The value of Doppler LiDAR systems to monitor turbulence, dust and ash intensity in order to enhance aviation safety in Iceland

Yang Shu[1], Guðrún Nína Petersen[2], David C. Finger[1]
1) Reykjavik University, School of Science and Engineering, Reykjavik, Iceland (contact: shu16@ru.is)
2) Icelandic Met Office, Reykjavik, Iceland

Summary

In this study, we use a ground-based LiDAR (Fig. 1) system stationed near Reykjavik Domestic Airport, Iceland (Fig. 2), to evaluate turbulence intensity, dust and ash concentrations. For this purpose, we retrieved radial wind velocity (Fig. 3) to compute eddy dissipation (EDR) and backscatter signals for aerosol mass concentrations. The method was used to monitor and characterize a storm event in fall 2016 (Fig. 7). The preliminary results (Fig. 8) have been compared with the method using the vertical scan (O'Connor et al., 2010), and it reveals that the LiDAR observations can detect and quantify atmospheric turbulence with high spatial and temporal resolution.

LiDAR Specifications

The Leosphere WINDCUBE 200s LiDAR

- Wavelength: 1.54 μm
- Maximum range: 12 km
- Azimuth angle: 0 ~ 360°
- Elevation angle: -10 ~ 190°

Fig 1. mobile LiDAR at IMO, Reykjavik

Fig 2. Location of Reykjavik (Left), the location of IMO (right, blue pin) and Reykjavik Domestic Airport (right, red pin).

LiDAR set up

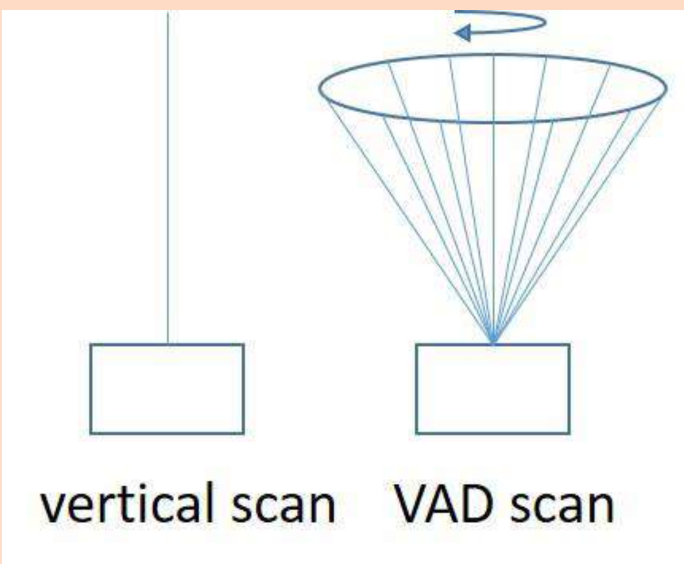

Fig 3. Two scan modes of LiDAR

For routine monitoring of turbulences the LiDAR system was programmed to do the following scans (Fig. 3):

- Continuous vertical scans
- 2 VAD scans four times an hour at 75° and 15° elevation angle, respectively
- Periodic technical scans during night

VAD Scan gets more information about horizontal wind component but requires homogeneous atmosphere.

Kolmogorov Theory

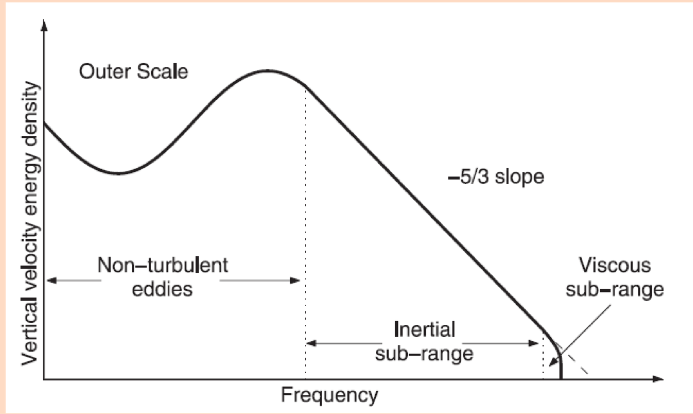

Fig 4. Schematic of vertical velocity energy density spectra vs frequency conforming to Kolmogorov's hypothesis (O'Connor et al., 2010)

The Kolmogorov Theory (see the algorithm section below) can be applied when the atmosphere is isotropic, i.e. the energy spectrum agrees with -5/3 slope (Fig. 4). Fig. 5 shows some examples. There are acceptable results where the theory can be applied directly and invalid data which should be disregarded.

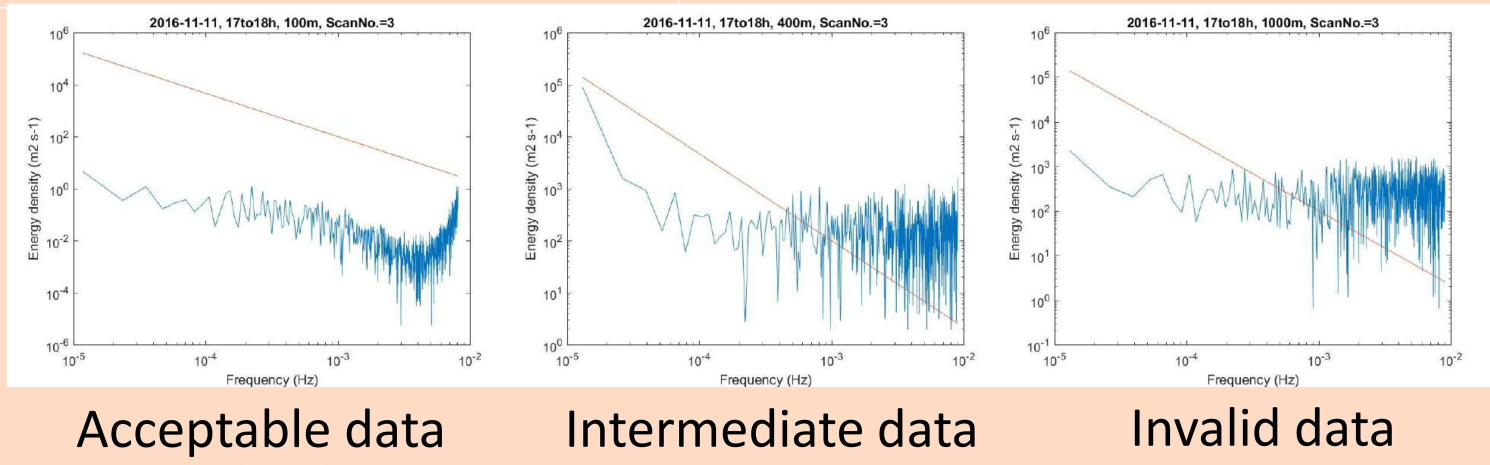

Fig 5. Some examples of energy spectrum

Algorithm to compute wind speed

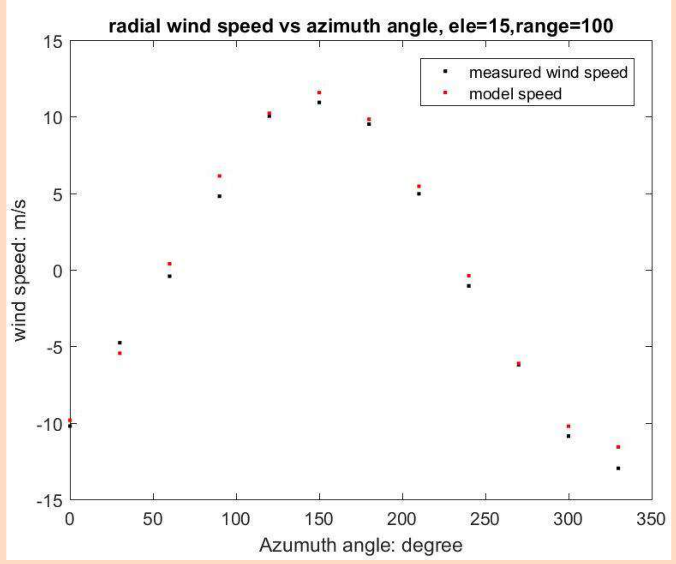

Fig 6. Measured and modelled wind velocity, the difference is fluctuation

EDR can be computed with the following algorithm:

- $D_v = C_v \epsilon^{2/3} s^{2/3}$
- Kolmogorov constant $C_v \approx 2$
- $D_v(s) = \langle [v'(r,\varphi,\theta) - v'(r,\varphi+\Delta\varphi,\theta)]^2 \rangle$
- $v'(r,\varphi,\theta)$ are the fluctuations

Fluctuations are the difference between measured and modelled wind speed (Fig. 6).

Application to real weather condition

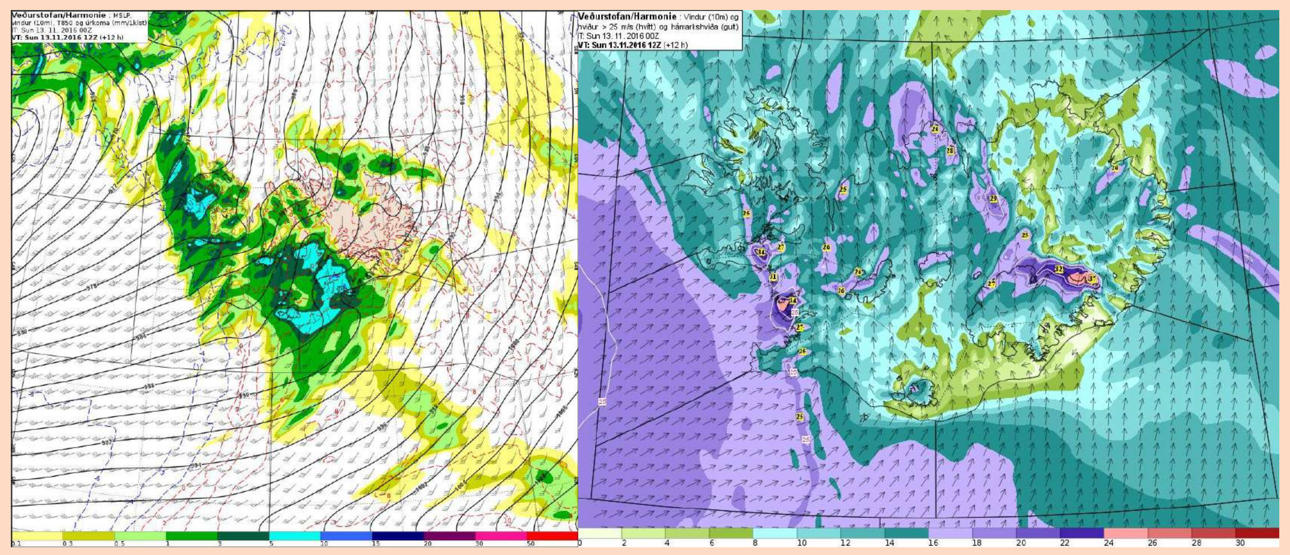

Fig 7. Weather forecast on 13 November 2016

The algorithm was applied to a selected storm event, 13 November 2016, shown in Fig. 7. Resulting wind speeds and EDR is shown in Fig. 8.

Results

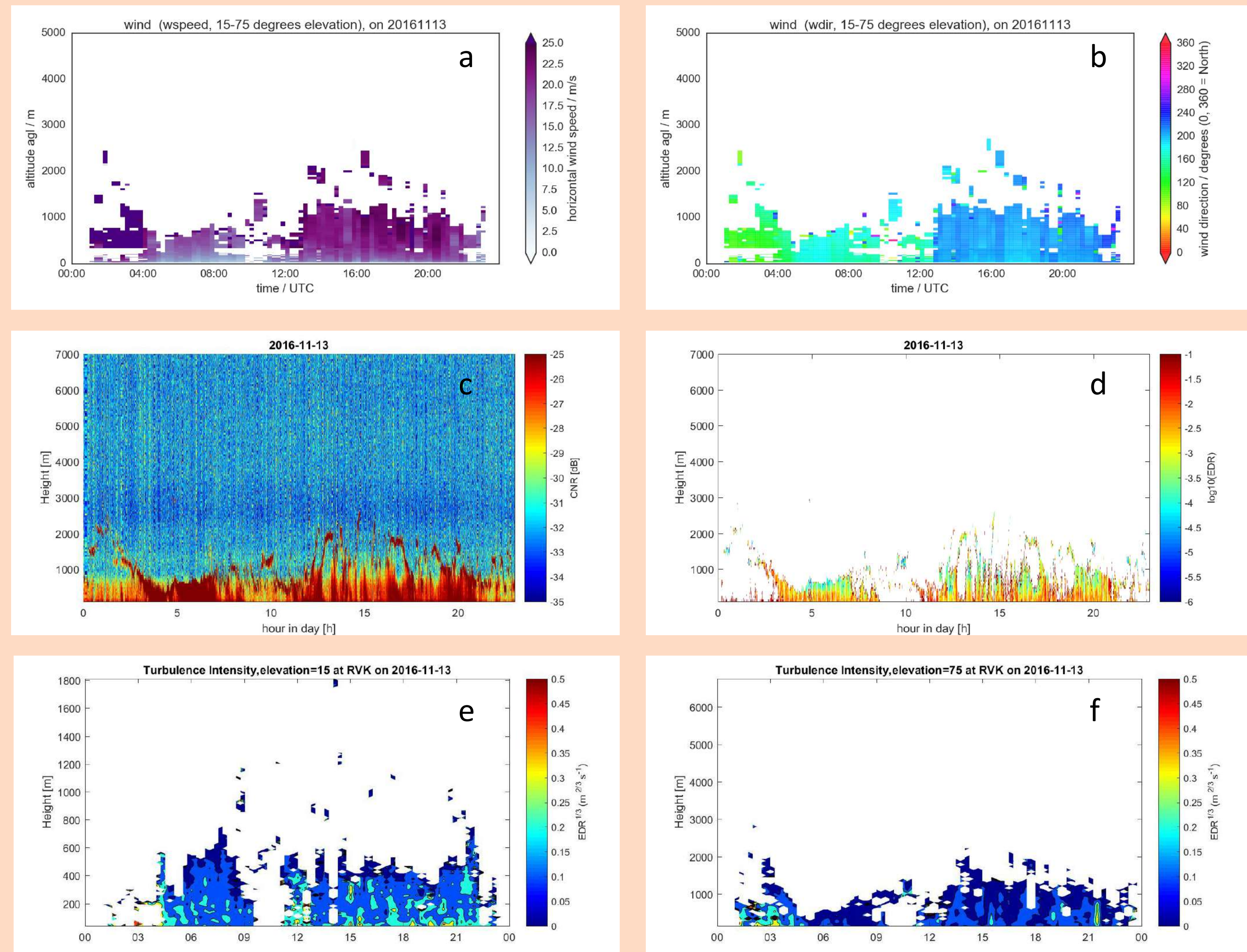

Fig 8. (a) Horizontal wind speed, (b) wind direction, (c) carrier-noise ratio, (d) eddy dissipation rate retrieved by vertical velocity (O'Connor et al., 2010), (e) eddy dissipation rate retrieved by 15° and (f) 75° degree VAD scan.

Conclusion

Fig. 8 shows that wind information can be obtained by LiDAR system, and the EDR retrieved from VAD scans (e,f) agrees with the vertical scan(d).
The preliminary result reveal that the LiDAR observations can detect and quantify atmospheric turbulence with high spatial and temporal resolution with the VAD scan.

References

1. Chan, P. W. (2010). LIDAR-based turbulence intensity calculation using glide-path scans of the Doppler light detection and ranging (lidar) systems at the Hong Kong International Airport and comparison with flight data and a turbulence alerting system. Meteorologische Zeitschrift, 19(6), 549-563.

2. O'Connor, E. J., Illingworth, A. J., Brooks, I. M., Westbrook, C. D., Hogan, R. J., Davies, F., & Brooks, B. J. (2010). A method for estimating the turbulent kinetic energy dissipation rate from a vertically pointing Doppler lidar, and independent evaluation from balloon-borne in situ measurements. Journal of atmospheric and oceanic technology, 27(10), 1652-1664.

3. Thobois, L. P., Krishnamurthy, R., Loaec, S., Cariou, J. P., Dolfi-Bouteyre, A., & Valla, M. (2015). Wind and EDR Measurements with Scanning Doppler LIDARs for Preparing Future Weather Dependent Separation Concepts. In 7th AIAA Atmospheric and Space Environments Conference (p. 3317).

Acknowledgements

This study was funded by ISAVIA, the Icelandic airport and air navigation service provider;
Jana Preissler provided the scripts for some data processing and figures drawing;
Ewan O'Connor, Sibylle von Löwis and Albert Oude Nijhuis provided valuable comments.