HYDRODAYNAMIC- STATISTICAL METHOD OF SQUALLS AND STORM WIND FORECAST OVER THE TERRITORIES OF EUROPEAN PART OF RUSSIA AND UKRAINE

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1. INTRODUCTION

- Development of successful method for automated statistical well-in-advance forecast (from 12 hours to two days) of dangerous summer winds, including squalls and tornadoes could allow to take proper measures against destruction of buildings and to protect people. Prediction of the phenomena involved has been a very difficult problem for synoptic till nowadays. The existing graphic and calculation methods using by the synoptic for the forecast of these phenomena are still in dependence on subjective decision of an operator. The synoptic usual gives the storm warning of the strong wind (V>19m/s) and dangerous wind (the velocity of V>24m/s) with the earliness of 3 hours only.
- Nowadays there is no hydrodynamic model for the forecast of such wind velocity in Russia, hence the main tools for objective forecast development are methods using the statistic model of these phenomena recognition.

2. THE STATISTICAL MODEL OF SQUALLS AND DANGEROUS WIND ALTERNATIVE FORECAST

The meteorological situation involved the dangerous phenomena –the squalls (V>19m/s) and dangerous wind including tornadoes was submitted as the vector $\mathbf{X}(A)=(x_1(A), x_2(A), \ldots x_n(A))$, where n – the quantity of the empiric potential atmospheric parameters (predictors). The values of these predictors for the dates and towns, where these phenomena are observed, were accumulated in the set $\{\mathbf{X}(A)\}$ – the learned sample of the phenomena A presence.

The learned sample of the phenomena A absence or the phenomena B presence ($\{\mathbf{X}(B)\}$) was obtained for such towns, where the atmosphere was unstable and the thunderstorms and the rainfalls were observed, but the velocity values were not so high.

The recognition model of the sets $\{\mathbf{X}(A)\}$ and $\{\mathbf{X}(B)\}$ was constructed by the using the bias approach ([1] and [2]), realized on FORTRAN.

$U(\mathbf{X})=\sum a_i x_i + c$, $i=1,\ldots,k$, and (1)

the decisive rule of the forecast of the strong wind is:

If $U(\mathbf{X})>0$, then the phenomenon A is predicting in given point,

If $U(\mathbf{X})\leq 0$, then the phenomenon B is predicting in given point. (2)

(If $U(X)>3$, then it is possible to observe the storm wind at the suburb of the town)

3. THE COMPRESSING OF THE PREDICTORS SPACE WITHOUT THE INFORMATION LOSSES

The problems of the compressing of the predictors space without the information losses and the problem of the informative vector-predictor choosing were decided before the problem of the recognition of the sets {**X**(A)} and {**X**(B)}. It was made with the help of a transmutation of a sample mean matrix **R** columns and lines.

For this purpose the sample matrix **R** was put in accordance to the connected graph **G**; 26 predictors are in correspondence to the graph vertices, and the binary coefficients **r**ij are in correspondence to ribs of the graph **G**. Given the threshold of the connection **r,** we'll keep only the ribs in graph **G** corresponding to the binary coefficient **r**ij ≥**r**. The connected graph **G** breaks up to several connected subgraphs **Gi** in this case. Each subgraph **Gi** was put in accordance to fix diagonal block of dependent predictors of the matrix **R**. Given optimal threshold **r**=0.5 we have obtained three blocks of the dependent predictors and the several isolated vertices, which are corresponding to the almost independent predictors. The informative predictors – the representatives from each block and two independent predictors have composed the informative vector-predictor of dimension k=6 [2].

The graf G of the predictors for the squalls forecast corresponding to the mean correlation matrix R. The breaking of the graf G to the several connected subgrafs Gi.

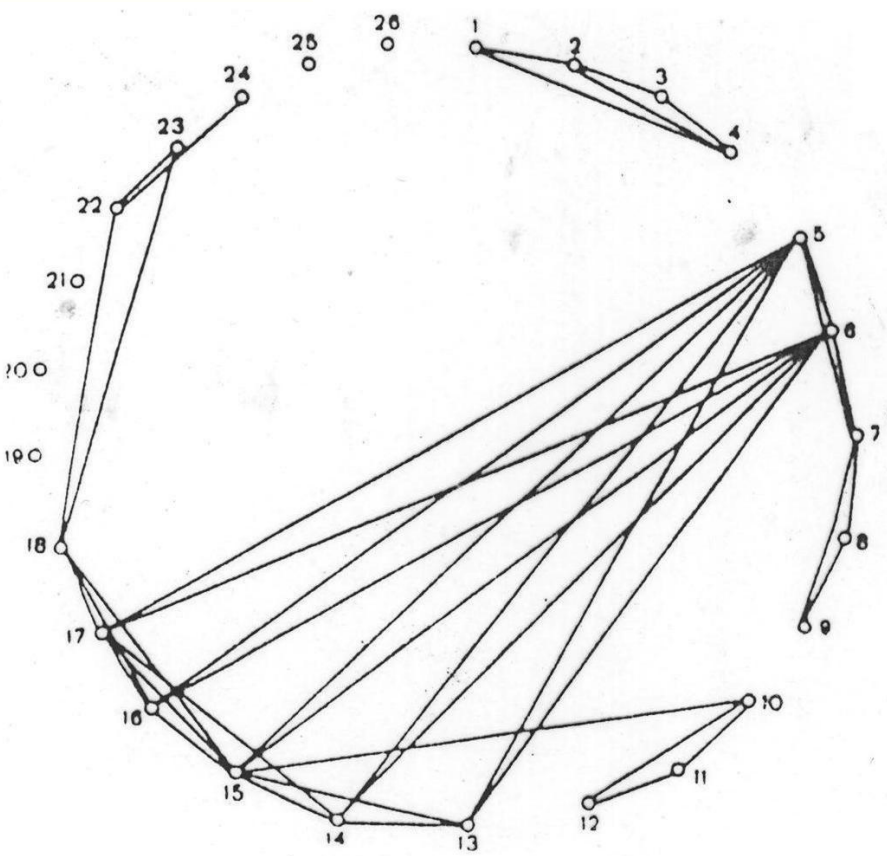


fig.1

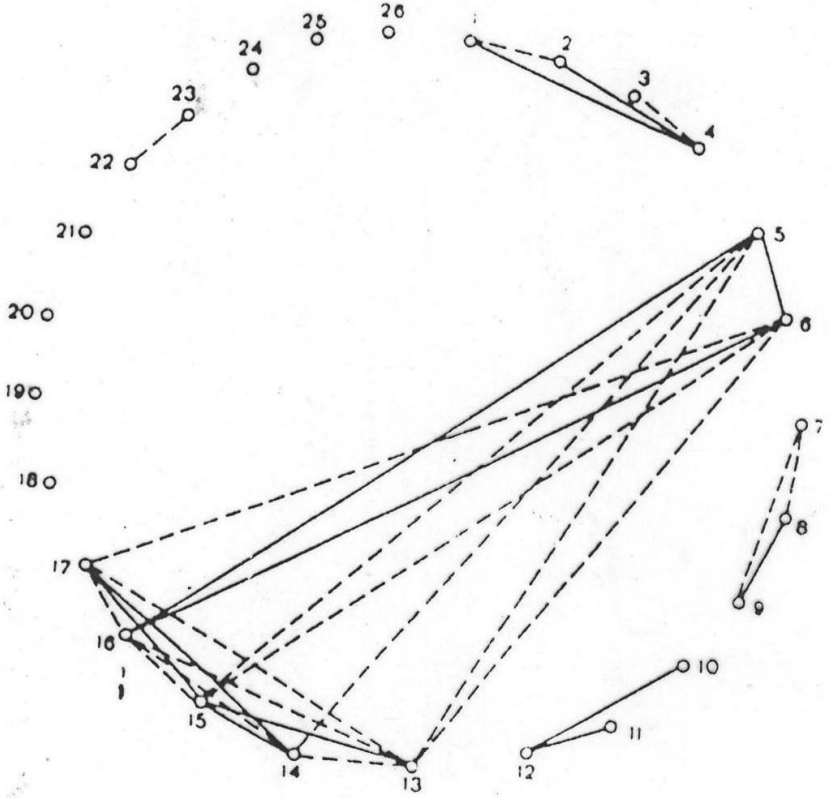


fig. 2

4. THE CRITERION OF MAHALANOBIS DISTANCE AND THE CRITERION OF ENTROPY MINIMUM

- The most informative predictors in each of the blocks was taken as a representatives from this block. For this purpose we have estimated the informativition of each predictors by using the Mahalanobis distance criterion Δ^2 :
  - $\Delta^2 = (m_i(A)-m_i(B))\uparrow 2/\sigma^2$,
- where $m_i(A)$ and $m_i(B)$ are the components of **M**(A) and **M**(B) - of the vectors of empiric expectation of the presence and absence of A respectively, σ^2 – the mean variance.
- The criterion of entropy minimum by Vapnik-Chervonenkis H_{min} was used for the assessment of the informativition of predictors too [3].
- The criterion Δ^2 is usual applied for the normal distribution as a rule. The temperature, the pressure, the geopotential, the mean velocity of wind at the different level are distributed close to the normal one, so we have decided to use this criterion as a simple enough method.
- The criterion H_{min} by Vapnik-Chervonenkis is nonparametric method, we have got the program for the calculation of the values H_{min} for each of the predictors.

Значения расстояния Махаланобиса и значения минимальной энтропии для 26 предикторов.

№№	Обозначение	Расстояние Махалонобиса	Минимальная энтропия	M (A)	M (B)
1	V_{850}	0.570	0.623	11.1	7.94
2	V_{700}	1.33	0.558	14.0	8.98
3	V_{500}	0.300	0.600	17.1	12.0
4	$V_{850}+V_{700}+V_{500}$	1.14	0.561	47.5	32.8
5	ΔH	0.382	0.625	583.0	503.0
6	δh	0.053	0.655	281.0	256.0
7	$H_{конд.}$	0.003	0.662	828.0	837.0
8	H_{-10}	0.571	0.608	547.0	580.0
9	H_0	0.746	0.588	669.0	715.0
10	D_{700}	0.003	0.653	5.51	5.8
11	D_{500}	0.002	0.667	8.15	8.4
12	$D_{700}+D_{500}$	0.011	0.668	13.7	14.2

Значения расстояния Махаланобиса и значения минимальной энтропии для 26 предикторов (продолжение).

№№	Обозначение	Расстояние Махалонобиса	Минимальная энтропия	M (A)	M (B)
12	$D_{700}+D_{500}$	0.011	0.668	13.7	14.2
13	$(T'-T)_{700}$	0.072	0.648	3.54	3.01
14	$(T'-T)_{500}$	0.626	0.610	5.30	2.91
15	$\Sigma(T'-T)_i$	0.093	0.622	8.89	5.93
16	$T_{конв.}$	0.41	0.624	-50.3	-40.6
17	$(T'-T)_{max}$	0.475	0.627	6.93	4.88
18	$H_{(T'-T)max}$	0.625	0.584	6.06	5.43
19	$dT/dn_з$	0.841	0.594	8.89	5.39
20	фронт	0.38	0.594	2.97	4.43
21	$\Delta P_з$	0.13	0.65	3.97	0.24
22	$T_з$	0.847	0.572	27.8	23.8
23	$Td_з$	0.978	0.58	15.4	11.6
24	dT/dn_{850}	0.464	0.624	4.69	2.94
25	ΔH_{850}	0.001	0.661	1.18	0.850
26	ΔT_{850}	0.005	0.656	-4.6	-0.73

- As a result, the groups of the most informative predictors calculating by Δ^2 and by H_{min} are coincided, and the informative vector-predictor has been composed from six atmospheric parameters after this selection:
- (V_{700}, H_0, $(T-T')_{500}$, dt/dn_{ea}, T_{ea}, T_d), where
- -V_{700} – the value of the mean velocity of the wind on the level 700 hPa;
- - H_0 – the level of the isotherm of 0°C , hPa;
- -$(T'-T)_{500}$ – the difference between the values of the stratification curve and the moist adiabat curve on the level 500 hPa, °C;
- -dt/dn_{ea} –the maximal difference between temperatures over the front on the earth level in the distance of 250 km from the forecast point.
- - T_{ea} – the maximal temperature on the earth level, °C;
- - Td – the maximal temperature of the dew point on the earth level, °C.
- The validation assessments of this statistical model and of the objective physic-statistical forecast of the dangerous wind (V>19m/s) in the accordance to (2) over the regions of the territory of Russia and Ukraine were good enough (the criterion by Pirsy-Obukhov for Ukraine equals $T = 1 – \alpha – \beta = 0,62$ ($T=0,27$ for the method by Prokh for Ukraine), where α – the error of first kind, β – the error of second kind) [4].

Таблица 2

Прогноз смерчей, наблюдавшихся в 1984–1986 гг., на текущий день по значениям дискриминантной функции U(X)

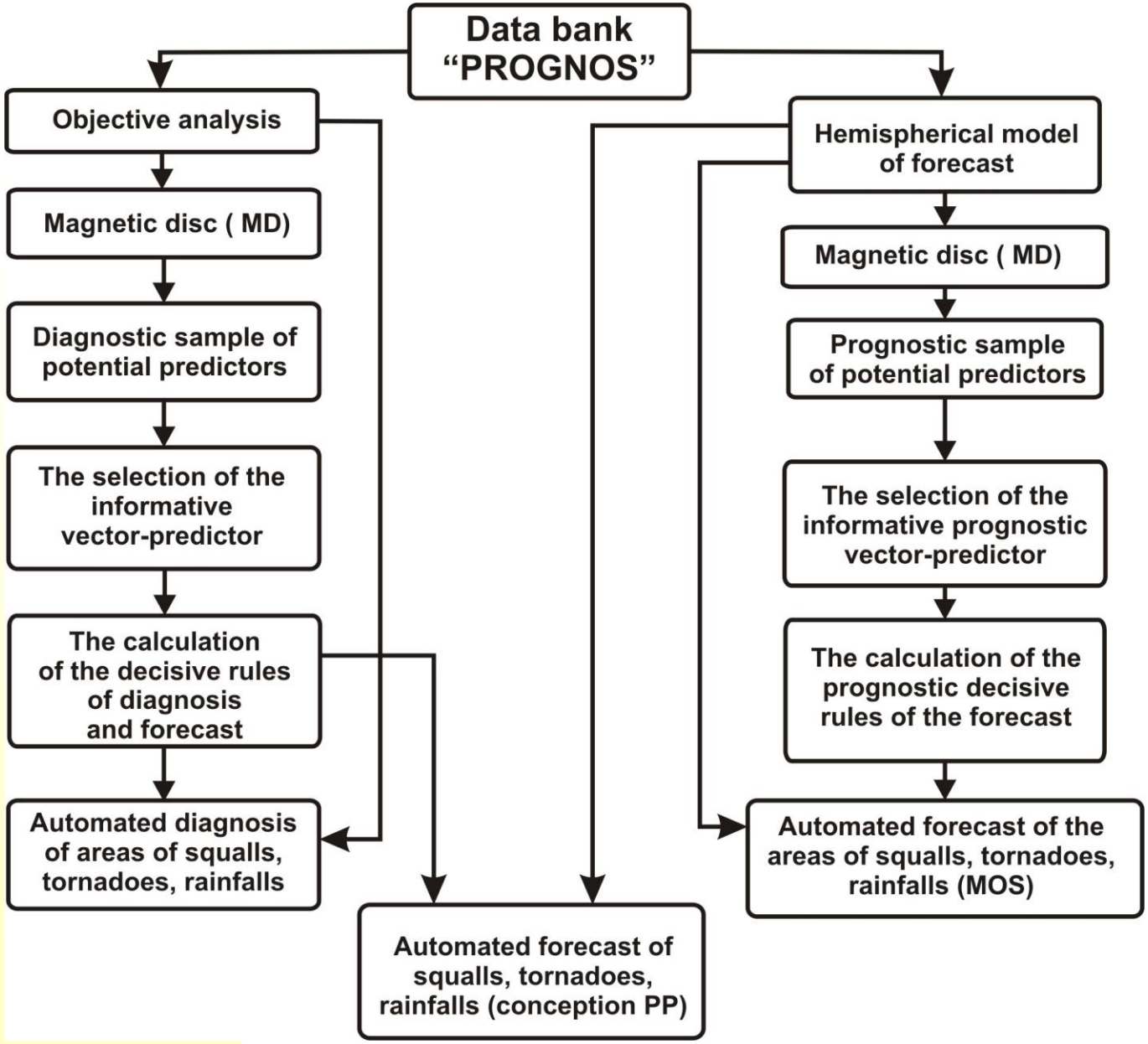
Пункт	Дата	V_{700}	H_0	$(T'-T)_{500}$	$\partial T / \partial n_3$	T_{max}	Td_{max}	U(X)
Иваново	9.06.1984	13	630	9	5	24	15,0	3,6
Пенза	21.08.1986	20	630	6	4	31	16,0	7,9
Рязань	26.08.1986	22	660	7	3	30	15,0	7,3
Москва	31.08.1986	18	615	2	3	31	13,5	7,9

Вечером 3 июня 2009 года на северо-западе Московской области в поселке Краснозаводск наблюдался разрушительный смерч. Скорость ветра по шкале Ботфорта превышала 25м/с. На ближайшей к пункту Краснозаводск метеорологической станции в г. Долгопрудный были отмечены в течение этих суток максимальные порывы ветра со скоростью V=18-22м/с. Как и в представленных в таблице 2 случаях, синоптиками прогнозировались в течение дня грозы и порывы ветра со скоростью 15-18м/с.

5. The model of the automated hydrodynamic-statistical forecast of the squalls and of the storm wind and its validation for the territories of Russia and Ukraine

- The values of atmospheric parameters used at this developmented 25years ago objective physic-statistical method of the squalls and of the storm wind were calculated by the synoptic. The development of the hydrodynamic models of the short-term weather forecast have allowed us to develop the automated statistical forecast of the weather phenomenon – squalls and dangerous storm wind.
- We have made the new selection of the atmospheric parameters informative vector-predictor from the new set of about forty potential predictors (38). The selection was made by same method [2] of diagonalization of new mean correlation matrixes $\mathbf{R_1}$ and $\mathbf{R_2}$ (for the velocity V>19m/s and for the velocity V>24m/s respectively). The two new discriminant functions were calculated for two classes: $U_1(\mathbf{X})$ and $U_2(\mathbf{X})$ - for the recognition of the wind of two classes.
- These functions and the probabilities of the wind forecast of two classes:
- $P_1(\mathbf{X})=1/(1+\exp(-U_1(\mathbf{X}))$ (3)
- $P_2(\mathbf{X})=1/(1+\exp(-U_2(\mathbf{X}))$ (4)
- were calculated in the nodes of the grid 150x150km of the hemispheric hydrodynamic model for the European part of Russia (the author –Berkovich L.V.). The assessments of the independent tests of this forecast method of the wind (V>19m/s) at the 1994-1995 years were submitted in [6].

The scheme of diagnosis and forecast of dangerous convective phenomena like squalls, tornadoes, rainfalls.



Перечень потенциальных предикторов гидродинамико-статистической модели прогноза

	Обозначение	Параметры атмосферы
1	P	Давление на уровне моря.
2–6	H_{1000}, H_{850}, H_{700}, H_{500}, H_{300}	Геопотенциал на уровне 1000, 850, 700 , 500 , 300 гПа
7	$T_з$	Температура у поверхности земли
8–12	T_{925}, T_{850}, T_{700}, T_{500},T_{300}	Температура на уровне 925 , 850 , 700 , 500 , 300 гПа
13	$Td_з$	Температура точки росы у поверхности земли
14–18	D_{925}, D_{850}, D_{700}, D_{500}, D_{300}	Дефицит точки росы на уровне 925 , 850 , 700 , 500 ,300 гПа
19–28	U_{925} и V_{925}, U_{850} и V_{850}, U_{700} и V_{700}, U_{500} и V_{500}, U_{300} и V_{300},	Горизонтальная и вертикальная компоненты скорости ветра на уровне 925, 850, 700, 500, 300 гПа
29	W	Значение упорядоченных вертикальных движений
30	Iw	Значение индекса неустойчивости Вайтинга
31	U_{850}-U_{925}	Разность горизонтальных компонент на уровнях 850 и 925 гПа
32	V_{850}-V_{925}	Разность вертикальных компонент на уровнях 850 и 925 гПа
33	U_{500}-U_{700}	Разность горизонтальных компонент на уровнях 500 и 700 гПа
34	V_{500}-V_{700}	Разность вертикальных компонент на уровнях 500 и 700 гПа
35–37	$\lvert\nabla T_з\rvert$, $\lvert\nabla T_{925}\rvert$, $\lvert\nabla T_{850}\rvert$	Модуль горизонтального градиента температуры у поверхности земли, на уровне 925, 850 гПа
38	$\Delta P_з$	Лапласиан давления у поверхности земли

The new informative vector-predictor was obtained $\mathbf{X}=(H_{1000}, T_з, Td_з, V_{700}, V_{500}-V_{700}, Iw, \nabla T_з, T_{300})$.

- The validation of forecast (to 12h and 24h ahead) of storm wind with the velocity V>24m/s was made in 2000 year with very good results for the territory of European part of Russia and Ukraine [5]. The areas , in which dangerous winds are predicted, one are extracted by the threshold probability **P**=60%. The examples of this forecast are submitted on next figures. The values of criterion T to different regions of Russia and Ukraine equals T=0.72-0.56.
- In connection with the successes of hydrodynamic forecast with the earliness 12-24h we have decided to use in the discriminant function U2(**X**) the output prognostic fields (with earliness 36h) of the new variant of the hemispheric model. The region of the possible storm wind was extracted by the isoline of the probability threshold **P**=55%. The independent tests of these phenomena forecast were implemented during 2003-2005 years. The assessments of the forecast (with the earliness 36 ahead) over three regions of Russia were successful and this method was recommended for the using at synoptic practice of the Departments of the Meteorology and Hydrology of Russia (next table).

Показатели успешности прогноза скорости ветра не менее 20 м/с

по регионам европейской территории России

УГМС	Автор метода	Заблаго-временность, ч.	N	F %	$И_я$ %	$И_{бя}$ %	$П_я$ %	$П_{бя}$ %	T
Северо-Западное	Переход цева	12	1110	92	25	99	76	92	0,69
			1110	98	56	99	39	99	0,32
	инерц.	24	1007	89	21	99	80	89	0,69
	Переход цева инерц.		1009	98	30	99	25	99	0,21
Центрально-Черноземных областей	Переход цева.	12	160	91	24	99	80	92	0,72
		24	158	91	22	99	80	91	0,71
	Переход цева.								
Верхне-Волжское	Переход цева	12	955	90	22	98	55	91	0,46
		24	995	90	14	98	48	91	0,39
	Переход цева								
Северо-Кавказское (равнинная территория)	Переход цева	12	405	78	24	96	78	77	0,55
		24	400	78	21	97	79	77	0,56
	Переход цева								

Примечание: N – количество испытываемых случаев прогноза; F – общая оправдываемость прогноза; $И_я$ – оправдываемость прогноза явления; $И_{бя}$ – оправдываемость прогноза без явления; $П_я$ – предупрежденность прогноза случаев с явлением; $П_{бя}$ – предупрежденность прогноза случаев без явления;

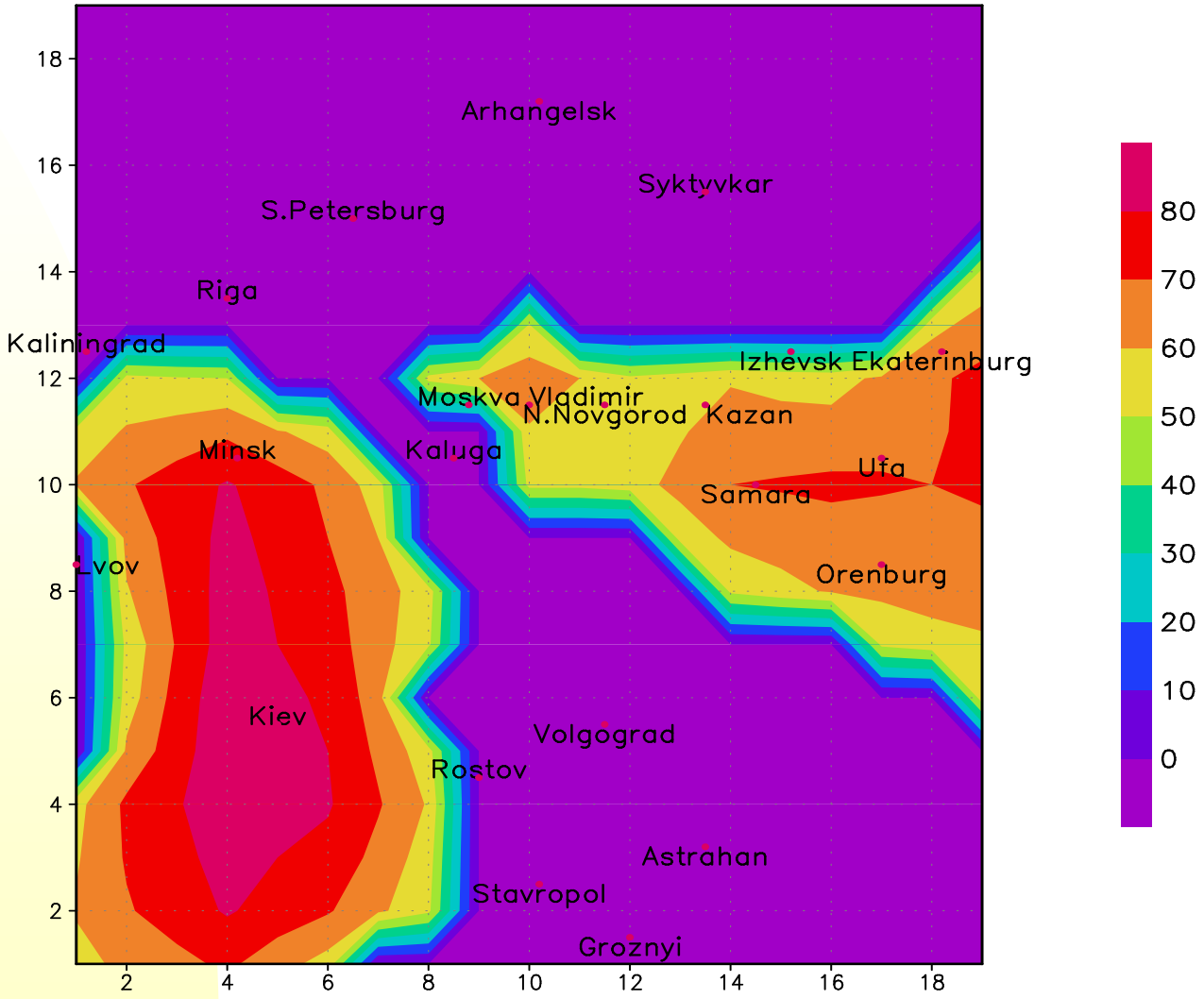
T – значения критерия Пирси-Обухова.

Результаты независимых испытаний гидродинамико-статистического метода прогноза летних опасных ветров скоростью не менее 25 м/с по территории ВВУГМС, СЗУГМС и УГМС Республики Татарстан за 2003-2005гг.

Количество прогнозируемых случаев.	Количество фактических случаев		Сумма	Оправды-ваемость прогноза, %	Предупр. прогноза, %	Общая оправд. прогноза, %	Критерий Пирси-Обухова
	С явлением	Без явления					
Верхне-Волжское УГМС							
С явлением	n_{11} **11**	n_{12} **157**	n_{10} **168**	Ия=**6,5**	Пя=**68,8**	F=**91,2**	Т=**0,60**
Без явления	n_{21} **5**	n_{22} **1662**	n_{20} **1667**	Ибя=**98**	Пб.я=**91**		
Сумма	n_{01} **16**	n_{02} **1819**	n_{00} **1835**				
Северо-Западное УГМС							
С явлением	n_{11} **14**	n_{12} **23**	n_{10} **37**	Ия=**38**	Пя=**93,3**	F=**97**	Т=**0,90**
Без явления	n_{21} **1**	n_{22} **829**	n_{20} **830**	Ибя=**99**	Пб.я=**97**		
Сумма	n_{01} **15**	n_{02} **852**	n_{00} **867**				
УГМС Республики Татарстан							
С явлением	n_{11} **7**	n_{12} **49**	n_{10} **56**	Ия=**12**	Пя=**87,5**	F=**87,5**	Т=**0,75**
Без явления	n_{21} **1**	n_{22} **344**	n_{20} **345**	Ибя=**99,7**	Пб.я=**87**		
Сумма	n_{01} **8**	n_{02} **393**	n_{00} **401**				

F – общая оправдываемость прогноза;
Ия – оправдываемость прогноза явления;
Ибя – оправдываемость прогноза без явления;
Пя – предупрежденность прогноза явления;
Пбя –предупрежденность прогноза без явления;
Т- значение критерия Пирси-Обухова

Прогнозируемая на текущий день 24.07.2001 по сроку 00ч. СГВ область опасных ветров, ограниченная изолинией вероятности 60%



Прогнозируемая с заблаговременностью 24 ч. область стихийных ветров (ограниченная изолинией 60%) на 24.07 2001г.

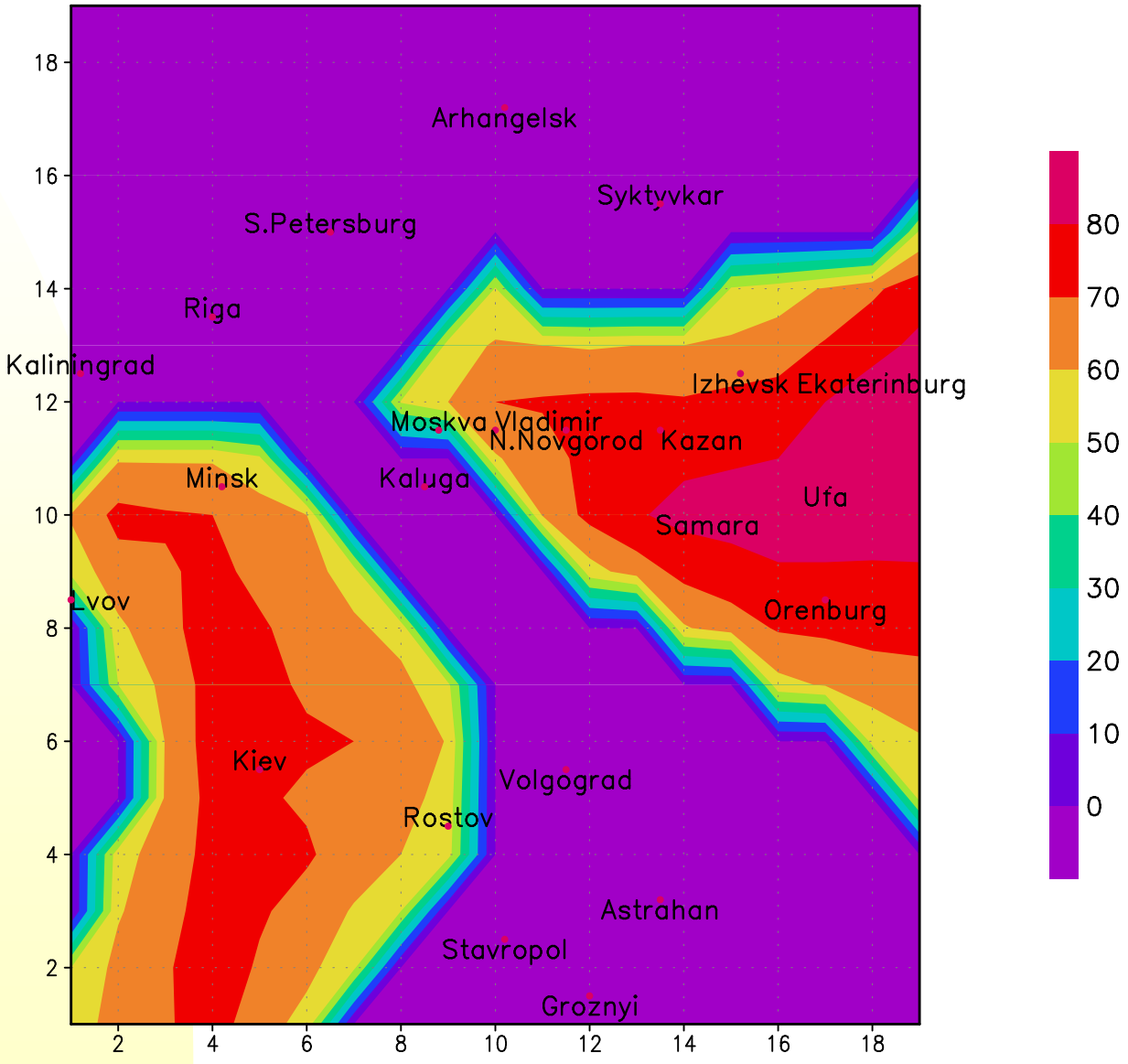


Fig. 1. The area of the storm forecast (V>24m/s) for current day of 05.07.02. The time calculating of the forecast is 00h WMT.

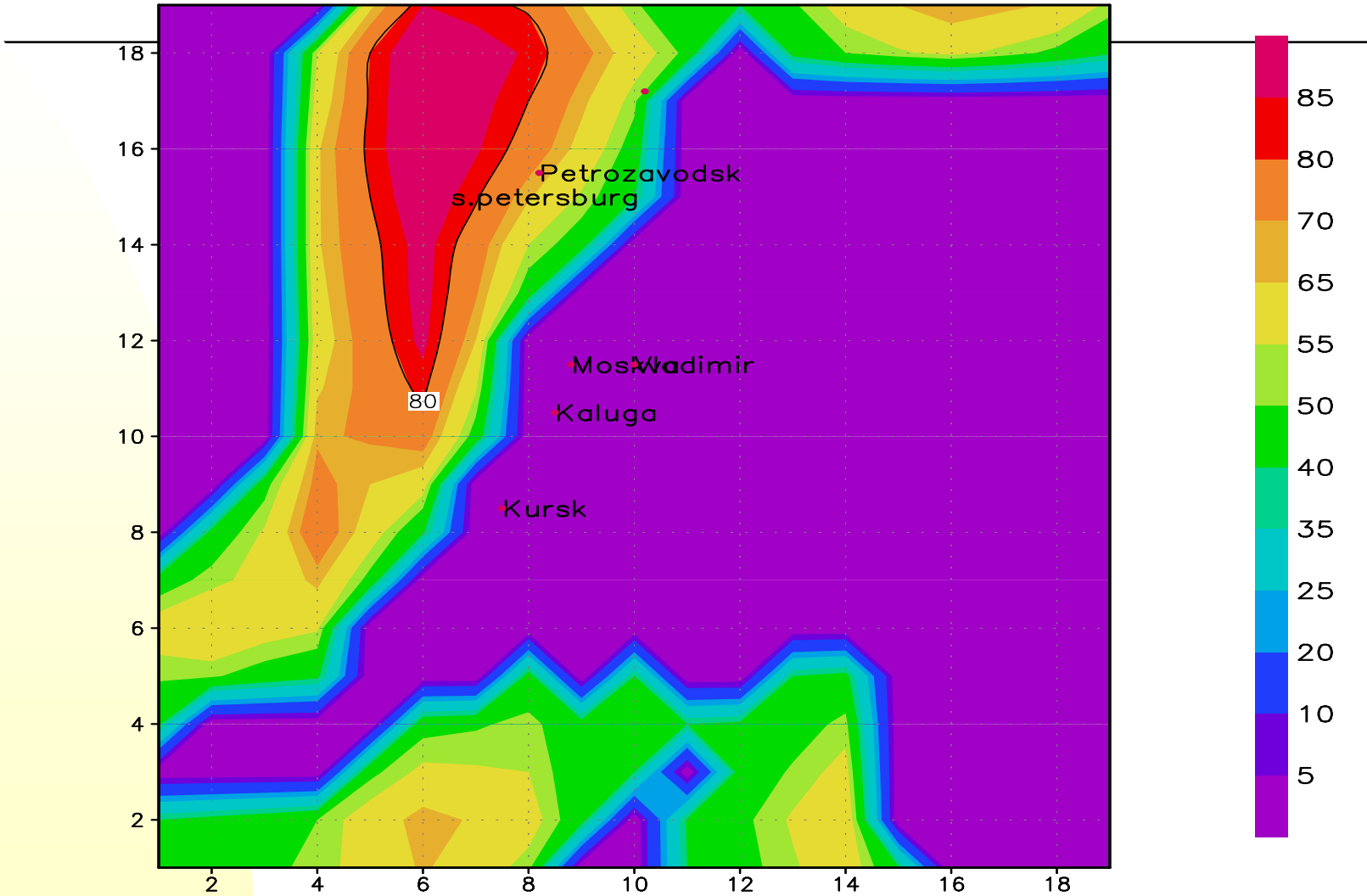
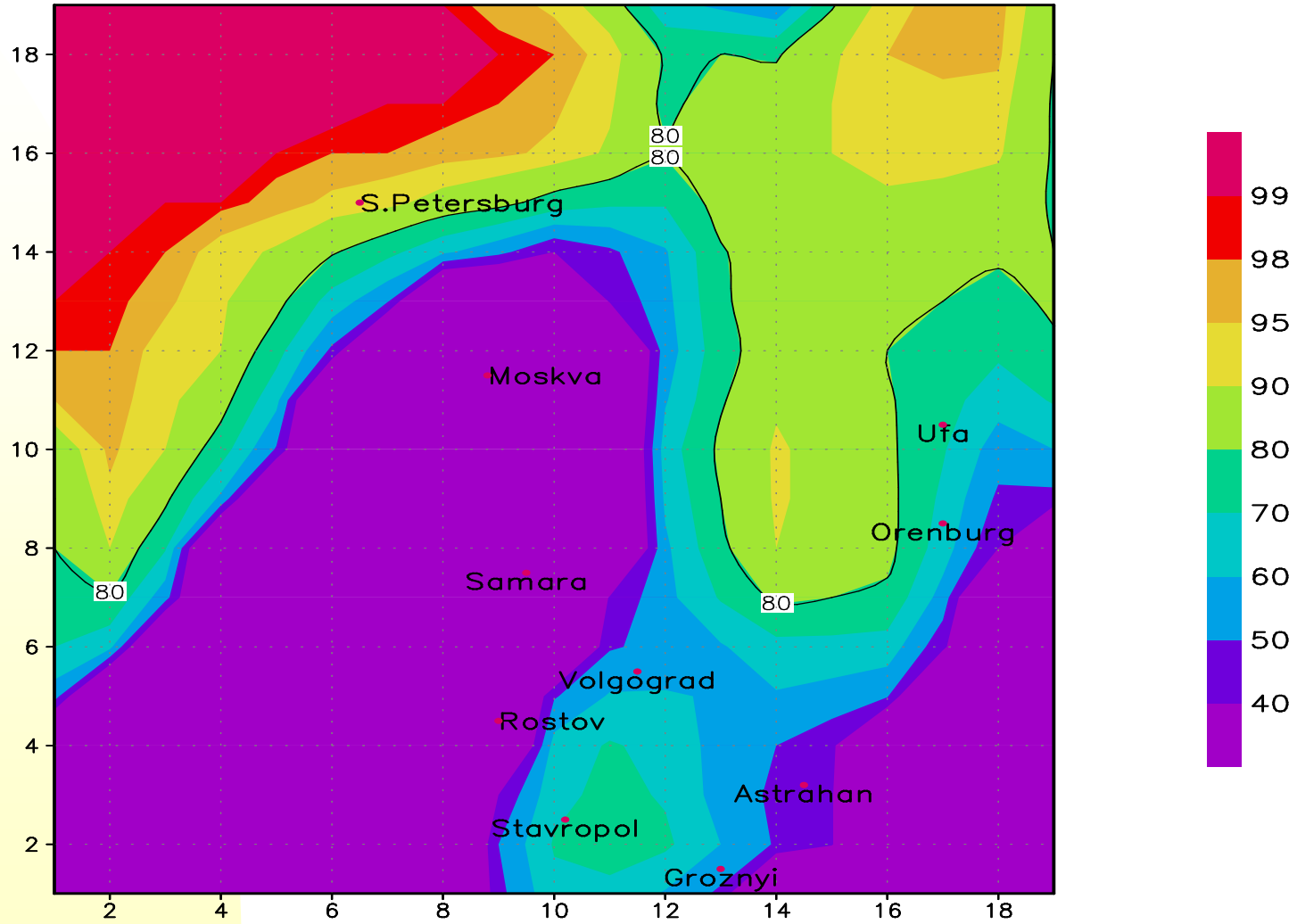
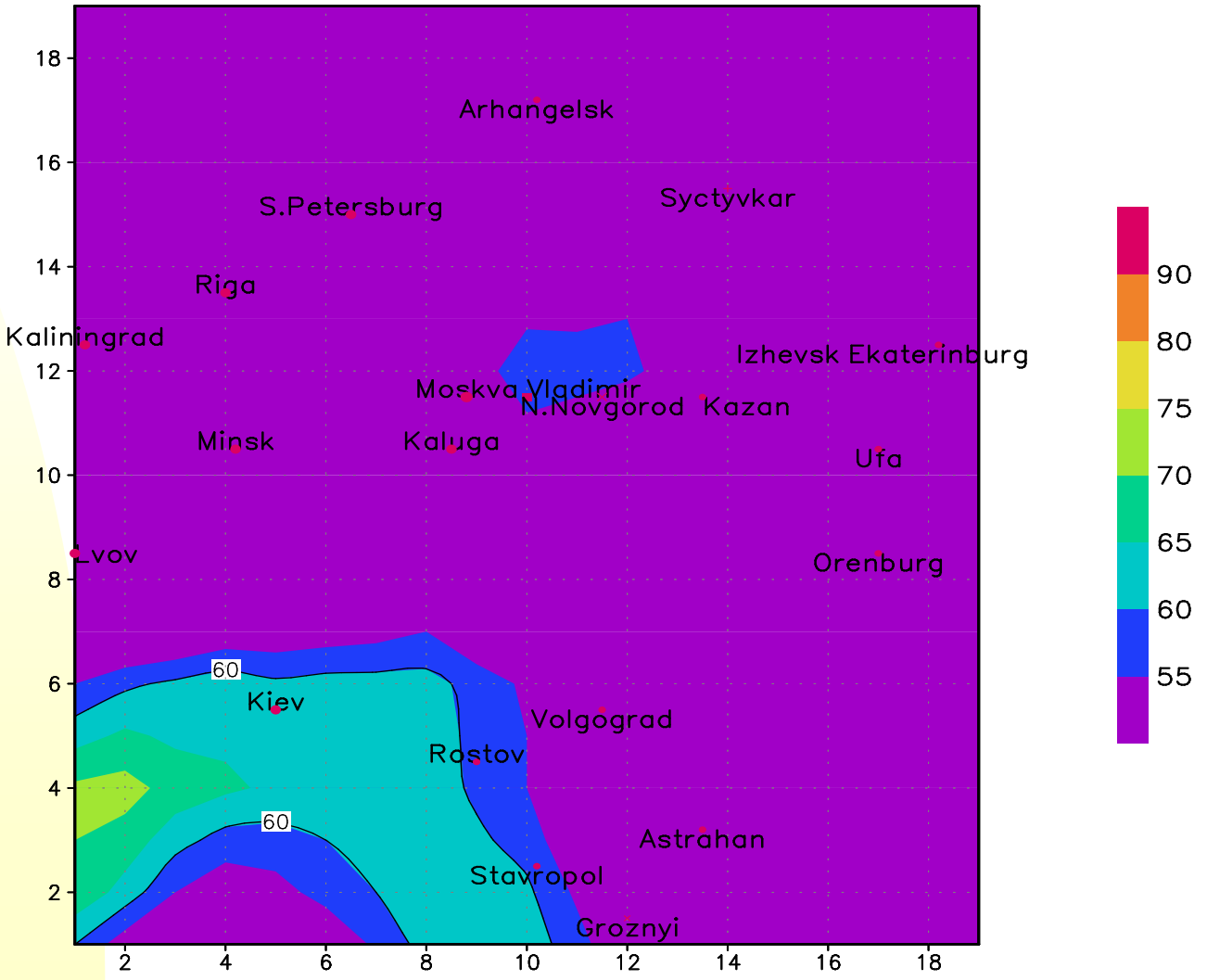


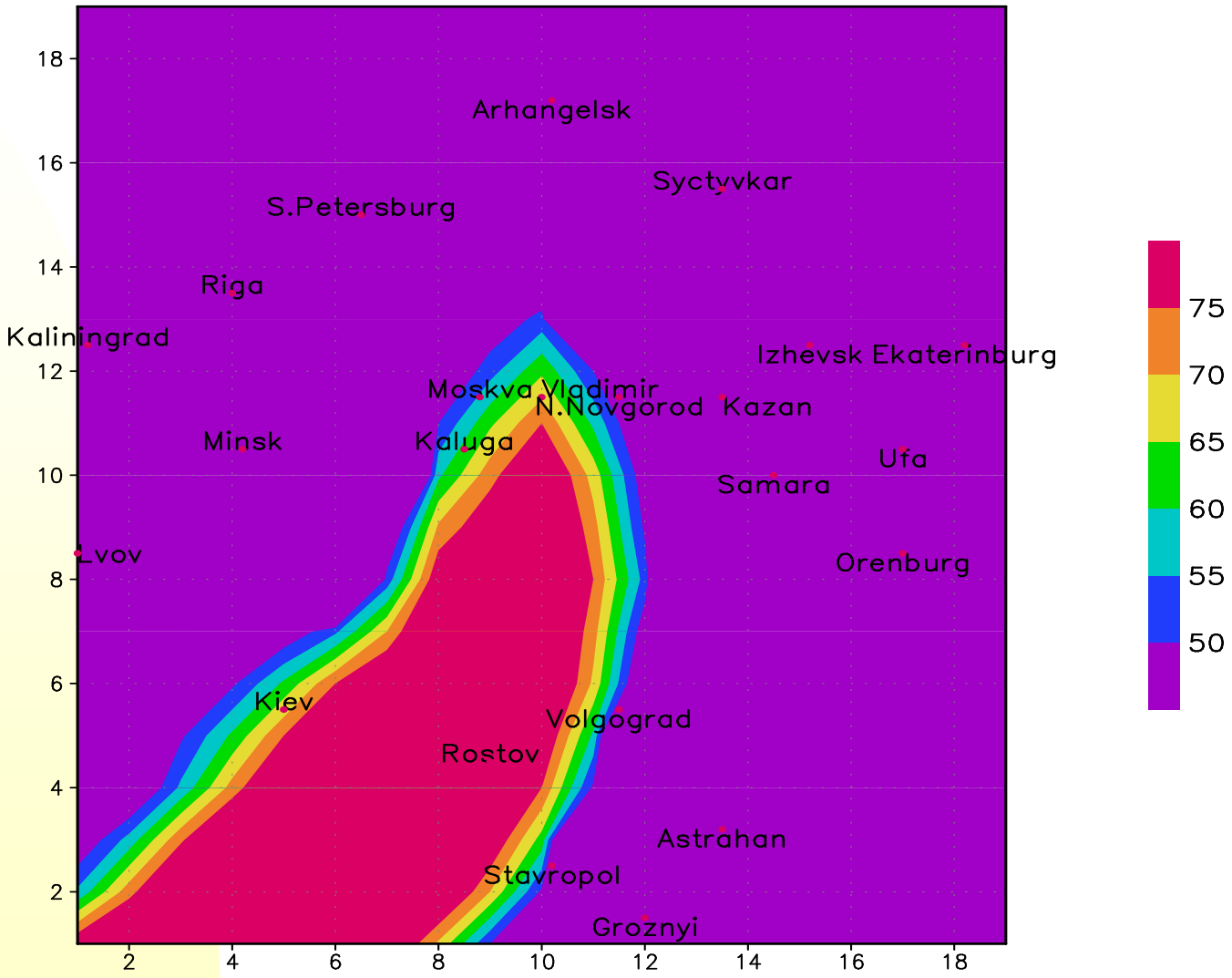
Fig. 2. The forecast of the storm wind (V>24m/s) to the night of 06.07.02. The earliness is 24h.



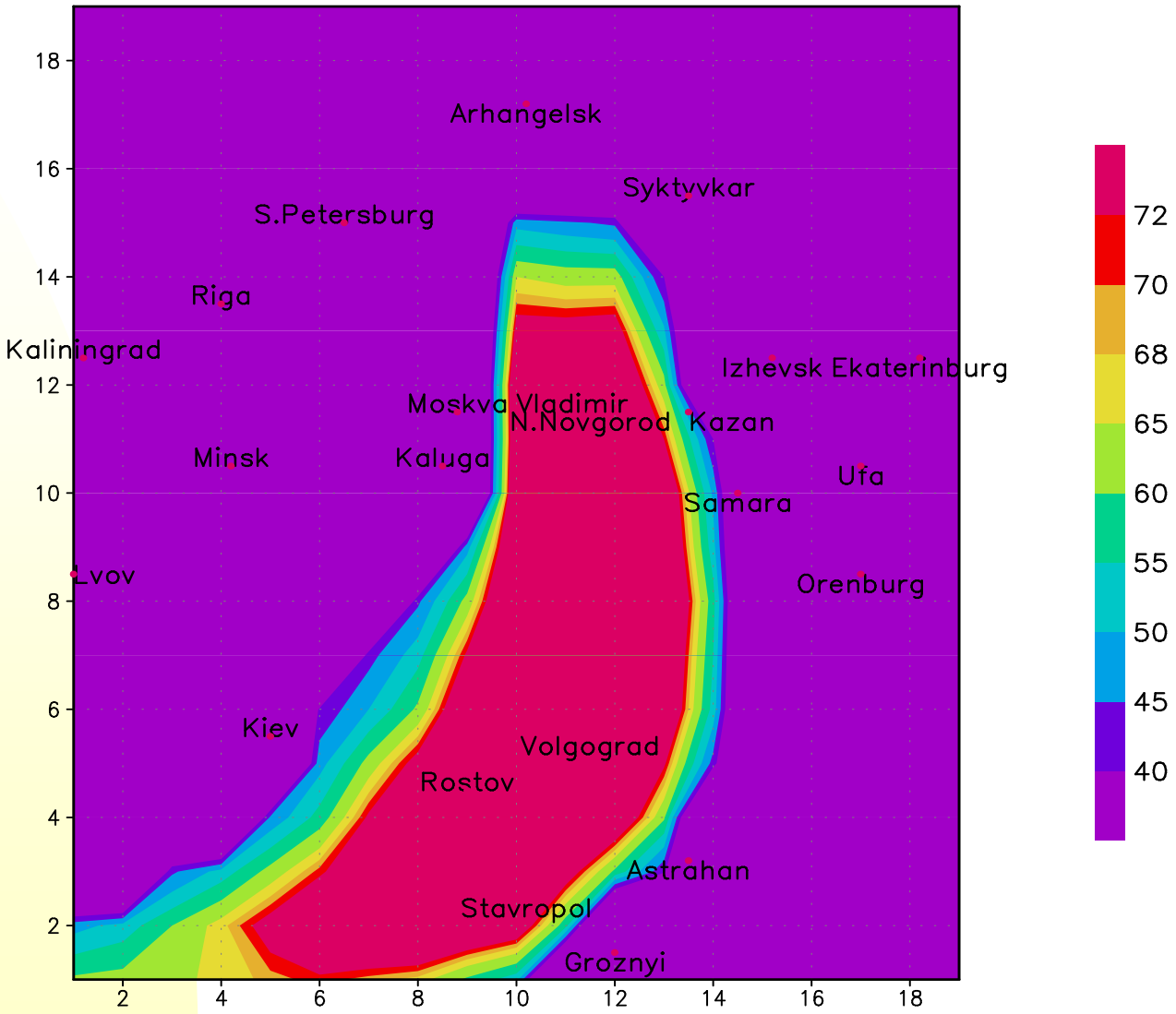
Прогноз опасных ветров на следующий день на 09.07.2002 г. с заблаговременностью 36 часов по сроку 00 ч. СГВ. по данным за 08.07.2002



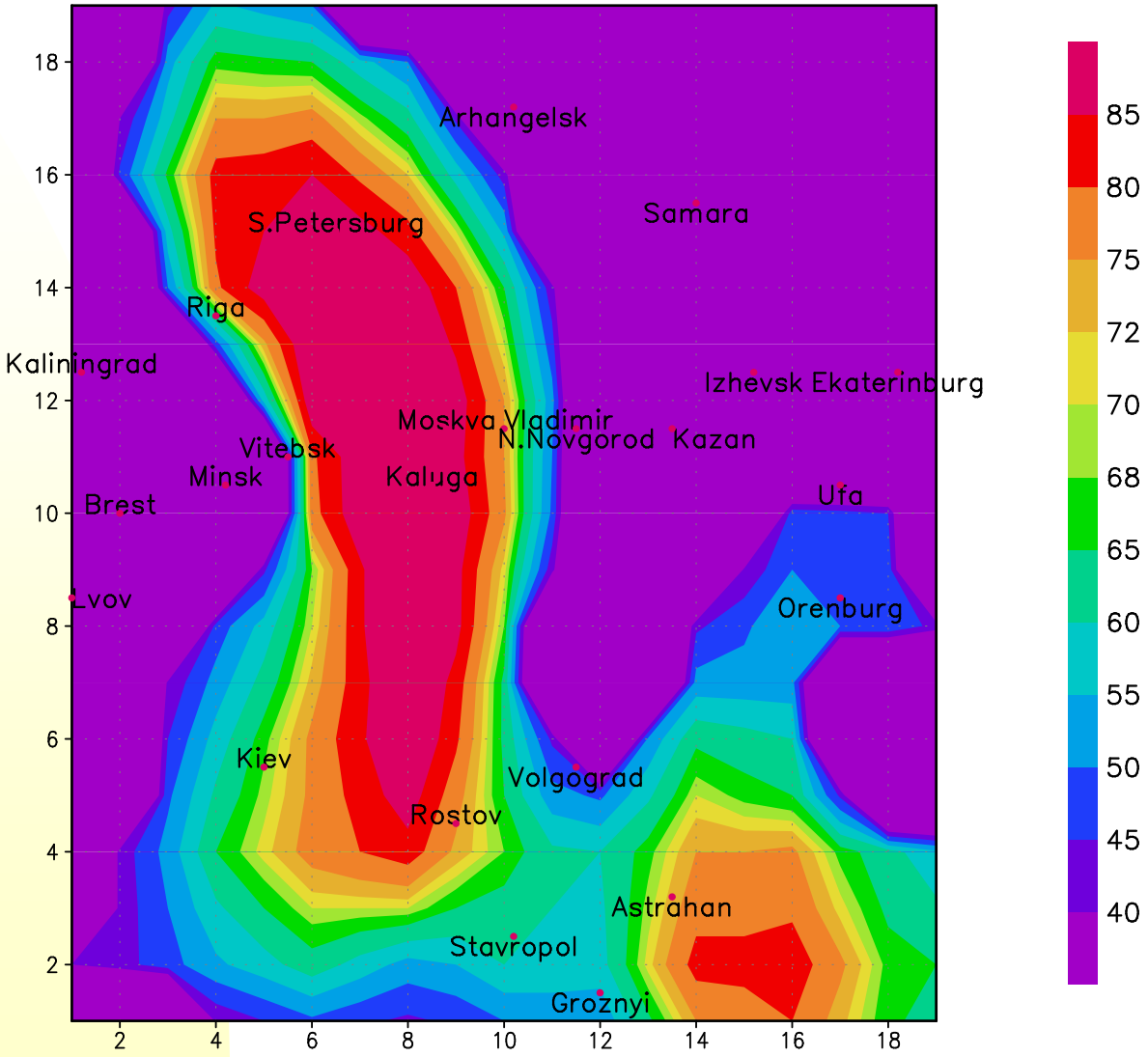
Прогноз стихийных ветров на 07.10.2003г. с заблаговременностью 36 часов



Прогноз опасных ветров на 07.10 2003 по сроку 00 часов СГВ с заблаговременностью 12 часов.



Прогноз ветров ОЯ на текущий день с заблаговременностью 12 часов по данным от 09.08.2005г.



Прогноз ветров ОЯ на следующую ночь с заблаговременностью 24 ч. по данным от 09.08.2005г.

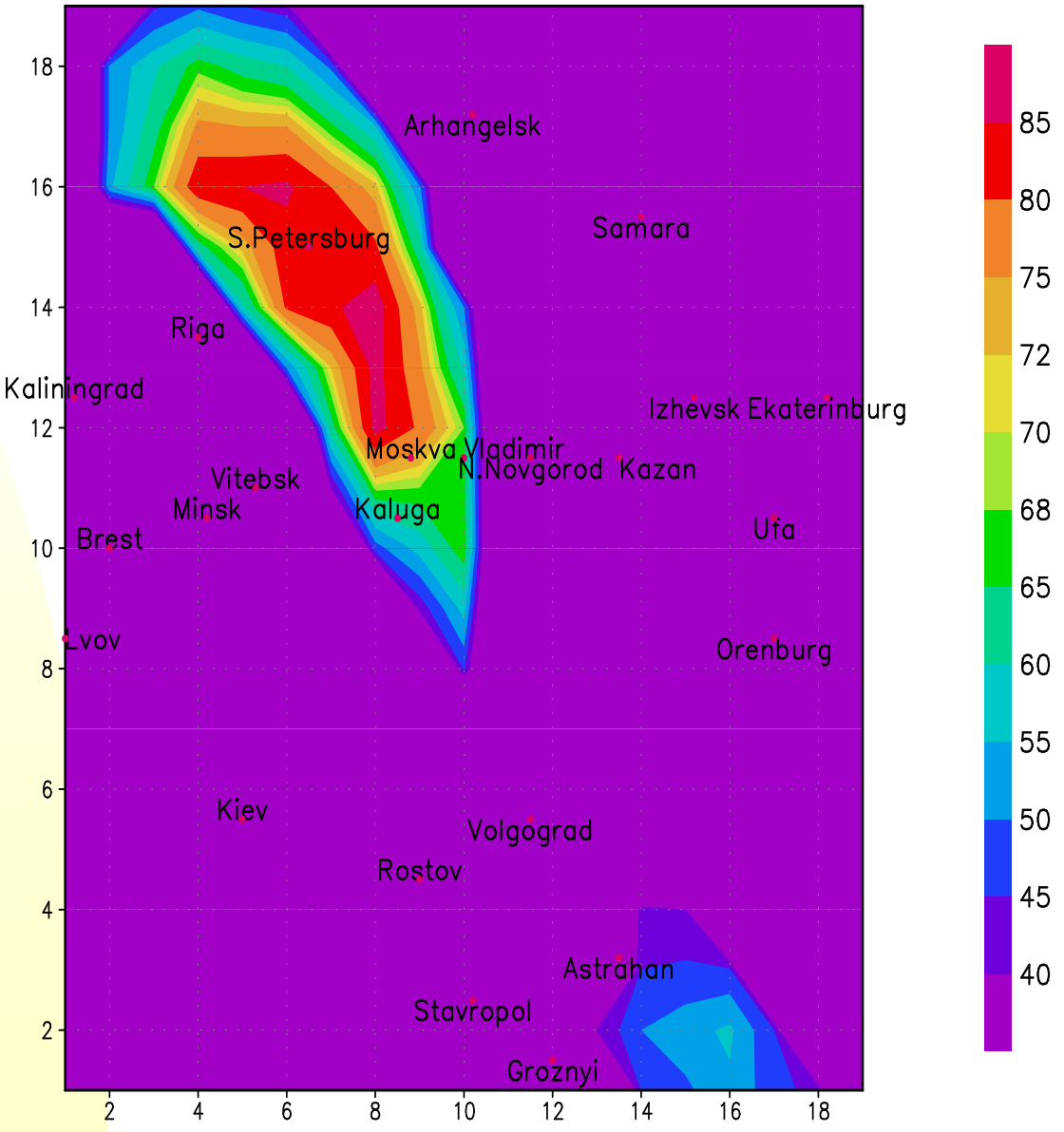


Fig 3. The forecast of storm wind (V>24m/s) to 29.11.99 for current day (the flood in Petersburg)

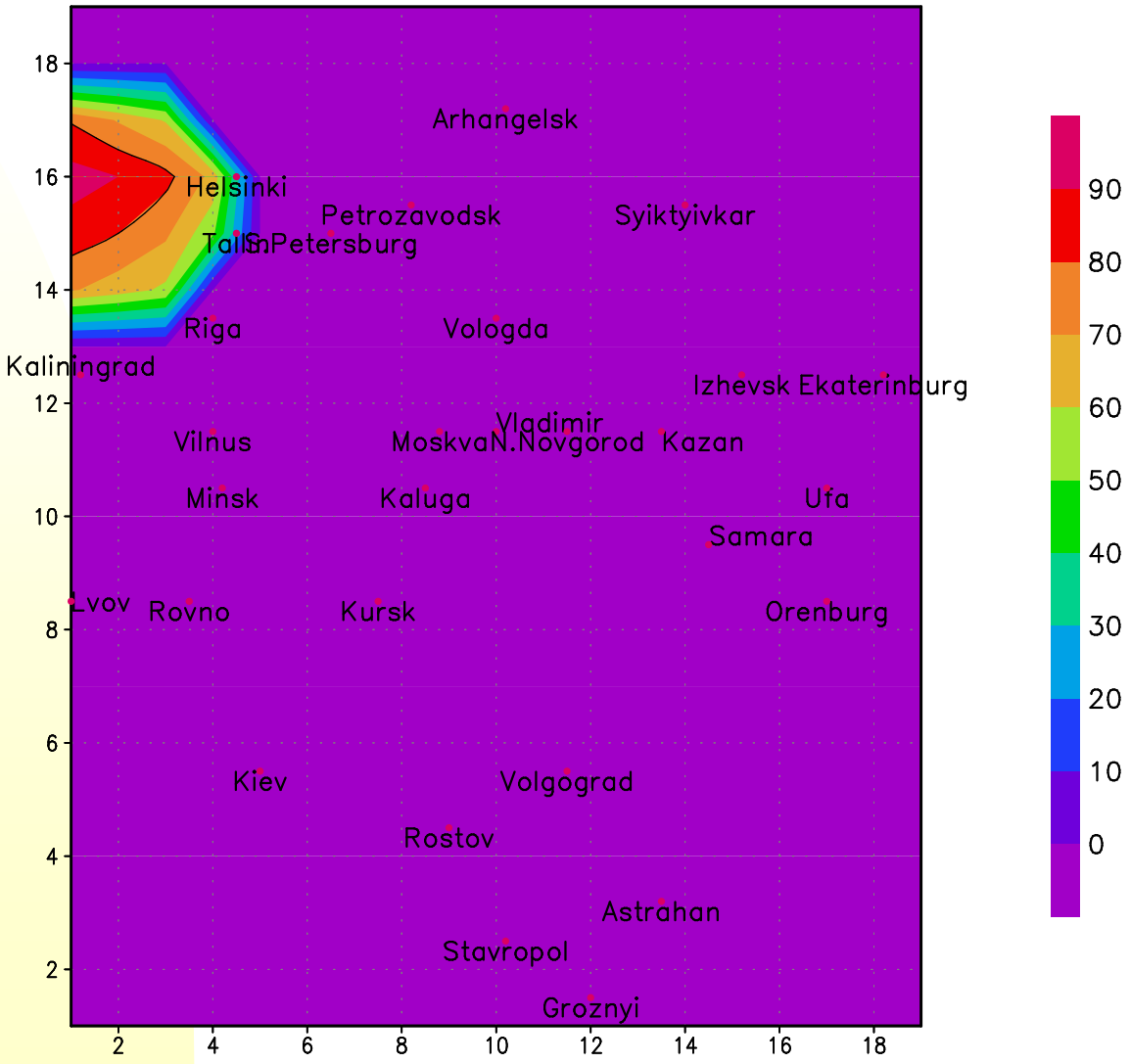
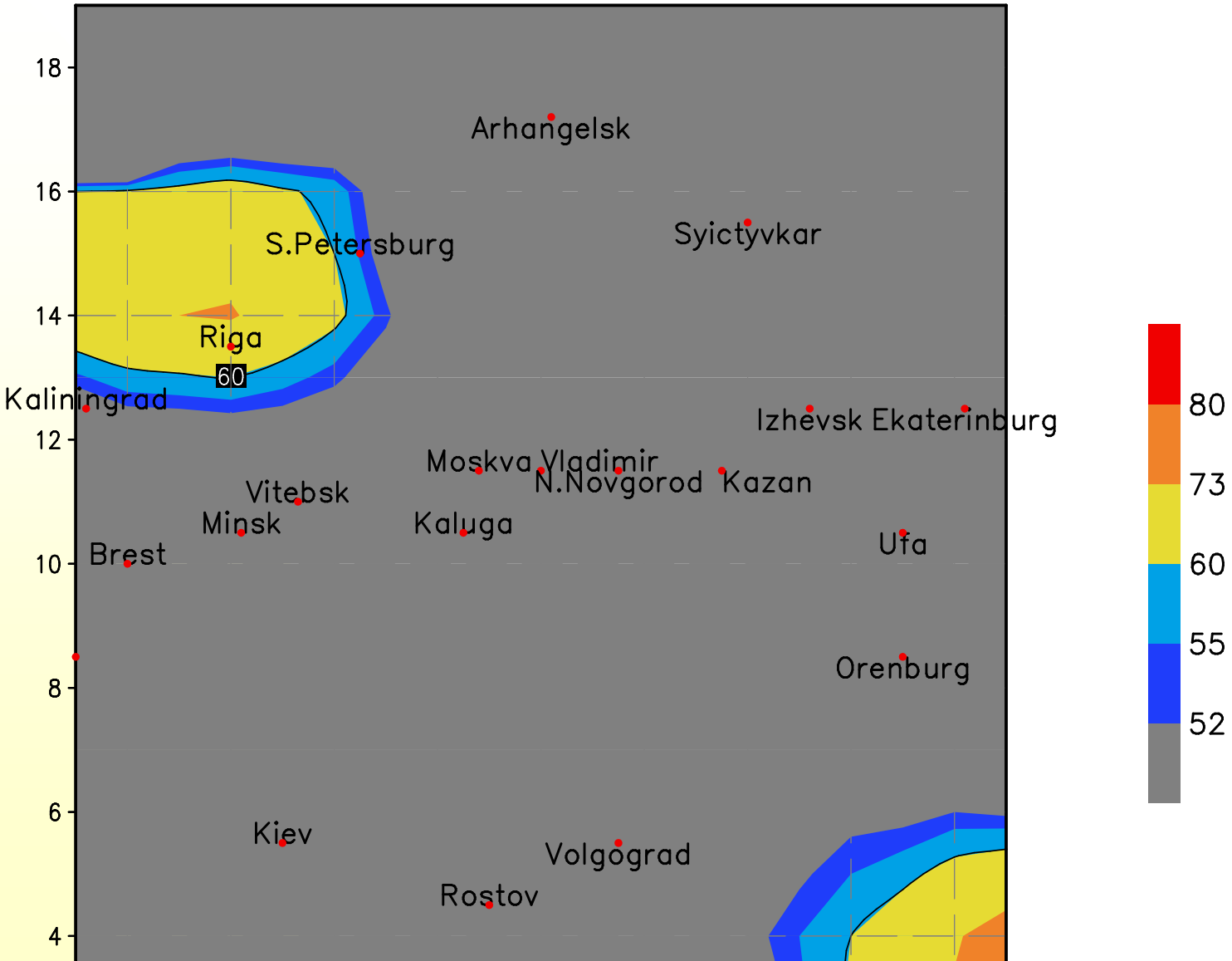


Fig. 4. The area of the forecast of storm wind (V>24m/s) to 25.06.05. The earliness of the forecast is 36h.



- Fig.5. The area of the forecast of the storm wind V>24м/s to 25.06.05
- for the current day,
- the time of calculation is 00h of WGT.

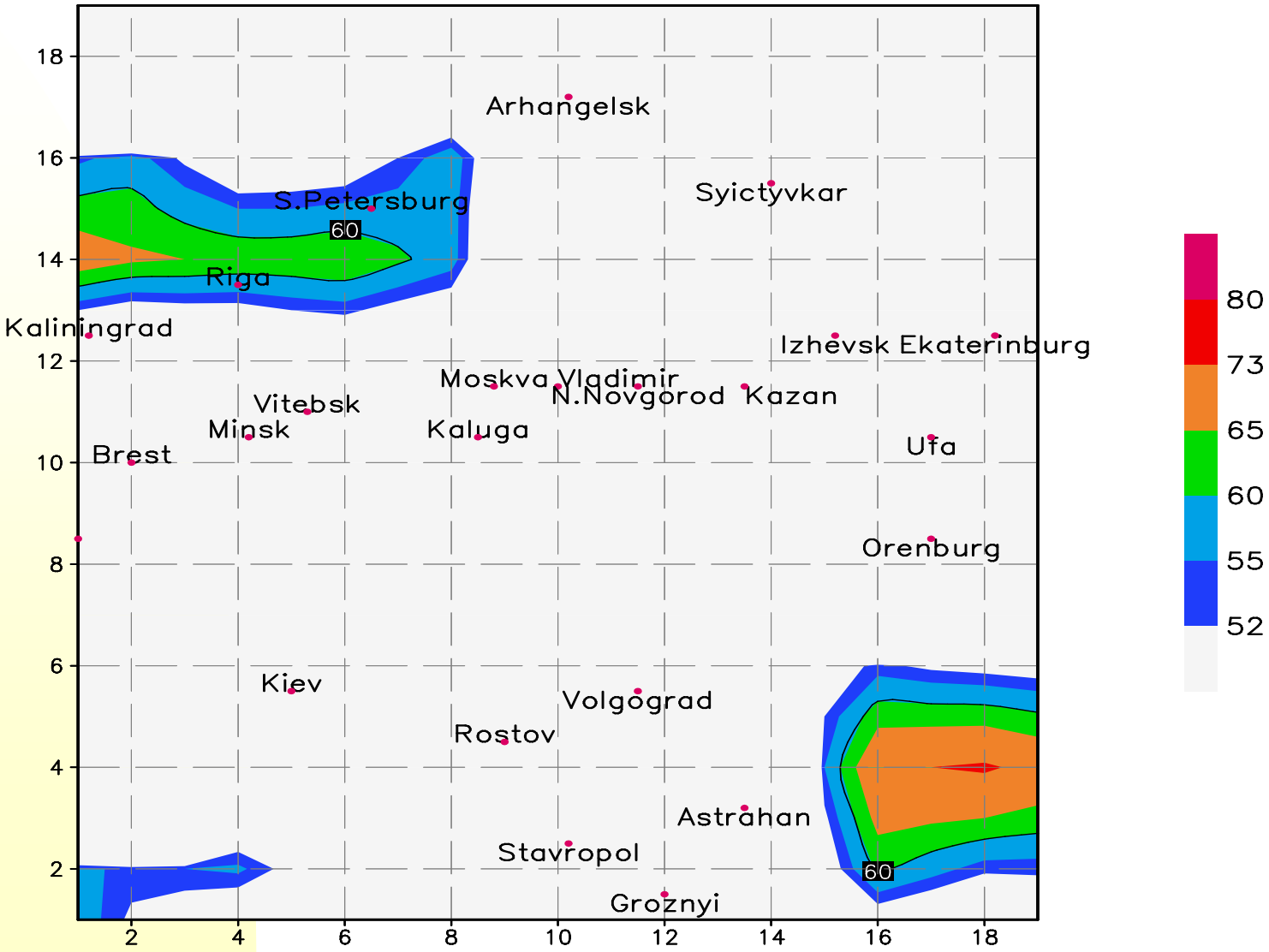
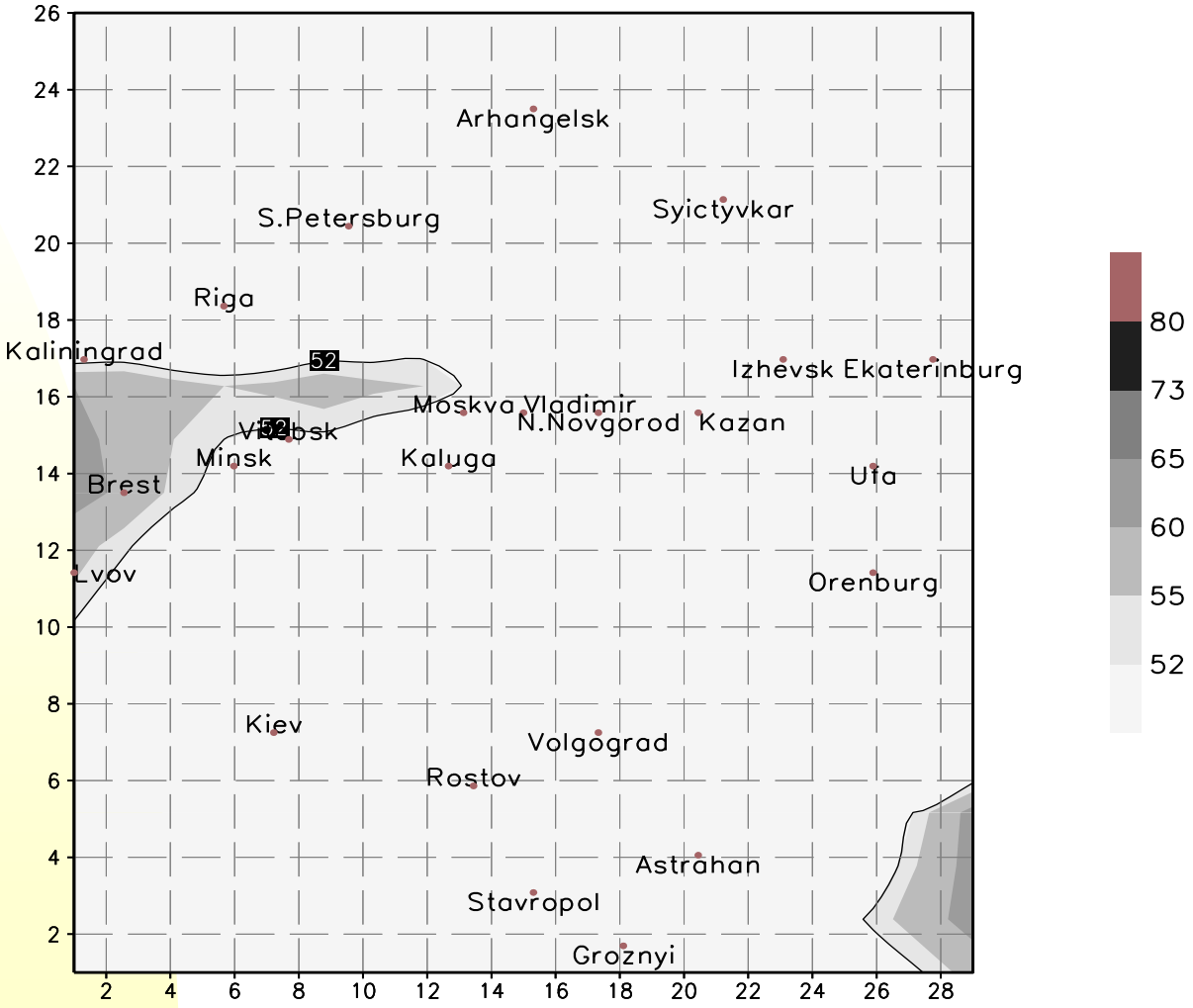
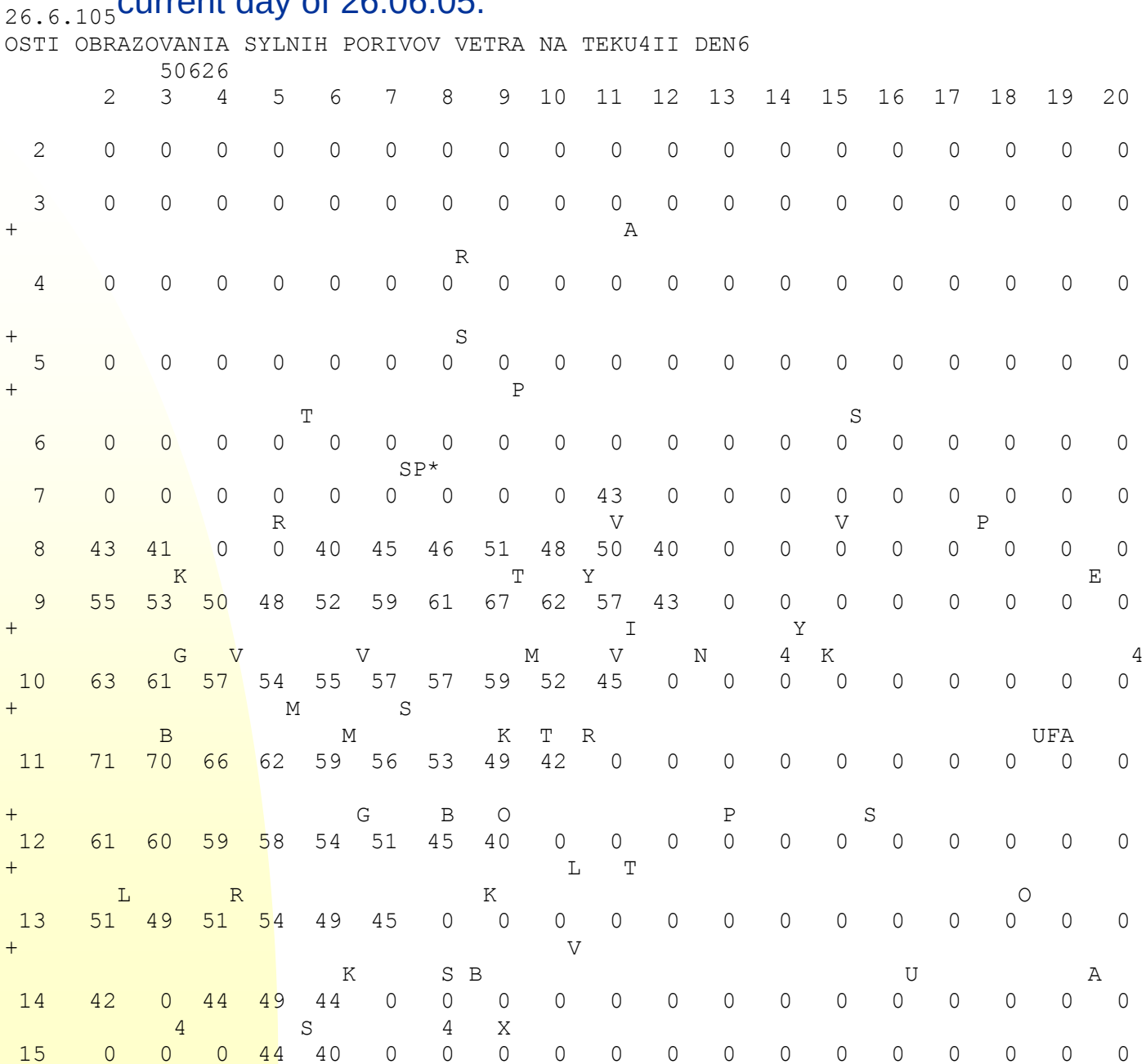


Fig. 6. The area of the forecast of the storm wind V>24м/s to 25.06.05 for the next day, the time of calculation is 00h of WGT.

The earliness of the forecast is 36h.



- Fig. 7. The probabilities of the forecast of storm wind (V>24m/s) in the nodes of the grid 150x150km for the current day of 26.06.05.



6. The model of the hydrodynamic-statistical forecast with the earliness 12-24-36-48h of the squalls and storm wind on the basis of the regional model HMC of Russia

The new regional model of short-term forecast in the sigma system of coordinates have got the horizontal grid 75x75 km (the author is Losev V.M.) The operative automated forecasts of the squalls and of the storm wind were calculated in 2008-2010 for the European part of Russia and Europe on the basis of the output production of this model to 12-24-36-48h ahead.

During period 2009-2010 the forecasts for the territories of Ukraine, of the republic Belorussia and of the Baltic countries were calculated in operative system ASOOI of HMC on the basis of this model.

We submit here the examples of the forecasts of the tornado in the town Krasnozavodsk near Moscow in the evening of 3.0.6h и другие примеры [7].

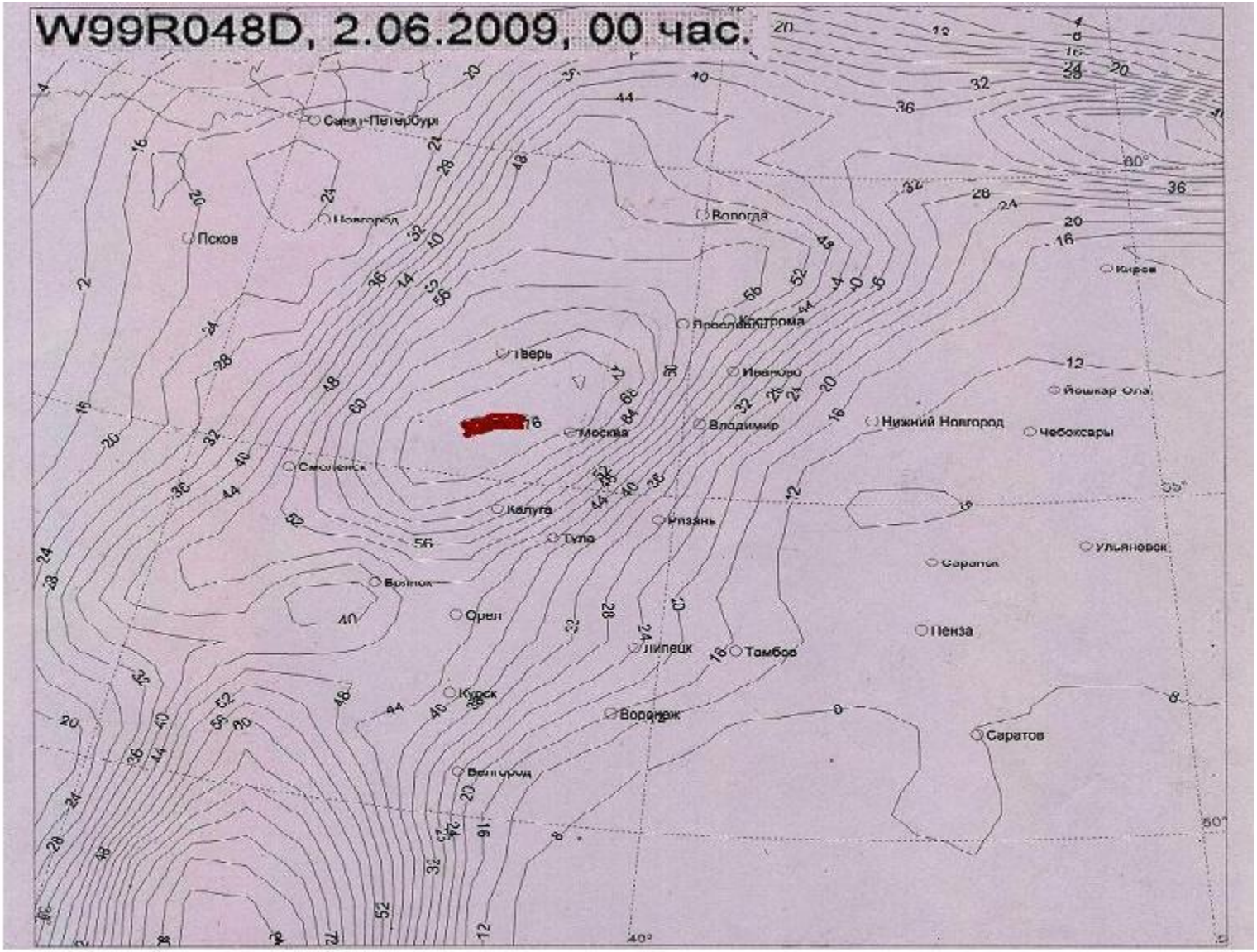


Рис.1. Область прогноза возникновения смерчей на вечер 03.06.09 – ночь 04.06.09, ограниченная изолинией P=72%. Область прогноза ветра скоростью V≥25м/с, ограниченная изолинией P=52%. Расчет прогноза от 02.06.09 по сроку 00ч СГВ с заблаговременностью 48ч.

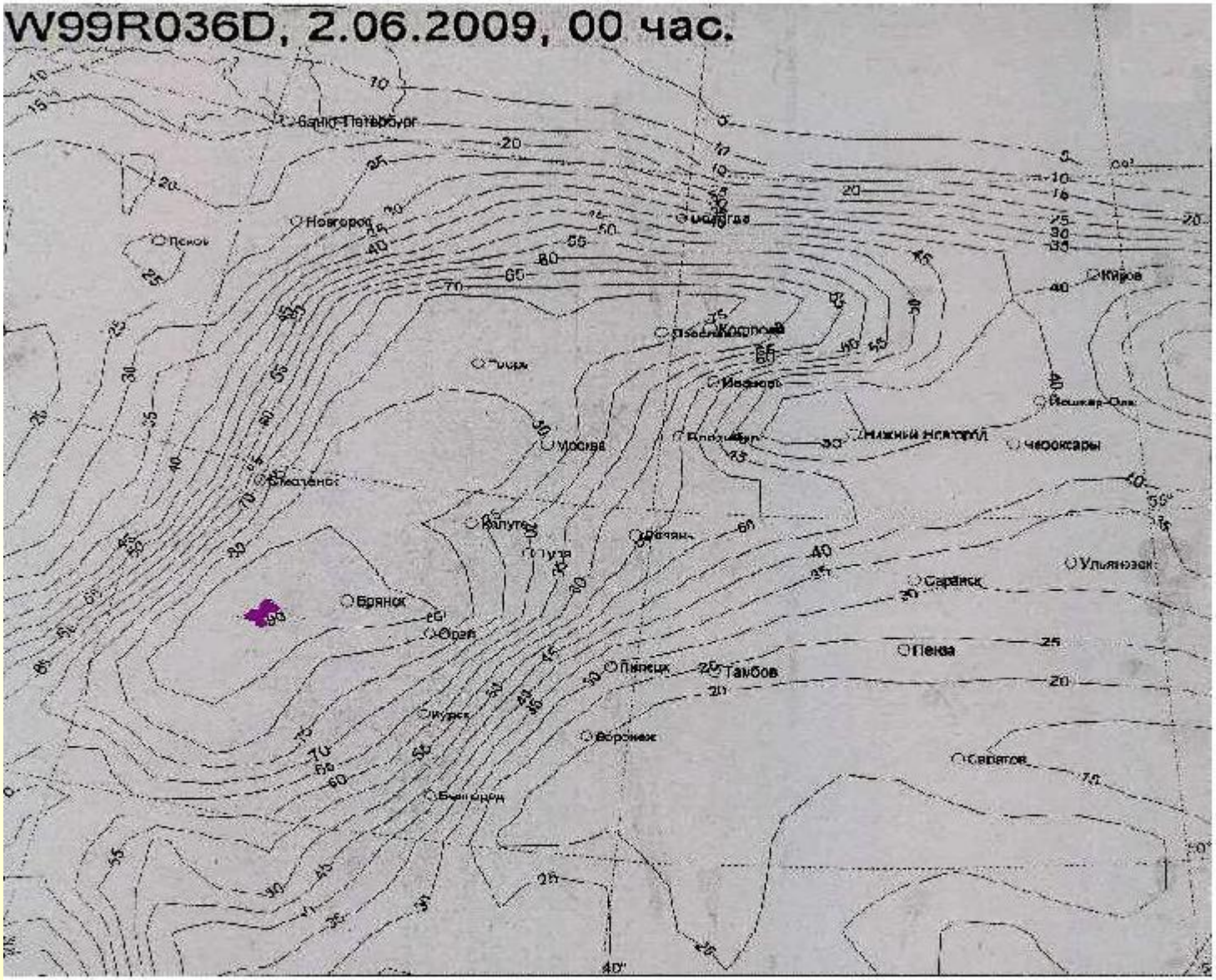


Рис.2. Область прогноза возможного возникновения смерчей на день 03.06.09, ограниченная изолинией P=80%. Область прогноза ветра скоростью V≥25м/с, ограниченная изолинией P=55%. Расчет прогноза от 02.06.09 по сроку 00ч СГВ с заблаговременностью 36ч.

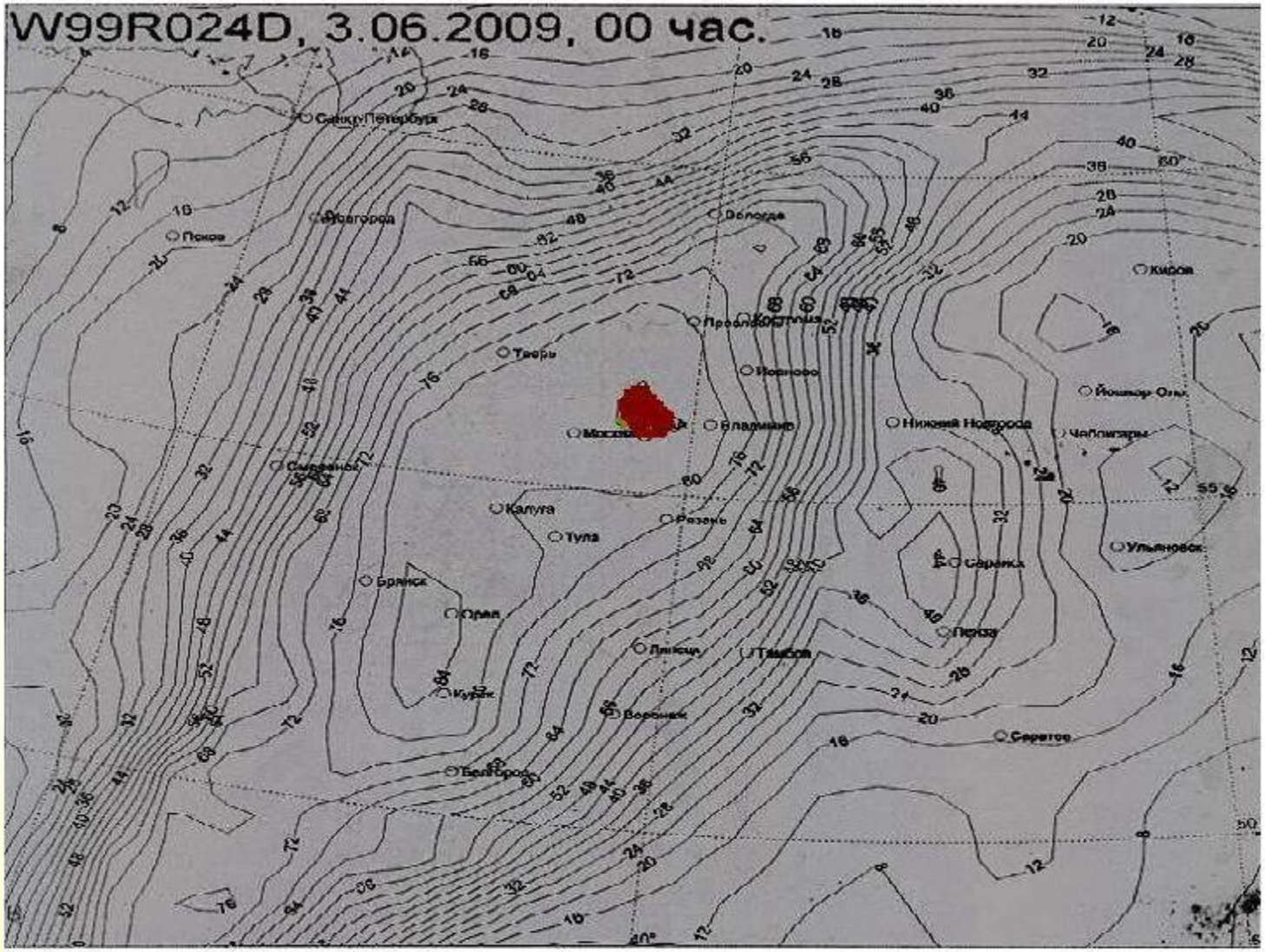


Рис.3. Область прогноза возможного возникновения смерчей на вечер 03.06.09 - ночь 04.06.09, ограниченная изолинией P=80%. Область прогноза ветра скоростью V≥25м/с, ограниченная изолинией P=60%. Расчет прогноза от 02.06.09 по сроку 00ч СГВ с заблаговременностью 24ч.

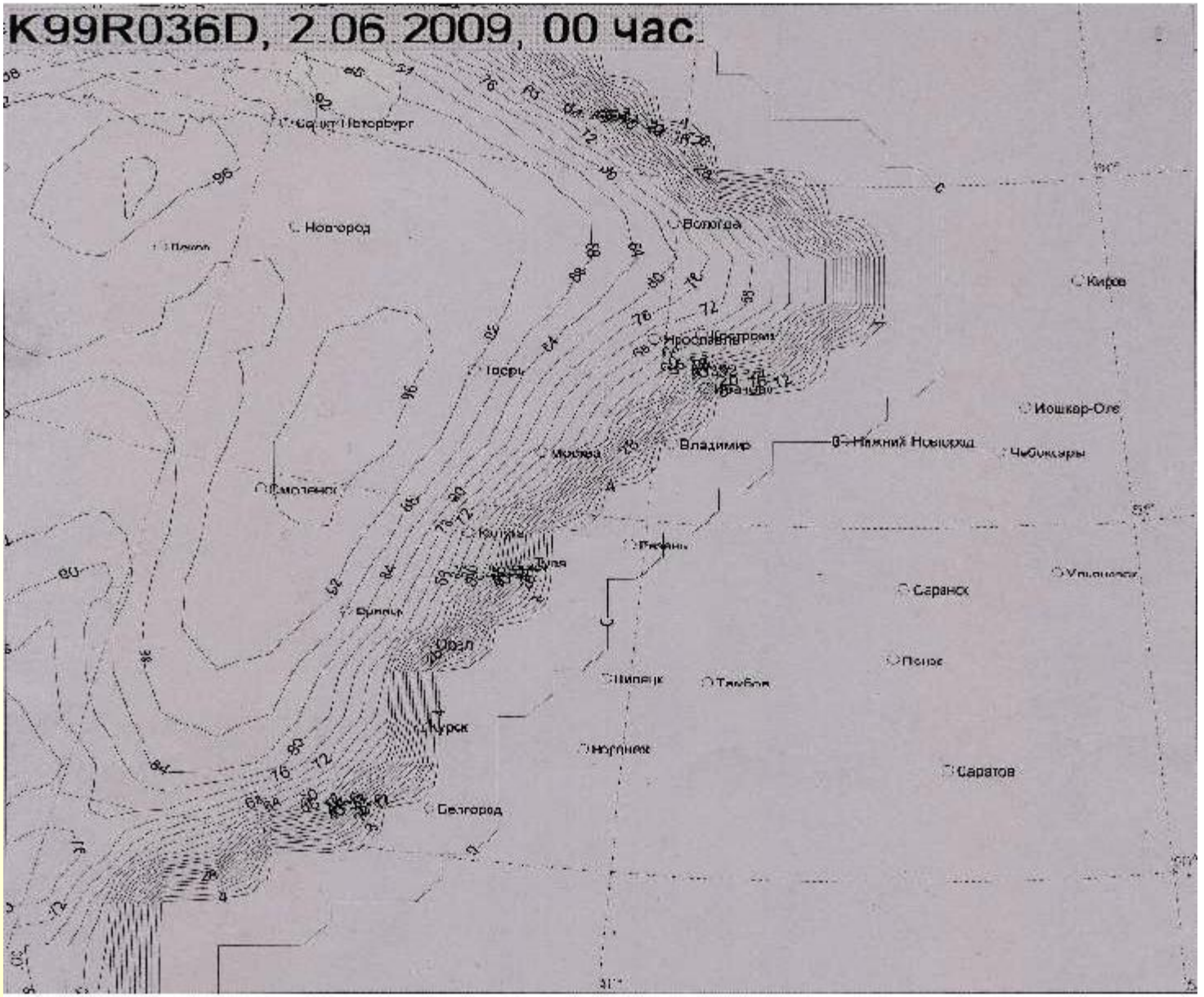


Рис.4. Область прогноза возможного возникновения смерчей на день 03.06.09, ограниченная изолинией P=92%. Область прогноза ветра скоростью V≥20м/с, ограниченная изолинией P=60%. Расчет прогноза от 02.06.09 по сроку 00ч СГВ с заблаговременностью 36ч.

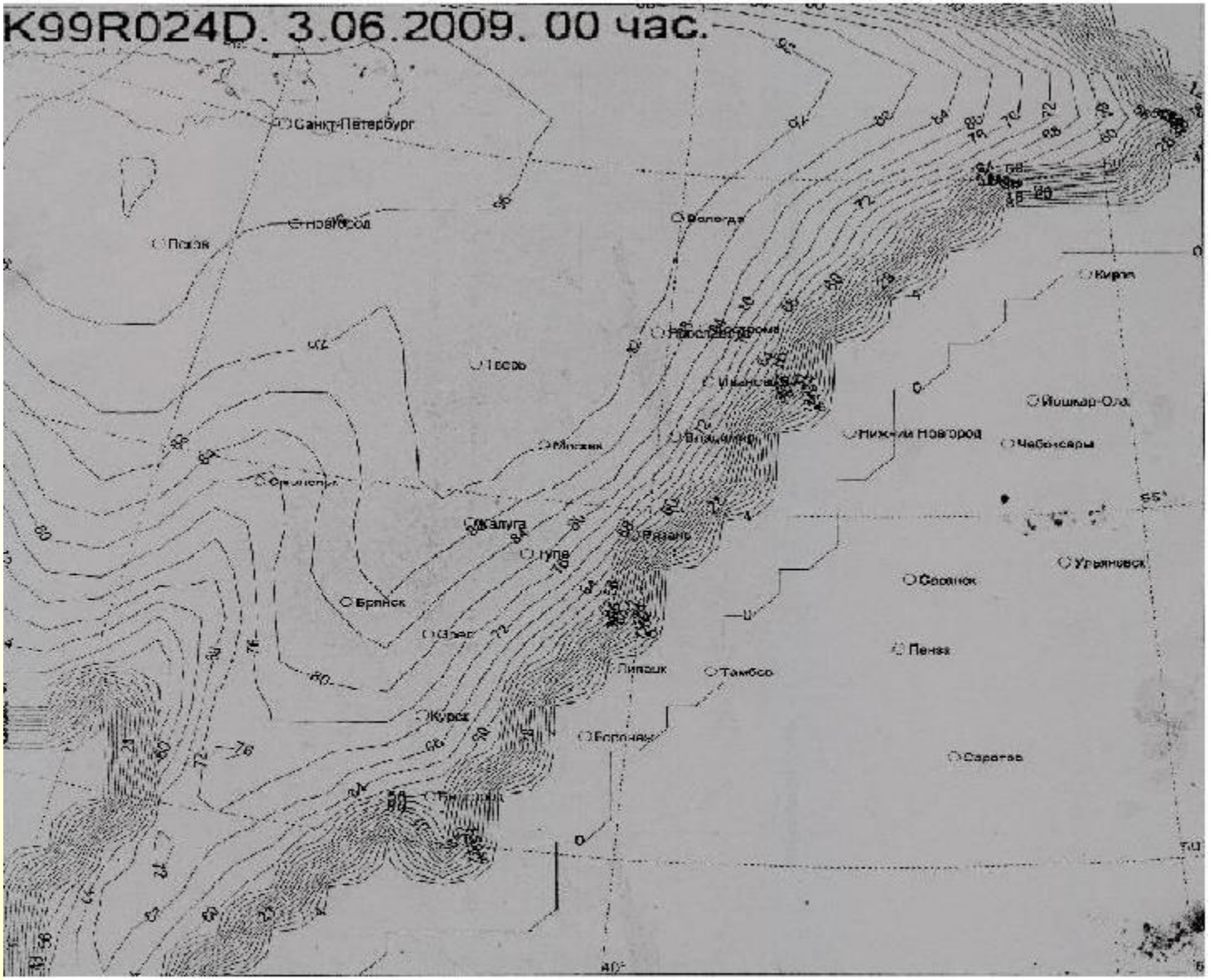


Рис.5. Область прогноза возможного возникновения смерчей на вечер 03.06.09- ночь 04.06.09, ограниченная изолинией P=92%. Область прогноза ветра скоростью V≥20м/с, ограниченная изолинией P=65%. Расчет прогноза от 02.06.09 по сроку 00ч СГВ с заблаговременностью 24ч.

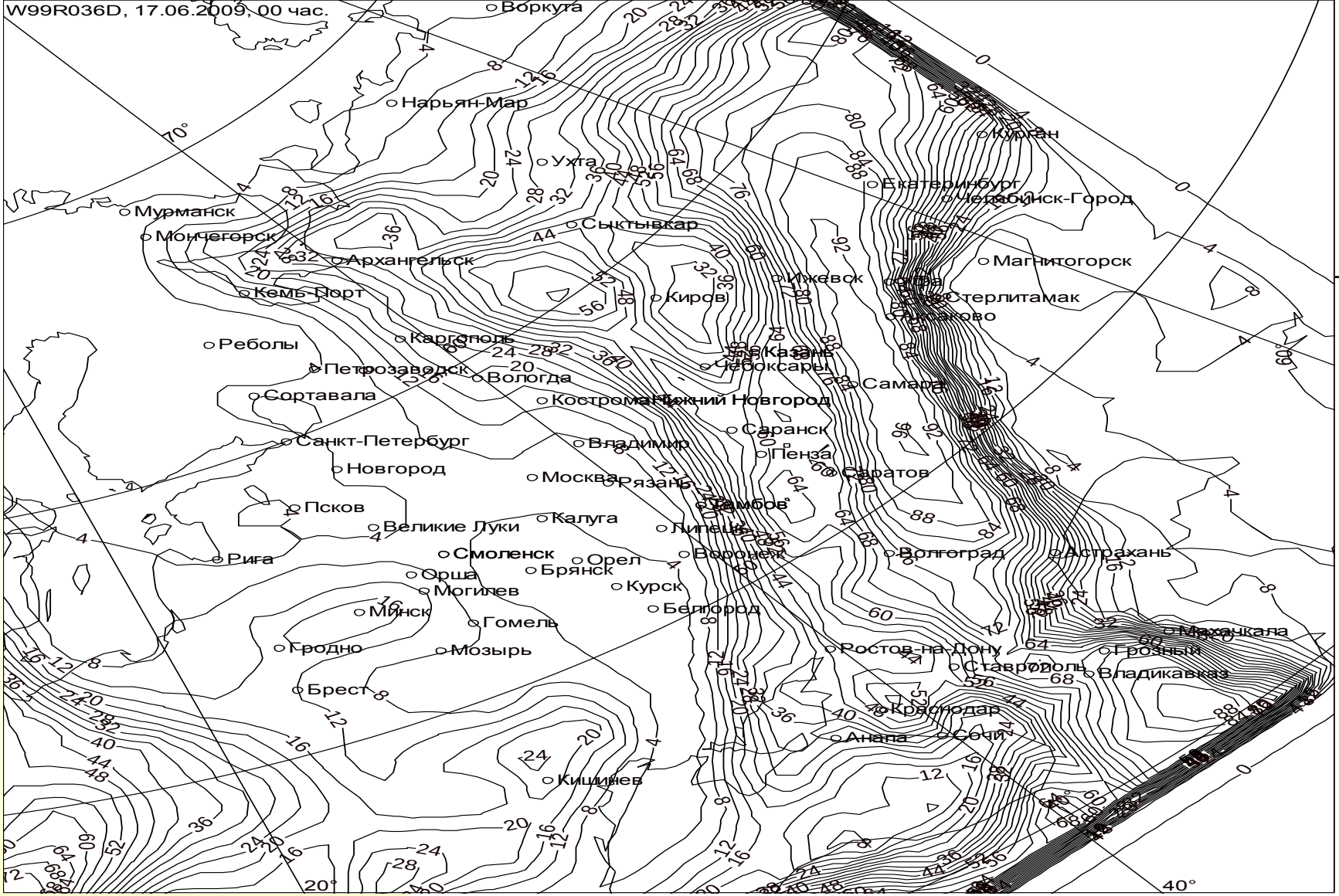
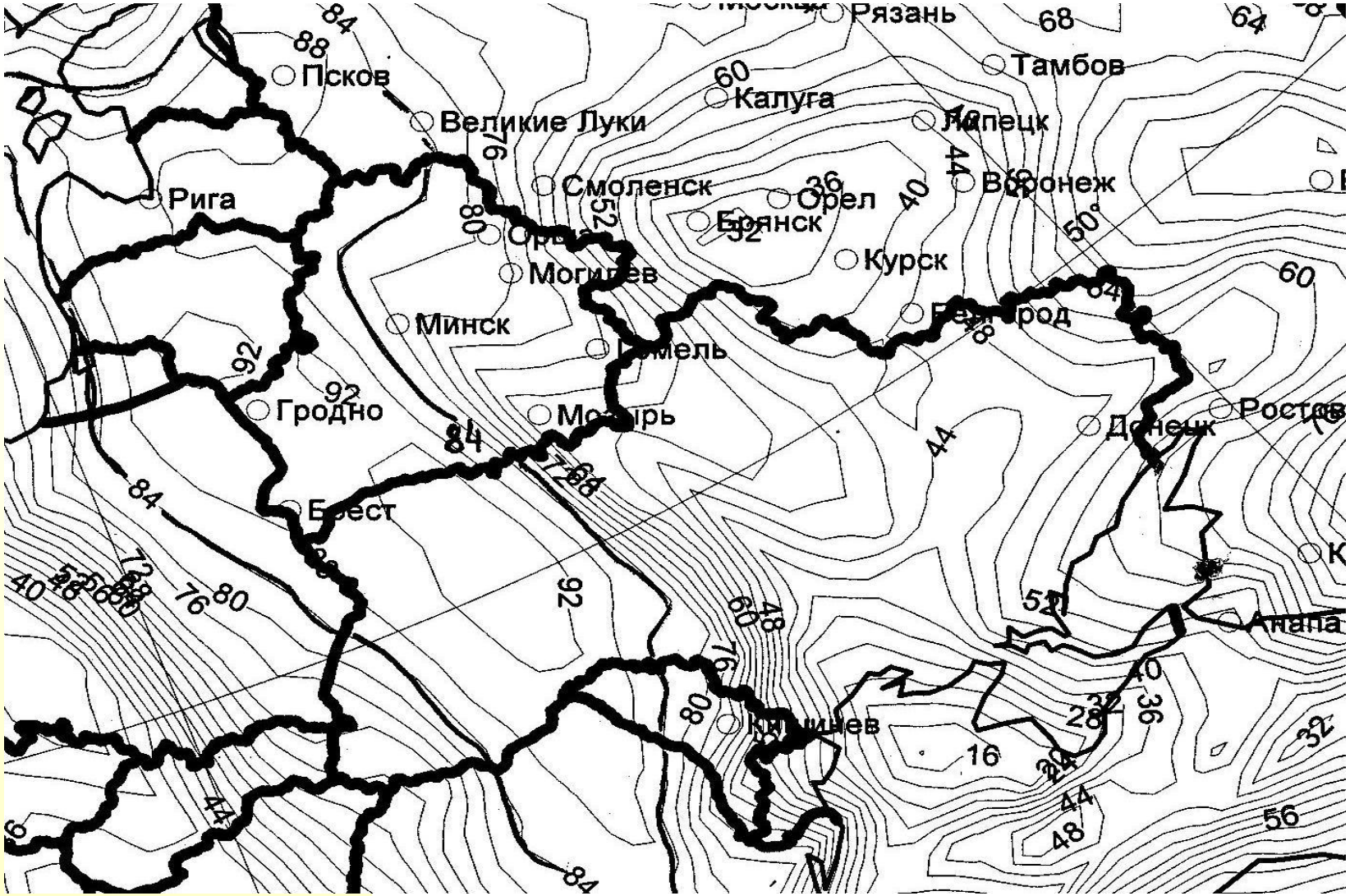
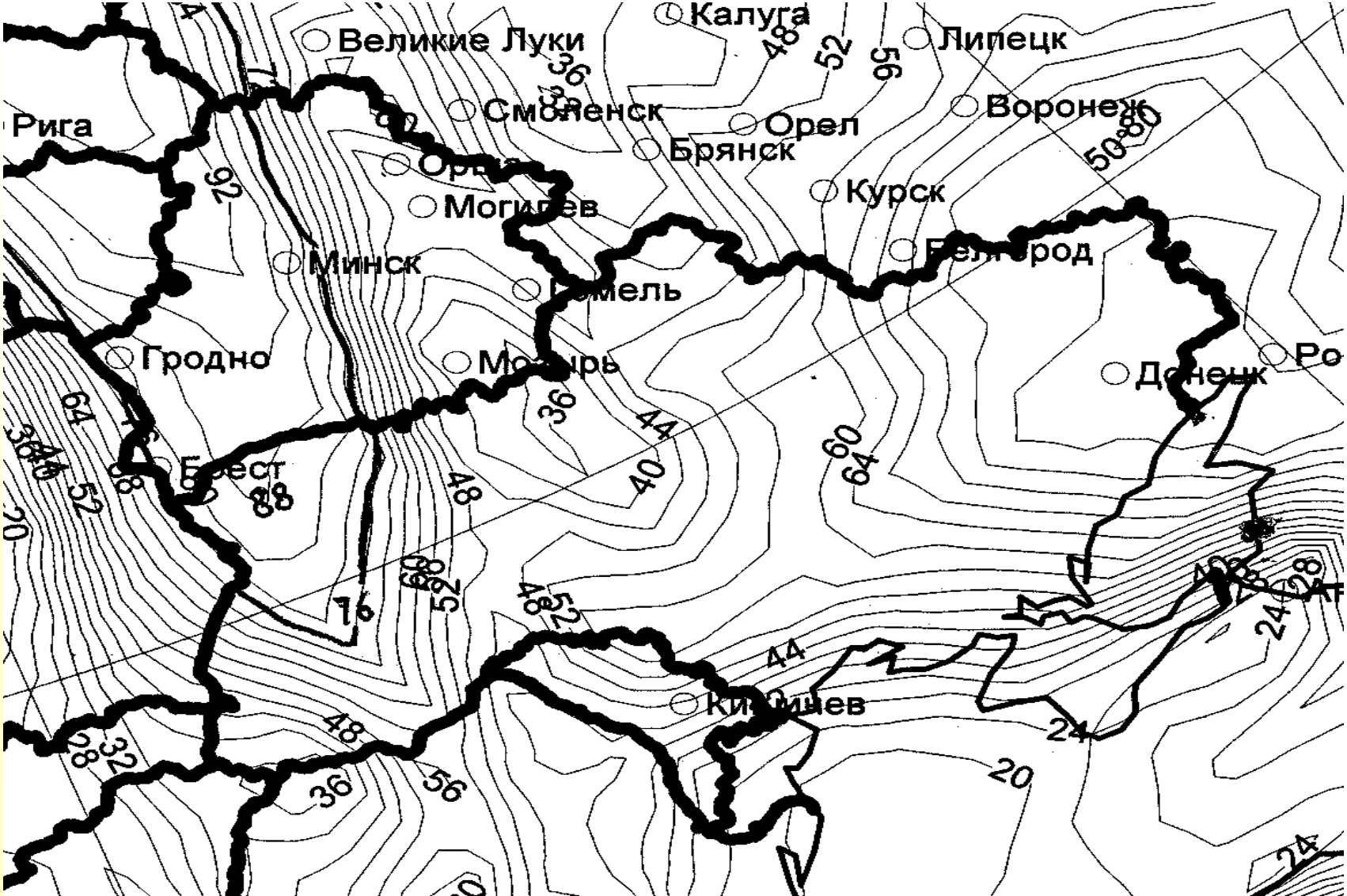


Рис.7. Область прогноза возможного возникновения смерчей и штормового ветра на день 18.06.09. ограничена изолинией **P**=80%. Область прогноза ветра V>24м/с ограничена изолинией **P**=55%. Дата расчета прогноза на 36ч - 17.06.09., - срок 00ч ВСВ.

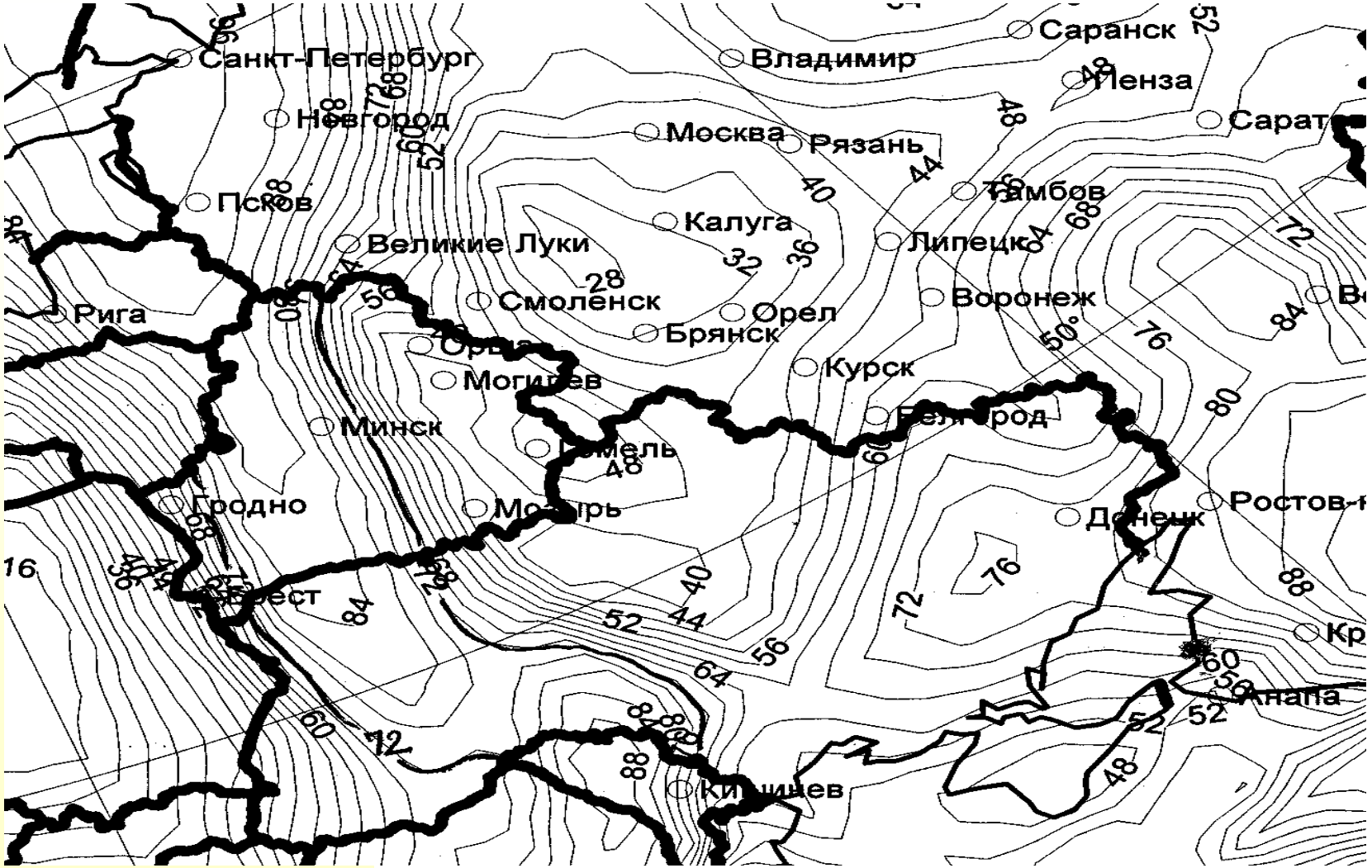
Прогноз опасного ветра V>24м/с на 8.08.2010 по сроку 00ч ВСВ



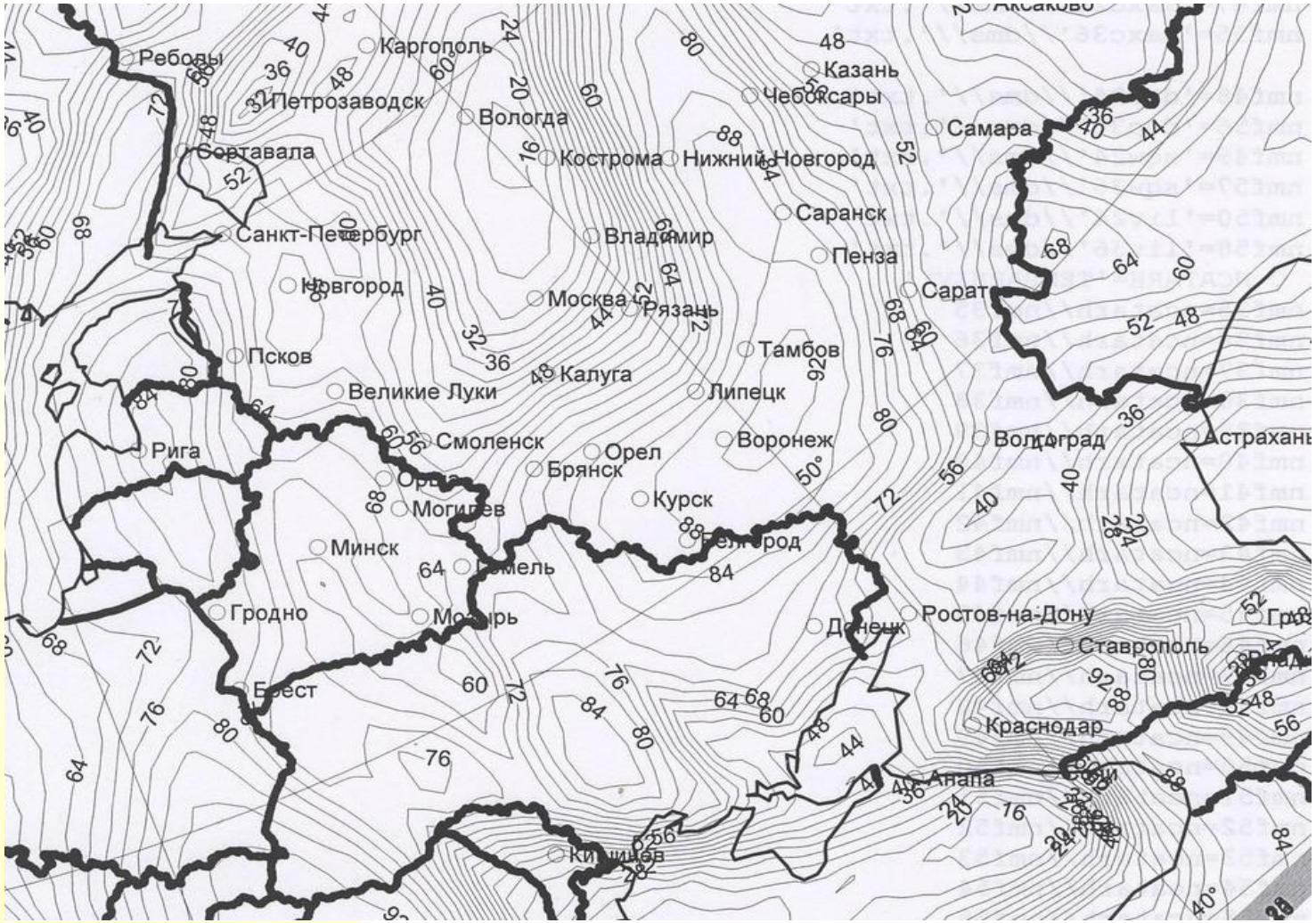
Прогноз опасного ветра V>24m/s на ночь 09.08.10 с заблаговременностью 24ч



Прогноз опасного ветра на 09.08.2010 по сроку 00ч ВСВ



Прогноз опасного ветра V>24м/с на 6.08.2010 с заблаговременностью 36ч. по сроку 00ч ВСВ



The conclusion.

The hydrodynamic-statistical models of the forecast of the squalls and the dangerous wind including tornadoes are successful with the using of the output prognostic fields of the operative hemispheric and regional models for the different regions of Russia.

The possibility of the using of this forecast model in other regions of the UIG is shown on the examples of the dangerous wind forecast for the Republic Belorussia.

The statistical model of the forecast turned out stabile besides output production of hemispheric and regional models of HMC. We are going to try to use the output production of the model WRF (the version 3.1) .

It seems to author that it‘ll be very useful to apply these obtained models and methods for the forecasts of the squalls and the dangerous wind over the territory of Ukraine. The set of the factice phenomena at the territory of Ukraine is big enough and two statistical models of the forecast of the squalls at the Ukraine were successful in the accordance to independent tests in the Department of Meteorology and Hydrology during period 1985-1992 years.

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Thanks

for your attention