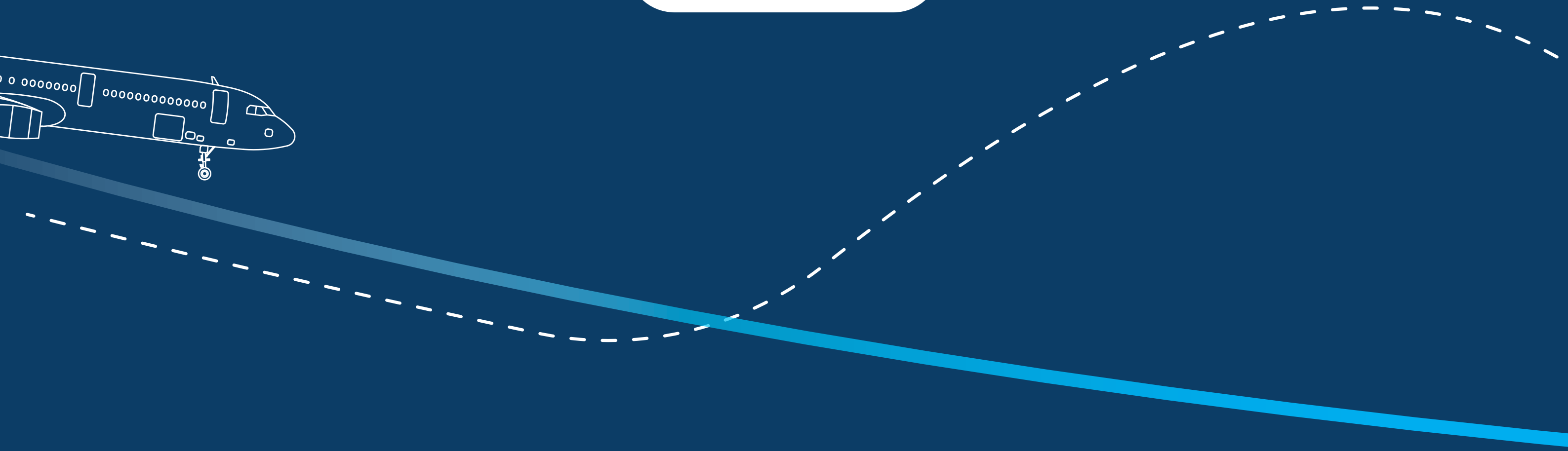
# Detection of low level wind shear by lidar

APVV-15-0663



MicroStep-MIS

*Weather experts who care*

# Project information

**Coordinator:** The Slovak Research and Development Agency (APVV)

**Project number:** APVV-15-0663

**Name of the project:** A Novel Method for Low Level Wind Shear Alert Calculation from Data Measured by Lidar

**Project duration:** 2016 - 2020

**Principal investigator:** Mgr. Gaál Ladislav, PhD.

## Low level wind shear

**Wind shear** is a change in wind direction or speed - or both attributes of wind speed vector at the same time. **Low level wind shear** plays an important role in aviation. It is defined by the International Civil Aviation Organization (ICAO) as wind shear approximately in the lowest 500 m above the runway level. Sudden changes in wind speed and/or direction can cause serious disturbance of aerodynamic flight conditions, thus, low level wind shear can jeopardize the safe take-off or landing of aircraft.

Low level wind shear in the atmosphere can be invoked by various causes, e.g.

- *orography* - causes air flow deformation around the mountain ridges or along the valleys;
- *gust front* - the front edge of cold air flowing downwards from a convective storm, and to the sides at the earth's surface;
- *microburst* - extremely strong downdraft in the area of convective storm cores with a maximum horizontal dimension of 4 km;
- *low level jet stream* - a significant amplification of airflow in the lower troposphere, which is manifested by a local maximum in the vertical wind profile;
- *onshore breeze* - caused by differences in the daily course of land surface temperature and that of larger water bodies;
- *temperature inversion* - causes vertical wind shear, characterized by different wind conditions above and below the inversion.

## Aircraft flight through a microburst

A microburst is an extremely strong downdraft in convective storms, which is characterized by the following features:

- intense downward movements,
- high pressure and cold air near the ground,
- significantly divergent ground flow, and
- one or more rotors developed at the edge with strong wind shear.

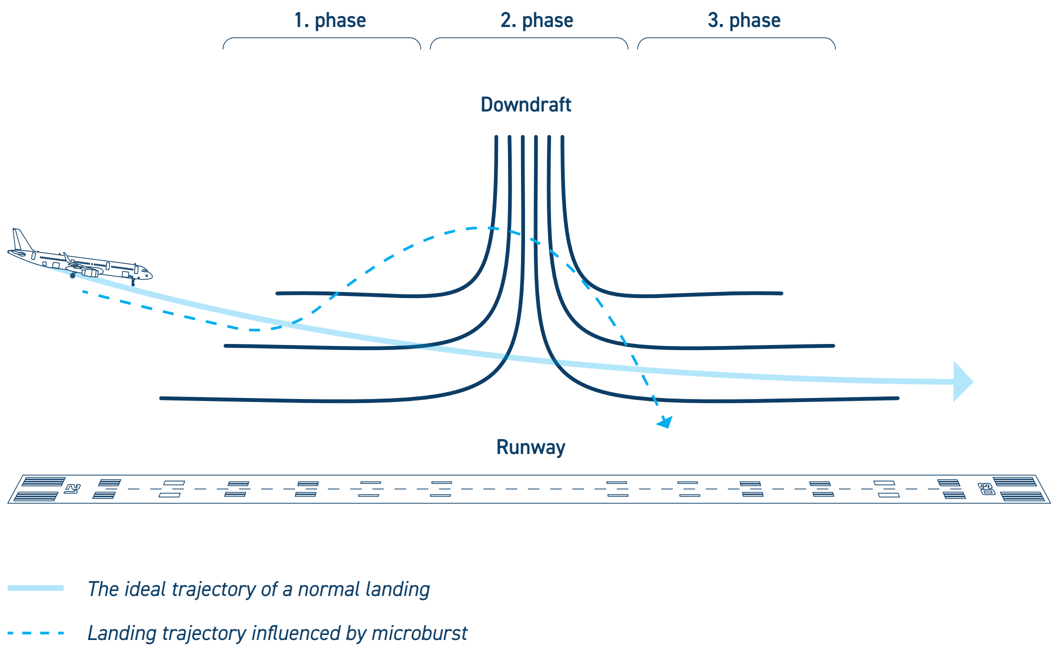
Microburst may or may not be accompanied by precipitation. Consequently, we distinguish dry and wet microbursts and this fact affects the possibility of their detection by radar or lidar.

If the aircraft enters the microburst zone, significant changes in aerodynamic flight conditions may occur:

1. **First phase:** The headwind lifts the aircraft above the planned trajectory and the pilot observes higher airspeed. The pilot retards the thrust (which may turn out to be a mistake in later phases) and tries to return to the planned flight level.
2. **Second phase:** In the downdraft area the aircraft starts to sink. The pilot further attempts to regain the ideal landing trajectory.
3. **Third phase:** The tailwind instantaneously decreases the aircraft lift and airspeed, thus, the aircraft keeps sinking. The pilot repeatedly attempts to return to the planned flight level, which, however, might be hindered by aerodynamic conditions and the reduced thrust.



*Aircraft flight through a microburst*



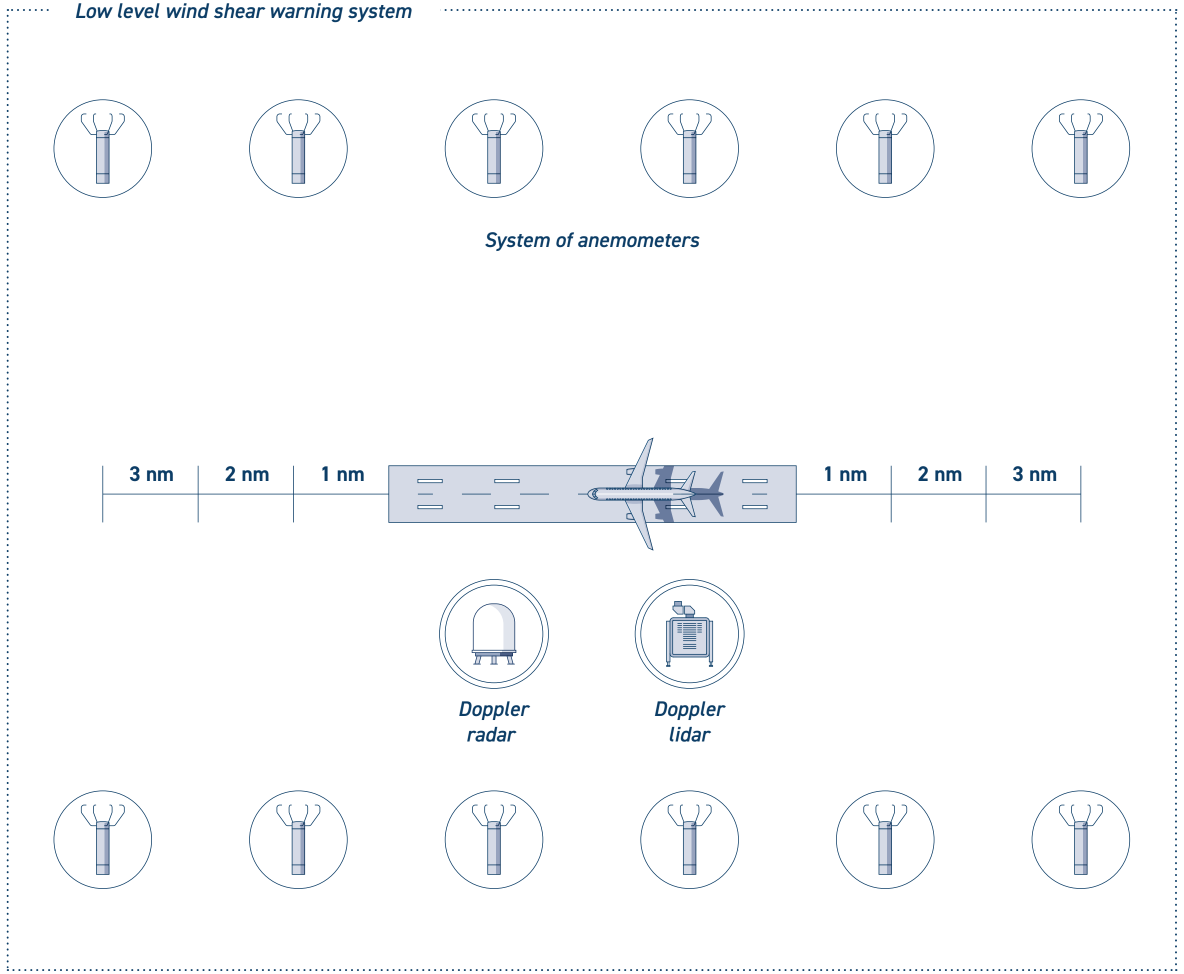

## Low level wind shear alert system

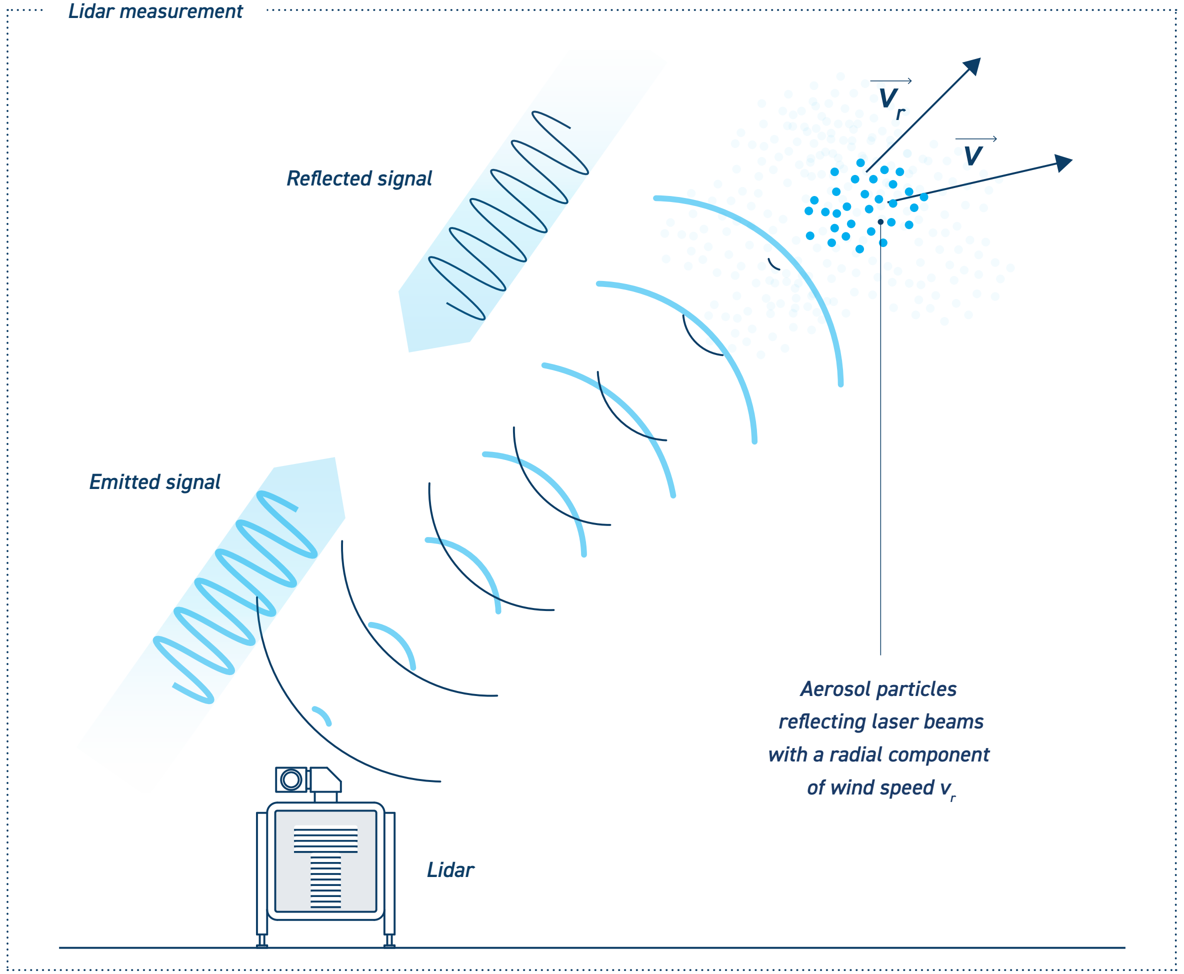
In the modern meteorological practice, a complete alert system on low level wind shear consists of three subsystems:

1. **System of anemometers** located on several masts near the airport;
2. **Doppler radar**, which obtains information on wind shear mainly in wet conditions (precipitation, fog, etc.), or
3. **Doppler lidar**, which detects wind shear in a dry atmosphere.

The development of the Low Level Windshear Alert System (LLWAS) was initiated by the Federal Aviation Administration (USA) in 1976. The LLWAS system consists of several anemometers (their number ranges from 6 to 30), located at a maximum distance of 3 nautical miles (approx. 5.5 km) from the runways. Low level wind shear is determined by mathematical algorithms between pairs or triplets of neighboring anemometers.

Airports worldwide are mostly equipped with meteorological radars of TDWR (Terminal Doppler Weather Radar) category. The term *terminal* indicates the fact that the radars are designed to monitor the atmosphere near the airport. The advantage of the TDWR system compared to conventional meteorological radars lies in the finer time and space scales. In addition to precipitation, these radars detect wind fields and dangerous wind shear in the airport area and within a radius of 90 km from it.



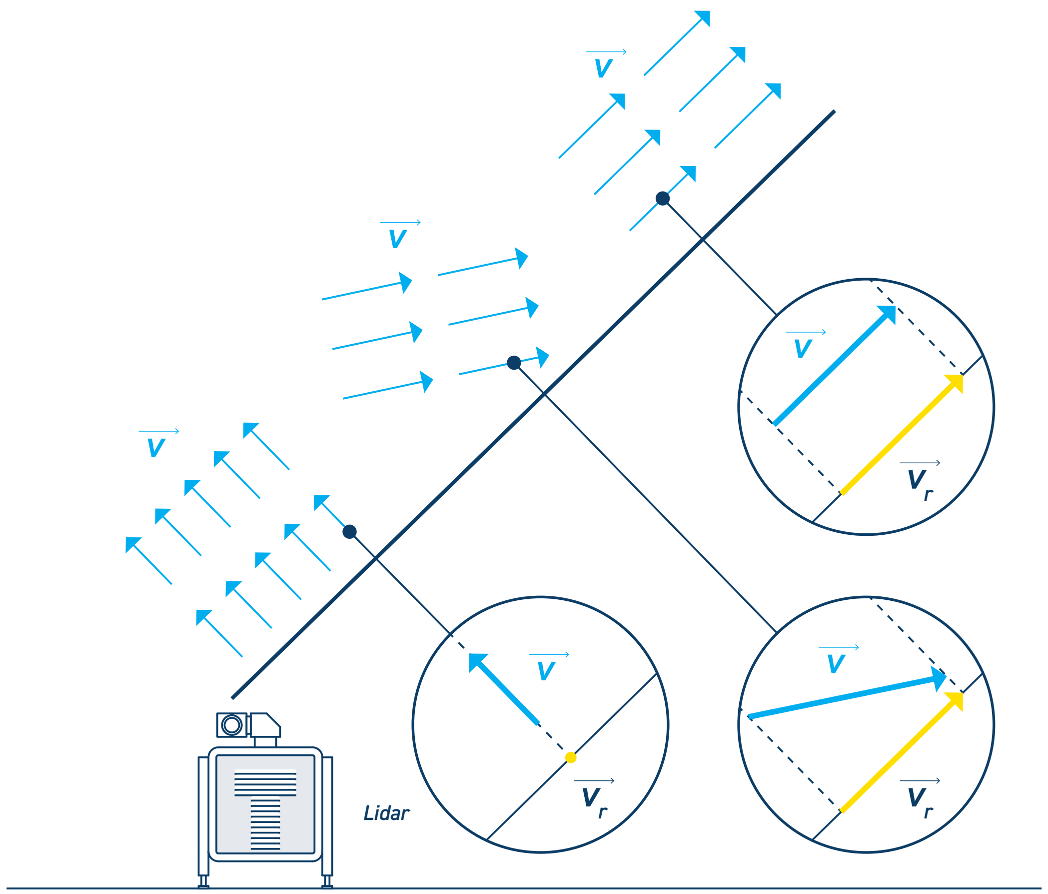

The acronym *LIDAR* stands for Laser Imaging, Detection, And Ranging or Light Detection And Ranging. A Doppler lidar emits pulses of infrared light into the atmosphere and detects beams that are reflected from aerosol particles of natural or anthropogenic origin floating in the air. The wind-induced movement of the aerosol particles changes the frequency of the lidar signal. The radial wind speed can then be determined on the basis of the Doppler law by comparing the frequency of the emitted and the reflected light beams.

The lidar only measures radial velocities, i.e. projections of the real wind speed vector in the direction of the beam. The lidar is not able to detect movements that are perpendicular to the direction of the beam.

The best conditions for lidar measurements are in misty or hazy atmosphere, since, in these cases, the concentration of aerosols is optimal. A very clean atmosphere is not favorable for lidars, because the concentration of aerosols is not sufficient to reflect the emitted signal. On the other hand, low visibility either due to too high concentration of aerosols or intense rainfall results in enhanced absorption (attenuation) of the lidar signal.

The fundamental differences between the meteorological lidar and radar are summarized in the following table. It implies that the combined remote sensing system of Doppler lidar and Doppler radar can cover the complete spectrum of meteorological phenomena in both dry and wet conditions.

*Detection of the radial component of wind speed by lidar*




| | Lidar | Radar |
|---|---|---|
| **wavelength of the emitted signal** | 1 – 10 μm | 1 – 10 cm |
| **part of the electromagnetic spectrum** | laser (infrared) waves | radio waves (microwaves) |
| **particles that reflect electromagnetic waves** | aerosols (dust, ash, salt crystals, water drops in clouds/fog) | hydrometeors (raindrops, snow, hail, ice crystals, etc.) |
| **what does it detect?** | phenomena in a dry atmosphere | phenomena in a wet atmosphere |
| **horizontal range** | 6 – 12 km | 200 – 300 km |


## Lidar at the Bratislava Airport

Lidar of type Windcube 200S from the French manufacturer Leosphere has been in test operation at the Bratislava Airport since June 2018. It is a compact block shape device weighing 232 kg, measuring 1008 × 814 × 1365 mm (a volume of approximately 1 $m^3$), and having a rotating optics on its top. The lidar Windcube 200S has an average horizontal range of up to 6 km defined by the manufacturer, but this value significantly depends on the setting of the device parameters or on meteorological factors such as the amount and type of the atmospheric pollutants, etc.

The lidar at the Bratislava Airport is located near the intersection of the runways - at a distance of approx. 250 - 300 m from the runway axes.

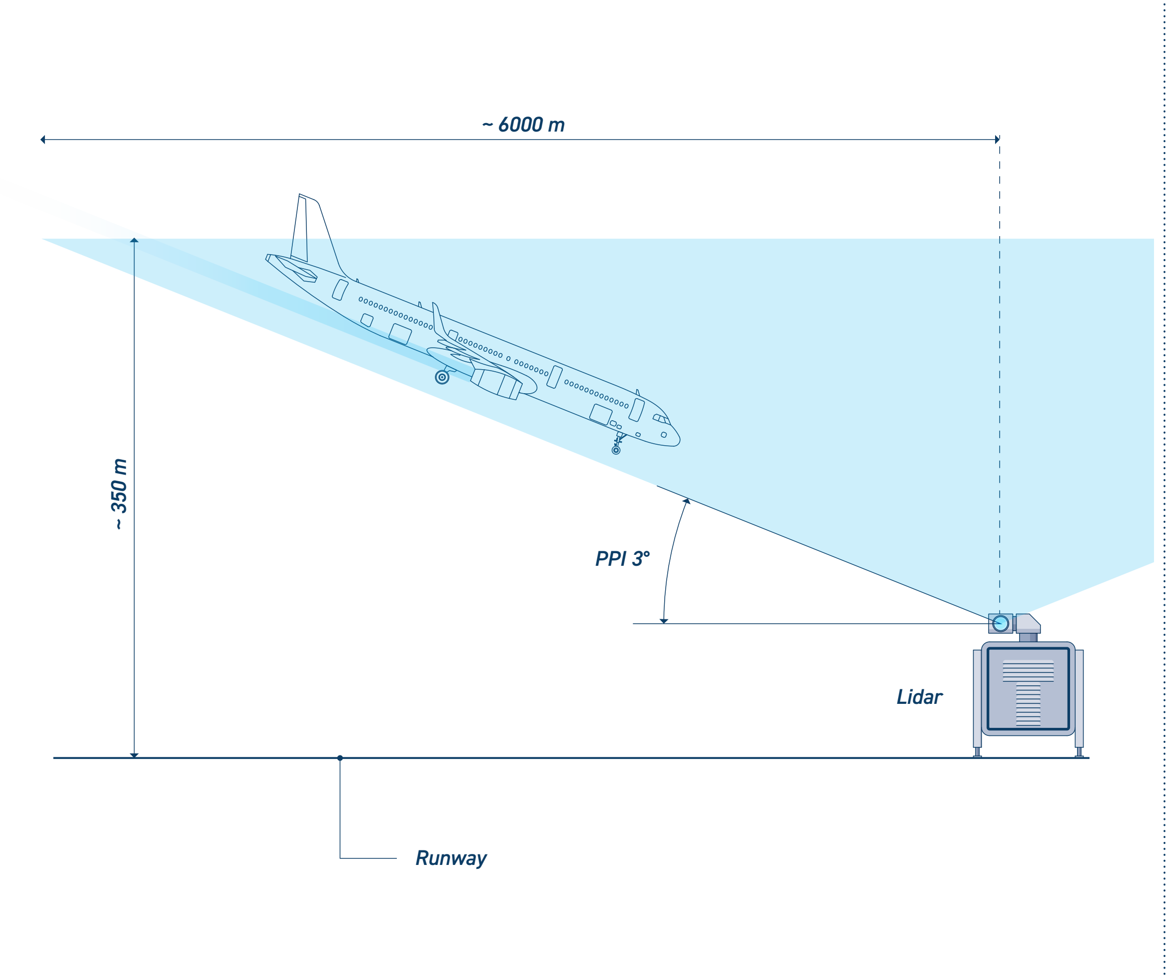
The basic regime of lidar monitoring is a PPI scan of 3°. PPI stands for Plan Position Indicator yielding a scanning mode, in which the elevation angle of the lidar is set to a constant value and the optical head of the instrument rotates repeatedly from the azimuth 0° to 360°. The value of the elevation angle is set to 3°, as this corresponds with the angle of the glide path of the landing aircraft. The laser beam of the lidar at this scan mode describes a conical surface, which is then displayed as a circle with a lidar in its center.

## Examples of weather situations

Lidar for the past approx. 2 years of test operation documented many interesting wind shear situations in the area of the Bratislava Airport. Four of them will be presented in the next sections. To understand the lidar snapshots better, here is a list of their general features:

- The Doppler lidar is located in the center of the snapshots and it is marked with a red and black "+" sign.
- There are other "+" signs in the picture, which gradually indicate the end of the runway, and distances of 1, 2, and 3 nautical miles (1.8; 3.6, and 5.5 km) from the end of a given runway.
- Two sectors are invisible to lidar beams emitted at the elevation angle of 3°. They are caused by the building of the fire station (between azimuths 228° and 255°), and the tower of the meteorological observatory (between azimuths 306° and 327°).
- A general convention regarding the wind direction: the wind is positive if it blows towards the lidar.

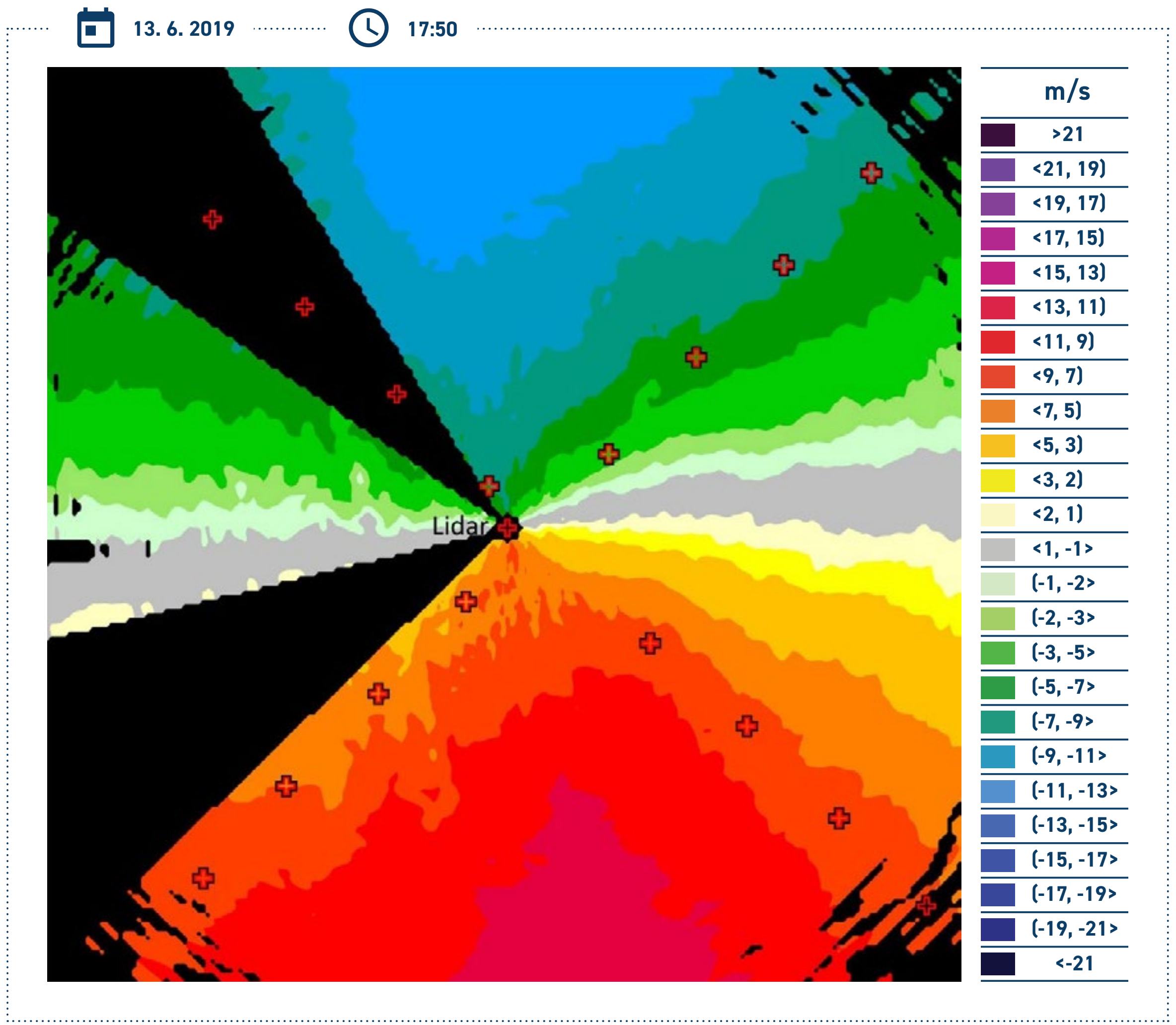
*Scanning in a PPI mode at the elevation angle of 3°*




**1. Increase of wind speed with an altitude**

The picture from 13 June 2019 represents a situation where the wind direction remains constant (southern, approx. 160°), but the wind speed increases with altitude, from the values of approx. 5 - 6 m/s at the earth's surface up to 13 m/s at altitudes of 350 - 400 m above the airport.

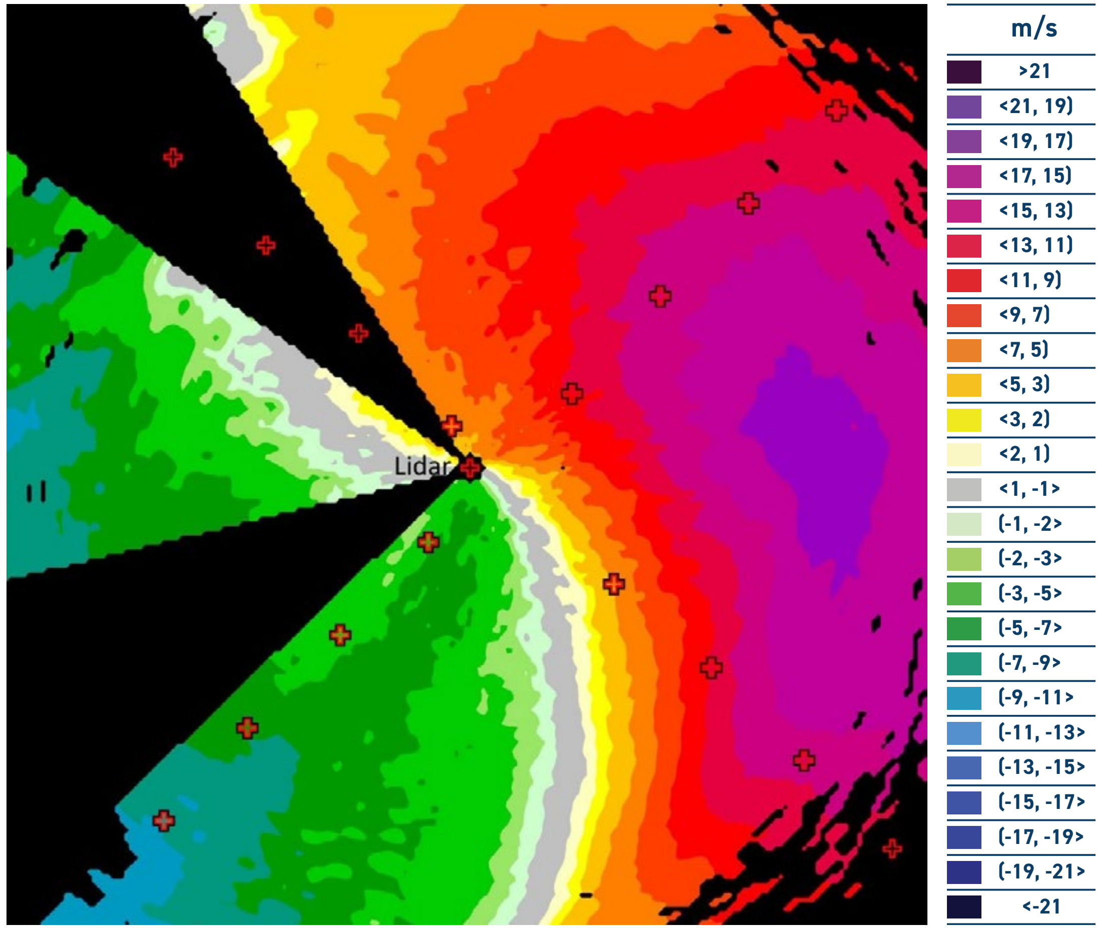
The radially arranged boundaries of areas with the same values of the radial component of wind speed are the proof that the wind direction does not change with altitude.



**2. Change of wind direction & speed with altitude**

We found an example from 27 July 2019, when both wind speed and direction change with altitude, while the wind speed shows a local maximum. The wind direction in the lidar snapshot changes from northeast (~ 60°) at the surface to east-southeast (~ 120°) at higher levels. The wind speed increases from 8 m/s on the surface, until it reaches its maximum 19 m/s at a height of approx. 300 m above the surface. Then it decreases slightly at higher levels. Unfortunately, the situation cannot be examined symmetrically since the assumed local maximum west-southwest of the device is invisible due to the blocking of lidar beams.

27. 7. 2019 21:28

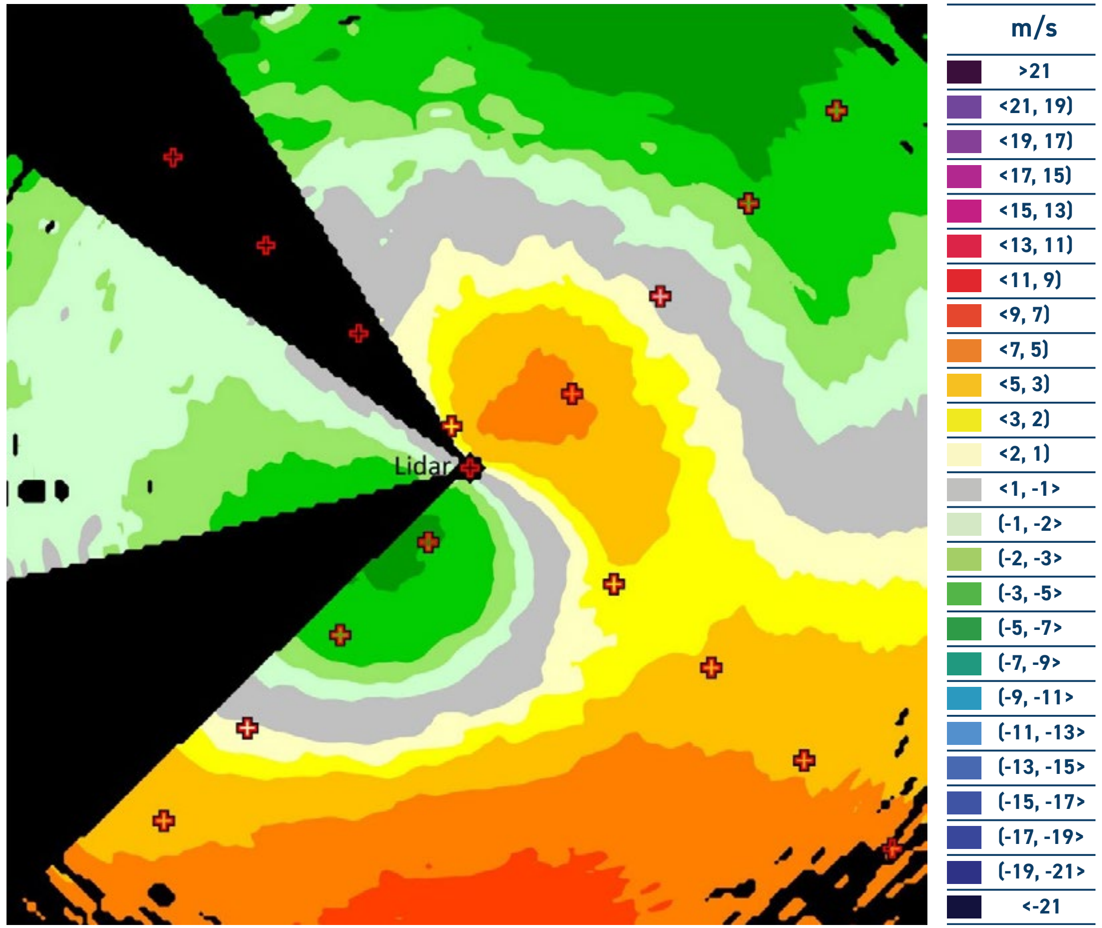



**3. Temperature inversion**

The example of 15 June 2019 shows temperature inversion when fundamentally different weather conditions dominate above/below the inversion level.

At the earth's surface, the northeast wind blows at a speed of 2 - 3 m/s, which reaches a maximum value of 7 m/s a few tens of meters higher. The inversion level is located at an altitude of approximately 200 - 250 m above the ground. Above this level, one can observe wind blowing from almost the opposite direction (south-southwest, approx. 210°) than at the surface whereas its speed is slightly higher (9 m/s) than at the bottom of the inversion.

15. 6. 2019 1:53

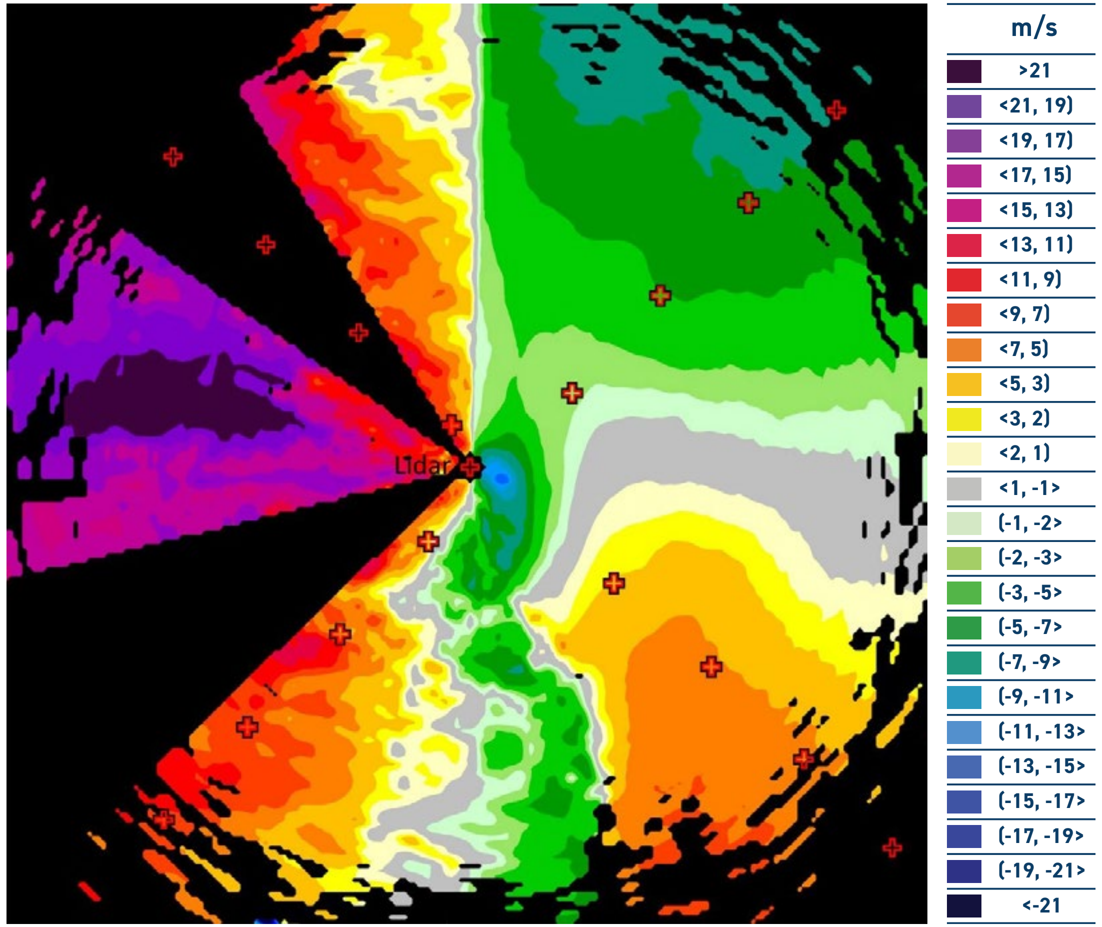


## 4. Gust front transition

The last sample from 19 July 2019 presents a situation where a gust front broke into the airport area. On the right side of the snapshot, one can see the wind field that prevailed in the target area just before this event: 5 m/s at the surface and a maximum speed of 11 m/s at higher levels.

Immediately, a gust front from the west appeared in the airport area, with a very strong wind speed of 10 - 11 m/s at the surface, in gusts up to 18 - 19 m/s, and at higher levels also with wind speed probably above 21 m/s. The lidar snapshot captures the superposition of these two wind fields approximately at the moment when the gust front reaches the level of the lidar.

19. 7. 2019 19:24



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