Vertical wind profile measurements on the operational weather radar in "wind profiler" mode

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(Dated: 22 June 2018)

1 Introduction

Preliminary results of the experiments started in 2017 on the measurement of the vertical wind profile by operational weather radar in a special high-resolution "Vertical Wind Profile" (VWP) observation mode are presented. The main goal of our experiments was to expand the list of radar secondary products of useful and demanded in operational aviation applications, nowcasting and numerical weather prediction.

Radar experimental observations were made in Dolgoprudny (Moscow region) by DMRL-C, Russian operational C-band dual-polarization Doppler weather radar with pulse compression [1]. The special VWP mode on operational radars considered in the report should provide a more accurate estimation of the wind field characteristics in the future.

2 Observation modes

Commonly operational DMRL-C radar make observations in “Reflectivity” and “Velocity” modes consistently every 10 minutes. In the first mode 60-μs step-phase-modulated pulse at PRF=380 Hz and antenna rotation rate - 40 °/s are used. In the second mode 25-μs step-phase-modulated pulse at PRF=1 KHz and antenna rotation rate - 25 °/s are used.

The VWP mode is added after completing of “Velocity” mode. The radar in this third mode performs one elevation scan on 30° (in some experiments – 60°). In the third mode 10-μs step-phase-modulated pulse at PRF=3,3 KHz is used. The 12 °/s antenna rotation rate gives better statistics of 278 distinct azimuthal packs per one degree in comparison with 10 azimuthal packs per degree for “Reflectivity” mode and 40 azimuthal packs per degree in “Velocity” mode. For example, Figure 1 confirms that due to improved statistics in VWP mode, the Doppler velocity observation has a higher quality than the same map obtained in the conventional "Velocity" mode.

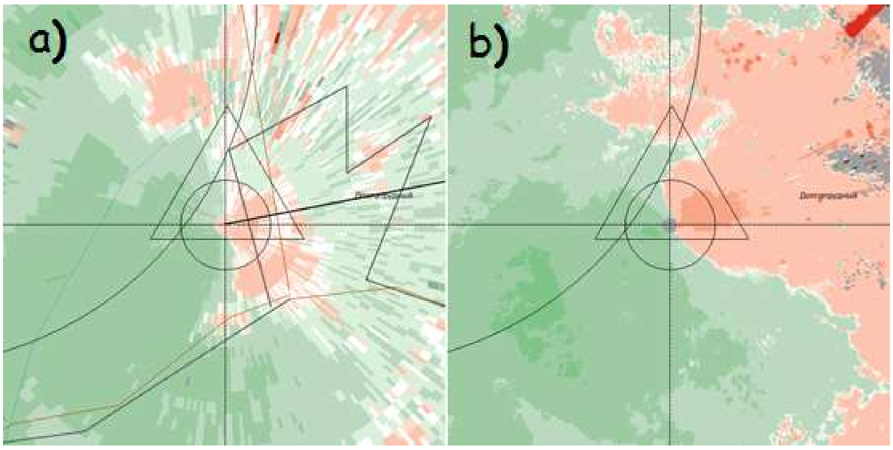


Figure 1: Doppler radial velocity PPI in "Velocity" (a) and "VWP" (b) DMRL-C modes.

3 Data processing procedure

For primary data processing at each range bin in VWP mode the *Discrete Fourier Transformation (DFT)* is used instead *Puls-Pair-Method* that is used in other observation modes. For data processing in VWP mode DMRL-C is equipped with additional processing GPU module based on the NVIDIA CUDA parallel computing platform [2]. The sampling rate of GPU module is 10 MHz compared to 1.25MHz sampling rate for “Reflectivity” and “Velocity” modes so that output data resolution is 15 m on the range and 0.5° on the azimuth compare to 250 m and 1° for “Velocity” mode.

For secondary data processing a conventional VAD technique is used to obtain the averaged horizontal wind profile [3]. Application of VAD to azimuthal circles at every distance of Doppler velocity PPI provides a vertical profile with wind speed components at height resolution *R (m)*:

$$R = 15 * sin(el),$$

where *el* – is the elevation angle. Our experiments were carried out with 30° and 60° elevation angles.

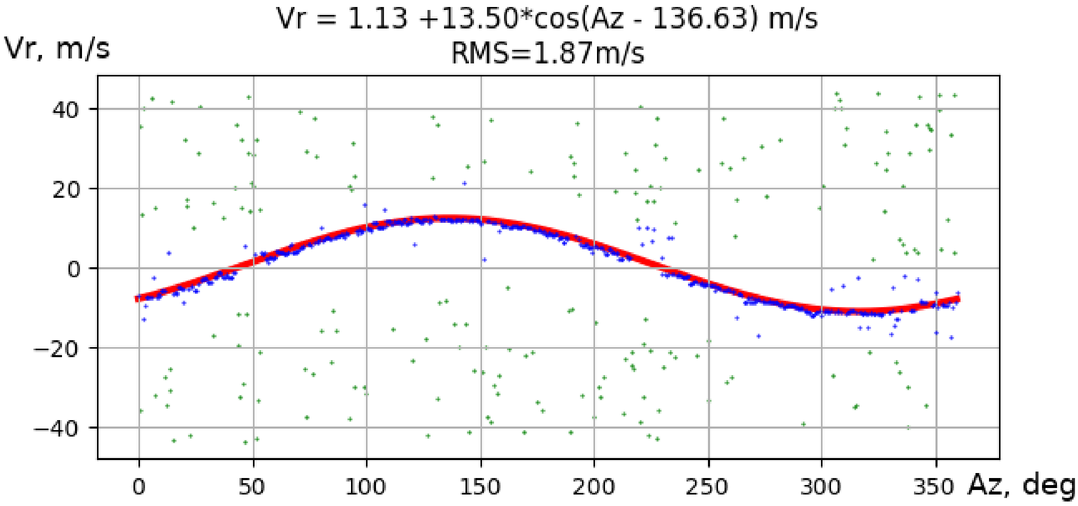


Figure 2: Example of VAD sinusoid fitting for data in VWP mode and filtered values

4 Case study

The radar wind measurements were compared with radiosonde soundings from the GCOS Reference Upper-Air Network (**GRUAN**, 2018 [4]) data of "Dolgoprudny" (DLG) station (WMO code: 27612). DLG is located near the radar. Height resolution of the radiosonde data is 100÷200 m. It is necessary to take into account in data analysis the distance of the radiosonde from the launch site. The results of radar observations in VWP mode were analyzed in the report under two different weather conditions: "Clear-sky" and "cloudy/rainy".

4.1 Cloudy/rainy condition

In cloudy or rainy conditions the number of profile points sometimes exceeded 1000. Each profile point corresponds to one VAD circle with 15 m thick in slanting distance. For example on January 29 at 00:00 UTC our radar was in the convergence zone of air flows with the center of low pressure situated near Stockholm.

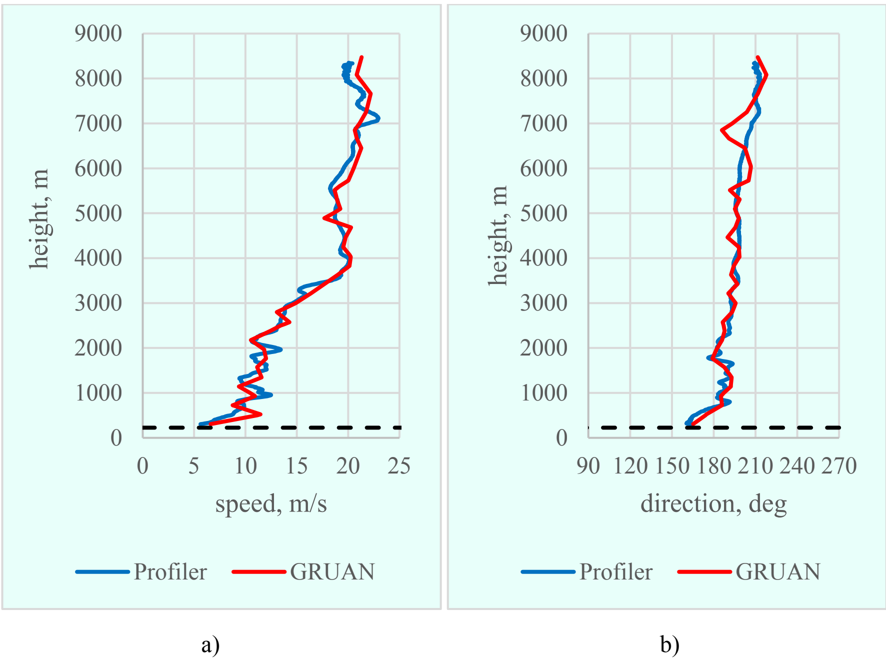
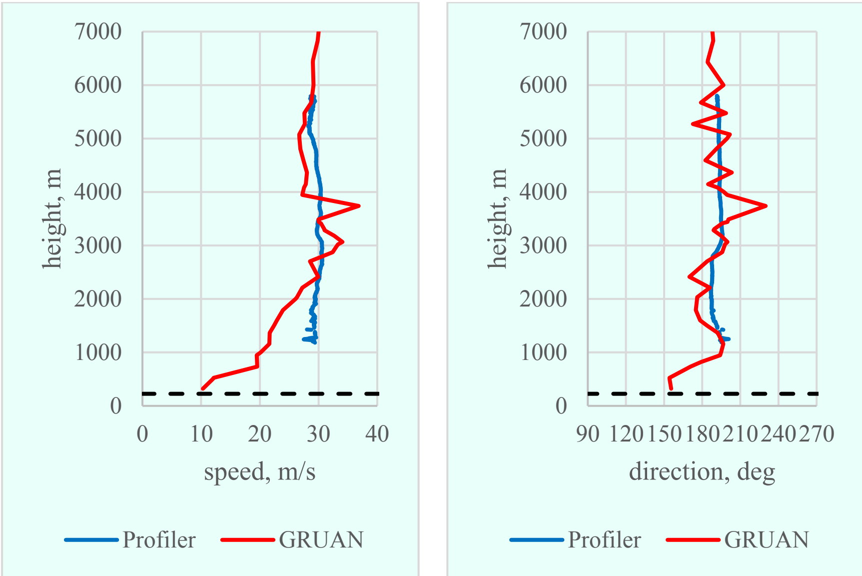


Figure 3: Profiles of wind speed (a) and direction (b) according to GRUAN (red) and profiler (blue) 01/29/2018 00 UTC. The black dotted line in the graphs below is the height of the radar installation above mean sea level.

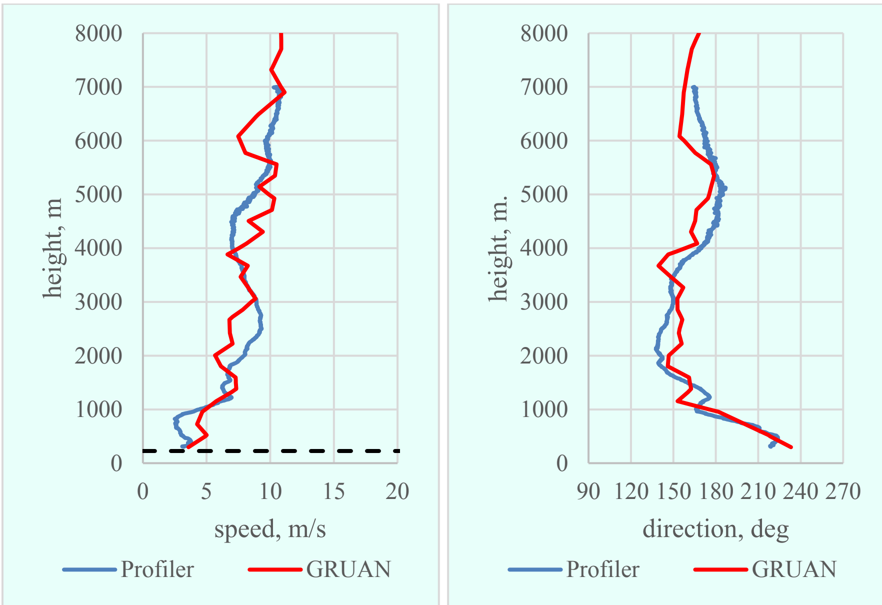
The profiles of wind speed and direction from GRUAN and VWP radar mode ("Profiler") are presented in Figure 3. The upper bound of the profile was ~ 8 350 m, the average deviation of the wind speed – 0,4 m/s and the direction – 0,4 deg. It is possible that the profiler-radiosonde difference increase with altitude is caused primarily by a significant distance of the radiosonde from the launch point (20 km – at height 7 km).

Small deviations of the profiler measurements from the radiosonde measurements are also observed with fewer points. For example, in the case of 04/02/2018 at 12:00 UTC (Figure 4) the average deviations was 0.75 m/s for velocity and 0.2 degrees for wind direction. Separate precipitation areas were in the radar observation zone at that time. The cloudy Echo Top was 5.9 km. The radiosonde quickly migrated from the launch site because high wind speed and its distance was 27 km at height 6 km. In the low troposphere (<1.5 km) the profile has a wide spread, which indicates a numerical instability in this layer.



a) b)

Figure 4: Profiles of wind speed (a) and direction (b) according to GRUAN (red) and profiler (blue) 04/02/2018 12 UTC. The black dotted line in the graphs below is the height of the radar installation above sea level.



a) b)

Figure 5: Profiles of wind speed (a) and direction (b) according to GRUAN (red) and profiler (blue) 05/15/2018 12 UTC. The black dotted line in the graphs below is the height of the radar installation above sea level.

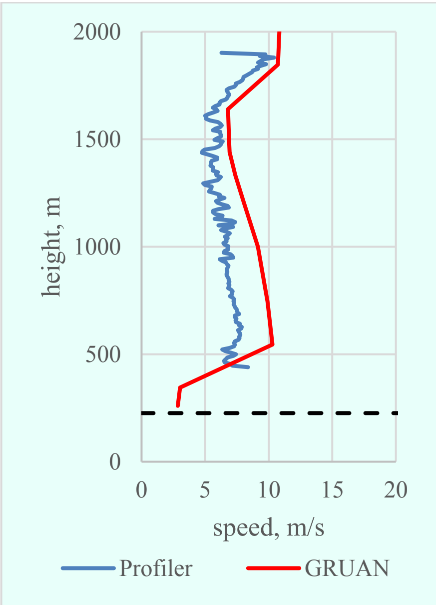
In the frontal systems, generally, strong wind shear is observed. In Figure 5 one of these cases is illustrated: on 05/15/2018 at 12:00 UTC frontal system passed through the Moscow region and frontal showers and thunderstorms were observed. In general, the error of the profiler during this period does not exceed the norm - 0.2 m/s in speed and 2.6 degrees in direction.

In this case the wind shift in the lower troposphere was well retrieved but the wind speed was slightly below the value measured by the radiosonde (the deviation was about 1 m/s). At the same time, the radiosonde distance from the radar was small - 13 km at height of 7 km.

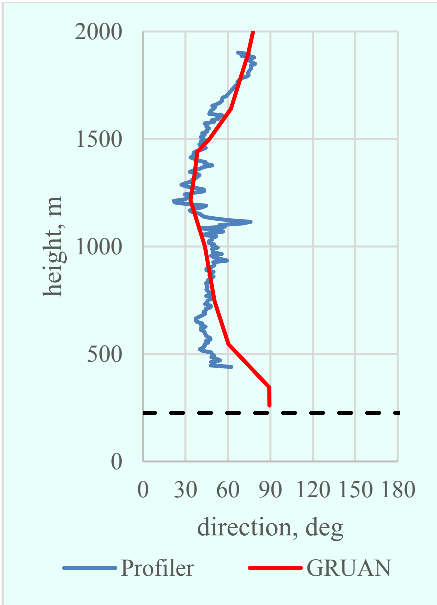
4.2 "Clear-sky" condition

Great attention was paid to the study of the wind profile retrieve in the cases clear-sky or little clouds conditions were above the radar. Analysis showed that in the cold period under these conditions the wind profile is not retrieved in each period and very little number of points pass VAD filters. E.g. on 02/24/2018 at 00:00 UTC in a diffused pressure field, the profile has only 6 points. However, even in such conditions the wind speed deviations was less than 1 m/s and the direction – 8.5 degrees.

In the warm period under conditions of strong warming of the surface and the appearance of the surface boundary layer (SBL), the profiler demonstrated the ability to retrieve the wind profile in the lower troposphere. Thus, on 05/10/2018 at 12:00 UTC in conditions of a cloudless sky (Figure 6) there were wind gusts up to 13 m/s at an altitude of 10 meters. The wind profile was not retrieved quite in "Velocity" mode because of insufficient data in the scan area and was retrieved in VWP mode in the SBL up to a height of 1.9 km but the profiler deviation from the radiosonde in this case was bigger (2.2 m/s for speed and 1.9 degrees for direction).



a)



b)

Figure 6: Profiles of wind speed (a) and direction (b) according to GRUAN (red) and profiler (blue) 05/10/2018 12 UTC. The black dotted line in the graphs below is the height of the radar installation above sea level.

5 Results

The 149 cases were analyzed in the period 10/01/18÷01/06/18 (1 case: 1 GRUAN radiosonde launch and 1 radar observation). There is a good agreement of wind data on the speed and direction up to the upper boundary of the radar echo.

The average deviation of VWP radar mode data from GRUAN sounding data was 0.9 m/s for wind speed and 6.8 degrees for wind direction, which meets WMO requirements for wind measurements.

VWP results are better in "cloudy and precipitation" conditions: 0.8 m/s – the difference in wind speed and 5.5 degrees – the difference in wind direction and worse in "Clear-sky" conditions: 1 m/s and 9.3 degrees respectively.

It is important to note that Doppler wind observations in VWP mode for a "Clear-sky" conditions retrieves a less detailed wind profile and in conditions where there are no radar echo above the position, the profile is not retrieved (But mentioned cases take place not so often).

Conclusions:

- the presented VWP radar observations mode has a higher spatial resolution of the vertical wind profile than conventional Doppler observations;
- the presented VWP radar observations mode makes possible the wind characteristics measurements in conditions of significant blocking areas;
- in the "Clear-sky" conditions with a strong surface warming it is possible to obtain a vertical wind profile by the presented VWP radar observations mode observations although the wind speed values are usually lower than that measured by the radiosonde;
- the presented VWP radar observations mode makes it possible to measure the wind profiles even under such conditions when common Doppler observations with a lower PRF do not allow it to be done.

References

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