Performances and Benefits of Coherent Doppler LIDARs For Aviation Weather applications

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Review of CDL technologies

Coherent Doppler LIDARs (CDL) have been developed to measure wind and its characteristics remotely up to a distance of 20km with typical spatial resolutions between 25 to 200m.

Brief history:

- 1980's: Emergence of CDLs based on solid state lasers (Yag Lasers)
- End of 1990's: First commercialized 2µm CDLs by LMCT formerly CTI
- 2000's: Development of CDLs based on Fiber Lasers by QinetiQ (UK), ONERA (F)
- 2005+: First commercialized 1.5µm Fiber based CDLs by HALOPHOTONICS (UK), LEOSPHERE (FR), ZEPHIR (UK) and then MITSUBISHI (JP)

Current status in 2017

- **More than 1800 CDLs** deployed (~1000 for LEOSPHERE, ~700 for ZEPHYR). Less than 200 long range CDLs mostly for met, aviation, wind energy researches
- **Less than 15 airports permanently equipped** with long range CDLs for measuring wind, wind shears, turbulence and wake vortex : Dublin (IRE), Keflavik (ICE), Hong Kong (CH), Tokyo (JP), Munich (GER), Frankfurt (GER), Palermo (IT), Paris/Charles de Gaulle (FR)
- **Publication in July 2017 of a joint ISO / WMO Standard on CDLs** (ISO/DIS 28902-2)
- **Many experiments** conducted in SESAR EU or NEXTGEN US programs

Technological review: One study published in 2010 by Steen et al. [1] for the WAKENET3 and GREENWAKE EU projects. Among the different CDL technologies, Fiber based CDLs emitting at 1.5micron were preferred for operation uses due to their lower costs of ownerships compared to solid state laser based CDL at slightly longer wavelengths.

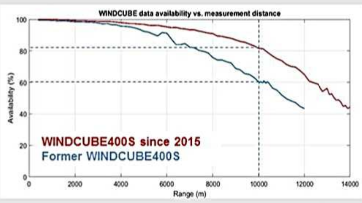
Low / Medium / High	TRL	Update-Rate	Latency	Coverage 1D/2D/3D	Range	Accuracy	Weather Resilience Very Clear / Clear / Haze / Fog /Very Low Visibility /	Low Cost
M-Scan X-band Polar	High	High	High	Medium	Medium	High	Medium	High
M-Scan X-band Pcomp	High	High	High	Medium	High	High	Medium	High
E-scan X-band Pcomp Pol	High	High	High	High	High	High	Medium	High
1.5 µm Lidar Scanner	Medium	High	High	High	High	High	Medium	High
1.6 µm Lidar Scanner	Medium	High	High	High	High	High	Medium	Low
2 µm Lidar	High	High	High	High	High	High	Medium	Low

Source: Candidate Technologies Survey of Airport Wind & Wake-Vortex Monitoring Sensors Sensors for Weather & Wake-Vortex Hazards Mitigation, M. Steen et al., INO, 2010

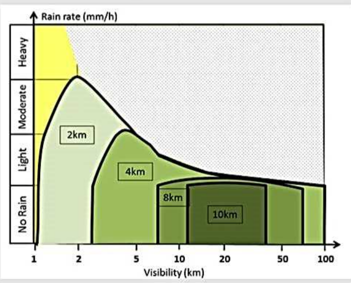
Measurement performances

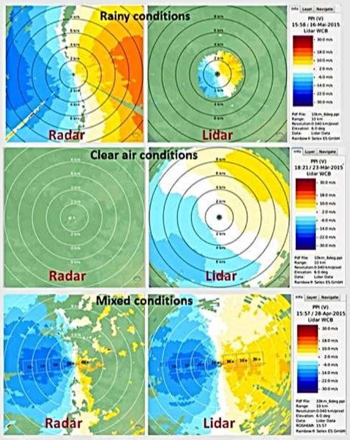
Range estimation

Measurement range can be estimated roughly by theoretical considerations or by statistical analysis as indicated in the WMO / ISO standard on CDLs. As an example, during an offshore project, a WINDCUBE400S has been deployed during 6 months . The statistical range showed a range of 10km 80% of the time with a 0.5s accumulation time.



CDL range depends mainly on met visibility (km) and rain rate making them a good candidate to complement X-Band radars.



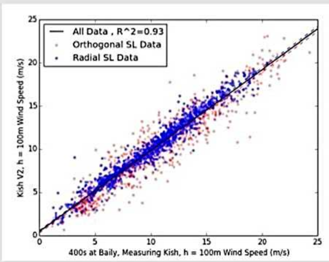


Combination of a SELEX X-Band and a WINDCUBE400S CDL during SESAR project

Wind accuracy & precision

During the same project, the wind data were compared to a reference wind profiler at 10km.

Height (m)	Data Used	Data Count	R^2	Slope	Intercept
100	All	380	0.93	0.94	0.46
	Radial	218	0.96	0.94	0.57
	Orthogonal	162	0.90	0.93	0.27
150	All	380	0.93	0.95	0.38
	Radial	220	0.96	0.95	0.54
	Orthogonal	160	0.90	0.95	0.16

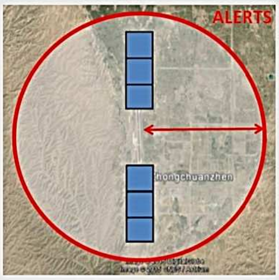


Wind precision of CDLs for two configurations as a function of the Lidar Signal (CNR in dB)

Example of Wind Shear measurements

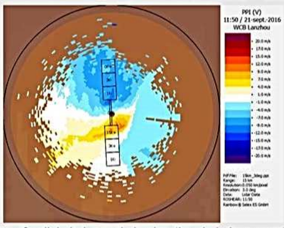
Demonstration of the use of a CDL at Lanzhou airport in Gansu, China to detect and better forecast low level wind shears under dry air conditions. A WINDCUBE400S from LEOSPHERE was coupled with the RAINBOW5 software from SELEX during 9 months.

As mentioned in ICAO Annex 3 and Manual nr9817, wind shear alerts were provided in the ARENA, ie the Area noted for attention composed of the runway + extension of 3NM (5.5km).

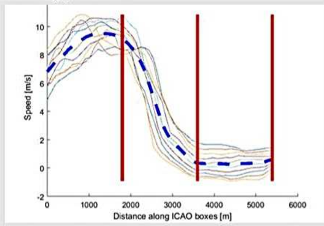


Performances evaluated	Results
Uptime ratio	99%
WindShear alert availability in the ARENA	91%
Wind shear detection according to - analysis of headwind profiles (Good Detection Ratio) - pilot reports (Probability of Dtection	GDR=100% out of 313 alerts POD=75% out of 18 PIREPs

Below wind shear event of September 21th, 2016 induced by a cold front from North. The wind shear reached 19kts over the 2nd box of the South approach.



Map of radial wind speed showing the wind shear event of the 21th of September 2016 with the wind shear intensity



Headwind profiles along the Southern approach at 11:50 the 21th September 2016

The forecasters of the airport were able to use the CDL data to improve the forecasting score of WS events of 50%.

Example of Wake Turbulence applications

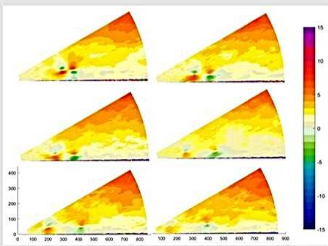
Distance separation minima imposed by ICAO PANS Doc 4444 were developed to avoid encounters by a follower aircraft of wake vortices generated by a leader aircraft. Overly conservative since designed without any detailed measurements, several programs were initiated by EUROCONTROL and FAA in 2000s to renew and optimize these regulations.

Visualization of wake vortices generated by an aircraft by clouds

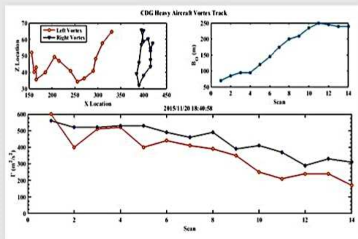
ICAO Distance separation minima matrix

RECAT-EU Distance separation minima matrix designed by EUROCONTROL and validated by EASA for EU deployments

Deployment of a WIDCUBE200S CDL by EUROCONTROL at Paris-Charles-de-Gaulle since 2015 to monitor continuously the wake vortices with vertical planes perpendicular to the runway repeated every 8s. A database of more than 50000 tracks of wake vortices has been generated with their localisation and their strength (circulation). The data are then analysed statistically to assess the safety of reducing distance separation.



Sequence of vertical planes measuring wake vortices induced by an heavy aircraft



Output data obtained by a algorithm developed by LEOSPHERE: Localization of the two wake vortices (Top left) vortex span (Top Right) and circulation (strength) decay (Bottom)

Perspectives

The use of CDLs in aviation weather is still new with only pioneer projects worldwide. Their benefits for measuring wind shears under clear air conditions and wake vortices have been already demonstrated and many operational projects are on-going. In the future, CDLs could be used for providing upper air winds in complement to surface winds. Besides, specific processing algorithms recently developed to calculate cloud base, visibility and aerosol hazards (ash) allow them becoming a versatile and multifunction met observation sensors.