Increasing flash droughts over China during the recent global warming hiatus

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The recent global warming slowdown or hiatus after the big El Niño event in 1997/98 raises the questions of whether terrestrial hydrological cycle is being decelerated and how do the hydrological extremes respond to the hiatus. However, the rapidly developing drought events that are termed as “flash droughts” accompanied by extreme heat, low soil moisture and high evapotranspiration (ET), occurred frequently around the world, and caused devastating impacts on crop yields and water supply. Here, we investigate the long-term trend and variability of flash droughts over China. Flash droughts are most likely to occur over humid and semi-humid regions, such as southern and northeastern China. Flash drought averaged over China increased by 109% from 1979 to 2010, and the increase was mainly due to a long term warming of temperature (50%), followed by the contributions from decreasing soil moisture and increasing ET. There was a slight drop in temperature after 1997, but the increasing trend of flash droughts was tripled. Further results indicate that the decreasing temperature was compensated by the accelerated drying trends of soil moisture and enhanced ET, leading to an acceleration of flash droughts during the warming hiatus. The anthropogenic warming in the next few decades may exacerbate future flash drought conditions in China.

Drought is usually a creeping phenomenon that persists for several months or years, and affects the food and water security significantly1,2, and heatwave usually lasts for a few days with sustained high temperature and notable impacts on human mortality and environment4. The two types of extremes have quite different time scales, but now they have a higher concurrent probability in many regions across the world under global warming1, where increasing heatwave exacerbates drought condition, and drought in turn creates a favorable condition for heatwave5-8. The concurrent drought and heatwave events with low soil moisture and high evapotranspiration (ET) are recently termed as “flash drought”9,10 due to their rapid onsets, unusual intensity and devastating impacts11,12. For example, a moderate drought condition combined with a heatwave initiated a flash drought event over the central United States in May and early June 20129, which was unexpected and brought a grand challenge for early warning due to limited prior external signals13,14, and led to widespread crop failure and billions of economic losses. Other flash drought events were reported in China10 and Europe. However, to date, there are limited studies that detect and attribute the change of flash droughts specifically.

Similar to traditional droughts, a change in flash droughts is not only associated with the change in terrestrial hydrological cycle, but also influenced by the change in terrestrial energy cycle (and the related heatwaves) as well as the interaction between the land and atmosphere15. Under global warming, the risk of heatwave is increasing3, and the terrestrial hydrological cycle is also expected to be intensified with increasing water vapor feedback16, leading to the changes in precipitation, soil moisture and ET, as well as characteristics of climate extremes (e.g., droughts). However, global mean temperature remained flat during the first decade of the twenty-first century17,18. The potential causes may include internal climate variability, such as the La Niña-like decadal cooling prevailed over the tropical Pacific19-21 and reduced radiative forcing due to the increased stratospheric aerosol concentrations22,23 together with the minimum solar activity around 200914,25. During the warming hiatus, the trend for global land ET declined as well, although it was mainly associated with limited moisture supply26. Land ET is a crucial variable that affects the forming and evolution of flash droughts because the increase in ET can amplify the
soil moisture anomalies and intensify the drought condition\textsuperscript{9,27}. The soil moisture is also an important index for the identification of flash droughts, but the change in soil moisture is unclear\textsuperscript{1,15} due to the observation and model uncertainties. Given the slowdown of temperature and ET, and the uncertain change in soil moisture, it remains unclear what changes have occurred in the flash droughts and whether the hiatus is responsible for the changes.

In this study, we focus on flash droughts over China, which is one of the most sensitive areas to the climate change, suffering from warming and drying significantly\textsuperscript{28}. Surface air temperature measurements for the period of 1979–2010 from over two thousand meteorological stations, and soil moisture and ET estimations from three global reanalysis products are used to investigate multidecadal changes in flash droughts over China and the underlying causes.

Results

Frequency of occurrence for flash droughts. Here we use the pentad-mean conditions to capture the short duration of flash droughts during crop growing seasons when they mostly occur\textsuperscript{29}. For each meteorological station and each pentad, a flash drought is defined as the condition in which surface air temperature anomaly is larger than one standard deviation, ET anomaly >0, and soil moisture percentile (SM%) <40%. If two or more consecutive flash drought pentads happen one after another, they will be treated as a single drought event. The ensemble mean is the average of the frequency from each reanalysis product. The unit is in events per decade. The boxes represent the locations of three sub-regions: southern China (21°–32°N, 98°–123°E), northern China (32°–42°N, 98°–126°E) and northeastern China (42°–54°N, 119°–135°E). The figure was created by the NCAR Command Language (Version 6.3.0) [Software]. (2016). Boulder, Colorado: UCAR/NCAR/CISL/TDD. http://dx.doi.org/10.5065/D6WD3XH5.

Figure 1. Ensemble mean frequency of flash drought events during the growing seasons (April to September). Flash drought pentad is defined as the pentad-mean surface air temperature (T) anomaly > one standard deviation, ET anomaly >0, and soil moisture percentile (SM%) <40%. If two or more consecutive flash drought pentads happen one after another, they will be treated as a single drought event. The ensemble mean is the average of the frequency from each reanalysis product. The unit is in events per decade. The boxes represent the locations of three sub-regions: southern China (21°–32°N, 98°–123°E), northern China (32°–42°N, 98°–126°E) and northeastern China (42°–54°N, 119°–135°E). The figure was created by the NCAR Command Language (Version 6.3.0) [Software]. (2016). Boulder, Colorado: UCAR/NCAR/CISL/TDD. http://dx.doi.org/10.5065/D6WD3XH5.

Trend and variability of flash droughts. Figure 2a shows the number of flash drought events per year averaged over China during 1979–2010. For the whole period, despite some differences among three reanalysis products, they all indicate an increasing trend over China. The flash drought events increased by 109% from 1979 to 2010 with a statistical significance of $p < 0.01$ (see Methods for details). Similar trends ($p < 0.01$) can also be found in the sub-regions, with the highest increasing trend over southern China, followed by northeastern China, and northern China the lowest (Fig. 3a).
During the period of 1979–2010, the warming rate is 0.36 °C per decade (p < 0.01) over China, with a sharp increase in the 1990s and a stabilization in the 2000s (Fig. 2b). In addition, there is a decreasing trend for soil moisture (p < 0.05) and an increasing trend for ET (p < 0.05), although less significant than the change in temperature (Fig. 2c–d, Table S1). For three sub-regions, the trends of three component variables are similar to those for the entire China, but with less significance for the soil moisture and ET over northern and northeastern China (Fig. 3a, Table S1).

A multiple linear regression is applied to quantify the contributions of temperature, soil moisture and ET to the trend in flash drought (see Methods for details), and the regression explains over 81% of the variability of the flash droughts across China and its sub-regions. For the entire continental China, the contribution of the surface air temperature variability to the flash drought variability is the biggest (50.1%), followed by soil moisture (29.6%) and ET (20.3%). For the southern China, the flash drought variability is also mainly contributed by surface air temperature (48.5%), followed by soil moisture (37.7%) and ET (13.8%). The contributions of surface air temperature to the flash droughts over northern and northeastern China are again dominant (64.6% and 53.3%), and the secondary contributors are the ET (22.7%) and soil moisture (40.7%) respectively.

Changes in the flash drought trend during the warming hiatus. From the analysis above, it is found that the surface air temperature variability accounts for most of the variability for the flash droughts across China and its sub-regions during the whole period of 1979–2010 (Fig. 3a). Before the big El Niño event in 1997/98, there was a warming trend over China, with a rate of 0.20 °C per decade (Fig. 3b). It switched to an opposite cooling trend with a rate of −0.05 °C per decade since 1998 (Fig. 3c), indicating that there is a warming hiatus in China. However, the increase in flash droughts does not seem to cease. The increasing trend over China for the period of
1998–2010 is 259% higher than for the period of 1979–1997 (Fig. 3b–c), and the difference in trends is statically significant (p < 0.1). In fact, the flash drought exhibits an accelerated increasing trend over most parts of China, especially in southern and northeastern China (Fig. 4a), although there is a warming hiatus across continental China except for the southwest and the Yangtze River basin (Fig. 4c). For the southern China, the significant increasing trend in flash drought (p < 0.05) in the last decade is mainly associated with an accelerated warming, an increased drying trend in soil moisture, and an accelerated increasing trend in ET (Figs 3c and 4d–e). But the increasing trend in temperature over southern China is not significant during 1998–2010 (Fig. 3c, Table S2) due to a decrease-increase-decrease triple pattern for the trend changes (Fig. 4c). For the northern China, the changes in flash drought trend are mixed (Fig. 4a), resulting in a decelerated increasing trend on average which is mainly caused by a cooling trend and a wetter soil condition (Figs 3c and 4c–d). For the northeastern China, the trend in flash drought is accelerated, which is mainly associated with the significant decrease of soil moisture (Fig. 4a,d).

Discussion
Flash drought is a kind of agricultural drought in nature, with concurrent events of extreme heat, soil water deficit and high vegetation transpiration demand. They are most likely to occur over humid and semi-humid regions (e.g., southern and northeastern China). This study uniquely investigates the trend and variability of the flash droughts over China, and is targeted at attributing the changes of flash droughts within the context of the understanding of the terrestrial water cycle in a changing climate.

Our results show that there are increasing trends for flash droughts over different regions in China, which is mainly associated with the temperature increase. This is similar to previous studies over California, where the global warming can increase the chance of concurrent droughts and heatwaves. In fact, high temperature may substantially exacerbate the drought condition. For example, the 1977 drought in California was only a 50 year extreme event, while the 2014 drought that co-occurred with heatwave was a 200 year extreme event.

In this study, the increasing trends of flash droughts do not decline after the big El Niño event in 1997/98. Although it is worthy of mentioning here that the trend statistics over 1998–2010 may not be robust due to the relative short period, the analysis does suggest that there exists significant increasing trends (p < 0.1) in flash droughts over China during the warming hiatus. The underlying mechanisms are attributed by investigating the
changes in temperature, soil moisture and ET. We find that increasing flash droughts during the warming hiatus is mainly associated with the accelerated drying trend of soil moisture over humid and semi-humid regions, and the accelerated increasing trend of ET over low and middle latitude regions (Fig. 4). The accelerated drying trend of soil moisture over southern China is mainly associated with an accelerated decreasing trend in precipitation (Fig. 4b) that might be caused by decadal climate variability and changes in anthropogenic aerosols. The accelerated increasing trend of ET over southern China seems to contradict with the drying trends both in precipitation and soil moisture, but it is actually coincident with previous findings that both the potential and actual ET exhibit increasing trends over southern China. This might be due to an increasing atmospheric demand under drought conditions, where the change in ET over humid regions is not necessarily correlated with the change in soil.

Figure 4. Ensemble means of the changes in trends between 1979–1997 and 1998–2010 for the flash droughts and different hydrometeorological variables. (a) Changes in trends for the number of flash drought events during April-September (pentads per year). (b) As for a, but for the trend changes for the standardized precipitation (P). (c) As for b, but for the trend changes for the standardized surface air temperature (T). (d) As for b, but for the standardized soil moisture (SM) anomalies. (e) As for b, but for the standardized ET. The figure was created by the NCAR Command Language (Version 6.3.0) [Software]. (2016). Boulder, Colorado: UCAR/NCAR/CISL/TDD. http://dx.doi.org/10.5065/D6WD3XH5.
moisture but rather with available energy, and less precipitation usually means more solar radiation. In addition, a greening trend\(^3\) with better vegetation conditions might also be responsible for the increasing ET.

The latest IPCC report suggests that global warming is going to continue well into the 21\(^{st}\) century. The observed increasing flash droughts reported in this study could potentially be strengthened further in the next few decades with more severe impacts on the water availability, agriculture, and ecosystem. As flash droughts occur mostly in humid and semi-humid regions where people are less aware and less prepared, their impacts on human society and livelihood are much more severe. Different from traditional drought events, this new phenomenon demands urgent research into its mechanisms, monitoring and early warning system development.

**Methods**

**Observational datasets.** We used the daily surface air temperature and precipitation observations from 2474 China Meteorological Administration (CMA) meteorological stations during the period of 1961–2014. A quantile mapping method\(^14\) that matches the cumulative distribution functions (CDFs) from the station data and the Global Land Data Assimilation System version 2 (GLDAS-2)\(^35\) global gridded forcing data at a 0.25-degree resolution, was used to fill the missing surface air temperature station data. After this procedure, about 22 stations were excluded due to the scale mismatch over the coastal areas. Observed precipitation for the remaining 2452 stations was also filled in the same manner. If the missing data remained after the quantile-mapping, an inverse distance weighting interpolation from the 0.25-degree gridded data was used to fill them.

**Reanalysis datasets.** We used the soil moisture and ET from three global reanalysis products: GLDAS-2 3-hourly products at a 0.25-degree resolution, ERA-Interim\(^36\) 3-hourly products at a 0.25-degree resolution and NCEP Climate Forecast System Reanalysis (CFSR)\(^37\) 6-hourly products at a 0.3125-degree resolution. GLDAS-2 provides the estimations of soil moisture and ET from a continuous simulation with the NOAH land surface model forced by meteorological observations. ERA-Interim and CFSR provide the estimations of land surface conditions by initializing a climate model every few hours. GLDAS-2 and ERA-Interim were verified against in-situ soil moisture observations over China, and showed some confidence in the drought analysis\(^10\). These datasets cover the base period from 1979 to 2010. First, we computed the daily mean of the variable of interest. Then, we matched the grid data to the corresponding or nearest stations. Soil moisture and ET were standardized for each reanalysis dataset to facilitate the ensemble, the comparison across regions and the trend analysis.

**Sensitivity to the definition of flash drought.** A sensitivity test of flash drought frequency to the thresholds of soil moisture and precipitation was presented in the supporting information. In the case of precipitation, the corresponding composite of soil moisture percentile was greater than 40% in most regions of China (Fig. S1d), which was too high to meet the requirement of a drought event. On the other hand, if the soil moisture percentile was used as the identification of flash droughts (Fig. 1), the corresponding composite of precipitation also showed an excessively negative anomaly (Fig. S1c). This is consistent with previous findings that precipitation anomaly is no longer needed if the soil moisture is used for the identification\(^9\). We also conducted the sensitivity test by changing the soil depths and soil moisture percentile thresholds (Fig. S2). We found that the difference in the magnitude of flash drought frequency by using different soil depths was smaller than that by using different percentile thresholds. If the threshold of 20% or 30% was used, the flash drought frequency over northern and northwestern China was too low to have a statistical meaning within a 32-year period. And the consideration of a 2-m soil would cover both surface and root-zone, which facilitated the analysis of the impact of flash drought on vegetation. Therefore, we used the 2-m soil depth with a 40% threshold for the flash drought analysis. In addition, we tested the sensitivity of flash drought frequency to the thresholds of the surface air temperature and ET (Fig. S3). We found that if the thresholds of 1.5 or 2 standard deviations were used for temperature, or if 0.5 standard deviation was used for ET, the flash drought frequency over arid and semi-arid regions was too low to have a statistical meaning for the whole period.

**Trend estimates and statistical significance test.** Trends were calculated as the Sen median slope\(^38\), which was widely used in detecting monotonic trend in hydrometeorological time series\(^39,40\). The nonparametric Mann-Kendall test was performed for the statistical significance of trends. Note that we obtained similar results by using the linear regression and Student's t-test in this paper.

**Contributions from component variables.** The multiple linear regression was used to quantify the contributions of the surface air temperature (T), soil moisture (SM) and ET to the trend in flash droughts\(^41,42\). First, we obtained the regressed flash drought frequency based on a multiple regression analysis at each station:

\[
S = a \times T + b \times SM + c \times ET + D
\]

(1)

where \(a\), \(b\) and \(c\) are the regression coefficients; and \(D\) is a constant; \(S\) is the flash drought frequency. Then, the contribution of the change in T to the change in flash drought (CT) was obtained as follows:

\[
CT = ((a \times \Delta T)/\Delta S) \times 100\%
\]

(2)

where \(\Delta S\) and \(\Delta T\) are the changes in mean \(S\) and \(T\) between the first and last five years. The contributions of the changes in SM and ET to the change in flash droughts could be calculated in the same manner. We should note that the estimates of contributions from component variables are based on a multiple linear regression by assuming that the component variables are independent from each other, while these components sometimes have interactions.

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References

1. Sheffield, J., Wood, E. F. & Roderick, M. L. Little change in global drought over the past 60 years. *Nature* **491**, 435–438, doi:10.1038/nature11575 (2012).

2. Lesk, C., Rowhani, P. & Ramankutty, N. Influence of extreme weather disasters on global crop production. *Nature* **529**, 84–87, doi:10.1038/nature16467 (2016).

3. Ciais, P. et al. Europe-wide reduction in primary productivity caused by the heat and drought in 2003. *Nature* **437**, 529–533, doi:10.1038/nature03972 (2005).

4. Hao, Z., AghaKouchak, A. & Phillips, T. J. Changes in concurrent monthly precipitation and temperature extremes. *Environ. Res. Lett.* **8**, 034014, doi:10.1088/1748-9265/8/3/034014 (2013).

5. Meehl, G. A. & Tebaldi, C. More intense, more frequent, and longer lasting heat waves in the 21st century. *Science* **305**, 994–997, doi:10.1126/science.1098704 (2004).

6. Mzdizayemi, O. & AghaKouchak, A. Substantial increase in concurrent droughts and heatwaves in the United States. *Proc. Natl. Acad. Sci. USA* **112**, 11484–11489, doi:10.1073/pnas.1422954112 (2015).

7. Mueller, B. & Seneviratne, S. I. Hot days induced by precipitation deficits at the global scale. *Proc. Natl. Acad. Sci. USA* **109**, 12398–12403, doi:10.1073/pnas.1204330109 (2012).

8. Trenberth, K. E. et al. Global warming and changes in drought. *Nat. Clim. Change* **4**, 17–22, doi:10.1038/nclimate2067 (2014).

9. Mo, K. C. & Lettenmaier, D. P. Heat wave flash droughts in decline. *Geophys. Res. Lett.* **42**, 4823–4829, doi:10.1002/2015GL064018 (2015).

10. AghaKouchak, A., Cheng, L., Mazdiyasni, O. & Farahmand, A. Global Warming and Changes in Risk of Concurrent Climate Extremes: Insights from the 2014 California Drought. *Geophys. Res. Lett.* **41**, 8847–8852, doi:10.1002/2014GL062308 (2014).

11. Ford, T. W., McRoberts, D. B., Quiring, S. M. & Hall, R. E. On the utility of in situ soil moisture observations for flash drought early warning in Oklahoma, USA. *Geophys. Res. Lett.* **42**, 9790–9798, doi:10.1002/2015GL066600 (2015).

12. Foster, G. & Rahmstorf, S. Global temperature evolution 1979–2010. *Environ. Res. Lett.* **6**, 044022, doi:10.1088/1748-9326/6/4/044022 (2011).

13. Hoerling, M. et al. Causes and predictability of the 2012 Great Plains drought. *B. Am. Meteorol. Soc.* **95**, 269–282, doi:10.1175/BAMS-D-13-00053.1 (2014).

14. Yuan, X., Roundy, J. K., Wood, E. F. & Sheffield, J. Seasonal forecasting of global hydrologic extremes: system development and evaluation over GEWEX basins. *B. Am. Meteorol. Soc.* **96**, 1895–1912, doi:10.1175/BAMS-D-14-00003.1 (2015).

15. Dai, A. Increasing drought under global warming in observations and models. *Nat. Clim. Change* **3**, 52–58, doi:10.1038/nclimate1633 (2013).

16. Huntington, T. G. Evidence for intensification of the global water cycle: Review and synthesis. *Rev. Geophys.* **43**, 1–15, doi:10.1029/2003RG000178 (2005).

17. Easterling, D. R. & Wehner, M. F. Is the climate warming or cooling? *B. Am. Meteorol. Soc.* **93**, 1–12, doi:10.1175/BAMS-D-11-00003.1 (2012).

18. Fyfe, J., Salzen, K. v., Cole, J., Gillett, N. &vernier, J. P. Surface response to stratospheric aerosol changes in a coupled atmosphere–ocean model. *Geophys. Res. Lett.* **40**, 584–588, doi:10.1002/grl.50156 (2013).

19. Fröhlich, C. Total solar irradiance observations. *Surv. geophys.* **33**, 453–473, doi:10.1007/s10712-011-9168-5 (2012).

20. Kaufman, R. K., Kauppi, H., Mann, M. L. & Stock, J. H. Reconciling anthropogenic climate change with observed temperature trends. *Proc. Natl. Acad. Sci. USA* **108**, 11790–11793, doi:10.1073/pnas.1102467108 (2011).

21. Jung, M. et al. Recent decline in the global land evapotranspiration trend due to limited moisture supply. *Nature* **467**, 951–954, doi:10.1038/nature1940 (2010).

22. Teuling, A. J. et al. Evapotranspiration amplifies European summer drought. *Geophys. Res. Lett.* **40**, 2071–2075, doi:10.1002/ gl.50495 (2013).

23. Zhang, Y. et al. Multi-decadal trends in global terrestrial evapotranspiration and its components. *Sci. rep.* **6**, 19124, doi:10.1038/srep19124 (2016).

24. Wood, A. W., Maurer, E. P., Kumar, A. & Lettenmaier, D. P. Long-range experimental hydrologic forecasting for the eastern United States. *J. Geophys. Res. Atmos.* **107**, doi:10.1029/2001JD000659 (2002).

25. Rodell, M. et al. The global land data assimilation system. *B. Am. Meteorol. Soc.* **85**, 381–394, doi:10.1175/BAMS-85-3-381 (2004).

26. Simmons, A., Uppala, S., Dee, D. & Kobayashi, S. ERA-Interim: New ECMWF reanalysis products from 1989 onwards. ECMWF newsletter **110**, 25–29 (2007).

27. Saha, S. et al. The NCEP climate forecast system reanalysis. *B. Am. Meteorol. Soc.* **91**, 1015–1057, doi:10.1175/2010BAMS3001.1 (2010).

28. Sen, P. K. Estimates of the regression coefficient based on Kendall's tau. *J. Amer. Statist. Assoc.* **63**, 1379–1389, doi:10.1080/01621459.1968.1048934 (1968).

29. Dorigo, W. et al. Evaluating global trends (1988–2010) in harmonized multi-satellite surface soil moisture. *Geophys. Res. Lett.* **39**, doi:10.1002/2012GL052988 (2012).

30. Sheffield, J. & Wood, E. F. Global trends and variability in soil moisture and drought characteristics, 1950–2000, from observation-driven simulations of the terrestrial hydrologic cycle. *J. Climate* **21**, 432–458, doi:10.1175/JCLI382.1 (2008).

31. Morino, I., Kusakir, Y., Seager, R. & Li, C. Forced and internal twentieth-century sst trends in the north atlantic. *J. Climate* **22**, 1469–1481, doi:10.1175/2008JCLI2561.1 (2009).

32. Cheng, S., Guan, X., Huang, J., Li, F. & Guo, R. Long-term trend and variability of soil moisture over East Asia. *J. Geophys. Res. Atmos.* **120**, 8658–8670, doi:10.1002/2015JD023206 (2015).
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Author Contributions
X.Y. conceived and designed the study. L.W. and X.Y. performed the analyses and wrote the paper. L.W. and X.Y. are co-first authors. All authors contributed to the interpretation of the results.

Additional Information
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