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Possibility and application of all-weather lidar-radio sensing complexes

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Abstract The article discusses the main problems of the development and applying of all-weather meteorological complexes of remote optical and radar atmospheric sensing. Discussed different areas of application depending on type of airports. The concept of a new mobile three-band true all-weather meteorological single platform complex for operational measurements in airports is proposed. Shown the results of multi-bands systems measurements in PPI mode and vertical profiler performed under various conditions.

1. Introduction

Aero navigation requires a comprehensive diagnosis of the meteorological situation for the real-time detection of dangerous weather phenomena in the take-off / landing zone, such as windshear in the boundary layer, wakevortex behind the aircraft, and also to determine horizontal and vertical visibility. The measurement of each parameter is carried out by separate systems, which does not provide all-season and all-weather measurements. Despite the complex market of remote detection systems, there is a certain tendency to develop all-weather meteorological systems for air navigation. So, for example, there are 3 independent groups working in this area abroad.

The Japanese company Mitsubishi electronics in 2011 released a concept project [1] on the integration of its own Doppler wind lidar with X and C band weather radar systems. In 2015, the company added another additional Ka-band radar range to the system.

In 2010, the American concern Lockheed Martin presented vision of an all-weather system for meteorological support for aero navigation. IR lidar Windtracer (Lockheed Martin) and X-radar METEOR 50DX (Selex), installed at the airports of Nice, Frankfurt and Munich [2]. This system showed high efficiency in various weather conditions, which proved the correctness of the merging approach of several measuring systems in one. It should also be noted that the Windtracer infrared lidar combined with the Weather Doppler Radar (TDWR) terminal is currently used at major airports in the world (Las Vegas, Munich, Frankfurt, Hong Kong).

Since 2010, the French company Leosphere (now Vaisala) has repeatedly tested its product (windcube - Doppler infrared lidar) with meteorological radars from Selex and Thales. The results each time showed that such integration of infrared systems and short-wave meteorological radars



allows the detection of windshear and vortex traces, both in clear weather and on rainy days [3]. All equipment is operated and serviced separately.

2. Multiband remote systems concept

Due to the complex network structure of the information of airport has required a specific software environment, often individual at each airport. Thus, in the short term there are no prospects for equipping meteorological facilities with a single all-weather hardware-software system, the advantage of which is mobility and a single infrastructure at the level of technical composition. In most cases, preference is given to manufacturers of serial equipment of a custom type, which solves a limited number of tasks in meteorology. The number of equipment types in this case exceeds several tens [4]. Nevertheless, the statement of the problem of creating all-weather single platform systems is extremely important and can be in demand in cases:

- small and «far away» airports when a fully automated hardware-software environment with remote operator is required;
- aircraft-carrying cruisers, since there is a limited take-off and landing sector, and there are no additional airfields [5,6];
- military aerodromes, where mobility and ease of use play an important role in deployment and operation.

A comparative analysis of existing remote meteorological systems capable of measuring altitude profiles of atmospheric parameters allows us to conclude that, unlike radio sounding, remote atmospheric sounding devices based on the Doppler Effect have qualitatively better characteristics, but their potential maximum measurement range depends on weather conditions. In Russia Federation, the first attempt to combine the lidar and the radar on a single platform to ensure all-weather measurements was made by the company Laser Systems JSC together with specialists from the BSTU VOENMEH and the Military Space Academy named after A.F. Mozhaysky [7]. It was shown that the functioning of classical X-band radar systems requires specific weather conditions, when the reflectivity of atmospheric objects is not lower than a certain value. Therefore, measuring wind speed, atmospheric turbulence, detecting the windshear in clear atmosphere by radar is impossible.

At the same time, for optical radar (lidar) using a laser as a radiation source, the opposite situation occurs. Since the radiation wavelength a value of the order of 1 μm , the presence of an insignificant amount of aerosol is sufficient for its effective scattering in the atmosphere, which takes place even in clear atmosphere.

The optical part of the dual-band complex is based on the WINDEX-2000 pulsed heterodyne Doppler lidar with two mirror scanning module, which makes it possible to scan the entire upper hemisphere.

To verify the accuracy of measurements, comparative tests of remote wind measurement systems based on WINDEX-2000 and a radiosonde operating on the differential-ranging method of measuring wind speed were carried out. The measurement accuracy was estimated by calculating the correlation using the Pearson method and estimating the error of the correlation coefficient. According to the results of more than 800 independent measurements from three different WINDEX-2000 during 12 sessions of launching a *GPS* radiosonde, the correlation of the wind speed for the V_x component was 0.91 and for the V_y component 0.97. The average value of the correlation coefficient was 0.95 with a correlation coefficient error of 1.15%. The error of the wind speed along two coordinates does not exceed 1 m/s [8].

This result indicates a high accuracy of measurements and, in the case of remote measurements, an increased speed of updating information (up to 3 minutes, opposite to 30 minutes during aerosounding).

3. Result of multiband system measurements

Numerical modeling of the effects of electromagnetic waves of different nature showed that a system with an X-band radar (3 cm) and an infrared lidar (1.5 μm) cannot be called completely all-weather system for two reasons:

- there is a range of atmospheric reflectivity (from 0 to 20 dBZ) when the signal from the IR channel begins to experience strong absorption, and for the X channel signal this type of reflectivity is almost transparent;
- for X-band systems, the dead zone of measurements is about 3 km, when the dead zone of the pulsed lidar of the IR range is 100 meters (see Figure 1).

These reasons make it difficult to integrate data, because in most cases, it turns out that these two ranges work independently and complement each other, but complete all-weather is not achieved, since there can be "blind" zone up to 3 kilometers. Screenshots of the lidar data processing software are presented in Figure 1 showing data gaps in range up to 3 km in PPI mode measurements with two-band X-radar and lidar systems. These gaps can be filled with Ka-band radar channel, which can operate in mists and moderate precipitation.

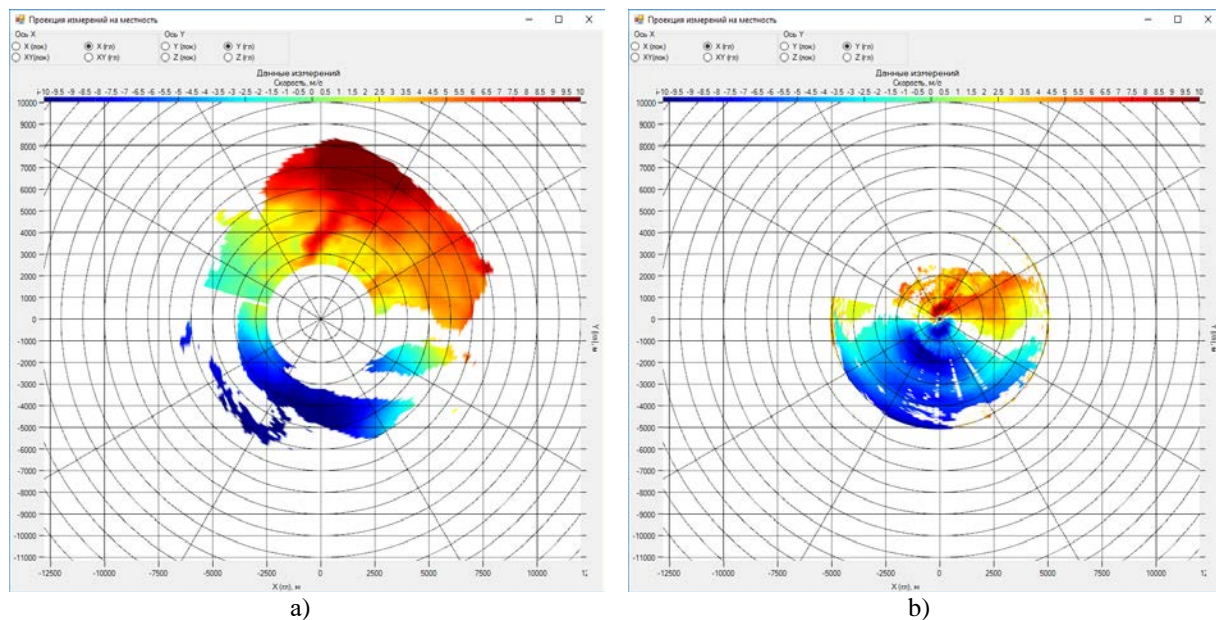


Figure 1. Horizontal wind speed measurement by two band system: a) X-radar; b) IR lidar

The next stage in the development of all-weather systems at the company Laser Systems JSC was the development of a prototype lidar - radar complex, which included an additional Ka-band radar, humidity and temperature profiler and local sensors. The main characteristics of the complex are listed in Table 1.

Table 1. Specification of LIRA-3

Parameter	Value
X-band system	
X-band radar	frequency 9,5 GHz
Beam width	3°
Pulse duration	10 us, 30 us, 100 us
Pulse Repetition Rate	1–5 kHz
Antenna type	slot antenna array
Array size:	760×760×200 mm
Ka-band system	
Ka-band radar	frequency 33.8 GHz
Minimum detection range	< 400 m

Parameter	Value
Range resolution	< 60 m
Average power	12 W
Beam width	3°
Accuracy	±0.5m/s
Wind lidar and Ceilometer	
Laser wavelength	1550–1570 nm
Maximum achievable detection range	> 10000 m
Minimum range	< 200 m
Range resolution	< 60 m
Maximum detectable wind speed	> 45 m/s
Minimum detectable wind speed	1.0 m/s
Погрешность измерения скорости	±0.5м/с
Temperature profiler	
Detection frequency	60±2 GHz
Measurements height	50 – 600 m
Vertical range resolution	50 – 100 m
Detection temperature range	minus 60 – plus 55°C
Accuracy	< 1°C
Humidity profiler	
Number of channels	7
Detection frequency	22–37,5 GHz
Measurements height	50 – 6000 m
Vertical range resolution	50 – 100 m
Detection range	30 – 100%
Accuracy	< 10%
Measurement time	300 s
Local sensors	
Wind speed measurement range	1 – 45 m/s
Accuracy wind speed	±0.5m/s
Atmospheric pressure measurement range	600 – 180 gPa
Accuracy	< 1 gPa
Temperature range measurement	minus 60 – plus 55°C
Accuracy	< 1°C
Humidity measurement range	30 – 100%
Accuracy	< 10%
Scanning module	
Azimuth angle	0 – 360°
Elevation angle	0 – 90°
Angular speed	< 20°/s
Position accuracy	< 1°.

As a result of previous work [6, 8–10], the three-band (X, Ka and IR) all-weather meteorological single platform complex “Lira-3” is currently undergoing trial operation. The results of measuring the vertical profile of the wind speed obtained in April 2019 in St. Petersburg are presented in Figure 2. The graphs show in green the data obtained from Ka-radar, red - infrared lidar and blue - X-radar.

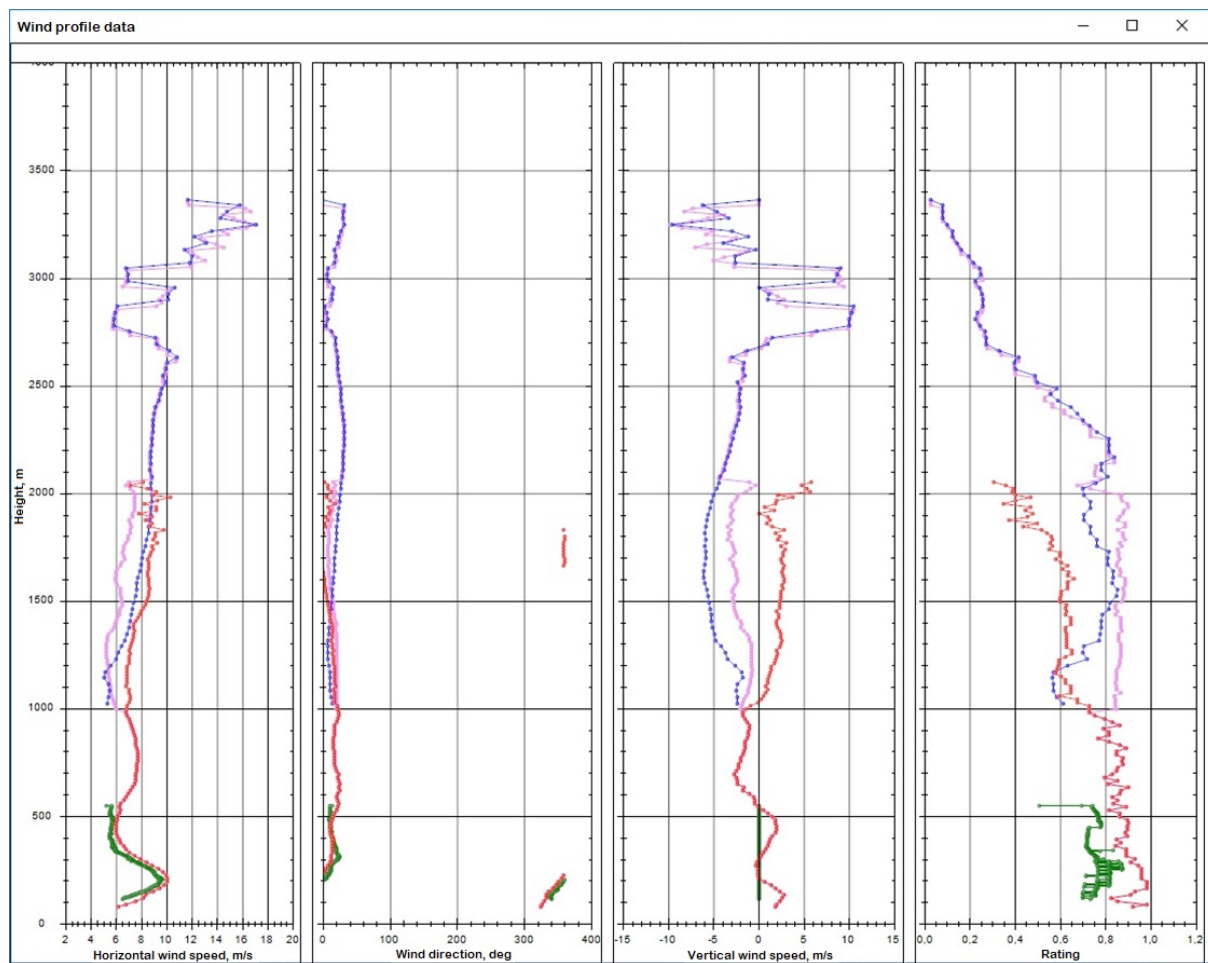


Figure 2. Vertical wind profiles from three-band meteorological system

As it can be seen from picture, multiband systems can provide wind speed and direction information in reasonable quality.

A promising way to develop systems for remote meteorological analysis is not only remote measurements but also local measurements, ensuring the implementation of a full range of meteorological work. Thus, the existing mobile meteorological lidar - radar complex for remote analysis must be supplemented with the following equipment:

- mast with local sensors (temperature, humidity, pressure, wind speed and direction);
- automated rainfall system;
- lightning detector;
- meteorological temperature profiler;
- equipment for receiving satellite and facsimile meteorological information;
- set of radio stations.

As a result of such a combination, the complex will be able to:

- short-term forecast of dangerous weather phenomena associated with clouds (thunderstorm, rain, hail);
- wind profile measurement in the atmospheric boundary layer;
- windshear detection;
- obtaining current meteorological information;
- automated processing and analysis of hydrometeorological information;
- indication of measurement results on a remote display device;
- forecasting hydrometeorological conditions;
- archiving of measurement results.

4. Summary

We can state that the use of an additional measurement channel based on the Ka-band radar in the dual band (X-radar and IR lidar) meteorological complex of remote measurement of wind speed and the detection of hazardous weather phenomena makes it possible to obtain real all-weather operation and get reliable data at distances from 200 meters without data gaps. The test results of the novel three-band single platform complex for remote measurement of wind speed in the atmospheric boundary layer showed that the height of the continuous profile reaches more than 3000 meters, while the height of measurements with a Ka-band radar is 500 meters, and with an infrared lidar 2000 meters. The addition of a mobile three-band complex for remote analysis with a set of local sensors and systems for the reception and transmission of information will provide a solution to the whole range of tasks of meteorological support.

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