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MIRAGES

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A mirage is a naturally occurring optical phenomenon in which light rays are bent to produce a displaced image of distant objects or the sky. The word comes to English via the French mirage, from the Latin mirare, meaning "to look at, to wonder at". This is the same root as for "mirror" and "to admire".

In contrast to a hallucination, a mirage is a real optical phenomenon which can be captured on camera, since light rays actually are refracted to form the false image at the observer's location. What the image appears to represent, however, is determined by the interpretive faculties of the human mind. For example, inferior images on land are very easily mistaken for the reflections from a small body of water.

Mirages can be categorized as "inferior" (meaning lower), "superior" (meaning higher) and "Fata Morgana", one special kind of superior.

Cause Cold air is denser than warm air and has therefore a greater refractive index. As light passes from colder air across a sharp boundary to significantly warmer air, the light rays bend away from the direction of the temperature gradient. When light rays pass from hotter to colder, they bend toward the direction of the gradient. If the air near the ground is warmer than that higher up, the light ray bends in a concave, upward trajectory.

Once the ray reaches the viewer’s eye, the visual cortex interprets it as if it traces back along a perfectly straight "line of sight". This line is however at a tangent to the path the ray takes at the point it reaches the eye. The result is that an "inferior image" of the sky above appears on the ground. The viewer may incorrectly interpret this sight as water which is reflecting the sky, which is, to the brain, a more reasonable and common occurrence.

In the case where the air near the ground is cooler than that higher up, the light rays curve downward, producing a "superior image".

The "resting" state of the Earth's atmosphere has a vertical gradient of about -1° Celsius per 100 meters of altitude. (The value is negative because it gets colder as altitude increases.) For a mirage to happen, the temperature gradient has to be much greater than that. According to Minnaert, the magnitude of the gradient needs to be at least 2°C per meter, and the mirage does not get strong until the magnitude reaches 4º or 5°C per meter. These conditions do occur when there is strong heating at ground level, for example when the sun has been shining on sand or asphalt and an inferior image is commonly generated because of this.

Inferior mirage The model given above explains the cause of the inferior mirage, called "inferior" because the image seen is under the real object. The real object is the (blue) sky or any distant object in that direction, meaning we see a bright bluish patch on the ground in the distance. For exhausted travelers in the desert it appears as a lake of water. On tarmac roads it may seem that water or even oil has been spilled. This is called a "desert mirage" or "highway mirage". Note that both sand and tarmac can become very hot when exposed to the sun, easily being more than 10°C hotter than the air one meter above, enough to cause the mirage.

Light rays coming from a particular distant object all travel through nearly the same air layers and all are bent over about the same amount. Therefore rays coming from the top of

the object will arrive lower than those from the bottom. The image usually is upside down, enhancing the illusion that the sky image seen in the distance is really a water or oil puddle acting as a mirror.

Inferior images are not stable. Hot air rises, and cooler air (being more dense) descends, so the layers will mix, giving rise to turbulence. The image will be distorted accordingly. It may be vibrating; it may be vertically extended (towering) or horizontally extended (stooping). If there are several temperature layers, several mirages may mix together, perhaps causing double images. In any case, mirages are usually not larger than about half a degree high (same apparent size as the sun and moon) and from objects only a few kilometers away.

Superior mirage A superior mirage occurs when the air below the line of sight is colder than that above. This is called a temperature inversion, since it does not represent the normal temperature gradient of the atmosphere. In this case the light rays are bent down and so the image appears above the true object, hence the name superior. Superior mirages are in general less common than inferior mirages, but when they do occur, they tend to be more stable, as cold air has no tendency to move up or warm air to move down.

Superior mirages are most common in polar regions, especially over large sheets of ice with a uniform low temperature. They also occur at more moderate latitudes, although in those cases they are weaker and less smooth and stable. For example, a distant shoreline may appear to tower and look higher (and thus perhaps closer) than it really is. Because of the turbulence, there seem to be dancing spikes and towers. This type of mirage is also called the Fata Morgana or hillingar in the Icelandic language.

A superior mirage can be right-side up or upside down, depending on the distance of the true object and the temperature gradient. Often the image appears as a distorted mixture of up and down parts.

Superior mirages can have a striking effect due to the Earth's curvature. Were the Earth flat, light rays that bend down would soon hit the ground and only nearby objects would be affected. Since Earth is round, if their downward bending curve is about the same as the curvature of the Earth, light rays can travel large distances, perhaps from beyond the horizon. This was observed and documented for the first time in 1596, when a ship under the command of Willem Barents in search of the Northeast passage became stuck in the ice at Novaya Zemlya. The crew was forced to endure the polar winter there. They saw their midwinter night come to an end with the rise of a distorted Sun about two weeks earlier than expected. It was not until the 20th century that science could explain the reason: The real Sun had still been below the horizon, but its light rays followed the curvature of the Earth. This effect is often called a Novaya Zemlya mirage. For every 111.12 kilometres (69.05 mi) the light rays can travel parallel to the Earth's surface, the Sun will appear 1° higher on the horizon. The inversion layer must have just the right temperature gradient over the whole distance to make this possible.

In the same way, ships that are in reality so far away that they should not be visible above the geometric horizon may appear on the horizon or even above the horizon as superior mirages. This may explain some stories about flying ships or coastal cities in the sky, as described by some polar explorers. These are examples of so-called Arctic mirages.

If the vertical temperature gradient is +11°C per 100 meters (reminder: Positive sign means temperature gets hotter as one goes higher), then horizontal light rays will just follow the curvature of the Earth, and the horizon will appear flat. If the gradient is less the rays are not bent enough and get lost in space. That is the normal situation of a spherical, convex horizon. But if the gradient gets larger, say +18°C per 100 meters, an observer would see the horizon as concave, the right and left ends turned upwards as if one were standing at the bottom of a saucer.

One form of superior mirage is so common that most scientists do not even recognize it as a mirage. When the full solar disk is directly on the horizon, all or part of it is below the horizon, but the bending of the solar rays by the atmosphere gives us the optical illusion that the sun is actually on the horizon. This happens at both sunrise and sunset each day and adds over 4 extra minutes of daylight to each day. As a result, daylight is a little longer than the night period on the date of the Equinox by about 4 minutes.

This effect on the setting/rising sun's position is mostly due to the increase in air density due to increasing atmospheric pressure as the solar rays come from the near vacuum of outer space toward the Earth's surface. (Similar effects also alter the observed position of the moon, planets and stars.) When the sun or moon are within a few degrees of the horizon, they can also lose their circular shape and appear flattened because of atmospheric refraction. There are several other refractive effects that are also of interest to sky watcher but we must leave them for a later date. In this piece I want to focus on refractive phenomena seen in the lower atmosphere under conditions of varying temperature with height which produce mirages.

Fata Morgana A Fata Morgana is an unusual and very complex form of mirage, a form of superior mirage, which, like many other kinds of superior mirages, is seen in a narrow band right above the horizon. The name of it comes from the Italian translation of Morgan le Fay from legend about King Arthur. Although the term Fata Morgana is sometimes incorrectly applied to other, more common kinds of mirages, the true Fata Morgana is not the same as an ordinary superior mirage, and is certainly not the same as an inferior mirage.

Fata Morgana mirages tremendously distort the object or objects which they are based on, such that the object often appears to be very unusual, and may even be transformed in such a way that it is completely unrecognizable. Fata Morgana can be seen on land or at sea, in polar regions or in deserts. This kind of mirage can involve almost any kind of distant object, including such things as boats, islands, and coastline, as shown in the photographs which accompany this article.

Fata Morgana is not only complex, but also rapidly changing. The mirage comprises several inverted (upside down) and erect (right side up) images that are stacked on top of one another. Fata Morgana mirages also show alternating compressed and stretched zones.

In calm weather, a layer of significantly warmer air can rest over colder dense air, forming an atmospheric duct which acts like a refracting lens, producing a series of both inverted and erect images. Fata Morgana requires a duct to be present; thermal inversion alone is not enough to produce this kind of mirage. While a thermal inversion often takes place without there being an atmospheric duct, an atmospheric duct cannot exist without there first being a thermal inversion.

To generate the Fata Morgana phenomenon, the thermal inversion has to be strong enough that the curvature of the light rays within the inversion layer is stronger than the curvature of the Earth. Under these conditions, the rays bend and create arcs. An observer needs to be within or below an atmospheric duct in order to be able to see Fata Morgana.

Fata Morgana can be observed from any altitude within the Earth's atmosphere, from sea level up to mountain tops, and even including the view from airplanes.

Fata Morgana can be described as a very complex superior mirage with more than three distorted erect and inverted images. Because of the constantly changing conditions of the atmosphere, Fata Morgana can change in various ways within just a few seconds of time, including changing to become a straightforward superior mirage.

Fata Morgana mirages are visible to the naked eye, but in order to be able to see the detail within them, it is best to view them through binoculars, a telescope, or through a telephoto lens.