Measuring Wake Vortices and Wind Shears in Real-Time with a Scanning Wind Doppler Lidar

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ABSTRACT

Measuring and foreseeing wind conditions near airports are crucial issues for air traffic safety. Since aircraft maneuverability is the worst during takeoff and landing phases, strong air movements near airports such as wind shears or wake vortices can have dramatic consequences on aircrafts. These phenomena are nevertheless very different since wind shears are generated by geography around airports, whereas wake vortices are created by aircrafts themselves. Wind shears usually appear in airports located near coasts, valleys, or mountains. These geographical items induce different winds in direction and in intensity depending on meteorological conditions. Wake vortices are generated by all the planes. Size and intensity of wake vortices are directly linked to the flight speed and also by plane characteristics, such as weight and wingspan. Even if strong efforts have been done to study and model wind shears and wake vortices, on-site measurements remain the best way to detect them as they depend a lot on meteorological conditions near airports especially wind and turbulence.
Coherent laser radars or LIDARs can be very powerful devices for measuring wind shears on dangerous airports or wake vortices. LEOSPHERE has developed a scanning wind doppler lidar, the Windcube200S for these needs. Deployed on a french airport in the framework of the european project SESAR, this lidar has been used to detect wake vortices and follow them under various atmospheric conditions. Given specific swept scenarios, the Windcube200S has been able to detect the wake vortices of heavy, medium and small aircrafts during takeoff and landing. Wake vortices have been monitored for a period of 30 to 60 seconds that allowed to analyze theirs trajectories and theirs shapes evolution. Several analysis have been achieved in order to determine the influence of the wind conditions on the trajectories of wake vortices. A variety of trajectories have been put in front. Finally, a dedicated post-treatment has been developed for identifying the cores of wake vortices and for calculating theirs circulations.

1. INTRODUCTION

Microscopic scales can have a strong impact on human activities: Wind gusts or wind shears may have impacts on air traffic control (flights delayed, misapproaching of aircrafts) or in wind energy, Wind turbines can be damaged or can age faster.
Wind hazards and micro-scales are short and local phenomena. They depend a lot on weather conditions. So it's necessary to develop refined numerical models and to use highly resolved unmanned and full time operational ground-based sensors.
As an example, in this paper, some results of scanning Doppler lidars are presented in order to demonstrate the capability of such sensor to monitor the dynamics inside the planetary boundary layer, like storms, wind shears and wake vortices. This kind of new sensor opens a new area in meteorology and all the domains, such as air quality and wind energy, where the 4D mapping of the wind fields is absolutely needed.

2. INSTRUMENTAL SETUP

Developed in cooperation with the French Aerospace agency (ONERA), the LEOSPHERE WINDCUBE 200S is the results of 20 years of research and development in the domain of fiber lasers. This is an active remote sensor based on Light Detection and Ranging technique (LiDAR). The heterodyne LiDAR principle relies on the measurement of the Doppler shift of laser radiation backscattered by the particles in the air (dust, water droplets from clouds and fog, pollution aerosols, salt crystals, biomass burning aerosols…).

Figure 1: The WINCUBE200S

The WINDCUBE technology [1] allows the user to get various quantities of the PBL: real-time radial wind speed, wind speed, wind direction, wind speed standard deviation as well as relative backscatter coefficient.
Thanks to its hemispherical scanner, multiple measurement scenarios can be assessed in any direction in order to map the wind around the lidar until 6.5 km. with high temporal (1s) and spatial (50m) resolutions.

SPECIFICATIONS	PERFORMANCE
LIDAR	WINDCUBE200S
Wavelength	1,54 µm
Mini-Max range (aerosols detection)	100m to 6,500 m
Averaging time	1s to 2s
Range resolution (range gate width)	50m to 200m
Number of programmable gates	58
Radial wind speed accuracy	0,2 m/s

Table 1: WINDCUBE200S Main specifications

These high resolutions are usually required to ensure the monitoring all kind of micro-scales in the PBL (wind shears, wake vortices, turbulence). WINDCUBE200S can detect plume dispersion, and also provide pollutant spatial variability around particle pollution sources.

3. PBL DYNAMICS

A scanning Doppler lidar allows to monitor the vertical structure of the wind fields inside the PBL. For instance, the WINDCUBE200S was deployed in 2011 at Paris -CDG airport. On the wind fields below, the evolutions within 3 hours of wind in the PBL for two consecutive days are displayed. The first case shows that a turbulent transition, whereas the second one increase of the wind at the lowest altitudes.

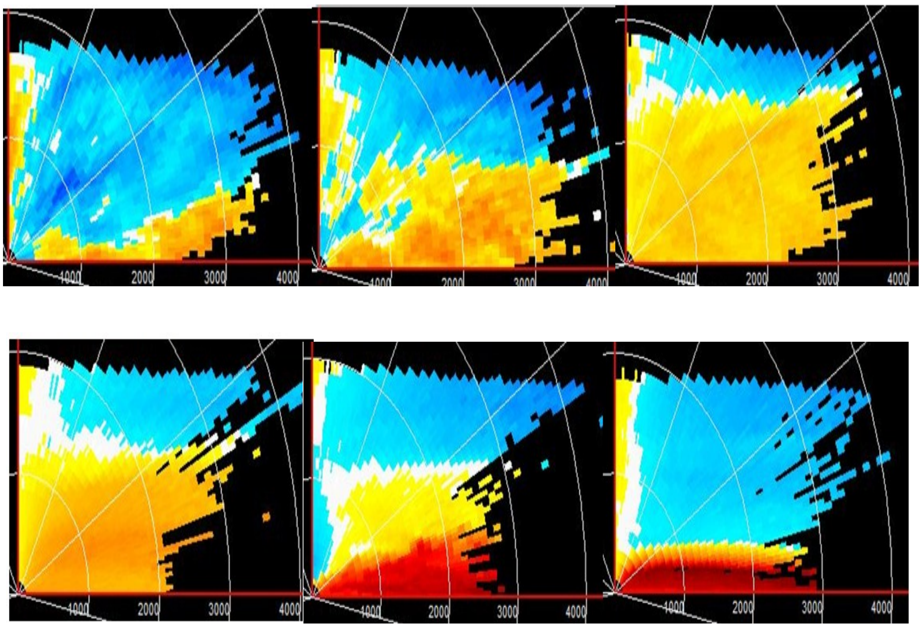

Figure 2: Evolution of two winds in the PBL for two consecutive days

4. WIND SHEARS

In horizontal scanning mode, a scanning Doppler lidar allows to monitor horizontal wind shears at low altitudes. This kind of micro-scales is of interest especially for the airport safety. To ensure the safety of landings and takeoffs of aircrafts, low level wind shears must be understood and forecast. In the example below, a horizontal wind shear can be observed which lasts less than 15 min and which is due to a specific orography.

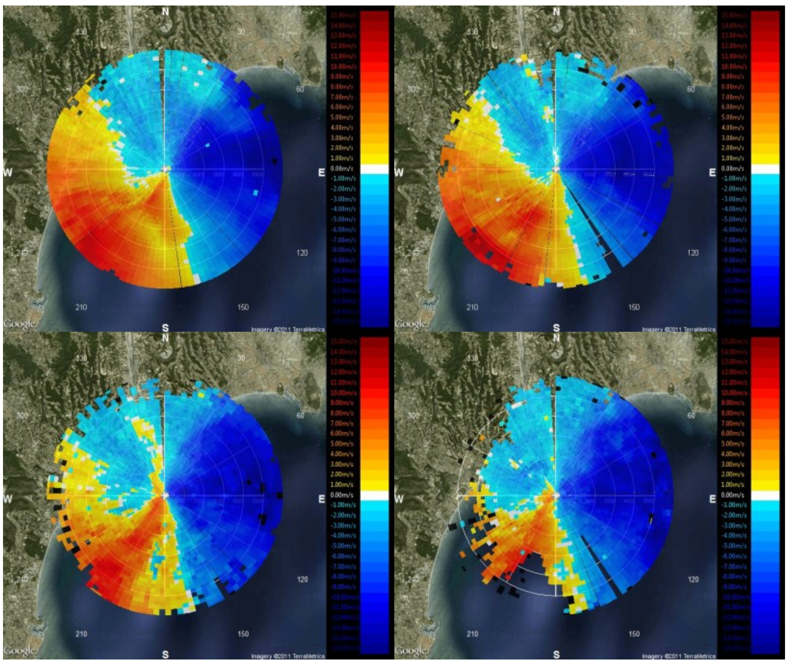

Figure 3: Example of a horizontal wind Shear

5. WAKE VORTICES

All aircrafts create wake vortices (WV), whose the strength is linked to weight, wingspan and speed. FAA (federal aviation administration in USA) specifies distance-based separation between two aircrafts for landing and takeoff. In the framework of the SESAR EU project, whose the aim is to fix the future recommendations for air traffic control in Europe, a WINDCUBE200S was deployed in 2011 at Paris-CDG Airport in the sub package dedicated to the detection of WV in real-time in partnership with Thales Air System.
More than 200 WVs have been detected for light, medium and heavy aircrafts, during take-off or landing configuration with an algorithm developed by ONERA [2].
Monitored by a wind Doppler Lidar, WVs look like a dipole with two zones, one with a positive wind speed and the other with a negative wind speed. Their cores are located in between these two zones. In the example below, four snapshots of the detection of WVs of a heavy aircraft during takeoff are represented.

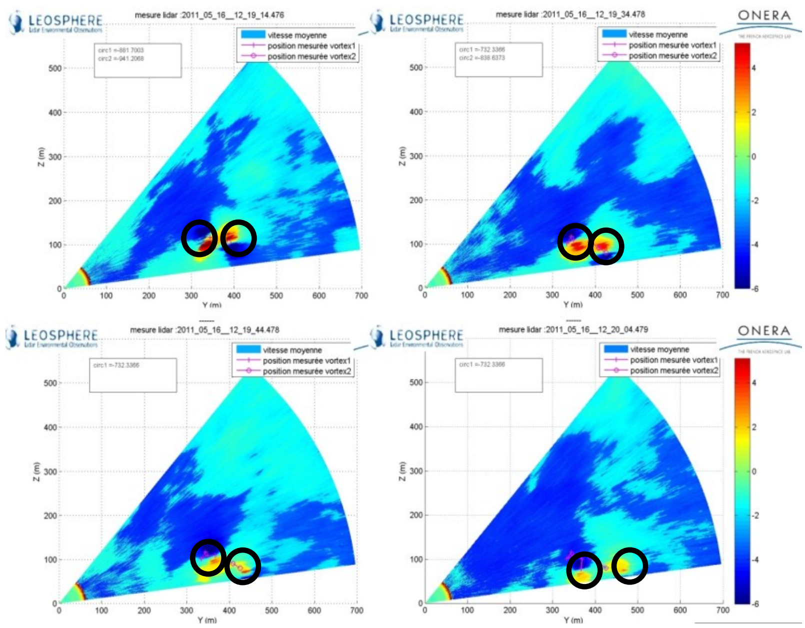

Figure 4: A monitoring of Wake Vortices during 1 min for a heavy aircraft at take-off

Many improvements must be done to automatically and accurately detect WVs until theirs dissipation. The final objective is to determine the intensities (ie. circulation) and the trajectories of the WVs in real-time thanks to advanced post-processing methods of the lidar measurements.

6. CONCLUSIONS

Scanning Doppler lidars open a new area to understand dynamics in PBL, if the lidar has a sufficient range, spatial and time resolutions and scan speed in adequation to micro-scales characteristics. These micro-scales are of interest for meteorology, climate, air quality and also operational purposes like air traffic safety.
Several deployments have demonstrated the ability of a Windcube200S to detect storms, wind shears and wake vortices.
Other potential applications of Windcube200S are large site assessment for wind energy and air quality studies for which a first trial has been achieved. Below, the Windcube200S has been able to detect plumes in an industrial area.

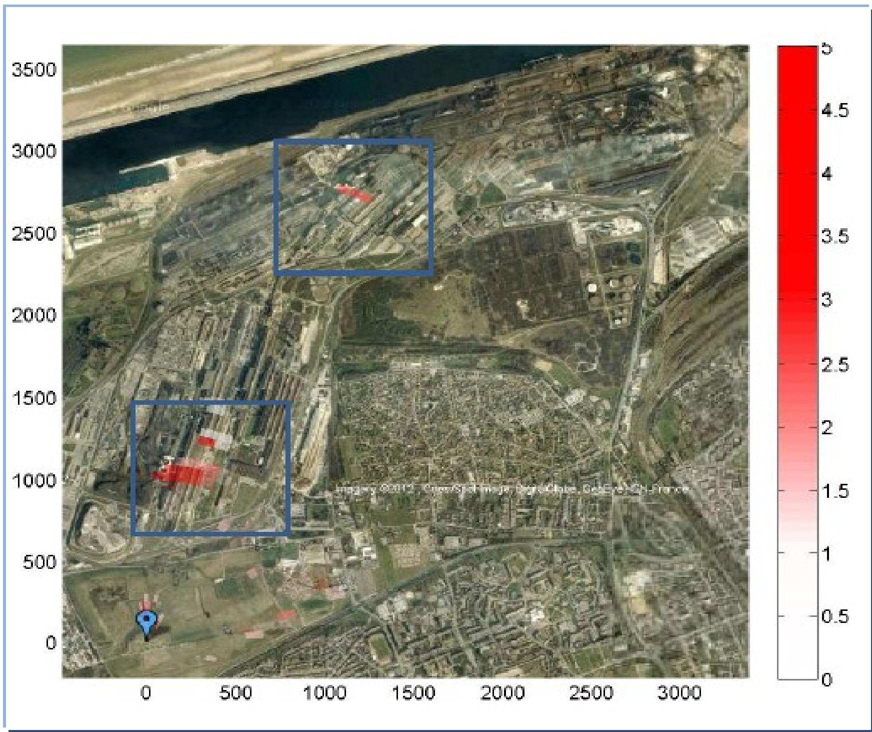

Figure 5: Plumes detection with WINDCUBE200S in an industrial area in France

7. ACKNOWLEDGEMENTS

The authors would like to thank Thalès Air system for being involved in the SESAR Project related to the study of wake vortices with lidars. The authors would like also to gratefully acknowledge the work done by ONERA on the analysis of lidar measurements in order to detect and monitor wake vortices.

8. REFERENCES

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