

Predicting the occurrence of visual Noctilucent Clouds

John Rowlands¹, Kerry A. Day¹, David A. Hooper², and Nicholas J. Mitchell¹

¹ University of Bath

² STFC Rutherford Appleton Laboratory

This article is published in:

book title Proceedings of the Thirteenth International Workshop on Technical and Scientific Aspects of MST Radar
pages 120 - 124
year 2013
editors R. Latteck and W. Singer
publisher Leibniz-Institute of Atmospheric Physics at the Rostock University, Kühlungsborn, Germany
ISBN: 978-3-00-044654-2
url <http://www.iap-kborn.de/>

This version was produced on 31st January 2014.

1 Introduction

Noctilucent clouds (NLCs) form as a result of exceptionally cold (< 150 K) mesopause temperatures at upper-middle and high latitudes during the mid-summer months. They are composed of ice crystals with sizes in excess of ~ 20 nm. In the northern hemisphere, they can often be seen during the twilight hours of June and July at latitudes poleward of $\sim 50^\circ\text{N}$ - see Figure 1 for examples. Records of their appearance at geographically-diverse locations are available thanks to the efforts of a mainly-amateur observing community. Smaller, sub-visible ice crystals play a role in the occurrence of strong Mesosphere Summer Echoes (MSEs), which can be observed by radars operating at frequencies of between 10s and 100s of MHz [Rapp and Lübken, 2004].

The mesopause temperature increases with decreasing latitude and it is relatively close to the frost point at upper-middle northern latitudes, i.e. $50^\circ - 55^\circ\text{N}$. Moreover, the characteristics of both NLCs and MSEs are highly variable at these latitudes. The fundamental aim of this work is to determine whether fluctuations in the mesopause temperature are responsible for the variations in NLC and MSE characteristics. A secondary aim is to determine whether daytime MSE observations can be used to predict whether NLCs are likely to be seen on the following night. This is motivated by the interests of the amateur observers and of the general public, who would like to know in advance which nights are likely to offer the best NLCs.

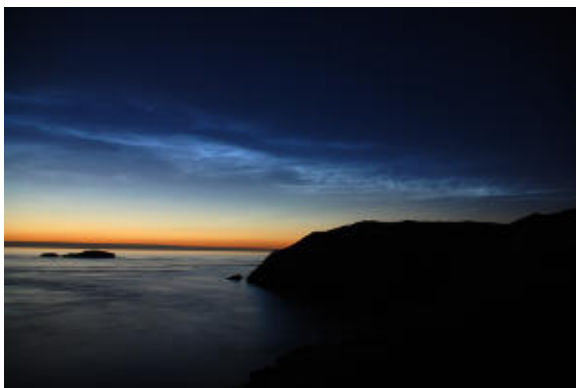


Figure 1: NLCs photographed by John Rowlands from Anglesey, 53.42°N , (left) on the morning of 2nd July 2011 and (right) on the morning of 3rd July 2011.

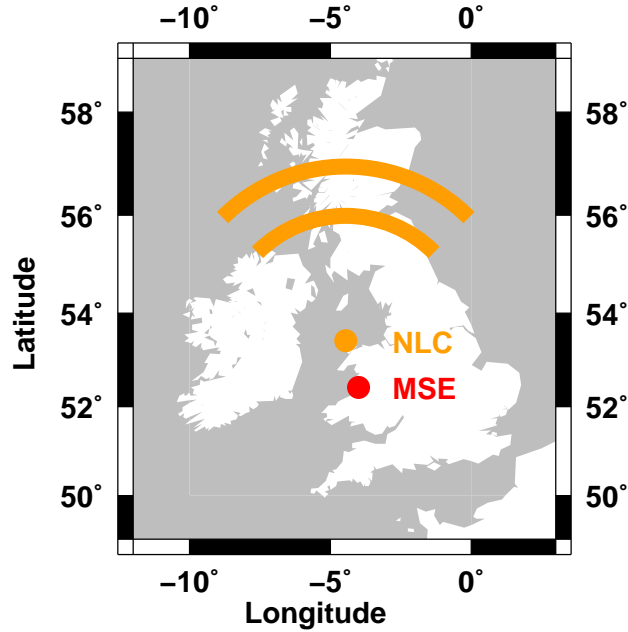


Figure 2: Locations of the Aberystwyth MST Radar (red dot) and of the NLC observation site (orange dot). The inner orange arc represents the potential locations of NLCs with an elevation angle of 15° and the outer arc an elevation angle of 10° .

2 Observations

NLC data from a single observer (Rowlands) are considered here. The observation site (53.42°N , -4.45°E) on Anglesey in North Wales - see Figure 2 - is characterised by low levels of light pollution and flat terrain in all directions. Visual observations were made on a nightly basis during June and July of each year since 2009. Periods for which low-level cloud obscured the sky are represented by vertical orange bands in Figure 3. For the 2010 season, no NLC observations were made after 17th July (day 198) and so the subsequent period has been blanked in the same fashion.

NLCs are typically seen between NW and NE, where they remain illuminated for a considerable period after the Sun has set from the lower atmosphere. Some studies [e.g. *Dalin et al.*, 2011] have considered the brightness of NLCs as the primary variable of interest. Here we consider the maximum elevation angle, which ranges between 2° and 180° i.e. NLCs were seen from the northern to the southern horizon. The inner orange arc in Figure 2 represents a great circle distance of $2.5^\circ/280$ km from the observation site, which corresponds to the median elevation angle of 15° . This assumes an NLC altitude of 82 km. The outer arc represents a great circle distance of $3.6^\circ/400$ km, which corresponds to an elevation angle of 10° . Owing to the large spread in elevation angles, and to the fact that they are more-clustered at the lower end of the range, log10 values are used: 0.5 corresponds to 3.1° , 1.0 to 10.0° , 1.5 to 31.6° , 2.0 to 100.0° , and 2.26 to 180.0° .

The Natural Environment Research Council (NERC) MST Radar at Aberystwyth (52.42°N , -4.01°E) - see Figure 2 - has been making a single Vertical beam observation of the mesosphere once every 5 minutes since April 2005. MSEs are commonly observed during June and July of each year. These are similar in nature to the PMSEs observed at polar latitudes, although their daily integrated durations - see Figure 3 - are considerably shorter [*Bremer et al.*, 2006]. This is assumed to be the result of the facts that the mesopause is not subject to continuous daylight at these latitudes and that its temperature is relatively close to the frost point.

Daily temperature data are taken from the University of Bath's (SKYiMET) meteor radar at Esrange in Northern Sweden (67.89°N , 21.08°E). Clearly there is a large (> 2000 km), principally-meridional separation between this and the other two sites, which are only 115 km apart. Consequently, the measured temperatures are expected to be significantly lower than those for the latitudes of interest. Nevertheless, it is known

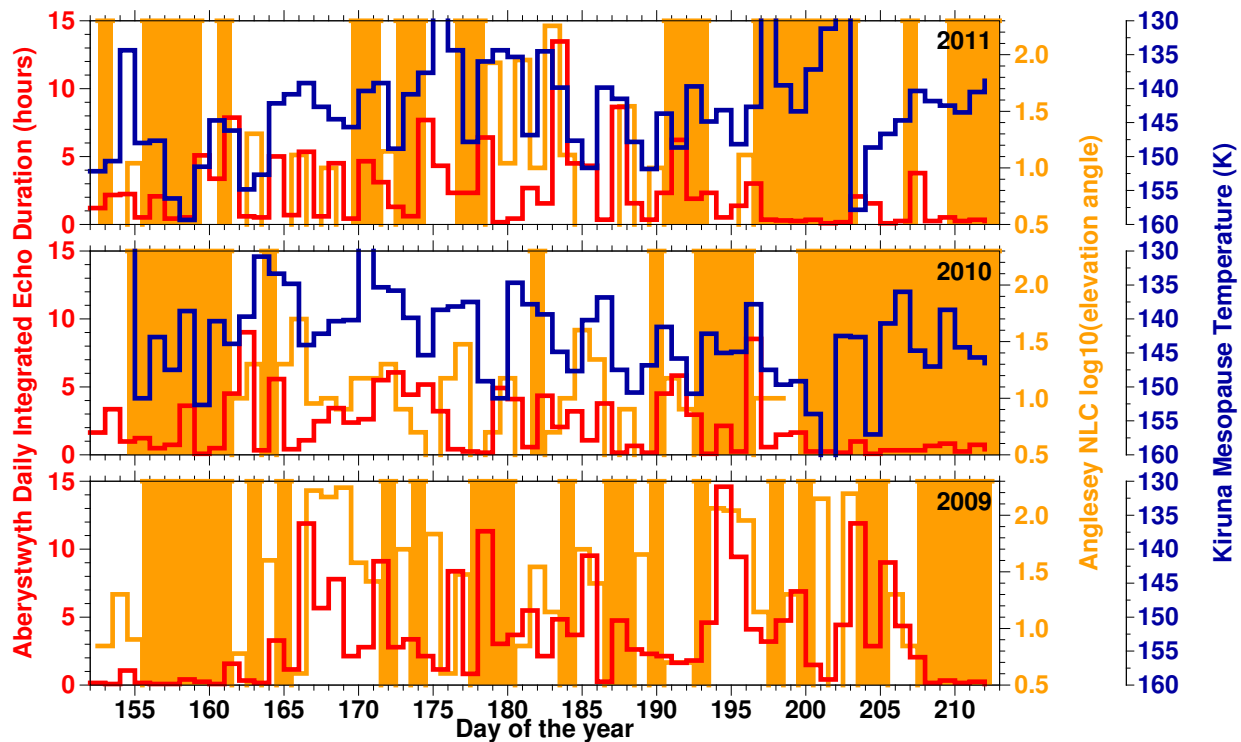


Figure 3: Time series of daily integrated echo duration (red), \log_{10} (NLC elevation angle) (orange), and temperature (blue). Note the inverted temperature axis. Orange bands represent periods when no NLC observations could be made. Tick marks represent 00:00 UT for days in the range between 1st June and 31st July.

that planetary waves - such as the wavenumber 1, westward-propagating, (W1) 5-day wave, whose period actually varies between 4 and 7 days - play a significant role in modulating the temperature of the upper mesosphere. The power spectrum of Kiruna data for 2011, shown in Figure 4, contains significant activity within this range (although this alone does not prove the existence of planetary wave activity). Modulations in NLC occurrence/brightness and in MSE occurrence at polar latitudes have been linked to such wave activity [e.g. *Kirkwood et al., 2001*]. The zonal separation of 25° between the meteor radar and the other two sites implies a phase difference of just 8 hours in the context of a W1 planetary wave with a period of 5 days.

3 Results and Further Work

The correlation coefficient of -0.48 between \log_{10} (NLC elevation angle) and temperature suggests that the Kiruna measurements have value in trying to understand the NLCs observed from the British Isles. Admittedly, this is based on a relatively small set of samples. The correlation coefficients between echo duration and temperature (-0.18) and between echo duration and \log_{10} (NLC elevation angle) (0.26) are not so good. Nevertheless, it can be seen from Figure 3 that the relatively rare echoes with durations in excess of 10 hours are associated with large NLC elevation angles, either on the previous or on the following night. This analysis is currently being extended with more-geographically-localised mesopause temperature data from the MLS instrument on-board the Aura satellite.

4 Public Engagement through NLC studies

During 2010, BBC Radio 4's "*Material World*" science programme aimed to promote the popular understanding of science using a contest format known as "*So You Want To Be A Scientist?*". John Rowlands' NLC project was one of four proposals selected from over 1300 entries. Nicholas Mitchell acted as John's mentor.

Through this radio production, the subject of NLCs was brought to the attention of an enormous popular

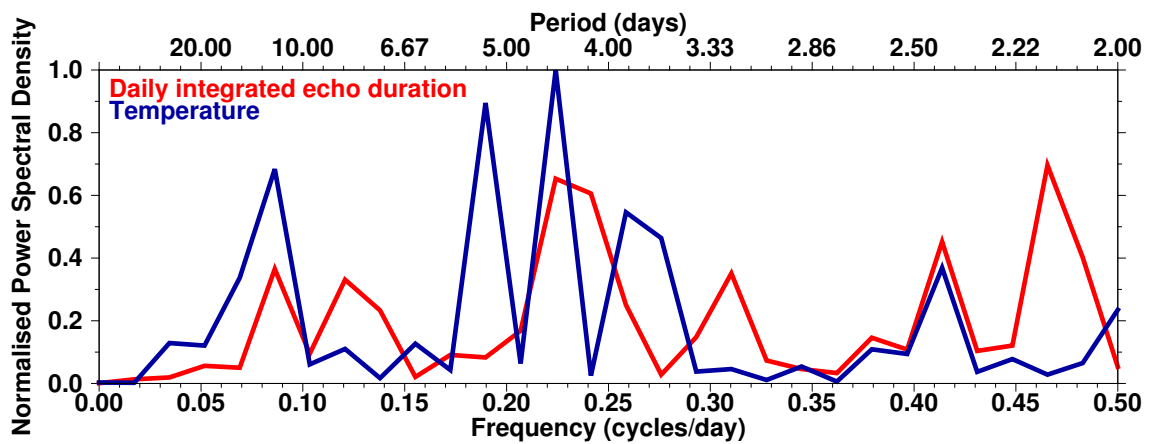


Figure 4: Power spectra for the period 4th June - 31st July 2011. The lowest frequency components have been removed by subtracting a 15 day running mean from the samples in the time domain. Power spectral densities have been normalised so that the total powers are equal for the temperature (blue) and radar echo (red) data.

audience. An “audio slide show”, featuring images of NLCs set to a narrative sound-track, generated over 1 million unique hits within the first few hours of its release. It remained the most-viewed item on the BBC website for the greater part of a week. Several British newspapers and magazines subsequently published features on NLCs. Moreover, the Japanese broadcaster NHK made an entire programme on the subject. This featured interviews with both John and Nicholas.

The possible influence of human activities on the remote mesosphere was of particular interest to the BBC audience. The ease with which anyone including those living under heavily light-polluted skies can observe NLCs was another attraction.

John has been systematically observing, and photographing, NLCs since 2008. This was initially motivated by the lead-up to solar minimum and the possibility that there might be corresponding increases in NLC occurrence and extent. John is also keen to improve the scientific-usability of the NLC observations that are submitted to amateur observation websites, which do not filter for the reliability of the submitted data. He has set up Facebook pages for the 2011, 2012, and 2013 seasons - see e.g. <http://www.facebook.com/NoctilucentClouds2013>.

The nocturnal observing schedule is extremely demanding and leads to the loss of approximately 120 hours of sleep each summer! Consequently John hopes to set up a series of automatic cameras. One is planned for the Falkland Islands in attempt to improve the detection of NLCs in the southern hemisphere. This will be carried out with the kind assistance of IRF-Kiruna and the British Antarctic Survey.

References

- Bremer, J., P. Hoffmann, J. Hoffner, R. Latteck, W. Singer, M. Zecha, and O. Zeller, Long-term changes of mesospheric summer echoes at polar and middle latitudes, *J. Atmos. Sol.-Terr. Phys.*, 68, 1940–1951, doi:10.1016/j.jastp.2006.02.012, 2006.
- Dalin, P., et al., A comparison between ground-based observations of noctilucent clouds and aura satellite data, *J. Atmos. Sol.-Terr. Phys.*, 73, 2097–2109, doi:10.1016/j.jastp.2011.01.020, 2011.
- Kirkwood, S., V. Barabash, B. U. E. Brändström, A. Moström, K. Stebel, N. Mitchell, and W. Hocking, Noctilucent clouds, PMSE and 5-day planetary waves: A case study, *Geophys. Res. Lett.*, 29(10), 1411, doi:10.1029/2001GL014022, 2001.
- Rapp, M., and F.-J. Lübken, Polar mesosphere summer echoes (PMSE): review of observations and current understanding, *Atmos. Chem. and Phys.*, 4, 2601–2633, 2004.