Dear Editors and Reviewer,

Thank you very much for your messages and your efforts in processing our manuscript "Spatiotemporal analysis of flash flooding events in mountainous area of China during 1950–2015" (MS No.: nhess-2019-150). My colleagues and I are very grateful to you for the valuable comments. Based on them we have revised the paper which is attached for your further consideration. Please refer to the enclosed "Responses to the reviewer's comments" for details on the substantial revisions we have made. Our responses are right after each comment.

Please feel free to contact me if you have any questions with our revision of this paper.

Sincerely,
Nan Wang

Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 11A, Datun Road, Chaoyang District, Beijing, China
Tel.: +86 13011870541
Email: wnan@lreis.ac.cn

Responses to the anonymous referee #1's comments

• General comments

The authors try to evaluate the spatiotemporal characteristics of the FFEs in China by using a very large database, formed only by date and location of the events. No further information is available for each FFE, such has peak discharge or intense precipitation. The work is surely interesting as the timing features of FFEs have been extensively mapped, and provide a valid frame for further analyses on flash floods at smaller spatial and temporal scale. Anyway, often the obtained results cannot provide substantial information just for the intrinsic nature of the data and the too large areas of the geomorphological regions, thus weakening some possible impacts of the work (such as enabling disaster estimation and prevention on the national scale, row 15). Classical statistical and mathematical methods have used to perform the analyses, nevertheless the results of some analyses are uncertain. Thus, many relevant issues need further deepening, as stated in the following.

Comments: First, in the title, the word "Statistical" may be added before "Spatiotemporal" to clearly indicate the approach followed in this study. Moreover, the authors specify that the analysis is focused to the mountainous areas of China, though in the text there is no mention at all about this fact. On the other side, the FFEs database is global, as shown in the figure 1. So, the call to the "mountainous areas" may be deleted, if not furtherly motivated in the text.

Response: Thank you for the suggestion. Modifications have been made on the title.

Revised:

-Title (in revised version): Statistical spatiotemporal analysis of flash flooding events in China during 1950–2015

Comments: The authors should provide further information about the specific criteria used for identifying the FFEs used in the analyses (e.g., distinguishing flash floods from normal floods). Moreover, a single climatic event may have caused different floods in a large watershed, or in conterminous smaller watersheds. Thus, within the database, the authors may have detected FFEs as floods caused by distinct climatic events (with different occurrence date), or as floods observed at different locations of a watershed at the same occurrence time. The reader may be confused in trying to understand the various analyses if this basic information is not clearly assessed. For the same aim, also the data aggregation used for the different analyses should be better defined all over the text (as correctly done in row 101).

Response: Thank you for the comments. The flash flooding events mentioned in this paper included the floods, debris flows and landslides etc., which occurred in the mountainous area and caused the economic losses or the people death. In addition, we have deleted FFEs at the same time to ensure that they are recorded only once in the same small watershed (with an area less than 50 km^2) at the same date. Finally, we added Table 1 (in revised version) to describe the data aggregation in each section.

Revised:

-Rows 87-89 (in revised version): The flash flooding events used in this paper included the floods, debris flows and landslides etc., which occurred in the mountainous area and caused the economic losses or the people death. In addition, we have deleted the repeated FFEs to ensure that they are recorded only once in the same small watershed (with an area less than 50 km^2) at the same date.

-Table 1 (in revised version):

Table 1 The data aggregation used for different analyses

Section	Data
4.1 Temporal variation analysis	the number of FFEs in each geomor-region at each year during 1950-2015
4.2 Temporal trending analysis	the number of FFEs in each watershed of six geomor-regions at

	each year during 1950-2015
4.3 Temporal period analysis	the number of FFEs at each year during 1950-2015
4.4.1 Intra-annual clustering	the number of FFEs in each watershed of six geomor-regions in each month during 1950-2015
4.4.2 Inter-annual clustering	the number of FFEs in each watershed of six geomor-regions at each year during 1950-2015
5.1 Potential factors of the FFEs trending	the number of FFEs in each watershed of six geomor-regions during 1950-2015
5.2 Typical peaks of the FFEs trending	the location of FFEs in China at 1998 and 2010

Comments: As previously stated, the spatial scale of the study is very large, though the database is subdivided into six (not enough) smaller regions. This basic choice evidently weakens the search for relations between FFEs and climatic/physical features, such as rainfall and soil moisture that are generally locally varying variables.

Response: Thank you for the comments. Firstly, using the six geomor-regions in this study, we can better summarize the global pattern on national scale and avoid the spatial differentiation of topographic features on large scale. Actually, the analysis of relations between FFEs and climatic features are based on the watershed, which can reflect the local variation to some extent. In the revised version, we add the topographic features throughout China, thus emphasizing the necessity and importance of subdivision of geomor-regions.

Comments: In fact, some results, only graphically visualized, show uncertain behaviours, probably due to peculiar features of the watersheds within the large regions. For example, this is the case of the skewness of the monthly frequencies (represented in figure 8 and in table 3), and of the regression analysis (represented in figures 11 and 12). To overcome partially the problem, the visualization of the results through further, properly detailed, tables can be useful for comparing the statistical behaviours of the six different regions of China. Some analyses show different behaviours within each geomor-region, that hardly can be averaged into a single specific behaviour. As an example, the intra-annual frequency distribution of FFEs has been divided into right-skew, left-skew and symmetry, but quite all the geomor-regions show great variability.

Response: Thank you for the comments. For one thing, the inconsistency of intra-annual frequency in the same geomor-region is explained in the revised version. For another, we discussed the interplay of extreme precipitation, terrain and soil, etc. in six geomor-regions, and analysed the similarities and differences caused by the climatic factors and underlying surface features.

Revised:

-Rows 297-303 (in revised version): However, some inconsistencies of intra-annual frequency in the same geomor-region can be detected. In NWB, FFEs occurred in June to August can be detected in most watersheds resulting from the heavy storms; while, some watersheds showed the high FFEs frequency in March to May, for the glaciers and snowmelt causing by the rising temperature. In SWM, the long storm period lasting from June to November and the variable topographic features bring about the diverse FFEs-rich period in different watersheds. In TP, the FFEs mostly likely to appear in June to August, with some peaks scatted in different months for the low frequency of FFEs overall.

-Rows 373-393 (in revised version): Usually, based on the complex interactions of terrain, soil and other underlying surface features, flash flooding mainly induced by the extreme precipitation with short duration and high strength. In China, EASM affected most regions (SEM, EP, SWM and southern of NCP) in summer, which makes them showed similar patterns on temporal. However, the local divergence in terrain and soil features contribute to the spatial differentiation in each geomor-region. In SEM, greatly affected by the tropical cyclone, it is easy to form strong surface runoff in red soil along the coastal mountains. The hills and mountains region in SEM are the most prone area to flash flooding in China. Similarly, NWB is the heaviest rainstorm inland region and is well-known for the complex topographic features. Affected by the Plateau Monsoon Climate, the active tectonic and the dissolvable Carbonate provide abundant materials for the formation of debris flow disasters. Specially, due to the complex topographic effects, severe flash flooding disasters often occurred in autumn in the Daba Mountains in the northern NWB. In EP, the flash flooding disasters mainly concentrate in two regions, one is the Daxingan Range, Xiaoxingan Range, and Changbai Mountains of northeastern EP, and another is the Yan-Taihang Mountains belt of southeastern EP. Together with the moving of rainfall belt, the FFEs-rich months show some time difference on intra-annual scale from south to north in EP. Another region severely affected by the monsoon is the Loess Plateau, which is the most widely loess distributed area in the word. The thick loess layer is prone to cause soil erosion, resulting in the broken surface and widespread gullies. Therefore, Losses Plateau is one of the regions with the severe debris flow disasters in China. Besides, blocked by the Himalayas, a large amount of water vapor brought by the Indian Ocean Southwest Monsoon form strong precipitation in southeastern of TP. Thanks to the sparse population distribution in TP, there is little chance to induce serious flash flooding disaster in this region. Moreover, due to the far distance from the ocean, NWB and northern of NCP are hardly affected by monsoon and they are indicated as the regions least affected by the heavy rainstorm. However, the spatial local terrain can also play an important role in the process of flash flooding disaster formation. For example, the trumpet-shaped topography in Ili valley watershed of Tian Mountains has a lifting effect on the water vapor coming from the west, thus forming heavy rainstorm and inducing severe disasters.

Comments: As concern the temporal periodic analysis, the search for the inter-annual variation of the FFEs should be performed at the geomor-region space scale, and then physically explained.

Response: Thank you for the comments. We performed the wavelet analysis at the geomor-region space scale and physically explained the results.

Revised:

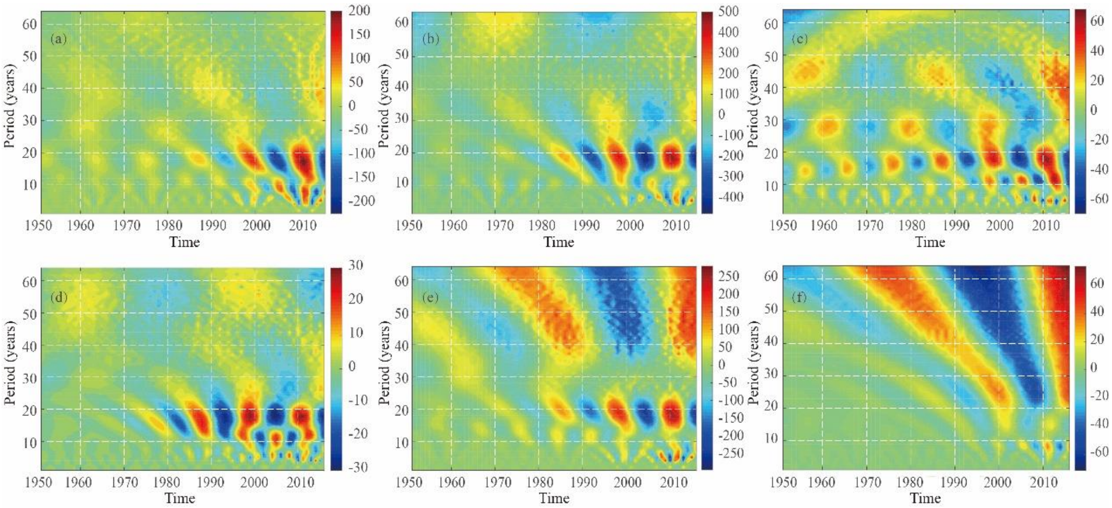

Figure 4: The real-part of the wavelet coefficient of FFEs in six geomor-regions of China. (a) EP; (b) SEM; (c); NCP; (d) NWB; (e) SWM; (f) TP.

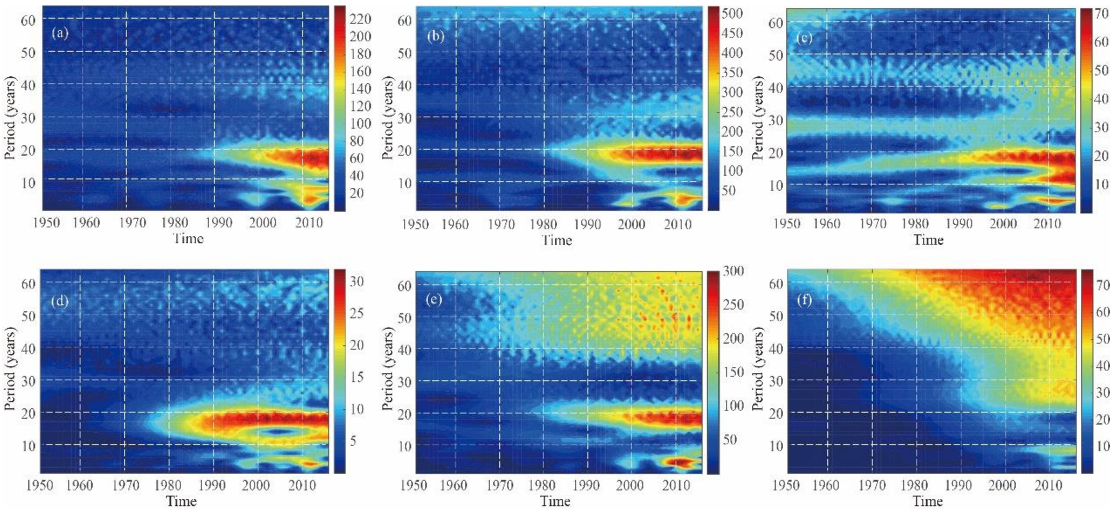

Figure 5: The modulus of wavelet coefficients of FFEs in six geomor-regions of China. (a) EP; (b) SEM; (c); NCP; (d) NWB; (e) SWM; (f) TP.

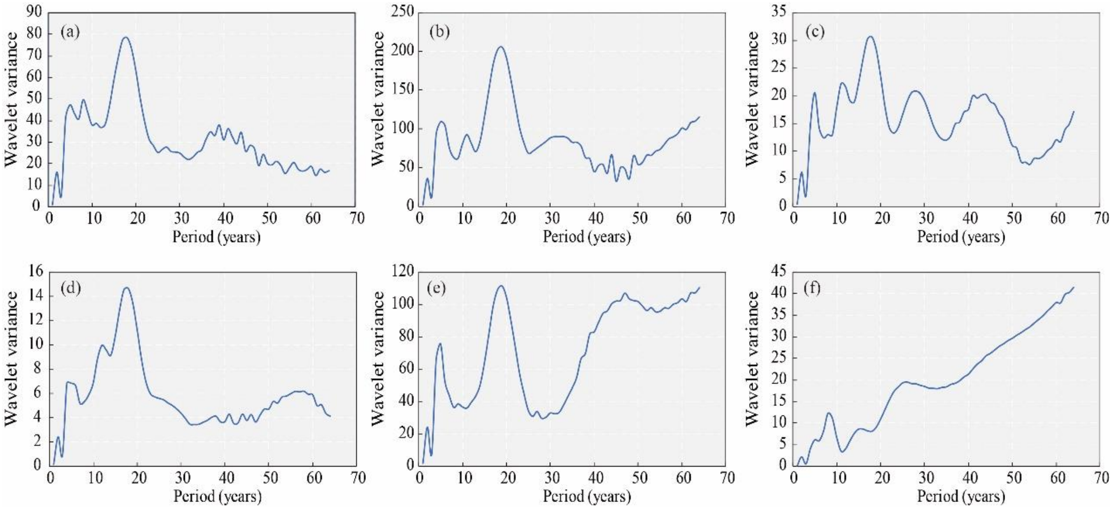

Figure 6: The wavelet variance analysis of FFEs in six geomor-regions of China. (a) EP; (b) SEM; (c); NCP; (d) NWB; (e) SWM; (f) TP.

- Rows 429-437 (in revised version): The Pacific Decadal Oscillation (PDO) phenomenon presents above the Pacific Ocean with alternating positive (warm) and negative (cold) phases, has a clear impact on the natural disasters as indicated in the studies (Seiler et al., 2012; Xiao et al., 2015; Zhong et al., 2017). The PDO has greatly affected the periodic climate change, resulting in the alternate variation of FFEs-poor and FFEs-rich in China since 1980s. Studies demonstrated that the warm phase of PDO is conductive to lead to the positive precipitation anomalies in eastern China for the period of 1960s-2010s (Zhu et al., 2015; Si, 2016). As the temporal periodic analysis in our study, the 10-20a periodicity of FFEs existed in the period of 1995-2000 and 2008-2013 in most of China. Moreover, El Niño and La Niña induced the alternative of flood and drought has been detected in first main period of 18-19a usually lasts for 7-7.5a, with about four rich-poor oscillations. Moreover, the fluctuation of El Niño and EASM activities also indicate a good correspondence between the variation of FFEs and global climate change in China.

From a formal point of view, the work is well structured, and it is based on a huge database, valuable for a statistical analysis. The subject is very interesting, and the text should be rewritten only in some specific section for the sake of clarity. The presentation of the results has to be improved in some parts. The list of references is exhaustive and well chosen. The quality of the figures is high, but some of them should be substantially improved. All the suggestions/corrections proposed for improving the text are listed in the following specific comments. As a result of the review, I recommend major corrections for this manuscript before publication on Natural Hazard and Earth System Sciences.

• Specific comments

Comments: - Section 2.3. The subdivision of the entire study area into 133 watersheds based on third-order stream is not a completely exhaustive information on their features. In fact, the large range of the watersheds area needs some further explanations that can be inserted in table 1.

Response: Thank you for the kindly comments. The division criteria have been added into Section 2.3 as the supplement of the watersheds' features. In addition, the typical characteristics of the representative large ranges have been inserted in Table 2 (in revised version).

Revised:

- Table 2 (in revised version):

Table 2 Description of the six geomorphologic regionalization (geomor-regions) in China

Name	Abbreviation	Description
Eastern Hilly Plains	EP	It located in the northern part of China comprising low terrains and the largest plain areas. Plains and platforms are dominant features of this region, which has well-developed fluvial accumulation landforms. Major rivers in this region include Songhua River watershed, Tumen River watershed, Huai River watershed, etc. The flash floods in Songhua River watershed are mostly caused by the heavy storm, 80% of the flash floods occur in July-August, especially in August. The flash floods in Huai River watershed can be caused by Meiyu and heavy storm, and the flash floods are generally concentrated in June-September of the flood season.
Southeastern Low-middle Mountains	SEM	It located in the southern part of the low terrain topography and is dominated by low elevation hills and low or middle relief mountains, with only 30% of its area occupied by plains and platforms. Major rivers in this region include middle and lower reaches of Yangtze River watershed, Poyang Lake watershed, etc. The flash floods are the most frequent and serious in middle and lower reaches of Yangtze River watershed, because of the Meiyu and heavy storm.
Northern and Central Middle Mountains and Plains	NCP	It located in the northeastern part of China's middle terrain topography and is characterized by a plateau landform composed of low or middle relief mountains, hills, platforms, and plains. The loess landform is well developed in this region. Major rivers in this region include the middle reaches of Yellow River watershed, Wei River watershed, etc. Ice flood is easily caused by ice jams, ice dams, etc. in the middle and lower reaches of the Yellow River from December to March. The flash floods also concentrate in late July to early August causing by the heavy storm.
Northwestern Middle and High Mountains and Basins	NWB	It located in the northwestern part of the middle terrain topography. It is composed of middle to high mountains, with flattened basins interposed between them, and is characterized by an arid desert geomorphology. Mountains with basins are made up of plains, platforms, and hills. Major rivers in this region include Tarim River watershed, Ili River watershed, etc. The flash floods in this region can be caused by the local heavy storm or the combination of heavy storm and snowmelt.

Southwestern Subalpine Mountains	SWM	It located in the southern part of the middle terrain topography. Evidencing a typical karst landform, middle or high mountains with middle or high reliefs are widespread with wide valley basins interspersed between them. Major rivers in this region include the upper and middle reaches of Yangtze River watershed, Jialing River watershed, etc. Influenced by the plateau monsoon climate, storms period in this region is long and the rainstorm is usually multi-peak.
Tibetan Plateau	TP	It covers China's high terrain topography. It is composed of plains and high mountains at elevations above 4000 m, accounting for three-forths of the area of this region. It is characterized by glacial and periglacial landforms. Major rivers in this region include the Yarlung Zangbo River watershed, Nu River watershed, Shiquan River watershed, etc. Local persistent heavy rain is the main cause of flash floods in the tributaries of the middle reaches of the Yarlung Zangbo River watershed.

Comments: - Section 3.1. The two-tailed test for the Sen's slope can be better defined.

Response: Thank you for the kindly comments. We have made some changes in the revised version.

Revised:

- Rows 134-1235(in revised version): Sen's slope is tested by a significance test at 90% confidence level.

Comments: - Section 4.1. At the start of the section 4.1, before presenting the results, it is useful a short mention to the method used for assessing the significance of the trends. Moreover, the mean annual change rates of the various regions (rows 171-173) do not coincide with the slope of the regression equations showed in figure 2. In order to increase readability, the authors should represent the regression equations as FFEs=a+b*(current year-1950). Moreover, the results evidenced high intensities in two phases (1985–1998 and 2000–2010) for most regions. Can the authors discuss about the probable reasons of the lower number of FFEs before 1985 (lower quality/quantity of information, lower precipitation…)?

Response: Thank you for the kindly comments. Firstly, the significance of the trends was assessed by the 5-year and 10-year moving average. Moreover, the regression equations showed in Figure 2 have been changed into the equations advised by the referee to better indicate the interannual variation. Finally, the probable reasons of the lower number of FFEs before 1985 has been discussed at the Section 5.

Revised:

- Rows 172-173 (in revised version): In this section, we analysed the large-scale change pattern for the six geomor-regions using the number of FFEs in each geomor-region from 1950 to 2015 based on the 5-year and 10-year moving average of time series.

- Rows 183-185 (in revised version): The mean growth of NCP, NWB and TP are 1.86, 1.21 and 1.86 per year, which showed a steady changing rate; and EP showed a consistent significant increasing trend with the mean change rate at 3.34 per year; while SEM and SWM increased sharply with the mean rate of 9.32 and 8.05 per year.

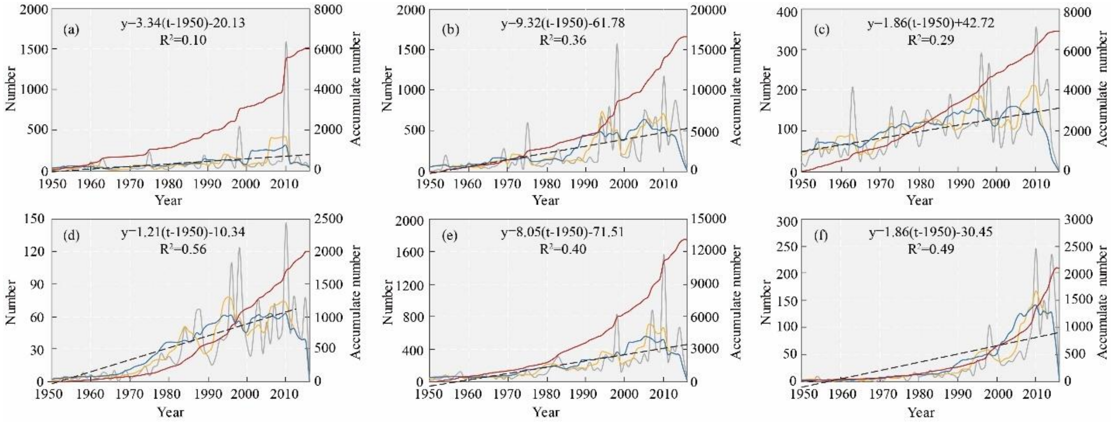

Figure 2: Time series of the annual mean number of FFEs in six geomor-regions of China from 1950 to 2015. The grey line is the original time series; the yellow line and blue line are the 5-year and 10-year moving average of time series, respectively; the red line is the accumulate number of FFEs; and the black dashed line is the trend line based on the least-squares linear regression. (a) EP; (b) SEM; (c); NCP; (d) NWB; (e) SWM; (f) TP.

- Rows 332-338 (in revised version): The long-term variation trending indicated that the number of FFEs in all six geomor-regions showed relatively low before 1980. On one hand, this variation may be attributed to the poor data acquisition method and the inadequate data records before 1980s, which may result in the lower occurrence in the historical period on some extent. On the other hand, some climate factors, e.g. precipitation, may also have an effect on the FFEs, for the increasing extreme precipitation in under the globe change in recent years may cause more flash flooding.

Comments: - Sections 4.1 and 4.2 need some further explanation as regards the database (data and location of FFEs) used for analyses. Section 4.1 copes with the trend in the FFEs global number series of each geomor-regions, while section 4.2 deals with the different watersheds of the geomor-regions. This different data aggregation should be better defined; otherwise, it can be easily misunderstood. Moreover, control the pertinence of the word "mutation" in the title of section 4.2.

Response: Thank you for the kindly comments. The explanation about the database used in Sections 4.1 and 4.2 have been added to the start of the sections, respectively. Moreover, we modified the title of Section 4.2 into "Temporal trending analysis".

Revised:

- Rows 172-173 (in revised version): In this section, we analysed the large-scale change pattern for the six geomor-regions using the number of FFEs in each geomor-region from 1950 to 2015 based on the 5-year and 10-year moving average of time series.

- Rows 196-197 (in revised version): Based on the number of FFEs in each watershed within six geomor-regions from 1950 to 2015, the trends in the time series of FFEs for each geomor-region were tested by MK testing and the magnitude of a trend was estimated by Sen's slope (Figure 3).

- Row 195 (in revised version): 4.2 Temporal trending analysis

Comments: - Section 4.3. This section tries to find oscillation periods of the FFEs database at large and small scales, but the global result shows a complex timing frame that should be adequately explained. The authors are requested to relate the potential periodic features to some external (physical, climatic or planetary) factors, which could reinforce this potential result. On the other side, the wavelet analysis has been referred to the whole China, while in the previous analysis the six geomor-regions have shown peculiar behaviours. Why did not the authors perform this analysis to the FFEs database of the different geomor-regions? Can the authors try to match this result with the two peaks, 1998 and 2010, closely related to the precipitation anomalies caused by the EASM and El Niño Modoki?

Response: Thank you for the kindly comments. We have added some discussion about the oscillation periods of FFEs and climate indices in Section 5.2.

Revised:

- Rows 227-228 (in revised version): The 12-25a periodicity mainly existed in 1995-2000 and 2008-2013, with the most obvious peaks occurred at 1998 and 2010.

- Rows 429-437 (in revised version): The Pacific Decadal Oscillation (PDO) phenomenon presents above the Pacific Ocean with alternating positive (warm) and negative (cold) phases, has a clear impact on the natural disasters as indicated in the studies (Seiler et al., 2012; Xiao et al., 2015; Zhong et al., 2017). The PDO has greatly affected the periodic climate change, resulting in the alternate variation of FFEs-poor and FFEs-rich in China since 1980s. Studies demonstrated that the warm phase of PDO is conductive to lead the positive precipitation anomalies in eastern China for the period of 1960s-2010s (Zhu et al., 2015; Si, 2016). Moreover, the fluctuation of El Niño and EASM activities also indicate a good correspondence between the variation of FFEs and global climate change in China. This is consistent well with our result that the 12-25a periodicity of FFEs existed in 1995-2000 and 2008-2013, with the most obvious peaks occurred at 1998 and 2010.

Reference:

Seiler, C., Hutjes, R. W. A. and Kabat, P.: Climate Variability and Trends in Bolivia, J. Appl. Meteor. Climatol., 52(1), 130–146, doi:10.1175/JAMC-D-12-0105.1, 2012.

Si, D. and Ding, Y.: Oceanic Forcings of the Interdecadal Variability in East Asian Summer Rainfall, J. Climate, 29(21), 7633–7649, doi:10.1175/JCLI-D-15-0792.1, 2016.

Xiao, M., Zhang, Q. and Singh, V. P.: Influences of ENSO, NAO, IOD and PDO on seasonal precipitation regimes in the Yangtze River basin, China, International Journal of Climatology, 35(12), 3556–3567, doi:10.1002/joc.4228, 2015.

Zhong, Y., Lei, L., Liu, Y., Hao, Y., Zou, C. and Zhan, H.: The influence of large-scale climate phenomena on precipitation in the Ordos Basin, China, Theor Appl Climatol, 130(3), 791–805, doi:10.1007/s00704-016-1904-9, 2017.

Zhu, Y., Wang, H., Ma, J., Wang, T. and Sun, J.: Contribution of the phase transition of Pacific Decadal Oscillation to the late 1990s' shift in East China summer rainfall, Journal of Geophysical Research: Atmospheres, 120(17), 8817–8827, doi:10.1002/2015JD023545, 2015.

Comments: - Subsection 4.4.1 and 4.4.2 have the same titles.

Response: Thank you for the kindly reminder and we have modified the title of subsection 4.4.2.

Revised:

- Row 319 (in revised version): 4.4.2 Inter-annual clustering

Comments: - Subsection 4.4.1. The results showed in rows 253-258 cannot be easily related to figure 8, which contains different coloured lines. Probably, the authors present the results related to the mean monthly frequency of each geomor-region. If my understanding is true, some uncertainties appear in the results (and in table 3). For example, the NWB region also shows a symmetry distribution like the SEM and SWM regions. If not, authors should help the reader in understanding the presented results. Moreover, the worthy attempt to relate behavior of FFEs with seasonality of precipitation can be further improved.

Response: Thank you for the kindly comments. Firstly, referred to July, we classified the distribution of monthly frequency of each geomor-region into three categories. We have added the reference line in the revised Figure 7. Secondly, the mean monthly frequency reflects the main seasonal pattern within the geomor-region, while the unique distribution has also been discussed in the text.

Revised:

- Figure 7 (in revised version)

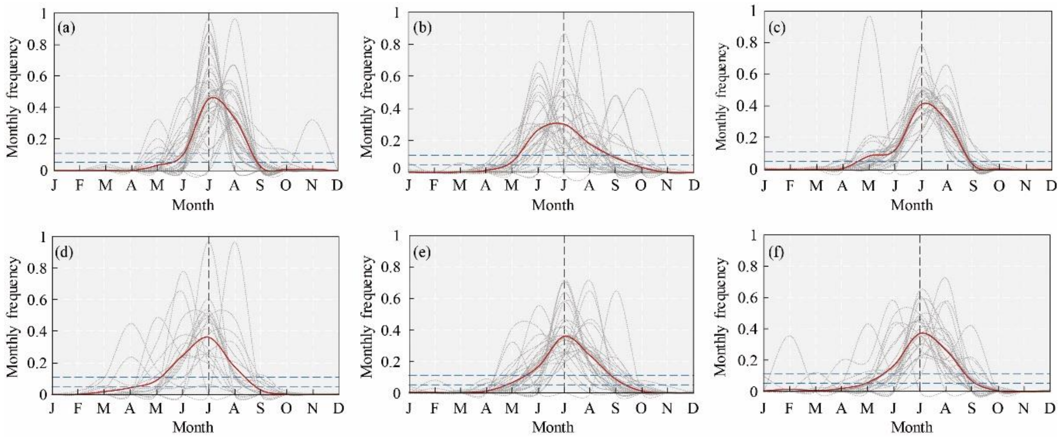

Figure 7: Monthly frequency of FFEs in six geomor-regions. The grey lines are the monthly frequency of the watersheds within each geomor-region; the red line is the mean monthly frequency of each geomor-region; the horizontal blue dashed line is the confidence intervals of 95%, in the case of a non-seasonality pattern. (a) EP; (b) SEM; (c) NCP; (d) NWB; (e) SWM; (f) TP.

Table 4 FFEs characteristics of six geomor-regions identified in China.

Region	Flood-rich months	Flood-poor months	Distribution pattern
EP	July, August	September to May	Right-skew
SEM	June to August	October to April	Left-skew
NCP	June to August	September to April	Right-skew
NWB	June to August	September to April	Left-skew
SWM	June to August	October to April	Symmetry
TP	June to August	October to April	Right-skew

- Rows 297-302: However, some inconsistencies of intra-annual frequency in the same geomor-region can be detected. In NWB, FFEs occurred in June to August can be detected in most watersheds resulting from the heavy storms; while, some watersheds showed the high FFEs frequency in March to May, for the glaciers and snowmelt causing by the rising temperature. In SWM, the long storm period lasting from June to November and the variable topographic features bring about the diverse FFEs-rich period in different watersheds. In TP, the FFEs mostly likely to appear in June to August, with some peaks scatted in different months for the low frequency of FFEs overall.

Comments: - Section 5. The title of the subsection 5.1 is not good. The section contains regression analyses between number of FFEs and some potential physical factors (not impacts) which may induce flash floods.

Response: Thank you for the kindly comments.

Revised:

- Row 338 (in revised version): 5.1 Potential factors of the FFEs trending

Comments: - Section 5.1 can be improved by writing it in a more clear way, in order to avoid repetitions and uncertainties (see notes for row 305 and figure 11). Moreover, the relations between number of FFEs and physical factors (precipitation index, soil moisture) are very uncertain, due to the large spatial scale of the study. The authors, when necessary all over the text, should better stress this fundamental point.

Response: Thank you for the kindly comments. The section 5.1 has been improved to better explain the relations between number of FFEs and physical factors. The reasons for taking the six geomor-regions as the subdivision to discuss the spatiotemporal pattern of FFEs lies in the following aspects. Firstly, the terrain conditions show a more static status for the long-term evolution, compare with the climatic factors, which shows the dynamic features under the globle change. Secondly, the terrain greatly affects the formation of extreme precipitation, people distribution and land use and land cover, which makes it the most fundamental factor in the disaster prevention. Thirdly, apart from the geomorphologic types, the subdivision of geomor-region also takes the climate and humanistic factors into consideration. Therefore, based on the geomor-region, the spatiotemporal differentiation of the climatic factors can be better discussed.

Revised:

- Row (in revised version):

- **Technical corrections**

- **Text**

Comments: - Row 18. "Periodic" is an adjective not a noun.

Response: Thank you for the kindly comments. The "Periodic" has been changed into "Period".

Revised:

- Rows 16-19 (in revised version): To bridge the gap in the research of the spatiotemporal characteristics of flash flooding events (FFEs), based on the longest time series of FFEs in China, this paper used Mann-Kendall (MK) test, wavelet analysis, monthly frequency and index of dispersion (D) to detect the temporal variation, temporal period and temporal clustering of FFEs in China.

-Rows 74-76 (in revised version): This is followed (Section 4) by the analysis of spatiotemporal characteristics of FFEs, including temporal variation, temporal mutation, temporal period, and temporal clustering. We finally (Section5) discussed the typical variations and potential impacts of FFEs trending.

- Row 219 (in revised version): 4.3 Temporal period analysis

- Rows 453-454 (in revised version): To reveal the spatiotemporal characteristics of flash flooding events (FFEs) in China, the longest time series of FFEs was analyzed to obtain the temporal variation, temporal period and temporal clustering on the national scale.

Comments: - Row 117. Change "Where" with "where". Add the information "i<j".

Response: Thank you for the suggestion.

Comments: - Row 121. Change "Formula" with "the following formula".

Response: Thank you for the suggestion.

Comments: - Row 123. Change "Where" with "where". Change "vise" with "vice".

Response: Thank you for the suggestion.

Comments: - Row 135. Change "Where" with "where".

Response: Thank you for the kindly comments.

Comments: - Rows 135-136. The sentence "here, Morlet wavelet was chosen as the mother wavelet function" may be inserted within round brackets.

Response: Thank you for the suggestion.

Comments: - Row 146. Change "Where" with "where".

Response: Thank you for the suggestion.

Comments: - Rows141-142. Move the sentence "However, if a monthly … 5% significance level" at the end of the row 149.

Response: Thank you for the suggestion.

Comments: - Row 157. Change "Where" with "where".

Response: Thank you for the suggestion.

Comments: - Row 168. Separate the words "Figure 2c".
Response: Thank you for the suggestion.

Comments: - Row 169. Separate the words "Figure 2f".
Response: Thank you for the suggestion.

Comments: - Rows 174-176. The increase of the number of FFEs for NWB is vaguely defined (speeding rate), though the NWB and TP regions seem to have the same exponential behaviour.
Response: Thank you for the kindly comments.
Revised:
- Rows 186-188 (in revised version): Additionally, the accumulation number for 1950–2015 indicated that the rates of change in FFEs followed three forms: the increasing of EP and NCP showed the linear pattern; and SEM and SWM increased at a speeding rate; however, the number of FFEs increased exponentially in TP and NWB.

Comments: - Row 179. Separate the words "yellow line".
Response: Thank you for the suggestion.

Comments: - Row 184. Separate the words "Figure 3". Change "33% watershed of all" with "33% of all watershed".
Response: Thank you for the suggestion.

Comments: - Rows 186-188. The sentence is not clear, rewrite in a better English style.
Response: Thank you for the kindly comments.
Revised:
- Rows 200-201 (in revised version): Significant upward trends ($p<0.1$) were detected in all geomor-regions. The most striking significant upward trends were detected in SWM and SEM, which accounted for 89% and 68% of all watersheds in each geomor-region, respectively (Figure 3).

Comments: - Row 187. Separate the words "Figure 3".
Response: Thank you for the suggestion.

Comments: -Row 189. Change "southeast" with "southeastern".
Response: Thank you for the suggestion.

Comments: - Row 200 (caption of figure 3). Change "Where" with "where".
Response: Thank you for the suggestion.

Comments: - Row 208. Separate the words "Figure 4".
Response: Thank you for the suggestion.

Comments: - Row 209. At this first appearance, define the meaning of the symbol "Xa", where X is a number.
Response: Thank you for the kindly comments.
Revised:
- Rows 225-227 (in revised version): On the large scale, the main periodicity characteristics is approximately 12–25a (here, a referred to one year), with three oscillation periods, and tend to be stable since 1980. On the small scale, the 2–8a time scale is prominent, with two oscillation periods, which started to stay stable since 2006.

Comments: - Row 224. Change "were" with "are".
Response: Thank you for the suggestion.

Comments: - Row 225. Change "corresponded" with "correspond".

Response: Thank you for the suggestion.

Comments: - Rows 227-229. The sentence is not clear, rewrite in a better English style.
Response: Thank you for the kindly comments. In the revised version ,this sentence has been deleted.

Comments: - Row 234. Separate the words "Figure 7".
Response: Thank you for the suggestion.

Comments: - Row 247. Separate the words "Figure 8".
Response: Thank you for the suggestion.

Comments: - Row 250 (caption of figure 8). Delete "Where".
Response: Thank you for the suggestion.

Comments: - Rows 254-255. The sentence is not clear, rewrite in a better English style.
Response: Thank you for the suggestion.
Revised: **- Rows 291-293 (in revised version):** EP, NCP, and TP tend to be right-skew distribution, with the high frequency of FFEs were more likely to appeare after July (Figure 7a, 7c, 7f). The intensive consecutiveconvective rainfall in these geomor-regions concentrated in mid to late-summer.

Comments: - Row 274. Separate the words "Figure 10".
Response: Thank you for the suggestion.

Comments: - Row 278. Do the authors intend "regular distribution of monthly FFEs occurrence"?
Response: Thank you for the suggestion.
Revised:
- Rows 321-323 (in revised version): Extensive significant clustering, large D up to 1, can be detected in EP, SEM, and SWM geomor-regions, with the largest one of 3.19 in Hainan Island of SEM, meaning that on average FFEs occur 3.19 times more often in FFEs-rich years than would be expected from the Poisson distribution.
- Rows 326-327 (in revised version): In this study, the characteristic under-dispersion of FFEs occurrence was mainly identified in NCP, SEM, and the junction zone between TP and SWM, which seem to have a more regular temporal pattern among years.

Comments: - Rows 290-291. The definition of the factor R90p is not clear (cumulative precipitation formed only by daily precipitation greater than 90th percentile of 1980-2010 precipitation?). Moreover, here it is indicated as seasonal precipitation, while caption of figure 11 indicates R90p as annual total precipitation.
Response: Thank you for the suggestion. The R90p was defined as the monthly total precipitation amount of the rainy days with daily precipitation greater than 90th percentile of 1980-2010 daily precipitation. We firstly obtained the 90th percentile of 1980-2010 daily precipitation, and then selected out the rainy days with daily precipitation exceeding the 90th percentile of 1980-2010 daily precipitation, finally calculated the annual total precipitation amount of these days.
Revised:
- Rows 350-353 (in revised version): In this paper, we selected the annual total precipitation amount of the rainy days with daily precipitation exceeding 90th percentile of 1980–2010 daily precipitation (R90p) and the mean soil moisture (SM) of summer (May to August) to detect the potential impacts that may be caused by these indicators.

- Figure 10 (in revised version): Relations between R90p and FFEs. Where, R90p indicates the annual total precipitation amount of rainy days with precipitation exceeding 90th percentile of 1980-2010 daily precipitation. (a) EP; (b) SEM; (c); NCP; (d) NWB; (e) SWM; (f) TP.

Comments: - Row 293. Separate the words "Figure 11".

Response: Thank you for the suggestion.

Comments: - Row 304. How is assessed the statistical significance of the correlation?

Response: Thank you for the suggestion. The statistical significance of the correlation was assessed by R value and p value, where the $R > 0.5$ and $p < 0.01$ was identified as significant correlation.

Revised:

- Rows 365-366 (in revised version): Figure 12 displayed the scatter plot of soil moisture and FFEs in all six geomor-regions, and the significant positive correlation (with $R > 0.5$, $p < 0.01$) between soil moisture and FFEs was identified only in TP (Figure 12f).

Comments: - Row 305. The importance of the role of the soil moisture on FFEs has been assessed before in row 289.

Response: Thank you for the suggestion. The description of the role of the soil moisture and precipitation has been adjusted to the first paragraph in section 5.1.

Revised:

- Rows 344-346 (in revised version): The variation of atmospheric circulations and monsoon activities on the large scale have great influence on the regional precipitation. The anomalies of atmospheric circulations could be the important reasons for the variability of the intensity and frequency of extreme precipitation in China (Lv et al., 2019; Ma et al., 2018).

- Rows 347-349 (in revised version): Soil moisture has an important role in the hydrological cycle, governing the evaporation, runoff, infiltration processes. Therefore, apart from precipitation, the overall soil moisture state of a catchment is another vital factor in the initiation of flash flooding.

Comments: - Row 330. The word "similar" is repeated in the same sentence.

Response: Thank you for the suggestion. The sentence has been modified.

Revised:

- Rows 414-416 (in revised version): The circulation anomalies were attributed to the tropical sea surface temperature anomalies pattern in the preceding seasons, i.e., the super El Niño and strong warming in the tropical Indian Ocean (Yuan et al., 2017).

Comments: - Row 334. It is not clear what is the heavy rainfall center. Maybe it has to be related to figure 13 (not cited)? Moreover, change "center" with "centre".

Response: Thank you for the comments. The heavy rainfall centre referred to the area with the anomalies of precipitation more than 100%.

Revised:

- Rows 418-420 (in revised version): However, the FFEs occurred in September and October were not detected in the heavy rainfall centre (with the anomalies of precipitation more than 100%) (Figure 12e, 12f), which indicated there may be other factors together with the precipitation anomalies to induce the flash flooding during this period.

Comments: - Row 344 (caption of figure 13). Delete "Where".

Response: Thank you for the suggestion.

Comments: - Row 356. Do not start a sentence with "And".

Response: Thank you for the suggestion.

Comments: - Row 360. "Periodic" is an adjective not a noun.

Response: Thank you for the kindly comments. The "Periodic" has been changed into "Period".

Revised:

- Rows 453-454 (in revised version): To reveal the spatiotemporal characteristics of flash flooding events (FFEs) in China, the longest time series of FFEs was analyzed to obtain the temporal variation, temporal period and temporal clustering on the national scale.

Comments: - Row 367. Delete the words "of all" or change the sentence.
Response: Thank you for the suggestion.

Comments: - Row 381. Change "the new insights" with "new insights".
Response: Thank you for the suggestion.

- **Figures**

Comments: - Figures 1 and 3. Change the NWP symbol into NWB (as in the description of the six geomorphologic regions of table 1).
Response: Thank you for the suggestion. The symbol has been changed in the revised version.
Revised:
- Figure 1 and 3 (in revised version):

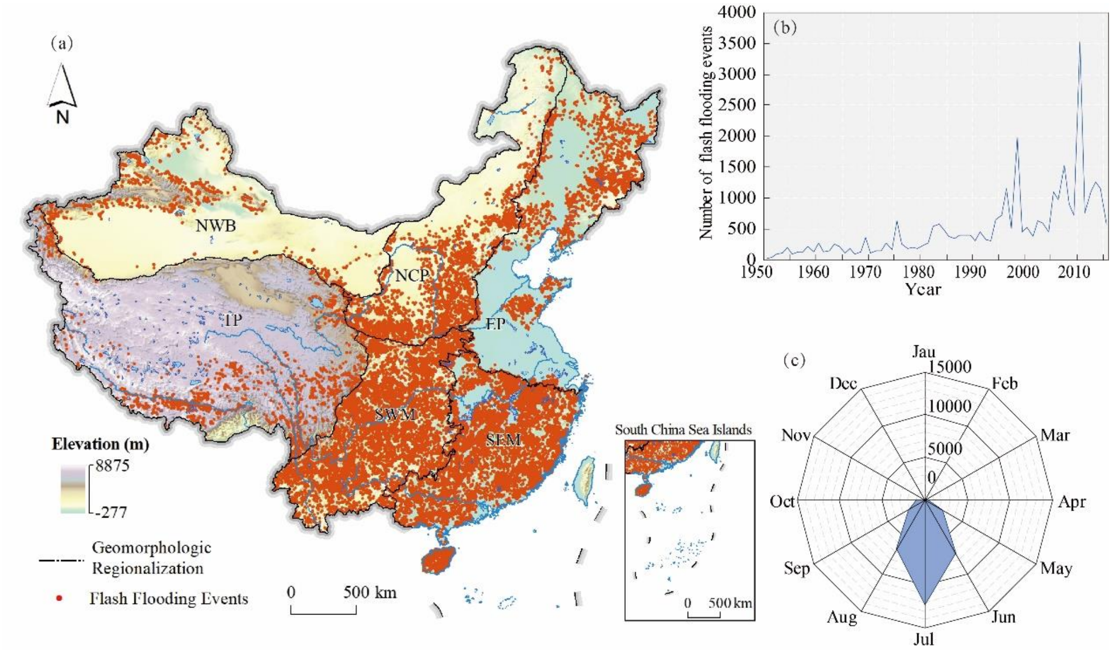

Figure 1: Location and intra-year and inter-year series of FFEs in China over 1950-2015. (a) the spatial location of the study area and the distribution of FFEs; (b) the intra-year series of the FFEs; (c) the inter-year series of FFEs.

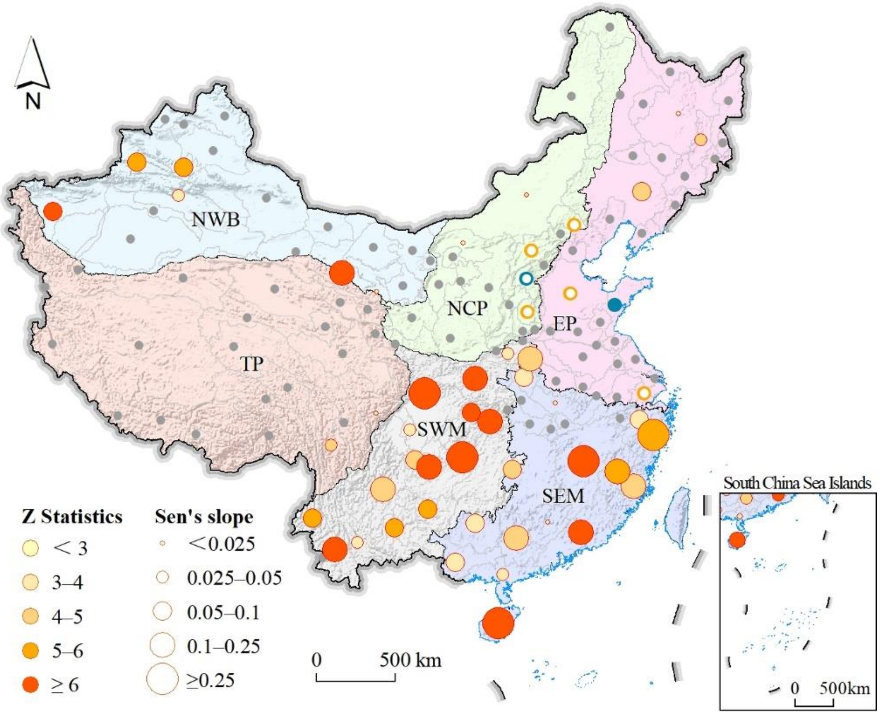

Figure 3: Trends in the annual frequency of FFEs through the MK test and Sen's slope estimation, where, the blue and yellow solid circles show significant downward and significant upward at a confidence level of 90%; the blue and yellow circles with white holes indicate downward and upward trends that are not satisfied with the confidence interval of 90%; the grey solid circles indicate insignificant trends.

Comments: - Figure 2. The equations represent the relationships between the year and the number of FFEs for each region. The suggestion is to change regression equations as previously suggested for rows 171-173.

Response: Thank you for the suggestion. The equations have been changed in the revised version.

Revised:

- Figure 2 (in revised version)

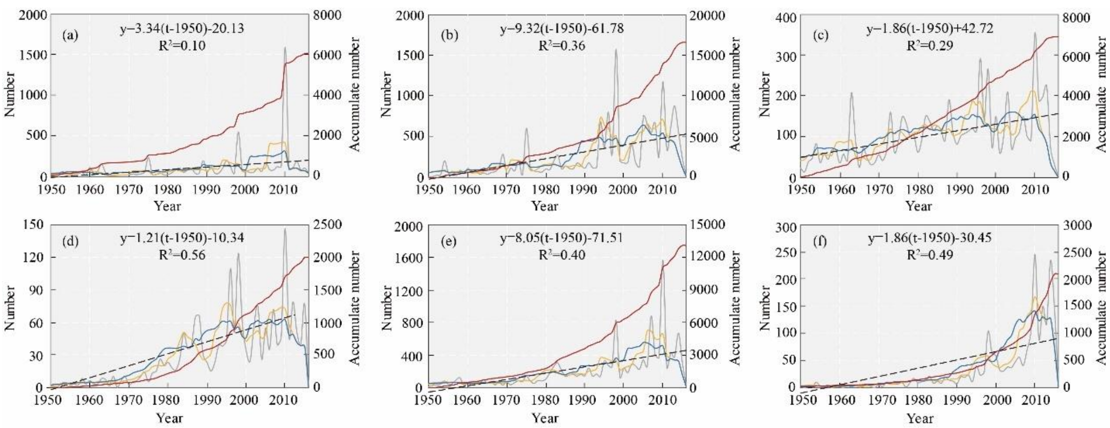

Figure 2: Time series of the annual mean number of FFEs in six geomor-regions of China from 1950 to 2015. The grey line is the original time series; the yellow line and blue line are the 5-year and 10-year moving average of time series, respectively; the red line is the accumulate number of FFEs; and the black dashed line is the trend line based on the least-squares linear regression. (a) EP; (b) SEM; (c); NCP; (d) NWB; (e) SWM; (f) TP.

Comments: - Figure 4. At the end of the caption, add the words "for the entire China".

Response: Thank you for the suggestion. The caption has been modified in the revised version.

Revised:

- Figure 4 (in revised version): Figure 4: The real-part of the wavelet coefficient of FFEs for the entire China.

Comments: - Figure 5. After the words "of FFEs" in the caption, add the words "for the entire China". Delete the article "the" at the start of the parts (a) and (b) of the caption.

Response: Thank you for the suggestion. The caption has been modified in the revised version.

Revised:

- Figure 5 (in revised version): Figure 5: The Morlet wavelet analysis of FFEs for the entire China. (a) modulus of wavelet coefficients; (b) energy spectrum of wavelet.

Comments: - Figure 6. At the end of the caption, add the words "for China".

Response: Thank you for the suggestion. The caption has been modified in the revised version.

Revised:

- Figure 6 (in revised version): Figure 6: The wavelet variance analysis of FFEs for China.

Comments: - Figure 8 seems not to agree with figure 1c, even if this can be a trivial problem of scale representation. In fact, some geomor-regions of figure 8 show regional FFEs values in months like February and November, which have no concordance in figure 1c. Can the authors provide an explanation?

Response: Thank you for the comments. The difference in Figure 1c and Figure 7 resulted from the problem of scale representation. On one hand, Figure 1c showed the number of FFEs, and the FFEs of September to February is much fewer than those in May to October, resulting the misleading representation. On the other hand, Figure 8 showed the monthly frequency (Fm), a dimensionless number, and the gap of the Fm values in each geomor-region is much little than on the national scale.

Comments: - Figure 9. The caption can be shortened deleting the words "Maps showing the" and "Where".

Response: Thank you for the suggestion. The caption has been modified in the revise version.

Revised:

- Figure 8 (in revised version): Monthly frequency of FFEs by different months. The color bar represents the monthly FFEs frequency (FFm) for each month; the yellow to red areas are the watersheds with significant FFEs-rich month (FFm larger than 0.11), while the blue areas are the watersheds with significant FFEs-poor month (FFm lower than 0.05).

Comments: - Figure 11. The graphs are in logarithmic scale; therefore, both the labels of the variables have to be indicated with logarithm. Moreover, the suggestion to be clearer in the definition of variables all over the work here is fundamental. In fact, it is not clear what the points could be (Number of FFEs for each location within a watershed of a region?). In other words, while the red points of figure 1 are obviously all the FFEs collected for this work, it is not clear what the points of figures 11 and 12 really could be.

Response: Thank you for the comments and suggestion. The labels of the variables have been clarified in the revised version. In Figure 11 and Figure 12, the points are the number of FFEs within a watershed of each geomor-region, which are different from the red points which are the location of each FFE.

Revised:

- Rows 354-356 (in revised version): Figure 10 showed the scatter plot of R90p and the number of FFEs in each watershed of six geomor-regions, and the significant positive correlations between R90p and FFEs were identified in SEM and NWB (Figure 10b, 10d).

- Rows 366-368 (in revised version): Figure 11 displayed the scatter plot of soil moisture and the number of FFEs in each watershed of six geomor-regions, and the significant positive correlation (with $R > 0.5$, $p < 0.01$) between soil moisture and FFEs was identified only in TP (Figure 11f).

- Figure 10 (in revised version)

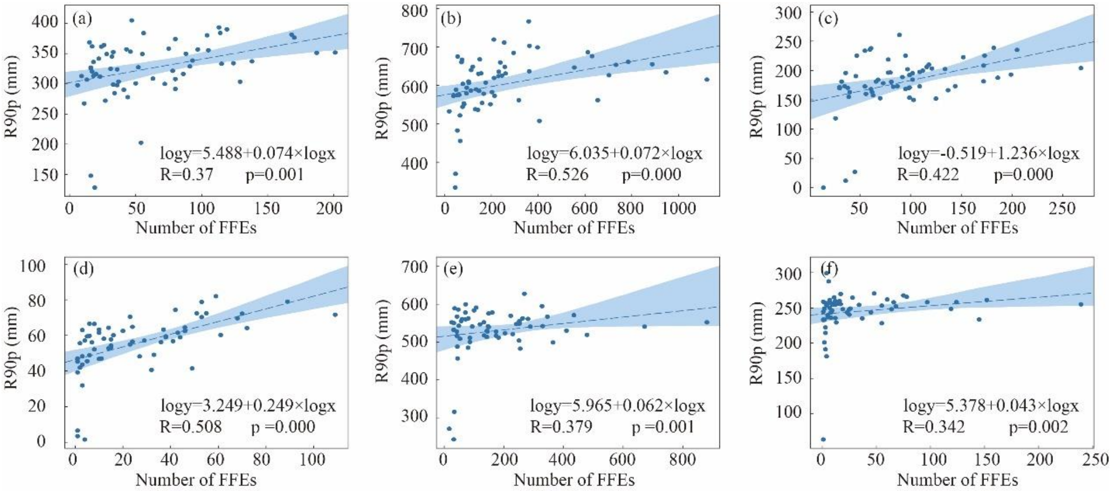

Figure 10: Relations between R90p and FFEs. Where, R90p indicates the annual total precipitation amount of rainy days with precipitation exceeding 90th percentile of 1980-2010 daily precipitation. (a) EP; (b) SEM; (c); NCP; (d) NWB; (e) SWM; (f) TP.

Comments: - Figure 13 is not cited in the text. The six graphs for each year do not correspond to the four months May-August of the caption.

Response: Thank you for the comments. We added the citation of figure 13 in the text. The six graphs for each year are May-October actually, and we modified in the caption.

Revised:

- Rows 411-412 (in revised version): In August, the main rainfall belt was located over the Yangtze River, with precipitation 100% and more above normal (Figure 12d).

- Rows 417-421 (in revised version): The anomalies of precipitation resulted in the rainfall belt moving from lower to upper reaches along the Yangtze river from June to August (Figure 12b, 12c, 12d). However, the FFEs occurred in September and October were not detected in the heavy rainfall centre (Figure 12e, 12f), which indicated there may be other factors together with the precipitation anomalies to induce the flash flooding during this period.

- Rows 425-427 (in revised version): The cluster centre of FFEs moved from Yangtze River to Huai River to Yellow River from May to July (Figure 12g, 12h, 12i), which showed closely connection with the precipitation anomalies.

- Figure 12 (in revised version): Percentage anomalies of precipitation averaged in May–October. The red points are the location of FFEs. (a–f) May–October of 1998; (g–l) May–October of 2010.

- **<u>Tables</u>**

Comments: - Table 2. For the sake of readability, add the total number of watersheds for each region. This can be very useful for a better understanding of the following analyses.

Response: Thank you for the suggestion.

Revised:

- Table 3 (in revised version)

Table 3 Number (percentage) of watersheds with upward/downward trends in the number of FFEs.

Region	EP	SEM	NCP	NWB	SWM	TP	All China
Upward	4(12%)	13(68%)	2(10%)	5(26%)	16(89%)	3(13%)	44(33%)
Downward	1(3%)	0(0%)	0(0%)	0(0%)	0(0%)	0(0%)	1(1%)
Total	34	19	20	19	18	23	133