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Evaluation of climate changes and their accounting for developing the reclamation measures in western Ukraine

Key words: climate changes, forecast, Polissia of Ukraine, irrigation and drainage systems, computer experiment

Introduction

The transition from the established practice of consideration the meliorative objects like not only technical system, but as complex natural, technical and ecological-economic systems, with a corresponding change in the entire methodology, technical and technological strategy for their creation and functioning, requires direct consideration of time-varying and uncertain weather and climate conditions, that are variable in nature, since they, together with meliorative factors, exert a decisive influence on the general natural-meliorative regime of the drained lands and the corresponding ecological and economic effect (Rokochynskiy, 2010, 2016).

The processes occurring on the meliorated field are characterized by sufficient inertia. The soil moisture reserves cannot change instantly, and the plants themselves react slowly enough to the fluctuations of the meteorological factors if they do not go beyond the established limits.

Therefore, the property of soils and crops inertia, as well as the periodic recurrence of weather conditions, that allows one to make forecasts, despite the rather strong variability of the latter in time.

Thus, the justification of optimal project solutions on ecological and economic bases requires the creation of a single complex of hierarchically linked models of the parameters of effect, re-

gime, technologies and designs, and therefore forecast regime calculations for the relevant models are an obligatory and integral component in the structure of general engineering and land reclamation calculations at all levels of decision-making in time for the implementation of hydromeliorative measures.

In the practice of developing land reclamation projects and projects of other natural and technical systems, carrying out ecological expertise, hydrological and agrometeorological forecasts with different levels of their lead time, it becomes necessary to use the appropriate meteorological information to select climatologically optimal strategies for managing such objects in the multi-year and vegetation periods.

This problem becomes a special actuality in the present conditions, when there are cardinal climate changes on the Earth both on a planetary scale and at the regional level. According to numerous hydrometeorological attribute and indicators, national climatologists come to the conclusion that a new climate has been formed in Ukraine over the past 10–25 years (Rokochynskiy et al., 2008; Rokochynskiy, 2010).

Warming disrupts the established functioning of ecosystems, affects on natural resources, people's living conditions and affects on other elements of their livelihoods. At the same time, soil erosion can be intensified; landslides become more frequent, flooding of coastal strips, an increase in areas of wetlands, and so on (Romashchenko, Sobko, Savchuk & Kulbida, 2003).

In complex natural and technical systems, including hydro-reclamation systems (HRS) on drained lands, the choice of regime-technological and technical solutions at different levels of acceptance over time, should be based on the use of appropriate meteorological information to select climatologically optimal control strategies for such systems in the multi-year and intra-vegetation periods (Rokochynskiy et al., 2007; Rokochynskiy, 2010).

For drained territories with a close groundwater table, on which the drainage systems of Ukraine are located, weather and climate conditions directly participate in the formation of the water regime of soils and groundwater, determining the direction of the soil processes both in the natural state and in certain technological periods of growing crops.

Since the decisive influence on the formation of the water and general natural-meliorative regimes on reclaimed lands and crops being grown is in many cases just climatic or weather conditions, so it is necessary to have at the disposal the data on their implementation for the relevant facility both for a number of previous years of retrospective observations and for the projected period of the object's operation. The number of such implementations and the choice of specific years depend on the long-term inter-seasonal variability of meteorological conditions, and undoubtedly should cover all their typical realizations for a given region.

In this regard, forecasting weather and climate conditions is an indispensable condition for the implementation of an assessment of the overall effectiveness of functioning of the HRS.

Methods

In addition, in the projects of construction, reconstruction and modernization of HRS, in the zone of drainage melioration, the solution of the problem of increasing the overall efficiency of functioning of the existing HRS, as complex natural-technical systems and the development of a strategy for their further development for the nearest and long-term perspective, it is necessary to perform appropriate forecasting regime calculations for such definite time periods: retrospective and present, which accordingly reflect the effectiveness of the operation of the HRS from the time it was put into operation and till present time; forecasted – that characterizes the nearest (present forecast) and distant (future forecast) perspective, taking into account existing and possible climate changes.

Experiments

Program of experiments

To solve these tasks, a large-scale computer experiment was carried out, based on long-term retrospective and modern observational data for the Zhytomyr Polissia zone. In this case, the models of long-term forecast estimation of the main meteorological characteristics in the multi-year and intra-vegetation periods using methods, information and software for their implementation developed at the Department of Environmental Engineering and Hydromelioration of the National University of Water and Environmental Engineering, the use of which is regulated by the current relevant industry standards (Rokochynskiy et al., 2008), were used.

Forecast models

The following research options were planned and implemented:

- variant 1 – «Base»: characteristic of main meteorological factors of the vegetation period (IV–X months), obtained from long-term historical data (1891–1964) (Hydrometioizdat, 1990);
- variant 2 – «Transitional»: normalized mean annual values of the values of the main meteorological factors and their distribution during the growing season, obtained under transitional conditions (1947–1990) (according to Sarny meteorological station);
- variant 3 – «Recent»: the dynamics and normalized mean annual values of the main meteorological factors and their distribution over the vegetation period, obtained under modern conditions (1991–2015) (according to Sarny meteorological station);
- variant 4a – «CCCM» and variant 4b – «UKMO»: normalized mean annual values of the main meteorological factors and their distribution over the vegetation period, obtained on the basis of available and possible climate changes according to the recommendations of (Romashchenko et al., 2003) by the models of Canadian Climate Center «CCCM» – as a more favorable forecast, and of the United Kingdom Met Office «UKMO» – as a less favorable forecast, which foresee an increase in average annual temperature up to 4°C and 6°C relatively – provided that the doubling CO_2 in atmosphere occurs (Shevchuk et al., 2001; Romashchenko et al., 2003).

The expediency of using the models «CCCM» and «UKMO» under appropriate operational forecasting calculations confirmed by taking into account as less and more critical scenarios of changes in weather and climate conditions, and best consistent with forecast models, estimates the normalized distribution of basic meteorological characteristics in the long and growing internal periods.

When performing long-term projective regime calculations with sufficient accuracy for engineering practice, on the basis of completed studies, the available statistical sequences of meteorological quantities were divided by us on five typical groups of vegetation periods regarding conditions of heat and moisture provision on the probability of exceeding – provision – (p) [%], their average vegetative values. Schematically, they are represented in the form of the following set $P = \{p\},\ p = 1, n_p (n_p = 5)$ with taking into account the natural change in the provision of meteorological characteristics in the typical groups according to Table 1 (Rokochynskiy et al., 2008; Rokochynskiy, 2010).

So, according to Rokochynskiy et al. (2008) and Rokochynskiy (2010), forecast made for the five groups of typical vegetation period (very wet – 10%, wet – 30%, average – 50%, dry – 70%, very dry – 90%) for the following main meteorological characteristics as air temperature – T [°C], precipitation – P [mm], relative air humidity – H [%], deficit of air humidity – D [mm], photosynthetically active radiation – PAR [MJ·m^2] and coefficient of moisture provision – K_W (the ratio of precipitation to evapotranspiration).

As a result of the analysis of multiyear data, we have established that PAR is a derivative value of the air temperature. PAR value is performed according to the empirical model we have established (r^2 = 0.90 … 0.92) (Mazhayskiy, Rokochinskiy, Volchek, Meshyk & Jeznach, 2017)

$$\left.\begin{aligned} Q^{III-VII} &= 0.297 \cdot \bar{T}^{III-VII} + 5.478, \tau = 1, n_\tau \\ Q^{VIII-X} &= 0.441 \cdot \bar{T}^{VIII-X} + 0.754, \tau = 1, n_\tau \end{aligned}\right\} \quad (1)$$

where:
$Q^{\text{III–VII}}$, $Q^{\text{VIII–X}}$ – PAR value for the corresponding period March–July and August–October within the estimated vegetation period [kJ·cm^{-2}];

TABLE 1. Estimated provision of meteorological characteristics, which corresponds typical groups of vegetation periods regarding conditions of heat and moisture provision

Provision – p [%] by precipitation – P and relative air humidity – H	Typical groups by estimated provision $P = \{p\},\ p = 1, n_p (n_p = 5)$	Provision – p [%] by air temperature – T and deficit of air humidity – D
0 ... 20% (10%)	p = 1, very wet	80 ... 100% (90%)
20 ... 40% (30%)	p = 2, wet	60 ... 80% (70%)
40 ... 60% (50%)	p = 3, average	40 ... 60% (50%)
60 ... 80% (70%)	p = 4, dry	20 ... 40% (30%)
80 ... 100% (90%)	p = 5, very dry	0 ... 20% (10%)

$\overline{T}$ – average value of air temperature for the estimated decade (τ) of the estimated vegetation period [°C].

Coefficient of moisture provision – K_W characterizes moisture as a ratio of the sum of precipitation during the vegetation period – P [mm] to the total evapotranspiration value during the vegetation period – E [mm], which is determined by the well-known formula N.N. Ivanova depending on the values of air temperature – T [°C] and relative air humidity – H [%] (Rokochynskiy et al., 2008)

$$K_W = P/E \quad (2)$$

Generalized results of calculation of vegetative values of main meteorological factors (precipitation, temperature, deficit and relative air humidity) and derived from them characteristics (PAR and coefficient of moisture provision) by calculated years and research options («Base», «Transitional», «Recent», «CCCM», «UKMO») for the conditions of the Zhitomir Polissia zone, are given in Tables 2, 3 (Mazhayskiy et al., 2017).

According to the obtained results of a comparative assessment of changes in current and forecasted vegetation values of the main meteorological characteristics under the conditions of the calculated years and on average between them, the following conclusions can be drawn:

– about precipitation: in transient conditions («Transitional») compared to the base variant («Base») have been seen the decrease in the amount of precipitation at all considered calculated years (from 0.47% in the dry year and to 17.9% in wet), which on average is 5.30%. Regarding present conditions («Recent»), there is some increase in the amount of precipitation (with their changes from 2.80% in very wet year to 11.87% in very dry), which on average is 4.07%. According to the forecast options, it is also possible to partially increase the precipitation for all calculated years, which on average is for «CCCM» – 1.69% and «UKMO» – 7.47%;
– about air temperature: in all the considered variants of studies there is an increase in air temperature as in the calculated years, and on average between them, which is less expressed in transitional conditions («Transitional») – 1.75%, more expressed in modern conditions («Recent») – 4.84%, and significantly increases in the forecasted conditions («CCCM» – 24.59% and «UKMO» – 34.93%);
– about deficit of air humidity: the variation of this index is similar to air temperature changes with some deviations of the calculated data and the average there between: for «Transitional» – 0.83%; «Recent» – 5.44%, for «CCCM» increase is 22.8%, and for «UKMO» – 27.19%;
– about the relative air humidity: respectively in transitional conditions («Transitional») she on average slightly increased 0.83%, and decreases in modern conditions («Recent») on 2.09%, and for forecasts «CCCM» – on 2.09%, for «UKMO» – on 6.9%;
– about PAR: The nature of the change in this indicator is consistent with changes in air temperature with a slightly lower intensity of increase: for «Transitional» – 1.09%; «Recent» – 3.03%; «CCCM» – 15.98%, «UKMO» – 22.57%;
– about coefficient of moisture provision: the character and values of

TABLE 2. Vegetative values of the main meteorological characteristics according to the research options for the conditions of Zhytomyr Polissia zone

Indexes, Models		Year of estimated precipitation				
		10%	30%	50%	70%	90%
Sum of precipitation, P [mm]	«Base»	575.12	509.06	443.01	376.96	310.90
	«Transitional»	544.38	471.93	434.86	375.20	307.90
	«Recent»	559.00	510.75	443.28	417.98	347.80
	«CCCM»	582.54	516.36	450.18	384.01	317.83
	«UKMO»	615.64	545.71	475.77	405.83	335.89
Average air temperature, T [°C]	«Base»	12.68	13.06	13.47	13.67	14.19
	«Transitional»	12.92	13.33	13.75	13.80	14.44
	«Recent»	13.30	14.01	14.20	14.51	14.26
	«CCCM»	15.94	16.33	16.77	16.98	17.52
	«UKMO»	17.26	17.69	18.16	18.39	18.98
Sum of deficit of air humidity, D [mm]	«Base»	698.0	785.0	849.0	943.0	1 036.0
	«Transitional»	722.0	805.0	884.0	923.0	1 044.0
	«Recent»	729.0	854.0	9 14.0	946.0	1 098.0
	«CCCM»	866.0	973.4	1044.0	1150.0	1 254.0
	«UKMO»	893.0	1005.0	1078.0	1207.0	1 295.0
Average relative air humidity, H [%]	«Base»	80.56	77.73	75.26	72.07	69.42
	«Transitional»	81.76	78.66	73.94	73.02	70.73
	«Recent»	76.65	75.81	73. 48	72.51	68.48
	«CCCM»	74.12	72.51	70.23	67.45	64.78
	«UKMO»	73.36	71.73	68.46	65.77	63.42
Sum of PAR [MJ·m^{-2}]	«Base»	1 586.0	1 616.0	1 646.0	1 665.0	1 705.0
	«Transitional»	1 594.0	1 634.0	1 673.0	1 680.0	1 727.0
	«Recent»	1 631.0	1 691.0	1 708.0	1 729.0	1 706.0
	«CCCM»	1 845.0	1 876.0	1 911.0	1 928.0	1 971.0
	«UKMO»	1 948.0	1 982.0	2 020.0	2 038.0	2 084.0
Coefficient of moisture provision, K_W	«Base»	1.35	1.06	0.86	0.66	0.49
	«Transitional»	1.24	0.85	0.81	0.67	0.48
	«Recent»	1.26	0.98	0.80	0.72	0.52
	«CCCM»	1.10	0.87	0.7 1	0.55	0.42
	«UKMO»	1.13	0.89	0.72	0.55	0.43

changes in the amount of precipitation and air humidity deficit both for the calculated years and on average between them, cause it to decrease somewhat in the transitional conditions («Transitional») – 6.84%, and less expressed decline in modern conditions («Recent») – 1.14%, and a

TABLE 3. Comparative evaluation of changes in vegetation values for the main meteorological characteristics for research options of the Zhytomyr Polissia zone [%]

Indexes, Models		Year of estimated precipitation					Average [%]
		10%	30%	50%	70%	90%	
Sum of precipitation, *P*	«Transitional»	–5.34	–17.90	–1.84	–0.47	–0.96	–5.30
	«Recent»	–2.80	+0.33	+0.06	+10.88	+11.87	+4.07
	«CCCM»	+1.29	+1.43	+1.62	+1.87	+2.23	+1.69
	«UKMO»	+7.05	+7.20	+7.39	+7.66	+8.04	+7.47
Average air temperature, *T*	«Transitional»	+1.89	+2.07	+2.08	+0.95	+1.76	+1.75
	«Recent»	+4.89	+7.27	+5.42	+6.14	+0.49	+4.84
	«CCCM»	+25.71	+25.04	+24.50	+24.21	+23.47	+24.59
	«UKMO»	+36.12	+35.45	+34.82	+34.53	+33.76	+34.93
Sum of deficit of air humidity, *D*	«Transitional»	+3.44	+2.55	+4.12	–2.12	+0.77	+1.75
	«Recent»	+4.44	+8.79	+7.66	+0.32	+5.98	+5.44
	«CCCM»	+24.07	+24.00	+22.97	+21.95	+21.04	+22.81
	«UKMO»	+27.94	+28.03	+26.97	+28.00	+25.00	+27.19
Average relative air humidity, *H*	«Transitional»	+1.49	+1.20	–1.75	+1.32	+1.89	+0.83
	«Recent»	–4.85	–2.47	–2.37	+0.61	–1.35	–2.09
	«CCCM»	–7.99	–6.72	–6.68	–6.41	–6.68	–6.90
	«UKMO»	–8.94	–7.72	–9.04	–8.74	–8.64	–8.62
Sum of PAR	«Transitional»	+0.50	+1.11	+1.64	+0.90	+1.29	+1.09
	«Recent»	+2.84	+4.64	+3.77	+3.84	+0.06	+3.03
	«CCCM»	+16.33	+16.09	+16.10	+15.80	+15.60	+15.98
	«UKMO»	+22.82	+22.65	+22.72	+22.40	+22.23	+22.57
Coefficient of moisture provision, K_w	«Transitional»	–8.49	–19.94	–5.73	1.69	–1.72	–6.84
	«Recent»	–6.94	–7.77	–7.05	10.53	5.55	–1.14
	«CCCM»	–18.36	–18.20	–17.36	–16.47	–15.54	–17.19
	«UKMO»	–16.33	–16.27	–15.42	–15.89	–13.57	–15.49

very significant decrease in the forecast conditions («CCCM» – 17.19% and «UKMO» – 15.49%).

Comparative assessment the dynamics of changes for the main meteorological characteristics of the growing season (precipitation, temperature, deficit and relative air humidity) for 1991–2015, with their retrospective and perspective norms is shown on the figure (Mazhayskiy et al., 2017).

The following characteristic moments can be shown:

– about precipitation: a considerable amplitude of their oscillations is observed during the considered period of time from 200 to 600 mm, at an average annual norm 443 mm with well-

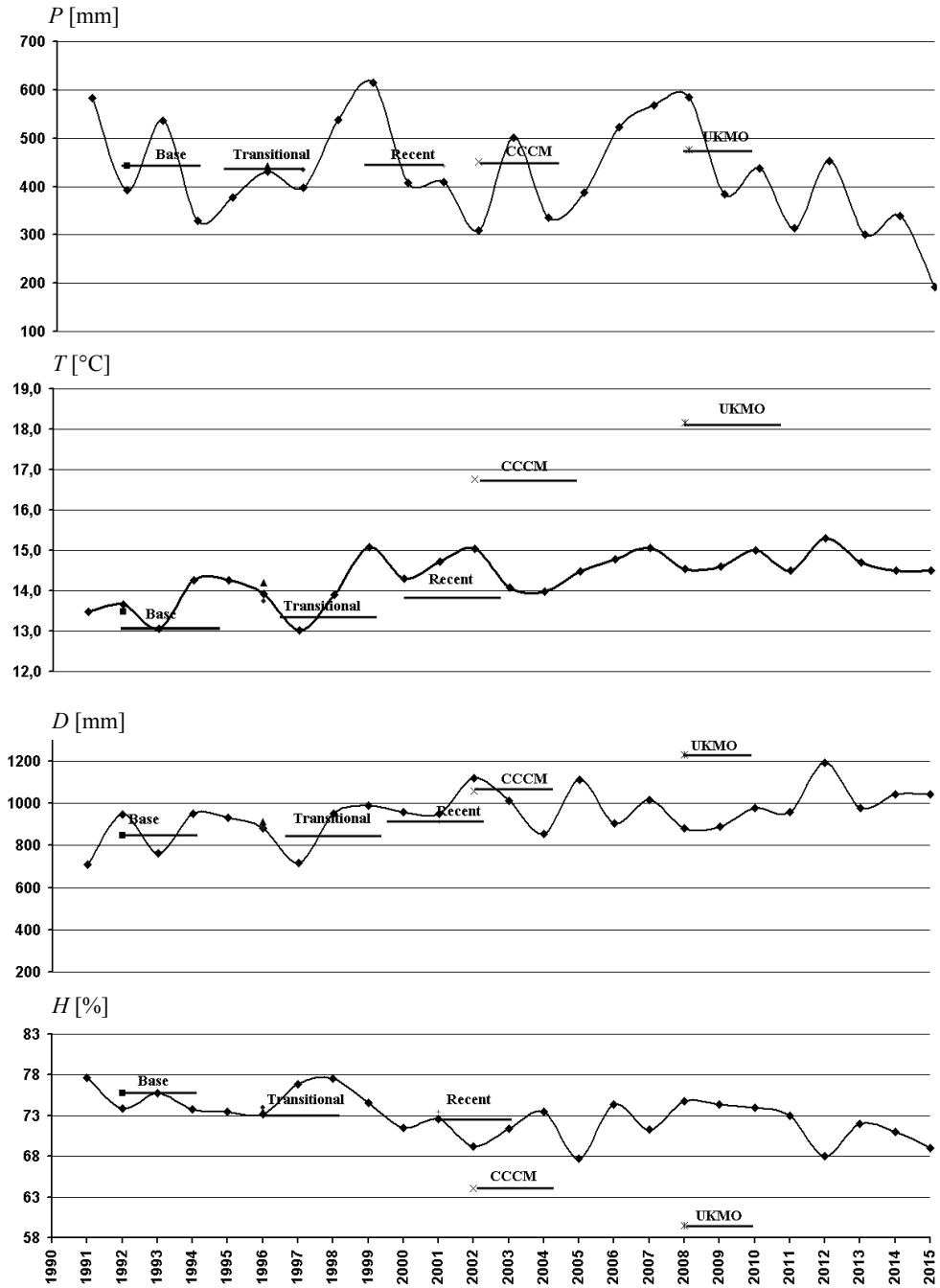

FIGURE. Comparative estimation of normalized values of the main meteorological characteristics by the research options regarding the dynamics of their valid values in conditions of the Zhytomyr Polissia zone

-defined maximums in 1991, 1999 and 2008, minimums in 1994, 2002, 2004 and 2015. In the subsequent years after 2008 there is a steady decrease in the amount of precipitation in all the study options considered. At the same time, the forecasted norms for the models «CCCM» and «UKMO» are already within the limits of the current fluctuations for the total vegetation values;

– about air temperature: takes place the opposite situation, Since 1991 there has been an increase in air temperature with expressed maximums in 1999, 2002 and 2012, which are respectively 15.1°C, 15.0°C and 15.3°C. At the same time, the average annual air temperatures over the considered period of time do not reach the forecasted values for models «CCCM» and «UKMO»;

– about deficit of air humidity: the dynamics of air humidity deficits changes as a whole reflects the characteristic features of the amplitude variation of air temperature: the air humidity deficits reaches the first and second maximums in 2002 and 2005, which are 1,118 mm, respectively, with an average vegetative value of 5.30 and 1,112 mm at 5.20 mm. After 2005, the total air humidity deficit vegetation value is somewhat reduced and has an insignificant amplitude of fluctuations, and then there is a sharp increase to the third maximum in 2012–1193 mm at 5.0 mm. In this case, the value of air humidity deficit by the model «Base» less than the average annual norms by model «Transitional» and «Recent», and its corresponding norms by models «CCCM» and «UKMO» are already within their present fluctuations;

– about the relative air humidity: The opposite situation is observed in the dynamics of change in the relative air humidity, here the two first maximums about 78% takes place in 1991 and 1998, after which there is a sharp decrease to its first and second minimums about 68% in 2005 and 2012. At the same time, the average long-term relative air humidity by the model «Base» above average annual norms by models «Transitional» and «Recent», and its relevant norms by models «CCCM» and «UKMO» are within the limits of the current oscillations of the average annual values.

Conclusions

The given data convincingly testify that the main meteorological characteristics, except of temperature and PAR, for the calculated years and on average between them, are already in the zone or at the level of their forecasted values under climate change conditions.

The obtained results of a comparative assessment of the weather and climate conditions for the Zhytomyr Polissya zone according to the examined variants of their studies, indicate that, for all the main meteorological indicators, excepted of the relative air humidity, first of all it concerns air temperature as the determining factor of present climate changes, as well as the PAR as its derivative, changes already occur, as well as the PAR as its derivative, changes already occur, which in the short term may exceed 10% of the critical environmental threshold, which will lead to irreversible changes of the environmental state in the region.

It is established, that at the current rates and levels of changes in weather and climate conditions, it is necessary to expect the deterioration of the natural and meliorative conditions, both in the zone of Zhytomyr Polissia and in the whole Ukraine. This will inevitably affect on the functioning of water-reclamation objects as a result of the corresponding changes in the ecological and economic resource, which requires the development of adaptive technical and regime-technological measures for the management of these facilities through appropriate comprehensive scientific sectoral, state and interstate research and programs.

Therefore, the issue of improving the efficiency of water management and land reclamation objects should be considered inseparably with the assessment and forecast of weather and climate conditions both at the current stage of the climate situation and in the context of possible climate changes in the immediate and distant future.

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Summary

Evaluation of climate changes and their accounting for developing the reclamation measures in western Ukraine. In modern conditions, there are cardinal climate changes on the Earth as at the planetary scale, as at the regional level. According to numerous hydrometeorological characteristics and indicators, climatologists specialists concluded that Ukraine also take place significant climatic changes in the last 10–25 years.

In complicated natural-technical systems, which include irrigation and drainage systems (IDS) on drained lands, the selection of regime-technological and technical solutions on different levels of the decision including the time, should be based on the appropriate meteorological information for selecting climatologically optimal management strategies for such systems in the long--term and annual periods.

The decisive influence on the formation of water and the overall natural reclamation modes of reclaimed land and harvest crops in many cases depends exactly from climate or weather conditions. Thus, it is necessary to have available data about their implementation to the relevant object as for number of previous years retrospective observations and the forecast period of functioning of the object. Therefore, forecasting of weather and climate conditions become an indispensable condition for implementation of assessing the overall effectiveness of IDS operation.

To solve this problem we performed large--scale computer experiment for multi-year retrospective and current data observations in the area of Zhytomyr Polissya. Were planned and implemented the following variants of studies – «Base», «Transitional», «Recent», «CCCM», «UKMO».

The forecast was done for five years of typical groups of vegetation periods regarding conditions of heat and moisture provision (very wet – 10%, wet – 30%, average – 50%, dry – 70%, very dry – 90%) on such basic meteorological characteristics: air temperature; precipitation; relative air humidity; deficit of air humidity; photosynthetically active radiation (PAR); coefficient of moisture provision (the ratio of precipitation to evapotranspiration).

Obtained results of comparative assess--ment of climatic conditions in Zhytomyr Polissya zone, suggests that for most of the basic meteorological parameters, already there are changes that in the short term may exceed 10% of the critical ecological threshold, which will lead to relevant irreversible changes in the state of the environment in the region.

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