Changes in duration of dry and wet spells associated with air temperatures in Russia

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Abstract

This study uses daily precipitation records from 517 Russian stations (1966–2010) to examine the relationships between continuous dry and wet day duration and surface air temperature for all four seasons. The study found that both mean and extreme durations of dry periods increase with air temperature at about 7.0% (0.24 day/°C) and 7.7% (0.86 day/°C) respectively, while those of wet periods decrease at about 1.3% (−0.02 day/°C) and 2.2% (−0.10 day/°C) respectively averaged over the entire study region during summer. An increase in the duration of dry periods with higher air temperature is also found in other seasons at locations with a mean seasonal air temperature of about −5 °C or higher. Opposite relationships of shorter durations of dry periods and longer wet periods associated with higher air temperature are observed over the northern part of the study region in winter. The changes in durations of both dry and wet periods have significant correlations with the changes in total dry and wet days but are about 2.5 times higher for dry periods and 0.5 times lower for wet periods. The study also found that locations with longer durations of dry periods experience faster rates of increase in air temperature, suggesting the likelihood of exacerbating drought severity in drier and/or warmer locations for all seasons.

1. Introduction

Changes in the frequency, intensity, extremity, and duration of dry and wet spells could affect our natural environment and society more than changes in total precipitation alone. The signals of changes in some of these characteristics appear to be stronger and easier to detect than the signals of total precipitation. For example, studies have found that precipitation has become less frequent (Ye 2008, Ye et al 2014, Ye et al 2016a), more intense (Ye et al 2015, 2016a) and with higher extremes (Lenderink and Maigaard 2008) over extratropical regions, including places in which annual total precipitation has not shown any significant change. Increases in precipitation intensity and extremes over northern Eurasia appear to be related to more frequent and stronger convective precipitation at the expense of non-convective precipitation (Ye et al 2016b, 2017). This implies that the duration of dry and wet spells may also be changing and thus the risk of flooding and drought as the climate continues to warm.

Although flooding is mostly related to the intensity of precipitation, the length of precipitation can also play a critical role. Drought can be exacerbated by a prolonged duration of consecutive dry days in any season. However, little research has attempted to examine possible changes in dry spell duration that might be accompanied by changing precipitation characteristics associated with a changing climate. Studies suggest that changes in wet day frequency may not be directly linked to the length of wet- and dry- day periods over European countries (Zolina et al 2010, 2013). Researchers (Chen and Zhai 2014) found that the duration of wet day spells of four days or longer decreased faster than total wet days in China, probably due to the re-grouping of wet days. It is necessary to examine consecutive wet and dry day duration separately to understand changes in their behavior that may or may not be associated with wet day frequency.
Studies that examine trends in the duration of wet and dry spells show complex geographical and seasonal patterns over different locations in Europe (Kuglitsch et al 2010, Schmidt and Frei 2005, Wiglb 2009, Zolina et al 2013). Studies over the United States show a decrease in long-duration storms (Brommer et al 2007), and increasing dry but decreasing wet day durations over the central United States (Groisman and Knight 2008, Groisman et al 2012). A general positive trend in dry day length during warm season but more negative trends during cool season are also found in the southwestern United States during 1951–2006 (McCabe et al 2010). Since the results of trend analysis are very specific to the time period and geographical region, it may be worthwhile to directly associate these parameters with those of surface air temperature to understand these relationships free from the restrictions of the available time period of the data set.

This study examines the relationship of dry and wet day duration with surface air temperature at interannual and longer time scales for all four seasons over Russia where relatively densely distributed stations with long historical records are available.

2. Data and methodology

The daily precipitation data are from the daily temperature and precipitation data for 518 Russian meteorological stations archived at the Carbon Dioxide Information Analysis Center (Bulygina and Razuvayev 2012, Ye et al 2016a). The original data were collected by Russian Hydromet and post-processing was done by the All-Russian Institute for Hydrometeorological Information. This data set has been quality controlled and adjusted for wetting, evaporation, and condensation due to instrumentation changes for the time period starting in 1966 (Groisman et al 1991, 2014). It includes daily precipitation (total accumulation for each calendar day), minimum, maximum, and mean daily air temperature. This study chooses the starting year of 1966 due to the consistency in rain gauge types, observation practices, and quality control methods for precipitation observation which began in that year (Groisman et al 1991). Since we are focused on the paired relationship between seasonal precipitation characteristics and air temperature rather than the trend, the number of missing seasons and the length of the time period is of less concern as long as there are enough data records to provide meaningful statistical significance. Thus, all available stations with varying record lengths ranging from 20–45 years are presented. There is one station that does not have any data record, thus a total of 517 stations are used for this study.

The duration of dry day periods is the total number of consecutive dry days (without any recorded precipitation) between the two nearest dates on which at least 0.1 mm of precipitation was recorded. The duration of wet day periods is the total number of consecutive wet days on which precipitation of 1 mm or higher was recorded. Since there is a significant number of days with less than 1 mm precipitation over the study region, especially during winter and summer, analyses are also performed using 0.1 mm as a threshold for wet day definition. Results are very similar using these two different threshold definitions for wet day duration. For easier comparison with studies in other regions that used 1 mm as the threshold to define wet days (e.g. Zolina et al 2010, 2013, Groisman and Knight 2008) and some concerns regarding the quality of precipitation records with less than 1 mm over high-latitude regions (Mekis and Vincent 2011), the rest of the paper only shows relationships using a daily accumulation of 1 mm or higher to define wet day periods.

A time series of the seasonal mean, extreme duration of dry and wet day periods, and mean air temperature is constructed for each season at each station. The extreme is defined as the longest duration of any single dry or wet period of each season at each station. If more than 10% of data records are missing (for either precipitation or air temperature) in any month, the season is considered missing. As a result, the available number of stations for a single season varies from 335–510 with the majority of years (1978–2009) having 475 or more stations during the study period. Pearson’s correlation analysis is used to examine the relationships between the duration of dry/wet periods and air temperature. In addition, simple linear regression analysis with duration of dry/wet periods as a dependent variable and air temperature as the independent variable is performed to estimate the rate of change for each degree of air temperature increase.

3. Results

3.1. Geographical distribution of climatological durations of dry and wet day periods

The climatological values for the mean duration of dry day periods range from 1.4–14.6 days during winter with the longest dry day periods along the southern edge of central Siberia and southeastern Russia (figure 1(a)). Shorter dry day periods are found in northern and central European Russia and eastern and central Siberia (2–3 days) during winter. For spring, dry day duration is slightly higher in most regions compared to that in winter, except for the southern edges of central Siberia and southeastern Siberia where the longest periods are below 12.7 days (figure 1(b)). During summer, the longest dry day periods shifted to the southern edge of European Russia between the Caspian Sea and Aral Sea where some stations record 8–10 days (figure 1(c)). The rest of the study region’s dry day periods range from 2–6 days. During fall, the longest of about 10 days is in the southern edge of central Siberia, and the rest of the region has a range of from 1.7–6 days (figure 1(d)).

The distribution of winter wet day duration shows large spatial variation and some localized highs and
lows. Higher values of 2–3 days occur around European Russia as well as the Kamchatka Peninsula in the east and lower values of 1.5–2 days over central and eastern Siberia (figure 2(a)). The general regional pattern resembles that of winter total precipitation. During spring and summer seasons, wet day duration is relatively small, ranging from 1.5–2.5 days with summer having even slightly shorter wet day duration at most stations. The fall season’s wet day duration distribution resembles that of winter though slightly longer over northeastern Siberia.

3.2. Correlations with air temperatures
There is a clear geographical pattern of correlation between duration of dry periods and air temperature in winter (figure 3(a)). A statistically significant negative correlation with a coefficient up to −0.8 is found in most of European and eastern Russia, and northern central and eastern Siberia (34% of stations are statistically significantly negatively correlated as shown in figures 3(a) and 4(a)). Significant positive correlations with coefficients up to 0.58 are found in the southern edges of central and eastern Siberia and a few stations between the Black Sea and Caspian Sea. Positive correlation stations seem to correspond to the longest dry duration areas in winter as shown in figure 1(a). The correlation between wet periods and temperature has a similar geographical pattern but with flipped signs, positive in European and western Siberia and northern central and eastern Siberia, and negative in southern regions (figure 3(b)). The geographical patterns of relationships between extreme duration dry/wet periods with air temperature are very similar to those of the mean duration and correlation coefficients are comparable among mean and extreme conditions (figure 4).

A much smaller number of stations with statistically significant correlations occur during spring and fall (15.7% for dry and 9.5% for wet day duration in spring and 17.8% for dry and 11.6% for wet day duration in fall). The dominant pattern for spring is a positive correlation between dry day duration and temperature in southern Siberia and the southern coast of Russia and negative correlation over northeastern peninsulas. The positive correlation stations correspond to similar geographical areas that show positive correlation stations in winter, but are more spread out and have more stations (figure 3(c)). Fall has a clearer split of opposite correlation between northern and southern study regions: positive correlation in southern and negative in northern regions for dry periods (figure 3(g)). The relationship of wet periods has a similar pattern but with opposite signs and fewer significant stations, with the exception of European Russia where negative correlation dominates (figure 3(h)). Similar geographical patterns are found in relationships between extreme dry/wet periods and air temperature.

During summer there is an overwhelming positive correlation between the mean duration of dry periods and air temperature (figure 3(e)) with 64.2% of stations statistically significant and no station with a significant negative correlation (figure 4). Correlation coefficients
Figure 2. Distribution of the seasonal mean duration of wet periods (in days).

Figure 3. Distribution of statistically significant correlation between seasonal air temperature and mean duration of dry/wet periods. Red: positive correlation; blue: negative correlation.
Figure 4. Correlation coefficients between the duration of dry/wet periods and surface air temperature plotted against the number of seasons available for all stations during winter and summer. Dashed lines are statistically significant at a 95% confidence level or higher given the sample size of number of seasons. A solid line separates positive from negative correlation coefficients.

at many stations reached 0.8 (figure 4(e). 48.9% of stations had a statistically significant positive correlation between the extreme duration of dry periods and summer temperature; none had a negative correlation. The relationship of summer temperature with mean and extreme duration of wet periods is dominantly negative with 23.1% and 19.3% stations statistically significant respectively (figures 3(f) and 4(h)).

Plotting the rate of change per each degree of air temperature increase against the corresponding stations’ air temperature (figure 5) shows that positive values become dominant at stations with a seasonal air temperature of about −5 °C or higher while negative values are dominant for locations below this threshold in spring and fall (figures 5(b) and (d)). In summer, it appears that the rate of duration for dry periods increases with stations’ summer mean air temperature exponentially at locations on the higher end of the air temperature spectrum (figure 5(c)). This suggests that hotter locations may experience faster increases in the duration of dry periods given the same amount of air temperature increase. If using the percentage rate of change per degree of temperature increase, the line still curves toward the higher end of temperatures, but a straighter upward line starting at a temperature of around 12 °C suggests a faster percentage rate of increase in the duration of dry days in relatively warm locations in summer (appendix figure 1).

The relationship of the percentage rate of change to corresponding air temperature is very similar to that of the rate of change in the other three seasons shown in figure 5.

The relationship for the duration of wet day periods (not shown) switches from slightly positive to slightly negative with a threshold temperature around −5 °C for winter and spring and around −2 °C for fall. There is no change in the decrease rate for the duration of summer wet day periods that is related to stations’ summer temperature. Similar conclusions are found for the plot of extreme dry/wet periods versus stations’ air temperatures.

To examine the hypothesis that the increase in the rate of dry period change for each degree of air temperature could be affected by locations with different climatologies of dry periods, the rates are plotted against the corresponding seasonal mean dry periods for each station (figure 6). This clearly shows that the rates of change for dry periods are more likely to be positive and higher at stations with higher climatology of the mean duration of dry periods for all seasons. If we only consider stations with a mean duration of dry periods equal to or longer than five days, we see higher rates of increase for all seasons. When the percentage rate of changes in duration of dry day periods is plotted against the corresponding seasonal mean value, the trend line is still statistically significant for all seasons.
Figure 5. The rate of seasonal duration of dry period change per each degree of air temperature increase plotted against corresponding station’s seasonal mean air temperature for all 517 stations. Solid lines are the averaged values for each 2 degree air temperature increment. Crosses are statistically significantly correlated stations. Triangles are non-significant correlated stations.

But there is no statistically significant increase in the trend line for stations with five days or longer for all seasons except for spring (appendix figure 2 available at stacks.iop.org/ERL/13/034036/mmedia). This implies that places that are more prone to drought experience more rapid increases in the duration of dry periods in both absolute value and percentage of change. There is no strong evidence that the rate of duration of wet periods depends on wet-day climatology in any season.

To further examine the summer season’s relationship in the entire study region, the time series of mean and extreme duration of dry/wet day periods and summer air temperature are derived from averaging all available stations during the study time period of 1966–2010. The average rate of increase for the mean duration of dry day periods is 0.24 day/°C (7.0%) and for extreme duration is 0.86 day/°C (7.7%; figure 7). The average rate of decrease for the mean duration of wet periods is −0.023 day/°C (−1.3%) and for extreme wet period duration is −0.098 day/°C (−2.2%) for the entire study region. The rate of dry day duration increase is more than triple that of decreasing wet day duration (figure 7). To give a proxy in trends, the summer surface air temperature has been increasing by 0.4 °C per decade and mean and extreme dry day duration have been increasing by 0.08 per day and 0.29 per day per decade respectively, while mean and extreme wet day duration has been decreasing at 0.01 per day and 0.04 per day per decade based on these averaged time series.

3.3. Relationship between total wet/dry day and duration of wet/dry period

To understand if changes in total wet/dry days may have some influence on changes in duration of wet and dry periods, correlation analyses between total wet (dry) days and mean and extreme duration of wet (dry) periods are performed. The relationships are dominantly positive for all seasons and the majority of stations have statistically significant correlations (figure 8).

The relationship between total dry days and mean duration of dry periods is statistically significant for all stations in all seasons, with the correlation coefficient reaching 0.9. Correlation results for extreme duration of dry periods are also dominantly significantly positive (figure 8).

The relationship between total wet days and mean duration of wet periods is a little weaker, especially during winter and spring seasons when a few stations have a negative but not statistically significant correlation. The relationships with extreme duration of wet periods is stronger; almost all stations have statistically significant positive correlations (figure 8).

The average rate of total wet days is −2.8% (0.76 day) and that of dry days is 2.7% (1.49 day) per degree of air temperature increase averaged from all
Figure 6. The rate of mean duration of dry periods per each degree of air temperature increase plotted against the corresponding seasonal mean duration of dry periods for all 517 stations and all four seasons. The black dashed line is the linear regression line for all stations between the rate of change and mean seasonal dry-day duration; the colored dashed line is the linear regression for stations that have a mean dry day duration of five days or longer.

Figure 7. Averaged annual summer duration of dry periods (red dots) and wet periods (green triangles) plotted against the corresponding average summer air temperature for all stations for the time period 1966–2010. Left panel: mean; right: the extreme.
stations in the study region in summer. The percentage rate of dry day duration of 7.0%/°C and 7.7%/°C for mean and extremes is about 2–2.8 higher than those of total dry days. On the other hand, the rate of the duration of wet days of −1.3%/°C and −2.2%/°C for the mean and extremes are lower than those of the total wet days. The results suggest that changes in total wet/dry days have certain influences on the duration of wet and dry periods but the regrouping in dry and wet periods may also play a role. For example, a study over China showed that the re-grouping of wet day periods leads to faster decreases in long wet day events of four days or longer compared to that of total wet days (Chen and Zhai 2014).

4. Conclusions

This study uses 517 historical daily precipitation records to examine the relationship of mean and extreme seasonal duration of dry/wet periods to corresponding seasonal surface air temperatures over Russia. The study found that higher air temperatures were consistently associated with the increased duration of dry spells and decreased duration of wet spells in summer. For the other three seasons of winter, spring, and fall, a similar relationship is observed only in the southern study region and opposite relationships are found in the northern study region, with a threshold of seasonal air temperature of about −5°C when the relationship changes its sign.

This study also found that locations with longer mean durations of dry periods have a greater rate of increase with air temperature. This implies that as air temperature increases, locations that are prone to drought may become more likely to experience severe drought due to accelerated lengthening of the duration of dry days. Averaged from the entire study region during summer, the rate of mean duration for dry period increase with air temperature of 0.24 days/°C (7.0%) is about ten times that of the decrease rate of wet day duration of −0.023 days/°C (−1.3%). Similarly, the increase in the rate of extreme duration of dry periods with air temperature of 0.86 days/°C (7.7%) is about 8.8 times the decrease rate of the extreme duration of wet spells of −0.098 days/°C (−2.2%).

The changes in duration of wet and dry periods appears to be associated with that of total wet and dry days in all seasons. But the rate of duration of dry periods is amplified compared to that of total dry days. This suggests that changes in total wet days alone cannot explain changes in the durations of dry and wet periods. A decreased duration of wet periods is consistent with increasing convective precipitation, possibly at the expense of non-convective precipitation (Ye et al 2016a, 2017). Since convective precipitation is more localized and has a shorter duration, wet day duration would likely decrease.
The above relationships may not stay static, so they cannot be used to predict future climate change with certainty. However, regional climate model projections based on an ABI emission scenario show that decreases in summer wet days are associated with increases in the number of multi-day dry spells and a lower likelihood of short dry spell occurrence in Switzerland (Fischer et al 2014). The Canadian regional climate model projected increases in return levels of maximum dry spell durations for future conditions of 2041–2100 over southern prairies during the warm season (Sushama et al 2010). These are consistent with observational results found in the historical data shown in this study.

Research on other European countries suggested a more complex picture. Data analyses on 60 years of precipitation records over Europe found that observed changes in the lengthening duration of winter wet periods and changes in duration of dry spells are mostly due to the regrouping of wet and dry days with no significant relationship to total wet days (Zolina et al 2010, 2013). It appears that changes in duration of wet and dry periods are geographically specific and the causes are far from simple.

Atmospheric circulation patterns such as Arctic oscillation, the Scandinavian pattern, Atlantic–Western Eurasian pattern, and Polar–Eurasian pattern, have certain impacts on precipitation daily intensity, partially caused by changes in wet days (Ye et al 2016a). Further research to examine the impacts of major atmospheric patterns and possible increased blocking conditions on the duration of dry and wet periods would shed some light on the causes. More research is also needed to better understand potential changes in the profiles of the duration of wet and dry periods because extremes appear to be more sensitive to temperature change, as shown by this study.

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