Capabilities and Benefits of Coherent Doppler LIDARs for Future Weather Observing Networks

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Abstract: In order to improve local weather forecasts especially of severe weather events and in complex environments (urban, specific orography…), accurate and high resolved wind measurements are required by numerical weather prediction models. This paper will study the potential use of coherent Doppler LIDARs to cover regional and local areas of interest. The intrinsic performances of Doppler LIDARs like data availability will be firstly presented as well as their technical siting constraints. The capabilities of LIDARs to better monitor severe weather and to improve local weather forecasts by assimilation will be described through a series of trials. The paper will finally highlight the main constraints for building LIDAR observing networks.

Keywords: Coherent Doppler LIDAR, observing network, weather forecasts, severe weather, data assimilation

1. Introduction

In spite of the constant effort to improve weather forecasts since a few decades, weather forecasts remain relatively inaccurate for predicting weather in a few days at a local scale. Today, there is a growing interest to focus on local and regional scales. Indeed, in case of severe weather, weather forecasts are crucial to drastically reduce the impact on human lives and economical activities where weather risk exposure is the highest (urban, business, industrial area). The goal is to anticipate the most possible the weather risk in supporting local authorities and decision makers. To reach this objective, numerical weather prediction models must be improved by increasing their spatial resolution. Since several years, their resolutions have been reduced from 20 - 50km to 1-5 km and are still decreasing. Such models require more local observations as initial conditions. But existing weather observation networks were designed for national coverage and not for providing dense observations to high resolution models. New sensors are then required for providing more local, dense, accurate observations with high spatial resolution inside the planetary boundary layer and close to the ground. Wind LIDAR technologies developed since the 1990s have expanded vastly in the 2000s with the introduction of commercial off-the-shelf fiber optics components developed for the telecommunication industry. This LIDAR technology allows to obtain cost effective sensors thanks to industrial manufacturing. Today, Coherent Pulsed Doppler LIDAR is evaluating worldwide in various projects to determine its benefits for weather observing networks [1][2]. In this paper, their capabilities in terms of wind and aerosol/cloud measurements are described. Their potential benefits for future observing networks are demonstrated by two examples related to severe weather monitoring and weather forecasts improvements. The main constraints to build future weather observing networks composed of coherent Doppler LIDARs are detailed.

2. Measurement capabilities

Roughly one thousands of Coherent Doppler LIDARs (CDL) is used worldwide for different applications but the largest majority for wind energy applications. Wind LIDAR profilers allow to measure the wind speed and direction from a few tens of meters above the ground to the height of the planetary boundary layer (1-2km) for the long range LIDARs. The typical accumulation time for providing individual
measurements is 1s but usually raw wind data are averaged over 10 minutes. Scanning Doppler LIDARs are based on the same technology whereas they allow to measure the 3D hemisphere around the LIDAR location and up to 10 km. There are several scanning scenarios that can be performed, such as Plan Position Indicator (PPI), Range Height Indicator (RHI), Line of Sight (LOS) and Doppler Beam Swinging (DBS). Both types of LIDARs allow to provide high resolution in space and time wind data typically from 20 to 200m and from 1s to 1min. The demonstrated wind accuracy compared to reference met masts is usually below 0.3m/s [3][4]. In DBS mode, CDLs can provide the vertical structure of the wind vectors, as shown by the figure below, as well the clouds and aerosols layers.

![Figure 1. Evolutions over two days of the wind speed (left) and LIDAR signal (right)](image)

The typical range of measurement is limited by the height of the planetary boundary layer delimiting the free atmosphere where no more aerosols are present and can then backscatter the light emitted by the LIDAR. Similarly, when pointing horizontally, ranges of CDLs are limited by atmospheric conditions more precisely the ones linked to aerosol contents like the atmospheric extinction or the visibility or also the type of aerosols. Basically, nominal range performances can be obtained under clear air conditions, which mean visibility above 10km and without rain. Due to these limitations, the coupling between LIDAR and RADAR is mostly developed worldwide to develop all weather observing systems. In addition to wind measurements, the signal reflectivity of CDLs can be retrieved from the signal strength. Aerosol and cloud functionalities have been developed like on WINDCUBE CDLs to detect the atmospheric structures (cloud/aerosol layers, PBL height) and provide relative to absolute backscatter observations [5][6]. Few examples of the combined use of wind and aerosol products are described later to demonstrate the potential benefits of CDL for building future weather observing networks.

3. Benefits of LIDAR for weather observing networks

3.1. Severe weather monitoring

If radars are already widely used for monitoring severe weather, their limited capabilities to measure in clear air conditions (before the arrival of storms) don’t permit to follow the prevailing winds that affect the trajectories of storms. It has been recently demonstrated that local wind conditions like sea breezes could enhance the occurrence and severity of severe storms. As suspected in Queensland, Australia, the Coastal Convective Interactions Experiment (CCIE) has been launched by University of Queensland [7]. The goal is to quantify thunderstorm hotspot activity and to better understand anomalous spatial behavior of thunderstorms. Many sensors (X-Band radar, WINDCUBE200S scanning LIDAR) were deployed during summer’14. The scanning CDL was configured to have the highest resolution 25m and in RHI mode to measure the vertical structure of severe storms.
As an example below, 4 RHI scans of the same storm are showed. The color scale corresponds to the backscatter whereas the dot and solid lines correspond respectively to positive and negative Doppler wind speeds. The CDL allows to better understand the arrival of the storm including the sequence of two gust fronts with a complex merging. At the end, the downdraft of the storm can be observed in spite of the strong heavy rains that limit the observations of its internal structure by the CDL.

### 3.2. Assimilation of LIDAR wind data into high resolved model

In the framework of the European project UFO, a data assimilation exercise was performed by assimilating WINDCUBE wind data into high resolution model HARMONIE developed by the Netherlands met office – KNMI [9]. The main results summarized on the figure below show a positive and slight improvement of the local winds thanks to a short range LIDAR profiler, especially on the wind deviation and slightly less on the wind bias.

![Figure 3](image)

Figure 3. Impact of the assimilation of different data (red – reference, green – aircraft data, blue – LIDAR profiler, purple – scanning CDL) on local wind forecasts during the three hours
4. How to build LIDAR networks

Latest CDL commercial products based on fiber technology have very low consumption and do not require specific siting except a proper alignment to the geographical North and a proper pitch and roll adjustment. High Reliability and robustness are mandatory to build weather observing networks with LIDARs as well as their low operational costs. In addition, all data provided by all the LIDAR sensors require to be consistent meaning that their data must be unbiased and with an averaged precision of zero. In LEOSPHERE, specific and demanding calibration and verification processes have been developed to ensure the proper and repeatable calibration of the main internal parameters like the noise level, 0 m/s frequency and to ensure the accuracy of precision of all CDLs compared to a reference and certified CDL. Still, range of CDLs changes with atmospheric conditions and could differ from one location of the network than another. Such variations can be simulated thanks to an appropriate tool taking into account internal CDL parameters and atmospheric conditions [8].

Figure 4. test floor of WINDCUBE lidars in LEOSPHERE facilities (left) and map of expected averaged horizontal ranges for WINDCUBE100S in US (right).

5. Conclusions

The current capabilities of CDLs reveal their potential benefits for better improving weather monitoring and forecasts. CDLs are under evaluation worldwide by different expert groups like the TOPROF [REF] to determine the way to integrate them into the European operational weather networks. Few other CDL networks are currently under construction like the NYC Mesonet in USA showing the potential interest of LIDAR to better anticipate severe weather.

6. References