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Decision criteria for the classification of meteorological phenomena in the weather radar complex of the near-airfield zone

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Abstract: The increasing need to obtain data on the meteorological situation to ensure the safety of aircraft flight actualizes the development of radar systems for remote collection and processing of information, including for solving the problems of classifying dangerous weather phenomena. This determined the primary development of the domestic weather radar complex of the near airfield zone (WR BZ). The article presents the features of the construction of the WR BZ, as well as the main tasks it solves. To classify meteorological phenomena from cloudiness to squall in the weather radar complex of the near airfield zone, it is proposed to take as a basis the criteria tested by weather radar stations of previous generations. These criteria are based on an analysis of the height distribution of reflectivity, taking into account the vertical temperature profile. In addition, a criterion for classifying thunderstorms in the cold period of time has been additionally introduced in the WR BZ. To calibrate the values of the criteria, a mathematical apparatus and special software were developed. To collect statistical data, WR BZ were installed in various climatic regions: the Central and North-Western Federal Districts and the Republic of Crimea. Further, an effective validation of the information received was carried out. At present, WR BZ has passed preliminary, acceptance, certification tests, trial operation, while demonstrating an effective classification of meteorological phenomena, thanks to the correct selection of decision criteria. The article considers the possibility of increasing the reliability and justification of the classification of dangerous meteorological phenomena through the additional use of information on the distribution of altitudes of the specific rate of dissipation of turbulent energy of the atmosphere, as well as an additional set of statistical data in various climatic zones of the European territory of Russia – the Upper Volga Region and the Krasnodar Region.

Key words: weather radar, near-airfield zone, dangerous weather phenomena, testing, certification, validation of meteorological data, decision criterion, classification of weather phenomena.

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Критерии принятия решений для классификации метеоявлений в метеорологическом радиолокационном комплексе ближней аэродромной зоны

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Аннотация: Возрастающая необходимость получения данных о метеорологической обстановке для обеспечения безопасности полета воздушных судов актуализирует разработку радиолокационных систем дистанционного сбора и обработки информации, в том числе для решения задач классификации опасных метеоявлений. Это определило первостепенную разработку отечественного метеорологического радиолокационного комплекса ближней аэродромной зоны (МРЛК БАЗ). В статье представлены особенности построения МРЛК БАЗ, а также решаемые им основные задачи. Для классификации метеоявления от облачности до шквала в метеорологическом радиолокационном комплексе ближней аэродромной зоны предложено взять за основу критерии, апробированные метеорологическими радиолокационными станциями предыдущих поколений. Данные критерии основаны на анализе распределения отражаемости по высотам с учетом вертикального профиля температуры. Кроме того, в МРЛК БАЗ дополнительно введен критерий классификации грозы в холодный период времени. Для калибровки значений критериев были разработаны математический аппарат и специальное программное обеспечение. Для набора статистических данных МРЛК БАЗ были установлены в различных климатических районах: Центральном и Северо-Западном федеральных округах и Республике Крым. Далее была проведена эффективная валидация полученной информации. В настоящее время МРЛК БАЗ прошел предварительные, приемочные, сертификационные испытания, опытную эксплуатацию, показав при этом эффективную классификацию метеорологических явлений благодаря корректному подбору критериев принятия решений. В статье рассматривается возможность повышения достоверности и оправдываемости классификации опасных метеорологических явлений за счет дополнительного использования в критериях информации о распределении по высотам удельной скорости диссипации турбулентной энергии атмосферы, а также дополнительный набор статистических данных в различных климатических зонах Европейской территории России – Верхнем Поволжье и Краснодарском крае.

Ключевые слова: метеорологический радиолокатор, ближняя зона аэродрома, опасные явления погоды, испытания, сертификация, валидация метеорологических данных, критерий принятия решений, классификация метеорологических явлений.

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Introduction

The extensive use of weather radars in the twentieth century, provided the further meteorology development, particularly in high space and temporal discretization weather phenomena research, along with providing the opportunity of weather radar data in synoptic practice and weather forecast models [1–6]. At the same time, studies in mesoscale weather phenomena, such as thunderstorm and hail cells, gust fronts, funnel clouds, q squalls, breezes, convective cells and supercells were directly due to the opportunity of hydrogeological formation radar scanning [7–12].

Nowadays there is a multitude of weather radar systems of different technical characteristics [13–15] in the Russian Federation, nevertheless, there is a necessity of small-scale weather radars, which will be able to work particularly in remote regions [16] and will be set between the Russian meteorogical service large-scale radars [17]. The experience of differently featured weather radar incorporation is currently positive [18, 19].

The weather radar WR BZ was developed by the “On-board Navigation Systems” for creating weather radar field in airfield inner area (up to 100 km from airfield reference point). Creation of the domestic WR BZ meets the current import phase-out demands [20].

WR BZ has currently passed the preliminary, inspection and certification tests, prototype testing, in this case having shown us the efficient weather phenomena, parameter and characteristic [21, 22] evaluation particularly due to the correct decision-making criteria selection for classification of weather phenomena.

WR BZ: application, responsibilities, areas of use

WR BZ provides the weather services and departments of airports of different aircraft types with weather radar information, along with other consumers of the data.

WR BZ responsibilities, meeting the national and international requirements, are:

- weather phenomena validation and classification at omnidirectional and sector surveillance;
- coordinate and size estimation of the validated weather objects and phenomena;
- dangerous turbulence and wind shear areas validation with aircraft takeoff and landing sectors being prioritized;

- estimation of the validated weather object movement direction and rate.

The feature of WR BZ is provision of weather radar data on wind characteristics (rate vector field, horizontal and vertical wind shear, turbulent energy dissipation specific rate) in SURVELLIANCE mode and SECTOR mode of the higher space and temporal discretization [23, 24].

The airdromes, takeoff and landing fields, possible emergency areas are the WR BZ area of application.

WR BZ decision criteria for weather phenomena classification

Nowadays the decision criteria, developed for WR-1,2,5 have become the grounds for weather phenomena classification criteria development for other present day domestic weather radars[1]. The following criteria are based on vertical atmosphere emanation reflectivity considering the freezing line. In fact, the radar is only a measurer, which quality the classification veracity depends on. In this work the reflectivity estimation veracity at fixed precisely measured heights is what is meant by work quality. Thus, weather phenomena classification criteria are evidence based, methodically adjusted and fundamental for differently featured weather radars. The following fact of identic basic criterion use for weather radars with different performance is seen in practice – in DWR-S (C-band) and WR BZ (X-band).

It was necessary to evaluate the certain weather phenomena criteria values for WR BZ operative work in different climate zones of the Russian Federation. The “raw” signal was recorded from the radar line output with the opportunity of complex special software post-setting. The following signal was recorded in different synoptic conditions, which allowed us to save further statistically significant data for different climate zones [21].

The criterion amount calibration procedure for BZ WR weather phenomena classification was conducted the following way:

1) the “raw” signal was recorded from the radar line output;

2) the maps of the classified weather phenomena were obtained from BZ WR signal display on the plan position indicator;

3) BZ WR classified weather phenomena data were correlated with valid weather sources: ground-based weather stations and certified Russian meteorogical service network radars. The correlation was made according to the developed method, described in [21];

4) the operator accepted and fixed the criteria amount of the observed phenomena in case of its justification. Otherwise, the criteria amount different from the previous ones were charted in weather criterion classification table (fig. 1), and then the points 2, 3, 4 were repeated.

Further there is a list of parameters, used for BZ WR weather phenomenon classification. Notes in parameter name:

H0 – absolute freezing line altitude 0 °C, m;

H3 – altitude (H0 + 2500), m;

Hll – radio echo lower limit, m;

Hul – cloud top, m;

Htrop – tropopause absolute altitude, m;

Z1 – radar reflectivity at altitude from 0 up to 2 km, dBZ;

Z2 – radar reflectivity at altitude from 2 up to 4 km, dBZ;

Z3 – radar reflectivity at altitude from 4 up to 6 km, dBZ;

ZHt0 – radar reflectivity at freezing term altitude 0 °C (H0 °C), dBZ;

ZH3 – radar reflectivity at H3, dBZ.

There is a list of criteria parameters for BZ WR weather phenomena classification in Table 1.

It should be noted that the authors[2] entered BZ WR the weather phenomena classification criteria which are not presented in current weather radars, (for instance, in DWR-S) for unknown reason,

[1] Guidance for observation and data use with non-automatized MSR-1, MSR-2, MSR-5 radars. WP 52.04.320–91. St. Petersburg, 1993, 342 p.

[2] Guidance for observation and data use with non-automatized MSR-1, MSR-2, MSR-5 radars. WP 52.04.320–91. St. Petersburg, 1993, 342 p.

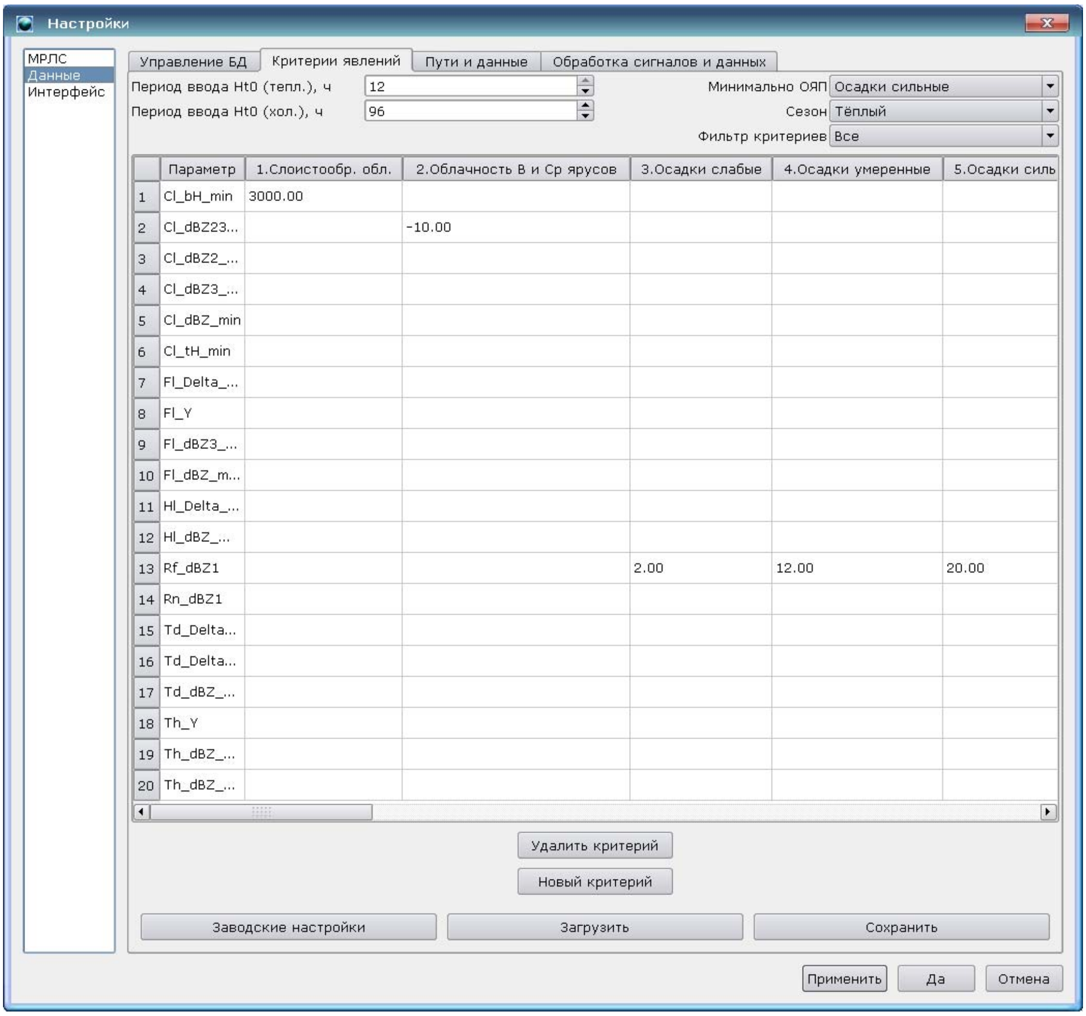

Fig. 1. Widget Setting

Table 1

List of criteria for the classification of weather phenomena in the weather radar complex of the near-airfield zone – WR BZ

Criteria parameter code in special software	Name and measurement units	Amount	Operation period
Cloud amount (stratiform cloud amount)			
Cl_dBZ23_min	Minimum radar reflectivity amount at Z_2 и Z_3 levels, dBZ	From 10 up to 0	All
Cloud amount (cumulus cloud amount)			
Cl_dBZ2_min	Minimum radar reflectivity amount at Z_2 level, dBZ	From 10 up to 40	All
Cl_dBZ3_min	Minimum radar reflectivity value at Z_3 level, dBZ	From 20 up to 50	All
Cl_dBZ_min	Minimum radar reflectivity value on the whole cloud volume, dBZ, not less	From 1 up to 10	All

Continuation of Table

Criteria parameter code in special software	Name and measurement units	Amount	Operation period
Cl_tH_min	Liminal value $H_{вг}$ for cumulus cloud amount, m	From 400 up to 6000	All
Cloud amount (of upper and lower layer)			
Cl_bH_min	Liminal value $H_{НГ}$ for high and middle cloud tier amount, m	From 1000 up to 5000	All
Precipitation (weak, temperate, strong)			
Rf_dBZ1	Reflectivity liminal value Z_1, dBZ	From 0 up to 30 (precipitation weak) From 5 up to 35 (precipitation temperate) From 10 up to 40 (precipitation strong)	All
Shower precipitation (shower is light, moderate and heavy)			
Rn_dBZ1	Reflectivity liminal value Z_1, dBZ	From 10 up to 40 (shower is light) From 20 up to 45 (shower is moderate) From 25 up to 50 (shower is heavy)	All
Thunderstorms (prob.: from 30 up to 70%; from 71 up to 90%; > 90%)			
Th_Y	Thunderstorm danger liminal value, $Y = 0{,}001 \cdot H_{ul} \cdot Z_{H3}$	From 10 up to 30 (thunderstorm probability 30–70%) From 10 up to 40 (thunderstorm probability 71–90%) From 10 up to 50 (thunderstorm probability more 90%)	Warm
Th_dBZ_H3_max	Maximum radar reflectivity value at H_3 level, dBZ	From 50 up to 70	Warm
Th_dBZ_H3_min	Minimum radar reflectivity value at H_3 level, dBZ	From 10 up to 40 (thunderstorm probability 30 – 70 %) From 10 up to 50 (thunderstorm probability 71 – 90 %) From 10 up to 60 (thunderstorm probability more than 90 %)	Warm
Th_dBZ1	Radar reflectivity liminal value at Z_1 level, dBZ	From 30 up to 70	Cold
Th_dBZ2	Radar reflectivity liminal value at Z_2 level, dBZ	From 30 up to 70	Cold

Continuation of Table

Criteria parameter code in special software	Name and measurement units	Amount	Operation period
Hail (light, moderate, heavy)			
Hl_Delta_H3_Ht0	Altitude difference liminal value H_3 и H_0, м	From 1000 up to 5000	Warm
Hl_dBZ_max	Maximum radar reflectivity value on the whole cloud volume, dBZ	From 30 up to 50 (hail is weak) From 40 up to 60 (hail is temperate) From 40 up to 70 (hail is strong)	Warm
Q squalls (light, moderate, heavy)			
Fl_Delta_tH_Htr	Difference liminal value H_{ul} и H_{trop}, m	From 3000 up to 3000	Warm
Fl_Y	Complex criteria liminal value $Y = 0{,}001 \cdot H_{ul} \cdot Z_{H3}$	From 300 up to 700	Warm
Fl_dBZ3_min	Minimum radar reflectivity value Z_3, dBZ	From 20 up to 50	Warm
Fl_dBZ_max	Maximum radar reflectivity value on the whole cloud volume, dBZ	From 40 up to 60 (Q squall is weak) From 45 up to 70 (Q squall is temperate) From 50 up to 70 (Q squall is strong)	Warm
Tornados (funnel cloud)			
Td_Delta_tH_Htr	$H_{вг}$ и $H_{троп}$ difference liminal value, m	From 2000 up to 5000	Warm
Td_Delta_V_max	Liminal value of the wind speed difference between the two nearest-neighbour rates, m/s	From 30 up to 50	Warm
Td_dBZ_max	Maximum radar reflectivity liminal value on the whole cloud volume, dBZ	From 50 up to 70	Warm

according to the source. For instance, the thunderstorm classification criterion for cold period was entered into BZ WR, as thunderstorms are common in middle latitudes[3] at any time of the year.

WR BZ classified weather phenomena data validation

WR BZ has currently passed the preliminary, inspection and certification tests, prototype testing. It was set in the following points:

1. Orlovka point – Tver region;
2. Saint-Petersburg point – the city of Saint-Petersburg;
3. Vishnevsky point – Moscow region;
4. Taman point – the Republic of Crimea.

The criteria liminal amounts were selected according to the value ranges shown in Table 1 for all the following calibration procedure sequence points.

There is the weather phenomena map in WR BZ cells in the 30 km vicinity of the meteorological service – Figure 1 on the left and the conjoint weather phenomena map in the Russian meteorogical service radar cells – on the right shown as an example. The weather phenomena map of the Russian meteorological ser-

[3] Ecological and climatic atmosphere characteristics in 2014 according to M. V. Lomonosov MSU Meteorogical observatory datum. M. V. Lomonosov MSU. Available at: http://www.momsu.ru/files/disk%20MO%20MSU_2014.pdf (accessed: 28.07.2022).

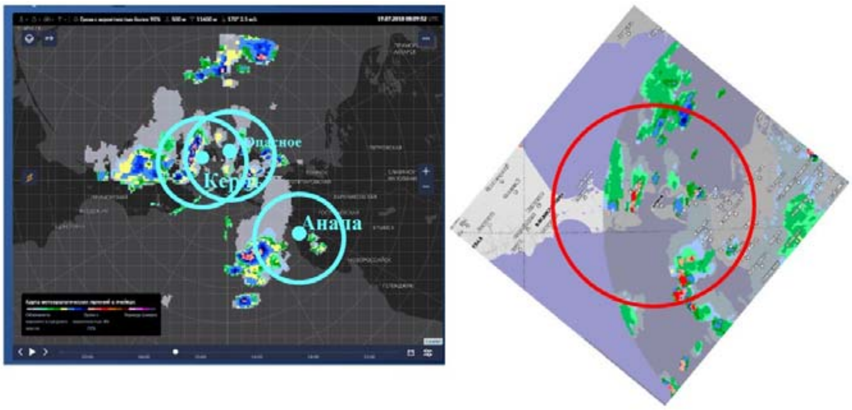

Fig. 2. Maps of weather phenomena in cells according to the WR BZ based "Taman" (left) and DWR-S "Krasnodar" (right) from 19.07.2018 08:10 UTC
The red circle shows the WR BZ radar range on the DWR-S map

vice radars was taken from the Russian meteorological service official source[4,5] .

According to the Methodology, thunderstorms monitored at meteorogical services are confirmed by WR BZ data in case of them being registered in 30 km vicinity of the meteorogical service.

Thunderstorms in 30 km vicinity of “Kerch”, “Opasnoe”, “Anapa” meteorological services (blue circle in Figure 2) were confirmed with WAREP “Kerch”, “Opasnoe”, “Anapa” meteorological services according to WR BZ data (thunderstorm in the vicinity from 07:35 to 10:03 UTC; thunderstorm in the vicinity from 07:50 to 11:10 UTC; thunderstorm in the vicinity from 07:14 to 10:01 UTC respectively).

There are other examples of WR BZ weather phenomena maps in comparison to the doublechecked veracious meteorological data in different WR BZ setting points (fig. 3, 4) below.

It was shown in work [21], that WR BZ classifies the weather phenomena with the level of success rate and veracity necessary from the weather radars. The necessary success rate and false alarm probability percentiles were taken from the Russian meteorological service[6,7,8] methodical documents. For instance, it was shown, that dangerous weather phenomena (showers, thunderstorms, hails) detection success rate was more that 86% while the minimum necessary success rate percentile is not less than 70%[7]. The dangerous weather phenomena false alarm probability was less than 1% while the maximum necessary value of false alarm probability is no more than 40%[8]. It was noted in work [21], that is possible to make a statistically based conclusion about the appropriate small scale weather radar complex of WR BZ inner airdrome zone performance according to the conducted statistical analysis.

The given WR BZ weather phenomena maps correlate with veracious weather information sources in terms of time, space and weather phenomena classification. Thus, the criterion liminal values were selected correctly according to the methodology mentioned above.

At the same time, it should be noted, that in some cases, particularly while thunderstorm and

4 Radar observation data. Russian meteorological service. Available at: https://meteoinfo.ru/radanim (accessed: 11.12.2019).

5 The Federal State Budgetary Institution “The All-Russian Hydrometeorological Datum Research Institute – The World Datum Center” data access. The Federal State Budgetary Institution “The All-Russian Hydrometeorological Datum Research Institute – The World Datum Center”. Available at: http://meteo.ru/data (accessed: 11.12.2019).

6 Methodology guidelines on DWR-S weather radar observation at Russian weather service network. St. Petersburg, 2013. 164 p.

7 Temporary methodic guidelines on DWR-S doppler weather radar data use in synoptical practice. Moscow, 2014. 110 p.

8 Temporary methodic guidelines on DWR-S doppler weather radar data use in synoptical practice. Moscow, 2017. 121 p.

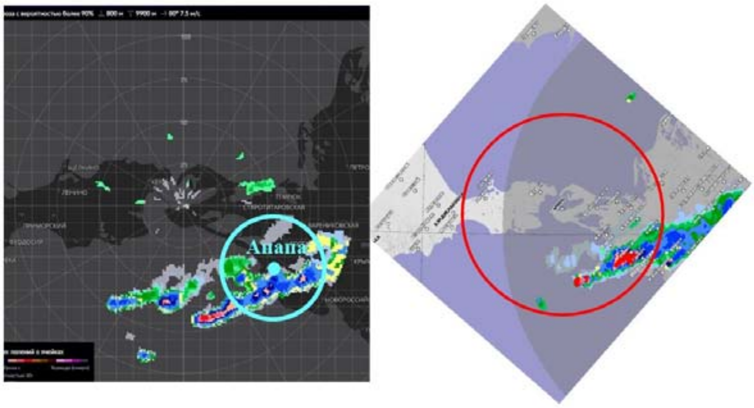

Fig. 3. Maps of weather phenomena in cells according to the WR BZ based "Taman" (left) and DWR-S "Krasnodar" (right) from 18.07.2018 03:20 UTC
The red circle shows the WR BZ radar range on the DWR-S map

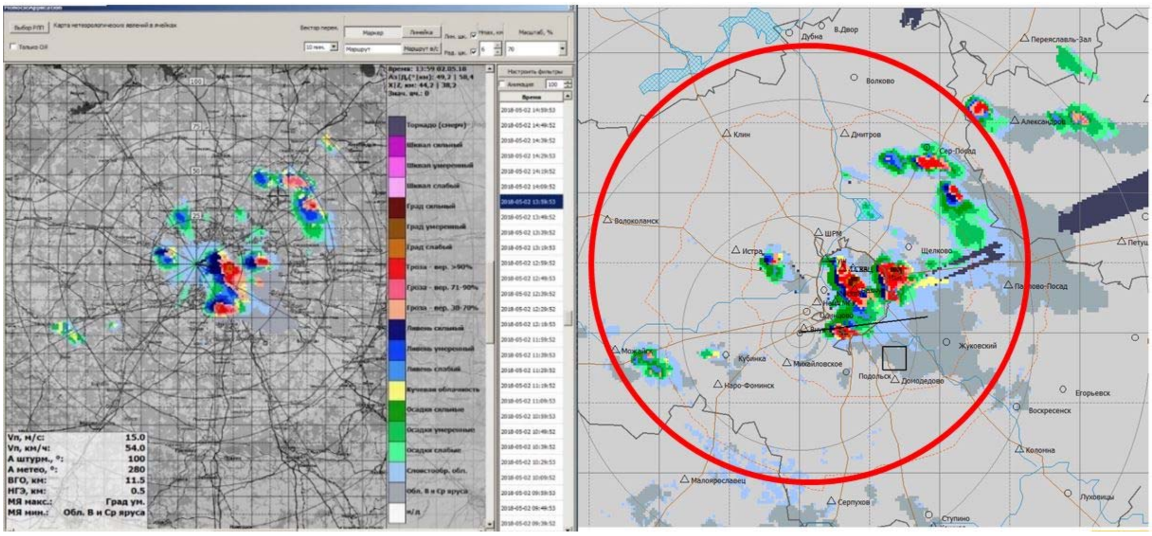

Fig. 4. Maps of weather phenomena from 13:59 UTC according to the WR BZ “Central Military Clinical Hospital named after A.A. Vishnevsky” (left) and from 14:00 according to the DWR-S “Dolgoprudny” (right) 02.05.2018 (the red contour shows the radar range of the WR BZ)

hail classification the turbulent energy dissipation specific speed data should be used for higher success rate and veracity amounts.

Thus, the further research aim is to develop the turbulent energy dissipation specific speed data obtaining for weather phenomena classification with the extra statistical data set in different climate zones of the European part of Russia – the Upper Volga Region and Krasnodar Region.

Conclusion

Thus, the unique domestic small-scale weather radar of the inner airdrome zone is currently being created, tested and certified. It meets the present day national and international requirements in full measure.

WR BZ weather phenomenon classification criteria were developed according to the Russian meteorological service guidelines, in which the general weather phenomena classification parameters for differently featured radars are given. In distinction from other current radars, thunderstorm classification parameters in cold period are considered in WR BZ. WR BZ classification criteria amounts were deduced with a large “raw” signal analysis in different synoptic situations.

It was shown due to the correctly formed WR BZ criteria, that the performance of a small-scale weather radar of an inner airdrome zone is appropriate.

At the same time, it should be noted, that turbulence is also an informative free-convection atmosphere activity feature. In such cases it is reasonable to consider a question of the turbulent energy dissipation specific speed data application in weather phenomena classification criteria, using the different statistic data of different European part of Russia climate zones in order to increase the shower, thunderstorm and hail classification veracity and success rate.

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