

Variations in the Area of the Global Field of Noctilucent Clouds of the Northern Hemisphere in 2007–2012 Seasons

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Abstract—Using daily distributions of noctilucent cloud fields obtained for 2007–2012 by the AIM satellite, we analyzed temporal changes in the area of the global field of mesospheric noctilucent clouds. These clouds have been shown to be characterized by some common features that can be approximated mathematically by simple functions reflecting the seasonal course of the temperature and humidity regime of the high-latitude mesosphere, allowing a clear physical interpretation. We discuss the specific features of changes in the cloud field area for individual seasons.

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1. INTRODUCTION

Noctilucent clouds and their high-latitude analog (polar mesospheric clouds), which form the polar cap over the appropriate hemisphere, are characterized by strong variability manifested on time scales of dozens of minutes to dozens of years. This and many other properties of mesospheric noctilucent clouds (MNCs) can be studied on the basis of space-based observations of the global field of mesospheric cloudiness. Specifically, in an analysis of long-term data obtained by the AIM satellite on the characteristics of the MNC field in the northern hemisphere, we showed that there are no fundamental differences in the features of noctilucent clouds observed from the Earth and polar mesospheric clouds observed from space (Solodovnik and Kudabaeva, 2011). It is generally accepted practice to use a combined approach to studying these objects, which differ mainly by the latitude of their manifestation (Gadsden and Schröder, 1989).

This goal of this study was to reveal properties of the global MNC field on the basis of space data obtained by AIM satellite instruments on the field of noctilucent clouds of the Earth's northern hemisphere (Russell et al., 2009). For example, the seasonal course of the activity of MNCs and their area are mainly controlled by the temperature and humidity of the upper mesosphere. According to data on ground-based observations of MNCs, the bulk of MNCs in the northern hemisphere was recorded in June and July, with a maximum of the long-term curve in the first half of July (Fogle and Haurwitz, 1966). However, this conclusion may be distorted by the effect of seasonal changes in MNC illumination and weather conditions. Some satellite data on seasonal changes in the frequency of occurrences of MNCs at latitudes of 60°,

65°, and 70° N can be found in (DeLand et al., 2006) and, without differentiation into latitudinal belts for individual years, in (Rong et al., 2012).

2. DESCRIPTION OF OBSERVATIONAL DATA

To solve this problem, we conducted a detailed analysis of daily distributions of the field of noctilucent clouds (often called daisies) obtained by the CIPS onboard instrument operating in the ultraviolet range. The array of these distributions for all the years since the launch of AIM (2007) is freely accessible and updated with the data for each subsequent season at the special-purpose website <http://aim.hamptonu.edu>. An example of such a distribution is shown in Fig. 1.

This paper analyzes the data on daily distributions for the latitudinal belt of 50–80° N during the summer seasons of 2007–2012. According to observational conditions (Fig. 2), these distributions correspond to the narrow range of local solar time (22–24 h for 50°–80°) and the slightly wider range of 18–24 h for 70°–85°.

The latitudinal limitation from the north is due to the satellite field of view at a given orbital inclination (Fig. 1). The influence of local time scatter in the latter latitudinal belt hardly affects the generality of our findings, because the physical conditions (the influx of solar radiation) here are almost unchanged due to the polar day. With daily accumulation, the distribution data are represented uniformly over all longitudes for the same local solar time interval.

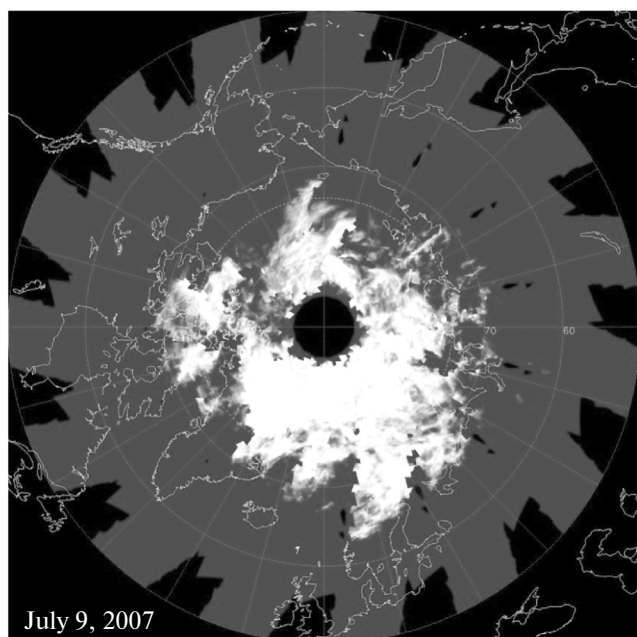


Fig. 1. Images of MNC fields (light points) over the northern polar region of the Earth. <http://lasp.colorado.edu/aim/browse-images.php>.

3. DETERMINATION OF THE MNC AREA AND TEMPORAL CHANGES

The original distributions of MNC fields were processed by a special-purpose program developed in the MathCAD program. The processing made it possible to find the MNC-covered areas, which were expressed as the number of pixels occupied by distributions of cloudiness fields at each date.

The algorithm of this program is as follows. The distributions of MNC fields were transformed into a matrix form. On the basis of distributions, we determined the background, which varies slightly within a single image and for each annual series (actually, by 1–2 at a background level of around 72 relative units). Later, the value of background luminance was subtracted pixelwise (taking into account the variance of its value). We calculated the total number of nonzero

brightness pixels (covered by clouds). The brightness of an individual pixel (~ 100 – 105 relative units), which is critical for distinguishing a cloud from the background, can be confidently applied to the case of developed cloud fields. The identification of MNCs incorporates also the influences of special characters on the distribution maps.

The seasonal indicators of the course of cloud formation intensity during each of the visibility seasons are shown in Fig. 3 and Table 1. Figure 3 shows a summary of plots demonstrating the variation in the area of the MNC field for all seasons of MNC observations recorded by the satellite from 2007 to 2012.

It can be seen from Fig. 3 that the epochs of maximum evolution of the area of cloud fields are close to each other and the dates of these maxima are close to those obtained from ground-based observations long before the launch of AIM (Bronshten and Grishin, 1970; Bronshten, 1984). The date of maximum of noctilucent clouds rather confidently falls on the time interval from July 1 to 15 (Fogle and Haurwitz, 1966). However, despite the seemingly apparent common form of the seasonal course of all plots for 2007–2012, Fig. 3 demonstrates interannual differences as well. Of interest is the season of 2007, when there was a double maximum of the MNC area (Fig. 4). Similar behavior with a double maximum for the same 2007 is demonstrated by the frequency of occurrence of polar mesospheric clouds and the observed mass density of ice by data obtained from the SOFIE instrument on the AIM satellite (Rong et al., 2012).

Similar behavior was also observed in some years from ground-based observations for the frequency of occurrence of noctilucent clouds (Bronshten, 1984; Fogle and Haurwitz, 1966). However, this comparison is not quite strict, because the ground-based observations in the past for sufficiently high latitudes always yielded a double-peak seasonal curve. This resulted from the influence of the period of white nights on observational conditions (Fogle and Haurwitz, 1966).

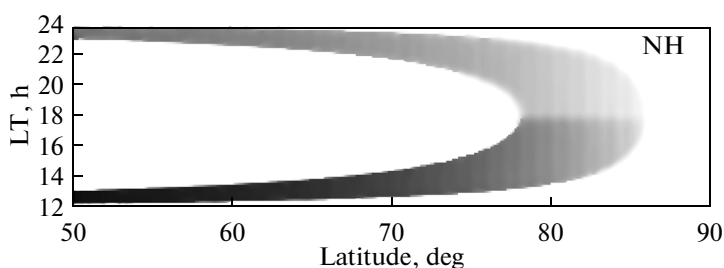


Fig. 2. Data sample from CIPS instrument (local time). Dark and light segments correspond to downward and upward orbits. <http://lasp.colorado.edu/aim/documentation.html>.

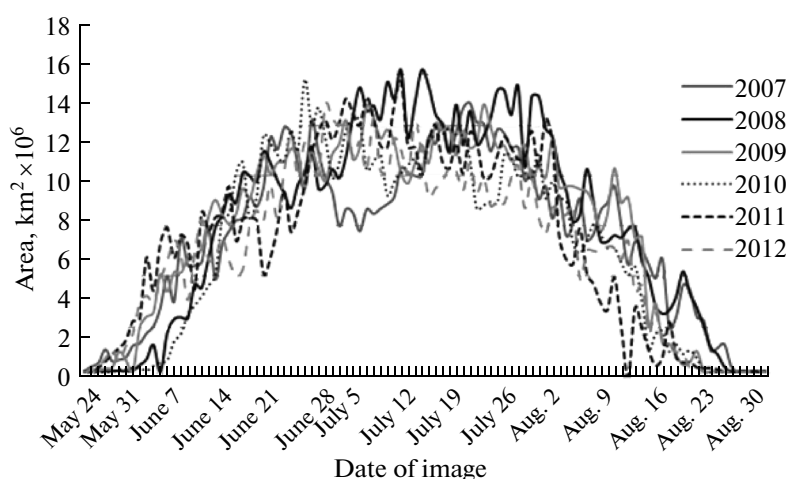


Fig. 3. Superposition of plots of MNC areas from 2007 to 2012.

4. APPROXIMATION OF CHANGES IN THE MNC FIELD AREA AND INTERPRETATION OF THE INVESTIGATION RESULTS

With data on changes in the field area of MNCs in the northern hemisphere, one can try to reveal both common properties and some peculiarities of the formation of noctilucent clouds in seasons when they are visible in different years. The first phase of the investigation was aimed at revealing the most common patterns of variation in the cloud field area for each season. This was conducted with the help of a specially designed program allowing one to choose an approximating function to the plot of change in the cloud field area. Figure 5 shows the results of a parabolic approximation of the evolution of cloud field area for the 2007–2012 season. The criteria for the approximation adequacy involve the minimality of the number of free functional parameters and deviations of the given dependence from it. It turned out that the change in the MNC area can be described by a parabolic function with good accuracy (the averaged approximation error with respect to the maximum area over the seasons does not exceed 9%) for each season and in total. A similar law for the summer season should be applied to the moisture content of the atmosphere at high latitudes of the northern hemisphere because this content is determined by the seasonal change in the thermal energy inflow (Matveev, 1965). These factors become particularly important in the context of a

mechanism that controls the formation of the recurrent field of MNCs over polar areas in summer seasons; here, a significant role is played by convection, which covers not only the troposphere but also the stratosphere and mesosphere. Among the successful attempts to simulate these fields of MNCs on the basis of similar ideas, we can mention the study by Kaidalov et al. (2004).

It should be noted that, unlike the ground-based visual observations of the last century, the plots of MNC fields built on the basis of satellite data are completely different at the beginning and end of their visibility season. Specifically, the noctilucent clouds in the period from March–April to early May as well in September–October mentioned in the survey (Fogle and Haurwitz, 1966) were never found by satellite observations. It should be noted that these findings are completely free from observer subjectivity. In this context, as described in (Fogle and Haurwitz, 1966), the current data seem to be closest to the results that were obtained by Scottish observers and can also be approximated by a parabolic dependence.

According to the obtained results, one can see some (though slight) difference in the length of visibility seasons of MNCs. For example, the first appearance of MNCs early on May 24 was never found. It is this date that can be taken as the conditional reference point on the plots. Table 1 shows the dates of peak evolution of the area of noctilucent clouds obtained from the approximation results.

Table 1. Dates of peak evolution of the area of noctilucent cloud field in seasons of 2007–2012

Observation season	2007	2008	2009	2010	2011	2012
Dates of peaks by plots	June 26 July 19	June 12 July 26	July 4 July 21	June 25	July 9 July 30	June 28
Dates of peaks by approximation	July 12	July 5	July 10	July 2	July 6	July 3

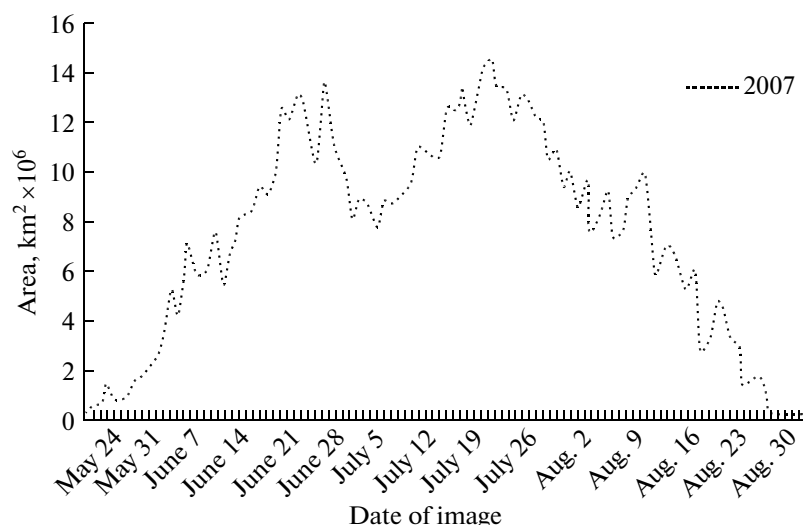


Fig. 4. Plot of MNC area in the season of 2007.

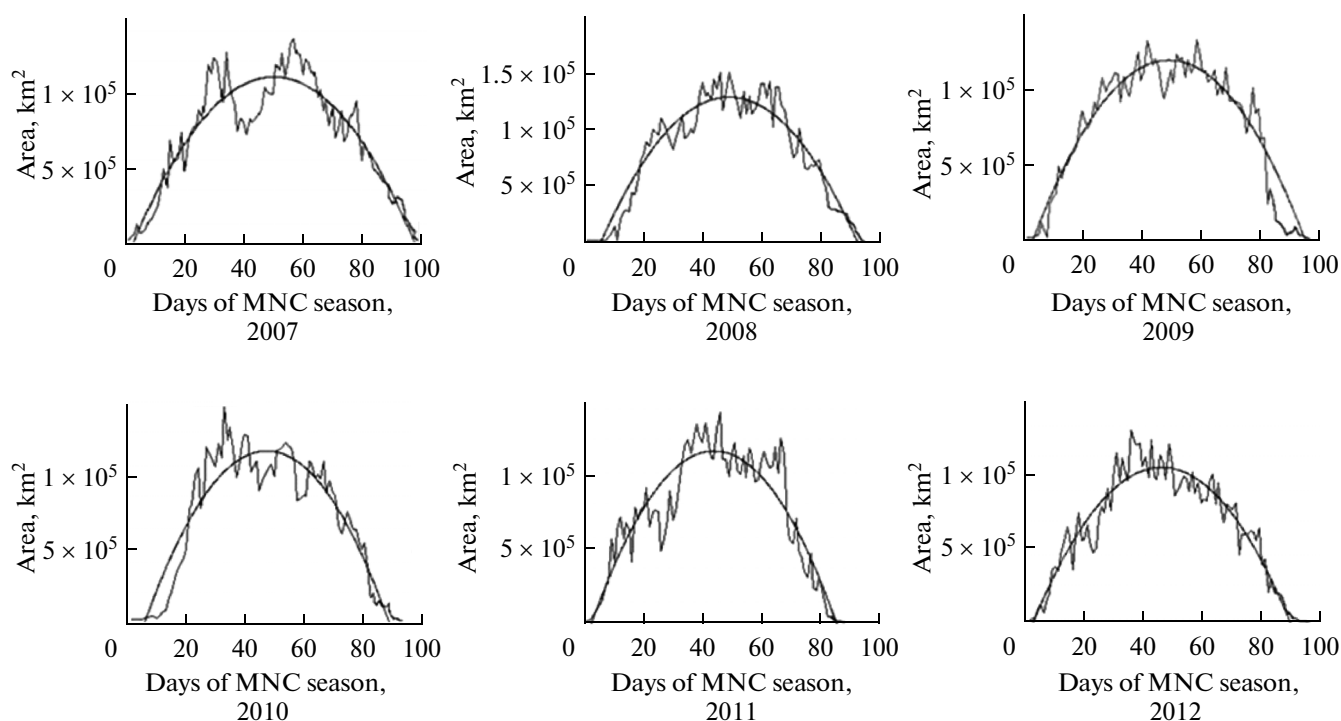


Fig. 5. Results of parabolic approximation of seasonal variations in the area of noctilucent clouds ("0" refers to the initial date of the season: May 24).

The temperature and humidity in the cloud formation area vary by latitude. It is useful to compare their values with the local characteristics of MNCs. This comparison was successfully performed in (Dalin et al., 2011; Rong et al., 2012). The area covered by MNCs is another polar mesospheric parameter that is not directly associated with other MNC parameters measured from satellites (primarily with the frequency of occurrence and albedo of MNCs). Although aver-

aged during the processing over the entire place of their location, the latter two quantities characterize the local properties of MNCs, while the area characterizes the size of the region that is favorable to the existence of MNCs due to its physical properties. However, it is of interest to compare the average long-term curves of the area and frequency of occurrence of MNCs according to data obtained by the same satellite. To ensure the same interval of years and the same

Table 2. Results of comparison between the curves of frequency of occurrence and area of MNCs in seasons of 2007–2010

Parameters of averaged curves for 2007–2010	Dates of peaks	Width of curve at the peak half
MNC area	July 4	70
Frequency of occurrence of MNCs	June 30	81

latitudinal data sample, we used the results of Rong et al. (2012), where the curves of frequency of occurrence of MNCs are presented for seasons of 2007–2010. Accordingly, these curves and the curves of the area obtained in this study were averaged over these four years. The comparison results are summarized in Table 2. It is possible that the slight difference in the dates of peak evolution and effective seasonal width for the two characteristics of MNCs reflects the greater inertia of the area in comparison with the frequency of occurrence of MNCs.

5. CONCLUSIONS

Thus, this paper for the first time presents the results of a study of the temporal change in the area of the global field of MNCs (MNCs in the Arctic) as revealed by satellite observation data for 2007–2012. We have found the following regularity: the course of the given characteristic of the global field of noctilucent clouds in the northern hemisphere is generally parabolic. We have revealed that the difference of changes in the area of observed MNC fields from the approximating function has some individual features in 2007; in this case, the dates of maximal evolution of the cloud field vary slightly from one season to another.

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