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SOFTWARE PROCESSING OF SATELLITE IMAGES OF FIELDS OF NOCTILUCENT CLOUDS TO IDENTIFY THEIR STRUCTURE

Abstract. Noctilucent clouds, which develop in the summer months mainly over the polar regions of our planet, are often observed in temperate latitudes. Moreover, it is these parts of the global field of mesospheric clouds that determine their total area and spatial configuration. As has been shown in a number of previous works, the features of the seasonal and interseasonal evolution of mesospheric cloud fields are largely determined by meteorological processes in the mesosphere. The influence of geophysical fields on their development is also possible.

The work describes the stages of developing a methodology that allows us to move from studying the integral characteristics of mesospheric clouds to its differential characteristics. At the initial stage, it is planned to search for the presence of a longitude structure of such clouds. To do this, 30-degree longitudinal sectors are identified on satellite images of noctilucent clouds fields, within which the cloud area is calculated.

Solving this problem requires the development of specialized software. A significant part of the work is devoted to the describing of the algorithm for constructing the program, choosing a programming language and implementing the task. The effectiveness of the newly created software product is compared with previously implemented approaches. It is shown, that the created technique for processing satellite images will make it possible to identify longitudinal inhomogeneities in the structure of noctilucent clouds global fields with significantly greater accuracy.

Keywords: noctilucent clouds, atmospheric communications, digital images, algorithm, programming languages, processing program, accuracy criteria.

Introduction.

Although noctilucent clouds (NLC), as is known, are an object of study for a number of sciences, but they are of the greatest interest for astronomy and geophysics. This interest was determined by the discovery of the fact of their existence, and subsequently the study of NLC became relevant from the point of view of atmospheric physics and comparative planetology.

These cloud formations are located at altitudes of about 80 km (mesosphere), have a very low moisture content and therefore do not attract the attention of meteorologists. At the same time, the seasonality of their appearance, associated with a change in the nature of atmospheric circulation, the effectiveness of the influence of cosmic factors on the highest layers of the atmosphere and, finally, the presence of similar cloud formations in the atmospheres of other planets, are attractive to specialists in the field of upper atmosphere physics, climatology, planetology [1 - 4].

The unique conditions for observing NLC in the twilight sky and the seasonality of their appearance determined the methods for studying these objects. In particular, the altitude of their location does not allow using the full power of experimental meteorological methods (balloon or aerial sensing). Therefore, the bulk of scientific data about them was obtained

using remote observation methods - ground-based or space monitoring. Of course, observations from space, not limited by meteorological conditions, provide a much larger amount of information compared to ground-based monitoring. One of the most successful missions to study the nature of NLC is associated with the operation of the AIM satellite [5]. Many of the measurement results performed during its implementation are freely available, and their processing makes it possible to identify some of the most important circumstances related to the genesis and evolution of NLC.

Materials and Methods.

The methodology of studying the influence of tropospheric processes on the evolution of NLC in temperate latitudes has proved to be extremely productive. This approach is based on a cartographic analysis of data on the daily dynamics of NLC in the northern hemisphere, correlated to the maximum extent with data on meteorological phenomena occurring at the same time [16-19]. When constructing images of the NLC field, data from the AIM mission was used [5], while meteorological information was received from relevant sources. The analysis of such maps has shown that in most cases there is a relation between the nature of the meteorological events development in the troposphere and the formation of the NLC field features. The main factors influencing mesospheric processes are the following: the movement of cyclones in the zonal direction with the intersection of the Ural Mountains, the meridional (from north to south) movement of cyclones, the development of occlusions and thunderstorm foci, as well as the oncoming movement of atmospheric fronts. These processes are effective sources of density waves (IGW) that reach the mesosphere and influence the temperature regime at significant heights (Figure 1).

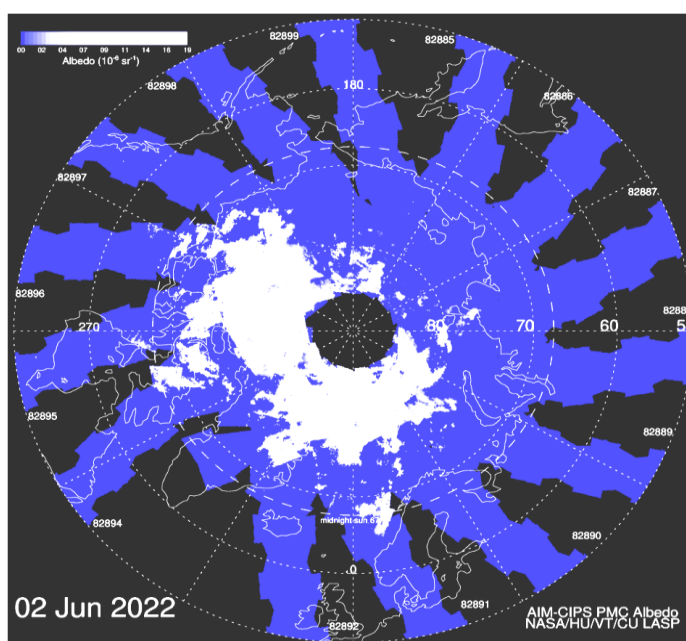


Figure 1 - Synthetic map of noctilucent cloud fields in the northern hemisphere
Obtained by the AIM satellite

Shown results are surface area of the noctilucent clouds for the southern hemisphere (red) and average daily temperatures of the South Pole (blue) for two seasons. Here it is important to note the climatic feature of Antarctica, where temperature changes in the pole region essentially reflect changes in the average temperature for the entire continent. When studying the relationship between temperature changes and changes in the area of the NLC

field in the North Pole region, it is necessary to move from determining the general characteristics of the NLC field to a differential representation, that is, to studying the longitude distribution of mesospheric clouds. But this requires the development of a new software package and processing of a large array of images with its help.

The program must meet the following requirements: the ability to work with an entire array at once, dividing each image in the array into 12 sectors of 30 degrees, calculating the area of the NLC in each of them and saving the result in an Excel table. This functionality allows you to reduce the time for obtaining data necessary for analyzing the development of an object.

Each image is accompanied by a file with data encoded in it, including the area in each pixel. This is necessary to convert the results of the program. The document file is in IDL dataset format. To extract this data, you will need a separate IDL reader program. Since the data of the entire dataset is not needed, it is advisable to create a compact version of the IDL reader that reads only the indicator that interests us.

To check the effectiveness of the developed software package, a control image was created and is shown in figure 2, the required information on which is easily accessible for direct calculation.

The image is represented by a background on which a white square of 100 by 100 pixels is placed. The area of this object is precisely calculated: 10,000 pixels are multiplied by 7.5 sq. km/pixel, which gives a result of 75 thousand sq. km. To eliminate the influence of the background, a complex method was chosen: a combination of threshold filtering, background subtraction and zones of interest.

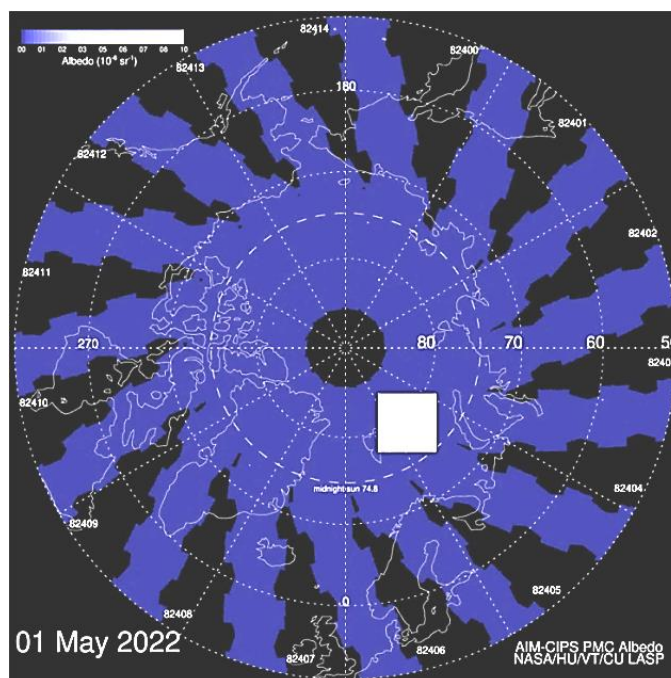


Figure 2 - Control image

Then the program algorithm was set up, as shown further.

1. Setting up GUI for directory selection: *Tkinter* is used to create an interface through which the user can select a directory of images for analysis.

2. Reading the image: using *OpenCV*, the program reads images from the selected directory, then *os* indexes and sorts them.

3. Binarization: *OpenCV* converts images into matrix form and applies threshold filtering.

4. Background subtraction: the absolute difference between the «background» matrix and the target image matrix is calculated.

5. Creating masks: a mask is created that completely covers the image with zero pixels, then a mask is created in the shape of a circle of a certain radius. Inside this mask, based on the angular geometry, masks of individual sectors are created, which in turn cancel the «shading» effect and allow the calculation algorithm to operate within its geometry.

6. Calculation of the sectors area: the number of pixels not covered by «shading» masks is counted and the area covered by the sector is calculated, converting the number of pixels into square kilometers.

7. Saving results: The results of sector area analysis are saved to an Excel file. After which cycle 2-6 is repeated until all images have been processed.

Two functions stand out in the general code. The «*slice_mask*» function accepts image and sector parameters, creating a mask to highlight the area of a particular sector. This is achieved by drawing lines and arcs that define the inner and outer boundaries of the sector. The areas of the image that lie outside the boundaries of the sectors are filled with zeros and excluded from the calculation. The «*calculate_sector_areas*» function applies a background subtraction algorithm, converts the image to binary format and uses masks created by the first function to determine the area of each sector [20].

In mathematical expression, the point search algorithm looks like this:

$$x = (c[0] + r \cdot \cos(\alpha)), \quad y = (c[1] + r \cdot \sin(\alpha)).$$

Where x is a point, c is the center (0 and 1 mean the axes, for each of which the center is determined separately), r is the radius, α is the angle.

Before data can be stored in Excel, it is collected and organized according to a format that is most readable and easy to analyze [19]. To organize the results of sector area measurements, the *DataFrame* method from the *Pandas* library is used. Each row of the *DataFrame* corresponds to one image, and the columns represent individual sectors. The program goes through all the images in the selected directory, analyzes them and fills the *DataFrame* with the received data. To save the *DataFrame* in Excel, the *to_excel* method is used, which is part of the *Pandas* library. This method specifies the path to the file where the data will be saved and the label for the index (index_label='Image'), which provides the addition of descriptive headers for rows in an Excel file.

As a result of executing the algorithm, the user, after a few seconds (depending on the size of the directory), receives an Excel file convenient for analysis with accurate and systematized data on the areas of the analyzed images sectors. For example, Table 1 shows data for two images: a test image and one working image, for June 1, 2020. The cells of the table show the sector areas for the conditional image (Figure 2) and the NLC fields (Figure 1), calculated in square kilometers, according to the described method. For the test image (Figure 2), a nominal value of 75 thousand km² is known.

Table 1 - Results of image processing shown in Figures 2 and 1

	Sectors												Calc. Nom.	
	1	2	3	4	5	6	7	8	9	10	11	12		
Fig.4	14775	6013 5	1103	0	0	0	0	0	0	0	0	0	7601 3	7500 0

Fig. 1	10297 5	6160 5	2764 5	996 0	455 3	2125 5	2024 3	13115 2	12288 8	10729 5	7150 5	10750 5	-	-
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We can compare this value with the calculated sum of indicators for all sectors obtained during the program: 76 thousand km². The observed error of 1 thousand km² (1.3%) may be caused by background scattering when changing images. It is also possible that the error is partially caused by the shot effect, which is characteristic of any discrete objects. The error varies depending on the threshold filtering parameter, but if this parameter is too high, there is a risk of data loss.

Results and Discussion.

Naturally, the main indicator of the practical value of the program can only be the results of processing satellite images of global NLC fields. In our case, we are talking about the seasons of their evolution from 2007 to 2022 (excluding the 2018 season). The lack of data on the AIM mission website for the 2018 summer season is due to technical reasons.

Table 2. Final data on the distribution of the cloud fields area

		Sectors											
		1	2	3	4	5	6	7	8	9	10	11	12
Seasons	2007	122601	124411	126350	124846	<i>121474</i>	129181	128701	137061	128037	122211	130344	135432
	2008	128283	120842	117123	118101	113286	117337	128473	118477	<i>111245</i>	<i>111287</i>	112750	135556
	2009	113429	113032	114379	<i>105623</i>	<i>106856</i>	119411	125047	124442	115057	108336	117975	135387
	2010	123277	126652	123245	118194	<i>113971</i>	126455	126258	130122	118444	<i>113009</i>	119484	130812
	2011	137475	136082	139701	138750	127739	131639	144846	143298	129263	<i>115371</i>	125453	149688
	2012	132468	123818	116832	121792	120925	124937	126614	124328	114381	<i>112243</i>	<i>112557</i>	132203
	2013	133645	123876	127421	127109	125155	133381	141900	137145	124888	<i>122010</i>	127701	146562
	2014	110886	104807	112024	108717	<i>102969</i>	<i>102125</i>	114820	115719	<i>102782</i>	104463	105302	119809
	2015	144096	133663	128889	<i>119840</i>	120822	127821	140253	138878	127618	124345	120545	137663
	2016	115647	98901	100761	100280	106067	105318	110933	119256	94661	96254	<i>88684</i>	100782
	2017	116102	110429	110199	104461	<i>101964</i>	107566	123241	125878	106725	113296	111475	106830
	2019	124333	124859	123104	118423	112784	<i>111894</i>	125015	131895	122845	113811	126065	121269
	2020	128248	134339	130372	123670	123854	127481	128995	146412	122379	<i>112798</i>	132670	132079
	2021	123580	126311	121126	121557	119537	122826	128685	135952	119991	<i>115836</i>	127007	124207
	2022	116016	116254	120530	114892	107116	113135	117100	122985	112432	<i>110530</i>	118948	126343
Aver.		124672	121218	120804	117750	114968	120034	127392	130123	116716	113053	118464	128975
Norm.		1,029	1,000	0,997	0,972	0,949	0,991	1,051	1,074	0,963	0,932	0,979	1,064

In each season, 90 daily pictures were included in the processing, that is, the total number of images studied was about 1350. In this case, the time required was no more than 10 hours. The final data on the distribution of the cloud fields' area, expressed in square kilometers, for 12 longitudinal sectors on average per season are presented in Table 2. The last lines show the average cloud area for all seasons (second line from the bottom) and the same values normalized to the average cloud area in all sectors and for all seasons. Cells corresponding to the maximum cloud field areas in the sector for a given season are highlighted in bold (differences of 1-2% are considered acceptable). Sectors with the minimum area of the cloud field are highlighted in italics and gray shading. The table data indicates the existence of stable trends, that is, sectors with a predominance of maximum or

minimum areas of cloud fields in relation to the average in the sectors. This fact is clearly illustrated in Figure 3, where the differences in the longitudinal structure are shown in the form of a bar graph.

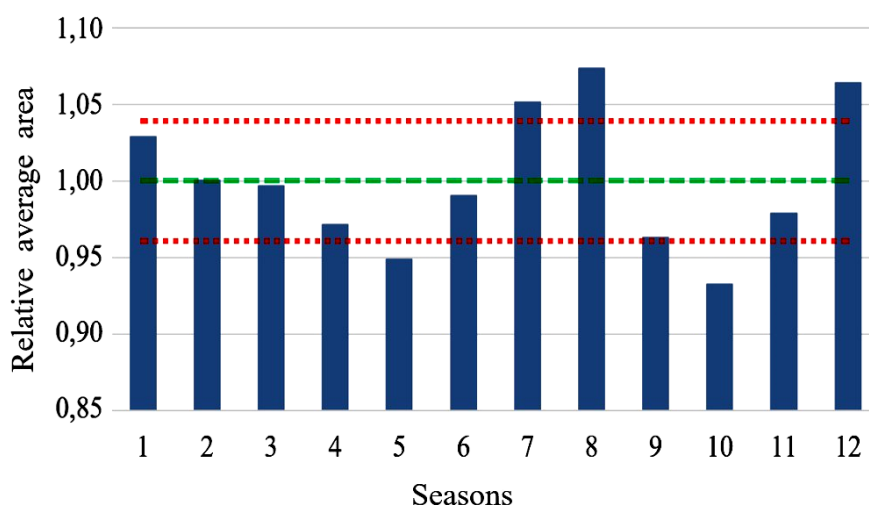


Figure 3 – Distribution of normalized average field area values NLC in the northern hemisphere by longitudinal sectors for all seasons

It should be noted that Figure 3 shows both the average value of the relative area of the cloud field and the maximum deviations of these values, corresponding to a confidence level of 98% (plus or minus triple the root mean square error of the average value). Thus, we can confidently speak about the existence of stable maxima in the development of the cloud field in sectors 7, 8 and 12. At the same time, minimal development of the area of NLC fields is typical for sectors 5 and 10. These facts, in our opinion, deserve further study as it can lead to discovery of new NLC relations with geophysical events or phenomena.

Conclusion.

The developed program is a convenient tool for analyzing longitudinal variations of NLC fields, being a reliable foundation in studies of the connection between various physical processes and the evolution of NLC. The program not only provides accurate data, but also allows you to automate routine image processing, which speeds up data analysis and improves its quality.

Acceptable accuracy has been achieved when processing working arrays. Distortions in the result caused by background dispersion create an insignificant error and, in the future, can be eliminated using machine learning algorithms or background subtraction methods. The structure of the program and its development environment are flexible enough to allow modification in the future. As an advantage over analogues, we can highlight the fact that the version from the current work, if necessary, can be provided with an executive file and a compact directory with the necessary libraries, which will allow it to be used with a minimum of presets.

Using the created program, a general analysis of the satellite images array of the northern hemisphere global NLC field was carried out over a long period of time. The results obtained reliably indicate the presence of longitude sectors with statistically significant differences in the development of mesospheric clouds. This suggests the need to continue research in this direction.

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ТҮНГІ БҰЛТ ӨРІСТЕРІНІҢ СПУТНИКТІК СУРЕТТЕРІН ОЛАРДЫҢ ҚҰРЫЛЫМЫН АНЫҚТАУ ҮШІН БАҒДАРЛАМАЛЫҚ ӨНДЕУ

Аңдатпа. Жаз айларында негізінен планетамыздың полярлық аймақтарында дамидын түнгі бұлттар қоңыржай ендіктерде жиі байқалады. Сонымен қатар, мезосфералық бұлттардың ғаламдық өрісінің дәл осы бөліктері олардың жалпы ауданы мен кеңістіктік конфигурациясын анықтайды. Алдыңғы бірқатар еңбектерде көрсетілгендей, мезосфералық бұлт өрістерінің маусымдық және маусымаралық эволюциясының ерекшеліктері көбінесе мезосферадағы метеорологиялық процестермен анықталады. Геофизикалық өрістердің олардың дамуына әсері де мүмкін.

Жұмыста мезосфералық бұлттардың интегралдық сипаттамаларын зерттеуден оның дифференциалды сипаттамаларына көшуге мүмкіндік беретін әдістеменің даму кезеңдері сипатталған. Бастапқы кезеңде мұндай бұлттардың бойлық құрылымының болуын іздеу жоспарлануда. Ол үшін түнгі бұлт өрістерінің спутниктік суреттерінде 30 градустық бойлық секторлар анықталады, олардың шегінде бұлт аймағы есептеледі.

Бұл мәселені шешу мамандандырылған бағдарламалық жасақтаманы әзірлеуді талап етеді. Жұмыстың едәуір бөлігі бағдарламаны құру алгоритмін сипаттауға, бағдарламалау тілін тандауға және тапсырманы орындауға арналған. Жаңадан құрылған бағдарламалық өнімнің тиімділігі бұрын енгізілген тәсілдермен салыстырылады. Спутниктік суреттерді өңдеудің құрылған әдістемесі түнгі бұлттардың

ғаламдық өрістерінің құрылымындағы бойлық сәйкессіздіктерді едәуір дәлдікпен анықтауға мүмкіндік беретіні көрсетілген.

Түйінді сөздер. түнгі бұлттар, атмосфералық коммуникациялар, сандық кескіндер, алгоритм, бағдарламалау тілдері, өңдеу бағдарламасы, дәлдік критерийлері.

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ПРОГРАММНАЯ ОБРАБОТКА СПУТНИКОВЫХ СНИМКОВ ПОЛЕЙ СЕРЕБРИСТЫХ ОБЛАКОВ С ЦЕЛЬЮ ОПРЕДЕЛЕНИЯ ИХ СТРУКТУРЫ

Аннотация. Серебристые облака, которые образуются в летние месяцы в основном над полярными регионами нашей планеты, часто наблюдаются в умеренных широтах. Более того, именно эти части глобального поля мезосферных облаков определяют их общую площадь и пространственную конфигурацию. Как было показано в ряде предыдущих работ, особенности сезонной и межсезонной эволюции мезосферных облачных полей в значительной степени определяются метеорологическими процессами в мезосфере. Также возможно влияние геофизических полей на их развитие.

В работе описаны этапы разработки методологии, позволяющей перейти от изучения интегральных характеристик мезосферных облаков к их дифференциальным характеристикам. На начальном этапе планируется поиск наличия долготной структуры таких облаков. Для этого на спутниковых снимках полей серебристых облаков выделяются 30-градусные продольные сектора, в пределах которых рассчитывается площадь облачности.

Решение этой задачи требует разработки специализированного программного обеспечения. Значительная часть работы посвящена описанию алгоритма построения программы, выбору языка программирования и реализации поставленной задачи. Эффективность вновь созданного программного продукта сравнивается с ранее реализованными подходами. Показано, что созданная методика обработки спутниковых снимков позволит со значительно большей точностью выявлять продольные неоднородности в структуре глобальных полей серебристых облаков.

Ключевые слова: серебристые облака, атмосферные зависимости, цифровые изображения, алгоритм, языки программирования, программа обработки, критерии точности.

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