Reports

Atmospheric Refraction and Lake Monsters

Abstract. *A survey of reported sightings of lake monster phenomena suggests that many of them may be attributable to atmospheric image distortion. The existence of the necessary conditions (surface temperature inversion and hence strong atmospheric refraction) can be inferred from most of the reports. Under such conditions familiar objects can easily take on unrecognizable form. Two photographs demonstrate the extent of the distortion that can occur.*

Lake monsters have been a part of legend among many peoples. Modern sightings, too frequent to be ignored, have intrigued many scientists, with the result that the subject of lake (and sea) monsters has become the focus of some serious research. Gould (*1*), Mackal (*2*), and others have collected enough careful reports from reputable eyewitnesses to dispel any doubt that the observers were indeed seeing unusual phenomena.

The one element missing from all of these reports (with the exception of Mackal's brief and somewhat incomplete appendix on mirages) is any consideration that the observed or photographed evidence might have been optically distorted by the atmosphere. It may well be that many sightings of monsters can be explained as the sighting of a distorted and hence unrecognized image of a familiar creature or phenomenon.

In the same way that Mackal carefully weeds out much "evidence" as representing standing waves, birds, otters, and so on, it may be possible to accomplish some further weeding-out on the basis of image distortion.

It is well known that approximately horizontal light rays are refracted slightly downward, toward the denser layers of the atmosphere (*3*). This refraction can become strong enough to cause visible distortions if a temperature inversion is present to steepen the density gradient near the earth's surface (*4*). Very interesting cases arise when the temperature gradient is nonuniform with elevation. A single point on the object can then be the source for several rays, all entering the observer's eye at different vertical angles. The eye assumes that the rays entering it are straight; hence the observer perceives such a point as several points at different elevations. When there is a continuum of many rays passing from the single object point to the eye, these image points appear to coalesce into a vertical line. The resulting vertical distension of features within this zone generally distorts them so much that they become unrecognizable (*5*).

A great many of the reports of monster sightings describe atmospheric conditions that are ideal for generating distorted images. Several relevant points are discussed in the following paragraphs.

According to Costello (*6*), monsters are frequently reported in Loch Ness, Scotland, as well as "in many other steep-shored lakes in the cold temperate regions of the Northern and Southern Hemispheres, roughly in a band on either side of the 10°C isotherms." The surface water temperature of such lakes is usually well below that of the air for the first half of the year, since the warming of the lake lags significantly behind the air temperature. Hence a temperature inversion near the water surface is virtually guaranteed for much of the time during the spring and summer months. Nighttime pooling of cold air draining down the slopes will further strengthen this inversion. The notion that surface temperature inversions are correlated with monster sightings is supported by Mackal's analysis (*2*, appendix I) of Loch Ness data: of 249 sightings, only 31 were made at air temperatures below 13°C. Also, of a similar number of sightings, 77 percent were made in May through August—the months when the lake temperature lags the air temperature. Mackal states that the surface water temperature rarely reaches 15°C at the height of the warming; during spring and early summer the surface water is much colder.

The steep shores that Costello mentions are not strictly necessary. The spring and summer inversions over prairie lakes (Lakes Manitoba and Winnipeg, for example) serve admirably for the generation of distorted images. Lake Manitoba is even reputed to have its own monster, Manipogo (*7*).

Another interesting correlation arises from Mackal's summary of lake surface conditions: 84 percent of the Loch Ness observations describe the lake as being calm or having only small ripples. Mackal is quite correct in stating that "disturbances at the surface are much easier to detect when the surface is otherwise calm" (*2*, p. 88). However, such conditions are also best for developing the strong shallow conduction inversion necessary for transmitting stable but distorted images.

Many of the sightings involve observer elevations close to the level of the lake itself—with the observer near the shore or in a boat. The distances along the line of sight are often of the order of 1 km or more (*8*). Either or both of these conditions require low, nearly horizontal light rays to pass from object to observer. Exactly these rays are most easily (and noticeably) deflected by refractive anomalies in the air.

Many different shapes are reported for the monsters seen in any particular lake. This is not surprising if some of the sightings are indeed distorted and unrecognizable images of different though familiar objects. Conversely, similar objects distorted in different ways would also result in different descriptions.

The type of motion described in many of the sighting reports is consistent with observation of refractive effects. Within a stationary inversion layer, the nature of the transmitted image is quite sensitive to variations in the observer's elevation. The image can undergo a large vertical shift in response to small vertical movements of the observer. Further, under the right conditions, inanimate objects can appear mobile even if the observer himself is stationary. If the inversion layer is in slow motion, perhaps containing wavelike undulations, the image can grow, shrink, or move about. It can also appear and disappear without a sound or a ripple, as many of the observations describe. Such undulations can impart a sinuous appearance to an otherwise straight horizontal object (*9*). Possibly some of the reports of sinuous neck and body movements can be attributed to this effect.

Of the many hundreds of observations, only one will be summarized here (*2*, pp. 103–104; *10*). The observation was made by H. L. Cockrell in the fall of 1958. Cockrell had spent several nights on Loch Ness in a kayak, hoping to photograph the monster at night. At dawn, at the end of his third night on the lake, the breeze suddenly dropped and left the

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lake surface mirror-smooth. As Dinsdale (*10*) quotes Cockrell, "Something appeared—or I noticed it for the first time—about 50 yards away on my port bow. It seemed to be swimming very steadily and converging on me. It looked like a very large flat head four or five feet long, and wide. About three feet astern of this I noticed another thin line. All very low in the water; just awash. I was convinced it was the head and back of a very large creature. It looked slightly whiskery and misshapen." Cockrell managed to take two photographs before a slight squall passed over the lake, and the object appeared to sink. After the squall had passed, he again saw something on the surface, but this time the object proved to be a floating stick, 4 feet long and 1 inch thick.

Mackal conjectures that the entire experience was the result of fatigue and "tremendous psychological bias," although this does not explain why the squall would interrupt the appearance. On the other hand, an explanation based on atmospheric refraction is quite consistent with the conditions described. The thickness of the stick could have been magnified by refraction due to a strong inversion over the lake. The refraction could even produce a second image vertically displaced from the first, to account for the second thin line seen slightly astern of the "head." These stable viewing conditions would be disrupted by the squall, causing the disappearance of the monster and the reappearance of the stick in its normal aspect.

An example of atmospheric distortion observed on Lake Winnipeg is provided by Figs. 1 to 3. The photographs were taken on the east shore of the lake on 25 April 1977. The air temperature was about 25°C, while the frozen lake surface was near 0°C. A very light east wind was moving warm air from the land to the lake. The calm air and extreme temperature differences permitted a very strong (nonuniform) conduction inversion to develop over the lake. Observations were made by theodolite, and photographs were taken from a fixed location with a Leitz 560-mm telephoto lens on Kodachrome 64 film. The lens elevation for all photographs was 1.4 m above the lake surface.

Figure 1 shows a general view looking north over the lake to Ironwood Point, 10 km distant from the camera. The stick that protrudes from the ice in the foreground is estimated to be between 1 and $1\frac{1}{2}$ km away from the camera. The vertical scale on the photograph is positioned to give the correct absolute elevation angle of the line of sight, as determined by theodolite measurement at the time of the photograph. The calibration is in terms of angles subtended at the observer's eye. Because of the anomalous refraction, the horizon is elevated 6′ above the level (*11*).

The photographs in Figs. 2 and 3 show different aspects taken on by the protruding stick at different times (*12*). The magnification is identical on both photographs, and the scale of subtended angles is provided along the edge of each (*13*). In Fig. 2, made at 3:56 p.m. central daylight time (CDT), the stick appears kinked and flattened, subtending an angle of only $1\frac{1}{2}$′. In Fig. 3, made only 3 minutes later, the stick looks entirely different. Its height is now 6′ and it appears to have developed a reverse curve. In this case, multiple ray paths originate from a point in the stick's "neck," causing vertical distension. Neither photograph looks very much like the real object itself. They are, however, not unlike

Fig. 1. East side of Lake Winnipeg; view of Ironwood Point, 10 km away, from Grand Beach. The scale shows angles (in minutes of arc) subtended at the observer's eye.

Fig. 2 (left). The protruding stick of Fig. 1, vertically compressed by refraction (3:56 p.m. CDT). Fig. 3 (right). The protruding stick of Figs. 1 and 2, vertically distended by refraction (3:59 p.m. CDT).

some of the photographs given as evidence for the existence of lake monsters.

In summary, many of the conditions under which lake monsters have been sighted are ideal for the existence of strong atmospheric refraction. A critical analysis of sighting reports and photographs could likely explain many of them as distorted images of familiar objects.

It is to be hoped that all future reports of monster sightings will include sufficient meteorological data, such as general weather conditions, air temperature, temperature gradient if possible, and water temperature. Then a reasonable assessment can be made of whether the observation can, wholly or in part, be attributed to anomalous atmospheric refraction.

It is not the aim of this report to discredit the existence of yet unidentified animals or species, for there is impressive evidence to the contrary from sonar data and underwater photography. Rather, the objective is to sharpen optical observation techniques and to provide one more stage of evaluation before accepting such observations as unequivocal evidence.

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References and Notes

1. R. T. Gould, *The Case for the Sea Serpent* (Philip Allan, London, 1930).
2. R. P. Mackal, *The Monsters of Loch Ness* (Swallow, Chicago, 1976).
3. An extensive literature exists. On atmospheric refraction, see texts such as J. M. Pernter and F. M. Exner, *Meteorologische Optik* (Braumüller, Vienna, 1922); M. Minnaert, *Light and Colour in the Open Air* (Bell, London, 1940); W. J. Humphreys, *Physics of the Air* (Dover, New York, 1964); H. R. Reed and C. M. Russell, *Ultra High Frequency Propagation* (Boston Technical Publishers, Cambridge, 1966). On image distortion see, for example, A. B. Fraser, *Appl. Opt.* **14**, A92 (1975); W. H. Lehn and H. L. Sawatzky, *Polarforschung* **45**, 120 (1975); W. H. Lehn and M. B. El-Arini, *Appl. Opt.* **17**, 3146 (1978); W. H. Lehn, *J. Opt. Soc. Am.*, in press.
4. The curvature of a nearly horizontal ray is approximately proportional to the temperature gradient. As an example, if the surface temperature is 0°C, an inversion with the relatively mild gradient of 0.11°C/m is sufficient to produce rays with the same curvature as the earth's.
5. See, for example, I. P. Koch, *Medd. Groenl.* **46**, 191 (1917); J. P. Koch and A. Wegener, *ibid.* **75**, 610 (1930). I have similarly made frequent observations of such zones of vertical distension.
6. P. Costello, *In Search of Lake Monsters* (Garnstone, London, 1974), p. 290.
7. I have observed and photographed numerous mirages on Lakes Manitoba and Winnipeg. One of the observations was made by chance while swimming in Lake Manitoba on a hot day (7 August 1976); a thin horizontal black strip appeared on the surface of the lake for a few minutes, at an apparent distance of 1 or 2 km. Experience dictated that the observation be attributed to atmospheric refraction, but very little help from the imagination would have been required to interpret the shape as a long black serpent. For a brief history of the Manipogo case, see Costello (*6*, pp. 229-232).
8. To estimate distances of this magnitude by eye is difficult enough in a normal atmosphere; to do it in the presence of refractive anomalies is virtually impossible [for example, see W. H. Hobbs, *Ann. Assoc. Am. Geogr.* **27**, 229 (1937)].
9. I have filmed such wavelike motion on Lake Winnipeg.
10. T. Dinsdale, *Loch Ness Monster* (Routledge & Kegan Paul, London, 1976), pp. 101-103.
11. For a camera height of 1.4 m, normal atmospheric conditions give a horizon elevation of about 2′ *below* the level.
12. Between 3:20 and 6:23 p.m., 22 exposures were made of this subject, each at a shutter speed of 1/250 second.
13. The photographs have been highly magnified, but not beyond the resolving ability of the unaided eye. Mackal (*2*, p. 205) gives the latter as 1/2′ of arc, and in a number of his cases the object observed subtended angles of this magnitude.
14. This work was supported in part by the University of Manitoba Northern Studies Committee, funded through the Federal Department of Indian and Northern Affairs, Ottawa, Canada.

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Reliability of Minor Planet Satellite Observations

Abstract. *In an examination of the reliability of occultation observations of minor planet companions, redundant photoelectric observations have been made of possible occultation events. These observations indicate that spurious events may be easily misidentified as true occultations, and that caution must be exercised in interpreting such occurrences. Further analysis of observations of the 1973 Pallas occultation suggests that earlier results may be unreliable.*

Although there are now several reports of minor planet occultation observations that support arguments for minor planet multiplicity (*1*), the evidence is as yet not conclusive. Only a single secondary body has been reported by more than one observer, the 532 Herculina event of 7 June 1978. Even that pair of observations is not ideal, since the visual observer recorded five unconfirmed and apparently spurious events and the photoelectric record of the remaining event was obtained when the asteroid was a mere 2° above the horizon (*2*).

There are, in fact, a number of circumstances which can produce spurious occultation observations. Drifting clouds, airplanes, and atmospheric turbulence may cause a sudden drop in brightness, while instrumental effects may also produce apparent events. Visual observations are necessarily subjective, producing no documentation which may be carefully examined and considered. Reports based on photoelectric observations are inherently more reliable since a quantitative record is obtained of the brightness of the star and minor planet. The reliability of a single observation is increased when the duration of the occultation event is significantly longer than the instrumental time constant and when the minor planet brightness is such that the signal during occultation is significantly different from either sky or asteroid-plus-star levels.

In an effort to study these spurious events, we designed a program for observation of the 28 February 1979 occultation of 13 Egeria in a manner which would provide redundant photoelectric data. The predicted occultation path passed near the U.S.-Canadian border, but observations made from nearly 1500 km away in Tucson, Arizona, still probed well within the gravitational sphere of influence of the asteroid. Three separate telescopes were utilized, each with its photoelectric photometer. The telescopes were all located along the same ground track of the occultation; one telescope (the Steward Observatory 21-inch reflector) was located on the University of Arizona campus, and two portable telescopes were located approximately 6 km west along the same occultation chord (*3*). Data were recorded for 10 minutes on either side of the predicted time of occultation. While the portable telescopes recorded several "occultations" each, most such events were noted as times when the star had wandered out of the measuring diaphragm and none were coincident. The data record from the fixed telescope showed two events which were not identified as guiding corrections but which were recorded as periods of constant brightness in the data from the remote locations. Thus, even these events are definitely of local origin (*4*).

The conclusion which we draw from this experiment is that singly observed occultation events are not uncommonly caused by instrumental or atmospheric effects. Only multiple photoelectric observations of events should be considered as firm evidence for minor planet satellites.

An example in which redundancy eliminated an otherwise plausible occultation event occurred during 11 December 1978 occultation by 18 Melpomene. Visual observations by P. McBride at Green Forest, Arkansas, suggested several brief "blinks," while B. Zellner, observing the event from within a few kilometers of the same occultation path, photoelectrically recorded no change in brightness (*5*).

We would like to discuss one reported occultation event in some detail. This event, the 6 February 1973 occultation of SAO 120836 by 2 Pallas, was observed

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