Study of cloud behavior in Camagüey (21.4°N, 77.8°W) using CALIOP information

Estudio del comportamiento de las nubes en Camagüey (21.4°N, 77.8°W), empleando información obtenida mediante CALIOP

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Received / Recibido: 15/02/2014. Revised / Revisado: 26/05/2014. Accepted / Aceptado: 28/05/2014.

DOI: <http://dx.doi.org/10.7149/OPA.47.2.115>

ABSTRACT:

In this paper the cloud optical depth (COD) and frequency of semitransparent clouds in Camagüey (21.4°N, 77.8°W) are studied. For this purpose level 2 version 3.01 cloud profile data spanning 7 years (2007-2013) from The Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument on board Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite was used. Seven cloud subtypes were retrieved from the analysis of the CALIOP data at the studied region that enclose province Camagüey, Cuba. The maximum frequency of COD is centered at 0.1 for almost all cloud types, except for Deep Convective (DCO) and Altostratus (As_o) opaque cloud subtypes. The maximum and minimum frequency for all cloud subtypes was found in June and February, respectively. Maximum frequencies were observed in the altitudes between 11 km and 14 km during June to October for all clouds subtypes.

Key words: Clouds, Cirrus Clouds, CALIPSO, CALIOP, Camagüey.

RESUMEN:

En esta investigación se estudian el espesor óptico y la frecuencia de ocurrencia de las nubes semitransparentes y opacas en Camagüey (21.4°N, 77.8°W). Para este propósito son empleados datos de perfil de nubes version 3.01 nivel 2 del Lidar con polarización ortogonal para el estudio de nubes y aerosoles (CALIOP, siglas en inglés) a bordo del satélite Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). Fueron encontrados 7 subtipos de nubes a partir del análisis de los datos de CALIOP en la región de estudio que comprende a la provincia Camagüey, Cuba. La frecuencia máxima de espesor óptico por nubes (COD, siglas en inglés) está centrada en 0.1, excepto para los subtipos de nubes opacas de convección profunda (DCO, siglas en inglés) y Altoestratos (As_o). La máxima y mínima frecuencia para todos los subtipos de nubes (ALL) fue encontrada en Junio y febrero, respectivamente. Las máximas frecuencias para todos los subtipos de nubes (ALL) son observadas en los meses desde junio a octubre y altitudes entre 11 km y los 14 km.

Palabras clave: Nubes, Nubes Cirros, CALIPSO, CALIOP, Camagüey.

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1. Introduction

Clouds have very important effects on the climatic system due to their contribution to the water cycle and the earth radiation budget. They cool and heat layers of the atmosphere where they are present through evaporation and condensation processes. They transport momentum and humidity between surface and atmosphere contributing to the maintenance of the Earth water cycle. They are the most important components of the earth radiation budget. They reflect a lot of solar radiation having a cooling effect on the earth surface. Cloud effects on solar radiation depend in first approximation on the altitude where it is present. For instant, low, middle and high clouds reflect about 80%, 48% and 20% respectively [1]. Cirrus clouds are an important sample of semitransparent clouds; they cover more than 30 % of the planet. They are very important to understand current and future climate but there are not still enough knowledge about them [2]. On the other hand, clouds absorb terrestrial radiation avoiding the leak into space and heating the atmosphere.

Despite the important role of clouds in the climatic system, the knowledge about themselves and the information of their potential response to climate change are very limited [3]. Climate observations and model outputs have been indicating cloud properties have changed and continue to change with climate warming [4].

Cloud studies have been made from surface based observations and measurements. It is a constraint because there are not enough

measurement points around the world. Satellite measurements have also been used for this purpose. Nowadays with the inclusion of active sensor as Radar and Lidar in satellite, these techniques become a strong tool for studying the profiles of atmospheric components such as clouds and aerosols. Lidar is able to profile a large fraction of the atmosphere being important for detecting multiple layers of clouds which contributes to study cloud radiative effects in depth [5–8].

Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on board of The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) represent a major advance in the remote sensing of the atmospheric components profile from the space.

There is a report using CALIOP and CloudSat on global and seasonal frequencies of cirrus clouds and on their heights and thicknesses obtained over the initial one year of data collected [6]. The authors found a global average frequency of occurrence of cirrus cloud of 16.7% [6]. Cirrus and deep convective clouds in the tropics were studied using the CALIPSO and CloudSat datasets during two years [7]. The authors show the relation between deep convective clouds and cirrus cloud frequency. A recent report found that clouds of the middle troposphere cover ~25% of the Earth's surface, one-third of the total cloud cover [8]. But these studies were not focused in our region and not cover the temporal extend of the all CALIPSO dataset. So, we have this propose in the present study: evaluate the frequency of different cloud

types following the classification of the CALIPSO dataset in our region.

In this paper cloud profile dataset of CALIPSO data level 2 version 3.01 are used for studying cloud behaviour in Camaguey Region (centred at 21.42°N, 77.85°W). Column cloud optical depth (COD) and frequency (monthly profile and monthly mean) are assessed.

2. Dataset and methods

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission is flying in formation with the A-Train satellite's constellation. They are in a 705 km sun-synchronous polar orbit with a repetition cycle of 16 days crossing the equator about 13:30 local solar time. CALIPSO provides a global coverage between 82°N and 82°S, on board there are three instruments: Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), The Wide Field Camera and The Infrared Imaging Radiometer. The first is the primary instrument being a near-nadir polarization Lidar. CALIOP operates continuously producing simultaneous co-aligned pulses at 1064 nm and 532 nm during both day and night. It has a mean sampling resolution of 30 m vertical and 333 m horizontal.

The Level 2 processing has three main steps. Algorithms of Scene Classification (SCA) use attenuated backscatter profiles at 532 nm to define clouds and aerosols layers. The Cloud-Aerosol Discrimination algorithm (CAD) allows the layer classification with presence of cloud or aerosol. CAD uses confidence functions created from the probability distribution functions of each layer averaged properties. Ice water phase is also determined in this step. The hybrid extinction retrieval algorithm (HERA) is used to retrieve profiles of particle backscatter and extinction coefficients [5].

Cloud-related products of CALIOP level 2 data are cloud layer and cloud profile. Cloud layer includes base and top height, cloud optical depth and ice water phase. They have 20 km of maximum altitude and 30 m of vertical resolution. The horizontal resolution for cloud layer products are 0.3 km, 1 km and 5 km. Cloud optical depths retrieved from CALIOP have

values below 5, because the attenuation of the laser in the clouds [5]. The primary parameters of cloud profile data are backscatter and extinction at 532 nm and 20 km of higher altitude. The used dataset have 5 km of horizontal resolution.

The survey region covers the Camaguey province at Cuba (Fig. 1) with longitude between 77.03°W and 78.61°W; and latitude between 22.17°N and 20.47°N. CALIOP measurements times around 6 GMT (Local Time (-5 hours GMT)) or 7 GMT and 18 GMT. In this paper cloud profile data from November 29, 2007 until February 2013 is used. Column optical depth at 532 nm from this dataset is also used.

Fig. 1. Survey region used in the study. Long: 77.03°W - 78.61°W, Lat: 20.47°N - 22.17°N.

To retrieve cloud types Atmospheric Volume Description (AVD) is used. CAD_Score and Extinction QC Flag_532 are also used to refine the data. Clouds subtypes defined in the CALIPSO cloud product are shown in Table I.

TABLE I
Cloud subtypes defined in the CALIPSO cloud product contained in the Atmospheric Volume Description parameter.

Cloud subtype	Symbol
Low Overcast, Transparent subtype	LOT
Low Overcast, Opaque subtype	LOO
Transition Stratocumulus subtype	Sc _t
Low, Broken Cumulus subtype	Cu _b
Altostratus (transparent) subtype	Ac _t
Altostratus (opaque) subtype	As _o
Cirrus (transparent) subtype	Ci _t
Deep Convective (Opaque) subtype	DCO
Cloud type, all subtype	ALL

Cloud frequency of the cloud subtype for the survey region was computed from the ratio of the cases where the cloud subtype is measured in the atmospheric column and total cases of measurements. A frequency profile of each cloud subtype is computed from the cloud presence in each altitude level, whenever this level is observable by the lidar.

3. Dataset and methods

COD frequency distribution for each cloud subtype is shown in Fig. 2. Frequency classes are set with 0.1 units of COD intervals. There are 2782 cases of COD belonging to all cloud subtypes (ALL). The maximum COD frequency is placed in the interval of 0.1, with 29.8%. COD values lower than 2 are 81% of the samples. There is a small increase of frequency between 2.5 and 3.5 being these intervals 13.2% of the total sample. C_i subtype has the highest amount of COD values (1358 cases, 50 % of all cloud cases). The maximum frequency of COD is centered at 0.1 with 46.2%, 90% of the samples are lower than value 1 of COD.

COD of LOT subtype (138 cases) show a frequency distribution with two main grouped values. The first one is lower than 0.2 (35.2%), inside it the maximum frequency is placed (26.6%) centered at 0.1. The second one is between 2.5 and 3.6 with the maximum of this group placed at 2.6 (11.7%). All COD of DCO cloud subtype are higher than 0.8, the main maximum frequency is centered at 1.3 (9%). The secondary maxima are centered at 2.6 and 3 with 7.6%. There are few COD cases of the remaining clouds, their value being lower than 30. COD sample of A_{c_i} has 96% lower than 1 with the maximum centered at 0.1. COD of S_{c_i} are lower than 0.6 with its maximum centered at 0.1. COD maximum of A_{s_0} is placed at 2.5 with samples below 3. From $C_{u,b}$, just 8 cases of clouds were found with its maximum centered at 0.1.

Monthly frequencies for each cloud subtype and ALL subtype are showed in the figure 3. ALL subtype has higher frequencies from June to November in agreement with the rainy season (May to October) in our geographical region. The maximum is placed in June (52.9 %) and the

Fig. 2. Cloud optical depth distributions for each cloud subtype. In the upper left side the symbol of the cloud subtype and in the upper right side the number of cases of this cloud subtype alone in the atmospheric column.

Fig. 3. Monthly cloud frequencies at the survey region.

minimum frequency is in February (33.3 %). The maximum frequencies of Ci_t are placed from June to October, in the rainy season. The main maximum frequency is in October (45.7 %) and the secondary maximum is in June (44.1 %). The lowest frequencies of Ci_t are during the dry or little rainy season (November to April), with the minimum on December (11.1 %). The highest frequencies of DCO are placed from June to October with the maximum in August (31.4 %). For this cloud subtype the minimum frequencies are in the dry season specifically in December (2.2 %). Ac_t cloud subtype has a similar behavior as DCO, before mentioned, but with a notable decrease of frequency in July. It has a maximum in June (29.1 %). Maximum frequencies for As_o subtype are in the rainy season and April. The mean maximum frequency is placed in August (20 %). On December this cloud type is not observed.

On the other hand Sc_t has an opposite behaviour from clouds mentioned before. It has the maximum frequencies placed in the dry season with the primary maximum in December (11.1%). There is no occurrence of this cloud subtype neither in June nor July. LOT subtype is almost steady along the year with maximum in August (43.2%) and minimum in May (26.5%).

Cu_b subtype behavior is variable along the year, there are some months where it is not observable. The maximum frequency of this cloud subtype is located in April (9%).

Monthly and hourly cloud frequency profile for ALL cloud subtype is showed in the Figure 4. It can be seen that the highest frequencies are in the upper altitudes during the rainy season. This is due to the increase of deep convection in the region during this season favouring the cirrus cloud formation in the highest levels. From June to October between 11 km and 14 km frequencies are higher than 20%. In June frequencies exceed 35% between 12.97 km and 13.92 km. The maximum frequency with a value of 37.4% was found in June at 13.15 km and 12.97 km. In September there are other maximum frequencies exceeding 35% at 14.16 km y 14.22 km, but lower than the June values. Lower Frequencies different of 0 are placed in the dry or little rainy season below 14 km. January and December are the only months which maximum frequencies are placed below 2 km. It is noted that in August there is a persistent presence of ALL cloud subtype in the Column showing frequencies larger than 10% at the low, medium and high levels. This is in

Fig. 4. Monthly and hourly frequencies profile of ALL subtype.

Fig. 5. Monthly and hourly frequencies profile of Ci_t .

agreement of higher frequencies of LOT, DCO and Ci_t in this month

It can be seen from the Figure 4 that the hourly cloud frequency profile at 18 GMT has its maximum at 12.97 km, higher than the maximum in the profile at 6-7 GMT (12.37 km). There is an “inflection” altitude (4.64 km) below of which almost all the frequency values at 18

GMT are higher than frequencies at 6-7 GMT, and contrary in the altitudes above.

Ci_t subtype has frequencies exceeding 15% between 12 km and 14 km from June to October (Fig. 5). The maximum in these months are higher than 20% exceeding 25% in August and September. In September between 13.33 km and 14.76 km frequencies are higher than 25%. The

absolute maximum with 29.08% is placed in September at 14.16 km.

From June to October, July is the month where the maximum frequency has the lowest value, at 12.49 km. It is important to note that the maximum frequency in April at 13.00 km with 16.47% is higher than in May (at 10 km with 9.64%). During the dry season the frequencies rarely exceed 5% between altitudes from 11 km to 13 km. In February and March maximum frequencies not exceed 12 km in altitude. Also in August and October Ci_t is above 8 km. Mean frequencies per altitude at 6-7 GMT are higher than the ones at 18 GMT. However the altitude of maximum frequency at 18 GMT (12.85 km) is higher than at 6-7 GMT (12.37 km).

4. Conclusions

Seven cloud subtypes were retrieved from the analysis of the CALIOP data at the studied region that enclose province Camagüey, Cuba. The maximum frequency of COD is centered at 0.1, except for DCO and As_o subtypes. The maximum frequency for ALL cloud subtypes was found in June and the minimum was found in February.

Ci_t , Ac_t , DCO, As_o cloud subtypes have the maximum frequencies in the rainy season.

However, Cu_{lb} and Sc_t subtypes have the maximum frequencies in the dry or little rainy season. LOT subtype is almost steady along the year.

From June to October between 11 km and 14 km the maximum frequencies of all clouds subtypes are observed. In December and January the maximum frequencies are below 2 km. Maximum frequencies of Ci_t subtype are located between 12 km and 14 km from June to October. The primary maximum frequency of Ci_t subtype was found in September with 29.04% at 14.16 km. In the dry or little rainy season frequency of Ci_t subtype decrease in depth and altitude.

Maximum frequency altitude of ALL cloud subtypes and Ci_t subtype at 18 GMT are higher than at 6-7 GMT in altitude. However frequency values at 18 GMT are less than at 6-7 GMT.

Acknowledgements

Authors from GOAC-INSMET want to thank to CALIPSO Search and Subsetting Web Application team for provide the information about COD from CALIPSO. This work has been supported by the Cuban National Climate Change Research Program under the contract number 01301204.