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Detecting Surface Layer Coherent Structures with Dual-Doppler Lidar and Tower Measurements: A Comparative Study using LES

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The combined application of two Doppler lidars in low-elevation scans enables measurements of the horizontal wind field on areas of several square kilometers. Coherent flow structures are visible in the retrieved data, albeit the reduced temporal and spatial resolution. Using LES, we compared virtual Dual-Doppler wind field data with the well-established structure detection techniques of time-series wavelet analysis to investigate if the reduced resolution impairs the potential for structure detection.

1. Dataset

For the comparison, we performed virtual lidar and tower measurements in a 30 min boundary-layer LES data-set (PALM). All wind field components were given on a 10 m-spaced grid of 5 km x 5 km x 2 km with a 1 Hz time resolution. The simulation was performed with 10 m/s geostrophic wind.

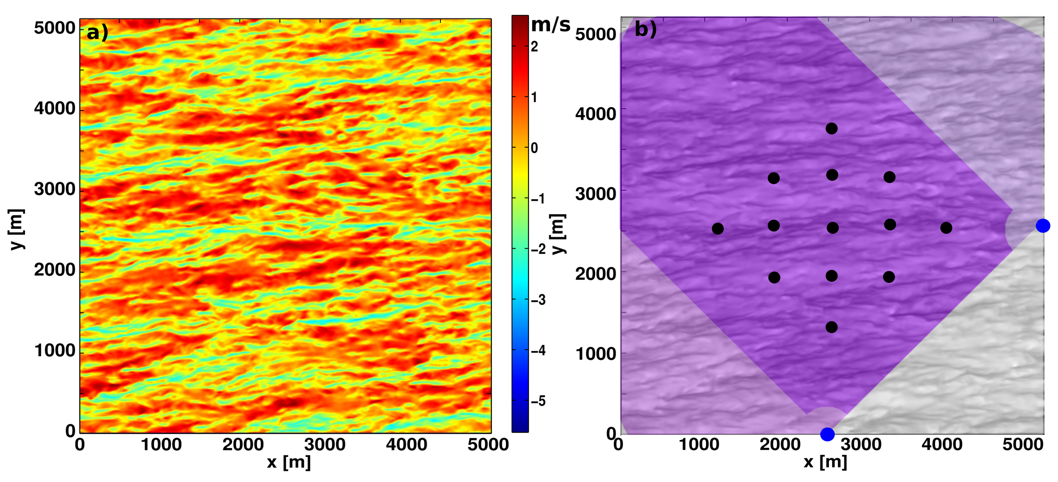

Fig. 1: a) The turbulent windfield component in streamwise direction, u', from LES data at 10 m height. b) Virtual lidar positions in LES area (blue dots) and virtual tower positions (black dots). The lidar scan areas are shaded, the dark shade is the lidar beam overlap region.

Lidar Simulation Data

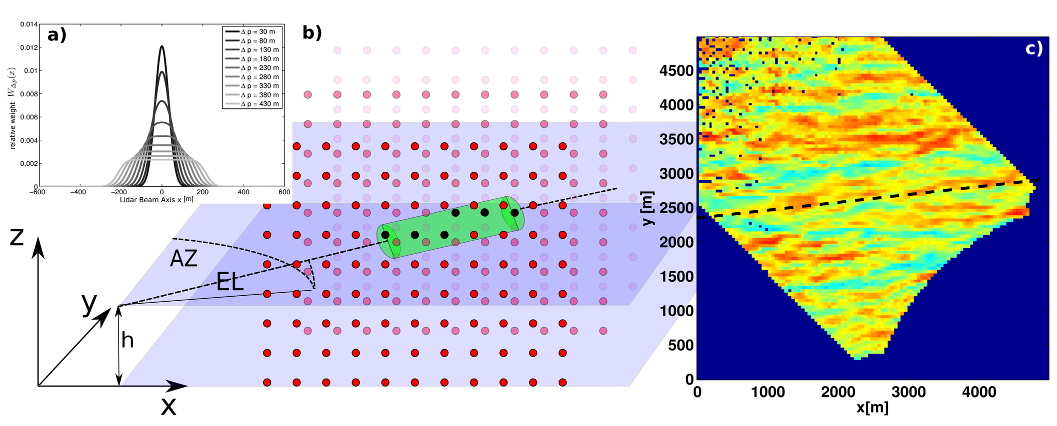

Fig. 2: a) Relative weights of radial velocity around lidar range gate center in velocity estimation b) Sketch of lidar simulator c) u' from DD-lidar retrieval, the dashed line indicates the direction of wavelet analysis.

Two virtual Doppler lidars were placed in the LES data-set. The lidar simulation tool computed radial velocities for each time step and range gate by weighting the surrounding LES grid points according to a lidar weighting function. The resulting horizontal wind field was retrieved from the radial wind velocities on a 55 m grid with 12 s resolution.

Tower Simulation Data

LES windfield data were interpolated to the positions of 13 towers (cf. Fig. 1) at a height of 10 m. The resulting time series of the wind field components were subsequently projected on the mean wind direction to retrieve the streamwise component u for wavelet analysis.

2. Wavelet Analysis

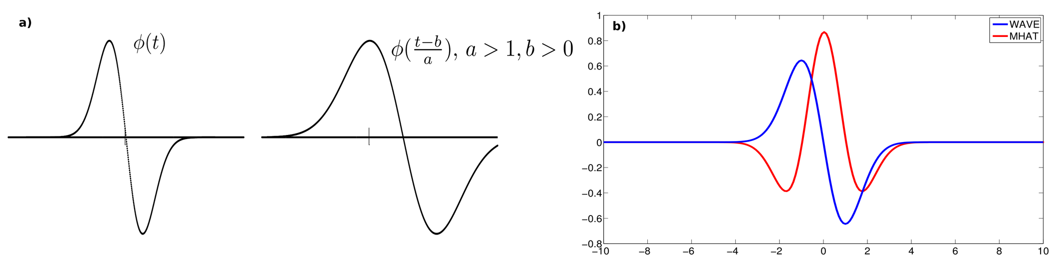

Fig. 3: a) Stretching and shifting of wavelet function. b) 'Wave' and 'Mexican Hat' wavelets

To detect structures, i.e. ejection-sweep cycles, we performed wavelet analyses using the *Mexican Hat* and *Wave* wavelets (cf. Fig. 3):

- identify the dominant scale a_0 in the *Wave* wavelet-spectrum
- detect structures at zero-crossings of the *Mexican Hat*-wavelet coefficient on the dominant scale, if the *Wave*-wavelet coefficient exceeds a threshold
- denote ramp lengths as the distance from detection point to previous *Mexican Hat*-wavelet coefficient maximum
- denote separation lengths as distance between adjacent detections

Units of time were converted to meters using Taylor's hypothesis. Fig. 4 shows an example of time series wavelet analysis.

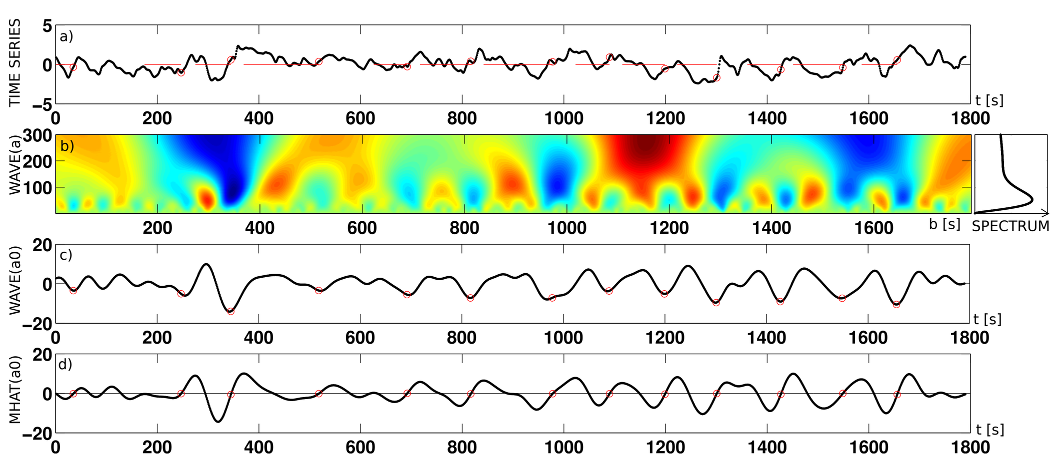

Fig. 4: Exemplary time-series wavelet analysis

For a comparison with the time series analysis, we analyzed one spatial series from each time step of retrieved Dual-Doppler data. The spatial streamwise series were extracted along a line in mean wind direction to obtain results comparable to the tower measurement (cf. Fig. 1), whereas the spanwise series were extracted along a perpendicular line. The same approach was used on the original LES data.

3. Results

Streamwise Analysis

- Lidar retrieval data slightly overestimated ramp lengths and separation lengths, which can be explained by decreased resolution.
- Tower data overestimated ramp lengths and slightly underestimated separation lengths
- Lidar data were a better fit on ramp lengths whereas tower data better matched the separation lengths.

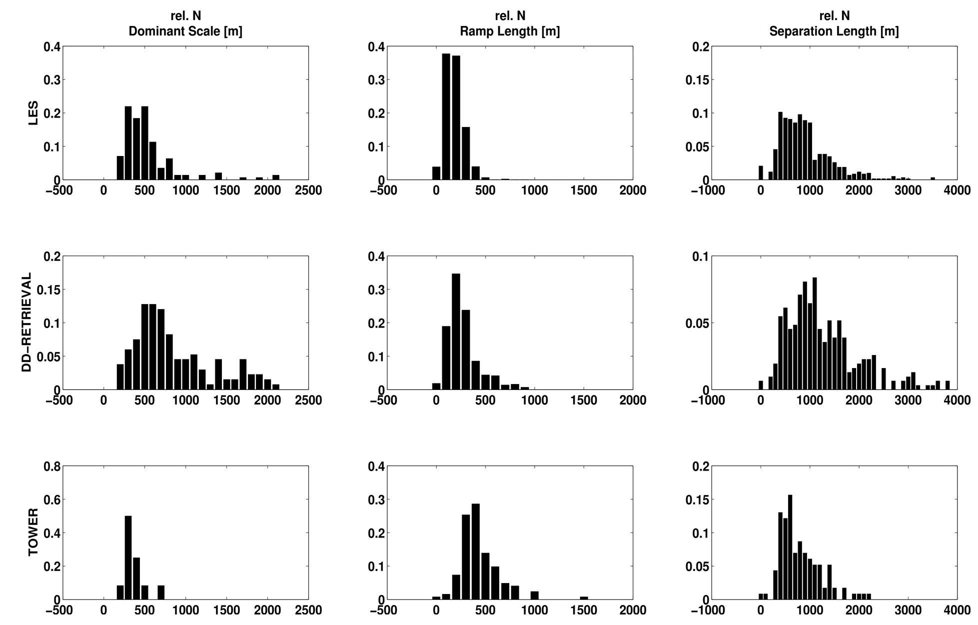

Fig. 5: Accumulated wavelet analysis results in streamwise direction: Relative frequency of dominant scales, ramp lengths and separation lengths.

Inaccuracies in tower data on larger scales could be due to the breakdown of spatial coherence for long time-lags (cf. Fig. 6).

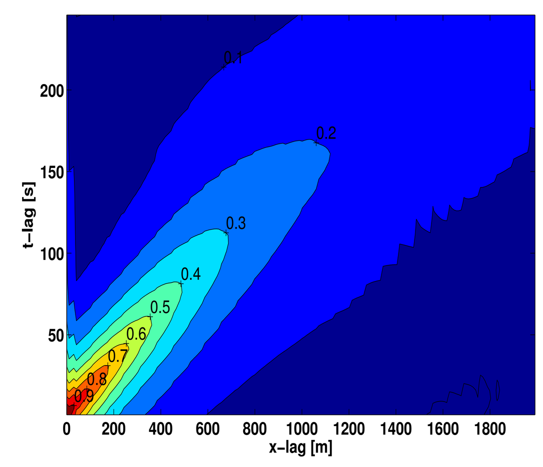

Fig. 6: Correlation coefficient of streamwise wind field LES data in 10 m height with x-lag in streamwise direction and t-lag along the time axis

Spanwise Analysis

- Although spanwise structure sizes bordered on the limit of scales resolvable by lidar, the lidar detected ramp lengths were in good accordance with LES results.
- The lidar slightly underestimated dominant scales and separation lengths.

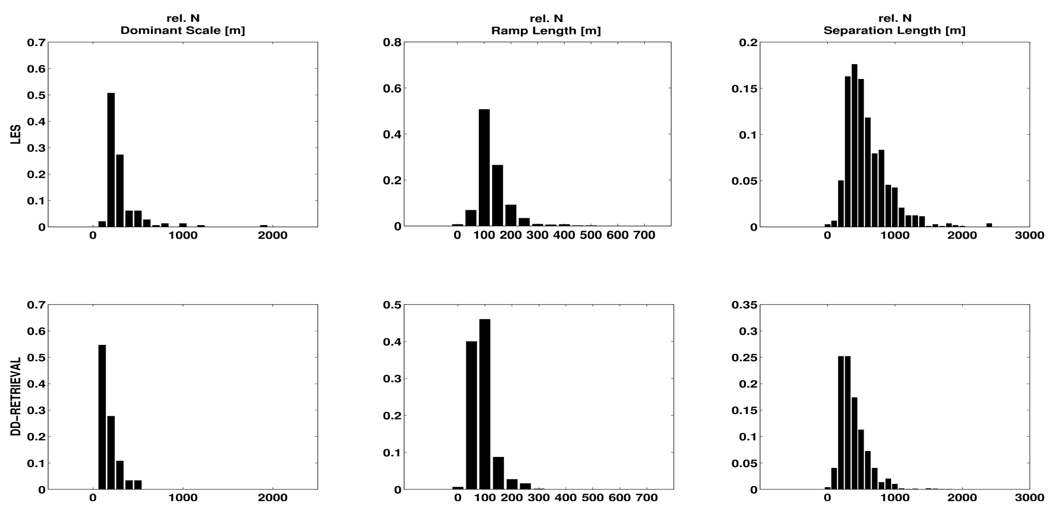

Fig. 7: Accumulated wavelet analysis results in spanwise direction: Relative frequency of dominant scales, ramp lengths and separation lengths.

4. Summary

Dual-Doppler lidar scans are a reliable method to extract coherent structures. Despite the reduced resolution, ramp length detection is more accurate than using tower data. Additionally, the method allows spanwise analysis, which makes a full characterization of the planar properties of coherent structures possible.