Space and time regularities and development factors of grass fires in the Volga-Urals region

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Abstract: The author generalizes the results of the studies devoted to obtaining reliable information on the long-term dynamics of grass fires in Volga-Urals region and analyzing the data to identify space and time regularities of their development. The results indicate a widespread and considerable extension of an area of fire propagation and frequency starting from the middle of the 1990th - the beginning of the 2000th. The primary precondition for activation of fires in steppe regions is a sharp reduction of agricultural production accompanied by a decrease in pasture load and formation of fallow lands. The modern stage of fire development is characterized by the increased impact of the weather and climate factor. The primary reasons for steppe fires is an ongoing practice of agricultural uncontrolled fires and careless handling of fire. The fire impact brings steppe ecosystems in the condition of long-term stress and has a negative nature as a whole. The conducted studies allowed obtaining actual data on the dynamics of grass fires, revealing seasonal distinctions and peculiar features of development in different natural zones, as well as evaluating the factors of their occurrence and spread. The results indicate a necessity of optimizing the steppe management of natural resources.

1. Introduction
During the past decade, there is a growing interest to the problematics of wildfires in different regions worldwide, especially taking into account great public response in case of material damage and extensive development of fires in forest regions. The research results on certain geographic areas of Northern Eurasia [1-6] indicate a tendency of wildfires activation. Due to a practically complete lack of official updated and statistical data on propagation of grass fires, the primary objective of the studies was to obtain reliable information on their long-term dynamics, which further enabled to reveal space and time regularities, evaluate the determining factors and consequences of fires development.

2. Materials and methods
The initial data for the studies were the materials of the Earth’s remote probing: images of Landsat, Terra and Aqua (MODIS) satellite series, which were the basis for generation of long-term databases on fires propagation to some important areas of the Volga-Urals region through different methods (visual interpretation, application of standard and specific spectral conversions) (figure 1). The region selection was grounded by a pronounced manifestation of horizontal zonality of landscapes, conditioning the formation of different land-use systems. The survey level of studies was ensured by analyzing the MODIS scene, occupying an area of 221.4 thous. km² and covering the landscapes of Trans-Volga regions, the Southern Urals, the piedmont of the western Urals and Trans-Urals, and
Northern Caspian region (hereinafter referred to as the Volga-Urals region). The initial data for the specified scene were the results of satellite image interpretation for specific years (2005, 2010 and 2017) and archive on thermal anomalies FIRMS (The Fire Information for Resource Management System) (2001-2018).

![Figure 1. Research region and location of important areas. 1 – key areas of Landsat images interpretation (1 – Talovskiy, 2 – Preduralskiy, 3 – Burtinskiy, 4 – Aituarskiy, 5 – Ashisayskiy); 2 and 3 – borders and indexes of natural zones and areas ([7], with supplements). Taiga zone (A): A-1 – subzone of sub-boreal forest (coniferous-broad-leaved), Broad-leaved forests (B): B-1 – subzone of broad-leaved forests, B-2 – subzone of forest-steppes. Steppe zone (C): C-1 – subzone of northern steppes, C-2 – subzone of medium (dry) steppes, C-3 – subzone of southern (desertified) steppes. Desert zone (D): D-1 – subzone of northern deserts, D-2 – subzone of medium deserts. Area of altitudinal zonation of mountains of the Southern Urals (U).]
A low frequency of Landsat satellite images is offset by greater duration (from early 1980th), which makes them irreplaceable for studying the long-term dynamics of fires. Based on visual interpretation of Landsat images, the databases for five key areas were generated, representatively reflecting the landscape and natural and economic non-uniformity of the depressed agricultural zone along the Russian-Kazakhstan border (figure 1). The key areas are located approximately on one altitude; the central position is occupied by the Orenburgskiy reserve areas with the same names, which enabled to identify the typical problems of steppe nature reserves associated with both introduction of reserve status and arrangement of fire prevention measures. For these territories with a total area of 5098 km², the greatest possible time series was obtained, describing a long-term dynamic of fires, which enables to chronologize the intensity of fires development as well as reveal and evaluate the impact of certain factors. Landsat images were also used to reveal unused croplands, representing fallow lands of different age. The data of thermal channel allowed evaluating thermal peculiarities of burnt places, features and duration of recovery of different steppe ecosystems, considering verification of results by monitoring instrumental surveys.

The analysis of interpreted data on FIRMS thermal anomalies for 2001-2017, taking into account their correlation with results of visual interpretation of MODIS and Landsat images, allowed evaluating the possibility of using (reliability and details) for further studies. Thus, the databases obtained allowed revealing the primary space (latitude-zonal and regional) and time (long-term and seasonal) regularities of fire development for a vast territory.

An essential element of conducted studies was a field expeditionary survey in the central part of the studied region, which obtained a comprehensive idea of the forest fire condition of the land cover was obtained as well as identified zones and core areas of sustainable and depressed agricultural production.

3. Results and discussion
The research results indicate that fires are characteristic but far not homogeneous (in time and space) phenomenon. At the same time, in general, there is a pronounced positive trend in the long-term dynamics of burnt areas in the studied region (figure 2). The data obtained prove the assumptions and some information on local territories about the tendency for activation of fire phenomena, which was generally observed from the late 1990th up to 2010 inclusive. The modern stage of fire development (from 2011 until present) in conditions of any essential conversion in agriculture of steppe regions is characterized by the increased impact of the weather and climate factors. The climate anomaly predicted before [8] and observed for the past eight years determines (and will probably determine further) a similar course in fires dynamics.

![Figure 2. Long-term dynamics of fires. Y1 – total area of burnt places (km²) for five key areas; Y2 – number (thou ea.) of thermal areas in Volga-Urals region.](image)
We observed a correlation between the number of livestock (sheep, goats and cattle in terms of municipal regions) and the area of fires in agriculturally developed area of the studied territories. In the dynamics of fire areas, there is a short cyclic frequency (3-4 years), which is due to the average duration of phytomass accumulation, sufficient for sustainable development of fires. In this regard, we considered the values of fire areas through the selection of years with maximum values as well as through the moving average method for three years. In both cases, there is the reverse correlation with rather high-reliability values: in the selection of maximum values 0.82 and 0.83 (separately for the number of cattle, sheep and goats), whereas by the values of moving average – 0.67 and 0.77, respectively. Thus, we have revealed that the pasture load is the most important factor for the development of steppe fires, especially during the periods of considerable changes in the number of livestock number.

To evaluate the possibility of applying the FIRMS data archive, we compared thermal anomalies (in terms of number and area) with generalized long-term data (figure 2) as well as with the actual areas of burnt places for territories with different dimensions. In the first case, conspicuous is a rather high level of similarity of these heterogeneous (actual and indirect) parameters for a total period of 2001-2017; the correlation ratio is 0.64. It implies that with all shortages of using FIRMS data, when analyzing the development of grass fires, this approach is one of the relatively labor-saving methods for obtaining information about space and time features of fires development, and it can be used pertaining to vast geographic regions. We may state that the studied territory, though rather inhomogeneous in terms of geographical and climate conditions, experiences similar tendencies in fires dynamics.

Statistical data prove the reduction of agricultural production in 1980-1990 in Russia and other countries of the former USSR, which caused practically widespread under-use of the land and plant resources. The analysis of the official statistical data on grazing livestock and dynamics of cropped lands (table 1) has proved a considerable dependence of steppe fires activation from the generally observed accumulation of the over-ground phytomass on pastures and hay-fields. Based on the analysis of a series of Landsat images, we have obtained the actual data on the formation of fallow lands on key areas.

**Table 1.** Change in the primary indicators of agricultural production.

| Region                            | Livestock dynamics, thous. units | Dynamics of cropped lands, thous. ha |
|-----------------------------------|----------------------------------|--------------------------------------|
|                                   | Cattle  | Sheep and goats | 1970  | 2014 | 1970  | 2014 | 1970  | 2014 |
| Russian Federation                | 51602   | 19264.3         | 66964 | 24711.2 | 121912 | 79319 |
| Orenburg Region                   | 1638.1  | 623.4           | 2302  | 319.7 | 5854.4 | 4196.3 |
| Samara Region                     | 915.6   | 243.5           | 1197.1 | 154.4 | 2930.3 | 2016.7 |
| Chelyabinsk Region                | 1174.2  | 298.3           | 1018.9 | 160.84 | 2823.4 | 1835 |
| Bashkortostan Region              | 2047.8  | 1220.2          | 3111.3 | 834.6 | 4320.6 | 3060.6 |
| Republic of Kazakhstan            | 7285.2  | 6032.7          | 31776.6 | 17914.6 | 30969.9 | 21023 |
| Aktobe Region                     | 426.2   | 378.5           | 2689  | 1007.3 | 1947.6 | 501.4 |
| Western Kazakhstan Region         | 510.9   | 456.2           | 2807.4 | 1075.4 | 1895.5 | 488.2 |
| Kostanay Region                   | 938.1   | 415.5           | 644.8 | 401 | 5026.5 | 5088 |

The indirect indicators have revealed that primary reasons for steppe fires occurrence are a conscious and commonly uncontrolled arson for agricultural purposes as well as careless handling of an open fire. In case of insufficient or irregular use of agricultural lands, the common practice of natural resources management has become a purposeful grass fire to improve the feeding quality of pastures, facilitate field’s treatment and destroy the excess of prepared plants.

Based on the prepared databases, we have also revealed the seasonal parameters of wildfires, which are reflected in the peculiar features of their occurrence and propagation as well as determine the severity of environmental consequences. The patterns of seasonal development of wildfires in the
Volga-Urals region were based on the data on some thermal sites per day; they are presented below (figure 3) in the average and absolute maximum values for the entire available period (2001-2018). The inter-annual variability was calculated per month.

Figure 3. Average long-term (2001-2017) and absolute maximum values of the number of thermal anomalies per day.

The March fires mostly propagate in azonal conditions, in the estuary and floodplain of the Volga River, and to a less extent – in the estuary of the Urals River. Active development of fires also continues here in April but, at the same time becomes widespread in other areas of the region, primarily due to agricultural burns of grass. Having excluded the data on the floodplain and estuaries of the Volga River from the calculation, we obtain a smooth growth of the number and total area of zonal grass fires up to the end of September, which is violated by a prominent (at the level of August and September) April peak in the number of flame development upon the completion of agricultural activities. In terms of area parameters, these two different season peaks are incomparable since the April one is characterized by narrow local (small area) flame developments. It should be taken into account that the time (season) of the fire has different consequences for both certain biological components and steppe ecosystems as a whole.

Fires are a limiting factor for the development of such significant elements of grass ecosystems as steppe bushes and hardy-shrub areas due to their high environmental significance, on the one hand, and duration of their post-fire recovery, on the other. Using time series of high spatial resolution images on open access (Google Earth service) for some key territories has revealed that despite the constant impact of pyrogenous factor, the forest-covered area commonly remains practically unchanged, which indicates high recovery capacity within the occupied ecotopes. The fires had the most considerable impact (depression, demise) on ravine forests and separate trees. The field studies have shown that fires limit the propagation of hardy-shrub elements of steppe ecosystems, which in some places are observed in conditions of decreased or ceased agricultural load on pastures and hayfields.

One of the negative environmental consequences of fire activation is the growing frequency and area of their impact. The data on key areas indicate that the average repetition of fires in herb-grass steppes is once in every four-five years. According to the conclusions on the duration of recovery processes of steppe plant communities after fires evaluated in a period from four to eight-ten years [9], the steppe vegetation (and consequently other components of ecosystems) is in a constant condition of
post-fire succession. At the same time, the post-fire recovery of the steppe ecosystem components takes place in specific ecotope conditions of burnt places characterized by a) increased temperature and essential daily variations in warm seasons; b) lack or smaller thickness of snow cover, and consequently, increased soil freezing in cold seasons; and c) worse moisture conditions in spring.

The role of steppe fires for the development of steppe ecosystems, despite having negative nature, is generally quite ambiguous. Their extensive propagation is in many respects due to the lack of hoofed animals in modern steppe ecosystems (as primary consumers of the over-ground phytomass) and functionally substitutes them in such conditions, contributing to the salinity of the over-ground phytomass and limiting the potential extension of tree and shrub vegetation elements.

4. Conclusion
The analysis of space parameters of fires propagation in the Volga-Urals region indicates their close interrelation with a natural and zonal differentiation of the region. The conditions for the generation of a fire-hazardous situation are the essential characteristics of natural zones, such as temperature mode and moisture conditions, as well as the resulting structure and productivity of the plant cover. Latitudinal-zonal change of natural conditions and their internal zonal inhomogeneity in many respects precondition the peculiar features of settlements and agricultural specialization, which is also an important factor for the formation of the modern forest fire situation. The sharp reduction of the agricultural production in Russia and Kazakhstan caused the formation of a stock of non-demanded lands, active recovery of vegetation cover, accumulation of dead grass and bedding. In addition to this, since the late 1990s, there is a clear tendency for growing occurrence frequency and areas of steppe fires propagation in poorly developed areas of the Volga-Urals region that have an important value for maintaining sustainable environmental development of steppe regions.

The conducted studies allowed obtaining actual data on the development of grass fires for a long-term period, which enables to evaluate the scales of the problem and use them in adjacent environmental studies. The obtained results can become one of the substantiations for the need to optimize the environmental policy in the sphere of steppe natural resources management and formation of the fire-preventive unit in the environmental monitoring, which the global experience of fires management confirms [10].

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