Agricultural Science & Technology, 2011, 12(9): 1396 -1400

Study on the Relationship among Forest Fire, Temperature and Precipitation and Its Spatial-temporal Variability in China

LU Ai-feng*

Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101

Abstract **[Objective]** The aim was to discuss the relationship between forest fire and meterological elements (precipitation and temprature) in each region of China. **[Method]** Firstly, the average precipitation and temperature in forest area of each province in fire season were obtained based on meterological data, forest distribution data, seasonal and monthly data of forest fire in China. Secondly, the relationship among forest fire area, precipitation and temperature was discussed through temporal and correlation analysis. **[Result]** The changes of precipitation and temperature with time could reflect the annual variation of fire area well. Forest fire area went up with the decrease of precipitation and increase of temprature, and visa versa. Meanwhile, there existed diffirences in the relationship in various regions over time. Correlation analyses revealed that there was positive correlation between forest fire area and temperature, especailly Northwest China ($R = 0.367$, $P < 0.01$), Southwest China ($R = 0.327$, $P < 0.05$), South China ($R = 0.33$, $P < 0.05$), East China ($R = 0.516$, $P < 0.01$) and Xinjiang ($R = 0.447$, $P < 0.05$) with obviously positive correlation. At the same time, the correlation between forest fire area and precipitation was significantly positive in Northwest China ($R = 0.482$, $P < 0.01$), while it was significantly negaive in South China ($R = -0.323$, $P = 0.03$), but there was no significant correlation in other regions. **[Conclusion]** Relationships between forest fire and meteorological elements (precipitation and temprature) revealed in the study would be useful for fire provention and early warning in China.
Key words Forest fire; Precipitation; Temperature; Spatial-temporal variability

Weather is one of important parts of fire environment composed of weather, topography and fuel [1]. Meteorologists and forest scientists suggested that some meteorological elements had great effects on the occurrence of fire [2]. Under specific conditions, weather has greater impact on fire compared with topography and fuel, so it is dominant in fire environment [1]. Many studies showed that there was good correlation between meteorological elements and forest fire [3-4]. The changes of meteorological elements with time can explain the seasonal and annual variation of fire frequency and area well [5]. It is easy to obtain meteorological data, so meteorological data has been mainly used to assess fire danger, which could provide references for the rapid establishment of decision by government departments [1]. As the complex ecological process affected by weather, topography and fuel, fire has great spatial-temporal variability. Fire and its relationship with weather will vary with space and time. Therefore, studying the relationship between meteorological elements and fire in various regions has important guiding meaning for fire prevention and early-warming in regional forest. As global warming, the frequency and intensity of forest fire will go up [6], and analyzing the relationship between meteorological elements and fire can help draw up the countermeasures to respond to climate change in future.

China is one of countries with serious forest fire in the world. From 1950 to 2000, the total frequency of forest fire in China reached 693 966 times, and the total area of forest fire was up to 3 864.00 hm^2, with annual frequency of 13 607 times. The frequency of forest fire per 0.1 million hm^2 forest was ten times, and the area of forest fire every year was 0.757 6 million hm^2 which accounted for about 0.6% of total area of forest, so the average area of each fire was 55.70 hm^2 [7-8]. As a main natural disaster in forest, fire can not only destroy forest ecosystem, but also bring great loss to people's lives and property. Thus, studying the relationship among forest fire, temperature and precipitation plus its spatial-temporal variability have a great significence to the prevention and mitigation of forest fire in China. At present, there are many relevant studies in different regions of China [9-12], but it is deficient in the relationship between meteorological elements and forest fire on the national scale.

In the paper, the relationship among forest fire, temperature and precipitation in various regions would be discussed by using spacial interpolation and geographic information system (GIS) technology. Firstly, data of meteorological elements (temperature and precipitation) in forest area in each province of China from 1980 to 2000 were obtained by means of space technology; afterwards, China was divided into eight regions according to fire season and regional characteristics in various provinces, and the temporal distribution of temperature and precipitation in each region was analyzed, then the corelation among fire area, precipitation and temperature and its regional difference were discussed through time series analysis; finally, the main conclusions and outlook for future study were expounded.

Material and Methods

Fire data

Data of forest fire, including the frequency and area of forest fire in each province of China from 1980 to 2000, were from *China's Forest Yearbook* [7] and *Forest Information Compilation* [8]. Data from 1980 to 2000 were analyzed, and it was because that the observation and statistics of forest fire from

Received: April 29, 2011 Accepted: August 22, 2011
Supported by National Natural Science Foundation of China (40801216/D011002).
* Corresponding author. E-mail: lvaf@163.com

1980 to 2000 were stable, and data had good continuity, so that the extreme value caused by human statistics could be eliminated mostly, and data series were more consistent with actual situation.

Meteorological data

Meteorological data [13] mainly contained daily maximum temperature, daily minimum temperature and daily precipitation. Daily meteorological data were collected from 476 stations, then the distribution of meteorological elements on the surface was obtained through spatial interpolation. Spatial interpolation adopted the improved interpolation model by Thornton *et al.* [14], which could use data from many stations to conduct space interpolation for daily meteorological parameters, and simplified treatment was carried out due to a small number and uneven distribution of meteorological stations plus complex and diverse climate in China [13].

Data processing

The distribution of forest is closely related to climatic characteristics, so there are great differences in climatic characteristics between forest area and other areas with vegetation. Meanwhile, the exact location of each fire couldn't be obtained, so it was supposed that fire would happen in any region of forest. Data of meteorological elements used in the analysis on the relationship between meteorological elements and fire were the average values of meteorological elements in forest area of each province. Firstly, taking the distribution map of forest as mask, then the distribution of meteorological elements in forest area was acquired from nationwide meteorological raster data by using the grid processing module of GIS software Arc/Info. Data of forest distribution were from a land use map (1:100 000) developed by Liu Jiyuan *et al* [15]. Afterwards, the average values of meteorological elements in certain period in forest area of each province were obtained by the command module Zonalmean of Arc/Info Grid.

In order to reflect the annual variation of meteorological elements and their relationship with fire variation better, data of meteorological elements and fire in each province from 1980 to 2000 were nomalized. That is to say, the original values minus the multi-year average of data series was divided by the standard deviation (SD), and its formula is as follows:

$$E_{i,\,normal(t)} = [E_i(t) - \overline{E_i}] / E_{i,\,SD} \quad (1)$$

$$E_{i,\,SD} = \left\{ \frac{\sum_{t=1}^{T} [E_i(t) - \overline{E_i}]^2}{T} \right\}^{\frac{1}{2}} \quad (2)$$

Where $\overline{E_i}$ is multi-year average; $E_{i,\,SD}$ is standard deviation.

Results and Analyses

Spatial distribution zone of forest fire season and regional features of weather in China

Forest fire happens all the year round in China. For Northeast China, it occured frequently in spring and autumn; in South China, it mainly appeared in winter and spring; Xinjiang often suffered fire in sumer. In spring, forest fire moved from south to north, while it moved from north to south in autumn [16].

Referring to the division of main large regions in China, the distribution of fire month in Xinjiang was obviously different from that of other provinces in Northwest China. Fire happened from April to October in Xinjiang, but fire season in other provinces of Northwest China was from January to April, plus November and December. In addition, there was great difference between Inner Mongolia and other provinces in North China. That is to say, fire season was February, March, June, October and November in Inner Mongolia, while it was from January to March and from November to December in North China. In other distribution zone, the distribution of fire season was consistent basically among various provinces in the same region. These differences mainly appeared in fire prevention period with lower fire prevention strength. Therefore, the summary of fire season in large area had little effect on each province. Thus, in order to reflect the correlation between meteorological elements (temperature and precipitation) and fire elements (fire frequency and area) in fire season better, Inner Mongolia and Xinjiang were as two single regions, so China was divided into eight regions (Fig. 1). The distribution of fire season in each region could be found in Table 1.

Fig. 1 Spatial distribution zone of forest fire season in China

In addition, the multi-year average precipitation and temperature of forest areas in each province of China from 1980 to 2000 were analyzed in the paper. As shown in Fig. 2, the characteristics of meteorological elements were similar in various provinces in the same region. Compared with monthly average precipitation and temperature in each region from 1980 to 2000, fire in most regions (such as Northwest China, Southwest China, South China, East China, North China and Northeast China) occurred in the months with less rainfall. Fire in Inner Mongolia happened in spring and autumn with less rainfall plus June with more rainfall. It is because that lightning activity is frequent in June, and it is easy to cause lightning fire [17]. In Xinjiang, fire appeared frequently in summer with higher temperature. It can clearly be seen that temperature played important roles in the distribution of forest fire within a year in Xinjiang.

Relationship between meteorological elements (temperature and precipitation) and area of forest fire and its spatial-temporal variability

In order to further discuss the relationship between meteorological elements and annual variation of forest fire in each region, the annual variation of normalized meteorological data and fire data from 1980 to 2000 were analyed. The changes of relationship among normalized average precipitation, temperature and fire area with time in each region could be found in Fig. 3. Besides, temperature and precipitation data were the monthly average values of temperatureand accumulated values of precipitation respectively in fire season. The results showed that fire area increased with the decrease of precipitation in most years, such as 1980, 1986, 1987 and 1995 in Northwest China, 1980, 1981, 1984 and 1986 in Southwest China, 1983, 1984, 1986 and 1987 in South China, 1980, 1983, 1986 and 1987 in East China, 1982 in North China, 1980, 1982 and 1985 in Xinjiang, and 1982 in Inner Mongolia. Meanwhile, fire area went down with the increase of precipitation, such as 1983, 1989 – 1991, 1993, 1994, 1997 and 1998 in Northwest China, 1989, 1990, 1992, 1994, 1997, 1999 and 2000 in Southwest China, 1989, 1990, 1991, 1993 and 1997 in South China, 1981, 1985, 1989 – 1991, 1997 and 1998 in East China, 1990, 1993 and 1998 in North China, 1980, 1986, 1989, 1990, 1994, 1995 and 1999 in Northeast China, 1981, 1984, 1987, 1988, 1992, 1993, 1996, 1998 and 1999 in Xinjiang, and 1984, 1989 – 1991, 1994, 1996 and 1998 in Inner Mongolia. In addition, fire area increased as the increase of temperature accompanying precipitation reduction in some years, such as 1980 and 1987 in Northwest China, 1984 in Southwest China, 1987 in South China, 1982 in North China, 1980 in Xinjiang and 1982 in Inner Mongolia. Accordingly, when precipitation went up and temperature went down in some years, fire area reduced, such as 1983, 1989 and 1997 in Northwest China, 1989, 1992 and 1997 in Southwest China, 1989, 1992, 1993 and 1997 in South China, 1981, 1985 and 1989 in East China, 1980, 1986 and 1999 in North China, 1981, 1984, 1987, 1988, 1992, 1993 and 1996 in Xinjiang, and 1984 and 1996 in Inner Mongolia.

Table 1 Monthly distribution of forest fire season in various regions

Region	January	February	March	April	May	June	July	August	September	October	November	December
Northeast China	–	–	+	+	+	–	–	–	+	+	–	–
Inner Mongolia	–	+	+	–	–	+	–	–	–	+	+	–
North China	+	+	+	–	–	–	–	–	–	–	+	+
Northwest China	+	+	+	+	–	–	–	–	–	–	+	+
Xinjiang	–	–	–	+	+	+	+	+	+	+	–	–
Southwest China	+	+	+	+	–	–	–	–	–	–	+	+
South China	+	+	–	–	–	–	–	–	–	–	+	+
East China	+	+	+	–	–	–	–	–	–	–	+	+

" + " and " – " refer to fire season and non-fire season, respectively.

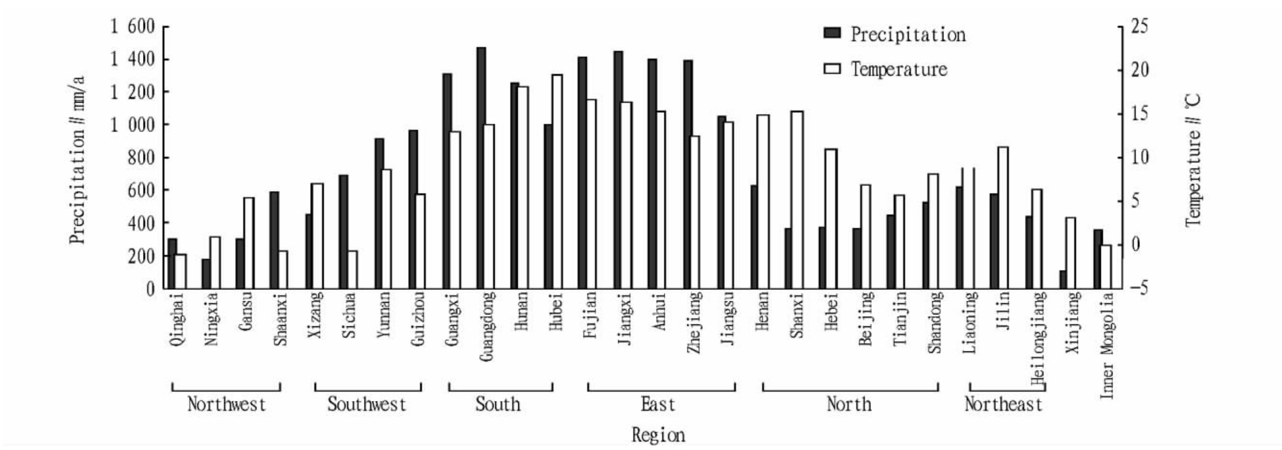
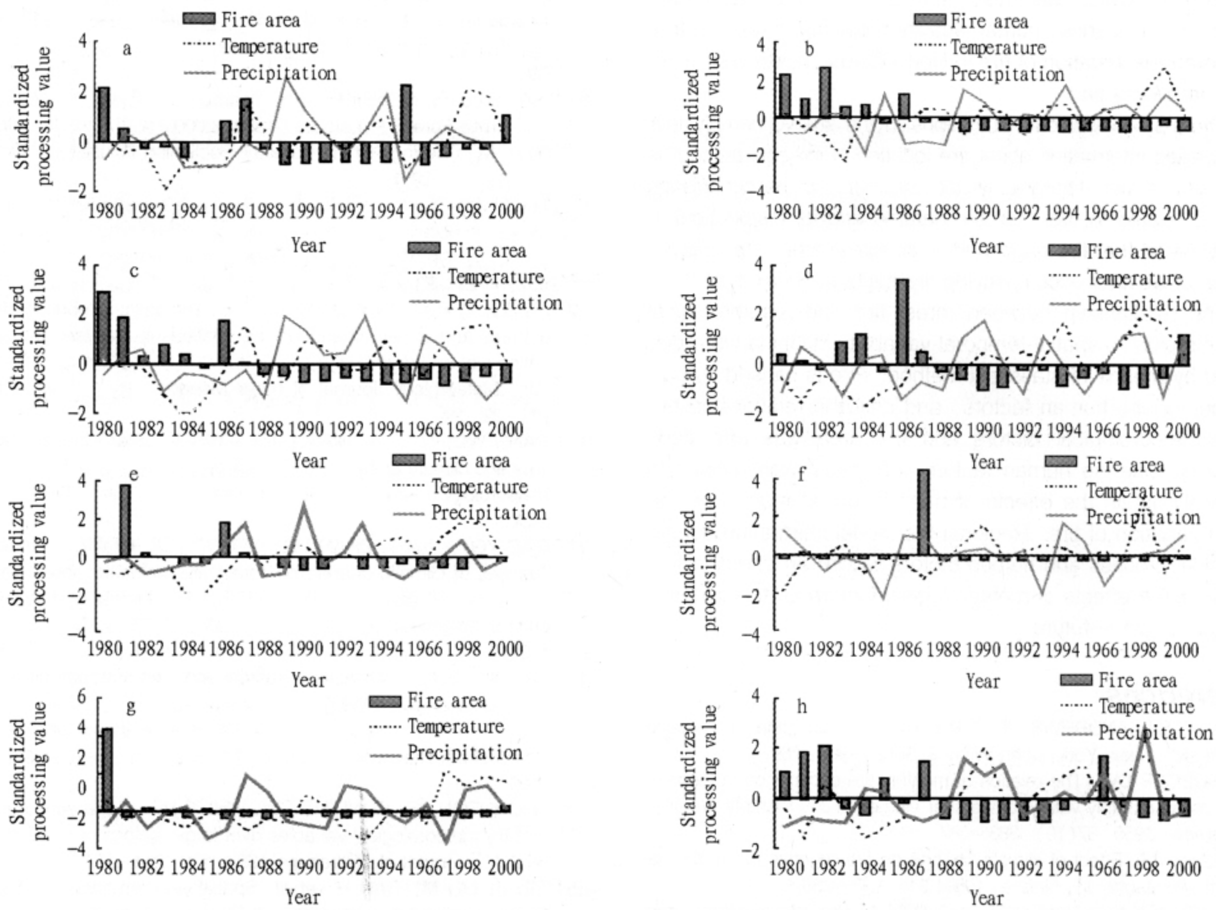


Fig. 2 Multi-year average precipitation and temperature in forest area in each province

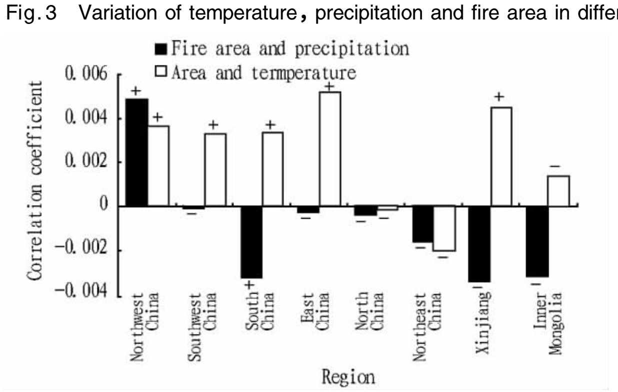
For the sake of studying the quantitative relationship of annual variation among temperature, precipitation and fire area better, the correlation of average temperature, precipitation and fire area in forest area of various regions was analyzed. Fig. 4 revealed that the area of forest fire had good positive correlation with temperature in most regions, such as Northwest China ($R = 0.367$, $P = 0.01$), Southwest China ($R = 0.327$, $P = 0.02$), South China ($R = 0.33$, $P = 0.02$), East China ($R = 0.516$, $P < 0.01$) and Xinjiang ($R = 0.447$, $P = 0.042$) with significantly positive correlation. There was obviously positive correlation ($R = 0.482$, $P < 0.01$) between precipitation and fire area in Northwest China, while negative correlation ($R = -0.323$, $P = 0.03$) could be found in South China, and there was no significant correlation in other regions.

The results above showed that the meteorological elements related to fire area and correlation coefficient were different in various regions. However, there was positive correlation between precipitation and fire area in Northwest China. It is generally assumed that it is easy to cause large area of fire under less rainfall and dry combustible material. However, fire area was positively correlated to temperature and precipitation in Northwest China. At the same time, there was obviously positive correlation between temperature and precipitation ($R = 0.634$, $P < 0.01$). As shown in Fig. 2, multi-year average precipitation was less in fire season in Northwest China. Therefore, in fire season in Northwest China, precipitation wen up as the increase of temperature. However, due to less rainfall in Northwest region, the changes of fuel moisture caused by rainfall (which could reduce the frequency of fire in principle) were weakened obviously by the increase of surface evaporation resulting from temperature increase (which can increase the frequency of fire), so there was positive correlation between precipitation (or temperature) and fire area in Northwest China. Based on the results above, it was suggested that temperature had more obvious effects on the annual variation of fire area compared with precipitation in Northwest China.



a: Northwest China; b: Southwest China; c: South China; d: East China; e: North China; f: Northeast China; g: Xinjiang; h: Inner Mongolia.

Fig.3 Variation of temperature, precipitation and fire area in different regions during 1980 - 2000



" + " and " - " mean significant correlation and insignificant correlation respectively.

Fig.4 The correlation among forest area, average precipitation and temperature during fire season in each region

In a word, the changes of precipitation and temperature can reflect the annual variation of fire area well. Precipitation variation can affect water content in combustible material, and further influence the combustibility of material. Thus, there was good synchronous relationship between the variation of precipitation and fire area. Meanwhile, the variation of temperature can affect the evaporation of water in fuel and surface temperature of fuel, and further influence the combustibility and burning point of fuel. Temperature reduction with the increase of precipitation and temperature increase with the decrease of temperature also have good synchronous relationship with the variation of fire area. Meanwhile, the results also revealed that there was certain difference in the synchronous relationship in various regions over time. This synchronous relationship was consistent with the results of fire season, monthly average temperature and precipitation in each province of China. In Xinjiang, there was good synchronous relationship between fire area and temperature in most years. However, there was good conformity between fire area and precipitation in other regions.

In addition, there was no obvious correlation among fire area, temperature and precipitation in North China, Northeast China and Inner Mongolia. From Fig.3e, Fig.3f and Fig.3h, fire area in the three regions varied slightly after 1987, and it was often negative. It was because that the measures of fire prevention was strengthened nationwide after the large forest fire in Heilongjiang in 1987. Therefore, human factors are crucial to the formation of regional fire in the three regions.

Conclusions and Discussions

Based on the data of temperature and precipitation in forest area of each province in China from 1980 to 2000, the spatial-temporal variability and correlation of temperature, precipitation and fire area were analyzed in the paper. The results showed that the variation of temperature and precipitation in fire season could reflect the annual variation of fire area well, but the relationship was different in various regions. From correlation analysis, there was obvious correlation between temperature and fire area in most regions, while there was certain correlation between precipitation and fire area in a few regions. Besides, with the constant enhancement of human disturbance, human activity replacing natural factors dominated the situation of fire in North China, Northeast China and Inner Mongolia.

There still exist some limitations in the study, namely lacking detailed information about fire location. Fire environment is composed of fuel, topography and weather, so the occurrence of fire is related to fuel, terrain features and its distribution. It was assumed that fire happened in all forest area, the characteristics of weather accompanying fire might be weakened.

The relationship between forest fire and meteorological elements plus its spatial-temporal variability in China were discussed by means of statistical method. Fire is caused by natural factors and human factors, and only the relationship between meteorological factors and fire area was analyzed, without considering human factors, so that it was difficult to accurately obtain the effects of meteorological factors on the annual variation of fire. Regional fire model integrating natural ecological process and human factors will be an effective tool to assess the effects of meteorological factors on the dynamic variation of fire in future.

References

[1] PYNE SJ, ANDREWS PL, LAVEN RD. Introduction to Wildland Fire [M]. New York: John Wiley & Sons, 1996: 769.

[2] KRUEGER DW. The relation of monthly fire occurrence in Georgia to mean monthly values of weather elements [J]. Monthly Weather Review, 1959, 87(10): 383-387.

[3] CLARK JS. Effect of climate change on fire regimes in northwestern Minnesota [J], Nature, 1988, 344: 233-235.

[4] WHITLOCK C, SHAFER SL, MARION J. The role of climate and vegetation change in shaping past and future fire regimes in the northwestern US and the implications for ecosystem management [J], Forest Ecology and Management, 2003, 178: 5-21.

[5] LIU YQ. Variability of wildland fire emissions across the continuous United States [J], Atmospheric Environment, 2004, 38: 3489-3499.

[6] LV AF(吕爱锋), TIAN HQ(田汉勤). Interaction among climatic change, fire disturbance and ecosystem productivity(气候变化、火干扰与生态系统生产力) [J]. Journal of Plant Ecology: Chinese Version(植物生态学报), 2007, 31(2): 242-251.

[7] State Forestry Administration, P. R. China(国家林业局). Forestry compilation: 1949-1987(林业资料汇编: 1949-1987) [M]. Beijing: China Forestry Publishing House(北京: 中国林业出版社), 1989.

[8] Editorial board of China Forestry Yearbook(中国林业年鉴编辑委员会). China Forestry Yearbook: 1988-2000(中国林业年鉴: 1988-2000) [M]. Beijing: China Forestry Publishing House(北京: 中国林业出版社), 2001.

[9] ZHAO FJ(赵凤君), SHU LF(舒立福). Climate anomaly and its influence on occurring forest fire under global warming(气候异常对森林火灾发生的影响研究) [J]. Forest Fire Prevention(林火研究), 2007, 1: 21-23.

[10] FU ZQ(傅泽强), WANG XH(王晓华). Dynamic distribution of forest fires and climate change in the relationship between the alternating wet and dry(森林火灾分布动态与气候干湿交替变化的关系) [J]. Meteorology Journal of Inner Mongol(内蒙古气象), 1998(4): 22-24.

[11] PANG WC(庞万才), WANG JZ(王桂芝). Inner Mongolia forest fires and climate analysis(内蒙古森林火灾及其气候条件分析) [J]. Meteorology Journal of Inner Mongolia(内蒙古气象), 1994(3): 22-32.

[12] GAO YG(高永刚), ZHANG GY(张广英), GU H(顾红), *et al*. Influences of climatic change on forest fire in Yichun forest region(气候变化对伊春林区森林火灾的影响) [J]. Journal of Anhui Agricultural Sciences(安徽农业科学), 2008, 36(28): 12269-12271, 12274.

[13] LIU ML(刘明亮). Chinese terrestrial ecosystem carbon cycle and land use change on the gas response(中国陆地生态系统碳循环对气和土地利用变化的响应) [C] // Chinese Academy of Sciences Postdoctoral Research Report(中国科学院博士后研究工作报告), 2003.

[14] THORNTON PE, RUNNING SW, WHITE MA. Generating surface of daily meteorological variables over large regions of complex terrain [J]. Journal of Hydrology, 1997, 190: 214-251.

[15] LIU J, LIU M, TIAN H, *et al*. Spatial and temporal patterns of China's cropland during 1990-2000: An analysis based on Landsat TM data [J]. Remote Sensing of Environment, 2005, 98: 442-456.

[16] YAO SR(姚树人), WEN DY(文定元). Forest Fire Management(森林消防管理学) [M]. Beijing: China Forestry Publishing House(北京: 中国林业出版社), 2002.

[17] Daxinganling Forestry Administration(内蒙古大兴安岭林业管理局). Blog of Daxinganling Forestry Administration(内蒙古大兴安岭林业管理局志) [M]. Hulunbeier: Inner Mongolia Culture Press(呼伦贝尔: 内蒙古文化出版社), 2000.

Responsible editor: YANG Ying-ying Responsible proofreader: WU Xiao-yan

我国森林火灾与气温、降水的关系及其时空差异研究(摘要)

吕爱锋* (中国科学院地理科学与资源研究所,北京 100101)

[目的] 从区域的角度来探讨森林火灾与气温和降水的关系。

[方法] 首先通过耦合站点气象数据、我国森林分布数据以及我国森林火灾季节月份分布数据,获得了气温和降水在每个省森林区域火灾季节时间段内的平均值。然后,通过时间序列分析、相关性分析等方法探讨降水、气温与森林火灾面积的关系。

[结果] 降水和气温的变化能够较好地反映火灾面积的年际变化。降水减少的同时温度升高以及降水升高的同时温度降低与火灾面积的增、减存在的较好的同步关系,且在不同地区、不同时间这种伴随关系有差异。对不同地区森林区域平均气温、降水与火灾面积的相关性分析发现,大多数地区森林火灾面积与气温具有较好的正相关关系,例如西北地区($R=0.367, P=0.01$)、西南地区($R=0.327, P=0.02$)、华南地区($R=0.330, P=0.02$)、华东地区($R=0.516, P<0.01$)、新疆地区($R=0.447, P=0.042$)都表现出显著的正相关关系;而降水与火灾面积除了在西北地区存在正相关关系($R=0.482, P<0.01$)、在华南地区存在负相关($R=-0.323, P=0.03$)之外,在其他地区不存在显著相关关系。

[结论] 揭示我国森林火灾与气温、降水关系对于开展森林防火以及火灾预警都具有重要意义。

关键词 森林火灾; 气温; 降水; 时空差异

基金项目 国家自然科学基金项目(40801216/D011002)。

作者简介 吕爱锋(1977-),男,山东莱芜人,助理研究员,博士,从事水土资源与灾害相关研究,E-mail: lvaf@163.com。* 通讯作者。

收稿日期 2011-04-29 **修回日期** 2011-08-22