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# Inferior mirages in the Netherlands

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Mit 8 Abbildungen

Inferior mirages can be observed in the Netherlands on many days a year. They occur when the surface of the ground or the water is warm and the air above is clear. When the sun warms the ground in spring and summer mirages can be seen in many places; on tarmac roads, railway tracks, sandy beaches, long stretches of sand on the Dutch North Sea Islands, on the extensive pastures, the long straight sea-defence walls and the cornfields of the Flevo-polders. These inferior mirages usually look like pools of water or lakes, and often distant objects seem to be reflected in them (see Fig. 1). In autumn and winter the sea-water near the Dutch coast is often warmer than the air above. The same situation sometimes occurs in spring, when cold dry air is advected from the north after a period of fairly warm weather. Then mirages are often seen over the North Sea, the Waddenzee and the IJsselmeer in the form of 'floating' ships and 'floating' coastlines (see Fig. 2). The mirage conditions can also cause the low sun to look $\Omega$-shaped (see Fig. 3) (*Floor*, 1981).

Fig. 1. Inferior mirage on a tarmac road, De Bilt (The Netherlands), May 15th 1977. The positions of the optical horizon ($h$), the limiting line ($l$) and the vanishing line ($v$) of the car have been marked on the right (focal length: $f = 1250$ mm).

Fig. 2. Inferior mirage over the Waddenzee, Schiermonnikoog (Dutch North Sea Islands), March 29th 1977.
The white dots in the water below the optical horizon are reflections of sunlight ($f = 1250$ mm).

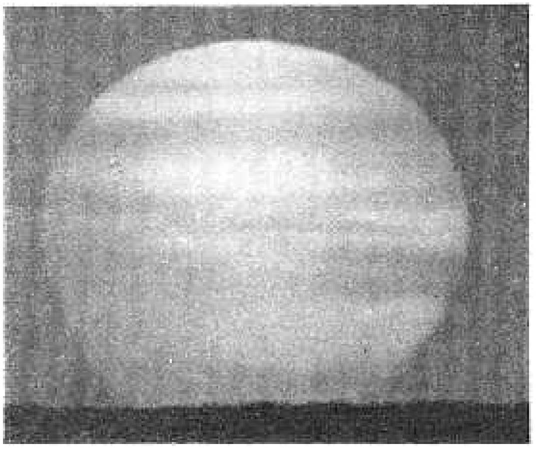

Fig. 3. Setting sun with inferior mirage, Camperduin (The Netherlands) September 3rd 1977. The sun's disc is $\Omega$-shaped ($f = 1250$ mm.

In this article we first introduce the 'mirage diagram'. The photographs of Dutch mirages, illustrating this article, are interpreted and explained with the help of this diagram. We go on to examine certain factors which affect the form that a mirage takes.

## The mirage diagram

When water or land is warm heat is transferred from the surface to the air above. The resulting temperature profile of the lowermost metres of the atmosphere resembles the one shown in Fig. 4a; the temperature gradient is at its maximum near the earth's surface, where the highest temperature occurs. Fig. 4b shows the matching pattern of the light-rays which pass through the lowermost layer of the atmosphere and reach the eye (0) of an observer at a given height above a flat surface (*Khular* et al. 1977, *Fraser* 1975). The light-rays received by (*o*) have a caustic: the vanishing line (*v*). Objects or portions of objects that are situated below the vanishing line cannot be seen by the observer, but he sees objects or portions of objects that are above this line as part of a mirage. The vanishing line meets the surface of the ground (or water) at a point called the optical horizon (*Fraser* and *Mach*, 1976). Beyond the optical horizon the ground (or water) is below the vanishing line and thus cannot be seen by the observer.

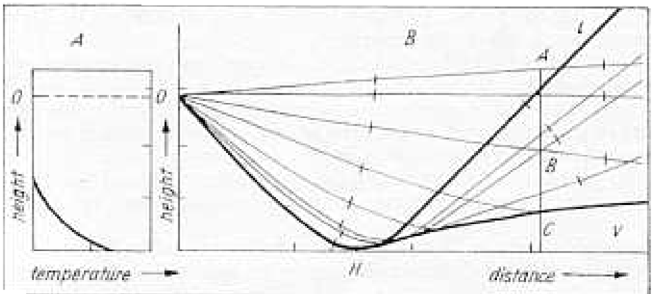


Fig. 4. (a) Temperature profile of the lowermost layer of the atmosphere above a hot surface.
(b) Paths of the light-rays propagating through the lowermost layer of the atmosphere if the temperature profile is as shown in (a)

Light-ray (1) reaches the eye of the observer at (*o*) after touching the ground (or water). In the part of the diagram between this line (1) and the vanishing line (*v*) light-rays intersect each other. Objects or portions of objects that are between these lines are seen as double images. Objects or portions of objects in the section of the diagram above (l) are seen as a single image. Light-ray (1) is the upper boundary of the region in which objects are reflected in the layer of warm air near the surface. We shall call (*l*) the limiting line.

Diagram *b* in Fig. 4 (as well as a simplified version of it, where all the light-rays have been omitted except for (l)), is a useful tool for interpreting inferior mirages. We shall start by interpreting the mirage shown inFig. 1 in terms of the mirage diagram. The car in the photograph is represented by the line AC in the diagram. (Note that the vertical dimensions in the diagram are exaggerated with respect to the horizontal ones). The car can be divided into three sections. The top section (A in the diagram) is above the limiting line and the observer sees this as a single image. The bottom section of the tyre of the car which is touching the road (or C in the diagram) is below the vanishing line, so it cannot be seen by the observer. The section of the car between the limiting line and the vanishing line is seen as a double image: one the right way up, and the other upside down as if it were reflected in a pool of water on the road (cf. point B in the diagram). The boundary of this imaginary pool of water which is nearest to the observer (i. e. the lower edge of the mirage phenomenon in the photograph) is the optical horizon. The positions of the limiting line, the vanishing line and the optical horizon are marked (l), (*v*) and (*h*) respectively beside the photograph.

Mirages over water, such as the floating distant coast shown in Fig. 2 or the setting sun in Fig. 3, can also be interpreted with the help of a limiting line, a vanishing line and the optical horizon.

## Factors affecting the form of a mirage

Using the mirage diagram we can study how the form of a mirage is affected by the following factors: (i) the distance between the observer and the object(s) seen in the mirage, (ii) the height of the observer's eye above the ground (or water) and (iii) the temperature difference between the ground and the air above at a height of 2–3 m. The influence of the distance (i) is easily seen in the diagram. Objects on the observer's side of the optical horizon look more or less unchanged; objects beyond the optical horizon are seen as a mirage. Furthermore, the greater the distance between an object and an observer, the higher the positions of the vanishing line and the limiting line. Example of this are shown in Figs. 1, 5 and 6. In Fig. 5 the ship on the right is on the observer's side of the optical horizon and is seen to be sailing on the water. The other ship (left) is beyond the optical horizon and looks as if it is floating above the surface of the water. In Fig. 6 the vanishing line is at different heights for different objects. The fishing-boat with its deck below its vanishing line is nearer to the observer than the floating distant coast; so the vanishing line of the boat ($v_b$) lies well below the vanishing line of the objects on the coast ($v_c$ ). In Fig. 1 the limiting lines are at different heights. The limiting line of the man on the left (partly hidden by the lamp-post) passes through the bottom part of his brief-case. The limiting line of the car, which is further away, marked (l) on the right of the photograph, is higher than the limiting line of the man.

Before we study the effect that the height of the observer's eye has on the form of the mirage we must bear in mind that the light-rays in the mirage diagram (Fig. 4b) can be reversed. If they are reversed the diagram will then show the light-rays emitted by an object at (*o*) and propagating through the lowermost layer of the atmosphere above a warm, flat surface. As can be seen in the diagram, the light-rays from (*o*) will not be able to reach the region below the vanishing line (*v*). So, for an observer in this

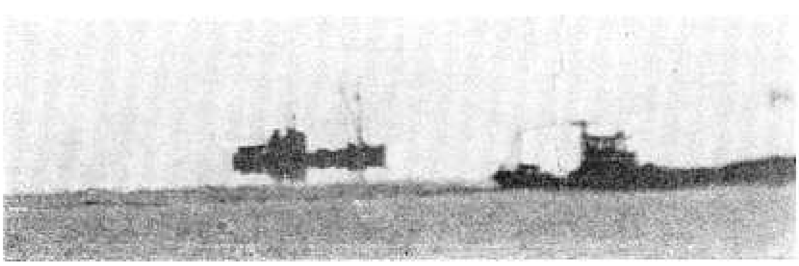

Fig. 5. Inferior mirage over the Waddenzee, West Terschelling (Dutch North Sea Islands) October 17th 1978. The ship on the right is on the observer's side of the optical horizon (h). The other ship (left) is beyond the optical horizon ($f = 2000$ mm).

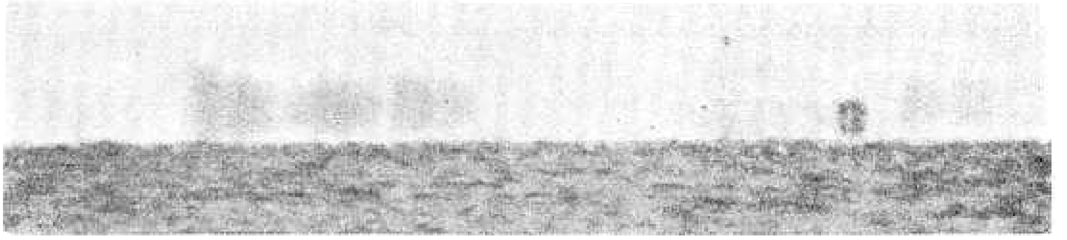

Fig. 6. Inferior mirage over the Waddenzee, Schiermonnikoog (Dutch North Sea Islands) May 22nd 1980. The position of the vanishing line of the fishing boat ($V_b$) is well below the position of the vanishing line of the objects on the more distant coast ($V_c$) ($f = 1200$ mm).

region (*o*) is invisible and must be below the vanishing line. There are two different ways in which light-rays from (*o*) can reach an observer's eye which is between the vanishing line and the limiting line. An observer's eye in this region sees (*o*) as a double image; so for the observer object (*o*) must be between the vanishing line and the limiting line. An observer's eye which is above the limiting line only sees (*o*) as a single image; so for the observer object (*o*) must then be above the limiting line.

By interpreting the mirage diagram in this way one can study the effect that the height of the observer's eye has on the form of a mirage. An observer's eye at (*A*) sees (*o*) as a single image. If the observer stoops, lowering his gaze from (*A*) to (*B*), he will see a double image of (*o*), so (*o*) must now be below the limiting line. When the observer stioops even further, lowering his eyes to (*C*), (*O*) disappears and therefore must be below the vanishing line. In other words: lowering the height of observation is equivalent to raising the positions of the limiting line and the vanishing line (distance kept constant). In the same way it can be deduced that increasing the height of observation is equivalent to lowering the positions of the limiting line and the vanishing line. These results agree with the observations made by the author. The results explain why an observer may see a mirage when he stoops, although he cannot see one when he stands upright.

Above warm ground (or water) the patterns of the temperature profile and the light-rays will usually resemble those shown in Fig. 4. However, the smaller the difference in temperature between the surface and the air above, the greater will be the distance between the observer and the optical horizon, and the smaller will be the slopes of the limiting line and the vanishing line. In other words if the temperature difference is only slight the light-ray pattern will be stretched out along the distance axis.

## Distorted reflections, and reflections of the sky

In our discussion of the mirage diagram of Fig. 4b we showed how it can be used for interpreting observations of photographs of inferior mirages. Note that when the diagram is used for this purpose there is another factor which can be of assistance in finding the position of the vanishing line. Objects that are just above the vanishing line often have irregular, vertically elongated or multiple images (Fig. 7). Conversely, the presence of these irregular images can be an indication that the object is just above the vanishing line; so the height of this line can be determined.

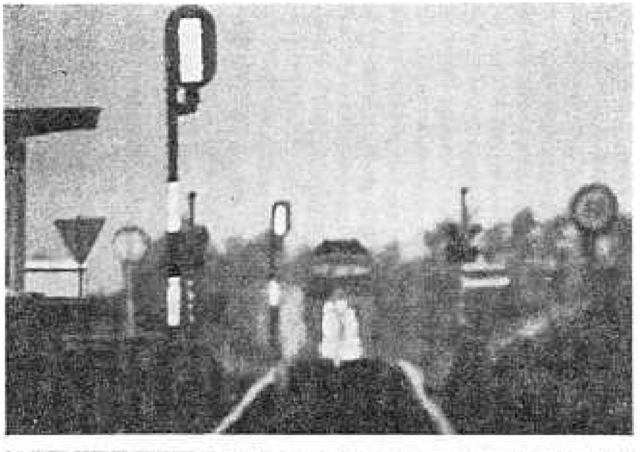

Fig. 7. Inferior mirage on the railway track at Workum (The Netherlands), July 8th 1979. The headings of the train are just above the vanishing line, as can be deduced from the distorted images of these lights. Note the compression of the image on the photograph, which is caused by the long focal length used (2000 mm). The little house of the bridge-keeper is 435 m away from the photographer, the nearest signpost is at 635 m, the crossing at 1025 m, the distant signpost at 1685 m and the round sign on the right at 1880 m The train is at a distance of ca. 3800 m from the photographer.

Fig. 8. Inferior mirage on the railway track at Bilthoven (The Netherlands), September 16th 1979. The reflection is distorted because of the uneven heating of the ground ($f = 2000$ mm).

We shall conclude our discussion of the mirage diagram by saying something about the fact that the earth's surface in the mirage diagram is assumed to be flat. This assumption usually holds for terrestrial objects seen in a mirage. (See however our remarks on Fig. 8 at the end of this article). In the case of distant objects, such as the sky or astronomical bodies the curvature of the earth prevents us from taking the earths surface to be flat. The positions of the vanishing line and the limiting line of the sky (or sun) are then seen by an observer at a constant angular elevation. An observer sees the reflection of a thin horizontal strip of the sky (or sun), which is between the elevations of the limiting line and the vanishing line, as a contiguous thin horizontal strip between the elevations of the vanishing and the optical horizon. Sky and reflected sky surrounding double images of terrestrial objects are characteristic features of many mirages. When the sky is reflected on the land the observer thinks there are pools of water on the road, beach etc. Over water the reflection of the sky between the optical horizon and the double image of distant objects makes these objects look as if they are floating. It is the reflection of a part of the sun's disc which causes the beautiful $\Omega$-shape of the low sun shown in Fig. 3.

The surface of the railway track shown in Fig. 8 is another example of a situation where the assumption of a flat surface does not hold. Here the rails are higher than the gravel of the track, so the ground is heated unevenly by the sun; therefore, the temperature in a horizontal plane is not constant. The photograph shows the side of a bus which is crossing a railway track. The reflected roof-line of the bus is undulating instead of straight, due to the uneven heating of the surface of the railway track.

Although the mirages discussed in this article have all been observed in the Netherlands, similar phenomena have been reported from flat regions and coastal areas in other countries.

## Acknowledgement

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## References

*Floor C.* (1981): "The $\Omega$-shape of the low sun" Weather **36** pp. 78–81
*Fraser, A. B.* (1975): "Theological Optics" Applied Optics **14** pp. A 93–94
*Fraser, A. B.*, and *W. H. Mach* (1976): "Mirages" Scientific American **234** (1) pp. 102–111
*Khular E.*, *K. Thyagarajan* and *A. K. Ghatak* (1977): "A note on mirage formation" Am J. Phys. **45** pp. 90–92

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