COINCIDENT LIDAR AND SAGE II CIRRUS CLOUDS MEASUREMENTS AT CAMAGÜEY, CUBA.

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Lidar and satellite measurements of cirrus clouds are important and complementary tools in the cirrus clouds research. The comparison of lidar and satellite measurements is a necessary step for the combined use of the measurements from both methods. In this work we carry out a comparison between the cirrus clouds measurements from the lidar located at Camagüey Lidar Station and the SAGE II (Stratospheric Aerosol and Gas Experiment II) instrument onboard ERBS (Earth Radiation Budget Satellite) satellite.

A criterion is used to determine the coincidence in space and time between both instruments cirrus clouds measurements. Lidar measurements of cirrus clouds dataset has been compiled from various days from 1993 to 1998. SAGE II dataset version 6.2 extends from October 1984 to August 2005. A total of 14 lidar measurements of cirrus clouds were coincident with SAGE II measurements. The method of the ratio between two SAGE II wavelengths, 0.525 µm and 1.02 µm, was used to find out the presence of cloud/aerosols mixture from the SAGE II extinction profile. The coincidence of profiles is analyzed and discussed.

1. INTRODUCTION

Cirrus clouds play a fundamental role in the atmospheric energy budget through latent heat exchange. In addition high-altitude ice clouds significantly modulate the flow of radiative energy into and out of the earth-atmosphere system. The influence of cirrus clouds on climate has been discussed extensively in the literature [e.g., 1, 12, 13, and 14]. A particular form of this type of clouds is the subvisible cirrus clouds. They have been proposed as an important aspect also as contributing to the Earth's radiation budget and exchange between the stratosphere and the troposphere [1]. Since these clouds are so important, it is desirable to learn more about their properties.

Measurements of cirrus clouds properties from the various lidar and satellite-borne sensors are highly important for the modelling and understanding the cirrus clouds behaviour and their role in the earth system.

Frequencies of occurrence and optical extinction of subvisible cirrus was routinely measured by the satellite-borne Stratospheric Aerosol and Gas Experiment (SAGE) II [2], and by lidars. Long-term lidar studies of cirrus including subvisible cirrus have recently been reported [3, 4, 5].

The complementary application of both methods is an attractive aspect in order to comparing the measurements of the high altitude cirrus clouds obtained with different instruments.

The subject of this paper is to show the preliminary results of the analysis and comparison of cirrus extinction profiles obtained from measurements made with lidar and SAGE II at the Camagüey Lidar Station site. A criterion is used to regard as coincident measurements in space and time between both instruments. A total of 16 lidar profiles and 11 profiles of SAGE II were selected as coincident profiles. The method of the ratio between two SAGE II wavelengths of 0.525 µm and 1.02 µm was used to determine the presence of cloud/aerosols mixture from SAGE II extinction profile dataset. The application of the previous mentioned method reduces the number coincident measurements to coincident measurements of cirrus clouds.

2. INSTRUMENTATION, DATA AND METHODS

The SAGE II instrument was launched aboard the Earth Radiation Budget Satellite (ERBS) in October 1984. The satellite instrument was in operation until august 2005. It is a seven channel radiometer that covers the wavelength range between 0.385 and 1.02 µm. It uses the solar occultation technique to measure the slant path transmission as a function of tangent height. During each satellite orbit with the period of 96.8 minutes, two measurements are provided; one during sunrise, when the satellite instrument emerges from the dark side of the orbit and another during sunset, when the instrument enter in the dark side.

The orbital characteristics of the ERBS and the earth rotation the consecutive measurements in the time are separated 24º in longitude approximately [6]. The field of view of the instrument is specified by coverage of 0.5 km in the vertical, by 2.5 km in the horizontal, at the limb tangent point. The data-acquisition and -inversion procedure assumes a spherically symmetricall atmosphere and is obtained a path length along the line of sight of about 200 km. Under favourable atmospheric conditions such as nonvolcanic, cloud free, and optically thin clouds, measurements from the four longer wavelengths also provide tropospheric data. The profiles have 80 levels with 0.5 km of resolution, covering the altitude range from the 0.5 up to 40 km.

The upper limit of the SAGE II measurements of the extinction coefficient to 1.02 µm wavelength is around $2x10^{-2}$ km^{-1}. Thus SAGE II measurable clouds correspond mostly to the subvisual cirrus clouds [2]. Evidently, the presence of SAGE II opaque clouds reduces the measurement opportunities of the instruments in the troposphere.

The dataset have been periodically re-evaluated and improved, in the present work have been used the version 6.2, the most up to date version [7] at the moment of this investigation. The temporal extension of the data set is from October 1984 up to August 2005.

Cirrus clouds lidar data was obtained by backscatter lidar located at Camagüey Lidar Station (CLS), Camagüey, Cuba at 21.2ºN and 77.5ºW, between 1993 and 1998. This equipment makes measurements in the night around the year once for week. The principal goal of this instrument is the detection of stratospheric aerosols. But in some cases when the measurements are interrupted by the interception of optically invisible cirrus-clouds for the human eyes, we achieve the cirrus-clouds measurements. The lidar uses a doubled Nd – YAG laser (532 nm, 50 Hz, 300 mJ/pulse). The receiving telescope has a diameter of 34 cm and the field of view is 3 mrad. The number of laser shot and resolution for cirrus measurements are 1000 and 75 m, respectively. The detailed specification of the instrument can be found in a former paper [8]. Our database has 132 individual measurements on 36 days. The profiles of the cirrus extinction coefficients were calculated from those of backscatter coefficients using a lidar ratio of 10 sr [9]. The molecular backscattering was calculated using the molecular density model for Camagüey up to 30hPa and the US Standard Atmosphere above.

The lidar cirrus clouds extinction profile was converted from the resolution of 75 m to 500 m with purpose of comparing with the SAGE II extinction coefficient data.

The data SAGE extinction coefficient profiles was analyzed for determining the presence of the clouds/aerosols mixture. For this we use the method of the coefficient extinction ratio (ER) at two wavelengths. We use the ratio between 0.525 µm and 1.02 µm coefficient extinction. Recently in [10] was suggested that the ER value decreasing below 2 indicate the phase change from aerosols (sub-micron) to ice particles (super-micron). By this the values of ER below 2 are indicate the presence the mixture of aerosols particles and clouds particles. The ER threshold value of 1.9 was taken for separating aerosol from aerosol/cloud mixture. Together with before criterion, the threshold values near to 5×10^{-4} km^{-1} for extinction coefficient at 1.02 µm was took. By this way the discrimination between aerosol and aerosol/cloud can be making with security [9].

Comparing the ground based and satellite measurements are a difficult task, principally in the case of SAGE II and lidar observations. Both types of instruments work with different principles and geometry. Thus, they do not have an exact match in space and time. Preferably, to compare individual measurements of the both instruments to see the agreements in cloud measured, they should be sampling the same clouds [11]. The two approaches are difficult to compare due to the different methods applied. SAGE II samples the atmosphere tangential to a point on the earth's surface, with a path length from tens of kilometres to near of one thousand of kilometres. By contrast, the lidar yields information in a spatially confined column. Also, we must take into account the high spatial and temporal variability of the cirrus clouds. Different criteria for SAGE II aerosols measurement comparison is reported in the literature, we select in our case one criterion based in the geometry of the SAGE II sampling used previously to the aerosols measurements [11]. We modified it and use the criteria of ±6º in latitude, ±25º in longitude, and ±24 hours in time. We choose ±6º in latitude due the insufficient number of perfect overpasses in the lidar measurements date. The criteria selected allow a maximum distance between the lidar site and the SAGE II measurements of 2738 km.

3. RESULTS AND DISCUSSION

After apply the space-time criteria we found 4 nights of lidar measurements with coincident SAGE II measurements. A total of 16 profiles of cirrus were found distributed irregularly during the nights. Table 1 show a summary of the coincident measurements.

Table 1. Summary of the coincident cirrus lidar and SAGE II measurements.

<table>
<tr><th>Lidar date and time</th><th>SAGE II date, Time and localization</th><th>Lidar date and time</th><th>SAGE II date, Time and localization</th></tr>
<tr><td>27-6-1993
2 profiles
03:02:32
03:52:46</td><td>26-6-1993
22:43:01
Lat: 15.43
Lon: -62.44</td><td rowspan="6">10-9-1996
1 profile
03:10:59</td><td>09-9-1996
09:17:34
Lat: 17.80
Lon: -52.86</td></tr>
<tr><td rowspan="5">25-8-1996
10 profiles
07:56:04
08:01:14
08:14:09
08:15:36
08:20:10
08:30:54
08:32:34
08:42:27
08:56:19
09:03:01</td><td>24-8-1996
23:12:17
Lat: 21.53
Lon: -72.35</td><td>09-9-1996
10:53:58
Lat: 18.21
Lon: -76.93</td></tr>
<tr><td>25-8-1996
00:48:40
Lat: 21.18
Lon: -96.54</td><td>09-9-1996
12:30:23
Lat: 18.60
Lon: -101.13</td></tr>
<tr><td>25-8-1996
23:18:09
Lat: 16.06
Lon: -75.21</td><td>10-9-1996
09:23:36
Lat: 23.46
Lon: -54.82</td></tr>
<tr><td>26-8-1996
00:54:32
Lat: 15.67
Lon: -99.39</td><td>10-9-1996
11:00:00
Lat: 23.82
Lon: -79.00</td></tr>
<tr><td></td><td></td><td>11-10-1996
3 profiles
06:24:51
06:41:21
06:55:00</td><td>10-10-1996
12:09:28
Lat: 20.92
Lon: -94.23</td></tr>
</table>

Following this step of finding the coincident profiles we determine the presence of cirrus clouds in the SAGE II profile, with the method explained briefly in the previous section. We found presence of cirrus clouds in the SAGE II profiles only in two days. The first date is for lidar measurement June, 27, 1993, and SAGE date is June, 26, 1993. The distance between these measurements points is 1715.6 km. The SAGE II overpasses took place 4 and 5 hours before the lidar measurements. Fig. 1 shows the profiles of the extinction coefficient for cirrus clouds by SAGE II and both lidar measurements. The presence of cirrus clouds at the altitude between 12.5 y 14 km is seen in the SAGE II and in the first lidar measurement. The optical depth for these cirrus clouds is 0.01 and 0.008 respectively to SAGE II and lidar measurements. These cirrus clouds are classified as subvisible. In the second lidar measurement there is no presence of cirrus clouds at this altitude.

SAGE 26-6-93 22:43:01 lat: 15.43 lon: -62.44
Lidar: 27-6-93 03:02:32 lat: 21.24 lon: -77.51
Distance: 1715.6 km Time: 04:19:31

Lidar: 27-6-93 03:52:46 lat: 21.24 lon: -77.51
Distance: 1715.6 km Time: 05:09:45

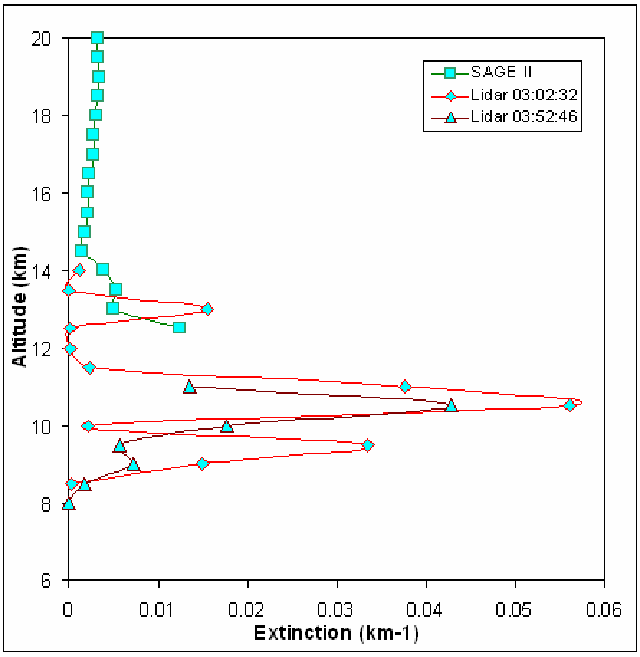

Fig. 1 Coincident cirrus clouds lidar and SAGE II measurements to the lidar date June, 26, 1993. The extinction coefficient of 0.525 µm for SAGE II and 0.532 µm for lidar measurements.

In addition the lidar data show cirrus clouds between 8.5 and 11.5 km. The optical depth of this cirrus clouds was 0.073 and 0.044 respectively to the first and second lidar measurements. For this day, visual daytime and nighttime observations of cirrus clouds and some convective activity were reported by the surface meteorological station in the region.

The second lidar date is August, 25, 1996, the times of the lidar profiles and the corresponding SAGE II coincident measurements from August, 24, 1996 to August, 26, 1996 are listed in the Table 1. One lidar profile for this day is selected for the analysis. It is representative of the all day lidar measurements. In contrast with the previous case, now we have two pairs of SAGE measurements coincident with the lidar measurement. Also the distances between the lidar site and the SAGE locations are 535.2, 1971.5, 624.8 and 2386.9 km respectively with the order of occurrence in the time. In this second case the differences in time between the measurements are larger than in the case of the year 1996, from 9 hours before the lidar measurements to 16 hours after the lidar measurements.

Fig. 2 displays the profile of the cirrus clouds extinction coefficient for one lidar measurement selected from the 10 measurements of this day. Together with the profiles of the two pairs of SAGE II profiles of the cirrus clouds extinction coefficient.

Lidar: 25-8-96 08:42:27 lat: 21.24 lon: -77.51
SAGE II-1: 24-8-96 23:12:17 lat: 21.53 lon: -72.35
Distance: 0.5352e+003 km Time: 09:30:10
SAGE II-2: 25-8-96 00:48:40 lat: 21.18 lon: -96.54
Distance: 1.9715e+003 km Time: 07:53:47
SAGE II-3: 25-8-96 23:18:09 lat: 16.06 lon: -75.21
Distance: 0.6248e+003 km Time: 14:35:42
SAGE II-4: 26-8-96 00:54:32 lat: 15.67 lon: -99.39
Distance: 2.3869e+003 km Time: 16:12:05

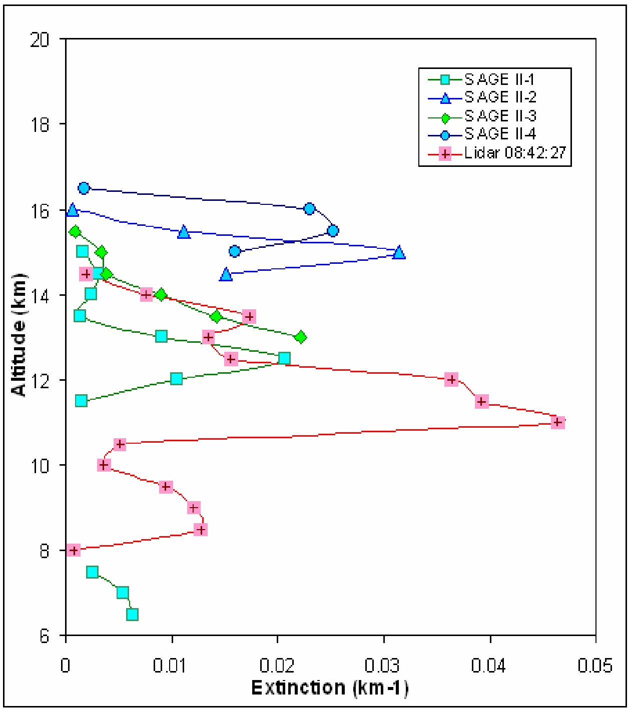

Fig. 2 Coincident cirrus clouds lidar and SAGE II measurements to the lidar date August, 25, 1996. The extinction coefficient of 0.525 µm for SAGE II and 0.532 µm for lidar measurements.

The simultaneous presence of the cirrus clouds in the lidar and SAGE II data is seen in the altitude between 12 and 14.5 km. The lidar profile shows one very thick vertically cirrus clouds. The SAGE II-1 and 3 profiles, as shown in Fig. 2, decay at the altitude near to 12 km like the cirrus clouds in the lidar signal is stronger.

Like the above case, visual daytime and nighttime observations of cirrus clouds and some convective activity were reported by the surface meteorological station in the region.

One interesting thing is how the altitude of the cirrus clouds in the pairs of the SAGE measurements increase in the time and space. The longitude of the measurements sites is similar, but the latitude change in -5º, the latitude decrease and the altitude of the cirrus clouds increase in the same longitude.

4. CONCLUSIONS

This is a preliminary result of the comparison of the cirrus clouds extinction coefficient derived from the lidar and SAGE II data, at the site of the Camagüey Lidar Station. Despite of the fact that we have a limited sample of the lidar cirrus clouds, we obtain some cases of coincident measurements.

It is important to conclude that is not possible to make a characterization of the same individual cirrus clouds with both instruments. It is obvious that the SAGE measurements, still, have considerable limitations. The comparison shows that complementary information on the cirrus clouds below the altitude accessible by the SAGE retrievals is needed.

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ftp://ftp-rab.larc.nasa.gov/pub/sage2/v6.20

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