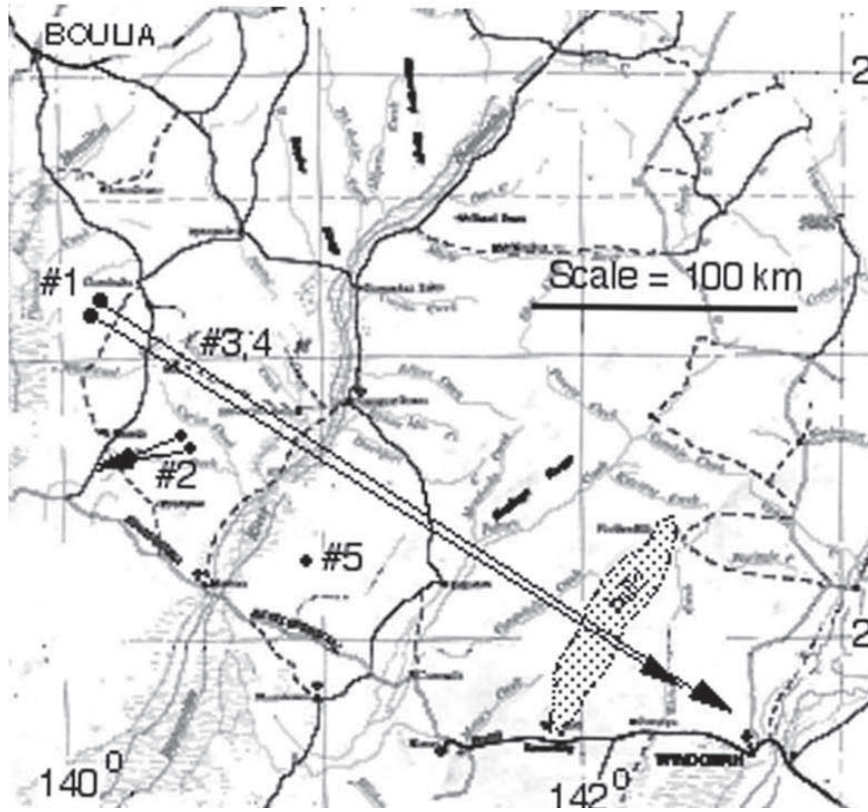


**Figure 1. Location of observations and demonstration of Min Min lights in the Channel Country of Western Queensland.**

**Observation 1. Two bearings of the light were taken using a car compass; the two points were separated by five kilometres. Note that the bearings converge on a fairly straight section of the Diamantina Development road that has both a direction and a distance from the observation site consistent with the road train known to be moving northwest along the road at that time, on the night. What is not consistent with this explanation is the great distance (more than 300 km) and the intervening line of hills that would normally preclude line of sight between the site of Observation 1 and the road east of Windorah. Temperature inversion and a F*ata Morgana* will enable these two distant sites to be made visible to each other.**

**Observation 2. Similar to Observation 1 but with a closer source light in the form of a vehicle at around 20 km.**

**Observation 3. Min Min light demonstration from a vehicle 10 km away, over a rise that normally precluded line of sight, during a temperature inversion.**

**Observation 4. Daytime *Fata Morgana* (shown in Figure 3) was observed in the same location as Min Min demonstration Observation 3 at sunrise immediately following, during the same temperature inversion.**

**Observation 5. Early observation of planet Venus that 'did not set' and conformed to many features of the Min Min phenomenon.**

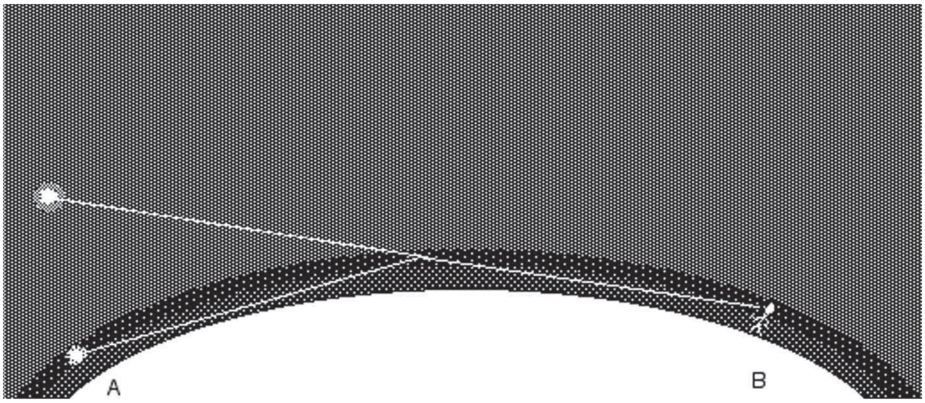


**Figure 2. Over-the-horizon refraction by the inverted mirage (*Fata Morgana*).**

**During a temperature inversion, there is a gradient of increasing refractive index toward the ground layer of air. This gradient can carry light rays around the Earth's curvature (exaggerated here to make the point clear). Because we are accustomed to light rays travelling in straight lines, the light source emanating from over the horizon at A appears to be floating above the horizon for the observer at B. Images of light sources can be transmitted fairly faithfully in this way hundreds of kilometres around the globe, so there will be neither accompanying sound nor any cues from nearby objects to help in their identification. The refractive index gradient acts like a very large light guide so that there is less dissipation and dispersion of the light as well as the possibility of magnification. If the light source is perceived as close (a very common perception), it will not respond in the usual way to changes in the observer's viewpoint, giving rise to bizarre apparent distortions like those seen in Patrick Hughes' 'reverspective' paintings where there are conflicting cues about distance. Light sources, both natural (for example, planets and bright stars) and man-made (for example, quartz halogen headlights), can give rise to the Min Min light phenomenon under conditions of *Fata Morgana* at night when the usual diagnostic features of this mirage phenomenon are absent. Because the inversion is usually changing constantly, the refracted light source will have a shimmering edge (the usual description of a Min Min) and will fluctuate irregularly in brightness with a resulting change in the apparent distance (as there are no other cues to the distance of such a light source except brightness).**

the accuracy of our estimate of the bearing, we calculated that the light was more than 300 km away. This astonishing value was so far away from our initial 100 metre estimate that we double-checked it, with the same result (within the error of our method). This is shown in the map of Figure 1.

The light was visible for about 20 minutes and then suddenly blinked off. When later plotted onto a map of the area, we found that the bearing and distance coincided with a section of straight road to the east of Windorah. This section of road had a general heading toward our observation sites on the plains (Figure 1). In addition to the surprisingly large distance, we noted that there were a couple of lines of relief between the observation site and the apparent source of the light. One of these lines of hills was more than 100 metres higher than the observation site and the apparent source (Hills near Mount Butler, Figure 1). A later check with Windorah residents revealed that a road train had arrived from the east at around the time of our observations. This section of road and the observation site were at elevations of approximately180 m and 200 m above sea level, respectively, with the Emu Bush hills near Mount Butler, elevation 303 m between. Even if there had been completely flat country between the observation site and the section of road concerned, it should have been impossible to see this far over the horizon from a vehicle. The presence of the intervening hills underlines the mystery by further ruling out a line-of-sight observation (Figure 2).

## Observation 2

Ingledoon 2 Bore, Davenport Downs Station: 140 deg 28 min E 24 deg 20 min S; 15 July 1992. On the night following Observation 1, under similar weather conditions, we were able to make very similar observations on another light to the south that appeared for 30 minutes and the location of which proved to coincide with a road that would normally be invisible because of intervening hills. At one point, this light split into two sources that moved away from each other, along a line that was parallel to the horizon, at about two degrees per second until the southerly light (on our left) disappeared. Through binoculars, we could see that the remaining light kept moving very slowly northwards, consistent with a vehicle on the Monkira-Coorabulka road, except for the fact that it was visible over the top of intervening hills.

## Observation 3

Ingledoon #2 Bore, Davenport Downs Station: 140 deg 28 min E 24 deg 20 min S; 15 July 1992, between 2300 hours and 0100 hours. The weather was calm and clear after a warm day. I drove a vehicle 10 km north of the camp, over a slight rise into a watercourse on the upper reaches of Nail's Creek at 140 deg 40 min E 23 deg 55 min S. Because of the intervening hill and the lower elevation of the creek, the campsite and the watercourse 10 km away are not normally visible to each other. When I pointed the vehicle in the direction of the camp, six observers there saw a light, floating above the horizon. One of the six observers had been present at Observation 1 and said that the appearance of the light was similar in this case, a disc approximately 0.2 deg in diameter with a blurred, dynamic outline. By radio, we could verify that switching the headlights on and off resulted in the disappearance and reappearance of the 'floating' light. By covering each headlight in turn with an opaque cover, we could verify that there was a single, roughly circular light source with fuzzy, dynamic edges regardless of whether one or both headlights were involved. The intensity of the light varied, even when the headlight source was known to be unchanging and there were also slight changes in apparent position, mostly in the vertical direction that were estimated to be around 0.5 degree by using binoculars and a steady reference. Its colour also changed, from a vivid red through orange, yellow and green. All observers agreed that the unusual light floating above the horizon that they observed must have been produced by the lights of my vehicle, although five were baffled and excited because the vehicle should not have been visible at all, because of both the distance and the intervening rise.

## Observation 4

This observation was made in daytime, the morning after Observation 3. Although it is not an observation of the Min Min light, it does illustrate the extraordinary optical effects of the atmospheric conditions at the time and emphasises that they can produce mystifying alterations that can be difficult to understand even when there are familiar reference objects. How much more difficult it must be to correctly interpret effects on a single light source, without any reference marks, under such atmospheric conditions. The weather was perfectly clear and calm.

At sunrise there was a striking alteration to our view of the landscape that seemed to originate in the northeast and then appeared to ripple across the plains as they were warmed by the rising sun. The alteration was a progressive revelation of the coolabah trees (*Eucalyptus microtheca*) in the channels where they normally lie invisible from this camp. First, a tree outline would pop up from the creek, then the one next to it and so on down the creek until the whole line of trees in the creek

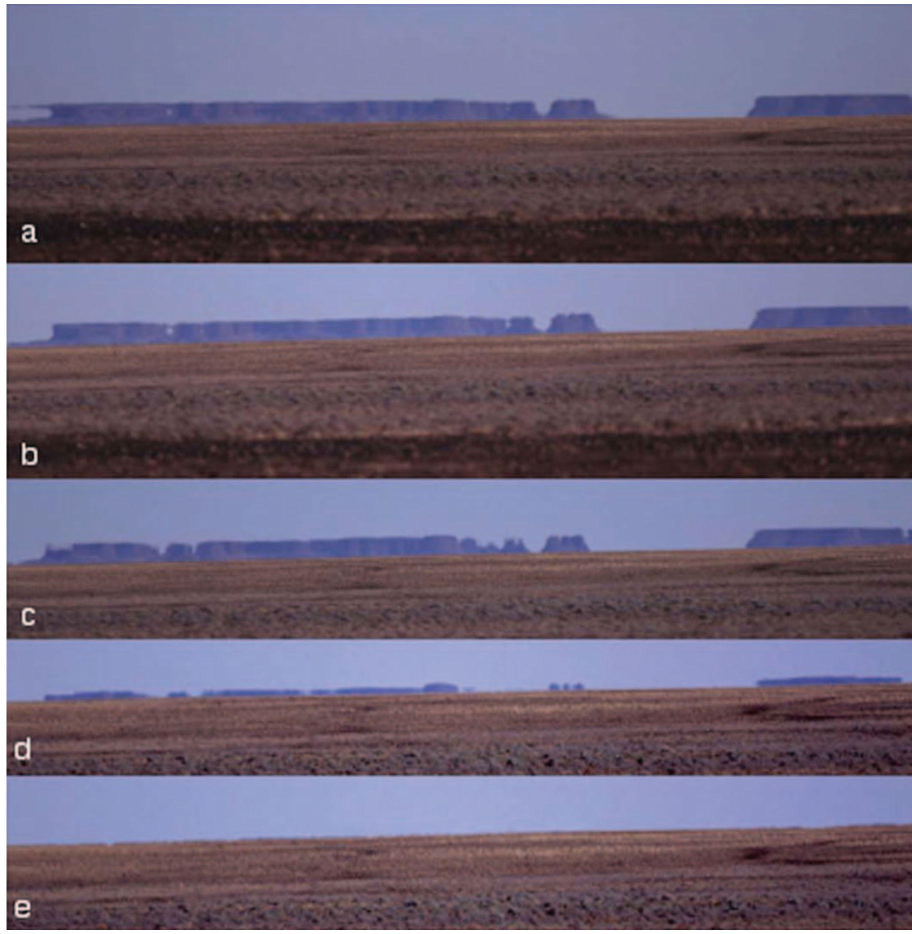


**Figure 3.** ***Fata Morgana*** **phenomenon observed at sunrise the morning after demonstration Observation 4 of Min Min lights.**

**Figures 3a–3e show a succession of views, top to bottom, earlier to later. The usual view from this site is shown in 3e, where the horizon is a featureless, slightly elevated plain. On the morning in question, a range of hills (Tent Hills) was clearly visible for about 10 minutes (a–d) just after sunrise as the temperature inversion of the previous night was enhanced briefly by the warming action of the sun. The hills become visible and are vertically elongated, with a horizontal axis of symmetry, the hallmark of the inverted mirage. Small 'holes' of sky then appear in the mirage (b) and expand, dissecting the 'plateau' into a number of 'mesas' (c) that multiply (d) and then sink beneath the horizon (e).**

**It is instructive to compare this daytime mirage with the Min Min lights that were demonstrated at night, a few hours before, at the same site.**

**By imagining the path of light from a single point in the range of hills, one can begin to appreciate better the strange behaviour that a single light source would take at night. This could move and split in a bizarre fashion that would be very puzzling without the corroborating input from lots of other points that we receive in a daylit scene. It is also very difficult to estimate the distance of such a mirage, so it would be likewise impossible for a single light source at night, the distance of which would almost always be underestimated.**

**The difficulties of recognising that Min Min lights are a nocturnal aspect of** ***Fata Morgana*** **and temperature inversions arise partly from the fact that a single isolated light source does not provide the suite of diagnostic features (such as vertical elongations, horizontal axis of symmetry, shimmering outline, dynamic dissections et cetera) that help one to recognise the phenomenon during the day.**

**Figure 4. 'Horizontal splitting' of *Fata Morgana*: same observation site as Figure 3 but viewed further to the west. Arrow indicates same rock in each view. This horizontal axis of symmetry is diagnostic of the *Fata Morgana*.**

was made visible over a few seconds. A similar effect became visible in creeks to the south, until there were dozens of lines of trees in their channels, all invisible a few minutes before. Through binoculars, each tree had a pointed top, instead of the usual rounded crown that characterises coolabahs. There was a constant shimmer and changeability of the altered landscape that made it difficult to be certain about all details of this change but it appeared that the pointed profile was produced because each tree now had a mirror image above it, reflected about the horizontal plane, so the top of the new view of each tree was its trunk rather than its crown.

As we were marvelling at the phenomenon in the channels and trying to photograph it, we noticed an even more bizarre scene to the north. Instead of the slight rise that normally dominates the view to the north, there was a plateau of brightly coloured rock that occupied a sweep of 20 to 30 degrees of the northern horizon. The plateau appeared to be made of layers of brown and red rock and through binoculars, we could see that it had a horizontal axis of symmetry. Just as we noticed this mirror symmetry, tongues of blue sky started to 'eat into' the mesa. Both horizontally along the line of symmetry and vertically in a few places, small 'holes' of sky appeared and became dissecting blue blades that invaded the plateau so that it was broken into smaller 'buttes' that continued to diminish in size (Figure 3). As we tried to integrate all the changes and photograph them, the buttes sank smoothly and vertically below the horizon. These changes are shown in Figures 3 and 4.

On an orientation tour later, we found that the plateau that we had observed was produced by a low lying rocky hill (Tent Hills, approximately 20 km north) that is not normally visible unless one drives at least about 10 km from the camp where we made the observations.

## Observation 5

On 26 July 1990, we were waiting for a colleague at a rendezvous on the plains in Sallen Creek. Around 2100 hours, we noticed a red light to the west. Thinking that it must be the tail light of Lindsay's vehicle, we set out across the plains in the 4WD to pursue. After a very bumpy ride on the Mitchell grass tussocks, we realised that we were getting no closer to the light and stopped to check it with binoculars. Through binoculars, we saw a light hovering above the horizon that changed colour from green to yellow to red and that had a fuzzy outline. The light was in the appropriate location for a setting planet, (Venus and Jupiter were close to the sun at that time and would have been visible to the west in the evening) but seemed at first to be getting no closer to the horizon, so we did not consider this interpretation. After another 10 minutes or so, the light disappeared over the horizon suddenly and we realised that we must have been watching Venus in some odd atmospheric conditions. At the time, I made no connection to the Min Min light but years later realised that this may have been my first experience of the phenomenon.

## DISCUSSION

Some of the findings presented here might seem to stretch scientific credibility. For example, it can be calculated that even a modern bright, quartz halogen headlight would be too dim to be seen from 300 km away under normal conditions at night. Such a calculation would make the usual assumption that light energy was being radiated according to the inverse square law, along with some atmospheric attenuation and gives a brightness around 0.006 cd/m$^2$ which is too close to the brightness of the night sky to be visible.[2] Similarly, at such distances the light source would be very much over the horizon and therefore unable to reach the observer, if light is travelling in straight lines as we expect it to do, even if there were no intervening hills (the distance of the horizon is $3.57\sqrt{h}$ kilometres where $h$ is the height above the ground in metres). At distances of hundreds of kilometres, a light source should also have had a much smaller angular subtense, so that it should have appeared as a point source rather than the disc that was observed.

How could the light be brought over the horizon and without the usual dissipation of intensity and reduction in size? An explanation is offered by the rare but well-described, atmospheric phenomenon called the *Fata Morgana* or inverted mirage.[3] In contrast to a 'normal' mirage, where light is reflected from a hot, rarefied ground layer of air (for example, so that we see the blue sky reflected in the surface of a hot road or desert), an inverted mirage occurs when light is refracted by a cold, dense ground layer of air, which acts to guide light over the horizon, sometimes for hundreds of kilometres, with the possibility of magnification and a reduced degree of dispersion and dissipation.[4] The observations of Min Min lights reported here, as well as most of those summarised in Kozicka's study,[1] are consistent with a light source that has been refracted by the *Fata Morgana,* a phenomenon that is produced by the refractive index gradient between a ground layer of cold, dense air and the warmer, less dense air above it. The name comes from the Morgan fairy, who was reputed to be able to conjure cities floating on the sea. This is a case where a myth has a solid basis in physics. The phenomenon is better known in the Northern Hemisphere, where sea ice or very cold sea and relatively calm weather conditions often favour the appropriate layering of air. In some northern languages there is a specific word for the phenomenon that reflects its common occurrence, for example, *hilldring* in Norwegian. The magnitude of the gradient varies considerably according to the atmospheric conditions.

The features of the *Fata Morgana* kind of refractive effect include the following, all of which can be seen to apply also to the observations of the Min Min.

## Refraction over the horizon

In the most celebrated cases, Irish sea cliffs have been observed clearly in the middle of the North Atlantic, many hundreds of kilometres away from their real origin.[4] Apart from the fact that they were far over the horizon, these cliffs should have been too small to be visible. A 100-metre cliff will subtend only a fraction of a minute of arc in height at that distance, instead of the many minutes of arc observed. This famous example of the *Fata Morgana* recalls the difficulties in explaining the present observations of the Min Min at more than 300 km in Observation 1. Another celebrated example, from Antarctica, concerns unexpected sunrises. Shackleton,[5] among many others, who experienced this subsequent to his early account, described how his party's first sunrise after an Antarctic winter occurred three days earlier than calculated because of atmospheric refraction. The reality of the refractive explanation was confirmed by the fact that the sun failed to rise at all on the following two days. This *Fata Morgana* effect was a source of some cheer to Shackleton's stranded men, at the thought that their fastidious meteorologist had calculated his dates wrongly.

If the 'ground layer' of air is very cold and still, transmission of light can be remarkably faithful, as in the Irish sea cliffs example described above, where the green of grass and brown of rock were distinguishable even though the image had been transmitted nearly 1,000 km. Similar fidelity is also apparent in the descriptions of icebergs over the horizon made by Shackleton below, where one also notes the changeable and distorting effects. In other cases, there is more diffusion of the transmitted image, such as may be occurring in Min Min observations of a single fuzzy ball with dynamic edges, even when there were two nearby sources of light such as two headlights. Under *Fata Morgana* conditions one cannot assume that light will obey the inverse square law, as it is not radiating perfectly from the light source but is being guided within the refractive index gradient, which may focus the light to some extent and thereby lead to the propagation of a much brighter source than expected on the basis of normal dissipation. There are many reliable reports of the Min Min casting a shadow and illuminating its surroundings. These become more understandable if the *Fata Morgana* effect is acting as a crude light guide and delivering a light source with little of the usual attenuation to an unsuspecting observer tens or even hundreds of kilometres away.

The over-the-horizon feature explains the most commonly observed location of Min Mins, like those described here, where the light is seen floating above the horizon (Figure 1). The over-the-horizon effect would explain how a Min Min light could be produced by a light 340 km away with 100 m of relief in between, as in Observations 2, as well as the other observations, such as 5, where the light source would not be visible under ordinary atmospheric circumstances.

## Vertical reflection and stretching of the mirage

Min Mins are commonly reported to split into a pair or more lights, which may be a result of this aspect of the *Fata Morgana* phenomenon. We did not observe any vertical elongation or splitting of the lights but the 'mesa' and coolabah observations of mirror images in daylight (Observation 4) illustrate this effect and emphasise how difficult it would be to interpret the behaviour of a single light source, uncorrelated with others, in the presence of these kinds of distortions. Observation 2 involved a horizontal splitting that can be related to the horizontal dissection of the *Fata Morgana* observed in Observation 4. Under extreme circumstances of this kind, it would be possible to see lights ahead that had originated behind, as observed for the Min Min described by Dr

Steve van Dyck (cited by Kosicka[1]). A 180-degree refraction would be required to explain this observation, again stretching credulity given the gentle curves usually described by light paths in mirages. Nevertheless, the observer was an experienced scientist and the terrain may have facilitated the formation of a giant refractive 'bubble' or lens, with greater than usual curvature of the refractive index gradient. This speculation could be tested with more detailed observation of the three-dimensional shape of temperature inversions in the sandhill country where this unusual Min Min was sighted.

## Colour changes

Spectral changes are common in *Fata Morgana*, resulting, for example, in a 'green flash' at sunset or sunrise.[3] While blue Min Mins are rare, presumably because of greater scatter at short wave lengths, green, yellow and red variants are commonly observed, as in the present observations.

## Great sensitivity to temperature changes

Slight changes in the gradient of air density and refractive index can produce dramatic changes in the refractive effects. In the present observations, shimmer and movement of the lights and presumably waves of changes in the daylight scene are caused by temperature fluctuations as the earth cools (night) or is warmed (as in the daylight example). This aspect could help explain the uncanny ability of the Min Min to move suddenly or to split as the refractive layers change with warming or cooling or wind.

The following lyrical description of icebergs during a *Fata Morgana*, from Shackleton[5] illustrates all these aspects: over the horizon refraction, vertical 'stretching', colour changes and temperature changes.

'The distant pack is thrown into towering, barrier-like cliffs, which are reflected in blue lakes and lanes of water at their base. Great white and golden cities of Oriental appearance at close intervals along these cliff tops indicate distant bergs, some not previously known to us. Floating above these are wavering violet and creamy lines of still more remote bergs and pack. The lines rise and fall, tremble, dissipate, and reappear in an endless transformation scene. The southern pack and bergs, catching the sun's rays, are golden, but to the north the ice masses are purple. Here the bergs assume changing forms, first a castle, then a balloon just clear of the horizon, that changes into an immense mushroom, a mosque, a cathedral. The principal characteristic is the vertical lengthening of the object, a small pressure ridge being given the appearance of a line of battlements or towering cliffs. The mirage is produced by refraction and is intensified by the columns of comparatively warm air rising from several cracks away north and south.'

## Animation and human factors

The above account has focused on the physical aspects of the phenomenon but it is important to recognise that many of the remarkable aspects of the Min Min light may be a result of contributions from the observer's side. This applies particularly to the common observation that Min Mins appear to be responsive to the observer. Kozicka[1] even has a chapter devoted to the many ways that were invented to handle the Min Min: 'How to get rid of it'. Certainly the hair-raising aspects of Min Min are usually connected to its apparent ability to respond to the observer. How can this feature be encompassed in the present account?

An answer to this question requires a recognition of the ambiguities present in all perceptual judgements and the large contribution required by outgoing brain activity to supplement passive sensory processing ('efference copy' or 'corollary discharge' in neurophysiological terms or 'expectations' in common parlance).

A single isolated light source is difficult to pin down in space when there are no obvious visual landmarks nearby. As a result, one's own eye movements and head movements may contribute motion to the Min Min, regardless of whether this is lateral motion or motion in depth. This effect varies between individuals, because the ability to subtract the self-induced motion signal (efference copy) from the retinal motion signals, to calculate real motion, is not constant, either from individual to individual[6] or from situation to situation. In keeping with this, sitting with one's head still against a rest tends to eliminate or reduce some of the lateral motions of the Min Min, as described above for Observation 2. The problem of motion is a common source of the strong emotions experienced by observers of the Min Min light. In support of this interpretation, careful observation with the head held steady against a support reduced the 'uncanny' aspects of the lights we observed. In fact, sometimes a calm observer will witness the phenomenon without realising that it is a Min Min. For example, I remember one case where some workers at a camp in the Channel Country referred to seeing 'Peter's light' on a few nights, in reference to a field scientist from Queensland National Parks whom they knew was camped about 10 kilometres away (at Observation site 2, 3). A low intervening hill would normally block any light coming from that direction but this was not realised by the workers because the undulations in that country are gentle. Because the light was in the appropriate direction and there was no-one else in this uninhabited area, they correctly assumed that it was Peter's light but failed to appreciate that the light would have had to travel a very unusual curved path to reach them. Ironically, one of the same workers expressed a regret that she had never seen a Min Min despite some time spent outdoors at night in the Channel Country.

Min Min lights will have no strong cue about their distance from the observer. They may be too far away to generate binocular cues, such as disparity between the two eyes. There are usually no nearby contours to provide relative motion cues. They have an indeterminate size or unfamiliar shape that prevents or confuses size constancy cues. Perspective and texture gradient cues are usually not available because reference surfaces such as the ground and the horizon are barely visible. Therefore, it is likely that changes in brightness might be interpreted as changes in distance, even if these fluctuations are related to atmospheric conditions instead of distance. Intense 'looking' can be shown to affect the vergence signals that activate the visual cortex of behaving monkeys in a way that exaggerates the changes in activity produced by fixating a closer object. This effect is only quasi-predictable because it depends on the personality of the monkey and the conditions of the experiment.[7,8] As with variations in efference copy associated with lateral motion, there are likely to be individual variations in the extent to which an individual human attributes motion in depth to a target when there is no other visual information available about this kind of motion. Generally. it is not appreciated that isolated cues (such as stereopsis or motion parallax alone) do not provide visual depth that is veridical. Our sense of depth from such cues is so strong that we may fail to appreciate that the information about the distance of objects is only relative and that it has to be 'truthed' by another system (such as the tactile system or by head movements) before we can achieve veridical distance. The artist Patrick Hughes takes advantage of this fact by the use of what he calls 'reverspective' in his paintings.[9] These paintings are real three-dimensional objects (for example, a truncated pyramid) that project out toward the observer but the projections are painted with perspective cues that make them appear to project in exactly the opposite direction (make your own, using http://www.perceptionweb.com/perc0999/wade.pdf). When they are viewed at a distance, or with one eye closed, so that stereo information does not dominate, the painted perspective cues give the impression that the solid objects are hollow. This will not be surprising to those of us familiar with a three-dimensional cast of a face. In the right kind of lighting, these hollow faces are not seen to be hollow but convex instead. The real surprise with such figures comes when one moves while 'holding in mind' the reversed view. For both the Hughes 'reverspective' paintings and for the hollow face, there is a very disturbing distortion as the brain tries to cling to its false perspective construction about depth relations despite the conflicting information coming from motion parallax. The face appears to turn and follow, even though we 'know' that this is impossible (hence the incorporation of such effects in entertainment parks such as Disneyland's 'Haunted House'), while the Hughes reverspective painting undergoes a similar impossible transformation (as if it has suddenly been made into stretchable rubber) that can be nauseatingly real to many viewers. Cues from one's past experience with real faces and solid objects tend to dominate the veridical ones in this battle of conflicting alternatives.

Similarly, an observer of a Min Min light, with finely-honed senses after years of working in the testing visual conditions of the Outback, will be likely to apply this past experience to the phenomenon. If the light is judged to be a short distance away when it is actually hundreds of kilometres, the changes in the light produced by the observer's movement clearly will not conform to expectations. If the observer's brain adheres for a time to the first perception, head movement will produce a very disturbing sensation, like that seen in the Patrick Hughes paintings, because the expected changes caused by motion parallax will not occur for a light source that is very far away. It is important to point out that these distortions can be just as disturbing when first seen by a visual scientist, even one completely familiar with the underlying psychophysics, such as myself. It is only after long experience with the phenomenon and 'truthing' from other sources of information that an observer can come to an acceptance of such mismatches between constructions and reality.

For this reason, observers with a long experience of photography or astronomy, for example, may be less taken in by the extreme aspects of the Min Min phenomenon. Most of us do not experience any surprise when the moon 'keeps up' behind the trees as we speed along in a car. The alarm at a Min Min doing the same thing is based on the assumption that the Min Min is not far away. Because the Min Min can be located hundreds of kilometres away 'over the horizon', the key contribution from the individual observer that makes the phenomenon so dramatic is the observer's assumption about its location. If one assumes that the light originates nearby, its ability to maintain its heading with respect to trees in the foreground as we speed is surprising. On the other hand, if it is far away, this would be no more surprising than it would be for the moon to maintain its bearing.

## Answers to frequently-asked questions about Min Min lights based on the *Fata Morgana*

#### WHY THE CHANNEL COUNTRY?

Hot days and cold nights favour the formation of temperature inversions in the Channel Country, while the channels themselves provide gentle hollows for the accumulation of cold air and the flat plains permit visibility right to the horizon.

#### WHY ARE SOME SO BRIGHT?

Although natural light sources such as fires, bright stars and planets may have been responsible for the origins of the Min Min legend among the indigenous population, the advent of the quartz halogen headlight has undoubtedly contributed to more recent stories of bright shadows generated against buildings. The surprising maintenance of brightness over great distances, when one would normally expect dissipation according to the inverse square law, can be explained by the refractive effect of the ground layer. A refractive index gradient can act to 'trap' light, in a fashion akin to a light guide, so that light can be carried long distances with less of the usual reduction in size and brightness caused by distance.

#### WHAT ABOUT THOSE CASES WHERE ONE CAN ABSOLUTELY RULE OUT A LIGHT SOURCE IN THE VICINITY?

Because light can be carried hundreds of kilometres with minimal distortion in a favourable *Fata Morgana*, one has to look more widely than the local vicinity to exclude possible light sources.

#### HOW DOES THE LIGHT FOLLOW AN OBSERVER?

None of the usual cues to distance is available in a refracted, isolated, small light source, so the perceived distance can vary widely and be subject to internal human factors. The act of scrutinising an isolated light source can make it appear to move as a result of tracking and vergence eye movements if there are no nearby reference targets.

**WHY IS MID-WINTER A PREFERRED TIME FOR MIN MINS?**

Cold stable air is necessary for the refractive effects of a temperature inversion. These conditions occur most often in midwinter in outback Queensland.

**HOW CAN THEY MOVE SO QUICKLY?**

There are two independent possible sources of rapid movement: from internal human factors such as eye movements, of which the saccadic variety are very fast and from optical changes in the refractive layers, which can occur rapidly because of wind or temperature change. One way that one can infer the kinds of rapid optical changes that might take place with a single light source is to look at a series of photos of a *Fata Morgana* landscape in daylight, where the same feature can be tracked from frame to frame as it moves about and sometimes splits (see http://www.jackstephensimages.com/Merchant/photographicgallery/Fatamorgana/fatamorganapage.html)

**HOW CAN THEY BE RESPONSIVE TO THE MOOD AND ACTIONS OF THE OBSERVER?**

Apparent direction and distance are ambiguous for isolated stimuli and change when the willed effort of the observer also changes. Firing a rifle will have an effect on the observer, for example, that will suddenly change the observer's viewpoint and therefore the perceived location of the light.

**WHY NO ASSOCIATED SOUNDS?**

At distances of kilometres to hundreds of kilometres, the origins of the Min Min light will be inaudible, even if they are associated with a sound source such as a vehicle.

## Apology

I know that there will be great resistance to the acceptance of this and any other explanation of the Min Min light from many in the Outback who are cynical about attempts by city slickers to reduce the magic and wonder of the phenomenon. I have some sympathy with this reaction but would plead that my approach to putting the phenomenon on a more understandable basis does not necessarily explain it away but rather may enhance one's experience of it. My detailed knowledge of the exquisite visual system of birds of prey has not taken away any of the wonder and enjoyment of watching these birds in their natural habitat. On the contrary, I would say that increased understanding has enhanced my enjoyment. Knowing more about the underlying principles can improve one's ability to interpret subtle features in the natural world. Likewise, my account of the Min Min may enhance viewing of it, if only by defining more precisely the atmospheric conditions under which it is likely to take place. If I had known what I know now about the *Fata Morgana* when Maureen Kozicka was alive, I may have been able to help her achieve her desire to witness one.

## Future research

The refractive index gradients produced by a temperature inversion are crucial to understanding the fluctuations of a Min Min light, along with the intrinsic human factors I have mentioned. Refractive index gradients have become an important topic in vision science, especially since the 'five dioptre surprise' where early calculations of the power needed in a replacement lens were in error because of the failure to recognise the greater effective power of the natural gradient index lens compared with the replacement of the same curvature and same average, but uniform, refractive index.[10] Determining the precise nature of the refractive effects involved in outback Australian *Fata Morgana* phenomena would require one to determine the profile of the atmospheric density changes during an inversion, using a probe on a helium balloon, for example. This could be done concurrently with observations of the kind I have described here, with the possibility of accounting in more detail for the bizarre aspects of the phenomenon, along with precise details of the changes in refractive gradients that I believe to be responsible for the sudden appearances and disappearances of the Min Min light.

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**Notes and websites on *Fata Morgana* and Min Min lights**

1. http://mintaka.sdsu.edu/GF/mirages/mirintro.html

This excellent website by Andrew T Young has a detailed description of the optical phenomena of mirages, including

the *Fata Morgana* (inverted mirage), with detailed ray-tracing diagrams, an account of the controversy over whether mirages reflect or refract light, a detailed classification of the three different inverted mirages (which I have placed into the *Fata Morgana* category but which Young distinguishes, giving the *Fata Morgana* title only to cases in which there is a stack of multiple mirages), the related 'green flash' phenomenon et cetera.

2. Arctic *Fata Morgana*

http://www.jackstephensimages.com/Merchant/photographicgallery/fatamorgana/fatamorganapage.html

Shows photos of Thule Rock in the arctic, with multiple images of the rock in some cases and a dramatic variation with time of the shape of the rock.

3. South Dakota *Fata Morgana*

http://www. crh.noaa.gov/unr/iwe/2000/1219/

Shows 'towers' and 'mesas' like those described here.

4. Accounts of the Min Min

http://www.castleofspirits.com/minmins.html

This site has excerpts from Maureen Kozicka's book, as well as some additional sightings.

It is interesting that some of the toughest and roughest people I have met, like shooters and drovers, had no qualms about admitting that they cried or wept when they encountered the lights.

5. Min Min High Overhead

http://www.strangenation.com.au/Casebook/minminlight.htm

This is a detailed description of an encounter with a Min Min by a truck driver. At the end of the encounter, the light moves from a position above the horizon to a more elevated position over the observers and then heads off to the horizon at great speed. Although the observers think that the sighting could be attributable to the 'phosphorescent bird' explanation, it should be borne in mind that refraction can also produce extreme deviations, particularly if there is a pocket of cool air in a hollow and the light encounters the edges of the hollow. In this case, the light moved overhead when the observers were in a slight hollow, after rain. The observers describe rain puddles on the ground, which may have had a cool layer that was responsible for the extreme deviation of the light.

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