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Are Noctilucent Clouds Truly a "Miner's Canary" for Global Change?

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Noctilucent clouds (NLC) occur close to 83 km altitude during summer at polar, high, and mid-latitudes. They are frequently visible to Earth-bound observers, provided the observers are on the night side of Earth and the clouds are still illuminated by the Sun. Under these conditions, NLC can become a quite impressive sight. NLC owe their existence to the extremely low temperatures (well below 150 K) which prevail during summer over a wide latitude band in the 82- to 90-km altitude region. For a major review of NLC science, the reader is referred to *Gadsden and Schröder* [1989].

Because of their likely sensitivity to the ambient water vapor mixing ratio and temperature, NLC could be expected to react with particular sensitivity to long-term changes in composition and thermal structure of our atmosphere as caused by human activities. Indeed, such speculations have been voiced earlier. In particular, *Thomas et al.* [1989] suggested that the NLC brightness has notably increased in the past century due to an increase of water vapor at mesopause altitudes. This increase is supposedly caused by oxidation of methane in the middle atmosphere, the enhanced levels of which are due to human activities. Subsequently, *Thomas* [1996] developed this picture by numerical modeling of the effects that increased levels of CH_4 and CO_2 will have on the latitude range of NLC. Thomas summarizes his results as follows: "I have described a mesospheric climate change that has been underway for over a century" (hence my term the "miner's canary" of global change). *Thomas and Olivero* [2001] recently discussed their views on the use of NLC as possible indicators of global change in the mesosphere.

In this article, I reflect on three aspects of NLC which, it seems to me, make their use as a miner's canary of global change problematic for the following reasons. (1) Over the past century, the occurrence and brightness of NLC have shown a rather large variability. Deriving evidence for global change from these two NLC properties should only be done after the global change signal has reached similar proportions as that caused by natural variability. (2) The one property of NLC which has been accurately measured over more than 100 years and also, lately, at many locations, is the altitude of NLC layers. This parameter shows surprisingly small variations and no significant long-term change. (3) Even if future observations will show us that the solar cycle-averaged NLC occurrence indeed increases, these observations will neither identify for us whether changes in temperature, water vapor, or condensation nuclei have caused the NLC change nor whether they are natural or anthropogenic.

The following is a discussion of these three aspects in more detail, in order to support the view that noctilucent clouds are not a miner's canary for global change.

The Variability of NLC Occurrence

Unambiguous observations of NLC go back to the summer of 1885, when NLC appeared above western Europe with a brightness and latitudinal extent which has never been reached again. One measure for the mean annual activity of NLC is the number of nights per summer season in which NLC have visually been observed in certain sectors of or in the entire northern hemisphere. For the years 1885 until 1969, *Fogle and Haurwitz* [1974] have provided such a record, which has been much quoted in recent years. Since 1963, a similiar record has been assembled independently by *Gadsden* [2002] and *Romejko et al.* [2003]. Both these records profit from the formation of networks of trained observers in the early 1960s. Gadsden has collected observations from northwestern Europe, and Romejko et al. from just one site near Moscow. (The latter's one-site concept makes them susceptible to bad weather, hence their numbers are smaller than those of Gadsden). The frequently re-published record of Fogle and Haurwitz will not be reproduced here in its entirety because of space limitations. The two modern records are shown in Figure 1, which also includes the last part of the Fogle and Haurwitz statistics.

These records show beyond doubt that the occurrence of NLC has exhibited a large

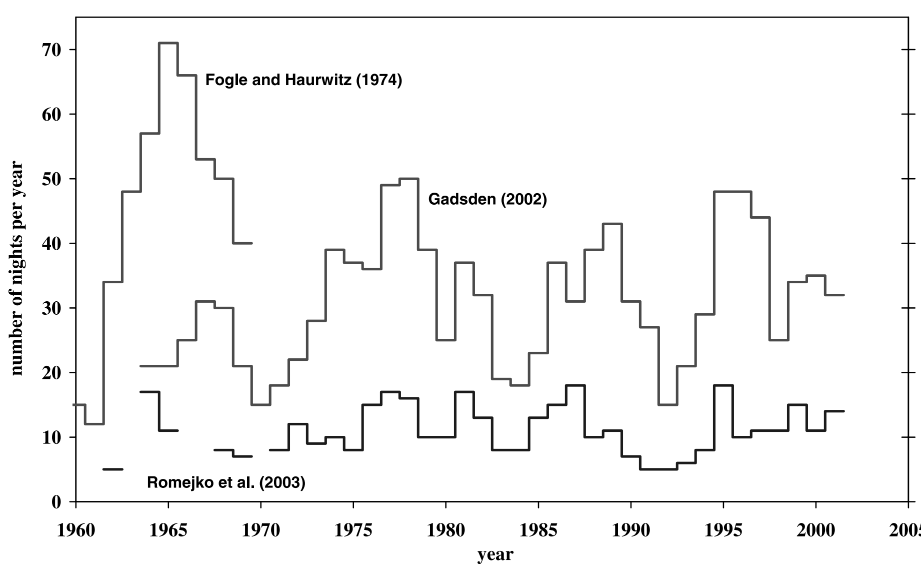

Fig. 1. Rate of occurrence of NLC 1960–2001 as measured by the number of nights per summer season in which NLC were observed visually from the ground. Three independently accumulated records (see text) are shown. In the 1960s, the record of Romejko et al. *[2003] is intermittent.*

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variability over the past century. Periods of multi-year intense activity (e.g., 1885–1888; 1963–1968) have been observed, as there are periods with just a few days of such intense activity (e.g., 30 June and 1 July of 1908) and multi-year-long periods with an almost total lack of observations (e.g., World War II). Included in this variability is a near-regular variation in activity, with a period between 10 and 12 years. The latter periodicity was identified already by *Vestine* [1934], disclaimed by *Fogle and Haurwitz* [1974], and "rediscovered" by *Gadsden* [1985]. Figure 1 indicates that the *Gadsden* [2002] record shows this periodicity most strongly, yet with its own variability in structure and amplitude. The comparatively shallow 1967 maximum in the *Gadsden* [2002] record is often taken as an indication that NLC activity has been lower 45 years ago than today. This conclusion requires, however, a total disregard of the large maximum in the *Fogle and Haurwitz* [1974] record which, as the authors explain, was caused by brilliant and extensive displays over North America. This large maximum was deleted from further consideration by *Thomas and Olivero* [2001; Figure 3] without provision of a convincing argument. In addition, the conclusion that a 1965–1966 maximum in NLC activity was of similar strength to the following three maxima is supported by the observational series of *Romejko et al.* [2003]. Their maximum in 1964 is close to the maxima which developed in the following 4 decades.

I conclude from the data shown in Figure 1 that (1) since the early 1960s, no long-term increase in NLC occurrence has been observed; and (2) the irregular variations are so strong that in order to establish any long-term change in NLC occurrence, the data base must span a period of more than 50 years [*Wetherhead et al.,* 1998]. Systematic studies of NLC by spaceborne instruments started, however, only in 1978 with the launch of the Nimbus-7 satellite and its SBUV instrument. Until today, the data from this and subsequent satellites can cover, even if strung together, no more than about two periods of major NLC occurrence variations. Based on the size of semi-regular and irregular variations displayed in Figure 1, I suggest that the time span of satellite observations is still much too short to derive from those observations a significant long-term change in NLC occurrence or brightness.

There is one more type of variability in NLC occurrence to be mentioned. Recent observations of NLC at latitudes below 50° have led *Taylor et al.* [2002] to suggest a "significant expansion of the NLC region to unusually low latitudes over the past several years."

I doubt that we can already talk about any "significant expansion" if we consider (1) the more than marginal statistics for these cases; (2) a simultaneous build-up of a mid-latitude network of professional observers of NLC; and (3) reports of repeated sightings in the 1970s of NLC by Soviet cosmonauts at latitudes as low as 45°N [e.g., *Avaste et al.,* 1980; *Vasilyev et al.,* 1987].

Table 1. Altitude of NLC Layers

latitude [°N]	altitude [km]	method (NLC seasons)	reference
78	83.6	K lidar (2001) (26 displays)	Höffner et al. [2003]
69	83.2	Rayleigh lidar (1997 - 2000)	Fiedler et al. [2003]
67	83.0	Rayleigh lidar (1994 - 2000)	Thayer et al. [2003]
62	83.0	photogrammetric triangulation (5 displays)	Grahn and Witt [1971]
northern hemisph.	82.9	literature review (1889 – 1979 / 23 displays)	Gadsden and Schröder [1989]
55/54	82.8	Rayleigh and K lidars (7 displays)	von Cossart et al. [1996] Alpers et al. [2001]
53	**82.4**	**photographic triangulation (8 displays)**	**Jesse [1896]**
42	82.2	Rayleigh lidar (1 display)	Wickwar et al. [2002]

Altitudes of NLC layers as measured by ground-based methods in the northern hemisphere. The value quoted from Thayer et al. *[2003] is the arithmetic mean of all their displays, derived from their Figure 6a. Note the early result of* Jesse *[1896], which is highlighted by bold lettering.*

Ground-based Observations of NLC Layer Altitudes

In order to identify long-term changes in NLC parameters, we look for observations which reach as far back into the past as we can find. Undoubtedly, the parameter which has been quantitatively measured the longest is the altitude of NLC layers. During the summers of 1889–1891, *Jesse* [1896] triangulated eight NLC layers by 2-station photography from Berlin, Germany. Their weighted mean altitude was 82.4 km. Jesse's stated errors for individual altitude determinations averaged to ±0.17 km. An historical record of NLC altitude measurements has been given by *Gadsden and Schröder* [1989]. For the time period 1900 through 1980, they list 14 altitude measurements of NLC, which yield a mean altitude of 82.6 km. More than 100 years after the pioneering NLC measurements of Jesse, NLC altitudes became measurable by ground-based lidars with high accuracy. Table 1 lists the results of the more significant of those measurements in Europe and the North American continent (the oldest reliable altitude measurement is highlighted by bold lettering). As can be seen, well-documented, ground-based observations prove a remarkable constancy of NLC altitudes in the northern hemisphere over 100 years of observations, and a wide range of latitudes, too. So far, they do not indicate a long-term change.

Can We Relate Potential Changes in NLC Occurrence to Human Activities?

The occurrence and brightness of NLC depend on the ambient temperature and water vapor mixing ratio, as well as on the availability of appropriate condensation nuclei. The ambient temperature and water vapor mixing ratio can clearly be affected by mankind in more than one way. The temperature will be affected by any anthropogenic changes of the CO_2 and/or O_3 abundances, as well as by anthropogenic changes in dynamics of the troposphere. The water vapor abundance in the mesosphere will sooner or later react to anthropogenic changes of H_2O and/or CH_4 abundances in the lower atmosphere. However, the temporal and spatial pattern of their future changes cannot be modeled or otherwise predicted yet with any certainty. Of the infrared radiatively most important gases (CO_2, O_3, O, and perhaps H_2O), none can currently be measured with sufficient accuracy at mesopause altitudes to establish its abundance there within anything like percent accuracy, not to speak of any significant long-term change.

Even worse is the current understanding and predictability of the process(es) by which the mesopause temperature is coupled to dynamic processes acting at, say, tropopause altitudes. The coupling process is very likely provided by the emission of a complex spectrum of internal gravity waves from tropopause altitudes, the ascent of these waves through the middle atmosphere, and their breaking at and above the mesopause. At the summer high-latitude mesopause, this breaking of gravity waves affects the large-scale circulation in such a way as to drive the ambient temperature down to the 130 K level, which falls about 75 K below the radiative equilibrium value of 205 K [*Fels*, 1985]. All currently available global circulation models can only crudely specify the spectrum of theses gravity waves and the altitude of their launching, and they can only parameterize their interactions with the background winds, tides, and themselves in the middle atmosphere, and the altitude level of their breaking in the upper mesosphere/lower thermosphere. There are many "loose ends" in our understanding of this complex chain of coupling processes.

It is this state of affairs which suggests that today we cannot model or otherwise predict how the temperature of the summer high-latitude mesopause will develop in the long term. To produce visually noticeable changes of NLC occurrence (and brightness), one needs, in the case of the temperature, a few percent change; in the case of the water vapor, many tens of percent; and in the case of condensation nuclei, changes by factors of, say, 2 to 5 in number density or size. Although the latter numbers still need quantitative verification by appropriate 3-D modeling (which is underway at the Leibniz-Institute of Atmospheric Physics), I argue that a given percentage change causes the largest effect on NLC if impressed on the temperature. And it is just that most important parameter of the summer high-latitude mesopause which we cannot model from first principles. Therefore, I am very pessimistic about our current capability to predict the future of NLC.

Even if future observations will show that indeed, the mean NLC occurrence increases, these observations will neither identify for us whether changes in temperature, water vapor, or condensation nuclei have caused the NLC change, nor whether they are natural or anthropogenic. The questions raised clearly require additional research into the history and current aeronomy of NLC. In fact, the contributions of both ground-based and satellite-based observations, complemented by careful modeling efforts, and efforts to reconcile the differences can only advance our understanding of NLC dynamics and resolve the issue of whether they provide evidence of recent anthropogenic change in the upper atmosphere.

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