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STUDY OF CIRRUS CLOUDS PHYSICAL PROPERTIES USING THE LIDAR-DUSTER SYSTEM AND RADIOSOUNDING DATA AT NATAL/RN- BRAZIL

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Abstract: *Cirrus* clouds are classified as the highest clouds in the atmosphere occurring generally from 7 to 18 km, depending on the global region of appearance, and have necessarily ice crystals in their composition. They still have an uncertain influence role in climate, therefore are seen as important atmospheric elements to be studied. Lidar systems (*LIght Detecting and Ranging)* have shown efficiency in the collection of cirrus characteristics which can help in its better parameterization in climatic and atmospheric models. In this work a collection of physical characteristics of cirrus was carried out, for January and February of 2017 and 2018, at Natal's atmosphere using Lidar DUSTER's data (5.84 S 35.20 W), a partnership UFRN/IPEN-SP. Morphological patterns of that clouds have been observed according to its heights as well as variations. Clouds with thinner depths and tenuous are observed at the top regions of troposphere, around 16.0 km. Otherwise, clouds with bigger vertical extensions are found around 12.0 km. The height of occurrence of cirrus in Natal, for the considered period vary from a minimum height of 7.0 km to a maximum of 16.0 km. Cirrus clouds most frequently occurred at a medium height of 12.0 km, considering both years. Those clouds had a considerable representativeness over the city atmosphere corresponding to 67% of total Lidar measured days. Besides the Lidar system was also used data from radiosounding technique. The behavior of the meteorological variables such as relative humidity was analyzed for the regions in which were found cirrus by the Lidar DUSTER. Within the region limits was verified a significant increase of relative humidity values. This behavior is not observed in lower regions where there is not any clouds presence as well in a day without cirrus appearance. In addition, future analyzes of the potential equivalent temperature profile will be studied in order to verify the effect of the cirrus clouds occurring in the temperature and humidity profile in a combined manner. Also, is expected to evaluate the possible impacts of cold air intrusion of the stratosphere in layers of cirrus clouds. In conclusion, Lidar DUSTER data demonstrates to be efficient in the identification of cirrus clouds over Natal's atmosphere contributing to a better comprehension of its behavior and role in the region of study.

Keywords: *Cirrus* clouds, Lidar-DUSTER, Radiosounding.

INTRODUCTION

Cirrus clouds are those found at the highest regions of the troposphere. They have a fibrous visual appearance and their height can vary generally between 7 and 18 km, depending on the region of the globe (SEINFELD; PANDIS, 2016). They have ice crystals in their composition and can be found at temperatures well below the freezing point necessary for homogeneous nucleation of water which is -41 ° C (LYNCH et al., 2002). It is known that clouds, in general, have an important influence on the terrestrial radiative balance. According to Chen, Chiang and Nee (2002), cirrus-like high clouds have both the ability to absorb long-wave radiation returning from the earth's surface and to reflect short-wave radiation from the sun. Therefore, a better understanding of the interference factors responsible for the balance between the warming and cooling of the atmosphere caused by these clouds is necessary. Characterization studies of the optical and physical properties of cirrus clouds are important in order to facilitate the understanding of their degree of influence on the climatic aspects on Earth. The Lidar remote sensing system allows the collection of information from the atmospheric vertical structure with high spatial and temporal resolution (WEITKAMP, 2005) and, therefore, is seen as an important tool in the studies of these clouds. The Lidar system, named DUSTER, installed in a container in Natal at the Federal University of Rio Grande do Norte contributes as a tool of extreme importance for the study of these clouds for the region. At the same time, relative humidity data obtained from radiosoundings released by the *Centro de Lançamentos Barreira do Inferno* were essential to allow the comparison with lidar data, reinforcing the validity of the Lidar product to study cirrus and vice versa. Thus, for the first time, a survey and discussion of the physical properties of cirrus clouds over Natal's atmosphere is carried out. This study intends to be the first step to further researches which may include not only macrophysical aspects but microphysical and optical properties of these clouds which are important parameters to enhance climatic models for the region.

METHODS

The Lidar DUSTER

The Lidar DUSTER system was installed in the city of Natal in January 2016 and began to be officially operated in the month of February of the same year. The DUSTER installation is done via a collaboration between the Center for Lasers and Applications (CLA) of the Nuclear and Energy Research Institute (IPEN) and the Federal University of Rio Grande do Norte (UFRN). The laboratory is located in a container at the Federal University of Rio Grande do Norte - Campus Natal Central, in the Department of Atmospheric and Climatic Sciences (5.84 S 35.20 W). Such a container allows the opening of a window in the ceiling through which the laser beam from Lidar is directed to the atmosphere for data collection of atmospheric profiles. The Laboratory can be seen at Figure 1 below:

Figura 1 – DUSTER Laboratory. Department of Atmospheric and Climatic Sciences of UFRN, Campus Natal - Central (5.84 S 35.20 W). *Source: The author's collection.*

Figure 2 presents the DUSTER Lidar system in operation. One can observe the main components of the DUSTER system which includes: the transmitter part consisting of the laser source(1), the beam expander *BMX* (2) - a device used to decrease the divergence of the laser - and a small mirror (3) that directs the laser into the atmosphere, all on the same axis of direction; the receiving part, consisting of a Cassegranian type telescope (4); the detector part (5), located just below the telescope, consisting of a box of sensors which select the wavelengths and polarization state of interest of the collected light; the data acquisition system, *Licel* (6) and the control box (7). The data logging, storing, and processing part is performed by the operator on a computer with specific softwares (located near the system but not shown in the picture).

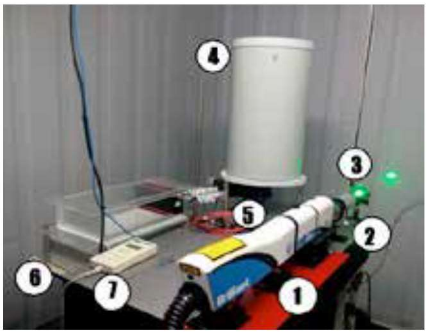

Figura 2 – Lidar DUSTER system in operation and its main components. *Source: The author's collection.*

Data Analysis

The data collected by the DUSTER system is so-called raw data. These data represent measures of the total backscatter signals from the interaction of the radiation emitted by the laser pulse with the atmospheric constituents, mainly molecules and particles. A pre-processing and processing data is done to get the final products as showed in the flow chart of Figure 3 below

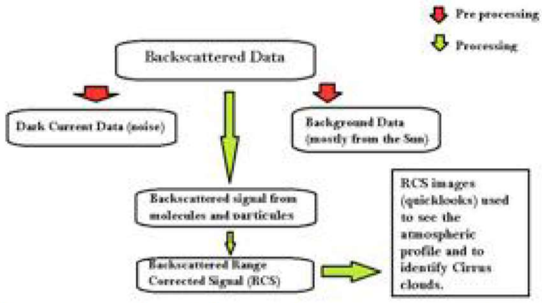

Figura 3 - Flow chart of the main data processing steps. *Source: Author.*

The dark current and background signals are removed in a pre-processing step so that only the signal of the backscatter of the particles and molecules remains in the vertical profile of the data (SILVA RIQUELME, 2015) which is corrected by the square of the distance to obtain the final products - the so called Range Corrected Signal (RCS) graphs. These steps are done using the LIdar RAnge COrrected Signal algorithm - LIRACOS, developed by IPEN's Laser Environmental Applications Laboratory and adapted by the UFRN research group once this methodology can be used for the different contexts in which applies, and in this case for Natal's data to obtain false-color graphics of the corrected signal for further interpretation and identification of cirrus clouds. The interpretation of the graphs is based on the analysis of the backscatter signal intensities represented by different colors on an arbitrarily defined scale. The final result/product is evidenced in the image plotted, in which is possible to identify the regions of greater and lesser intensity of the signal according to the respective colors defined. Thus, the final image will represent the temporal distribution of the atmosphere, retrieved by the vertical intensity profile of the total backscattered signalThe RCS images provides the so-called courtain plots of the atmosphere, which is possible to identify the Atmospheric boundary layer and also clouds of the Cirrus type.

The measurement period considered for this study comprises data from two measurement campaigns carried out in Natal named MOnitoring campaign LOng-range Transportation OVer Natal I and II (MOLOTOV I and MOLOTOV II). The months of January and February of 2017 and 2018 were used from the respective campaigns. The data analysis was divided as follows:

1) Block I:
Corresponding to MOLOTOV I and II for afternoon period (from 14 and 18 hours, local time, varying within the range): Survey of the physical characteristics of the clouds with the definition of minimum, maximum and average heights, frequency of occurrence and morphology analysis comparing the same period for both campaigns.

2) Block II:
Only MOLOTOV I data was used for its morning period (from 09h to 11h30, local time). The purpose was to compare DUSTER data with Radiosounding data which is released at the nearest to Lidar measurements (09h local time) similar to what was done by Gouveia, Barbosa and Barja (2014). This allows the investigation of correlation between cirrus physical characterization with vertical profiles of relative humidity collected by the radiosondes.

FINDINGS AND ARGUMENT

In a total 77 days were processed for both blocks from which 52 days presented cloud of the Cirrus type. This corresponds to approximately 68% of the days, a significant value over the data. From these 52 days, 35 corresponds to Block I and 17 to Block II which are analysed as follows.

Block I: Survey of physical characteristics of cirrus clouds in Natal

Figures 4 and 5 are quicklooks also named RCS graphs, obtained from the DUSTER's processed data which shows the minimum and maximun heights (emphasized by the red lines) identifyed for cirrus for the total period of data (MOLOTOV I + MOLOTOV II). This was carried out for the total data to account for physical properties of cirrus on the vertical profile. These two figures were chosen from all graphics to exemplify the final product from which is possible to see the cirrus signal in the vertical profile as a cyan colour in both graphs.

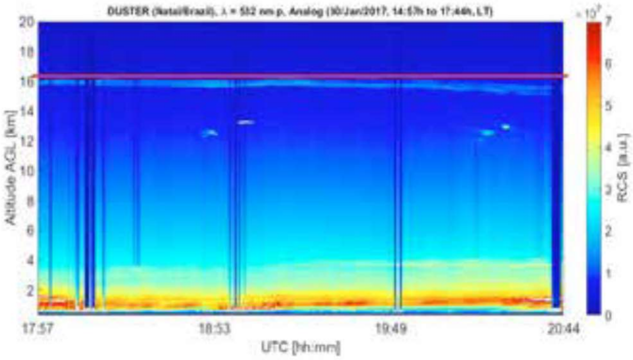

Figure 4 - RCS graphic showing the maximum height of cirrus over Natal on 30 January 2017, around 16.0 km (red line at the top of the cloud). MOLOTOV I. *Source: Author.*

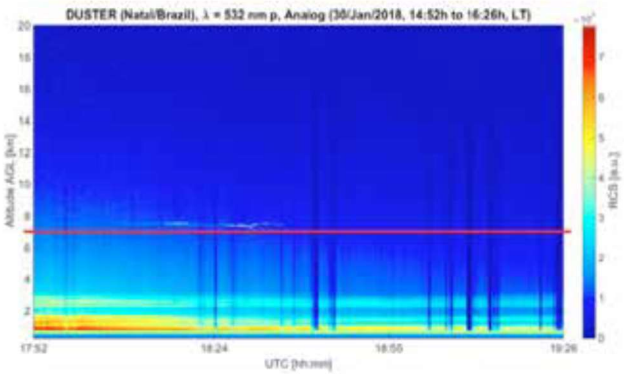

Figura 5 - RCS graphic showing the minimum height of cirrus over Natal on 30 January 2018, around 7.0 km (red line at the bottom of the cloud). MOLOTOV II. *Source: Author.*

In terms of morphology, it was possible to observe a similar morphological behaviour of the cirrus according to the time they were observed in the MOLOTOV I campaign. When they are observed in higher heights, at the top of the troposphere, they have finer, thin and dispersed thicknesses, with less intense backscatter signal; whereas when observed at medium heights they generally present large extensions, thicknesses and high density, returning a much more intense backscatter signal. An example of these two main morphology patterns can be seen in Figures 6 and 7 as follows.

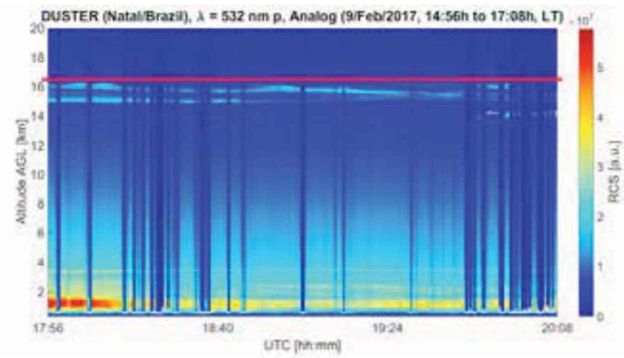

Figure 6 - RCS graphic showing a typcial cirrus cloud shape at higher altitude over Natal on 09 February de 2017, maximun height around 16.0 km (red line at the top of the cloud). MOLOTOV I. *Source: Author.*

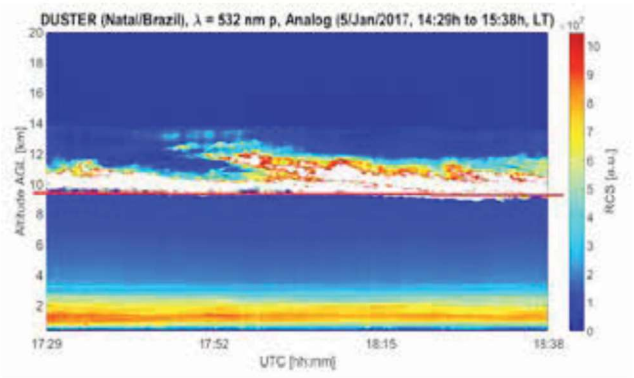

Figura 7 – RCS graphic showing a typcial cirrus cloud shape at medium altitude over Natal on 05 de Janeiro de 2017, minimun height around 10.0 km (red line at the bottom of the cloud). MOLOTOV I. *Source: Author.*

In general, it is possible to say that, during the MOLOTOV I campaign in its afternoon period, there was a considerable presence of cirrus clouds over the city's atmosphere. They covered more than half of the data collected for the two months, representing 74% of the entire campaign, corresponding to 23 days out of 31. MOLOTOV II presented a wider variation of morphology. Examples of this varied morphology can be seen at Figure 8, 9 and 10.

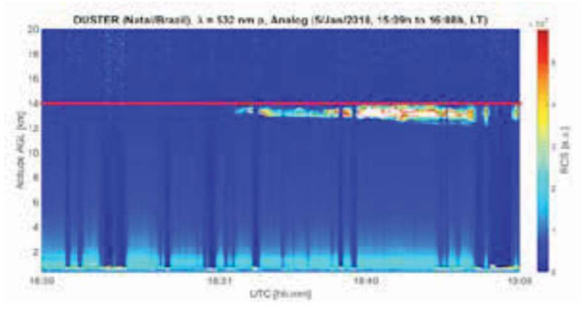

Figura 8 - RCS graphic showing morphological variation of cirrus over Natal on 05 de Janeiro de 2018, the maximun height is around 14.0 km (red line at the top of the cloud). MOLOTOV II. *Source: Author*

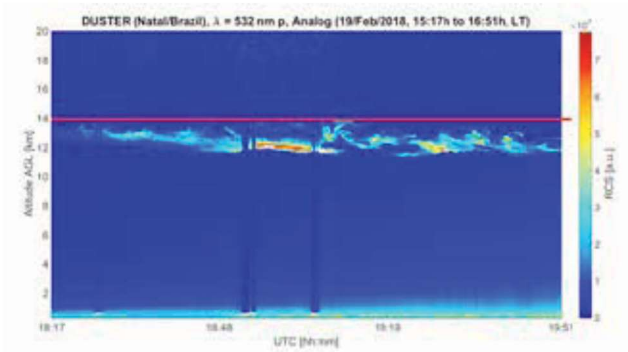

Figure 9 - RCS graphic showing a morphological variation of cirrus over Natal on 19 February 2018, the maximum height is around 16.0 km (red line at the top of the cloud). MOLOTOV II. *Source: Author.*

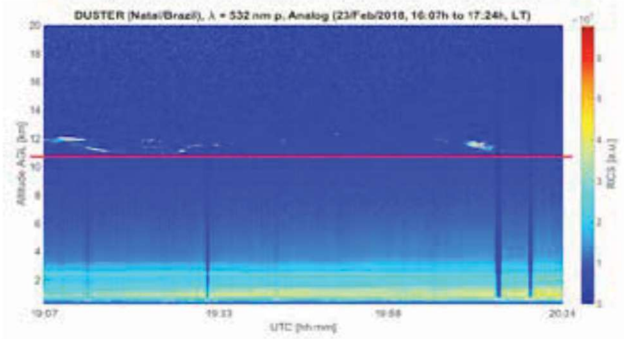

Figure 10 - RCS graphic showing a morphological variation of cirrus over Natal on 23 February 2018, minimun height around 11.0 km around (red line at the bottom of the cloud). MOLOTOV II. *Source: Author.*

The second campaign presented a smaller number of cirrus occurrences than its previous which corresponded to 57% of the total number of days, accounting for 12 days out of 21. Despite this, the presence of cirrus is still considerable once it corresponds to more than half of the total measurements.

Below at Figure 11 is the graph of frequency of cirrus average heights for total period of data.

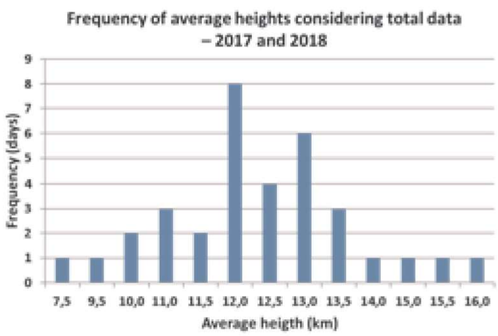

Figure 11 - Frequency chart of average cirrus occurrences in Natal for the total of the two campaigns corresponding to Block I. *Source: Author.*

As can be seen in Figure 11, the more frequent average height of occurrence of cirrus within the period of the two campaigns is around 12.0 km. Thus, it can be said that for the afternoon of January and February at Natal's atmosphere will be more likely to observe cirrus at an average height of approximately 12.0 km.

The chart 1 shows the summary of results, the main findings and physical parameters obtained related to Cirrus occurrence over Natal's Atmosphere for the First Block of data.

Chart 1 – Summary of results

DESCRIPTION	AFFTERNOON		
	MOLOTOV I (2017)	MOLOTOV II (2018)	TOTAL
LIDAR MEASUREMENTS DAYS	31	21	52
MEASURED DAYS WITH CIRRUS	23	12	35
% DAYS WITH CIRRUS	74%	57%	67%
MINIMUN HEIGHT OF CIRRUS OCURRENCE	8,0 km	7,0 km	7,0 km
MAXIMUM HEIGHT OF CIRRUS OCURRENCE	16,0 km	14, 0 km	16,0 km
AVERAGE HEIGHTS OF CIRRUS OCCURRENCE	12,6 km	11,6 km	12,3 km
MORE FREQUENT AVERAGE HEIGHT	13, 0 km	12,0 km	12,0 km

Source: Author.

Cirrus demonstrated to have a considerable percentage of appearance over the data correspodning to 67%. Its minimum height, considering its bottom, was 8.0 km for MOLOTOV I and 7.0 km for MOLOTOV II and its maximum height, considering its top, ocurred at 16.0 km and 14.0 respectively. The average height of ocurrence were similar for both campaigns as well as its more frequent average height basically around 12km.

Block II: Association of DUSTER data with radiosounding data

To compare the height of cirrus with the meteorological variable of relative humidity corresponding to these heights, the days with more expressive presence of cirrus in the two months of the campaign were selected. Data from January 2017 (morning), counted the total of 17 days of measurements. Of these, the days with presence of cirrus totalized 9 which corresponds to approximately 53% of the measures. For the month of February 2017, only 8 days were measured, due to atmospheric conditions that made it impossible to collect data, with cloudy sky and rainy days. From this total measured, all the quicklooks showed presence of cirrus, counting 100% of the data with presence of the same ones.

One day of each month was selected to investigate these characteristics. In addition, for the month of January a day was also selected in which no presence of cirrus was observed in the quicklook to investigate any differences in the vertical profile corresponding to the relative humidity for this day compared to the profiles of days with cirrus. In the figures 12 and 13 below it is possible to see one day with cirrus presence and one day without from lidar RCS graphs and also the respective radiosondes vertical profiles of relative humidity for each day.

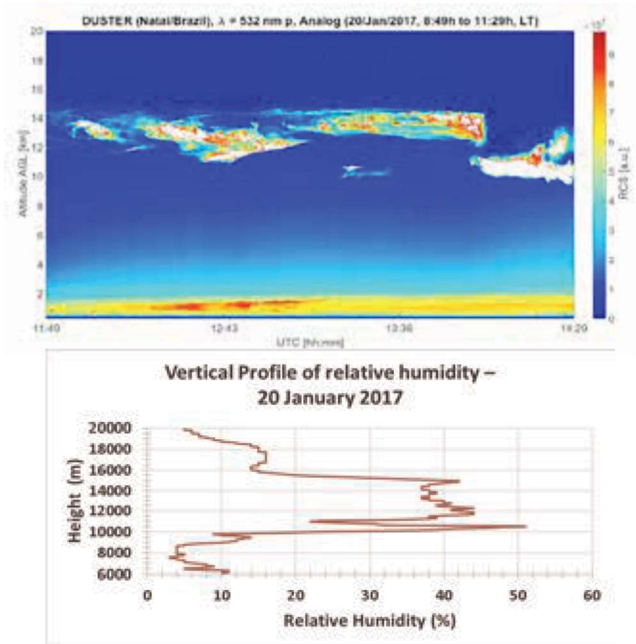

Figure 12 - Quicklook and relative humidity vertical profiles, respectively, for a day with Cirrus presence from around 10.0 to15.0 km. Day: 20 January 2017. ***Source: Author.***

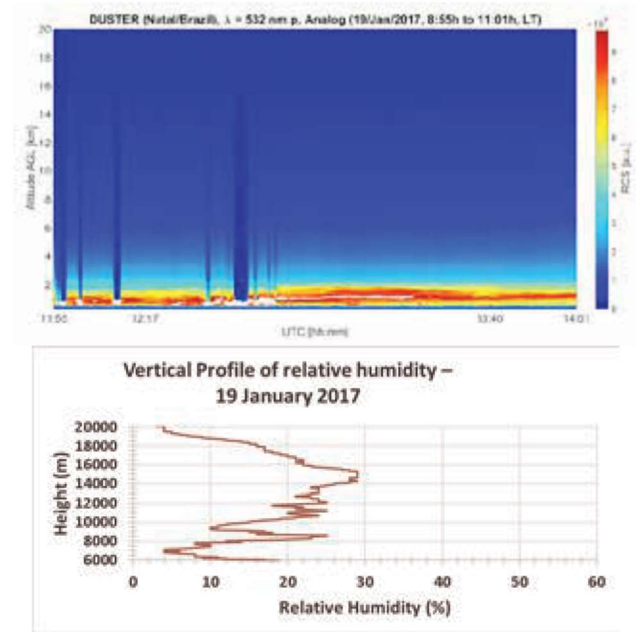

Figure 13 - Quicklook and relative humidity vertical profiles, respectively, for a day without Cirrus presence in the

atmosphere vertical profile. Day: 19 January 2017. *Source: Author.*

Figure 12 shows the quicklook for January 20, 2017. On this day, it is clearly observed cirrus clouds signal between the altitudes of 10.0 km and 15.0 km on Lidar profile. This signal varies from less intense to more intense colors, from cyan through red to white, showing regions where there is less and more signal intensity and consequently density of cirrus.The graph of Figure 12 shows the relative humidity variable (collected with the radiosonde) and how it varies with altitude on the same day. The x-axis corresponds to the values of relative humidity (in percentage). In the range of the region of interest, where the presence of cirrus was visualized on the RCS image, is observed that relative humidity was around less than 15% (slightly below 10000 m). As the altitude increases in the vertical profile of the graph, this value suffers a great variation reaching a maximum of 50%. In the delimited region, from 1000 m to 15000 m, a higher relative humidity value is verified, compared to the lower and higher regions, indicating a variation in the presence of water vapor in this region and thus cloud presence. This is something expected when there are clouds in general and also cirrus clouds, since the presence of water vapor is a prerequisite for the formation of ice crystals characteristic of this type of cloud.

On the other hand, in Figure 13, the RCS image for January 19, 2017, demonstrates a profile in which no signal is verified that could possibly corresponds to the appearance of cirrus that day over the city's atmosphere. Thus, a quicklook is observed in which the blue colour, close to zero intensity, remains for the entire range varying between 7.0 and 18.0 km where some cirrus signal would be expected. When the relative humidity chart is observed for this day, it can be seen that its values do not exceed 30% remaining below it along the vertical profile. These values indicate a lower presence of water vapor in the atmosphere in this day, not sufficient to form cirrus, in the regions where those clouds could appear confirming that there is no cloud presence in the region as visualized by the Lidar.

CONCLUSIONS

Cirrus clouds are still the subject of few studies, mainly in Brazil. However, due to its growing importance related to the investigation of its role in climate change studies, this perspective has changed. The Lidar equipment provides the opportunity to study these clouds and obtain information about their main characteristics, such as their physical properties. In Natal, for the first time, through this study, it was possible to survey and discuss these characteristics. More specifically the study of physical characteristics of cirrus clouds corresponding to their minimum, maximum and average occurrence heights, coverage and thicknesses. It was possible to survey their representativeness in two campaign periods, corresponding to the years 2017 and 2018; their frequency of occurrence according to average height of appearance; and their morphological patterns and their variations. For a first study, the results obtained are of great relevance once now there are data of great temporal and spatial resolution about cirrus clouds for the atmosphere of Natal. At the same time, it was possible to combine the data obtained by Lidar with the radiosonde data. This is an important analysis since two sources of data are used to giving consistency and reliability to the information about the target of interest. In future studies, to reinforce this analysis it can be considered more days and also the inclusion of other relevant meteorological variables for comparison. Future analyzes of the potential equivalent temperature profile will be studied in order to verify the effect of the cirrus clouds occurring in the temperature and humidity profile in a combined manner and also is expected to evaluate the possible impacts of cold air intrusion of the stratosphere in layers of cirrus clouds. It is important to maintain the operation of the Lidar continuously to obtain more seasonal data to verify the behaviour of the physical characteristics of these clouds throughout the year, for example. It is known, however, that this operation will always depend on the weather conditions of the city, something that limits the data collection.

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