The current climatic trends and meteorological conditions of the fire dangerous situation formation in the Ural-Caspian region

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Abstract. Weather-climatic conditions are one of the leading factors forming fire dangerous situations in the arid and semi-arid regions. Intra-continental position of the Ural-Caspian area promotes to reveal the diversity of climatic conditions and estimate the current trends in terms of the latitudinal-zonal change of landscapes and an increase of gradient of continentality. Results of analysis of the principal weather-climatic conditions – temperature, air precipitation, hydrothermal terms, wind regime, insolation) are summarized in the paper. Also, we identified spatio-temporal peculiarities of their long-time and current dynamics. The received results were analyzed in the aspect of the formation of fire dangerous situations in different landscapes of the examined region. Long-term archives on heat anomalies FIRMS served as principal data on grass fires. We have detected and confirmed that the most significant trends of the regional climate change are: a) growing air temperature occurring everywhere in frost-free seasons of a year; b) the cyclic dynamics of precipitation with the modern trend to aridization; c) annual distribution of rainfall; d) intensification of anomaly of principal climatic parameters with the display of contrasting waves of heat and cold. All these tendencies directly (fire dangerous weather situations) or indirectly (productivity and a state of the vegetation cover) form the dynamics of grass fires. Nevertheless, the role of separate meteorological indicators and weather-climatic conditions, on the whole, are not often statistically significant in wildfires' development. It is conditioned by the more substantial role of an anthropogenic factor that, in its turn, combines stochastic and purposeful agricultural sources of fires' emergence.

1. Introduction

Wildfires are typical for practically every region of the Earth. In the steppe and semi-desert regions, fire emergence and spreading represent complex (multi-factors) and unpredictable phenomena. It was ascertained before [1, 2, 3, 4] that a pyrological state of steppe landscapes used, as a rule, as agricultural areas – pastures and hayfields, is the most significant factor in fires' development. A degree of demand and the actual removal of vegetation products mainly specify conditions to the emergence of an initial fire and stable flame propagation.

Meanwhile, weather-climatic conditions have a significant meaning in steppe fires' development [1]. Latitudinal-zonal and regional peculiarities of climatic conditions mainly define the heterogeneity of the vegetation cover and steppe landscapes. Simultaneously, the weather conditions in different years are extremely changeable in the concrete areas. The totality of weather and climatic conditions as the pyrogenic factor becomes apparent in two aspects – as spontaneous (the formation of a...
favorable or limiting fire dangerous situation, the frequency of fires depends on the geographical position), or mediately through the structure, productivity, and state of vegetation communities ("fuel" to support burning).

It should be noted that the significance of the weather-climatic factor in fires' development is difficult enough to be estimated. It is often conditioned that the emergence of separate inflammation is a chance circumstance or, contrary, it is caused by purposeful activity (agricultural arsons). Due to it, a closeness of correlated relations between described parameters (fires and conditions of their emergence and spreading) depends on the significant number of preconditions of an environmental and anthropogenic character, including factors of "uncertainty" and "fortuity." Nevertheless, long-term increased temperature, a lack of considerable precipitation, and high wind speed are favorable factors to fires to be originated and spread.

Numerous studies in different areas showed that global and regional climate has considerably changed for the last decades [5, 6, 7, 8, 9, 10, 11]. Also, geodynamic processes [12, 13, 14] connected with climate change and nature management problems in the study region [15, 16] have transformed themselves. We can expect the weather climatic conditions to intensify their role in the fire dangerous situations formation and fire regimes in separate geographical regions to be changed.

The study's task is to detect current trends of the principal climatic indicators in the long-term dynamics to estimate the weather-climatic factor's role in forming and realizing fire danger situations. The study was conducted in the vast territory (marked later as the Ural-Caspian region) enveloping mainly plain landscapes of Trans-Volga, the Cis-Urals region, Trans-Ural, the Caspian sea region, the Aral sea region, Turgay, and low-land forest-steppe landscapes of South Ural. The area's coverage was promoted to estimate spatial heterogeneity in climatic conditions and fire development, mainly caused by the latitudinal change of hydrothermal terms (from forest-steppe to middle deserts) with the growth of a gradient of continentality from west to east.

2. Materials and Methods
Research of the weather-climatic conditions of fire development was conducted in three directions: a) identification of long-term dynamics of a change of principal meteorological parameters (temperature, precipitation, insolation, hydrothermal conditions of the humidification); b) detection of trends in changes of temperature and precipitation anomaly for the long-term period; c) an analysis of a level of realization of fire dangerous situation based on specialized indexes using correcting coefficients, an assessment of the reliability of received data taking into account pyrologic peculiarities in the steppe zone.

Data on 23 meteorological stations (figure 1) having a different duration of the monitoring was used in the study [17]. Data on monthly average temperature (mainly for 1936-2018 – the united period for the most meteorological stations) and the sum of precipitation (1977-2018) was analyzed as principal parameters. Information on their spatial position in the aspect of the landscape-pyrologic differentiation of the area was systematized. Based on these results, we drew a conclusion about the heterogeneity of the weather-climatic conditions and trends of long-term changes.

Tendencies in the dynamics of temperature and precipitation were estimated by calculating values of linear trends promoting to identify total orientation and size of these tendencies according to calendar seasons of a year. We have calculated indicators characterizing the variability of long-term course. A degree of anomaly of the long-term course was calculated based on Bagrov and Tokarev's indexes [19] used in Russia. One of the most frequently used indexes – G.T. Selyaninov's hydrothermal coefficient of humidification (HTC) was employed to understand the meteorological fire hazard of separated years and compare the given results with rows of data on steppe fires [20].

We have chosen a comprehensive fire hazard indicator (CFHI, or Nesterov's index) as the most suitable to reveal the role of the weather-climatic factor in fire development. This index's calculated data was correlated with rows of data on heat points FIRMS [21] in the frame of twenty-four hours of different years for 2005-2018. Based on Nesterov's index, we have computed fire hazard classes. A
degree of reliability (correspondence to the compared parameters) of several correcting coefficients used in Nesterov's index calculation was estimated [22, 23].

![Figure 1](image-url)

**Figure 1.** Location of meteorological stations on the scheme of landscape-pyrological zoning.

1 – borders of natural zones of; [18]; natural zones and subzones: 2 – forest, 3 – forest-steppe, 4 – northern steppe, 5 – middle steppe, 6 – southern steppe, 7 – northern deserts, 8 – middle deserts; areas of altitudinal zonation: 9 – a mountain-forest area of South Ural; 10 – places of meteorological stations location; lines: 11 – meridional profiles (latitudinal zonality), 12 – latitudinal profiles (a gradient of continentality); 13 – borders of sectors (I – the European-Black sea; II – the Trans-Volga-Caspian; III – the Ural-Turgay).

3. **Results and Discussion**

3.1. **Temperature**

Considering long-term rows of data and calculations of linear trends, we ascertained that within every meteorological station, a positive trend was seen in the dynamics of temperatures for 1936-2018, on average, in a diapason of 0.25-0.30°C per 10 years. The maximum growth of temperatures was noticed in winter and spring seasons of a year from forest-steppe to northern deserts; to the south (central and southern steppes), seasonal transformations became practically single-valued. From north to south, the visible growth of summer temperatures was noticed from 0.13 to 0.28°C/10 years, and the autumn values, on the whole, remained of the same type for all subzones.

According to the increase of continentality (from west to east within one subzone), we could not see visible even regularities.

It was ascertained that the most significant long-term transformations of the heat background were observed in the beginning and at the end of the fire hazard season (in April and October). Trends of temperature growth were less expressed in the spring and autumn months (May and September). Average temperatures of the summer months remained more constant and suffered fewer years-to-year
variations. It confirmed the prospect of lengthening the fire hazard period in different years, especially considering fire development risks in periods of agricultural works.

3.2. *Precipitation*
Considering the air precipitation, we noticed the visible annual transformation in humidification conditions: in the summer and autumn seasons of a year – precipitation decrease occurring everywhere, in the spring season – the same all-round, but more uniform (in space), growth of precipitation. The winter period was an exception; it experienced diverse trends, not having a geographical community. Precipitation showed more considerable long-term transformations than temperature values as in months and seasons of a year so different years. However, simultaneously, precipitation amount was characterized by higher variability, various directions on seasons of a year, and in the whole, the similar orientation in space. In the aspect of long-term trends, in the formation of the pyrological situation, precipitation decrease falling on most of the fire hazard period appeared remarkably.

3.3. *Solar radiation conditions*
An analysis of the insolation regime is a significant addition in estimating peculiarities of pyrological situation formation. Data on solar radiation serves as direct indicators of precipitation lacking, increased temperature regime, and aridity. Correspondingly, in the long-term aspect, solar radiation indicators reflect the dynamics of fire hazard conditions. Additional data on insolation can be used as a criterion to estimate reliability and opportunity for application of the initial information (heat points archives FIRMS, and satellite imagery).

The received results indirectly confirm a dominance of an anticyclone character of the summer's weather conditions and the trend to increase their significance in the long-time aspect. Simultaneously, we should repeat that the modern period (2011-the present time) of fire development, in conditions of some cardinal transformations in agriculture of the steppe regions, is characterized by the increased impact of the weather-climatic factors. Climate anomaly forecasted before and registered for the last eight years forms (and, likely, will form in the future) a similar course in the dynamics of fires.

3.4. *The wind regime*
The significance of wind power, as a rule, attends as one of the indicators in foreign rating systems of fire hazards (USA, Canada, Australia, and others) [24, 25, 26, 27, 28]. However, we could not express the wind regime's role in the formation of fire danger situations and fire spreading. Thus, the introduction of correcting coefficients to calculate Nesterov's fire danger indexes on the wind speed did not lead to considerable changes in the ratio of Nesterov's index and fires' areas (some heat points).

Wind as a fire development factor is the most significant for arid steppes and sparsely populated interfluvial areas where natural and anthropogenic borders practically limit fire development. In such conditions, fires, as a rule, spread during several days enveloping large areas. It promotes calculating an approximate dependence of the speed of fire spreading on wind power by analyzing a series of daily satellite imagery. Thus, considering the fires' series, we calculated that in the average speed of wind 2.0-2.5 m/sec, the fire spreading rate reached about 0.5 m/sec; in the moderate wind 5.0-7.0 m/sec, fire spreading had a rate of about 0.9 m/sec. In agricultural regions, fires usually spread no more than twenty-four hours. In the condition of reclamation and fragmentation of the steppe lands, fire spread is limited by environmental and anthropogenic borders; people put out a fire in the case of its threat to populated areas. Therefore a factor of the wind regime has a secondary character.

3.5. *Hydrothermal coefficient of humidification*
One of the most frequently used indexes – G.T. Selayninov's Hydrothermal Coefficient (HTC) was introduced to understand a degree of meteorological fire hazard for different years and compare it with rows of data on steppe fires [20]. The long-run annual average (on rows of data for 1947-2015) promotes the estimate of natural zones and landscape provinces (table 1).
Table 1. The long-run annual averages of HTC.

| Meteorological station | Zone and subzone | Average | Coefficient of variation |
|-------------------------|------------------|---------|--------------------------|
| I. Latitudinal row (within the same natural area) | | | |
| *Southern steppes* | | | |
| Elista | 0.53 | 0.34 |
| Elton | 0.39 | 0.53 |
| Uil | 0.30 | 0.52 |
| Turgay | 0.29 | 1.20 |
| II. Meridional row (in the sectors of natural areas) | | | |
| *Trans-Ural and the Aral sea region* | | | |
| Troitsk | forest-steppe | 0.79 | 0.35 |
| Kostanay | northern steppe | 0.63 | 0.33 |
| Bredy | northern steppe | 0.67 | 0.44 |
| Adamovka | middle steppe | 0.56 | 0.42 |
| Turgay | southern steppe | 0.26 | 0.50 |
| Aralsk | northern desert | 0.15 | 0.64 |
| *The Cis-Urals u Caspian sea regions* | | | |
| Sterlitamak | forest-steppe | 0.94 | 0.34 |
| Orenburg | northern steppe | 0.55 | 0.45 |
| Aktobe | middle steppe | 0.43 | 0.47 |
| Uil | southern steppe | 0.30 | 0.52 |
| Atyrau | northern desert | 0.21 | 0.46 |
| III. Azonal | | | |
| Zilair | mountain-forest | 0.91 | 0.41 |

Based on the received data, we can notice HTC values to vary according to the growth of a gradient of continentality that confirms interzonal heterogeneity on hydrothermal conditions. For a space of more than 1.5 thousand km between extreme meteorological stations (Elista-Turgay), HTC’s average values reduce 1.8 times, and the variability of values increases. Such degree of differences cannot help reflecting in a state of the vegetation cover and (in combination with the hydrothermal conditions) on a degree of fire hazard.

In the latitudinal-zonal rows in the Cis-Urals and Trans-Ural regions, HTC values show an appropriate, and on the whole comparable with one another, decrease from forest-steppe to northern deserts in combination with the variability increase. The only exception of row values from Atyrau station located nearby the Black sea, heat- and weather forming functional significance of which decrease the high variability of HTC values typical for the desert zone. Azonal stations (Zilair) show the maximum values, but, simultaneously, there is a visible trend to reducing long-term values.

Thus, the hydrothermal coefficient, in the full degree, reflects a general picture of spatial differentiation of the thermal regime and humidification conditions caused by heterogeneity connected with a change of latitudinal-zonal conditions and continentality growth. Hydrothermal conditions have a dual impact on the formation of a pyrological situation. On the one hand, they participate in the construction of background vegetation cover (including define peculiarities of the structure of communities, productivity, and a degree of the cover). On the other hand, they specify weather conditions.

### 3.6. Anomaly of the principal climatic indicators

The growth of weather anomalies is one of the trends of climate change noticed and forecasted for the future [5]. Following it, to reveal regional tendencies, we calculated indicators of anomaly from 8 meteorological stations. These stations are located, mainly, in the subzone of the northern steppe...
(except Uralsk and Aktobe stations in the arid steppe subzone). They represent meteorological conditions in Trans-Volga, South Ural, and Trans-Ural. The period of 1961-1990 was taken as the primary period accepted in climatology. Values of standard indicators reflecting a degree of climate anomaly was identified (Bagrov and Tokarev's indexes, average normalized indexes, and others) for 1940-2015.

The following tendencies were revealed in temperature indicators. Bagrov's index (a mean-square value of normalized anomaly) does not show brightly expressed trends in changing temperature parameters as for different years, so for the fire danger period (April-October). In its turn, Tokarev's index, taking into account a value of the abnormity's sign, reflects the constant and increasing growth of values for the examined period within all stations. The long-term distribution of average normalized parameters shows similar dynamics.

According to precipitation, there was no definite dependence for a long-time period (on Bagrov's index). The course of annual abnormality indicators is relatively homogeneous; a series of maximums was noticed in the 1950s. Separate months (May-June) show decreased abnormality, and July is characterized by the most considerable amplitude of this indicator variation.

Summarizing results belonging to linear trends and abnormality of climatic indicators, we should note that the study of the weather-climatic conditions for fire development should be considered in two aspects. The first aspect (the most evident) demands to be considered as a factor of the weather conditions' opportuneness to fire development for twenty-four hours or the long-time period. Revealed regional climatic characteristics (temperature, precipitation, solar radiation) confirm the ongoing formation of the conditions favorable to wildfires development in the steppe regions. This fact cannot be ignored in estimating and forecasting fire hazards. According to separate parameters (temperature, solar radiation), we notice an all-round increase of indicators with active growth for the last decades. It should be mentioned that the fire danger situation is limited by the precipitation number, spatial and long-term trends of which are implicit.

The second aspect (mainly debatable and insufficiently developed) is the weather-climatic trends as a factor defining long-term changes of the vegetation cover structure (including productivity) under the influence of external factors. Despite evidence that ecosystems' biotic components are considerably transformed under the impact of external factors, it is impossible to single out the climatic factor on the background of an anthropogenic influences' increase, including a lack of long rows of observations for a biota state.

3.7. The analysis of fire dangerous situation's realization based on the specialized Nesterov's index

Fire dangerous situations and their realization as fires have formed too unevenly and depended on the weather conditions for a year. The fire danger index was correlated with rows of data on heat point's amounts in the frame of twenty-four hours for different years for 2005-2018. The selection was made in the subzone of the northern steppe proceeding from the meteorological station's central position – a source of the weather data (Orenburg). Received rows of data were analyzed by detecting the closeness of relations between them and were visualized by adjoint diagrams.

The necessary conclusions of the fire danger index approbation are in the following. Most years are characterized by an evident discrepancy between the weather conditions and fire development in the spring period (approximately from 1 April to 15 May) that can be explained by the influence of external factors uncharacteristic for the other seasons of a year. Thus, indirect data proved by us has confirmed results of field studies, in the course of which all-round practice of agricultural burnings realized to the extent of snow melting, formation of the weather conditions sufficient for access to lands and a start of farming works.

The weather conditions of different years are incredibly uneven in the fire dangerous situation's formation, except for an appropriate increase of temperature in the summer.

Correlation of the fire danger index's values and several heat points do not reveal a close relation – the coefficient's weight was 0.2, on average, for 2005-2017; it varied from 0.5-0.6 to negative parameters. Leveling of peaks of heat point's amount values by the moving square method intensifies
dependence insignificantly. We revealed periods of the most significant and constant spring anomalies to detect the discrepancy of the number of flame formations to the weather conditions (1 April - 15 May).

Fire hazard indicators (including foreign rating systems) were primarily developed for forest areas connected with it; their calculation included different variations of correcting coefficients reflecting humidity of the surface cover and forest litter. In Nesterov's fire danger index, such coefficients are absent; nevertheless, resetting the index values to zero in precipitation more than 3 mm is, in our opinion, reasonable for reforesting territories. Special features of grassy landscapes are the rapid infiltration of air moisture and its evaporation. Therefore the vegetation cover (as "fuel" for fires) restores pyrological properties after rainfalls for a short period. As opposed to forest areas, we should consider a vegetative state of the cover accumulating stocks of dry plant mass to the middle of summer. These factors define a necessity to correct (to develop and explain) the steppe conditions' methodology.

The opportunity to receive a general picture of fire dangerous situation formation for different years (despite a necessity to adapt methods of complex fire danger class' calculation to the steppe conditions) was one of the consequences of the twenty-four hours' analysis of the weather conditions for fire development (figure 2). The transition of complex fire danger index into fire hazard classes (rate setting of values) promotes to receive methodologically proved data on fire dangerous terms duration and correlate them with actual (or interpreted) information on the burnt areas.

![Figure 2](image)

**Figure 2.** Distribution of number of days (%) on fire hazard class for fire danger period (April-November).

Thus, based on the analysis of the complex fire danger index, we got an idea and concluded about:

a) heterogeneity of the weather conditions and fire dangerous situation for different years taking into account the duration of the period (2005-2017);

b) a week degree of correlation of scales of fire development with fire hazard classes;

c) a necessity to correct the fire danger index for the steppe regions;

d) an anthropogenic (agricultural) source of flame development in the spring.

Exposed discrepancies between a level of the fire danger situation and its realization as fires were caused (except objective reasons of a stochastic character) by insufficient universality and objectiveness of the used formula to calculate the complex fire danger index [22, 23, 29, 30]. As an experience of proceeding studies shows, correcting coefficients offered by the authors (intended,
mainly, for forest areas) are not suitable for special conditions of air humidification and evaporation in steppe landscapes.

4. Conclusion
The weather conditions are though essential, but not the only factor of fire development and spread. The long-term dynamics of fires are defined as general regional conditions (mainly, a state of the vegetation cover), so the weather conditions characterize extremely diverse fire situations in different years. We can suppose that the following dynamics of steppe fire development and spreading will stay at the current high level and, on the whole, will be limited by the weather conditions in different years. In humid and cold years (separate periods or a series of years), plants' active vegetation will accumulate a considerable volume of dry phytomass that later will entail a vast fire spreading.

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