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Light Phenomena Over ESO's Observatories IV: Dusk and Dawn

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Several interesting atmospheric phenomena take place during dusk and dawn, associated with the setting and rising of the Sun and Moon. Here, the most important of these are discussed in the context of ESO observing sites. This is the fourth article in a series about a range of light phenomena that can be experienced at ESO observatories.

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Figure 2. Alpenglow seen from above ESO's Paranal Observatory. The VLT and VISTA domes are coloured red during the sunset.

Sunsets

Sunsets mark the daily transition from light to darkness and can be among the most beautiful and evocative light phenomena that can be seen in the sky[a]. Everyone on the planet has experienced the change in light and its effects on their mood when the Sun disappears and the night begins.

The colours of sunrise and sunset are usually very dynamic in the Atacama Desert. At the Paranal and La Silla observatories, they are enhanced by three additional factors: the high altitude, where the air is thinner and clearer; unobstructed views; and the relative vicinity to the ocean, where high levels of humidity lead to strong scattering effects[1] (Zieger et al., 2013). The sunsets in particular often paint deep colours over the horizon (Figure 1).

The colour and appearance of the sunset are very sensitive to clouds and the aerosol content of the upper atmosphere — no two sunsets are identical. Exceptional circumstances can have a big impact too; powerful volcanic eruptions, for example, can increase the dust content at 15–30 km altitude in the atmosphere which can create particularly magnificent sunsets (Moreno et al., 1965). In 1883, the volcano Krakatoa erupted in Indonesia and spectacular sunrises and sunsets were subsequently seen all over the world, glowing with unusual colours. There have also been strong "volcanic sunsets" in living memory, including those related to Mount St. Helens in 1980, El Chichón in Mexico in 1982, and Mt. Pinatubo in the Philippines in 1991–92. The most significant sunsets observed in recent times were seen worldwide after the eruption of Mount Kasatochi (Waythomas et al., 2010). They lasted from the end of August 2008 until at least January 2009. It may well be considered an irony of nature that volcanoes, which are so powerfully destructive, give rise to such beautiful light phenomena.

At least once within the last hundred years or so there has been a different, quite exciting, cause of exceptional sunsets: an astronomical event. In 1908, an object — most likely a 100-metre sized meteoroid — exploded over Tunguska in Siberia (Gladysheva, 2007), and in the following period unusual colours at sunset followed by very bright nights were observed in many parts of the world (Kundt, 2001; Longo, 2007).

Alpenglow

When the Sun is just below the horizon, the colour of the sky on the western horizon takes on a warm yellow or yellow-red hue and mountains and buildings to the east appear to glow red (Figure 2). This phenomenon is named Alpenglow. A well-known example is Uluru in Australia, whose red colour becomes intensified at twilight. Alpenglow can even be seen in cities.

Crepuscular and anticrepuscular rays

Most of you will have witnessed the rays of light that sometimes shine through gaps in cloud cover and illuminate the land below. Especially in rainy weather,

Figure 1. Looking east at dusk at the Paranal Observatory. The pink-coloured Belt of Venus is followed by the Earth shadow over the horizon.

R. Wesson/ESO

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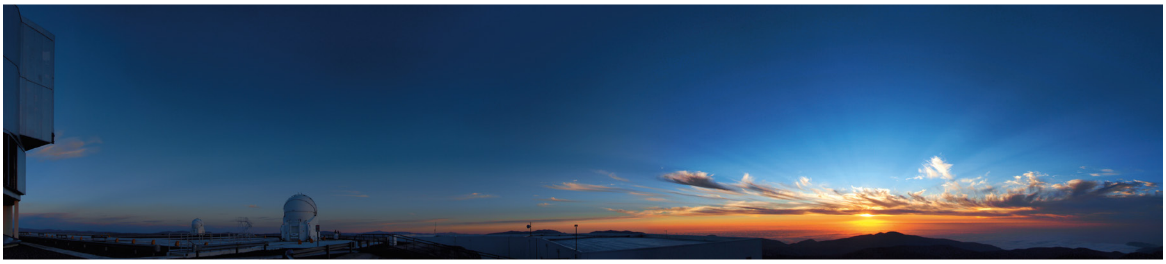


Figure 3. The Sun sets over Paranal Observatory, painting an array of subtle hues across the sky. Crepuscular rays — and shadows from the clouds — are streaming from the Sun and appear to converge at the antisolar point.

these rays can make for a dramatic scene. They are also quite often visible at sunset, when they shine over the tops of clouds or through gaps within the clouds (Figure 3). They are called crepuscular rays and have been known by various poetic names in different cultures, for example, "Maui's rope" — based on a Maori tale; "Buddha's rays" in parts of south-east Asia; and "Jacob's ladder" in the UK (Lynch & Livingston, 2001).

When the Sun sets behind high mountains to the west, the mountains create broad crepuscular rays by partially blocking the light. Some dust or haze in the air will serve to highlight the rays. Under perfect conditions, when crepuscular rays can be followed all the way across the sky, they appear to expand at first and then narrow towards the east. In reality, they remain in parallel but only appear narrower at greater distances from us. Crepuscular rays in the east are called anti-crepuscular rays (Figure 4).

Refraction, differential refraction and the green flash

There is a whole subset of interesting phenomena related to the shapes of the Sun and Moon as they rise and set.

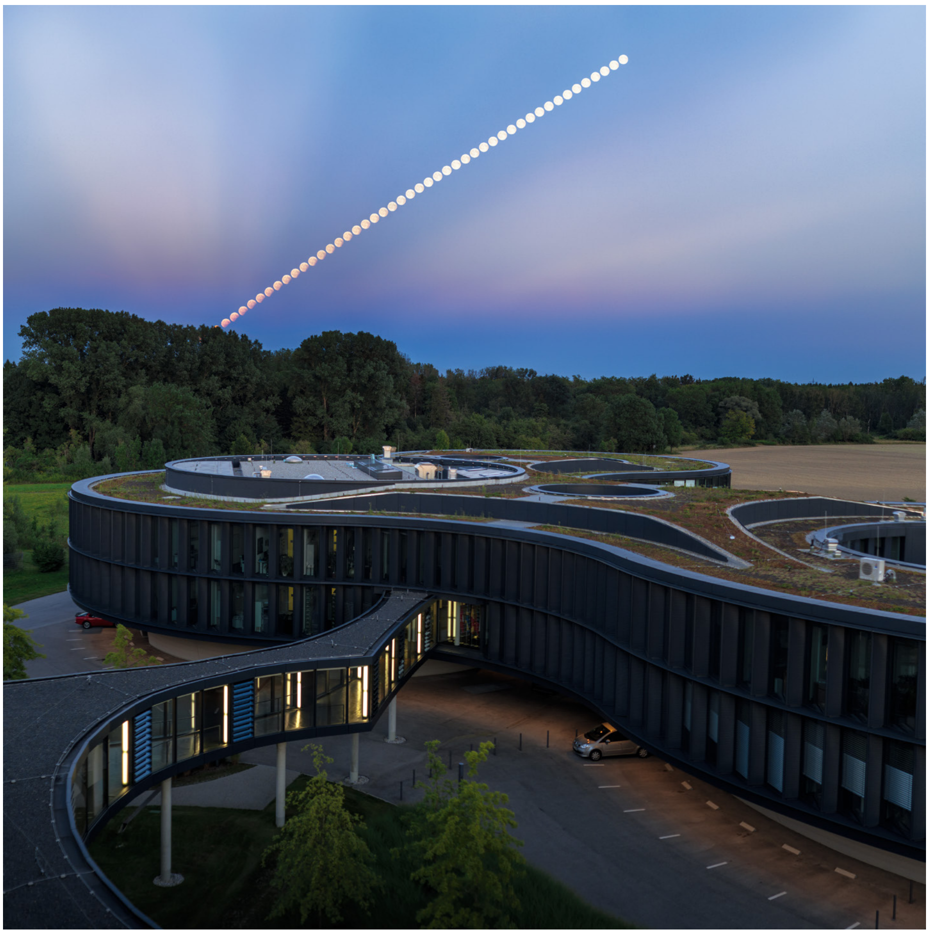
Few people are aware that we still see the Sun for a few minutes after it has moved below the horizon. The reason we still see it in the sky is that its rays are refracted by the atmosphere, raising the image of the solar disc by about a diameter on average as it sets[2]. In other words the Sun's apparent movement towards the horizon is slowed down by the refraction.

The refraction happens because light rays travel more slowly as they pass through the Earth's atmosphere. The lower the Sun is, the further the light rays travel through the atmosphere, the slower they become, and thus the more they are refracted. The effect is measurable — even when the Sun is high in the sky — and it can be important for navigators and astronomers. The extent of the refraction varies from day to day, so the observed sunset time can change from one day to the next by as much as 5 minutes. We cannot therefore rely on an ephemeris to predict the observed sunset time with perfect accuracy.

A more specific variation of this phenomenon is visible in the Arctic regions.

In 1596, the ship carrying polar scientist Willem Barents (c. 1550–1597) was caught in the ice on what is now called the Barents Sea at Novaya Zemlya Island. There were two weeks until sunrise, but the tip of the solar disc had already peaked above the horizon (de Veer, 1876). Polar explorer Sir Ernest Henry Shackleton (1874–1922) also reported repeated sunrises "ahead of time" in the Arctic

Figure 4. During the early evening of 7 August 2017, a partial lunar eclipse was visible in the sky above the ESO Headquarters. While the Moon was rising, significant anticrepuscular rays were visible in the antisolar direction.



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P. Horálek/ESO

Figure 5. The setting crescent Moon deformed by the atmosphere over the Pacific Ocean, as seen from Paranal on 19 November 2017. The effect of layers with different temperature and density in the atmosphere caused different parts of the Moon's image to be refracted by different amounts as it neared the horizon.

(Shackleton, 1919). The explanation is once again the atmosphere's refraction of light or rather, the variation in that refraction. In the case of Barents, the refraction must have lifted the solar disc by about 5 degrees to peek over the horizon, but this is one of the more extreme cases. The phenomenon is known as the Novaya Zemlya effect (Lehn, 1979; Lehn & German, 1981).

Another effect of refraction is that the Sun and Moon never appear perfectly round as they approach the horizon, they appear flattened — as also evidenced in many of the photographs in this article. The amount by which the rays are refracted increases closer to the horizon, so rays from the upper edge of the solar disc are refracted less than those from the lower edge, flattening its shape. Occasionally, the shape of the disc may be further disturbed if the layers in the atmosphere have different temperatures and refract the light by different amounts — called differential refraction. It gives rise to a Chinese lantern effect in which the solar or lunar disc appears layered. The subtle details of the layered lantern effect can best be observed with the Moon (see Figure 5), as the Sun often saturates on pictures. The "lifting" effect of the lower layers of the atmosphere can also be seen on stars as they set (Figure 6).

Compared to other natural light phenomena, the green flash has an aura of mystery and supernaturality. The green flash is rare and very difficult to observe, but, when the conditions are right, the observer's perseverance is rewarded with a quick green gleam at the top of the setting Sun, amid the red and orange shades.

At sunset the blue and green light rays are refracted a little more than the red light, which means that the blue-green colours are "lifted" slightly more in the sky. You could almost say there are two solar discs — one blue-green and one red (Young, 2013). Where they overlap, we see a yellowish-red Sun, with the reddening of the Sun due to atmospheric

Figure 6. Several effects are seen on the setting stars in this multi-exposure photo: atmospheric scattering (reddening) and absorption, and differential refraction ("lifting" of the stars).

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scattering. With the right equipment it is not so rare to see the Sun with a greenish top, called the green segment, even before it reaches the horizon (Figures 7 and 8).

However, differential refraction alone does not result in more than the green and red segments. To produce a proper flash such as those seen in Figures 8 and 9, the red light is spectrally separated from the blue-green light. Without spectral separation, only a green (upper) or a red (lower) fringe would be seen in the solar image. The ozone layer is responsible for the spectral effect, since the light path through the atmosphere is longer at sunrise and sunset and the ozone layer covers altitudes between about 12 and 40 km. The Chappuis band of ozone absorbs light in a broad band centred close to 590 nm in the orange. Owing to the long path, the effect from this band strengthens when the Sun is near the horizon, effectively removing much of the yellow, orange and red light. In the right conditions this can produce the apparent spectral separation needed to produce a noticeable flash.

Simple atmospheric modelling[3] shows that in order to see a green flash at all, the aerosol content of the atmosphere needs to be very low where the sunlight grazes the horizon. It also turns out that in rare circumstances, when the light path is guided by differential refraction to take an unusually long track through the ozone layer, the flash is significantly shifted towards shorter wavelengths to produce the magnificent (and very rare, Figure 9) blue flash; lucky is the person who witnesses that!

Dutch researcher Marcel Minnaert (1893–1970) saw the green flash shoot up like a flame from the horizon (Minnaert, 1993). Because the green-blue rim on the solar disc is very thin (just a few arc-seconds), it is only alone over the horizon for approximately one second. Accordingly, the green flash is seen to last for a similarly short length of time at ESO observatories. It can, however, last much longer. Polar explorer Richard E. Byrd (1888–1957) and his crew claimed to have seen a "green sun" persist for up to 35 minutes while on an expedition to Antarctica in 1929 (Lock, 2015). Despite this unique observation, there are relatively few pictures of the

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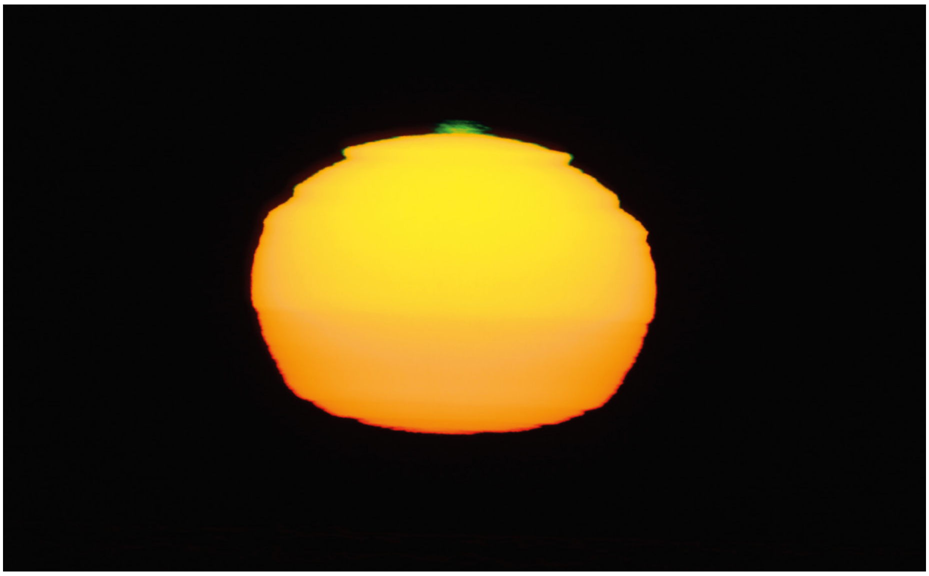
Figure 7 (above). This sequence taken at La Silla on 16 November 2017 shows the phenomena of red (below the solar disc) and green flashes (above) that can occur when the Sun sets and the atmosphere refracts the sunlight into different colours.

Figure 8 (below). An example of a green segment seen from Cerro Paranal. The image was taken by Stéphane Guisard (ESO). Light phenomena connoisseurs argue that this is strictly speaking not the green flash.



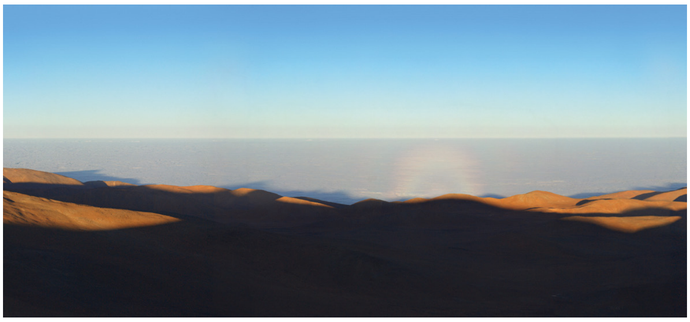
ESO/S. Guisard

G. Blanchard/ESO

Figure 9. ESO staff member Guillaume Blanchard was able to capture the very rare blue flash while observing the sunset on Christmas Eve 2007 from the Paranal Residencia.

phenomenon, which contributes to the whole mystery surrounding the flash and makes it something quite special to look for.

The green flash is best seen on a completely unobstructed western horizon, like the view from the Paranal platform. The weather must be very clear, and the atmosphere needs to have complex layers and a low aerosol content. Happy hunting!



ESO/C. Malin

Figure 11. A glory caused by sunlight backscattering off tiny droplets of water in the atmosphere. Glories appear at a point directly opposite the position of the Sun, so they are only visible at sunrise or sunset.

The Earth shadow and the Belt of Venus

As the Sun reaches the horizon, an orange-yellow twilight arch forms to the west, and the blue-grey Earth shadow slowly rises to the east; stretching from the horizon upwards as the Sun goes down. The twilight arch is the arc of light that forms over the place where the Sun has set. It is usually red at the bottom, yellow for a wide stretch above the red, and arches over in a peach-coloured, green, turquoise or slightly purple band that merges with the background colour. It is created by scattered sunlight in the atmosphere. Even when the Sun has set, it can continue shining on parts of the atmosphere that lie on the horizon or high above our heads. The Earth shadow emerges and its visibility is best when there is little dust or haze in the air.

The clarity and low humidity of the air at the high altitudes of the Atacama Desert provide extraordinary opportunities to regularly observe the phenomenon called the Belt of Venus, followed by the projection of the dark Earth shadow onto the

D. Kordan/ESO

Figure 10. The pink Belt of Venus and Earth shadow as seen at ALMA.

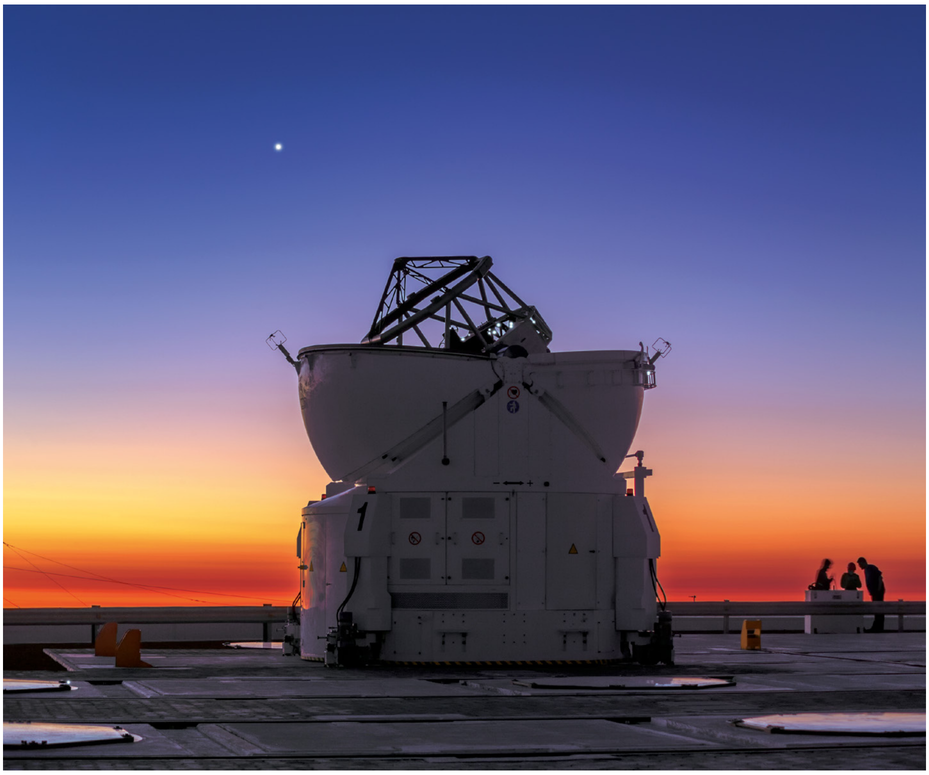


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Figure 12. Looking west just after sunset at ESO's Paranal Observatory on 25 January 2015. The bright object is Venus. In this view rich dusk colours can be seen. They were likely caused by volcanic ash from the January 2015 eruption of Tongan volcano and possibly even the 2014 eruptions of the Indonesian volcano Mount Sinabung.

atmosphere (Figure 10). Looking towards the antisolar point some minutes after the sunset or before the sunrise, the sky over the horizon seems like a dark curtain bounded by pink, while the dusk or dawn sky above is much brighter.

Seen from the ground when the Sun is below the horizon, the Belt of Venus is the result of light from the setting or rising sun being backscattered by fine dust particles and aerosols that are present higher in the atmosphere (Lee, 2015). It is most easily visible just a few minutes after sunset or before sunrise. The belt appears as a glowing, pinkish arch that extends roughly 10–20 degrees above the horizon.

The glory

Observers at La Silla or Paranal can at times see a phenomenon called a glory when looking down on a cloud layer. Glories are concentrated coloured rings around the shadow of the observer's head (or the shadow of a camera; see Figure 11). They occur by backscattering on tiny water droplets in clouds or fog at the antisolar point and look like circular rainbows (Nussenzveig, 2011). This is a rather complicated case of Mie scattering (and not the special divine importance of a person!). If two people are standing on a mountain and look at both of their shadows, they will each see only one glory and claim it to be around their own head. Looking down at a plane's shadow when flying, you will often be able to see a glory on the cloud tops.

Planets in dusk and dawn

The clear air at the high altitudes of the observatories makes dawn and twilight colours very intense, but also followed by a steep darkening gradient. For these reasons, very bright objects, such as planets in our Solar System or the brightest stars in the sky, can be visible in the sky very early after sunset (Figure 12) or very shortly before sunrise. Usually just minutes after sunset the brightest stars appear while the Belt of Venus becomes larger and the sky above is "swallowed" by the Earth's shadow.

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Notes

[a] Please don't forget that looking at the Sun itself, especially through an optical device (camera, telescope, binoculars, etc.), is very dangerous, and could cause immediate blindness. Do not attempt to observe the Sun unless you know what you are doing.

Links

[1] The colors of sunset and twilight (Corfidi, S. F. 2014, NOAA/NWS SPC): https://www.spc.noaa.gov/publications/corfidi/sunset/
[2] Effect of atmospheric refraction on the times of sunrise and sunset (Tong, Y. 2017, HKO): https://www.hko.gov.hk/m/article_e.htm?title=ele_00493
[3] The telluric spectrum of the green flash (Fosbury, R. 2018): https://www.flickr.com/photos/bob_81667/39604010580/
[4] Green and red rims (Young, A. T. 2013): https://aty.sdsu.edu/explain/simulations/std/rims.html

References

Christensen, L. L. et al. 2016, The Messenger, 163, 40
Gladysheva, O. 2007, Solar System Research, 41, 314
Horálek, P. et al. 2016a, The Messenger, 163, 43
Horálek, P. et al. 2016b, The Messenger, 164, 45
Kundt, W. 2001, Current Science, 81, No. 4, 399
Lee, R. L. 2015, Applied Optics, Vol. 54, Issue 4, B194
Lehn, W. H. 1979, Journal of the Optical Society of America, Vol. 69, Issue 5, 776
Lehn, W. H. & German, B. A. 1981, Applied Optics, Vol. 20, No. 12, 2043
Lock, J. A. 2015, Applied Optics, Vol. 54, Issue 4, B54
Longo, G. 2007, *Comet/Asteroid Impact and Human Society*, 303
Lynch, L. K. & Livingston, W. 2001, *Color and Light in Nature*, (Cambridge: Cambridge University Press)
Minnaert, M. G. J. 1993, *Light and Color in the Outdoor*, (New York: Springer)
Moreno, H. et al. 1965, Science, 148, 364
Nussenzveig, H. M. 2012, Scientific American, 306, 68
Shackleton, E. H. 1919, *South: The Story of Shackleton's 1914–1917 Expedition*, (London: William Heinemann)
de Veer, G. 1876, *The Three Voyages of William Barents to the Arctic Regions: 1594, 1595 and 1596*, (London: Forgotten Books, 2017)
Waythomas, C. W. et al. 2010, Journal of Geophysical Research, 115, B12
Zieger, P. et al. 2013, Atmospheric Chemistry and Physics, 13, 10609