Analysis of the Fickle Fires in Global Regions

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Abstract. Forest fires occur in a wide range with distinctive fire elements, including fire size, expansion, speed and duration. To investigate when and where fire occurs in recent years and how the four factors differ in various regions, we here to analyse the chronological and terrestrial distribution of these fires, seeing the tendency to change four main fire elements. We focus on fourteen regions, including BONA (Boreal North America), TENA (Temperate North America), CEAM (Central America), NHSA (Northern Hemisphere South America), SHSA (Southern Hemisphere South America), EURO (Europe), MIDE (Middle East), NHAF (Northern Hemisphere Africa), SHAF (Southern Hemisphere Africa), CEAS (Central Asia), SEAS (Southeast Asia), EQAS (Equatorial Asia), AUST (Australia and New Zealand), BOAS (Boreal Asia. We finally conclude that the high level of precipitation, decrease in vegetation coverage and human intervention account for the decreasing fires in NHAF, SHAF, CEAS, NHSA. We also confirm that the increasing fires in BONA, TENA and MIDE are because of the rising temperature globally or more specifically, in these areas.

1. Introduction

Over 400 million years ago, vascular plants rose on land. From then on, fires have occurred naturally [1], dividing different regions to different biomes and affecting climate through of the carbon cycle and emissions of greenhouse gases and aerosols [2]. The fires in Indonesia, Malaysia, and Papua New Guinea have caused wide attention among local people. The habitat losses combined with forest conversion, the tons of carbon burned, and due to the alternation of emissions from year to year, the inter-annual variability for atmospheric CO2 and CH4 have caused lots of problems. The total amount of carbon emissions from these fires during 1997–1998 El Nino were estimated at between 0.8 and 2.6 Pg C, equal to up to 40% of global fossil fuel emissions at that period. Though other estimates are not as much as this, they are still globally significant, and affect the regional air quality to a large extent [3]. The damage of wildfires to human is also not negligible. In western US forests, wildfires have a broader and broader effect in recent years, and the local land-management agencies are now spending exceed US$1 billion/year (1). Hundreds of homes are destroyed by severe wildfires, and the degradation of natural resources is very severe. Widespread public attention is drawn by the recent media reports of large wildfires burning in western forests [4]. Factors that drive forest fires become a popular area of research. Temperature change under changing climate is an important factor that needs to be considered. In western US forests, the incidence of large wildfires increased in the mid-1980s. Subsequently, wildfire frequency reached four times the average value from 1970 to 1986, and the total burning area was more than 6.5 times its previous level. The inter-annual variability in wildfire frequency is strongly related to regional spring and summer temperatures. From this case, we may see many more wildfires are burning in hotter years compared to colder years. Our study focuses on different global regions considering several fire elements, including fire size, spread and speed. We
analyse the time series of different fire elements from 2003 to 2016. We also create graphs for global change of fire size, spread and speed. In the following sections, I will discuss them in detail.

2. Methods
We use Global Atlas Data to gather data from different regions and analyse them. For example, in 2007, the largest fire in Australia reaches a size of 40025.69 km². The duration is 72 days with an expansion of 555.91 km²/day and speed of 18.76 km/day. From Global Fire Atlas Data, we gained the data from 2003-2016 in several regions. Then we use python to analyse the data we gained. Firstly, we mainly focus on the largest, longest and fastest fires in different continents. We use python to build up a global map and distribute all these fires in different regions. We colored these fires with different colors to see which year did this fire occur. From three different maps standing for largest, longest and fastest fires respectively, we can see the fire location and occurrence year. We also use linear regression to see the trend of different fire elements in various global regions. This time we cite all the fire data in Fire Atlas Data to analyse the trend in each region. We firstly obtain a form for all these data which shows the global values of fire size, spread, speed and duration. By combing all these fire elements, we then plot four graphs to show the data more clearly for each region. We also create a graph of seasonal cycle of fire size for each region. The graphs include lines of prediction with slope and correlation. The data we gathered covers 2003 to 2016 and graphs show clear trend. The graph of seasonal cycle shows which months have more fires and whether fires are decreasing in recent years. We also combine these data to plot graphs for global trend of these elements. The graphs for global better show the general change globally. This gives us chance to analyse the global change more easily.

3. Results and discussions

3.1. Distribution
Generally, all largest fires occur between 60°N and 60°S (Figure 1). Big fires rarely occur in high-latitude areas because of the cold weather. North America, South America and Australia are prone to have largest fires. There is no obvious decreasing tendency from past years to recent. In 2010-2012, we could see the largest fires. To be more specific, the highest concentration of largest fires is in the North and Middle Australia. In the Middle South America, largest fires occur frequently as well. It is interesting that the largest fires in Asia nearly occur in the same latitude of 50°N. The environmental condition in this latitude may be very suitable for fires to occur. For longest fires, generally, they always occur in North America, South America Europe and Australia (Figure 1). Compared to past years, there are less longest fires occurring in recent years. Most of fires still occur between 60°N and 60°S expect from the one in North America. Compared to largest fires, longest fires occur more concentratedly. Longest fires in Australia concentrate in North part while that in Europe, a high concentration is at Mediterranean region. The middle part of South America and the south part of Africa also have a high concentration of fires. There are two longest fires are recorded in Philippines but no largest fires and fastest fires occur there. Fastest fires have a wider range, covering almost every continent with a highly likely occurrence. No evidence shows the number of fastest fires decreases in recent years (Figure 1). All the fires are still between 60°N and 60°S. We can see a high concentration in Australia, Mediterranean region and North America. In Australia, the fires occur in northeast; In Mediterranean region, fires spread along the coast lines; and in North America, fires are in the middle and south part. We can hardly find two fastest fires occurring in the same region at the same time. This may be because the burning materials require time to replenish after a wild fire.
Figure 1. Distribution of 10 (a) largest fires, (b) longest fires and (c) fastest fires in each continent from 2003-2016

Figure 2. Fire trends in global regions: (a) global (b) Northern Hemisphere Africa (c) Southern Hemisphere Africa (d) Central Asia (e) Northern Hemisphere South America (f) Boreal North America (g) Temperate North America (h) Middle East
Fire size has peaks in 2004, 2007, 2011 and 2014 and troughs in the year between (Figure 2). It changes in a regular pattern with alternative peaks and troughs. The highest value is in 2011, which means 2011 has most regions suffering from fires. The global fire size pattern fails to indicate an increasing or decreasing trend. But it shows there is a peak and trough for fire size for about 3~4 years. The global pattern of the mean spread of fire follows the pattern of fire size. High values and low values occur nearly at the same time as that for fire size. Peaks are at 2004, 2007, 2011 and 2014 with intervals of 3 or 4 years. This corresponds to the strong correlation between fire size and expansion. The global trend of mean speed also has a similar pattern as the pattern for spread and size with little deviation. The time interval for the middle two peak values are little bit longer than the former two.
graphs. This corresponds to the positive relationship between speed and spread or size with a relatively weak correlation. Though the mean duration pattern also contains peaks, it is a little bit different from the three I’ve mentioned. It only has three peaks with one distinctly high. This may be related to the weak positive or even negative relationships between duration and the other three elements. The largest mean value for duration is in 2012, which is much higher than the values in other years. The global patterns for these four fire elements, namely fire size, spread, speed and duration, may show the global change in time series. Next, we conduct trend analysis for specific regions (Table 1).

3.3. Decreasing fires in NHAF, SHAF, CEAS, NHSA

From the results above, we see decreasing fires in NHAF, SHAF, CEAS, NHSA. The fire size decreases dramatically sharply in NHAF with a slope of -21350.9km2/year (Table 1) and negative correlation of -0.79 (Figure 2). This means the fire occurs in a more and more small scales in time series. So less regions in NHAF would suffer from forest fires. In 2005 and 2007, the same as the shape for fire size, there are two peaks. The fire speed has little changes with slope of 0km/day and correlation of -0.64. The peak is in 2007 and the trough is in 2015. The shape for duration is also interesting. The peaks and troughs occur alternatively with very large differences. The slope is -0.01days and correlation of -0.4. Generally, the fire size from 2003 to 2008 is higher than that from 2011-2016(Figure 3). The curve for 2003-2008 is always above the curve for 2011-2016 expect the overlap in June, July and August. The fire size in SHAF also decreases sharply with a slope of -25450.65km2/year and a negative correlation of -0.1(Figure 2). The highest peak occurs in 2008 with a value of 4.25*106. Some high values also occur during the period from 2010-2012. The fire speed has nearly no change with zero slope and correlation of -0.38. The values are high during 2010-2013. Fire duration decreases slowly with slope of -0.01days and correlation of -0.68. The lowest value is in 2014, which only has a duration of 4 days. It is obvious that the value of total fire size from 2003 to 2008 is much higher than that from 2011-2016(Figure 3). The main difference is from July to October though from October to December the fire size for 2011-2016 is a little bit higher. In CEAS, the fire size changes frequently and sharply between consecutive years with many peaks and troughs (Figure 2). It also decreases quickly with a slope of -18274.79km2/year and negative correlation of -0.61. The tendency shows less regions would suffer from forest fires. From 2003 to 2016, the fire size decreases from 40000km2 to 20000km2. The pattern for fire speed is similar to that for spread but has one more peak in 2006. It has nearly no change in time series with a slope of -0.0km/day and a correlation of -0.29. The duration is also in a decreasing tendency with a slope of -0.03days and a correlation of -0.75. The three peaks are at 2006, 2008 and 2013 with decreasing height. Generally, the fire size from 2003 to 2008 is higher than that from 2011-2016(Figure 3). But the high value for 2003-2008 occurs in June and that for 2011-2016 occurs in April and August with relatively lower value in June. The curves from January to March and from November to December nearly overlap. The fire size in NHSA keeps decreasing, with a slope of -263.2km2/year and correlation of -0.3(Figure 2). The two peaks are at 2004 and 2008. The strange point is that a trough of 10000 km2 is at 2011 when there are lots of largest fires. The speed of fire is largest in 2010. It has no change with a slope of 0.0km/day and correlation of 0.16. The duration of fire is extremely low in 2011. The duration is relatively high and falls in 2005 and 2011. It has a negative correlation of -0.1 and slope of -0.01days. The fire size from 2003-2008 is generally larger than that from 2011-2016 (Figure 3). Two curves are nearly the same from April to December. The largest difference could be seen in February.

The reasons for the reduction may not be the same for every region. There is an overall decline of fire rates, which is continuous in time series and related to the cropland expansion in northern sub-Saharan Africa. However, the high precipitation for years has caused an initial increase in fire rates in southern Africa, but it is reversed in the following years. The fire rates begin to decrease. This decline is due to a high occurrence of dry years leading to very low fuel loads, suggesting that drought happening in recent years causes burned areas to decrease [5]. Indeed, fires are strongly related to the interaction of climate, topography, local micro-environments as well as the alternation in land use. Human intervention may also cause large effect on fire regimes, while a severe debate is about the relative importance of weather versus fuels in controlling fire. The effects of fire on ecosystems and landscapes may be different from region to region, as a result of local fire history, regeneration
patterns and topographic constraints [6]. At the end of the wet season, terrestrial water storage becomes very significant in controlling fire activities during the following dry season. The finding is important for fire forecasts and drought management, as well as a better understanding of some potential changes in fire activity related to climate change. Previous studies have focused projections of dry season precipitation to estimate the possibilities of changes in Amazon fire activity. Nevertheless, fewer models in the IPCC Fourth Assessment Report showed a decreasing trend in wet season precipitation over the Amazon region, a key controlling factor on terrestrial water storage [7]. The reasons for decreasing fires in these regions may not only contain the ones above. In South America, precipitation indices, in spite of the large and expected spatial variability, indicate that though no dramatic rise in the total amount, rainfall events are intensifying and the contribution of wet days are expanding [8]. By making some assumptions related to vegetation coverage, we suppose vegetation may also be account for decreasing fire activities. Statistical analyses show that, in Asia, spring NDVI (Normalized Difference Vegetation Index) is significantly correlated with spring temperature. That is to say, temperature is the main factor for limiting spring vegetation growth in most regions of Inner Asia [9]. The vegetation coverage may also account for the decreasing fires in Africa. There is a 57% increase in agriculture area at the expense of natural vegetation which has decreased by 21% over the period, with nearly 5 million hectares forest and non-forest natural vegetation lost per year. This sharp decrease in natural vegetation is mainly because of the human activity. The local economies are mainly based on natural resources, including woods. The exploitation of resources causes a severe degradation of forests, increasing water shortages. This large change could be ascribed to the fact that rapid population requirement may not be able to be fulfilled by current natural resources. Population increase and economic growth could increase the utilization of fossil fuel energy, mostly in terms of firewood and charcoal which accounts for over 75% of final energy consumption in sub-Saharan nations. The conversion of natural vegetation to agriculture occurs due to the demand of more resources. As a result, it causes land degradation and erosion processes. It is estimated that about 25 percent of the land is subject to water erosion and 22 percent to wind erosion and desertification affects over 45 percent of the land area of which 55 percent at high to very high risk. The degradation of land and lack of burning materials largely decrease the fire occurrence in Africa. Based on the previous studies and self-research, we could conclude that the high precipitation, decrease in vegetation coverage and human intervention may be some reasons for the decreasing fires in these regions.

3.4. Increasing fires in BONA, TENA, MIDE under climate change
We also see some increasing tendency of fire size in BONA, TENA and MIDE. In BONA, the size of fires increases from 2004 to 2016 with a slope of 1145.42km2/year and correlation of 0.18(Figure 2). An extremely high value could be found in 2014. The total fire size from 2010 to 2016 is much greater than 2004 to 2010. It can also be shown by the seasonal cycle graph. The curve standing for 2011-2016 has a higher peak than that from 2003-2008. The speed is also in a decreasing trend with a correlation of -0.49km/day and slope of -0.01. The fastest fire occurs in 2007 with a speed of 1.235 km/day. The trend of fire duration is a steady line with a weak correlation of 0.02 and slope of 0days. Two maximum points are at 2008 and 2014. The fire size is the largest in June and gradually decreases when moving to January and December (Figure 3). The trend of size of fires in TENA keeps increasing from 2004 to 2016(Figure 2). It has a slope of 997.38km2/year and a correlation of 0.16. There are two peaks for 2006 and 2012. The peak in 2012 is distinctively high, which may correspond to one of the largest fires in 2012. The fire speed nearly has no change in time series. It has a slope of 0km/day and a weak correlation of 0.07. The two peaks also correspond to that for size and spread. The duration also changes a little. The slope is 0.01days and correlation is 0.15. The most interesting point for TENA is that all these four figures have peaks nearly at the same time though the relationship between some of these four elements may be very weak or even negative. The shape of size of fires from 2003-2008 and from 2011-2016 is quite similar (Figure 3). Except from October to March, the fire size for 2011-2016 is larger than that for 2003-2008. The fire size in MIDE changes much slowly with a slope of 55.89km2/year and correlation of 0.2 (Figure 2). High values of fire size are at 2007, 2010 and 2015. The highest peak is at 2015. The fire speed changes more frequently with alternative
peaks and troughs. Its trend has a slope of 0 km/day and correlation of -0.15. The duration decreases with a slope of -0.03 days and correlation of -0.55. High duration is in 2004, 2006 and 2013. The shapes of seasonal cycles for different time periods are quite similar with little deviation.

These increasing trends may strongly relate to the climatic change. The global temperature rose by 0.2 °C between the middle 1960's and 1980, yielding a warming of 0.4 °C in the past century. The temperature increase is strongly related to the greenhouse effect due to increased amount of atmospheric CO2. The change in volcanic aerosols and possibly solar luminosity may be the primary causes of observed fluctuations about the mean trend of rising temperature. Potential effects of this on climate in the 21st century is not only the creation of drought-prone regions in North America and also the shifting of climatic zones containing part of central Asia, erosion of the West Antarctic ice sheet followed by a rise in sea level, and opening of the fabled Northwest Passage. [10] From this we are able to see that the North America and Asia is largely affected by the increasing temperature, which may be the primary cause of increasing fires. The increase in temperature may be strongly related to human activities. Without dramatic decrease in emissions, the rise in annual average global temperature compared to preindustrial times could reach 9° F (5° C) or more by the end of this century. Though emission rates have slowed down because economic growth is becoming less carbon intensive, this slowing trend is not yet at a rate that would limit global average temperature change to 3.6° F (2° C) above preindustrial levels by century’s end. According to the statistical data, annual average temperature over the contiguous United States has increased by 1.8° F (1.0° C) over the period from 1901 to 2016; in next few decades (2021 – 2050), it is expected to rise by about 2.5° F for the United States, relative to the recent past (average from 1976 – 2005). It is reported that the higher are expected to increase the intensity and frequency of extreme events in global regions. These extreme events are particularly significant for human safety, infrastructure, agriculture, water quality and quantity, and natural ecosystems [11]. Climate scientists have identified that Middle East is one of the world’s worst affected climate change regions in the present time, even in future, with a large increase in summer temperatures from Syria to Yemen and everywhere in between, at a rate twice the global average. According to a 2018 study, the Middle East will experience extremely high temperatures of higher than 115 degrees five times more often by 2050 than they were at the beginning of current century. According to another newly published study in the journal Science Advances, the emergence of rising heat and rising humidity is making more and more risks [12]. The data and previous studies give us valid evidence to confirm that the increasing fires in these regions are related to the rising temperature globally, or to be more specific, in these areas.

Conclusion
We analyse the distributions and long-term trends of wildfires globally. Analysing the general trend of fire size, fire spread, fire speed and fire duration in global regions, we make some discussion about how these changes in fire elements occur based on the previous studies and on some data. Though the reasons we give for these changes seem reasonable, to make a more accurate explanation, we need to consider more factors like wind or something else, since these factors are also essential to determine how the fire would be or where the fire occurs. Plus, the research we do only includes the date from 2003-2016, the most recent data are not taken into consideration, so the current trend may differ. Future research will benefit from direct connection with meteorological and human factors to give a more accurate explanation of the drivers of long-term trends in fires.

4. References
[1] Scott, A. C., & Glasspool, I. J. (2006). The diversification of Paleozoic fire systems and fluctuations in atmospheric oxygen concentration. Proceedings of the National Academy of Sciences, 103(29), 10861-10865.
[2] Van Der Werf, G. R., Randerson, J. T., Giglio, L., Van Leeuwen, T. T., Chen, Y., Rogers, B. M., ..., & Yokelson, R. J. (2017). Global fire emissions estimates during 1997-2016. Earth System Science Data, 9(2), 697-720.
[3] Van der Werf, G. R., Dempewolf, J., Trigg, S. N., Randerson, J. T., Kasibhatla, P. S., Giglio, L., ... & Dolman, A. J. (2008). Climate regulation of fire emissions and deforestation in equatorial Asia. Proceedings of the National Academy of Sciences, 105(51), 20350-20355.

[4] Westerling, A. L., Hidalgo, H. G., Cayan, D. R., & Swetnam, T. W. (2006). Warming and earlier spring increase western US forest wildfire activity. Science, 313(5789), 940-943.

[5] Wei, F., Wang, S., Fu, B., Brandt, M., Pan, N., Wang, C., & Fensholt, R. (2020). Nonlinear dynamics of fires in Africa over recent decades controlled by precipitation. Global Change Biology.

[6] Turco, M., Bedia, J., Di Liberto, F., Fiorucci, P., Von Hardenberg, J., Koutsias, N., ... & Provenzale, A. (2016). Decreasing fires in mediterranean Europe. PLoS one, 11(3), e0150663.

[7] Chen, Y., Morton, D. C., Jin, Y., Collatz, G. J., Kasibhatla, P. S., van der Werf, G. R., ... & Randerson, J. T. (2013). Long-term trends and interannual variability of forest, savanna and agricultural fires in South America. Carbon Management, 4(6), 617-638.

[8] Aguilar, E., Peterson, T. C., Obando, P. R., Frutos, R., Retana, J. A., Solera, M., ... & Valle, V. E. (2005). Changes in precipitation and temperature extremes in Central America and northern South America, 1961 – 2003. Journal of Geophysical Research: Atmospheres, 110(D23).

[9] Mohammat, A., Wang, X., Xu, X., Peng, L., Yang, Y., Zhang, X., ... & Piao, S. (2013). Drought and spring cooling induced recent decrease in vegetation growth in Inner Asia. Agricultural and Forest Meteorology, 178, 21-30.

[10] Hansen, J., Johnson, D., Lacin, A., Lebedeff, S., Lee, P., Rind, D., & Russell, G. (1981). Climate impact of increasing atmospheric carbon dioxide. Science, 213(4511), 957-966.

[11] Wuebbles, D., Fahey, D. W., & Hibbard, K. A. (2018). How will climate change affect the United States in decades to come? Eos, 99(1), 18-23.

[12] Werleman, C. (2020), Record Temperatures in the Middle East Threaten Vulnerable Populations, accessed on November 13, 2020, from: https://insidearabia.com/record-temperatures-in-the-middle-east-threaten-vulnerable-populations/