ТРАНСПОРТНЫЕ СИСТЕМЫ
2.9.1 – Транспортные и транспортно-технологические системы страны, ее регионов и городов, организация производства на транспорте;
2.9.4 – Управление процессами перевозок;
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Analysis of informativeness of features of classification of dangerous weather events based on radar observation results

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Abstract: One of the crucial factors affecting the safety and regularity of state and civil aviation flights is the meteorological situation. The European territory of Russia is most characterized by dangerous meteorological phenomena associated with cumulonimbus clouds: shower, thunderstorms, hail, accompanied by high atmospheric turbulence. Currently, meteorological radar stations are an indispensable source of information about the weather situation for air transport. The criteria for the classification of meteorological phenomena used in modern radar stations are formed for each event separately and are based on knowledge only about the altitude distribution of radar reflectivity and air temperature, despite the fact that radar data assess the wind characteristics of the atmosphere. It is shown that optimization of the classification criteria for the mentioned meteorological phenomena should be realized by generalization of the criteria and their construction in accordance with the theory of statistical hypothesis distinction, as well as by additional use of information on atmospheric turbulence. Based on the analysis of radar signals reflected from the meteorological events of shower, thunderstorm, and hail, probability distributions of reflectivity and specific dissipation rate of turbulent energy were obtained. Statistical analysis of probability distribution densities was carried out for: the maximum value of reflectivity Zmax, its dependence on height H(Zmax), as well as the maximum specific dissipation rate of turbulent energy EDRmax and the value H(EDRmax). The classification criterion based on the maximum probability functional was chosen to determine the structure of classification algorithms and decision rules. At the same time under the acceptable confidence is accepted the value of the probability of correct classification not lower than 0.8. For the accepted criterion the decision thresholds are constructed and the complete matrices of classification probabilities are calculated. The results of calculations showed that the worst informativeness in the classification of dangerous meteorological events of cumulonimbus cloudiness have parameters H(Zmax), H(EDRmax). Parameters Zmax, EDRmax have greater separating ability, but even for them the confidence of classification is unacceptable. In the article to increase the confidence of classification the joint use of features in the form of multivariate probability distribution densities of information parameters was applied. The best results are achieved when three p(*Zmax,H(Zmax),EDRmax*) and four p(*Zmax,H(Zmax),EDRmax,H(EDRmax)*) features are used. In the probability matrices for these cases, the maximum and acceptable at 0.8 level of probabilities of correct classification are achieved. Thus, the expansion of the feature space due to atmospheric turbulence is justified in the problem under consideration. These results will be refined with increasing observation time and will vary for different climatic zones. In general, the decision thresholds for classifying dangerous meteorological events of cumulonimbus cloudiness should be adaptive.

Key words: weather radar, dangerous weather phenomena, classification of weather phenomena, pattern recognition, feature separation function, Bayesian approach, decision threshold.

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Анализ информативности признаков классификации опасных метеоявлений по результатам радиолокационных наблюдений

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Статья подготовлена в рамках поддержанного грантом Российского научного фонда проекта № 23-29-00450

Аннотация: Одним из решающих факторов, влияющих на безопасность и регулярность полетов государственной и гражданской авиации, является метеорологическая обстановка. Для Европейской территории России наиболее характерны опасные метеорологические явления, связанные с кучево-дождевой облачностью: ливень, гроза, град, сопровождающиеся высокой турбулентностью атмосферы. В настоящее время метеорологические радиолокационные станции являются незаменимым источником информации о метеообстановке для воздушного транспорта. Критерии классификации опасных метеоявлений, используемые в современных РЛС, сформированы для каждого явления отдельно и основаны на знаниях лишь о высотном распределении радиолокационной отражаемости и температуры воздуха, несмотря на то, что данные РЛС оценивают ветровые характеристики атмосферы. Показано, что оптимизация критериев классификации указанных метеоявлений должна быть реализована путем обобщения критериев и их построения в соответствии с теорией различения статистических гипотез, а также дополнительным использованием информации о турбулентности атмосферы. На основании анализа радиолокационных сигналов, отраженных от метеоявлений ливень, гроза, град, были получены вероятностные распределения отражаемости и удельной скорости диссипации турбулентной энергии. Проведен статистический анализ плотностей распределения вероятностей для максимального значения отражаемости Zmax, ее зависимости от высоты H(Zmax), а также максимума удельной скорости диссипации турбулентной энергии EDRmax и величины H(EDRmax). Для определения структуры алгоритмов классификации и правил принятия решений был выбран критерий классификации, основанный на максимуме функционала правдоподобия. При этом под приемлемой достоверностью принято значение вероятности правильной классификации не ниже 0,8. Для принятого критерия построены пороги принятия решений и вычислены полные матрицы вероятностей классификации. Результаты вычислений показали, что наихудшую информативность при классификации опасных метеоявлений кучево-дождевой облачности имеют признаки H(Zmax), H(EDRmax). Большей разделяющей способностью обладают признаки Zmax, EDRmax, однако и для них достоверность классификации неприемлема. В статье для повышения достоверности классификации было применено совместное использование признаков в виде многомерных плотностей распределения вероятностей информационных параметров. Наилучшие результаты достигаются при использовании трех $p(Zmax, H(Zmax), EDRmax)$ и четырех $p(Zmax, H(Zmax), EDRmax, H(EDRmax))$ признаков. В матрицах вероятностей для этих случаев достигнуты максимальные и приемлемые на уровне 0,8 значения вероятностей правильной классификации. Таким образом, в рассматриваемой задаче расширение признакового пространства за счет турбулентности атмосферы является оправданным. Данные результаты будут уточняться при увеличении времени наблюдения и варьироваться для различных климатических зон. В общем случае пороги принятия решений при классификации опасных метеоявлений кучево-дождевой облачности должны быть адаптивными.

Ключевые слова: метеорологический радиолокатор, опасные метеорологические явления, классификация метеорологических явлений, распознавание образов, разделяющая функция признаков, байесовский подход, пороги принятия решений.

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Introduction

One of the contributing factors affecting the safety and regularity of state and civil aviation flights is the meteorological situation. The European territory of Russia is most characterized by dangerous meteorological phenomena associated with cumulonimbus clouds: shower, thunderstorms, hail, accompanied by high atmospheric turbulence[1] [1, 2]. The given dangerous meteorological phenomena pose threat for both takeoff and landing and flight performance, unlike conventional precipitation, wind and clouds[2]. Besides that, dangerous meteorological phenomena associated with cumulonimbus clouds, containing water in different phase conditions as a radar reflector, are available for meteorological radar stations surveillance[3].

Currently, meteorological radar stations are an indispensable source of information about the weather situation for air transport.[4] Now there are two domestic meteorological radar stations in the Russian Federation: DMR-S [3–5] and MR-NZ "Monocle" [6,7] with C and X ranges respectively, completely meeting the current requirements. The given meteorological radars operate using the pulse-doppler principle, also allow to estimate the wind characteristics of the atmosphere, such as vector velocity field, turbulence presence and value, on condition clutter return is available. The mentioned mospheric factors may be used as highly informative signs of dangerous meteorological phenomena associated with cumulonimbus clouds.

The criteria for the classification of meteorological phenomena were formed in accordance with guidance documents[5] [8]. At the same time all criteria used in modern radar stations are formed for each event separately and are based on knowledge only about the altitude distribution of radar clutter return and air temperature, despite the fact that radar data assess the wind characteristics of the atmosphere quite exactly.

Optimization of the classification criteria for the mentioned meteorological phenomena should be implemented by:

- generalization of the criteria and their construction in accordance with the theory of statistical hypothesis distinction [9–14];
- additional use of information on atmospheric turbulence.

Task for classification criteria optimization is specified in [15], parametrical description for maximum clutter return and turbulence distribution densities by values and altitudes is formed.

The paper continues the aimed research.

Problem statement

Classification problem of weather phenomena associated with cumulonimbus clouds is to solve the following mutual issues basing on radar observations:

- forming the classification alphabet, in this case these are: "shower-thunderstorm-hail";
- choosing the sign space of the maximum value of reflectivity Zmax, as well as the maximum specific dissipation rate of turbulent energy EDRmax, its dependence on height H(Zmax), and the value H(EDRmax);
- forming of sign probability description with data parameters $p(Zmax/\omega_i)$, $p(EDRmax/\omega_i)$, $p(H(Zmax)/\omega_i)$, $p(H(EDRmax)/\omega_i)$, where $i \in \{l, gz, gd\}$ probability distribution densities;
- choosing the statistical criteria of dangerous weather phenomena associated with classification for decision making threshold values, basing on data quality and classification veracity required.

The iterative sequence of problems is to correct signs and criteria in order to reach veracity required.

There is a probability sign description in [13]. Distributions close to Gaussian ones: lognormal, Weibull, Riley, Riley-Rice, β-distribution were observed to estimate the empiric datum meeting the theoretical ones. For probability density distributions $p(Zmax/\omega_i)$, $p(EDRmax/\omega_i)$, $p(H(Zmax)/\omega_i)$, $p(H(EDRmax)/\omega_i)$, where $i \in \{l, gz, gd\}$, different Pearson χ^2 agreement criteria hypothesis testing for 0.01 relevance level has shown experi-

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1 The federal service for hydrometeorology and environmental monitoring third estimation report on climate change and its consequences on territory of the Russian Federation. General summary. (2022). St. Petersburg: Knowledge-intensive technologies, 124 p. (in Russian)

2 Ministry of transport order "on federal aviation rules establishment "The Russian Federation civil aircraft flight preparation and performance", no. 128 dated July 31 2001. *GARANT.RU.* Available at: https://base.garant.ru/196235/ (accessed: 19.11.2023).

3 Ministry of Transport Order "On Federal Aviation Rules Establishment "Meteorological data provision for aircraft flight performance", no. 60 dated March 3 2014. *GARANT.RU.* Available at: https://base.garant.ru/196235/ (accessed: 19.11.2023).

4 The Russian Federation armed forces meteorological service guidance, (AFMSG – 95). (1995), 92 p. (in Russian)

5 Observation and data use guidance with non-automatic DMR-1, DMR-2 and DMR-5 radars. (1993). SPb.: Hydrometeopublish 350 p. (in Russian)

Table 1

Rice distribution parameters for rain shower, thunderstorms and hail

Parameter	Shower	Thunderstorm	Hail
		H(*Zmax*)	
ME-mean	$\mu = 2$	$\mu = 3.5$	$\mu = 4$
SD	$\sigma_x = 2.5$	$\sigma_x = 3$	$\sigma_x = 4$
		H(*EDRmax*)	
ME-mean	$\mu = 2$	$\mu = 3$	$\mu = 4$
SD	$\sigma_x = 2.5$	$\sigma_x = 4$	$\sigma_x = 4.5$
		Zmax	
ME-mean	$\mu = 22$	$\mu = 29$	$\mu = 42$
SD	$\sigma_x = 7$	$\sigma_x = 8$	$\sigma_x = 10$
		EDRmax	
ME-mean	$\mu = 0.2$	$\mu = 0.5$	$\mu = 0.61$
SD	$\sigma_x = 0.2$	$\sigma_x = 0.12$	$\sigma_x = 0.08$

mental relative frequences maximally meeting the general Riley-Rice distribution

$$p(x_i, \mu_i, \sigma_i) = \frac{x_i}{\sigma^2} \exp\left(\frac{-(x_i{}^2 + \mu_i{}^2)}{2\sigma_i{}^2}\right) I_0\left(\frac{x_i \mu_i}{\sigma_i{}^2}\right), \quad (1)$$

where $I_0(z)$ is a modified Bessel function of the first kind and zero-order. μ and σ parameters are strictly not the mathematical expectation mean (ME) and standard deviation (SD), nevertheless they express respectively the distribution form. There are μ and σ values for maximum reflectibility and turbulence, along with their altitude distribution for rain shower, thunderstorms and hail basing on experimental studies in Table 1. The given table is essentially a parametrical dangerous weather phenomena associated with cumulonimbus clouds "rain shower-thunderstorm-hail" sign classification description.

Let us take the obvious assumption: in case of reliable radar observance range data absence and justified loss matrix while taking mistakeable decisions the relative sign **x** distribution densities while ω_i $p(\mathbf{x}/\omega_i)$ weather phenomenon observation, where $i \in \{shower, tstorm, hail\}$. The given statistics allows decision making based on the maximum-probability criterion to meet $\omega = i$, which is chosen.

$$p(\mathbf{x}/\omega_i) > p(\mathbf{x}/\omega_k) \text{ for all } k \neq i. \quad (2)$$

Sufficient statistics for conditions adopted define the optimal decision structure and data proceeding approach [16–18].

"Other event" class is to be included in the alphabet whole forming the whole event group in case of strict classification problem statement. In the given statement the weather phenomenon "rain shower" is the lowest by its danger and essentially not threatening neither by precipitation intensity, nor by cumulonimbus clouds with continuous precipitation ("rain shower"), along with "tornado" which is higher by danger, nevertheless, not frequent for European part of Russia temperate latitudes. The latter defines integration limits while calculating respective decision-making probabilitys, like it will be further shown [19].

Besides that, let us take an assumption about sign independence, which will significantly simplify problem solution without considerably influencing its result.

Thus, let us define vocabulary classification signs information value and their impact on decision-making reliability for assumptions and limits taken. At the same time let us take the right classification probability value not less then 0.8 as an appropriate reliability.

Analysis of dangerous weather phenomena associated with cumulonimbus clouds signs information value

Maximum plausibility criterion (2) forms alternative threshold $i, k;\ i \neq k$ considering (1) as an equation

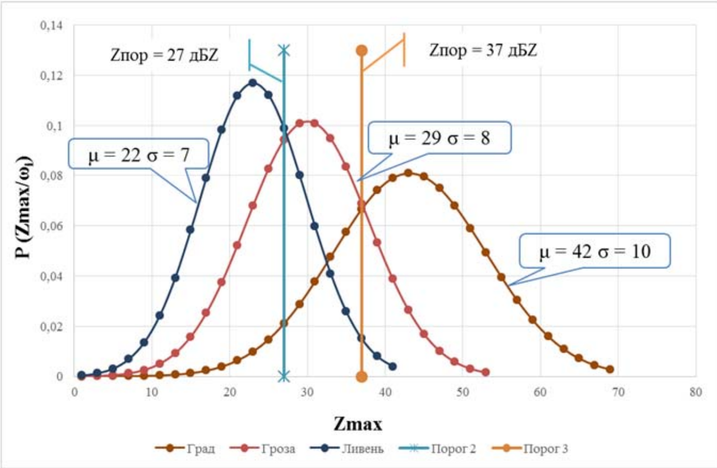

Fig. 1. Decision thresholds for the Zmax parameter

$$h_{\text{пор}}(i,k) = \frac{x}{\sigma_i^2} e^{-\frac{x^2+\mu_i^2}{2*\sigma_i^2}} I_0\left(\frac{x*\mu_i}{\sigma_i^2}\right) - \frac{x}{\sigma_k^2} e^{-\frac{x^2+\mu_k^2}{2*\sigma_k^2}} I_0\left(\frac{x*\mu_k}{\sigma_k^2}\right) = 0. \quad (3)$$

Forming a threshold pair $h_{sh,tstorm}(Z_{max}) = 27.4\ dBZ$, $h_{sh,tstorm}(Z_{max}) = 37.2\ dBZ$ is the example of the pdf pair of equation solved p(Zmax/ωi),at $i \in \{sh, tstorm, hail\}$.

The full matrix of classification probabilities [9] can be formed for any x sign for Zmax, EDRmax, H(Zmax), H(EDRmax) multitude

$$\mathrm{P}(x) = \begin{vmatrix} \mathrm{P}_{\boldsymbol{shsh}}(\boldsymbol{x}) & \mathrm{P}_{shtstorm}(x) & \mathrm{P}_{shtstormhail}(x) \\ \mathrm{P}_{tstormsh}(x) & \mathrm{P}_{\boldsymbol{tstormtstorm}}(\boldsymbol{x}) & \mathrm{P}_{tstormhail}(x) \\ \mathrm{P}_{hailsh}(x) & \mathrm{P}_{hailtstorm}(x) & \mathrm{P}_{\boldsymbol{hailhail}}(\boldsymbol{x}) \end{vmatrix}, \quad (4)$$

which elements are calculated as

$$\begin{cases} P_{sh,sh}(x) = \int_0^{h_{sh,tstorm}(x)} p(x,sh)\,dx; \\ P_{sh,tstorm}(x) = \int_{h_{sh,tstorm}(x)}^{h_{tsorm,hail}(x)} p(x,sh)\,dx; \\ P_{sh,hail}(x) = \int_{h_{tstorm,hail}(x)}^{\infty} p(x,sh)\,dx; \\ P_{tstorm,sh}(x) = \int_0^{h_{sh,tstorm}(x)} p(x,tstorm)\,dx; \\ P_{tstorm,tstorm}(x) = \int_{h_{sh,tstorm}(x)}^{h_{tstorm,hail}(x)} p(x,tstorm)\,dx; \\ P_{tstorm,hail}(x) = \int_{h_{tstorm,hail}(x)}^{\infty} p(x,tstorm)\,dx; \\ P_{hail,sh}(x) = \int_0^{h_{sh,tstorm}(x)} p(x,tstorm)\,dx; \\ P_{hail,sh}(x) = \int_{h_{sh,tstorm}(x)}^{h_{tstorm,hail}(x)} p(x,hail)\,dx; \\ P_{hail,hail}(x) = \int_{h_{tstorm,hail}(x)}^{\infty} p(x,hail)\,dx, \end{cases} \quad (5)$$

where diagonal elements define right decision-making veracity.

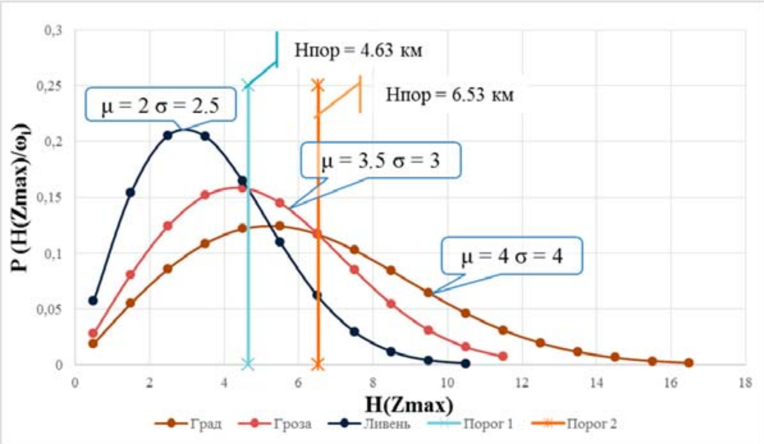

Fig. 2. Decision thresholds for parameter H(Zmax)

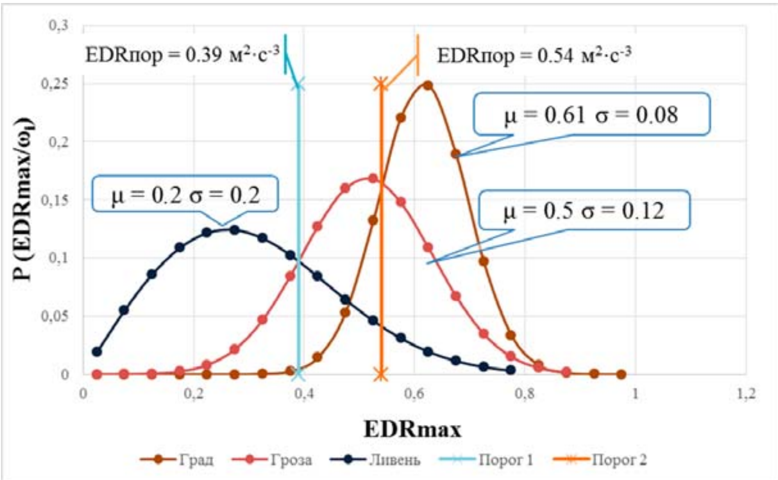

Fig. 3. Decision thresholds for the EDRmax parameter

Using 0 and ∞ as integrity limits is not totally correct, nevertheless analysis of dangerous weather phenomena associated with cumulonimbus clouds signs information value problem statement allows it.

For case in Figure 1 there is

$$\mathrm{P}(Zmax) = \begin{vmatrix} \mathbf{0.715} & 0.263 & 0.022 \\ 0.347 & \mathbf{0.463} & 0.19 \\ 0.05 & 0.218 & \mathbf{0.732} \end{vmatrix}. \quad (6)$$

In (6) there are high probabilities of mixing up in case of non-sufficient right classification values, especially in terms of thunderstorm. For $H(Zmax)$ (fig. 2) decision making thresholds have the values $h_{sh,tstorm}\left(H(Z_{max)}\right) = 4.63\ km$; $h_{tstorm,hail}\left(H(Z_{max})\right) = 6.53\ km.$

High curve overlapping square is expressed in inappropriate classification matrix values, each in its own quality.

$$\mathrm{P}(H(Zmax)) = \begin{vmatrix} \mathbf{0.759} & 0.153 & 0.088 \\ 0.518 & \mathbf{0.205} & 0.277 \\ 0.374 & 0.177 & \mathbf{0.449} \end{vmatrix}. (7)$$

Almost the same can be seen for $H(EDRmax)$ where the thresholds have the values $h_{sh,tsorm}((EDRmax)) = 5.09$ km; $h_{tstorm,hail}(H(EDRmax)) = 6.89$ km

$$\mathrm{P}(H(EDRmax)) = \begin{vmatrix} \mathbf{0.791} & 0.156 & 0.053 \\ 0.463 & \mathbf{0.220} & 0.317 \\ 0.359 & 0.208 & \mathbf{0.433} \end{vmatrix}. (8)$$

The situation for $EDRmax$ (fig.3), thresholds are $h_{sh,tstorm}(EDRmax) = 0.39\ m^2s^{-3}$, $h_{tstorm,hail}H(EDRmax) = 0.54\ m^2s^{-3}$ is hardly ever better. In case of a thunderstorm the plausibility of decision is unacceptable.

$$\mathrm{P}(EDRmax) = \begin{vmatrix} \mathbf{0.712} & 0.205 & 0.083 \\ 0.146 & \mathbf{0.440} & 0.414 \\ 0.002 & 0.170 & \mathbf{0.828} \end{vmatrix}. (9)$$

Thus¸ H(Zmax), H(EDRmax) signs possess the worst informative value in terms of dangerous weather phenomena associated with cumulonimbus clouds classification. Zmax, EDRmax signs present more dividing abilities, nevertheless thunderstorm classification reliability is also inappropriate for them.

Estimation of dangerous weather phenomena associated with cumulonimbus clouds classification in multidimensional sign space

The recognition theory is an obvious solution of the problem occurred [9, 20]. Joint use of signs, for instance, as multidimensional random data parameters Zmax, EDRmax, H(Zmax), H(EDRmax) [21] distribution densities is necessary in the given class alphabet in order to increase weather phenomena classification reliability. For the assumption about sign statistical independence their probability distribution density n looks like

$$p(x_1, \mu_1, \sigma_1, x_2, \mu_2, \sigma_2, \dots, x_n, \mu_n, \sigma_n) = \prod_{i=1}^{n} p(x_i, \mu_i, \sigma_i), \quad (10)$$

where $p(x_i, \mu_i, \sigma_i)$ is (1).

There are two-dimensional distribution densities p(Zmax, H(Zmax)/ω_i) and p(EDRmax, H(EDRmax)/ω_i) respectively in Figures 4 and 5.

Thresholds for two-dimensional cases by numerical method [18, 22] are planes, crossing each other in Figures 6 and 7, presented as curves.

The respective probability matrixes look like

$$\mathrm{P}(Zmax, H(Zmax)) = \begin{vmatrix} \mathbf{0.753} & 0.243 & 0.004 \\ 0.320 & \mathbf{0.505} & 0.175 \\ 0.040 & 0.216 & \mathbf{0.744} \end{vmatrix}, \quad (11)$$

$$\mathrm{P}(EDRmax, H(EDRmax)) = \begin{vmatrix} \mathbf{0.761} & 0.175 & 0.064 \\ 0.146 & \mathbf{0.463} & 0.391 \\ 0.003 & 0.181 & \mathbf{0.816} \end{vmatrix}. \quad (12)$$

For the most informatively valuable Zmax and EDRmax signs matrix is equal to

$$\mathrm{P}(Zmax, EDRmax) = \begin{vmatrix} \mathbf{0.769} & 0.161 & 0.070 \\ 0.141 & \mathbf{0.683} & 0.176 \\ 0.031 & 0.159 & \mathbf{0.810} \end{vmatrix}. \quad (13)$$

Matrix (13) predictably presents the best classification reliability markers. Let us analyze the increase of this marker with the given problem dimension increase. Thus,

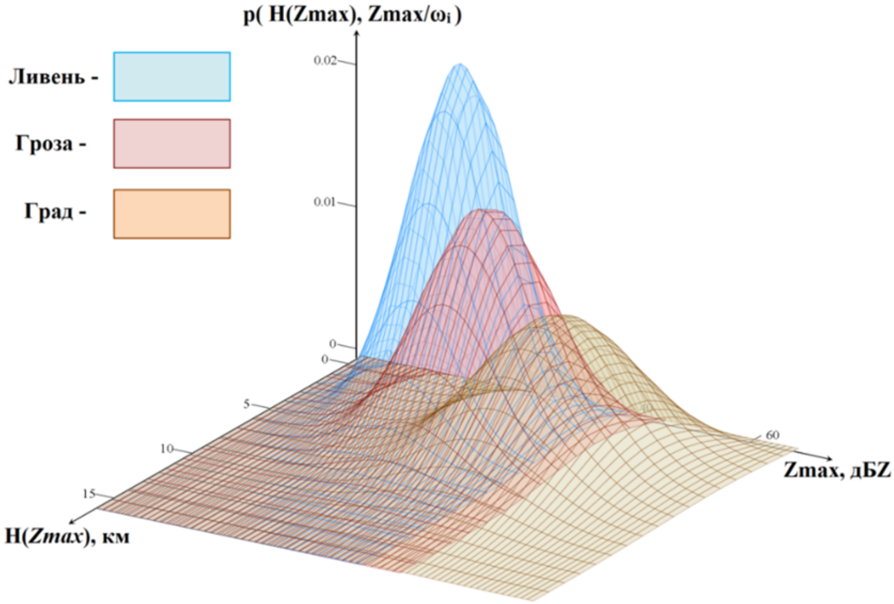

Fig. 4. Surface of the two-dimensional probability density of the radar reflectivity

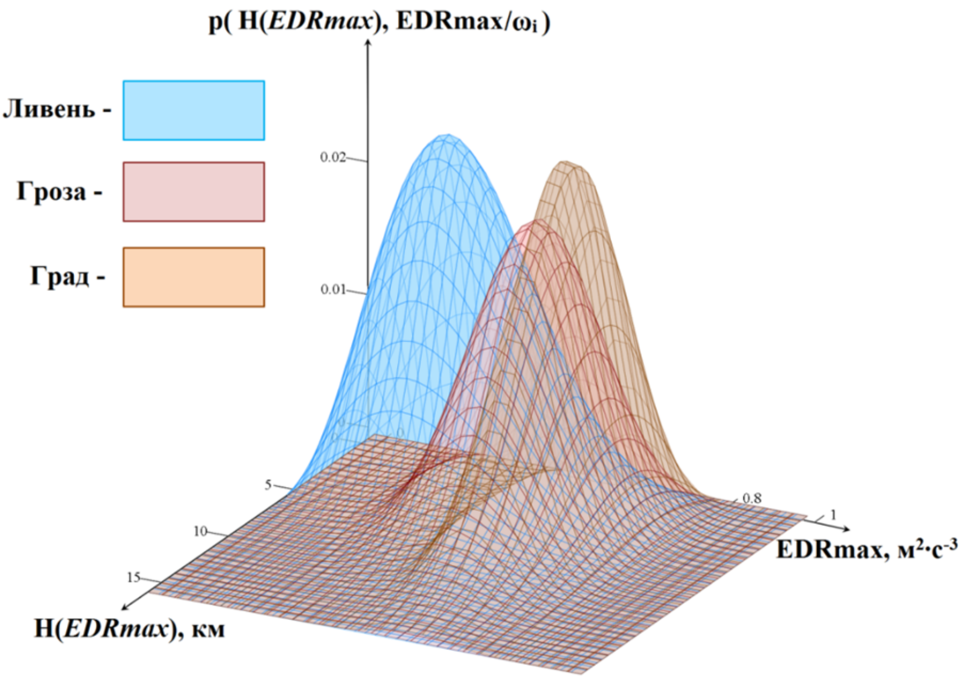

Fig. 5. Surface of the two-dimensional EDR probability density

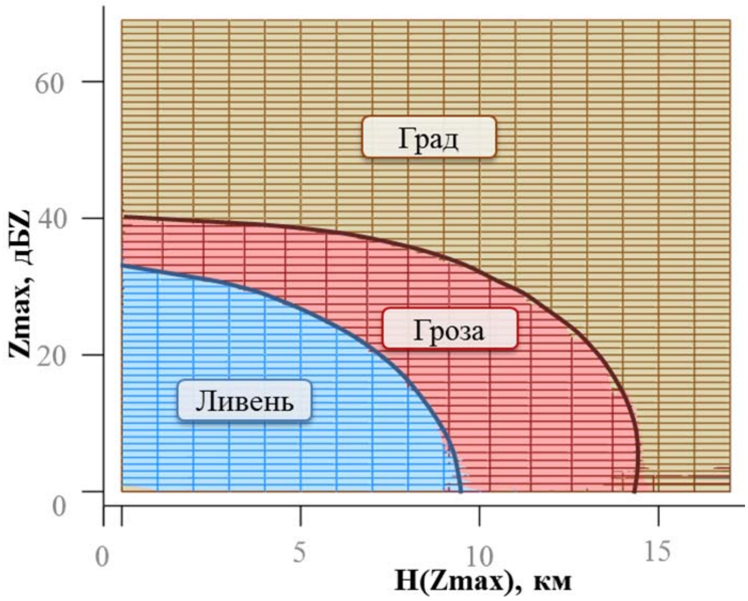

Fig. 6. Projection of the dividing plane onto the horizontal plane for p(H(Zmax), Zmax/ω_i)

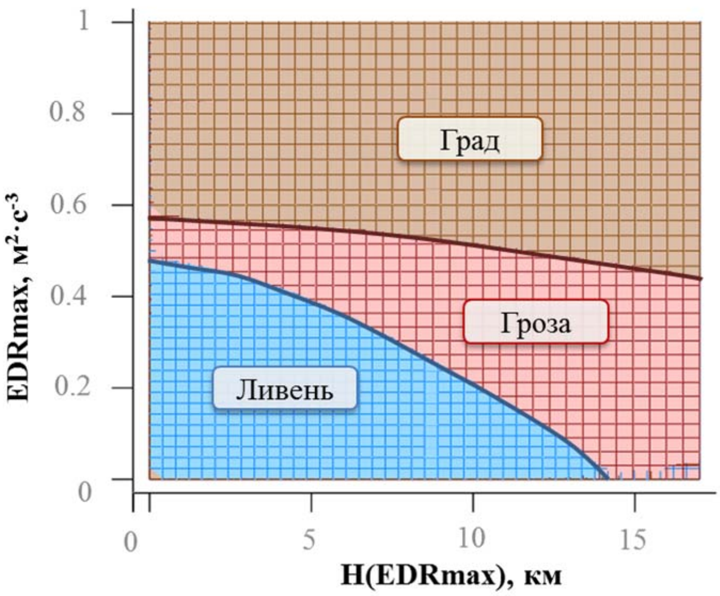

Fig. 7. Projection of the dividing plane onto the horizontal plane for p(H(EDRmax), EDRmax/ω_i)

$$\mathrm{P}(Zmax, H(Zmax), H(EDRmax)) = \begin{vmatrix} \mathbf{0.809} & 0.174 & 0.017 \\ 0.231 & \mathbf{0.553} & 0.216 \\ 0.075 & 0.173 & \mathbf{0.752} \end{vmatrix}, \quad (14)$$

$$\mathrm{P}(EDRmax, H(EDRmax), H(Zmax)) = \begin{vmatrix} \mathbf{0.788} & 0.146 & 0.066 \\ 0.251 & \mathbf{0.497} & 0.252 \\ 0.049 & 0.144 & \mathbf{0.807} \end{vmatrix}, \quad (15)$$

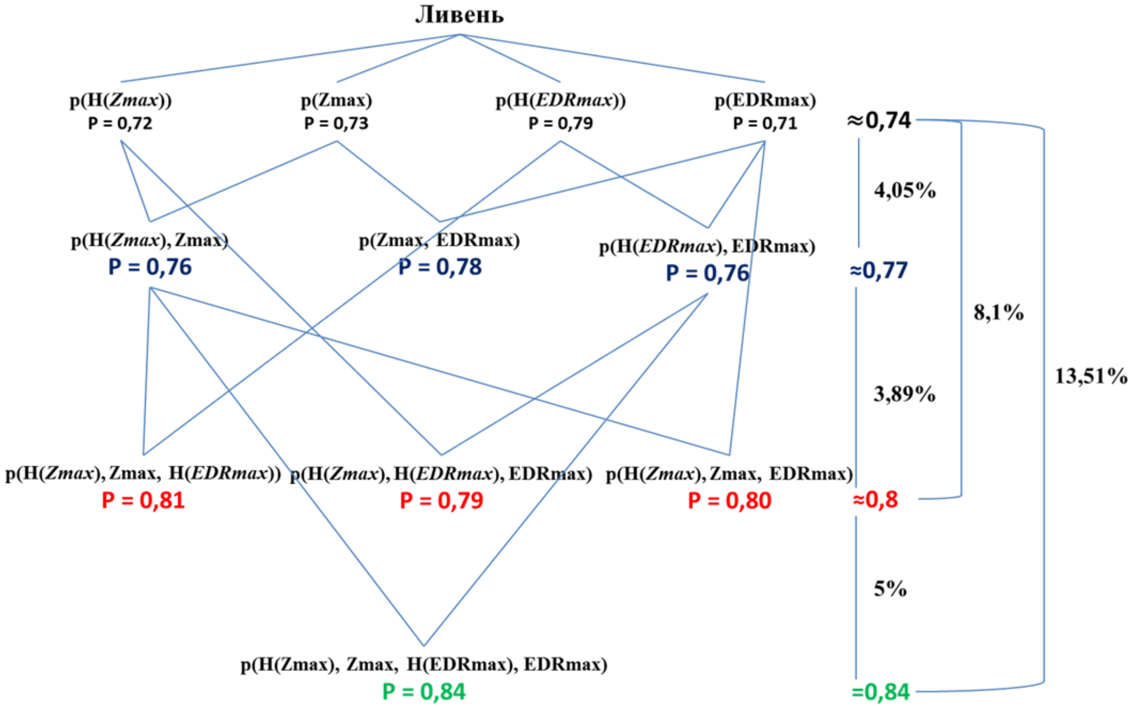

Fig. 8. Relative increase in plausibility of heavy shower classification with increasing number of features

$$\mathrm{P}(Zmax, H(Zmax), EDRmax) = \begin{vmatrix} \mathbf{0.800} & 0.195 & 0.005 \\ 0.162 & \mathbf{0.691} & 0.147 \\ 0.024 & 0.159 & \mathbf{0.817} \end{vmatrix}. \quad (16)$$

And then

$$\mathrm{P}(Zmax, H(Zmax), EDRmax, H(EDRamx)) = \begin{vmatrix} \mathbf{0.839} & 0.138 & 0.023 \\ 0.145 & \mathbf{0.701} & 0.154 \\ 0.022 & 0.157 & \mathbf{0.821} \end{vmatrix}. \quad (17)$$

Probability matrix (17) has predictably reached the maximum correct classification probability values. Only the plausibility of thunderstorm classification is below the required level. However, in case of practical implementation the threshold $h_{sh,tstorm}$ may be slightly lowered, considering the greater hazard of the thunderstorm, or both thresholds $h_{sh,tstorm}$ and $h_{sh,tstorm}$ and C to equalize the plausibility for all classes.

There are sums and probability right classification increase for rain shower, thunderstorm and hail respectively with different nomenclature and number of signs in Figures 8, 9, 10. In case of rain shower increase from one-dimensional problem to four-dimensional one was only 13.5 %. Almost appropriate reliabilities for rain shower occurred already in two-dimensional variants. The whole increase for thunderstorm was 100%. Nevertheless, the appropriate classification reliability is not reached even in a four-dimensional variant. Zmax и EDRmax signs possess the most informational value. The given parameter distribution by altitudes is correlated and by this reason is less informative. The percent sum of decision-making reliability increase in “one- to two dimensional” problem interchange is 30.22 %, “one- to three-dimensional” – 34.6 %, “one- to four-dimensional” – 49.3 %. This confirms that the sign space in this case is necessary considering the “dimension curse” [9].

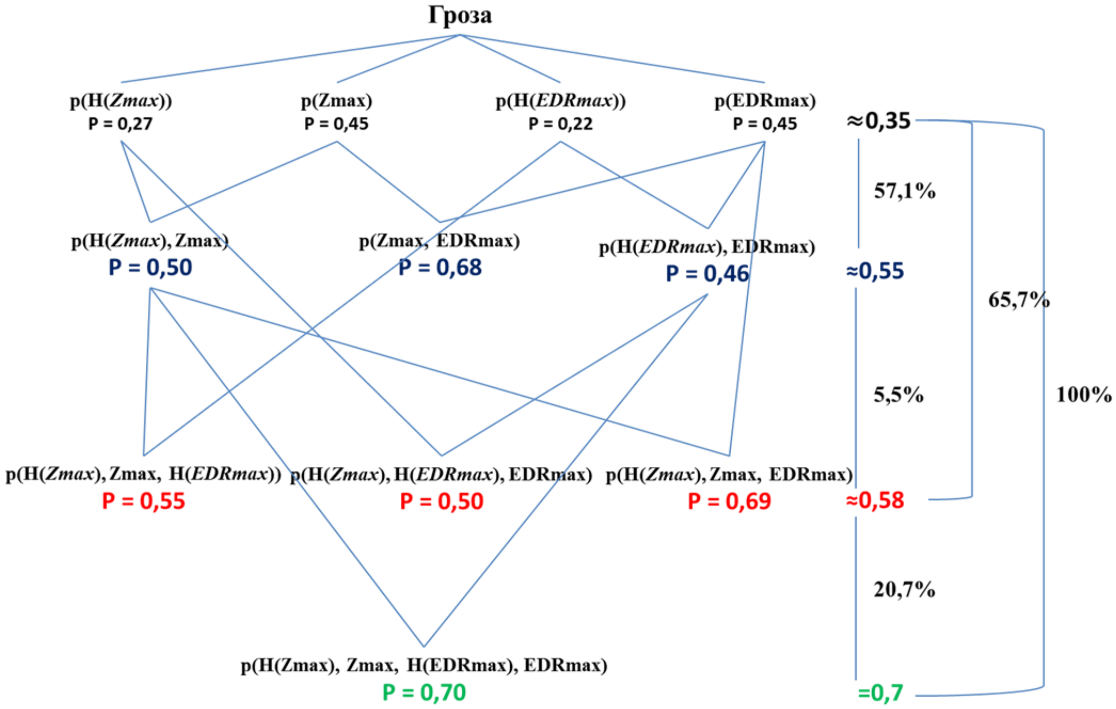

Fig. 9. Relative increase in plausibility of thunderstorm classification with increasing number of features

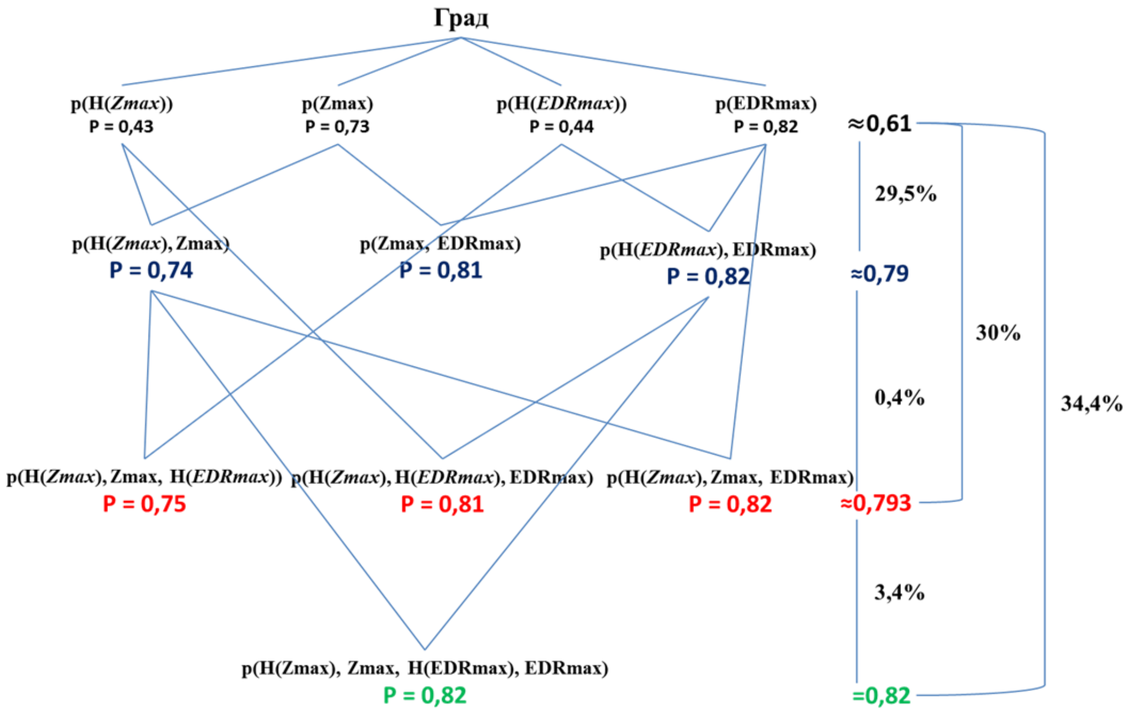

Fig. 10. Relative increase in plausibility of hail classification with increasing number of features

Conclusion

It is shown that maximum plausibility criterion is the most productive for dangerous weather phenomena associated with cumulonimbus clouds classification problem in case there is no reliable data or respective loss matrix. Decision making thresholds are calculated and full probability classification matrixes are formed for one-, two-, three- and four-dimensional sign spaces for the criterion taken.

Results analysis has shown that H(Zmax), H(EDRmax) signs are the least informatively valuable in dangerous weather phenomena associated with cumulonimbus clouds classification. Zmax, EDRmax possess the more dividing ability. Thus, sign space expansion due to atmosphere turbulence is justified in the given problem. The percent sum of decision-making reliability increase in "one- to two dimensional" problem interchange is 30.22%, "one- to three-dimensional" – 34.6%, "one- to four-dimensional" – 49.3%. The best results are obtained while using three $p(Zmax, H(Zmax), EDRmax)$ and four $p(Zmax, H(Zmax), EDRmax, H(EDRmax))$ signs. Maximum and appropriate (up to 0.8) right classification probability values are calculated for these cases in probability matrixes. Thunderstorm classification veracity is insignificantly lower. However, in case of practical implementation the threshold $h_{sh,tstorm}$ may be slightly lowered, considering the greater hazard of the thunderstorm, or both thresholds $h_{sh,tstorm}$ and $h_{sh,tstorm}$ and C to equalize the plausibility for all classes.

The given results are based on observations in Upper Volga region for one summer period. They will obviously be refined during a longer observation period and vary for different climate zones. The authors are currently researching and estimating the dangerous weather phenomena associated with cumulonimbus clouds statistic characteristics variability for different European part of Russia meteorogical zones during a number of summer periods. The paper is being prepared for publication. In general decision making thresholds for dangerous weather phenomena associated with cumulonimbus clouds classification should be adaptive and will be formed automatically in the foreseen future.

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