The Novaya Zemlya Effect

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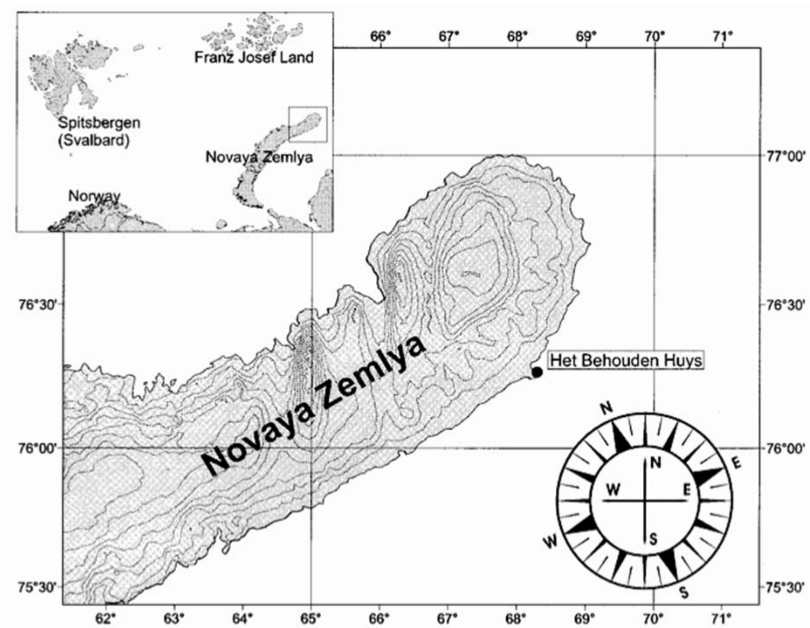
History

The Novaya Zemlya effect is an optical phenomenon of the air. It is the premature return of the Sun at the end of the polar winter night. It entered recorded history in 1597, when it was seen on the Siberian island of Novaya Zemlya by a Dutch expedition led by Willem Barents, in his search for the Northeast Passage.

Barents and his crew lost their ship in Fall 1596, and were forced to overwinter on the island (at 76°15′ N).

On November 3 they saw the Sun for the last time. They did not expect to see it again until February 8.

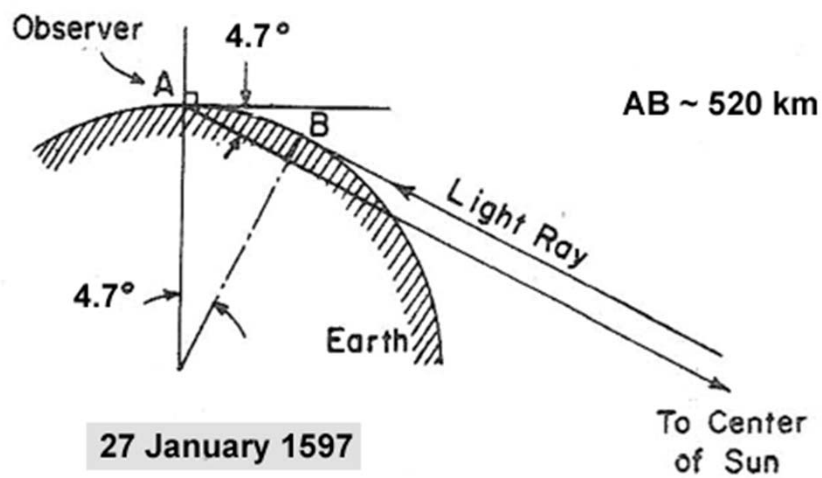


However on January 24, 1597, three of the crew caught a glimpse of the Sun. Barents, the expert navigator, did not believe them, since he knew that the Sun's center *h* was 5º26′ below the horizontal.

Yet on January 27, Barents himself saw the Sun, "in its full roundness, just free of the horizon". On this day, $h = -4^\circ 41'$. Gerrit de Veer recorded these events in his journal.

This observation became known as the Novaya Zemlya effect.

Barents verified the first date by observing a conjunction between the Moon and Jupiter (predicted by Scala of Venice to occur on January 25).



The explorers returned to the Netherlands in the summer of 1597. Barents died on this journey. De Veer immediately published his journal, in Dutch. An English translation was published in 1609.

News of the Novaya Zemlya observation spread with incredible rapidity through the scientific community. In his treatise on optics (1604) Kepler wrote that “everyone has heard of the adventures of the Batavians in the Arctic”. His book includes a surprisingly good attempt at explaining it.

Controversies

Right from the start, de Veer’s account was challenged. Navigational specialist Robbert Robbertszoon considered it as erroneous or even fraudulent. The controversy remained alive until the early 20th C.

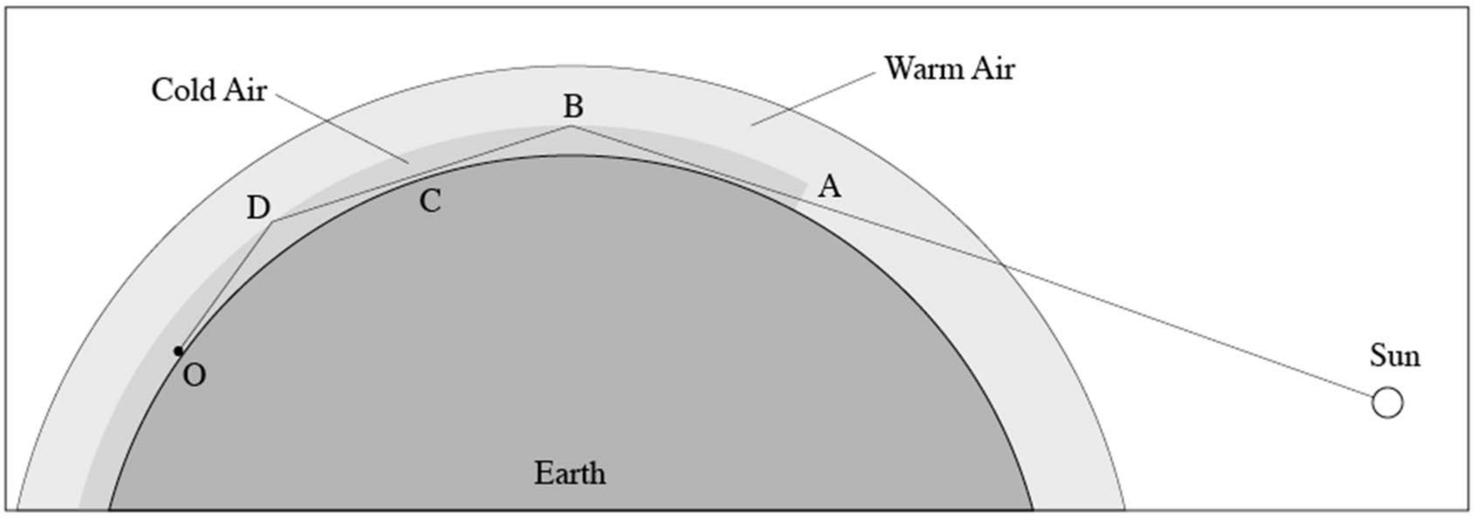
Issues of contention: the calendar and day-counting

- The Gregorian calendar had just been introduced (1582). It shifted dates by 10 days. If de Veer had been using the old Julian calendar, his January 24 and 27 would convert to February 3 and 6, more believable dates for an early return of the Sun.
- The actual day counting was also challenged; Robberts did not believe that an accurate count could be kept under such harsh conditions, after months of perpetual darkness.
- Robberts considered the observed Moon/Jupiter conjunction to be a fabrication.

Rebuttal

- De Veer clearly marked all of his dates as “New Style”.
- Modern studies (e.g. van der Werf) have verified the accuracy of the dating.
- Robberts (unwittingly) had a point about the conjunction: Jupiter would have been 2˚ below the horizon! I will return to this later.

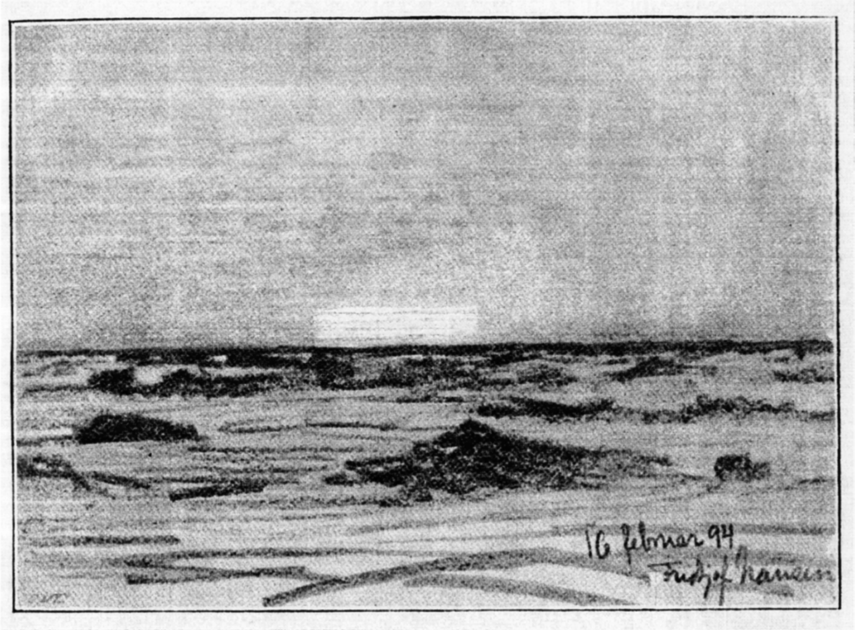
Soon, interest subsided; nothing seems to have been published for some 200 years. Then in 1875 a paper by Baills gave the correct explanation: a large scale temperature inversion with a sharp thermocline could produce total internal reflection within the atmosphere.



In 1956 Visser took up Baills' model. He calculated the necessary parameters for total internal reflection, and verified that inversions of sufficient geographical extent sometimes existed in the high latitudes. But Visser did not calculate any images.

Modern Observations

- Nansen
  16 February 1894; Arctic Ocean at 80°01′N. Premature return of the Sun; $h = -2°22'$.
- Shackleton
  8 May 1915; Antarctica. Sun returned 9 days after its ‘final’ setting; $h = -2°37'$.
- Liljequist
  1 July 1951; Antarctica at 71°03′S. Premature return; $h = -4°18'$. Rivals the 1597 event.



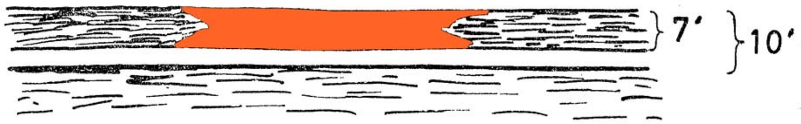


Fig. 8. Novaya-Zemlya phenomenon, July 1, 1951. The sun was seen like a red and partly bipartite strip, situated wholly within a relatively dark horizontal strip of the same breadth and with its lower rim about 3′ above the ice-shelf horizon.
Solar altitude: 4,3° below the horizon.

Refraction of Air

- The refractive index of air depends on its pressure and temperature:

  $$n = 1 + \varepsilon\beta p/T$$

  where $\varepsilon = 226 \times 10^{-6}$ and $\beta = 0.00348$.

- With this equation we can reproduce Visser's results, i.e. find the strength of a (discontinuous) inversion required to produce total internal reflection.

- Calculation of images requires ray tracing.

- Basic assumptions:
  - a spherically symmetric atmosphere concentric with the Earth,
  - a continuous temperature profile (more realistic), which produces continuously curved (rather than kinked) rays.

- The curvature of a light ray is given by

$$\kappa = \frac{\varepsilon \beta p \sin\theta}{nT^2}\left(\frac{dT}{dz} + g\beta\right)$$

  Here, z = elevation, g = acceleration of gravity, and θ = zenith angle of the ray.

- Sign convention: positive curvature is concave towards the Earth.

- In the bottom 100 m of air, most of the terms in this equation are nearly constant. The dominant term is the *temperature gradient*.

Sample calculations

- Standard atmosphere: $p = 1.013 \times 10^5$ Pa, $T = 288$ K, and $dT/dz = -0.0065^\circ$/m. Radius of curvature of a horizontal ray is about 38,000 km. The ray curves slightly downward. Total refraction is about 35 arcminutes.

- Rays with the same curvature as the Earth (radius = 6370 km): under STP conditions, dT/dz must be $+0.113^\circ$/m. The Earth appears to be flat.

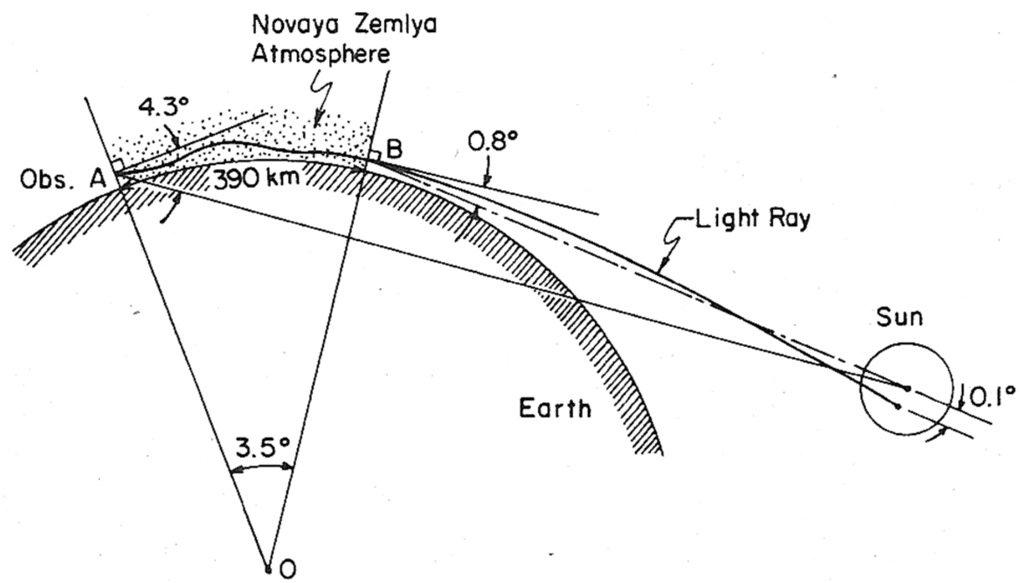
- Gradients exceeding 0.113°/m: an upward heading ray is turned back and sent downward. This is analogous to the total internal reflection of the previous models.

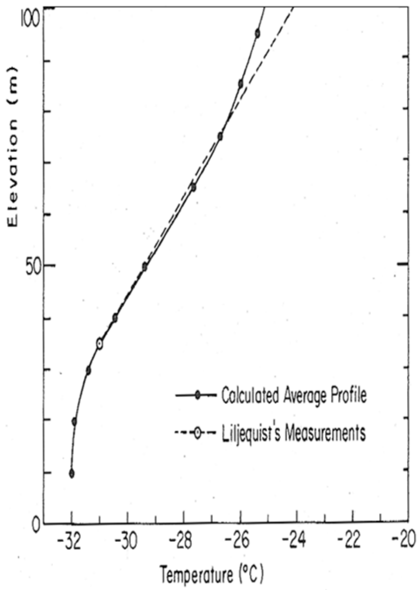
Summary

The only practical way that light can travel long distances around the curve of the Earth is by repeated returns from an inversion layer. The atmosphere behaves as a light pipe. The process is called *optical ducting*.

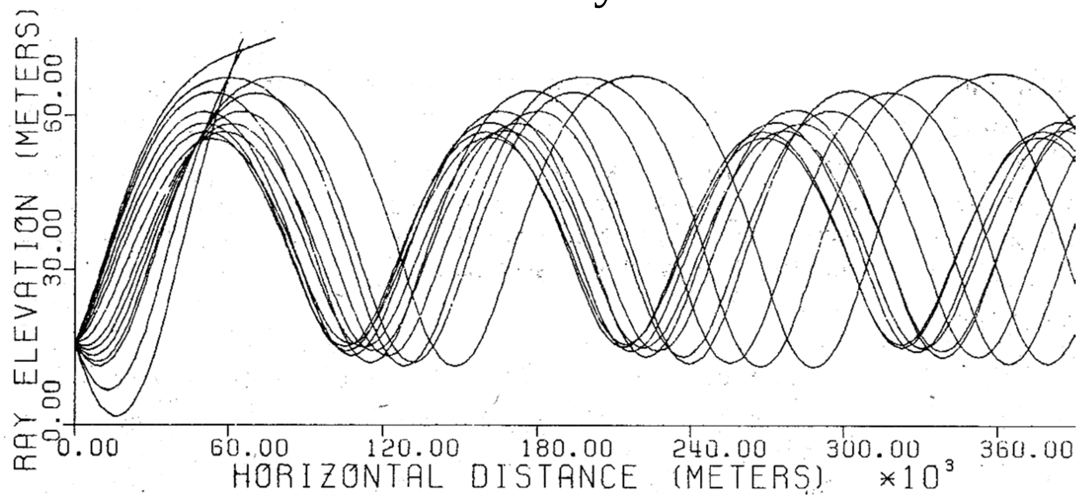
Reproducing Liljequist's Observation of 1 July 1951

- Trace all of the rays that connect the Sun to the observer.
- Ray intersections with the Sun are mapped into the visual space of the observer: all rays are perceived as if they were straight.
- The initial calculation used Liljequist's measured temperature profile. Repeated calculations were then made with small adjustments to the profile. The length of the duct was also varied.
- Geometry of my reconstruction:

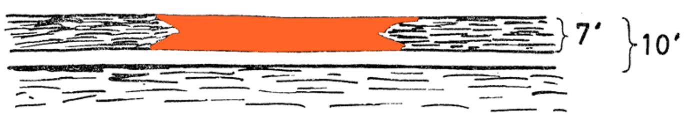




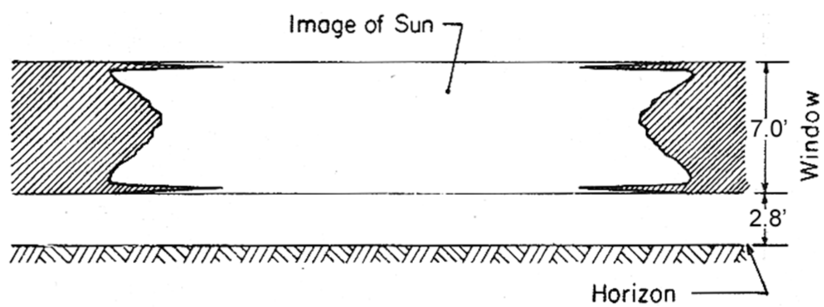
Rays



Recall Liljequist's image:

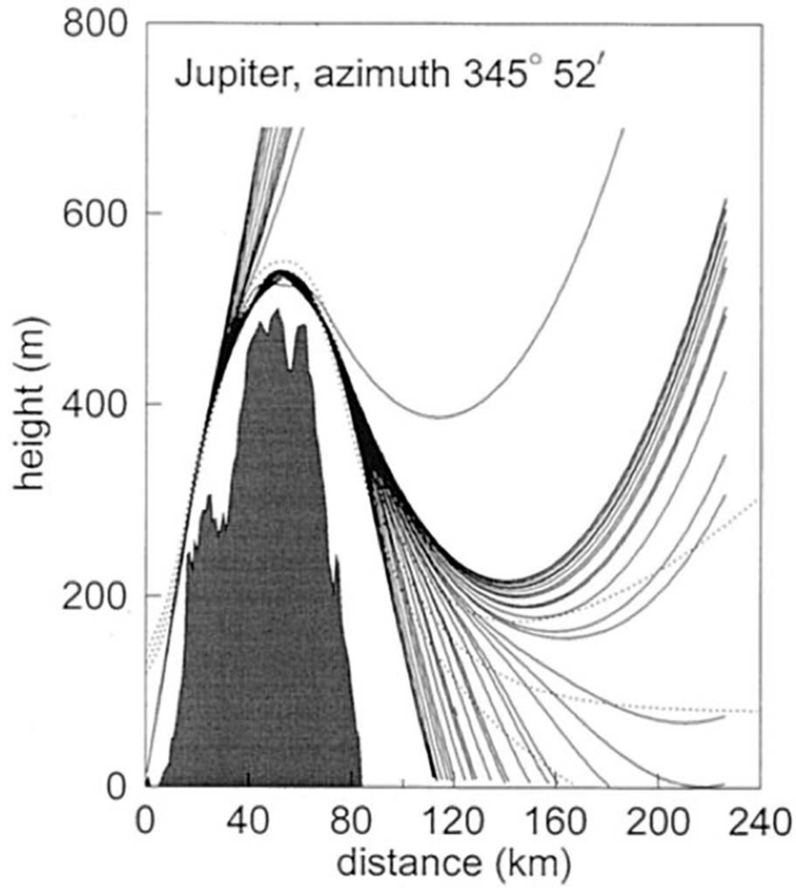


My calculated image:

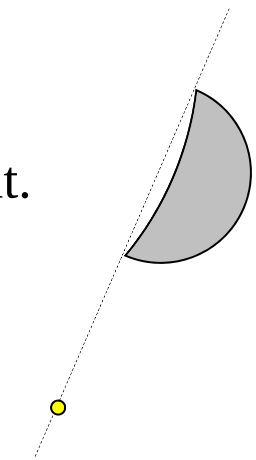


Return to the Barents observations:

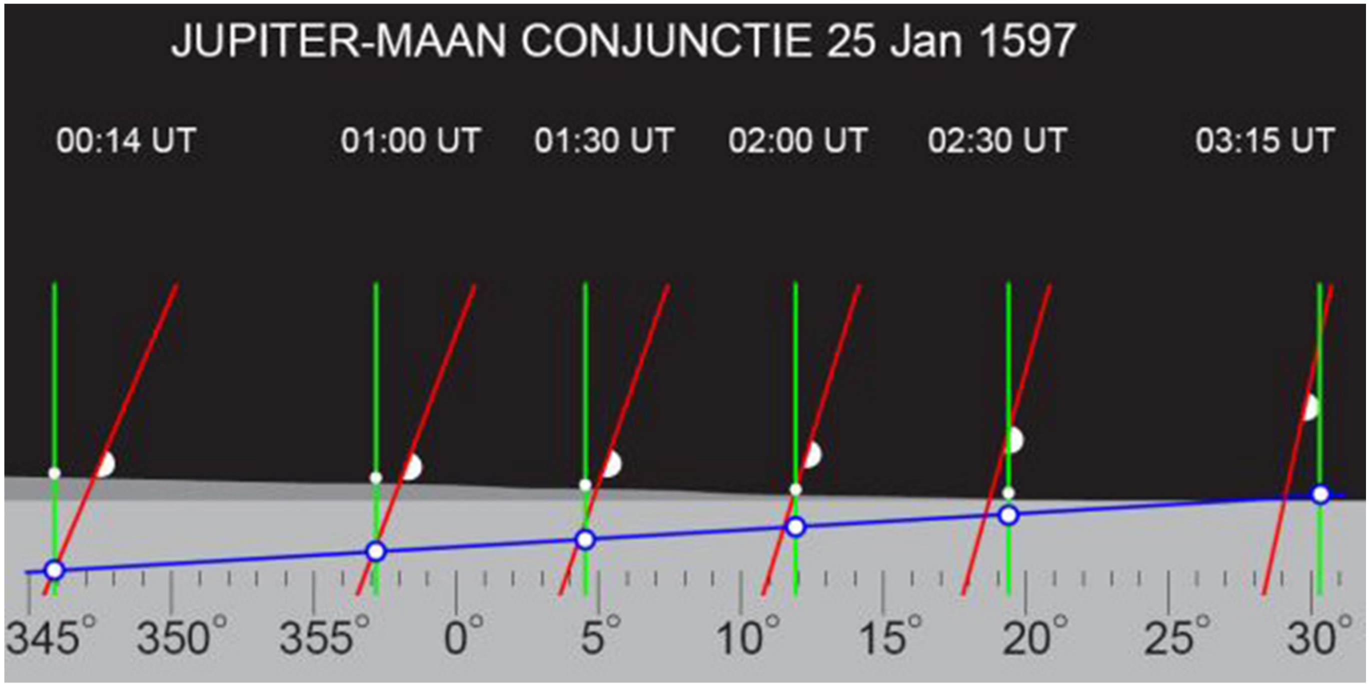
- The premature return of the Sun on Novaya Zemlya has been explained; controversy no longer exists.
- There remains the sighting of Jupiter, standing 2° below the horizon to the North. The line of sight passed over a line of hills up to 400 m in elevation. Can refraction handle this case?
- An inversion can follow the profile of the landscape. Then light from Jupiter could be ducted around the horizon and over the hills, finally to be seen by Barents.



- For an ecliptic conjunction with the half moon, Jupiter must lie on a line drawn through the points of the Moon’s crescent.



- Refraction will affect the time of the apparent conjunction: the Moon was up enough not to be seriously refracted, but Jupiter was lifted by several degrees. It would appear to slide along the tops of the hills.
- The conjunction would be at a later time, and at a different bearing.
- De Veer reported a bearing of 11˚E, which agrees very well with the bearing we calculated for the refracted conjunction.
- De Veer reported that the conjunction occurred at 6 AM local time.
- The refracted conjunction should have been at 2:00 UT, which converts to 6:20 AM local time at *Het Behouden Huijs*.
- For an observation made with the naked eye, this is very good agreement.



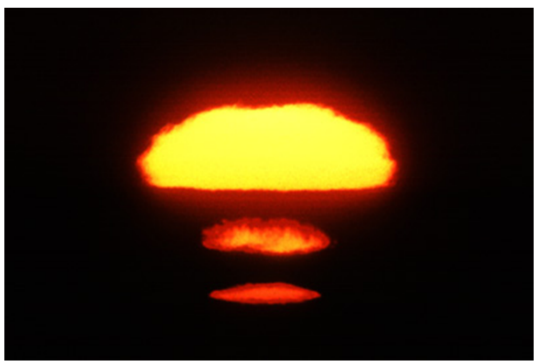
The true conjunction occurred at 00:14 UT, while Jupiter was below the horizon. But if the planet appears to slide along the horizon, the apparent conjunction would be at 02:00 UT, almost 2 hours later.

Summary

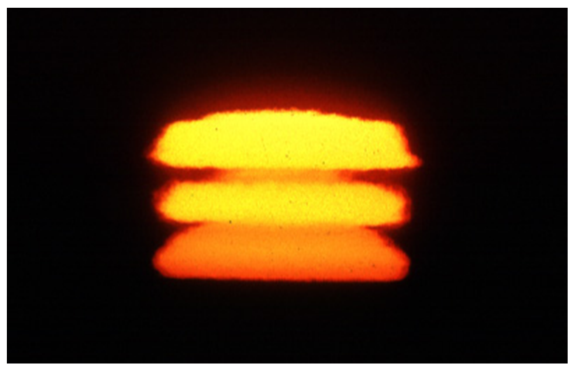
We can conclude that de Veer’s report, of both the return of the Sun and the Jupiter conjunction, was correct in every respect. All of the apparent discrepancies are explained by strong atmospheric refraction.

My Observation of the Summer Novaya Zemlya Effect

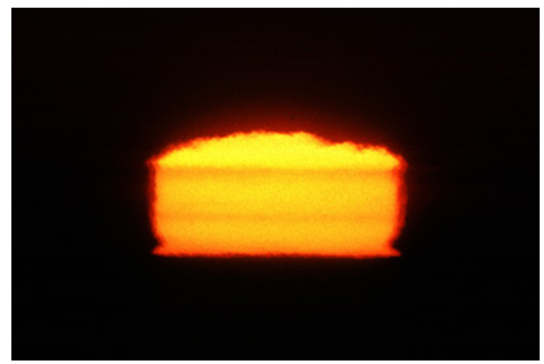
- My field trip to Tuktoyaktuk, NWT, in 1979 included an attempt to document a premature midnight Sun.
- Latitude of Tuktoyaktuk: 69˚26′ N. Expected commencement of the midnight Sun: May 20.
- My student and I observed it on May 16, at 2:45 AM (solar midnight). As the Sun descended, its shape was distorted into very strange forms.



1:34 AM
h = -35′



1:42 AM
h = -46.5′

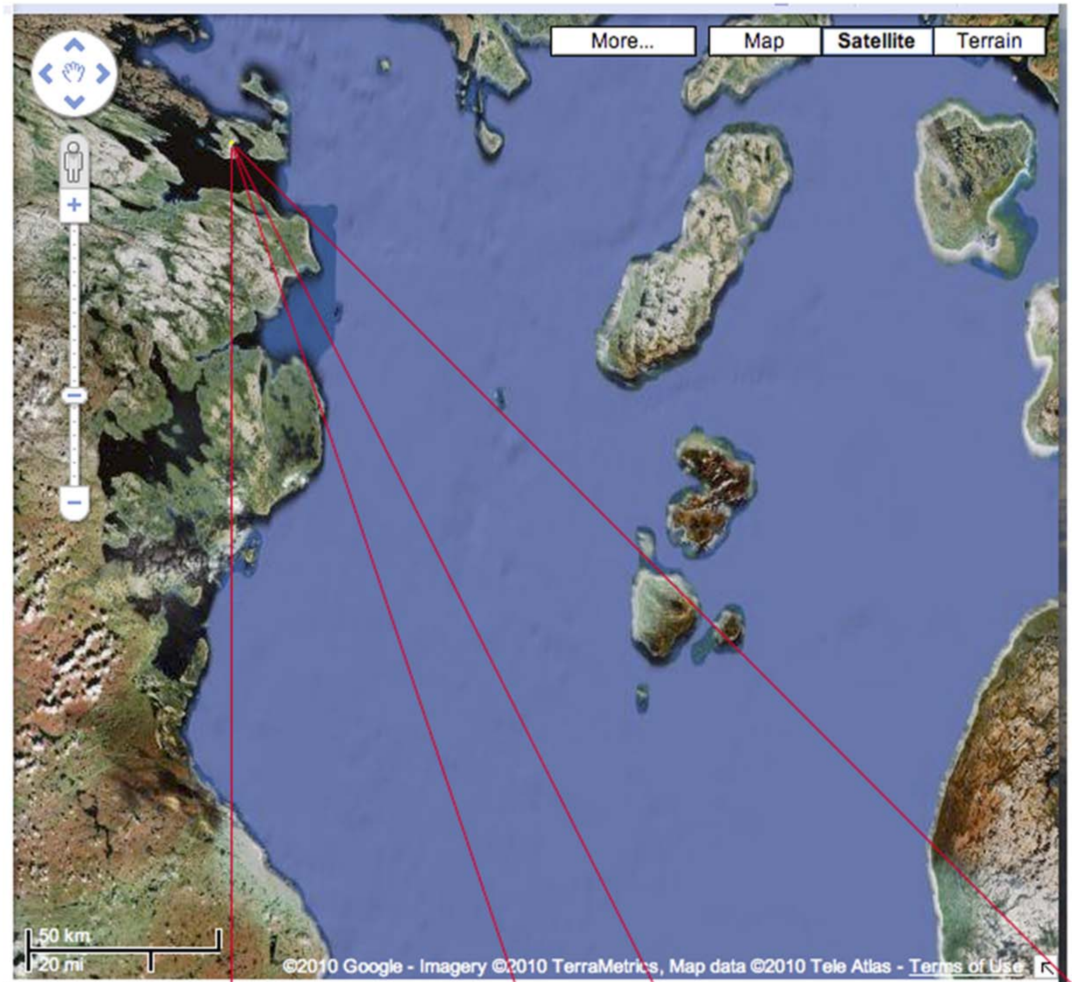


1:49 AM
h = -57′

- Full Novaya Zemlya effect, at solar midnight (2:44 AM): $h = -1^{\circ}34'$.
- Angular duct height: from $+1'$ to $+14'$; duct length ~50 km.
- The image is reminiscent of Nansen’s sketch.

Inuit Observations and Arctic Warming

- Some Inuit elders are claiming that, with the warming of the Arctic, the polar night is getting shorter and brighter, and that the Sun sometimes returns in the wrong place.
- Ian Mauro (U. of Victoria) and Zacharias Kunuk have interviewed many of these, and made a documentary film: “Inuit Knowledge and Climate Change”. It is viewable at `www.isuma.tv/ikcc`.
- The Inuit observations might well be caused by more frequent optical ducting in the atmosphere.
- A warmer climate may increase the frequency of warmer air aloft, that could drift in from the south and ride above the cold surface air of the north: the conditions for the Novaya Zemlya effect.
- Even if the Sun does not become visible, the effect could bring in more twilight from the south.
- If the Sun is seen early, it would have the wrong bearing.



Lines of sight from Igloolik, Nunavut.
69˚23′ N

Observations of 12 January 2010: the Sun appeared at 10:40 AM, and vanished at 11:15 AM.

Time: 9:20 AM
Bearing = 135˚
h = -7.4˚

Time: 10:40 AM
(sunrise)
Bearing = 153˚
h = -3.3˚

Time: 11:15 AM
(sunset)
Bearing = 161˚
h = -2.1˚

Due South
Time: 12:35 PM
h = -1.0˚

Note: h is the altitude of the center of the Sun

W. Lehn 18 March 2010

Conclusions

The Earth’s air has a property that is not often realised: it has the power to bend light.

Well-known appearances : road mirage, flattened setting Sun, lengthening of the day.

Dramatic but rarer appearances: the Novaya Zemlya effect - premature return of the Arctic Sun in winter, or premature midnight Sun in summer.

Arctic warming appears to be causing more frequent occurrences of the Novaya Zemlya effect.

An observation of the Winter Novaya Zemlya effect at Resolute, Nunavut:

- Photographed by Julie Crowther, 15 November 2001, at 12:41 CST, which is 36 minutes after solar noon.
- $h = -3^\circ 34'$, bearing $= 188^\circ 40'$. Latitude of Resolute: $74^\circ 44'$ N.

Terrestrial Mirages - seen at Tuktoyaktuk on the night of the Sun photographs:

Whitefish Summit, 20 km from the camera