LONG-TERM FORECASTS OF HEATING PERIOD DURATION FOR THE VOLGA FEDERAL DISTRICT

Nadezhda A. Vazhnova
Kazan Federal University, Institute of Environmental Sciences, tel. 89520366195; e-mail:
Nadezhda.Vazhnova@kpfu.ru

Abstract

The principal fundamentals of the forecast method for heating period duration are considered in this paper, taking into account the date of a stable autumn decrease of the mean daily air temperature through 8 °C. The largest average forecast errors (up to ± 9 ÷ 9.4 days) were observed in the northern and the northwestern parts of the Volga Federal District (VFD) - in the zone with the greatest spring variability of circulation and thermal regimes. Nevertheless, the main result of the work is that methodological forecasts proved to be much more effective than formal ones, which inspires certain confidence in the future prospects of their scientific and practical basis use.

Keywords: Long-term forecast, heating season duration, the transition of the average daily air temperature below 8 °C

1 INTRODUCTION

The autumn decrease of the mean daily air temperatures (MDAT), when they reach the threshold value of 8 °C and then kept below this value steadily, is the decisive argument to start heating networks and a heating period (HP) (Vazhnova & Vereshchagin, 2015; Vazhnova & Vereshchagin, 2017; Vazhnova, 2016; Isaeva & Sherstyukov, 1996; Kobysheva, 2001; Almasi, 2016).

According to the same ideas (Isaeva & Sherstyukov, 1996; Vazhnova & Vereshchagin, 2017; Vazhnova, 2016; Isaeva & Sherstyukov, 1996; Kobysheva, 2001), the transition of MDAT through 8 °C in the spring, after which they are stably maintained above their indicated value, marks the end of a HP, and the time interval between the dates of the specified stable MDAT transitions determines the duration of a HP (Kobysheva, 2001; Perevedentsev et al., 2000; Silva et al., 2016).

A great interest to the study of the meteorological conditions for the development, subsequent course and duration of a HP (Isaeva & Sherstyukov, 1996), as well as for the results of its indicators statistical generalization (Gnevko, 1980) is conditioned by the fact that the beginning of a HP leads to a number of very important circumstances: a sharp increase of fuel resources and electricity consumption, the deterioration of the ecological situation in cities and large settlements (Vasiliev & Frolov, 1999), etc.

The financial costs associated with the meeting of a HP needs grow with the increase of its duration, which is characterized by significant spatial and interannual variability (Panovsky & Brier, 1972), (Table 1).

The indicators of a HP duration are minimal in the southern part of the district, from where they increase quickly in the northeast direction. For example, in Saratov the average long-term duration of a HP makes 184 days, and its absolute amplitude makes 53 days. In the extreme north-eastern part of Perm region (Biser station), the same indices are much higher and make 250 and 81 days respectively.

The overcoming of uncertainties arising in this case is possible only with the use of forecasting results for all known HP indicators (Gnevko, 1980; Isaeva & Sherstyukov, 1996; Perevedentsev et al., 2000; Özer, 2018), based on the application of sufficiently reliable methods. Thus, the urgency of new and effective methods development for the forecasting of HP parameters and, in particular, its duration is quite obvious.

The purpose of this paper is the experimental verification of prediction possibility concerning the duration of a HP taking into account the date of MDAT stable autumn transition through 8 °C.

In order to achieve the abovementioned goal, the following tasks were accomplished: 1) the development of the methodology for the forecasting of a HP duration; 2) the testing of experienced forecast quality.

The practical significance of the forecasts discussed here is not limited to their direct purpose and in fact it is much broader. These forecasts provide a direct access to the predictions of the dates for stable spring shifts of MDAT below 8 ° C and, therefore, can be useful for the expansion of the informative base concerning monthly and seasonal weather forecasts (for a spring period) (Batyreva & Vilfand, 1999; Kryzhov, 2012; Khan et al., 2009; Shishvan & Ebrahimnejad, 2018).

2 MATERIALS AND METHODS

The work relied on the use of the VNIIGMI-MTSD archive data on the annual (1966-2010) dates of the stable autumn and spring transitions of MDAT through 8 °C for six stations indicated in Table 1.

The above-mentioned 45-year (1966-2010) archival sample of data on the dates of MDAT stable transitions below 8ºC was divided into a training (1966-1995) and an independent (1996-2010) subsample. The first one was used to determine the optimal values of the parameters a and в of the regression equation (2), on the basis of which experimental predictions were developed. The second sub-sample was used to determine the quality of pilot forecasts.

The dates of MDAT stable transitions through 8 °C in the above-mentioned archive of initial data are presented according to the calendar (discrete) time scale, which creates certain inconveniences for their subsequent statistical processing. In this regard, the calendar dates of the stable MDAT transitions through 8 °C were previously adapted to a continuous time scale.

According to the definition of (Vazhnova & Vereshchagin, 2015; Isaeva & Sherstyukov, 1996; Kobysheva, 2001), the duration of a HP (also known as predicant) (ζ) was defined as the following residuation:

$$\zeta = x - y \qquad (1)$$

of stable spring (x) and autumn (y) MDAT transition dates through 8 °C.

In the experimental predictions of HP durations the dates of MDAT stable autumn transitions through 8 °C (y) were taken into account as a predictor. The calculations of a HP expected duration (z) were performed using the regression equation:

$$z = ay + b. \qquad (2)$$

The constants of this equation were sought using the "least squares method" (Bagrov et al., 1985; Perevedentsev et al., 2000) (for each station individually).

The choice of a predictor (y) was conditioned by a sufficiently high level of its information content in relation to the predicate behavior. The determination coefficient Ry (ζ) (Bagrov et al., 1985) (0≤Ry (ζ) ≤1,0) was used (Table 1) as the measure of informative value of the predictor (y) with respect to the predicate (ζ). The proximity of Ry (ζ) to the upper limit indicates a high level of the predictor informative value, and vice versa, if Ry (ζ) → 0.

Following (Bagrov et al., 1985; Panovsky & Brier, 1972), experimental predictions can be considered as some experiments on the reproduction of the predicate expected behavior variety, the strict measure of which is its variance σ2 (ζ). The latter can be represented in the form of the following development (Table 1):

$$\sigma^{2}(\zeta) = \sigma^{2}(x-y) = \sigma^{2}(x) + \sigma^{2}(y) - 2r(yx)\sigma(y)\sigma(x). \qquad (3)$$

Here $\sigma^{2}(y)и\sigma^{2}(x)$ are the variances of the stable autumn (y) and spring (x) MDAT transitions through 8 °C (respectively), and otherwise, the absolute values of the variability contributions of these dates to the total variance $\sigma^{2}(\zeta)$ without taking into account the effects of the relationships between the date y and x fluctuations; $\sigma(y)и\sigma(x)$ are mean square deviations of the corresponding dates; $r(yx)$ is the coefficient of the asynchronous (long-period) correlation between the fluctuations of stable autumn and the following spring shifts of MDAT through 8 °C.

Thus, the third term on the right-hand side of (3) describes the contribution to the total dispersion $\sigma^{2}(\zeta)$ of the same fluctuations concerning the dates of MDAT autumn transitions (y) by the means of some fluctuations excited by them concerning MDAT spring transition dates through 8 °C (x).

Taking into account the foregoing, the expression for the determination coefficient (otherwise, for the definite behavior function ζ (Storm, 1970)) Ry (ζ) can be put down as the ratio.

$$R_y(\zeta) = \frac{[\sigma^{2}(y) - 2r(yx)\sigma(y)\sigma(x)]}{\sigma^{2}(\zeta)}. \qquad (4)$$

At that $0 \le R_y(\zeta) \le 1{,}0$.

The determination of the coefficient Ry (ζ) value can be described in a different way, taking into account the following equality

$$R_y(\zeta) = r^{2}(y\zeta), \qquad (5)$$

in which $r(y\zeta)$ is the correlation coefficient between the fluctuations in the dates of MDAT stable autumn transitions through 8 °C (y) and HP durations (z).

The advantage of $R_y(\zeta)$ determination by the formula (4) is that it allows you (if necessary) to analyze the internal structure of the coefficient $R_y(\zeta)$.

According to equality (5), in order to test the reliability of the estimates $R_y(\zeta)$ one can use tabular data on the largest random correlation coefficients r_α (Khan et al., 2009). Here α is an accepted level of significance. With a sample size of n=30 and α=0,001 we have the following (Khan et al., 2009): $r^{2}_{0{,}001} = R_y(\zeta)_{0{,}001} = (0{,}57)^{2} = 0{,}32$.

As can be seen (Table 1), the estimates of Ry (ζ) are much larger than the indicated threshold value, that is, the probabilities that the coefficient Ry (ζ) is nonrandom one is much more than 99.9%.

The data on the coefficients $R_y(\zeta)$ (Table 1) show that the consideration of stable autumn MDAT transitions through 8 °C (y) as the predictor of dates allows us to provide a large (on average 64% (Table 1)) part of the predicate total dispersion $[\sigma^2(\zeta)]$ in forecasts. This circumstance was the decisive one for the choice of the abovementioned predictor (y) in the experimental predictions of a HP duration (ζ).

The quality of the experimental forecasts z (2) was estimated by its comparison with the quality of formal (inertial, climatological) forecasts (Bagrov et al., 1985; Vazhnova & Vereshchagin, 2015).

In inertial (и) forecasts, the duration of a HP ($z_{\text{и}}$) during the winter of the end of the year j and the beginning of the year (j+1) was indicated as it was during the winter at the end of (j-1)-th and at the beginning of the j-th year. In climatological (k) forecasts of the of a HP duration its average multi-year value ($\bar{\zeta}$) was provisioned in all cases.

In the end, the quality of tested methodological (m) forecasts was estimated using the following indicators:

а) average absolute ones

$$\Delta_{\text{м}} = \pm\frac{1}{n}\sum_{i=1}^{i=n}|z_i - \zeta_i|, \qquad (6)$$

б) mean square ones

$$\delta_{\text{м}} = \frac{1}{n}\sum_{i=1}^{i=n}|z_i - \zeta_i|^2, \qquad (7)$$

в) relative errors of forecasts

$$S_{\text{и}} = \delta_{\text{м}}\left[\frac{1}{n}\sum_{i=1}^{i=n}|z_{\text{и}i} - \zeta_i|^2\right]^{-1}, \qquad (8)$$

$$S_{\text{к}} = \delta_{\text{м}}\left[\frac{1}{n}\sum_{i=1}^{i=n}|\bar{\zeta} - \zeta_i|^2\right]^{-1}. \qquad (9)$$

Here i are the forecast numbers ($i = \overline{1, n}$), n is the number of experimental forecasts (n=14), z and ζ is the predicted and the actual duration of a HP (respectively), $\bar{\zeta}$ – the average multi-year duration of a HP.

It can be seen that the denominators of fractional expressions (8), (9) describe the mean square errors of inertial ($\delta_{\text{и}}$) and climatological ($\delta_{\text{к}}$) forecasts (respectively). Thus, the equations (8), (9) describe the relations of forecast errors $\delta_{\text{м}}/\delta_{\text{и}}$ and $\delta_{\text{м}}/\delta_{\text{к}}$ (respectively).

The indicators of methodical forecast advantages over formal ones are the inequalities $S_{\text{и}}<1,0$ and $S_{\text{к}}<1,0$ (Table 2).

3 RESULTS AND DISCUSSION

The results of the undertaken study are presented by Table 1,2 in their condensed form.

Table 1: Dispersions of a HP duration with the results of their decomposition into the components and the determination coefficients R$_y$(ζ)

Stations				$-2r(yx)\sigma(y)\sigma(x)$	$_y(\zeta)$
Perm	59,8	73,7	25,6	60,4	,66
Kirov, MDAT	30,3	00,0	02,6	27,36	,55
H N.Novgorod, Myza	00,6	33,2	13,8	59,5	,65
Kazan, CHME	68,9	25,4	1,1	51,8	,66
Saratov	46,6	30,2	8,7	47,6	,72
Orenburg, ZGMO	21,2	07,5	0,8	32,9	,63
Average	72,2	28,3	7,1	46,6	,64

The fundamental result of the work should be considered the established highly reliable, close, negative relationship [$r(y\zeta) < 0$] between the changes in the dates of autumn MDAT stable transitions through 8 °C ($\bar{y}$) and a HP duration (ζ).

According to the data of Table 1 it follows that such a close, negative relation [$r(y\zeta) < 0$], referred to here, is the result of the combined, unidirectional action of two unequal reasons. The first of them (and the main one) consists in the relatively more stable date of MDAT spring transitions in comparison with the stability of autumn transition dates (y) through 8 °C (x) (x) [$\sigma^2(x) < \sigma^2(y)$], Table 1]. Thus, earlier (late) autumn stable MDAT transitions through 8 °C are accompanied in most cases by longer (shorter) HP.

The effect of the second, less significant cause is related to the presence of negative asynchronous correlation [$r(yx) < 0$, Table 1] between the dates of autumn (x) and spring (y) MDAT transitions through 8 °C (Table 1). In this case, the direction of this cause action coincides with the direction of the main (first) cause action.

These circumstances served as the occasion for the approbation of possible use concerning the dates of stable autumn transitions (y) as an informative predictor in the experimental forecasts of a HP duration.

The results of the work also testify to the great practical importance of observations for the daily changes of MDAT during the autumn period and the date when they fall below 8 °C for the first time, and then remain below this index for 4 days at least (Panovsky & Brier, 1972).

Depending on whether this MDAT shift occurred earlier or later than usual, it is possible to draw up some plausible idea about the duration of an upcoming HP (should one expect it to be longer or shorter one) without any calculations.

In the course of the work, they determined the reproducing ability of the abovementioned linear prognostic model (z). It was shown that the consideration of MDAT stable autumn transition dates through 8 °C as the predictor allows to reproduce 64% of the total variance of an expected HP duration on the average, which was reflected in the results of the experimental quality control for the forecasts (Table 2).

Table 2: HP duration prediction errors

Stations	±Δм, days	days²			и	к
Perm	9, 4	36,5	38,7	83,2	,18	,35
Kirov, MDAT	9, 0	08,2	32,8	05,8	,46	,52
N.Novgorod, Myza	9, 3	30,7	35,4	80,7	,39	,45
Kazan, CHME	7, 4	5,4	48,7	33,7	,24	,25
Saratov	7, 5	6,4	54,6	2,5	,56	,93
Orenburg, ZGMO	8, 3	13,6	77,5	06,6	,24	,37
Average values	8, 5	10,1	81,3	67,1	,35	,48

According to the data of all six stations an average absolute error of the forecasts makes Δm = ± 8.3 days (Table 2) averaged over the 14-year period of the tests, not exceeding 4.4% of a HP average duration in the south (Saratov station) and 3.3% in the extreme north-east of the Volga Federal District (station Perm).

If the allowable error of the forecasts is taken conditionally as Δm = ± 10 days, then the shares (from the number of trials n = 14) of the justified forecasts make from 71.4% (for Nizhny Novgorod, Myza, Saratov, Orenburg, ZGMO) to 78,5% (for the station Kazan, CHME).

The share of justified forecasts is the smallest one (64.2%) for the northern part of the Volga Federal District (Perm, Kirov, AMSG stations). The circumstances of such an insufficient level of forecast reliability for this part of the district will be discussed below.

As can be seen, the error level (Δm, Table 2) of the tested forecast method for the central latitudinal band and the southern part of the district does not cause much doubt as to the possibilities of its use in applied (mainly advisory) purposes.

The forecast errors Δm (Table 2) reach the highest values (up to ± 9 ÷ 9.4 days on the average) in the northern and the northwestern parts of the VFD territory (Perm, Kirov, AMSG, N.Novgorod, Mysa). As can be seen the thing is about the latitude space closest to the migration zone of the Arctic atmospheric front (Vazhnova & Vereshchagin, 2015), with the most unstable regime of the atmosphere spring circulation and, thus, the maximum variation of the thermal regime and the dates of the stable MDAT spring shifts through 8 °C (Table 2). The greatest forecast errors (Δm) for this part of the district are explained by the action of precisely these factors.

To the south of this latitude space, the average absolute errors of forecasts (Δm) decrease regularly and do not exceed ± 7,4 ÷ 8,3 days, which is quite natural.

The comparison of the forecast errors (Δm) (Table 2) with the mean square deviations of MDAT stable spring shifts through 8 °C ($\sigma^2(x)$) (Table 1) shows that the forecast errors are in direct, positive dependence on the changes in the instability indicators concerning the dates of the indicated spring transitions $\sigma^2(x)$ and follow them.

It is not difficult to see that the mean absolute error of a HP duration for Moscow during (1986-1995) 10 year period, followed from (Isaeva & Sherstyukov, 1996), makes ±7,1 days, which is very close to our results (Table 2) and serves as the indication of their reliability.

Let's also note that the feasibility of the inequality $S_{к}>S_{и}$ (Table 2) indicates that the climatological forecasts, yielding to the accuracy of methodical ones ($\delta_{к} > \delta_{м}$) are much more accurate than inertial ones ($\delta_{к} > \delta_{и}$) at the same time.

The number of tests undertaken for methodical forecasts (n = 14) is not yet quite sufficient. In order to determine the stability of the received quality estimates, additional tests are expected.

4 CONCLUSIONS

1. It was shown that the main source of highly reliable, close, negative relation is the stability of MDAT stable spring transitions through 8 °C (in comparison with the stability of autumn transitions). Thus, the early autumn transitions of MDAT through 8 ° C are accompanied (as a rule) by the increase of a HP duration, and vice versa.
2. The consideration of the dates of the autumn stable transitions as the only predictor in the linear regression model, allows to reproduce 64% of the total variance on the average (the fullness of the behavior variety) concerning a HP duration (ζ), which predetermined the results of the performed experiment. At that it was found that the absolute error of forecasts ζ makes Δm = ± 8.4 days for six stations, which is no more than 4.4% of a HP average duration in the south and 3.3% in the northeast of the Volga Federal District.

5 SUMMARY

According to the results of the work, the methodological forecasts of a HP duration are much more accurate than formal forecasts, and the level of their reliability for the central latitudinal band and the southern part of the Volga Federal District allows their use for practical purposes.

6 ACKNOWLEDGEMENTS

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

This work was supported by the research grant of Kazan Federal University.

References

1. Bagrov, N. A., Kondratovich, K. V., Ped, D. A., & Ugryumov, A. I. (1985). Long-term meteorological forecasts. - L., Gidrometeoizdat,- 248 p.

2. Batyreva, O. V., & Vilfand, R. M. (1999). Forecast of the average monthly air temperature anomaly using the fields H500 and N500/1000. Proceedings of the Hydro meteorological Center of Russia. 380:73-89.

3. Vazhnova, N. A., & Vereshchagin, M. A. (2015). A long-term forecast of the thermal regime conditions on the territory of Volga Federal District, RAN news. Geography series. 3:85-93.

4. Vazhnova, N. A., & Vereshchagin, M. A. (2017). Long-range forecasting of the dates of the stable 8° C crossing in average daily air temperature in the Volga Federal District. *Russian Meteorology and Hydrology*, *42*(1), 38-45.

5. Vazhnova, N. A. (2016). Climate characteristics of heating period for Volga Federal District. *Research Journal of Pharmaceutical, Biological and Chemical Sciences, 7*(5), 1298-1303.

6. Vasiliev, A. A., & Frolov, A. V. (1999). Hydro meteorological center of Russia on the threshold of a new century. From the collection: 70 year anniversary of Hydro meteorological Center of Russia. - St. Petersburg., Gidrometeoizdat:3-16.

7. Wilfand, R. M., Tishchenko, V. A., & Khan, V. M. (2007). Statistical forecast of air temperature course in a month with the use of hydrodynamic model output data. Meteorology and hydrology. 3:5-13.

8. Gnevko, G. T. (1980). Statistical characteristics of the period with the air temperature below + 8 °C on the territory of ETS and Western Siberia. - Obninsk, VNIIGMI-MTSD. 100 p.

9. Isaeva, A. A., & Sherstyukov, B. G. (1996). Variations in the climate characteristics of the heating season and the evaluation of their potential for very-long-term forecasting (taking Moscow as an example). *Vestn. Mosk. Univ. Ser. 5. Geografiya*, (2), 68-75.

10. Kobysheva, N. V. (Ed.). (2001). The climate of Russia. Petersburg, Gidrometeoizdat. - 654 p.

11. Kryzhov, V. N. (2012). Downscaling of the global seasonal forecasts of hydrometcenter of Russia for North Eurasia. *Russian Meteorology and Hydrology*, *37*(5), 291-297.

12. Perevedentsev, Yu. P., Vereshchagin, M. A., Shantalinsky, K. M., & Naumov, E. P. (2000). Dynamics of the heating season climatic characteristics in Kazan for the last 100 years. Bulletin of the Tatar branch of Russian Ecological Academy. 1:24-28.

13. Panovsky, G. A, & Brier, G. V. (1972). Statistical methods in meteorology. - L., Gidrometeoizdat, - 209 p.

14. Khan, V. M., Vilfand, R. M., Sadokov, V. P., & Tishchenko, V. A. (2009). Weather forecasts for a month: state and prospects. From the collection: 80 year anniversary of the Russian Hydro meteorological Center, St. Petersburg: 235 - 246.

15. Storm, R. (1970). Probability Theory. Mathematical Statistics. Statistical Quality Control [Russian translation].

16. Almasi, M. (2016). New method based on Image processing to enhanced the Accuracy and Precision Of table tennis player's performance. *UCT Journal of Research in Science, Engineering and Technology, 4*(3), 1-3.

17. Silva, J., Teixeira, C., & Pinto, J. S. (2016). Banking desmaterialization using cloud computing. *Journal of Information Systems Engineering & Management, 1*(2), 123-140. https://doi.org/10.20897/lectito.201618

18. Özer, G. (2018). Autonomic Dysfunction in Epileptic Patients. *Journal of Clinical and Experimental Investigations*, *9*(2), 76-80.

19. Shishvan, H. H., & Ebrahimnejad, H. (2018). A study on the ability of panoramic, CT, Cone-beam CT, MRI and ultrasonography in detecting different foreign-bodies in the maxillofacial region (an in-vitro study). *European Journal of General Medicine, 15*(3).