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OPTIMIZATION OF LIDAR SYSTEMS MEASUREMENTS FOR DETECTION OF CLEAR AIR TURBULENCE

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ABSTRACT. In this paper we analyse the optimization of lidar systems in order to investigate Clear Air Turbulence (CAT), which is a dangerous weather phenomenon affecting especially the commercial aircrafts. It is assumed that aircrafts can cause air turbulence that can be detected by lidar, since pressure gradients could cause slight variations of the molecular depolarization values. This study will assess the capability of the lidar systems to highlight air turbulence from depolarization profiles. In order to do this, lidar measurements were performed at two sites in Romania: one in Magurele, near Bucharest and one in Cluj-Napoca. The measurements were accompanied by continuous flight path monitoring to mark the incidence events above the measuring locations.

Keywords: *lidar, CAT- Clear Air Turbulence, aircrafts*

INTRODUCTION

One of the most dangerous aviation hazards is represented by the Clear Air Turbulence (CAT). CAT is defined as the turbulent movement of air masses in the absence of any visual clues, such as clouds. It is caused when bodies of air moving at widely different speeds meet (Stull, 1988). Usually this is a high altitude, sudden phenomenon encountered outside of convective clouds that causes violent buffeting of aircrafts. The part of the flight most prone to injuries from CAT is the cruising phase, because passengers and crew are often unbuckled (Sharman et al., 2006). CAT produces one of the largest causes of weather-related aviation accidents, accounting for 24% of all weather related accidents (Kim and Chun, 2011). Storer et al., in a 2017 study, noted that currently there are strong increases in the number of clear air turbulence over the entire globe, especially in mid latitudes where the busiest flight routes are located.

Remote sensing instruments, such as lidar systems and sun radiometers are currently widely used for measuring atmospheric dynamics and optical and microphysical properties of different components like clouds and aerosols (Calinoiu et al., 2018). Lidar techniques for atmospheric studies are one of the most powerful tools used in studying the composition and vertical structure of the atmosphere.

In this paper we analyse the optimization of lidar systems in order to investigate the Clear Air Turbulence phenomena. This work was done during the first measurements campaign within the CONTUR - Emerging Technologies to Counteract the Effects Induced by the Turbulent Flows of Fluid Environments 87PCCDI/2018 research project. This project aim is to develop emerging technologies to counteract effects induced by the turbulent flows. It is divided into two complementary component projects: the first one is dedicated to the study of the clear air turbulence, while the second is aimed at designing new active control technologies to reduce vibrations (Radu et al., 2018). The main objective of the campaign was to assess the detection capabilities of the Clear Air Turbulences by using the lidar systems from 2 sites in Romania: Măgurele, near the capital city of Bucharest and Cluj-Napoca in north-western part of Romania. The campaign focused on the detection of turbulences produced by large aircrafts – the wake turbulences.

EXPERIMENTAL

It is assumed that airplane's wings and engines can cause air turbulence that can be detected by lidar systems, since pressure gradients could cause slight variations of the molecular depolarization values. The Raman lidar systems detect the Raman backscattering radiation from atmospheric molecular nitrogen and water vapour and Mie / Rayleigh backscattering radiation from atmospheric molecules and aerosol particles. Two multi-wavelength Raman depolarization lidar systems capable of measuring molecular depolarization at 532 nm (Belegante et al., 2018, McCullough et al., 2017) were used during the CONTUR campaign.

One system – RALI – is located at the National Institute for Research and Development in Optoelectronics INOE 2000 in Măgurele, near Bucharest. The laser emission wavelengths are 1064 nm (90mJ), 532 nm (50mJ) and 355 nm (60mJ) and the detection channels are 1064, 532 cross, 532 parallel, 355 nm (elastic wavelengths), and 607, 387 and 408 nm (Raman channels). The laser pulse duration is 7-9 ns, repetition rate 10 Hz, and the beam diameter between 5.5-7 mm. The dynamic range covers 2-15 km depending on atmosphere transmission, with a 3.75 m spatial resolution. The reception has a 400 mm Cassegrain telescope with 1.73 mrad field of view, and the system acquisition is both analogue and photon counting, with a 20 MS/s analogue sampling rate and 250 MHz photon counting count rate. The output parameters are the backscatter coefficient, the extinction coefficient, water vapour mixing ratio (for 407 nm), particle depolarization ratio for 532 nm (Belegante et al., 2015).

The second LIDAR system – CLOP – is located at the Faculty of Environmental Science and Engineering within the Babes-Bolyai University, in Cluj-Napoca. The emission system is based on a Nd:YAG laser (Continuum INLITE II -30) with a repetition rate of 30 Hz. The laser beams at 1064 nm, 532 nm and 355 nm are simultaneously emitted into atmosphere. The dynamic range covers 2-12 km depending on atmosphere transmission, with a 3.75 m spatial resolution. The backscattered radiation is collected by a Raymetrics D300 Cassegrain type telescope with a focal length of 1500 mm. The signal detection unit has 4 detection channels, acquisition being both analogue and photon counting, for the elastically backscattered radiation at 1064, 532 (cross and parallel) and 355 nm and 2 detection channels for the Raman radiation backscattered from the N_2 molecules at 607 and 386 nm (Ajtai et al., 2017).

In order to obtain the lidar profiles, measurements were divided into data sets with 3 integration times: high (1 minute), average (30 seconds) and small (15 seconds), corresponding with the temporal scale of this type of turbulence. The measurements were accompanied by continuous flight path monitoring to mark incidence events above the measuring location. For this, an area of interest was defined, which included several degrees of incidence with flights in transit over stations (200, 500, 1000 and 2000 m) (figure 1).

a. b.

Fig. 1. Distances of interest overlapping the 2 lidar systems:
a. Măgurele b. Cluj-Napoca

RESULTS AND DISCUSSION

The testing campaign to detect CAT events took place between 10 and 14 September 2018. The campaign was focused on the detection of turbulent phenomena caused by the passage of large - scale airplanes - wake turbulence. This type of turbulence can be marked in space and time by continuous air traffic monitoring over the two sites with lidar systems at INOE 2000 (National Institute for Research and Development in Optoelectronics, Bucharest and UBB (Babes-Bolyai University), Cluj-Napoca, Romania).

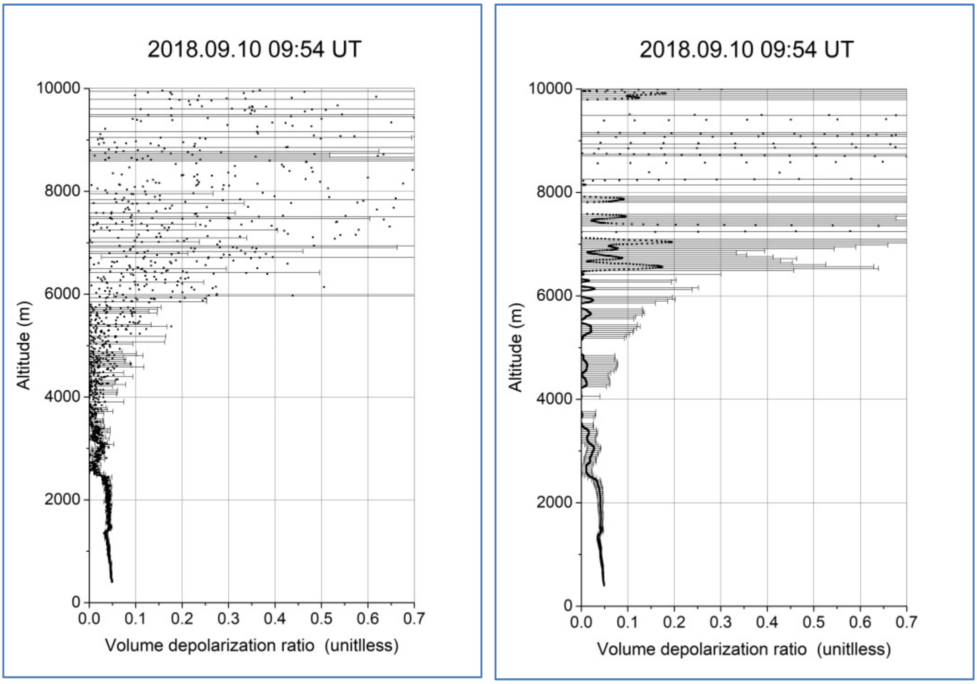
Profiles obtained during the campaign did not highlighted patterns that may be associated with turbulence events. At Cluj-Napoca station, out of a total of 86 flights, only 6 cases where within the 500 m radius as seen in table 1. At Bucharest station 5 cases where within the 500 m radius out of a total of 15 flights within the 2000 radius.

Table 1. Flights within a 500 m radius of the LIDAR sounding point at Cluj-Napoca station

Date	**Time**	**Altitude (m)**	**Ground speed (km/h)**	**Airplane type**	**Estimated distance from LIDAR sounding point (m)**
10.09.2018	14:23	9,140	770	Boeing 777	190
10.09.2018	14:58	9,750	760	McDonnell Douglas	200
13.09.2018	9:05	10,360	820	Airbus A 321	160
13.09.2018	10:35	876	285	Airbus A320	395
13.09.2018	11:39	1,700	390	Boeing 737	410
13.09.2018	13:43	2,725	330	ATR 42	175

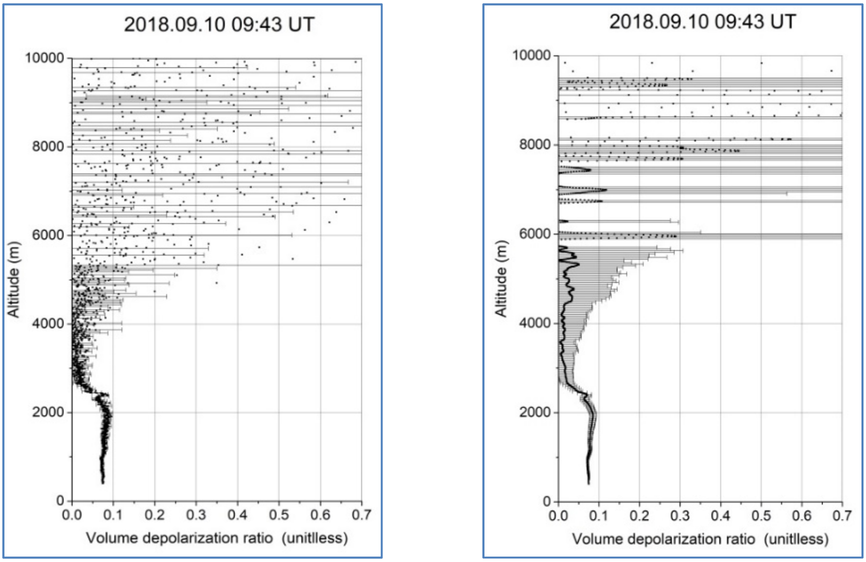
In order to assess the performances of the lidar systems, the profiles with the shortest integration time (15 seconds) were analysed. The most suitable integration time for obtaining the LIDAR profiles coincided with the lowest possible statistical error as this was the main indicator for determining the quality of the signal.

The obtained lidar profiles show a good signal to noise ratio for altitudes up to 3 km in all cases. After the smoothing process was applied to the lidar profiles, one can observe an improvement in the signal, but even in this case, the systematic error shows a good signal up to maximum 4 km for Măgurele station (figure 2) and maximum 5 km for Cluj-Napoca station (figure 3). In the case of night measurements performed in 13.09.2018 at Măgurele station, one can observe that the relative error is improving and the profiles are useful up to 8 km as seen in figure 4. This is due to the reduced signal noise specific to the lidar night measurements.



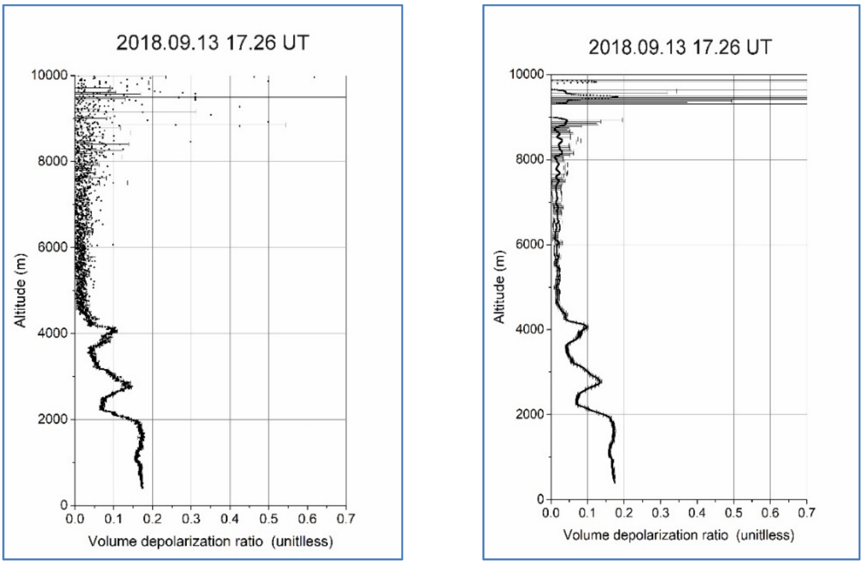
a b

Fig. 2. Volume depolarization ratios profiles for 10.09.2018, Măgurele, at 15 seconds: a. raw signal, b. smoothed signal



a b

Fig. 3. Volume depolarization ratios profiles for 10.09.2018, Cluj-Napoca, at 15 seconds: a. raw signal, b. smoothed signal



a b

Fig. 4. Volume depolarization ratios profiles for 13.09.2018, Magurele, at 15 seconds: a. raw signal, b. smoothed signal

CONCLUSIONS

During the first CONTUR ("Emerging Technologies to Counteract the Effects Induced by the Turbulent Flows of Fluid Environments 87PCCDI/2018 research project") campaign that focused on the investigation of air turbulence events, lidar depolarization profiles were used together with CCD imaging to monitor the airplane overpass occurrences over Măgurele and Cluj-Napoca for assessing the performance of CAT detection.

By analysing the measurements, we concluded that integration times of 15 seconds and lower should be used in the next campaigns in order to be able to identify the air turbulences. Lidar profiles indicated a useful signal up to 5 km for daytime for both lidar systems, while for night time the useful signal was up to 8 km. The contrails produced by aircrafts engine exhaust or changes in air pressure may have an influence on the depolarization profiles. Based on these findings the next campaign aims to conduct night-time measurements at low integration times, 15 seconds and lower, focusing on altitudes upwards of 6 km for a greater chance of turbulence detection.

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