OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 4, No. 12, December 2010, p. 1952 - 1955

# Cloud height comparison from SEVIRI and LIDAR

L. MARMUREANU*, C. TALIANU, R. RADULESCU, J. VASILESCU
*National Institute of Research and Development for Optoelectronics, 409 Atomistilor Street, RO-077125 Măgurele, Ilfov, Romania*

Depending on their characteristics and height in the atmosphere, clouds can influence the Earth energy balance and also have an important role in climate and climate change. This paper presents a preliminary study on cloud top height (CTH) estimation using passive and active techniques. Cloud top height estimation using active techniques is based on a cloud top height detection algorithm that uses the gradient method. Data from SEVIRI, satellite imagery based on infrared reflectance at 10.8 μm was used as a passive remote sensing tool. As active remote sensing instruments, two Lidar (LIght Detection and Ranging) systems, ground based has been used. They sound the atmosphere up to high altitudes due to their high sensitivity and long range detection. Depicted CTHs from measurements performed in Măgurele (located near Bucharest at 44.35 latitude N and 26.03 longitude E), using the LIDAR systems and satellite imagery have shown a good agreement. Differences of less than 500 meters are seen between these two techniques.

(Received November 22, 2010; accepted November 29, 2010)

*Keywords*: Cloud height top, Satellite, Lidar

## 1. Introduction

Clouds play an important role in the Earth climate system 0.The amount of radiation reflected by the Earth–atmosphere system into outer space depends not only on the cloud cover but also on their characteristics. The capability for predicting global climate variability in the short to medium terms has improved significantly, but cloud fraction remain amongst the most unknown factors in climate studies 0. Clouds play a fundamental role in modulating atmospheric horizontal and vertical radiation fluxes.

The satellite products used are MSG, the new generation of geostationary, meteorological satellites developed by the European Space Agency (ESA) in close co-operation with the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). The satellite's main payload is the optical imaging radiometer so called Spinning Enhanced Visible and Infrared Imager (SEVIRI). Its 12 different spectral channels provide cloud imaging and tracking, fog detection, measurement of the earth surface and cloud top temperatures, tracking ozone patterns etc. The EUMETCAST system used for this study is a tool for dissemination of various meteorological data operated by EUMETSAT. The satellite's 12-channel imager observes the full disk of the Earth with repeat cycle of 15 minutes in 12 spectral wavelength regions or channels. Spectral Range is between 0.4 – 1.6 mm (4 visible /NIR channels), 3.9 – 13.4mm (8 IR channels) with resolution of 1 km for the high resolution visible channel and 3 km for the infra-red and the 3 other visible channels 00.

This instrument offer a big opportunity to characterize the cloud properties using infrared, near infrared or visible channels that give information about identification of pixels containing cloud, classification as cloud type, particle single scattering properties, radiative transfer, gaseous transmission and clear atmosphere etc. The most suitable channels to characterize cloud boundaries are in the infrared domain 3.9, 8.7, 10.8 and 12 μm. Using different channels we can obtain different penetration depths of radiation and therefore the cloud temperature effectively observed is not the same in each channel. These effects are small, but possibly not insignificant. They arise essentially because the envisaged simple cloud model and plausible radiative transfer do not handle clouds with vertical gradients.

The comparison between cloud height from Lidar and satellite imagery were made using 532 nm and 1064 nm wavelengths from LIDAR and one infrared channel 10.8 μm from SEVIRI. Even though the CTH is a very important parameter needed to be estimated, several studies showed that satellite imagery have same important limitations.

This study was made to identify more accurately the differences between satellite IR measurements using standard atmospheric model and measurements made with high resolutions and powerful lidars, providing information not only about base of the clouds ( like Ceilometers) but also about cloud tops. This study is based on a method developed by our research group, to determine cloud boundaries based on gradients in the lidar signal 0.

## 2. Methodology

**SEVIRI** retrievals of CTH are based on entirely different physical principles than those from lidar. In particular, cloud brightness temperature, as measured by SEVIRI at 10.8μm, can be related to the cloud top height. Colder clouds are generally located at higher altitudes in the troposphere. This is the basic idea behind the IR retrieval.

Simple methods are based on the emission equation for an observed radiance:

$$R_\lambda = \varepsilon_\lambda B_{\lambda c} + (1 - \varepsilon_\lambda) B_{\lambda s} \quad (1)$$

where □$_\lambda$ is the cloud emissivity, $B_{\lambda c}$ is the radiance from an opaque cloud (at the same height / composition) and $B_{\lambda a}$ is the upwelling radiance at cloud base. This, it may be noted, ignores atmospheric effects above the cloud and any reflection effects; of down welling radiance or surface cloud. It does implicitly include scattering effects since the emissivity can be taken as an effective value 0.

The model to estimate the cloud height from SEVIRI was the standard atmospheric model 0, where the standard temperature is modified from 15 $^0$C to 20 $^0$C. This modification was made to improve cloud top height estimation in accordance with lidar data. Also, this modification was necessary because the standard temperature does not correspond with the Romanian climate characteristics during summer.

**Lidar Systems**

The second type of instrument used for cloud high estimation was a Lidar. This active remote sensing technique is based on the emission of laser pulses (ns) into the atmosphere and the analysis of the return signal. Depending on the emitted and selected wavelength at the detection, different characteristics of atmosphere can be measured 0.

The ground base measurements were made with two lidar systems. One is an elastic backscatter Lidar for aerosols (LISA) with two detection channels 532nm and 1064 nm, performing measurements in the lower part of the troposphere (5 km maximum range at 15 m range resolution). Second Lidar is a multiwavelength Raman lidar (RALI), performing measurements in the lower to upper troposphere (15km maximum range at 3.75m range resolution). This is a state-of-the-art instrument, operating at seven wavelengths and with a maximum of 12 channels that is intended to measure aerosol optical coefficients. The pre-processed data offers information about clouds. They are visible directly in the range corrected signal along with information regarding PBL (Planetary Boundary Layer), troposphere aerosol layers and also temporal evolution of layers with 1min resolution 0.

PBL top and layer base and height, including cloud base, can be derived directly from the Range Corrected Signal (RCS) of Lidar, by identifying signal's peaks and valleys.

$$RCS = \left(S - S_0\right) \cdot r^2 \tag{2}$$

In equation (2) r is the distance between the laser source and the target (it is also called range), S is the lidar signal and $S_0$ is the background signal.

Atmospheric layers determination including cloud boundaries from lidar signal can be detected using Continuum Wavelet Transform or through Gaussian analysis 0. In this paper the lidar data was analyzed through a method developed in our research group and implemented: LiSA Model. Initially it was developed to determine only the bottom and the top of PBL and troposphere layers 0 and is based on gradient method 0, but in here we try to extend its application to cloud boundaries.

This method finds the altitudes $h_{min}$ and $h_{max}$ at which the absolute minimum and maximum of the first derivative of the RCS signal occur:

$$h_{\min} = \min\left(\frac{\partial RCS}{\partial z}\right);\ h_{\max} = \max\left(\frac{\partial RCS}{\partial z}\right) \tag{3}$$

The difference between $h_{max}$ and $h_{min}$ gives the semi-width of the peak, and the altitude $h_0$ at which the first derivative becomes null gives the position of the peak. The amplitude is given by the value of the signal in $h_0$. The peak is considered representative if the associated transition interval contains at least 5 points.

Whenever the signal to noise ratio is sufficiently high (e.g. greater than 3), the optimum results in the retrieval of layer altitude are obtained by applying LiSA method to the RCS. This is due to the fact that this method is not very sensitive to layer substructure and returns only the major peaks of the RCS derivative.

Clouds scatter the laser radiation very powerful therefore they produce a significant useful signal even if they are at high altitudes. So this method can be applied for cloud boundaries identification. But the first derivate is noisy for the cloud boundaries determination, so we have analyzed just the sharp increase and decrease of the first derivate. We consider the bottom of the cloud, the altitude where the slope start to increase and the top where the first derivate is close to zero.

## 3. Selection of case studies

The data collected was analyzed in order to find the cases where data from both satellite and lidar systems can be compared. Both systems have their own limitations for this study. The lidar give us precise data, but a vertical profile only in a fixed location. When the clouds are very low and very dense or is raining, the signal is not useful because the lidar's photomultiplier will become saturated. This represents the main limitation of the system.

Discrepancies in the spatial resolutions of the lidar and satellite retrievals were a concern. The Lidar is a vertically pointing instrument that takes measurements along a very narrow line-of-sight. On the contrary, retrievals from SEVIRI correspond to 3 Km$^2$/pixel. The Lidar instrument may or may not detect the cloud depending on whether it is located under the cloudy or clear portion of the corresponding satellite images. In an attempt to avoid any biases introduced by such instances, each comparison period discussed in this paper has incorporated only the satellite data that indicates a complete cloud cover.

The cases considered were just for only single-layer clouds. This represented the best scenario for the comparison by avoiding the satellite errors related to multilayer clouds. Clouds are considered to be single-layer if the lidar retrievals indicate the presence of just one cloud layer.

## 4. Results and discussions

The time interval considered for this study was March-August 2010. We have recorded cases with clouds at different altitudes.

### 4.1. Case 1: clouds higher than 5 Km

Our first approach was to identify cirrus clouds (usually up in the atmosphere from 6 to 10 km). Not many cases were identified due to satellite limitation in deriving useful information about thin clouds.

Satellite imagery in infrared and also in visible provide sufficient information about cloud cover (Fig. 1) but there are some cases when pixels are identified as cloud even there are no clouds 0. Through special analyzes these pixels can be validated. In our case the validation of cloud pixels wasn't necessary because the measurements made with the lidar confirmed the presence of clouds.

One particular case of satellite retrieval is presented in Fig. 1 where the presence of clouds above Romania can be observed. Depending on the gradient colored map we can identify the cloud altitude, but accurate data is extracted from the pixel of interest. The satellite retrieval gives us information with an estimation path of 100 m. In this example cloud top height estimated from satellite imagery, above Măgurele is at 9.5 Km. The RCS is represented in Fig. 2 highlighting the presence of a cirrus cloud during several hours.

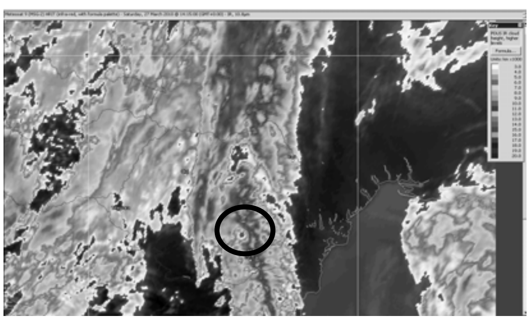

*Fig. 1. Satellite imagery of cloud top height for March 27 2010, 14:30 GMT; circle is above Magurele location.*

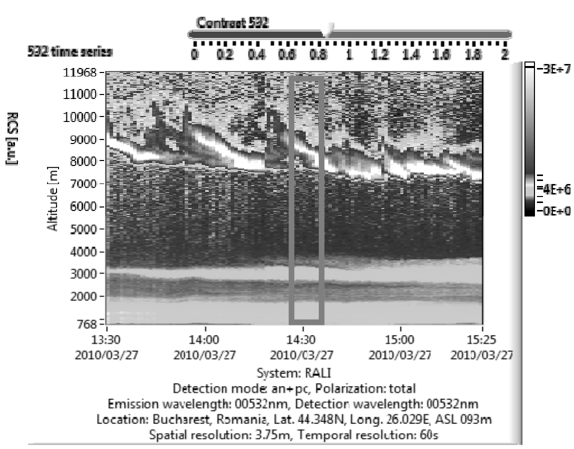


*Fig. 2. Temporal evolution of the cloud, RCS for March 27 2010, from13:30 to 15:35 GMT; rectangle identifies the time when satellite recorded data.*

Depolarization ratio time series present a better, realistic structure of the ice crystals clouds (Fig. 3). Depolarization ratio is computed from 532 nm depolarization channel of RALI. The laser backscatter depolarization technique was one of the first to be tested in the atmosphere 0, and remains the only remote sensing tool that can unambiguously discriminate between water and ice clouds through its ability to sense particle shape and orientation 0.

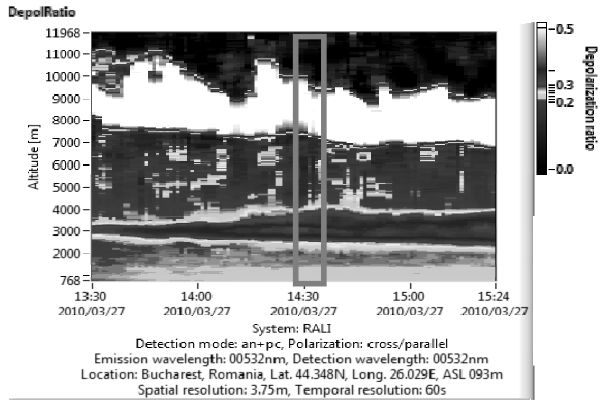


*Fig. 3. Time series of depolarization ratio, 532 nm channel, March 27, 2010 from13:30 to 15:35 GMT, rectangle identifies the time when satellite recorded data.*

Even though the cloud base is visible directly in the RCS at about 7.5 km altitude and top at around 9.5 Km (Fig. 2), the precise boundaries of the clouds were extracted applying LiSA method on RCS (Fig. 4). In this case the bottom of the cloud is at 7002 m and top at 8794 m; even from depolarization we can observe that the top is a little bit higher.

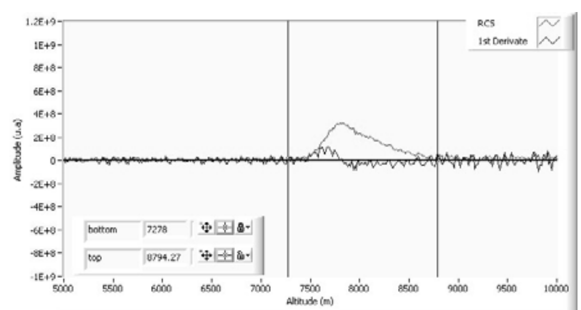


*Fig. 4 LiSA method for cloud top height of March 27 2010.*

### 4.2. Case 2: clouds lower than 5 Km

In Fig. 6 is an example of clouds with top altitude at 3100 m. We can identify by eye the altitude of the cloud top in the RCS around 3800 m. Cloud top height estimated from satellite imagery, above Măgurele is at 3.1 Km. Differences between these two methods are high, but using LiSA method the cloud top height it is identified around 3400 (Fig. 7) more closely to the satellite retrieval.

During the period of measurements for all the cases with lower clouds than 5 we were able to establish the cloud boundaries applying LiSA method on RCS. (e.g. Fig. 7). In this case depolarization information is not useful because the lower clouds are made from water drops with low index of depolarization.

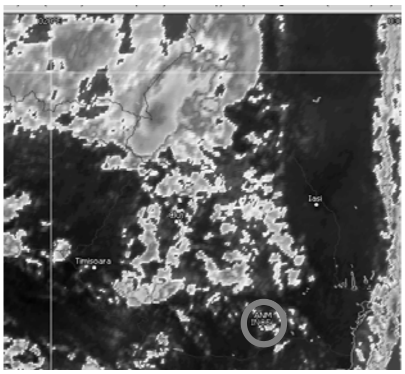


*Fig. 5. Satellite imagery of cloud top height for April 21 2010, 14:00 GMT; circle is above Magurele location.*

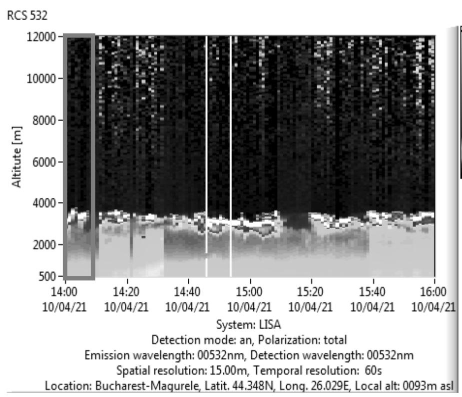


*Fig. 6. Temporal evolution of the clouds, RCS for April 21 2010, 14:00to 16:00 GMT; rectangle identifies the time when satellite recorded data.*

After analyzing the differences between CTH estimation from Lidars and CTH estimate from satellite for all cases March to August, we find an average difference of 497 m with standard deviation of 405m. This represents a good agreement between the methods.

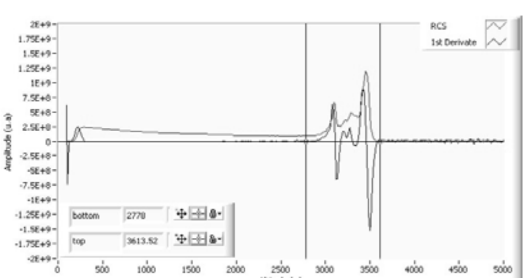


*Fig. **7.** LiSA method for cloud top height, April 21 2010, 14:30GMT.*

## 3. Conclusions

In this study we have tried several methods for a better estimation of the cloud top height from lidar measurements and we have compared the results with satellite data. Even though both systems have limitations; we consider that using powerful lidars, cloud boundaries can be better estimated by using first derivate of RCS. The estimation of cloud top from satellite is not so precise, strongly depending of cloud optical thickness.

These preliminary analyses underline that both techniques passive and active can estimate cloud top height within a 0.65 km differences. Combining these techniques with LiSA model we can improve the accuracy of cloud top height estimation at ±0.49 Km.

The accuracy of heights obtained from satellite imagery is limited by the known accuracy of the vertical atmospheric temperature profile and surface temperature. The study will be continued using several satellite channels to estimate cloud top height and more cases in order to overcome systems limitations and to improve the satellite cloud estimation.

**Acknowledgements**

The authors wish to acknowledge DELICE grant contract FP7 REGPOT-2008-1 Contract no. 229907.

This work was supported by a grant from Norway through the Norwegian Co-operation Programme for Economic Growth and Sustainable Development in Romania- RADO grant contract STVES 115266.

## References

[1] K. Y. Kondratyev, V. I. Binenko, 1984, Gidrometeoizdat, Leningrad, (1984).
[2] G. L. Fiona, Geophys Res Lett, **28**(9), 1675 (2001).
[3] S. Hollars, Qiang Fu, J. Comstock, T. Ackerman, Atmos Res, **72**, 169 (2004).
[4] Schmid J., The SEVIRI Instrument, http://www.eumetsat.int
[5] J. Schmetz, P. Pili, S. Tjemkes, D. Just, J. Kerkmann, S. Rota, A. Ratier, B Am Meteorol Soc, **83**(7), 977 (2002).
[6] Stull, Roland B., Kluwer Academic, 666 (1988).
[7] Murry L. Salby, Academic Press, (1996).
[8] S. Stefan, D. Nicolae, M. Caian, Ars Docendi, Bucuresti, (2008).
[9] C. Talianu, D. Nicolae, J. Ciuciu, M. Ciobanu, V. Babin, J. Optoelectron. Adv. Mater., **8**(1), 243 (2006).
[10] R. M. Schotland, K. Sassen, R. J. Stone, J. Appl. Meteor., **10**, 1011 (1971).
[11] V. Noel, K. Sassen, J. Appl. Meteor, **44**, 653 (2005).
[12] B. A. Baum, R. M. Welch, P. Minnis, L. L. Stowe, J. A. Coakley, Jr. J. Titlow, V. Tovinkere, P. W. Heck, Q. Trepte, D. R. Doelling, S. Mayor, T. Berendes, Q. Han, S. A. Christopher, K.-S. Kuo, M. Penaloza, A. Logar, P. Davis, NASA Reference publication **1376**, 43 (1995).

*Corresponding author: mluminita@inoe.inoe.ro