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Variations in the sky brightness during a lunar eclipse

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Abstract. A total lunar eclipse is conjectured to have influence on the physical conditions of an environmental area, particularly on the brightness of the sky. The phenomenon might also be relevant on weather parameters change on Earth, such as temperature, humidity and pressure, though a straightforward correlation is not easy to establish. This work mainly aims at measuring the brightness of the sky and also meteorological variables like temperature, humidity, and pressure during the total lunar eclipse that occurred on April 14 and 15, 2014, by using sensors registering the variation of luminance, and a weather station. Analysis of the changes in the sky brightness during all the eclipsing event allows for the observing conditions to be quantified and rated according to various international scales.

Keywords: Sky Quality; Brightness; Lunar Eclipse; Weather; Dark Skies

1 Introduction

A total lunar eclipse is an astronomical event that occurs when the Earth locates between the Sun and the Moon. The phenomenon takes place when the three celestial bodies (Earth, Sun and Moon) line up or are very close to perfect coalignment, making the Earth to obstruct the solar rays that otherwise would fall on the Moon's surface. Lunar eclipses only occur during full Moon periods, and arise when the natural satellite enters completely in the threshold zone or passes through the central region of the Earth's shadow cone, where the solar rays meet almost horizontally. Moon turning red during the eclipse depends on the terrestrial environment (presence of clouds, dust particles, clouds of gas due to the volcanic eruptions, nearby fires and other kinds of gas emissions close to the zone or point of observation), but also due to the Earth-Moon distance [9, 2].

1.1 Astronomical observations and brightness of the sky

Astronomy has relied on the detailed observation of celestial bodies by using the naked eye, telescopes and other astronomical instrumentation. When pursuing ground-based observations one of the main problems we encounter is the effect of the Earth's atmosphere affecting the quality of the images, and introducing degradation in the acquired data sets. Moreover, light pollution from different sources, i.e. natural and artificial lighting, are also affecting

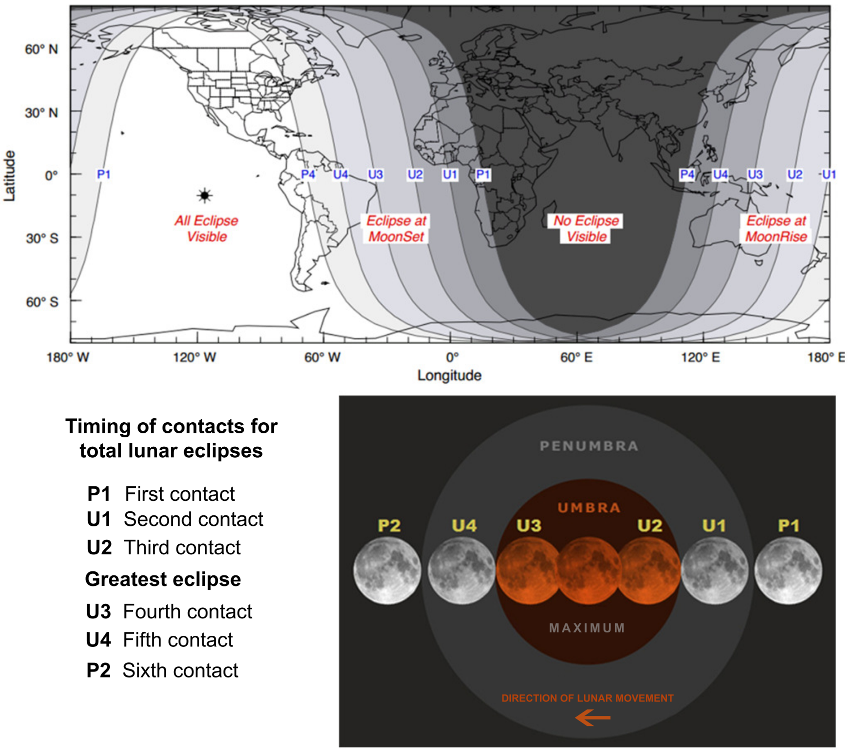

Figure 1: Upper panel: Observing locations for the lunar eclipse on 14th and 15th of April 2014. Lower panel: Stages of the lunar eclipse. Credits GSFC-[6].

the optimal conditions for night astronomical observations. In particular, the presence of the Moon (in all it's different phases) has direct impact on the number of visible objects, by the amount of natural light reflected which disturbs the observation.

A total lunar eclipse displays different phases that can be taken as analogous to the complete lunar cycle in terms of the amount of the illuminance of the Moon's surface. Therefore, it allows to register and quantify in just a few hours, the variations on the sky brightness that otherwise would take a full synodic month, i.e. 29.5 days.

2 Observations and data acquisition

Figure 1 displays the observing locations for the total lunar eclipse on the 14th and 15th of April, 2014 (upper panel), and the stages of contact (lower panel). To accomplish this work, an observing campaign was planned to follow the total lunar eclipse from the astronomical observatory of Tatacoa (close to the town of Villavieja-Huila) at coordinates 3° 14" North and 75°10" West (Fig. 2), and from other places in Colombia.

The resulting observations depended much on the local meteorological conditions. We aimed at measuring sky brightness changes to classify the sky conditions during the observation according to the official global scales and for computing the air mass.

The Tatacoa desert is believed to be one of the most exotic landscape in the colombian geography with an area of 370 km^2. It is actually a dry tropical forest, sub-humid: 10-

Figure 2: Location of the Tatacoa observatory encircled in red in the map of the Huila department in Colombia (left) and light pollution of closer towns (right).

30 scale), according to Martone classification [5] which is the second more arid zone of the country (after the Guajira, semi-arid: 5-10), with geomorphism dominated by *estoraques and cavarcas*, among others. The selection of the place was based on several previous successful observing campaigns with stable meteorological conditions (Fig. 3).

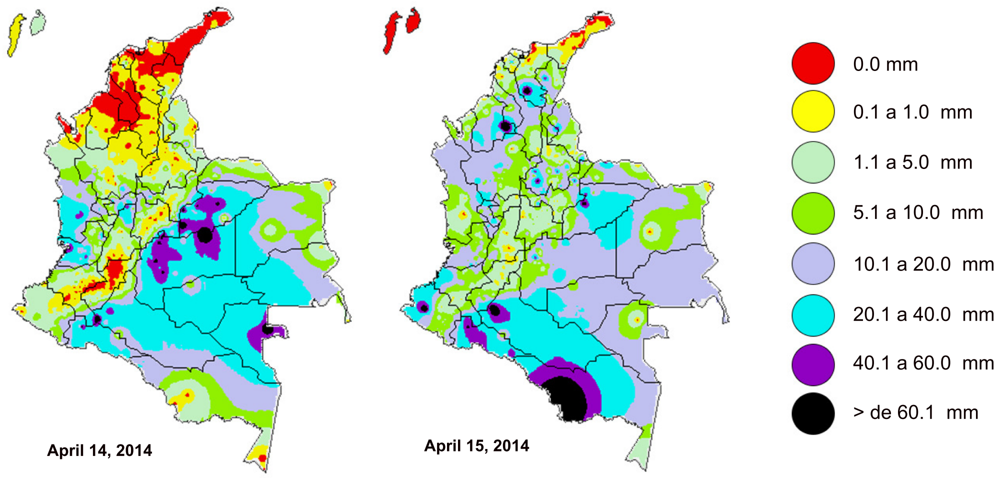

Figure 3: Meteorological conditions in Colombia. Precipitation (mm). [5].

The observations, measurements and records started at 00:40 UT (19:40 PM in local time[1]), however the sensor calib grations were ready from 17:30 PM (photometers, light meters, weather station, telescopes, computers, and CCD cameras). Sky brightness and

[1]From now on all time references will be expressed in local time (UT/GMT -5 hours).

Phase	Time (local)	Time (UT)
P1	23:53:37 PM	04:53:37 (following day)
U1	00:58:19 AM	05:58:19
U2	02:06:47 AM (beginning of totality)	07:06:47
Maximum	02:45:40 AM (totality)	07:45:40
U3	03:24:35 AM (competition of totality)	08:24:35
U4	04:33:04 AM	09:33:04
P2	05:37:37 AM	10:37:37

Table 1: Contact times of lunar eclipse for Colombia on 14th, 15th of April, 2014.

meteorological variables were acquired starting at 19:40 PM, from the night of the 14th of April, 2014, to the early morning (04:35 AM) on 15th of April, 2014. The contact times for Colombia are shown in Table 1.

Figure 4 shows the main instrumental components used to pursue the observations. We used a light meter, called SQM-LE, to measure the sky brightness, a weather station WMR200, with wireless sensors and receivers, two CCD cameras attached to a telescope to acquire white-light images of all the stages during the eclipse (U1, U2, U3 and U4), a calibrated telescope Meade ETX-90 (method of two stars) with a permanent follow up of the Moon to get the altazimuth values during the event. SQMs are commonly used for registering quantitative information, such as for the Dark Sky Quality Monitoring [3].

The light meter allowed us to take the data in a scale of mag.arcsec^{-2} (measure of brightness per area on the sky), the records of the sky brightness, humidity, pressure and the horizontal coordinates of the Moon were taken with a cadence of 5 minutes.

Figure 4: Equipment used for measuring meteorological variables, including a photometer (SQM-LE) and a weather station (WMR200).

3 Results and discussion

Figure 5 plots the variation of sky brightness during all the different stages of the lunar eclipse. It can be seen that between the closer periods to U1 and U2, registered values vary between 14.28 and 20.95 mag.arcseg^{-2}, taken from 00:55 AM to 02:05 AM. During the closer periods to stages U2 and U3, the values were between 21.03 and 21.26 mag.arcseg^{2} related to the period of totality. Changes of brightness during the totality phase are noticed in the figure, getting a brightness average of 21.5 mag.arcseg^{-2}. From the brightness measurements, there is a decreasing trend that allows to classify the sky in scale from 1 to 6 based on the international measurement scale [1]. Figure 5 also shows superimposed sequence of photographies taken through all the different phases, in which the characteristic color variations of the Moon can be evidenced.

Figure 6 shows a 3D representation for the measurements of the sky brightness against the Julian date and the Moon height during the event.

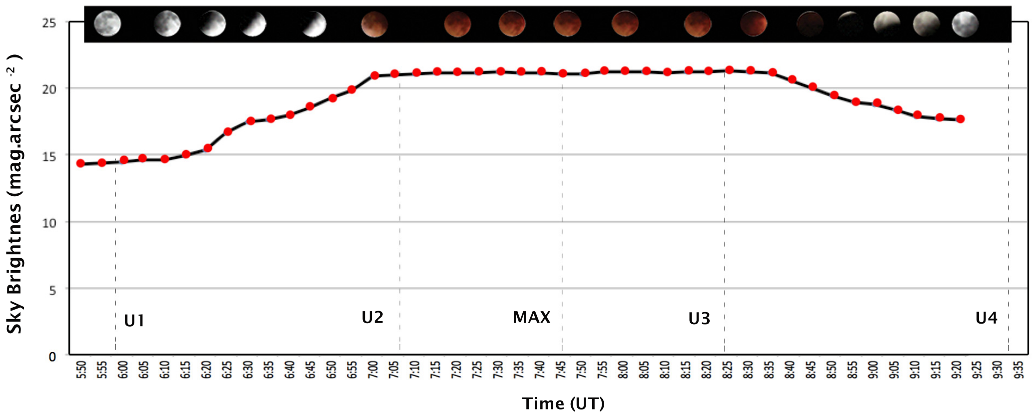

Figure 5: Sky brightness measurements (SQM) registered every 5 minutes (red dots). Main phases of the total lunar eclipse (U1, U2, MAXIMUM, U3, U4) are marked with vertical dashed lines. Eclipse sequence and photographs in different phases are superimposed on the upper part of the plot.

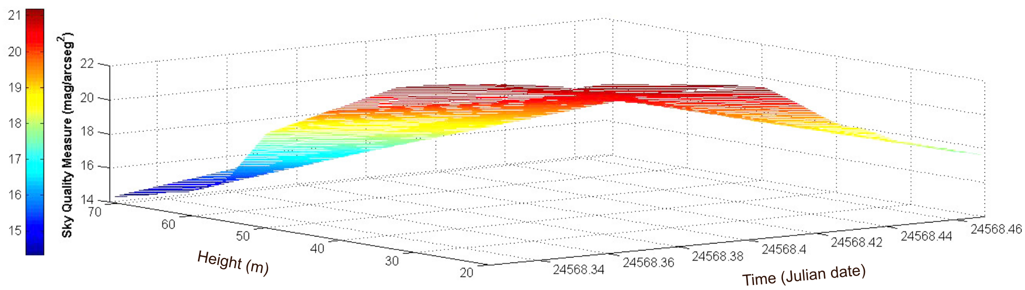

Figure 6: 3D representation of the measurement of the sky brightness against the Julian date and Moon height.

The distribution of the temperature (°C) and humidity (%) related to the local time and the Julian date are displayed in Figures 7 and 8 respectively. The maximum of the total lunar eclipse occurred at 02:45:40 AM on the 15th of April, 2014, in which this study established a temperature of 29.7 °C.

On the other hand, pressure measurements showed minor variations, between 1002 mbar and 1004 mbar.

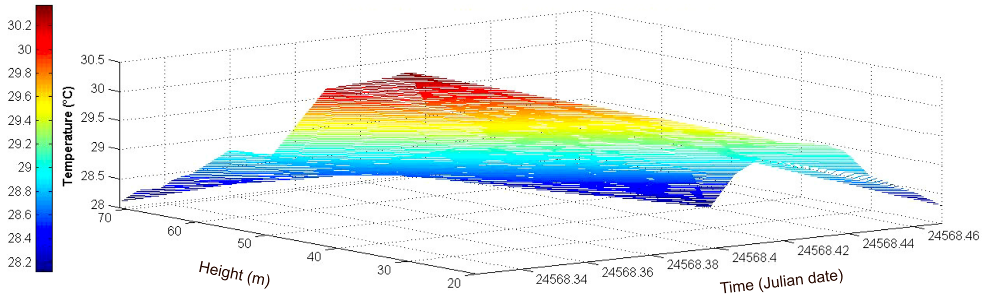

Figure 7: Tridimensional analysis about temperature during the eclipse of the 14th and 15th of April, 2014.

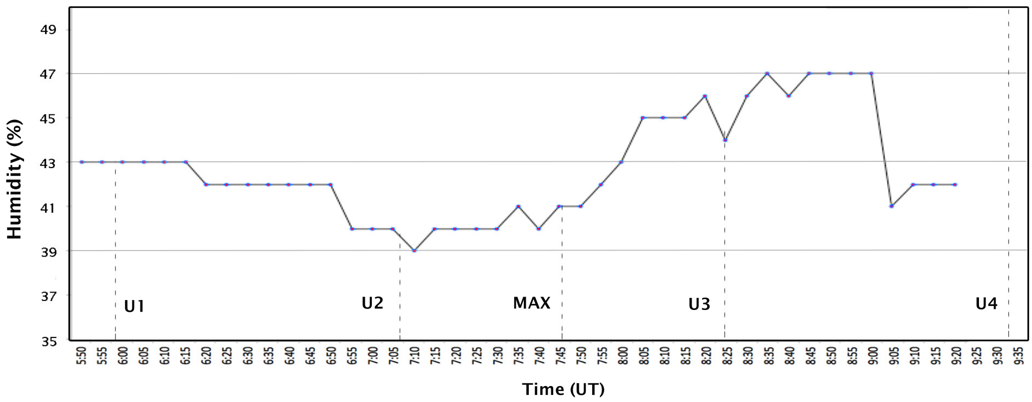

Figure 8: Humidity (%) variations during the total lunar eclipse on 14th and 15th of April, 2014.

Although we measured variations in temperature and pressure (listed in Table 2), they may not be strictly associated to the eclipse and it can not be discarded that are due to evolution of local weather conditions, such as movement of air.

Figure 9 plots the different heights of the Moon (every 5 minutes) for all different phases. It can be established that the air mass is related to curvature and refraction in the atmosphere, through equations 1 and 2.

Equation 1 stands for the ideal case where atmosphere is considered as a plane-parallel plate (see Fig 10).

$$x = \frac{1}{\cos z} = \sec z, \tag{1}$$

where x and z are airmass and zenith angle respectively, with $z = 90 - h$ being h the height of the object.

In the real case, due to the curvature of the atmosphere, the calculation of the air mass must be computed as:

$$x = \sec z[1 - 0.012(\sec z - 1)], \qquad \text{for } z \leq 4 \tag{2}$$

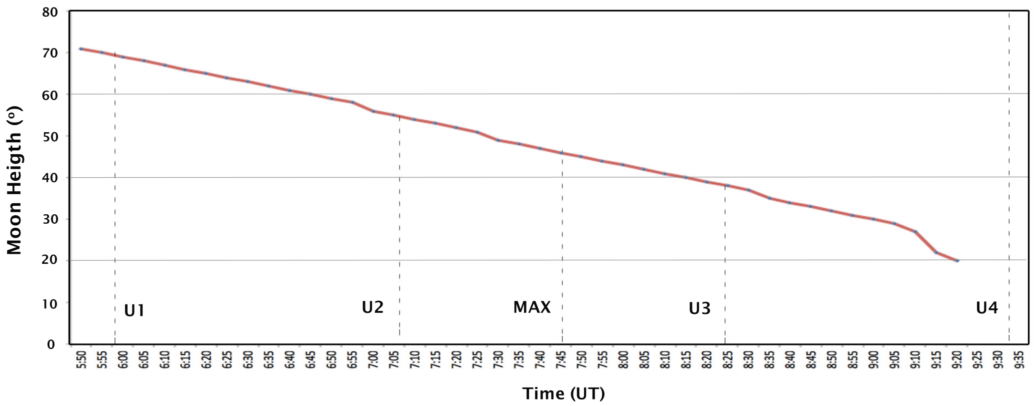

Figure 9: Variation of the Moon height during the total lunar eclipse of the 14th and 15th of April, 2014.

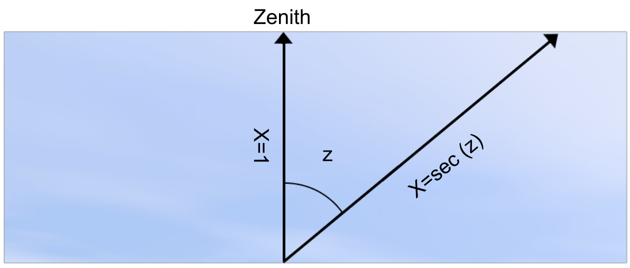

Figure 10: Sketch representing the various air masses related to different zenith heights. Extinction is grater for shorter wavelengths.

The numerical value of air mass (x), listed in Table 2, directly indicates the amount of *thickness of the atmosphere* that the radiation is passing through.

The maximum Moon height registered was 71° at 00:50 AM and the minimum value during the follow up time was 20° at 04:35 AM. During the totality phase (02:45:40 AM), the Moon height was 46° and the azimuth was 251° from the observation zone.

We can calculate the refraction of light (R_{real}) in arcminutes, through the Saemunsdsson formulation [8], as follows:

$$R_{real} = 1.02 \cot \left(h_{real} + \frac{10.3}{h_{real}+5.11} \right) P_S$$

where h_{real} is the true altitude in degrees, and P_S is a correction parameter that depends on the location and weather conditions, expressed as:

$$P_S = \frac{P}{101} \frac{283}{273+T}$$

Time (UT)	Temperature (°C)	Pressure (mbar)	Height	Phase	Air Mass
05:50	28.1	1003	71	U1	1.06
05:55	28.3	1003	70	U1	1.06
07:00	30.2	1003	56	U1	1.20
07:05	30.3	1003	55	U1	1.22
07:40	29.8	1002	47	U2	1.36
07:45	29.7	1002	46	MAXIMUM	1.40
08:20	28.3	1003	39	U3	1.58
08:25	28.1	1002	38	U3	1.61
08:30	28.4	1002	37	U4	1.65
08:35	28.3	1002	35	U4	1.73
09:25	28.5	1004	22	U4	2.62
09:35	28.3	1004	20	U4	2.86

Table 2: Information and measurements of weather conditions during the various stages of the total lunar eclipse observed from Tatacoa, Colombia.

Color Magnitude	Bortle Class	mag/arcsec^2	Artif./Natural
7.6 - 8.0	1	>21.90	<0.01
7.1 - 7.5	2	21.90 - 21.50	0.01 - 0.11
6.6 - 7.0	3	21.50 - 21.30	0.11 - 0.33
6.3 - 6.5	4	21.30 - 20.80	0.33 - 1.00
6.1 - 6.3	4.5	20.80 - 20.10	1.00 - 3.00
5.6 - 6.0	5	21.1 - 19.10	3.00 - 9.00
5.0 - 5.5	6.7	19.1 - 18.00	9.00 - 27.0
<4.5	8.9	<18.00	>27.0

Table 3: Scales measurements of the sky quality.

with pressure P expressed in kPa and temperature T in K.

Table 3 lists the different scales of measurement and classification of the sky. For this study, we took into account the scale corresponding to mag.arcseg^{-2}, that can be converted into cd.m^{-2} through the following expression:

$$[\text{value in cd/m}^2] = 10.8 \times 10^4 \times 10^{-0.4[\text{value in mag.arcsec}^{-2}]}$$

Figure 11 and Table 4 summarize the data distribution for the variation of sky brightness during the lunar total eclipse stages. We use a graphical convenient data representation known as box plot (left panel in Fig. 11) and a histogram (right panel in Fig. 11) plot the values of sky brightness in mag/arcseg^2 taken with the SQM instrument.

A box plot for all the different measured values (sky brightness , temperature, humidity and height of the Moon) is shown in Fig. 12.

4 Final remarks and future work

During the totality phase we got an average brightness of 21.5 mag.arcseg^{-2}. The measurements recording environmental changes related to humidity, temperature and pressure that

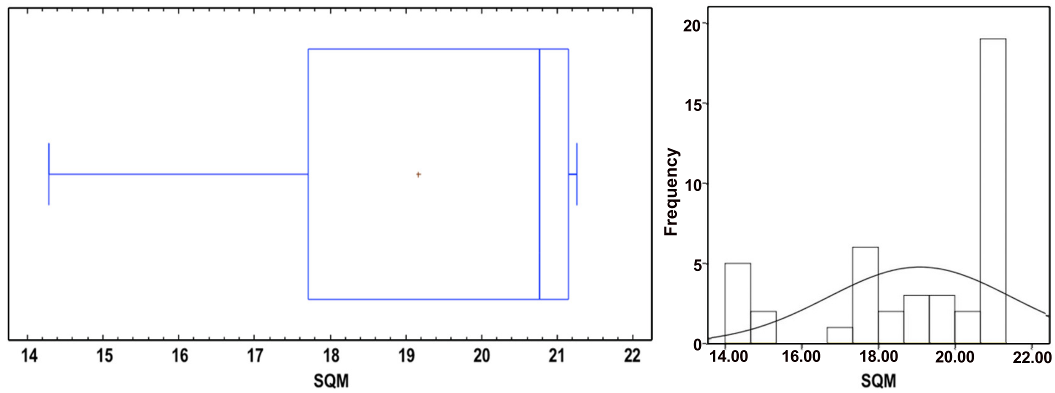

Figure 11: Sky brightness measurements (in mag/arcseg^2 taken by the instrument SQM). A graphical convenient data representation or box plot (*left panel*) and a distribution of values frequencies (histogram)
(*right panel*).

Statistics	Value
Number of measurements	43.00
Standard average error	0.37
Median	19.87
Standard Deviation	2.39
Maximum	21.26
Minimum	14.28
Rank	6.98

Table 4: Scales measurements of the sky quality

can not be directly associated to the astronomical phenomenon. Regarding the brightness, during the totality, the registered sky conditions allowed us to classify the sky of the Tatacoa according to the mag.arcseg^{-2} scale.The maximum total lunar eclipse took place at 02:45:40 AM on the 15th of April, 2014. The month of April is a known period of high rainfalls in Colombia. Fortunately, the conditions presented during the total lunar eclipse event allowed us to observe and take records under a favorable atmospheric condition, i.e. clear skies with no rain for extended periods.

Nevertheless, from 04:35 AM cloudiness was presented at the observation area, and acquisition of data was not possible from 04:35 AM to 05:37 AM corresponding to the penumbral phase. These conditions might also had influenced the humidity and temperature values taken close to the ending of the partiality phase.

We are planning to extend the study, based on the experience already acquired in this work, to register several measurements during upcoming total lunar eclipses. The acquired data would be used for further comparison and evaluation of the sky brightness depending on the different locations.

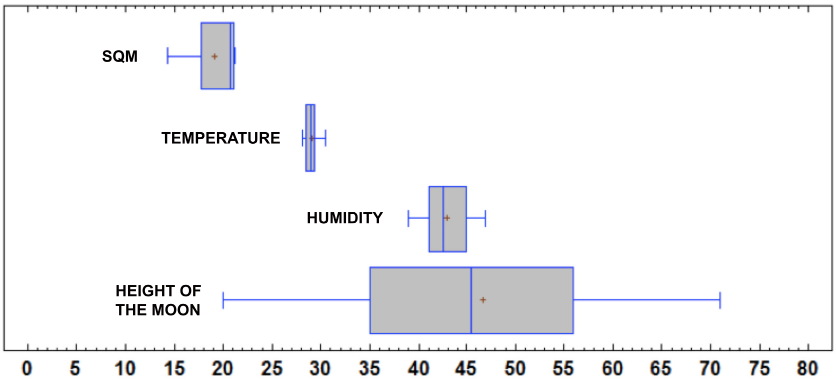

Figure 12: Box plot summarizing the measured values for weather conditions during the total lunar eclipse. See the text for details.

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