Detection Threshold of Noctilucent Clouds and its Effect on Season Sighting Totals

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Abstract

Synoptic observations of noctilucent clouds (NLC) in 1967–1977 during a North American observing campaign are studied in order to determine observers' ability to detect NLC. The average detection threshold of brightness varies, sometimes greatly, from observer to observer and group to group. The average initial brightness of a sighting is brighter than the average final brightness as an observer follows a display to its faint conclusion. Ability to detect faint NLC indeed plays a role in the number of NLC-active nights tallied during a season. When a group is showed a series of NLC photos of varying brightness, there is good agreement with regard to what constitutes a bright, moderate, or faint display, with observer experience not being a factor.

Noctilucent clouds (NLC), the beautiful ice clouds that form in Earth's mesosphere in the boreal and austral summers and that can be seen in twilight in May–August and November–February in the respective seasons, are a marvel to watch (Figure 1). At the point they are bright enough in the local twilight sky to recognize, they enchant the observer with their eerie blue-white glow, their fine filamentary structure, and mesmerizing, albeit barely perceptible motion. The phenomenon has only been known since June 1885, when they appeared to many individuals (amateurs and scientists) in Europe and Russia. This rather sudden onset has caused scientists to speculate that they are a result of changes occurring in Earth's atmosphere. Thomas et al. (1989) concluded that the appearance of NLC is the result of gradually increasing levels of methane originating from Earth's surface. The methane diffuses to the stratosphere where it is broken down by sunlight into water vapour, among other compounds. The water vapour continues to diffuse upward through the stratosphere and into the mesosphere, where NLC form at the topmost level, around 80–85 km. Part of the theory states that around the 1880s, NLC brightness reached

Figure 1 — Photo of NLC display by the automated NLC camera at Athabasca University Geophysical Observatory, 2016 July 24–25, 0940 UT. This photo was Picture 6 in the Brightness Survey. Of the 12 participants, 6 judged a brightness of 3, 5 - a 2, and 1 - a 1.

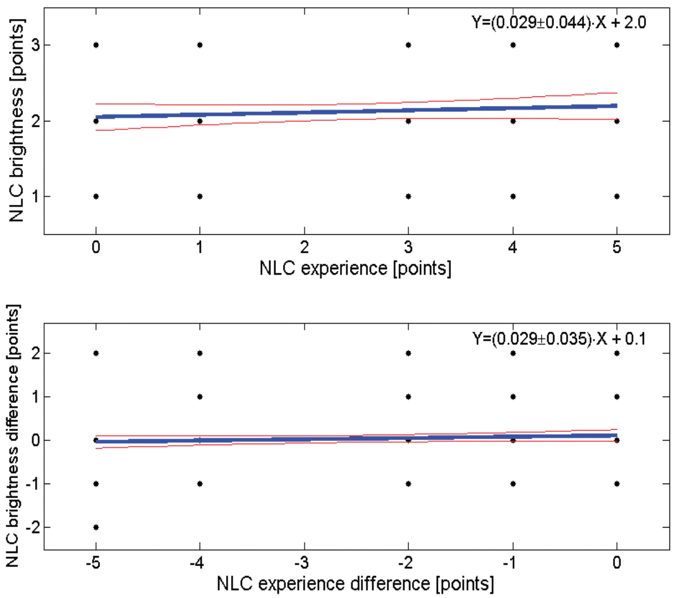

FIGURE 2 — Graph showing the agreement of brightness estimates among a group of 12 participants. Top panel - agreement of brightness values; Bottom panel - agreement based on observer experience.

a threshold allowing them to be seen by the naked eye. The onset of visibility may have been enhanced by the August 1883 Krakatoa catastrophic volcanic eruption, which injected huge amounts of fine dust and water vapour into the atmosphere.

The noticing of a display of NLC is of course dependent on the brightness of the clouds at the time, and as is the case with other natural phenomena, the detection of the NLC will depend on the individual observer's ability to pick out, in this case, a faint display from the background twilight. It could be contended that the onset of NLC globally in 1885 was in part thanks to those European viewers who were observant enough to discover displays of NLC and recognize them as a distinct, new phenomenon, and then to report them to various authorities, usually educational institutions.

In the ensuing decades, NLC have become a more-reported phenomenon. In the 21st century, the prevalence of media to extoll their beauty and mystery has yielded a dramatic increase in reports, especially in the form of photographs by various forms of digital cameras that can now record natural phenomena with ease and ever-greater sensitivity. But this increased exposure has frankly done little to help us conclude that there may have been an actual increase in NLC activity in the last 130 years. Actually, organized synoptic observations since the 1960s have yielded studies. For example, Pertsev et al. (2014) and Dalin et al. (2020) have concluded that there has been an increase in the frequency of nights with NLC during the season, but the increase has been slight and statistically insignificant.

The brightest NLC displays are so conspicuous, even members of the general public with little interest in atmospheric phenomena recognize the displays as something extraordinary. Fainter displays are often missed because they are simply too feeble in brightness, or because they look like ordinary cirrus clouds that may be perceived as being lit by the last vestiges of twilight. Even in the latitude zone of highest NLC incidence, 55–60 N in the Northern Hemisphere, seasonal sighting totals vary greatly. Why? For observers in this zone, the total is usually 10 to 15 displays (Noctilucent Clouds around the World Facebook Group [www.facebook.com/groups/120898778545736], personal communication). An observer such as Edmonton's Mike Noble, who travels nightly to reach clear skies and uses digital photography to aid NLC detection, can increase the NLC number well into the 40s (Zalcik and Noble, 2019). The current record for a fixed research camera is Vilnius, Lithuania, with 35 active nights (Pertsev et al., 2014). Conclusions about the strength of NLC activity during a particular NLC season must take into consideration the varying ability of people and cameras watching the sky to detect the clouds, with whatever ease and acuity.

Organized campaigns for NLC monitoring have usually included NLC brightness as one of the key characteristics to be recorded. Personnel at weather stations participating in such programs are at the outset briefed as to what NLC look like and are instructed to estimate the brightness of the NLC according to an established scale. If a bright patch of NLC appears from behind tropospheric clouds, the initial brightness value recorded by the observer will be a 3 (bright, on a 1–3 scale, whereby 2 is moderately bright and 1 is faint). But the vast majority of displays seem to start out faintly. If a display starts during the twilight period, the clouds usually appear very close to the horizon, at which time they start out as faint, even though they can quickly increase in brightness. Similarly, the rarer displays that are already well up in the sky in evening twilight are faint until the contrast improves as the sky gets darker.

To verify that most NLC displays indeed start out as faint, we looked at photographic data by Mike Noble from the years 2019 and 2020. Mike's avid observing regimen involves setting up digital cameras in twilight, in readiness for the first faint hints (using Mike's own terminology!) of NLC. The first images of the displays recorded had their NLC brightnesses estimated on the 1-3 scale. Of a total of 44 displays surveyed, 40 had an initial brightness of 1, 4 of 2, and 0 of 3, with the average initial brightness being 1.1. The fact that the overwhelming majority of initial NLC in Noble's data were faint, fully 91%, shows that displays indeed show up inconspicuously.

We will now look at historical NLC observation data to see if naked-eye NLC observations echo the above photographic ones in that the initial NLC seen are feeble in brightness. The data set being studied is the observation program conducted by Canadian and American (all in Alaska) weather stations and airports from 1967–1977. This 11-year campaign was the continuation of a program under the direction of Fogle

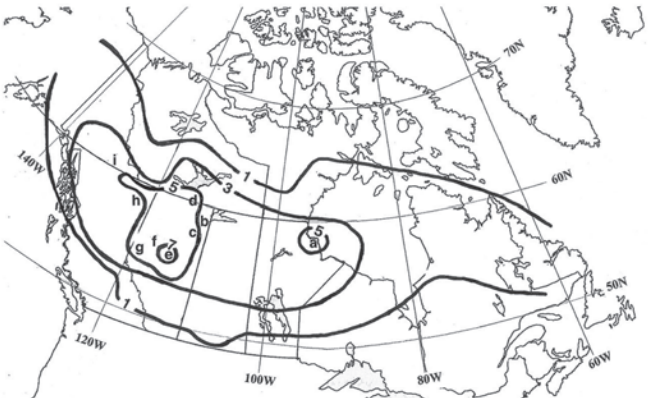

Figure3 — Map showing locations of nine weather stations in the detection threshold study. a – Churchill, b – Ft. Chipewyan, c – Ft. McMurray, d – Ft. Smith, e – Slave Lake, f – Peace River, g – Grande Prairie, h – Ft. Nelson, and i – Watson Lake

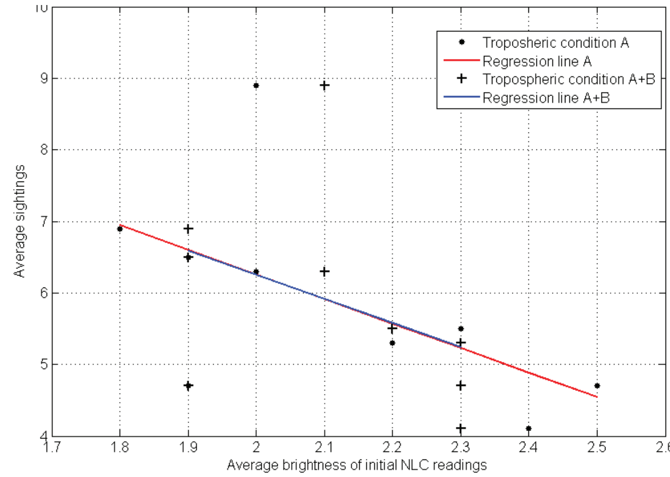

Figure 4 — Graph showing relationship between average initial brightness and average seasonal sightings for the nine sites in the study. Lines are shown for both tropospheric conditions A and B.

(1966) of the University of Alaska. In total, over 40 stations kept watch for NLC, with staff entering observation data onto dedicated forms when NLC were seen. Details on annual totals of network-wide sightings during the program, variation of average NLC brightness with respect to latitude, and comparisons of activity and brightness at specific sites, were presented by Zalcik et al. (2016).

The scale for brightness estimation used by Fogle, and for that matter put forward by global NLC observing programs (Grishin, 1957; WMO, 1970) is a 5-point scale with the following values:

1 – faint

2 – not very bright, but easy to recognize

3 – clearly visible

4 – very bright

5 – extremely bright, illuminating objects facing them.

The scale adopted by the North American surveillance network NLC CAN AM is the more simple and easier to remember 3-point scale mentioned previously. The "4" and "5" brightness values of the global program were seldom entered on the observing forms, with the "3" designation used far more often to indicate bright NLC. In essence, then, the "3" value of the North American program was roughly the equivalent of the combined "3", "4", and "5" values of the global program.

What degree of agreement is actually established within a group of observers with regard to the brightness of a display of NLC? To find out, one of us (MZ) conducted a survey of attendees at the 2017 June 23 "Astro-café" talk, one of a series of talks organized by the RASC Edmonton Centre. For the survey, a set of 25 images of NLC was shown to the attendees, who were asked to rate the brightness of the NLC in each image. The results of the survey are shown in Table 1; the NLC photo in Figure 1 is one of the test photos. The attendees had varying experience in observing NLC. Results (Figure 2) suggest that there is good agreement in the group with regard to the full spectrum of brightness. Interestingly, agreement in test answers was also good for observers with lots of NLC observing experience compared with those with minimal experience.

Of the aforementioned 40 sites contributing synoptic NLC data in the 1967–1977 program, we chose 9 Canadian sites in the prime NLC viewing zone of 55–60 N. These sites consequently tallied more seasonal sightings, and hence more brightness values to contribute to this study. A map showing the locations of these sites is shown in Figure 3.

Table 2 shows the average brightness values of initial and final nightly sky checks of NLC from the above sites. Table 3 shows a season's sightings at one particular site, Churchill, during the 1968 season, with the aggregate brightnesses based on a reading every 15 minutes recorded during each of the active nights. The global observing program estimated tropospheric opacity on a 4-letter scale:

A – sky completely clear

B – sky with some scattered tropospheric clouds present

C – most of the sky covered with tropospheric cloud with only small holes between clouds

D – sky overcast with tropospheric clouds.

Table 2 incorporates NLC sightings with corresponding tropospheric cloud values of "A" and "B" only. The problem that may arise if including "C" observations was previously mentioned, that being, bright NLC could briefly appear between broken tropospheric clouds, giving the impression that this "initial" sighting was actually of bright NLC, not necessarily a true indication of the progression of NLC brightness over the course of a night's display. Not surprisingly, NLC sightings with a corresponding "A" value are the most valuable as there is no chance of tropospheric cloud interference.

From Table 2 it is readily apparent that the average initial brightness of these sightings is *not* faint, with the majority of sites in both the "A" and "B" scenarios having an average initial brightness of 2.0 or more. Thus, a significant number of displays were already of moderate brightness when detected; still others were not noticed until the display was bright. A possible factor in the elevated initial brightness readings is the periodicity of sky checks by the weather and airport personnel doing the observing. Typically, sky checks were performed on the quarter hour. Hence, a display exhibiting a rapid increase in brightness could conceivably jump from a brightness of 1 to a 2 or even a 3 in a 15-minute time span. For all sites, the brightness of the final NLC reading was significantly fainter than the initial reading, indicating that once the NLC were unequivocally detected, the observers were able to follow the display to the point where it became faint.

Picture	A0	B1	C1	D3	E1	F4	G4	H1	J4	K5	L1	M5
1	2	2	2	3	3	2	2	3	2	2	3	2
2	1	1	1	1	1	1	1	1	1	1	2	1
3	2	1	2	2	2	2	2	2	2	2	1	2
4	2	1	3	3	3	3	2	3	1	2	1	2
5	1	1	2	2	1	2	3	2	2	2	1	1
6	1	2	3	2	2	3	3	3	2	3	3	2
7	2	3	3	3	3	3	3	3	3	3	3	3
8	1	1	1	1	1	1	2	1	1	1	1	1
9	3	3	3	3	3	3	3	3	3	3	3	3
10	3	3	3	2	3	3	3	3	3	3	3	3
11	1	2	1	2	1	2	2	2	2	2	2	2
12	1	1	1	1	1	1	1	1	1	1	1	1
13	3	3	3	3	3	3	3	3	3	3	3	3
14	2	2	2	2	2	2	3	3	2	2	2	2
15	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	2	2	1	2	2	2	2	1	2	2
17	3	3	3	3	3	3	3	3	3	3	3	3
18	1	2	1	1	1	2	1	1	2	1	2	1
19	1	2	2	2	3	3	2	3	3	2	3	3
20	1	2	1	1	1	1	2	1	1	3	1	2
21	2	3	3	2	3	3	3	3	3	3	3	3
22	2	3	2	2	2	2	3	3	3	3	3	3
23	3	3	3	3	3	3	3	3	3	3	1	3
24	3	3	3	3	3	2	3	3	3	2	3	3
25	2	2	2	2	1	1	2	2	2	2	1	2

Table 1 — Results of the NLC Brightness Survey Observer (experience factor 0 [none] to 5 [much])

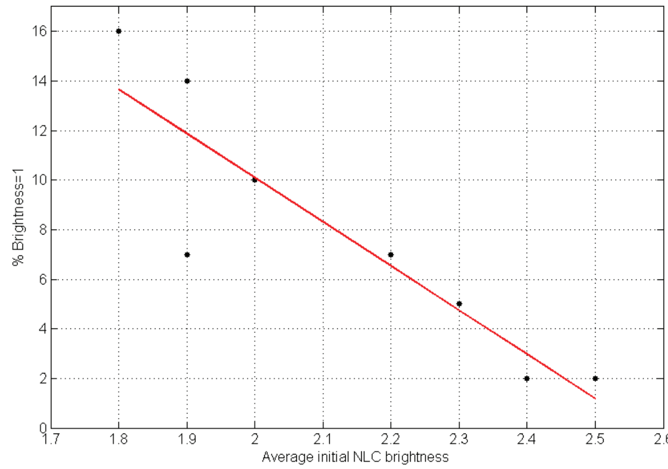

Figure 5 — Graph showing the effect on average brightness by percentage of active nights during which the NLC brightness remained at a level of 1 through the entire display.

There is no clear advantage of having completely clear skies, condition "A", during the initial observation versus skies with some tropospheric cloud, condition "B". Some sites had a fainter average initial observation under "A" conditions; others under "B" conditions. A comparison of the individual sites' average initial brightness values indicates that some sites, for example Ft. Nelson, Churchill, and Peace River, were <2, whereas others, such as Ft. Chipewyan and Watson Lake, were significantly higher, 2.4–2.5. With these higher values it could be expected that initial sightings with faint NLC were in the minority. Is the reason for the marked difference between some sites simply personal factors such as experience and visual acuity? A more comprehensive list of such factors is outlined by Zalcik et al. (2014). The Churchill site had an average of 6.9 active nights per season despite having poorer weather conditions than sites further inland (Yorke and Kendall, 1972). Notice, however, that Churchill also had the lowest average initial brightness, 1.8, suggesting that many of the initial sightings had a brightness value of 1. Perhaps unfavourable weather at this site was more than offset by the staff's ability to detect NLC while they were still faint.

Figure 4 attempts to show a relationship between average initial brightness and average number of sightings for the nine sites. The curves show that an average initial brightness of 1.8 yields about twice as many sightings as a brightness of 2.5. Recall the aforementioned data from Mike Noble; his average initial brightness of 1.1 has contributed to his lofty sighting totals, into the 40s during some seasons. Zalcik et al. (2016) pointed out that an increase in NLC sightings at the Baker Lake, NU Flight Service Station (64°N, 96°W) in 2003–2009 may have been due to a high proportion of faint displays detected.

In Figure 5, we show the relationship between average initial brightness and the percentage of total nights for each site when the brightness for the entire display remained at 1. From the curve, one can see that at an average initial brightness of

Site	No. Sightings	Yrs	Avg		A	a	b	B	c	d	a+c	b+d
Churchill	62	9	6.9		25	1.8	1.5	25	2.0	1.6	1.9	1.5
Ft. Chipewyan	52	11	4.7		21	2.5	1.6	16	2.0	1.6	2.3	1.6
Ft. McMurray	61	11	5.5		21	2.3	1.3	18	2.1	1.3	2.2	1.3
Ft. Smith	58	11	5.3		27	2.2	1.9	15	2.5	2.1	2.3	2.0
Slave Lake	71	8	8.9		24	2.0	1.3	22	2.1	1.4	2.1	1.3
Peace River	72	11	6.5		27	1.9	1.4	20	1.7	1.5	1.9	1.4
Grande Prairie	63	10	6.3		33	2.0	1.3	10	1.7	1.5	1.9	1.4
Ft. Nelson	42	9	4.7		22	1.9	1.4	9	1.8	1.3	1.9	1.4
Watson Lake	41	10	4.1		11	2.4	1.5	9	2.2	1.5	2.3	1.5

Table 2 — Weather station NLC data from the 1960s–1970s.

A – number of nights having sightings with clear tropospheric conditions a – average initial brightness b – average final brightness

B – number of nights having sightings with scattered tropospheric clouds c – average initial brightness d – average final brightness

2.0 or fainter, four of the five sites have >10% of their sightings staying at a brightness of 1; at an average initial brightness of 2.4–2.5, this percentage drops to only 2%.

The Flight Service Station at the airport at La Ronge, Saskatchewan (55°N, 105°W), has been the best site at yielding synoptic observations in the NLC CAN AM surveillance network, which has been monitoring NLC in North America since 1988. Fully 24 seasons of data, from the 1990 to the 2013 NLC seasons, were compiled (Zalcik et al., 2014), and the average number of NLC-active nights at La Ronge in this time period was 9.7. Note that this average is nearly one full active night per season higher than Slave Lake ("e" in Figure 3), also situated at 55°N. Whether the difference is because of better ability by the La Ronge staff to detect NLC, or because of an actual increase in NLC frequency in the La Ronge epoch compared with the earlier Slave Lake one, is unclear.

Zalcik et al. (2016) introduced the concept of the "average detection threshold" of a group of observers. Such a threshold is the average brightness at which a display of NLC is unequivocally recognized. The threshold is dependent on the actual brightness of the NLC present, but also on a number of personal factors among observers, such as experience, acuity, dark adaption, and fatigue, as well as site factors, such as flatness of horizon and degree of ambient lighting. The averages derived in column "a+c" in Table 2 essentially constitute the average detection thresholds of observers at the sites listed in the table. The range of averages in these values from site to site harkens to the above factors at play when determining the presence of an NLC display.

To aid the ability to increase one's seasonal sighting total by detecting faint displays, a couple of different strategies can be employed. One would be the use of such optical aids as binoculars, which have proven to be invaluable in picking out the fainter NLC displays. Employing digital photography to bring out the faintest displays would work just as well.

However, as faint NLC detection, as shown here, can vary greatly from observer to observer, the pursuit of finding weak NLC displays can actually be a detriment in determining the true frequency of NLC and, by extension, determining decadal trends in NLC frequency. It may be preferable to use only bright NLC displays when making such comparisons, this strategy already being suggested by Zalcik et al. (2016).

Conclusions

For an individual observer or group of observers of NLC, the average detection threshold of NLC varies, sometimes markedly, from one observer to another or one group to another.

The average initial brightness of NLC for an observer or group of observers is brighter than the average final brightness, presumably because of the ability to follow a display of NLC to a fainter brightness once the display is recognized.

The difference in average detection threshold from one observer or group of observers to another determines the difference in NLC seasonal active-night totals. The individual or group who is better able to pick out faint NLC displays, which seem to constitute a high proportion of total displays, will with no surprise end up with more NLC-active nights during that season.

When a group of observers evaluates a quantity of NLC images to estimate brightness of each display, there is good agreement among the individuals as to what constitutes a bright, moderately bright, or faint display.

There is good agreement among experienced and non-experienced observers with regard to judging what constitutes a bright, moderately bright, and faint NLC display. ✷

Date	Times	Brightness Values	Weather
Jun 15–16	0600–0815	4,4,4,4,4,4,3,3,3,1	A
25–26	0500–0645	2,2,3,3,3,3,3,3	B
27–28	0500–0645	2,2,2,2,2,2,2,1	D
30–Jul 1	0545–0715	1,2,2,2,3,3,3	A
Jul 6–7	0500–0715	1,2,2,2,3,3,3,2,2,1	A
20–21	0600–0730	1,1,2,2,1,1,1	C
Aug 1–2	0800–0900	4,4,2,2,1	C

Table 3 — Brightness values of NLC recorded at the Churchill weather station during the 1968 season. Only data from the nights with weather values of "A" and "B" were used in the analysis as only under these conditions is tropospheric cloud not a detrimental factor. Hence, in 1968 only four of the seven nights were usable. Brightness values of "4" for Jun 15–16 were converted to "3" to conform to the 3-point brightness scale used in this study.

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