Reply to the referee comments on "Analysis of the Relationship between Official Rain-Praying Rituals and Droughts in China over the Past 2000 Years" by Shuo Wang et al

Dear editors and reviewers,

Thank you for your valuable comments and thoughtful suggestions on our manuscript. Following your comments on the manuscript, we made careful revisions, and the point-to-point response of the comments is listed below. We hope these revisions would make this manuscript more acceptable for publication. Please feel free to contact me if you have any questions.

Many thanks again. With best wishes.

Sincerely yours,

Shuo Wang

Anonymous Referee #1

1. The rain-praying data are mainly derived from sources such as The Twenty-Four Histories, Draft History of the Qing, and the Veritable Records of the Ming and Qing Dynasties. However, the recording density of these sources differs substantially. For example, the Ming and Qing Veritable Records are archival documents with near-daily entries, whereas earlier sources such as the dynastic histories of the Han and Tang periods are largely retrospective narrative compilations. This raises the possibility that rain-praying events in the Ming and Qing periods were more likely to be recorded than those in earlier periods. The manuscript briefly acknowledges this issue but does not conduct any quantitative correction. This potential bias needs to be addressed more rigorously.

Response 1: Accepted and revised. We sincerely thank the reviewer for this insightful comment. We fully agree that differences in recording density among historical sources may introduce structural bias into the long-term series of official rain-praying activities.

To address this issue, we have substantially revised the dataset and introduced a standardized Official Rain-Praying Index (ORPI). The index was normalized to a scale of 0–1 to reduce the influence of uneven documentary preservation and source-recording intensity across historical periods. The construction of the index considers both the frequency and temporal distribution of official rain-praying records while minimizing the potential bias caused by the greater abundance of historical documentation in the Ming and Qing dynasties.

When calculating the index of official rain-praying rituals, if the maximum number of official rain-praying rituals over a ten-year period is uniformly set at 82, this would artificially lower the composite index for earlier periods due to the scarcity of historical data from the past and the abundance of it in more recent times. Therefore, the composite indices for each period are calculated separately, using the breakpoints of 900 AD, 1730 AD and 1830 AD obtained from Ordered Cluster Analysis as the boundaries. Here, C_{max} represents the maximum number of rain-praying rituals per decade for each period, specifically:

Stage 1 (200 BCE – 900 CE): C_{max}=5

Stage 2 (910 CE – 1730 CE): C_{max}=29

Stage 3 (1740 CE – 1830 CE): C_{max}=82

Stage 4 (1840 CE – 1910 CE): C_{max}=72

In addition, we further clarified the data collection procedure and ensured that duplicate records were removed through manual cross-checking of all identified events. The official rain-praying dataset was reconstructed using the Twenty-Four Histories, Draft History of the Qing, and the Ming and Qing Veritable Records, with each event retained only once in the final database.

The methodology used to calculate the Official Rain-Praying Index has now been added to the revised manuscript, and the original frequency and occurrence-year statistics are still preserved and discussed in Section 3.1.3 and Figure 3 to facilitate comparison with previous studies.

2.2.5 Construction of the Rain-Praying Index Series

To mitigate the bias in the rain-praying rituals series caused by the scarcity of ancient records and the abundance of modern records, the Official Rain-Praying Index (ORPI) is constructed, following the famine index methodology proposed by Teng et al. (2014). This index reflects both the frequency and intensity of rain-praying rituals. The calculation steps are as follows:

$$ORPI_i = \left(\frac{Y_i}{Y_{max}} + \frac{C_i}{C_{max}}\right) \quad (7)$$

where Y_i (C_i) represents the number of years (or number) of official rain-praying rituals within period i, and Y_{max} (C_{max}) represents the maximum number of years (or number) of official rain-praying rituals within a given period.

The resulting time series of the index of official rain-praying rituals is shown below:

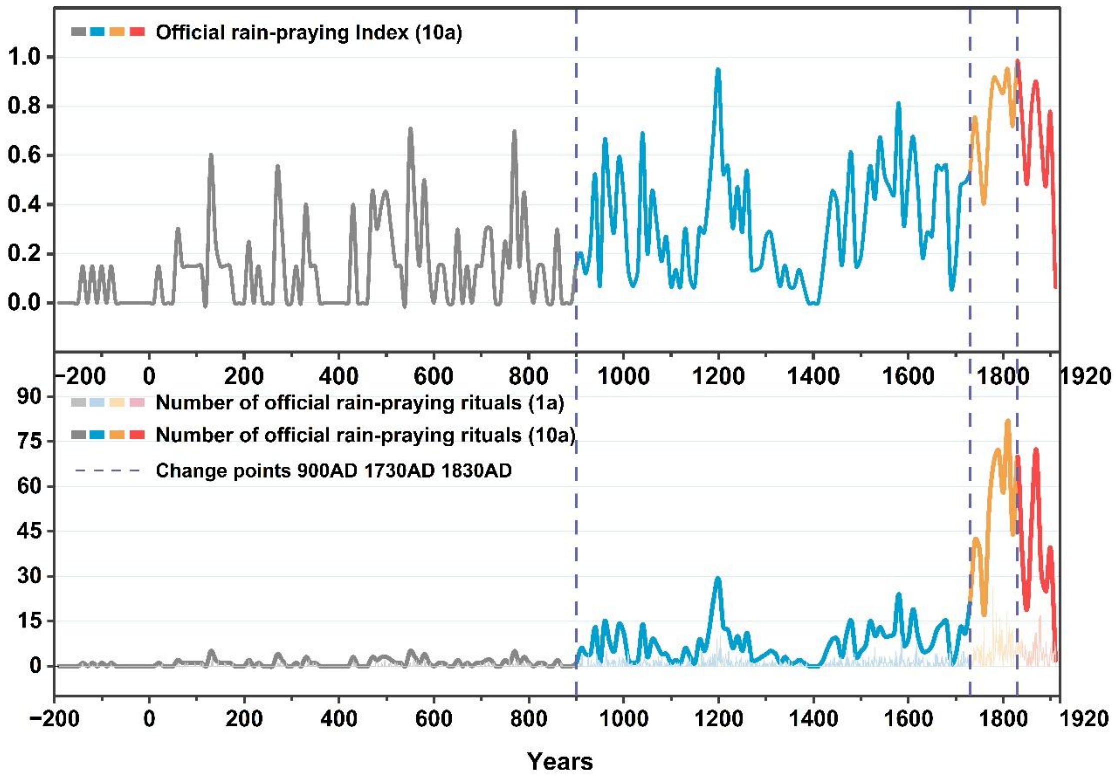

Figure: Number of Official Rain-Praying Rituals (10a) and Official rain-praying Index rituals series (10a).

2. Related to the issue above, I also have concerns about the comparability of the drought dataset. Although the authors use the authoritative source *Collection of Meteorological Records in China for the Past 3000 Years*, it is still possible that drought records from the Han to Yuan periods are underrepresented compared with the much richer documentary evidence from the Ming and Qing periods. This may lead to an underestimation of drought indicators in earlier periods. The authors are encouraged to incorporate additional proxy records reflecting drought variability for comparison and cross-validation in order to improve the reliability of the dataset.

Response 2: Accepted and revised. We appreciate the reviewer's valuable suggestion regarding the comparability of the drought dataset.

Although the drought records used in this study were derived from the authoritative Collection of Meteorological Records in China for the Past 3000 Years, we acknowledge that documentary evidence from earlier dynasties may be less complete than that from the Ming and Qing periods.

To improve the robustness of the analysis, in order to improve the reliability of the dataset, we incorporate additional proxy records reflecting drought variability for comparison and cross-validation. The precipitation reconstructions of Shi et al. (2021) for North China (NC), Central China (CC), and East China (EC) were generated through data assimilation that integrates instrumental observations, multiple proxy records, and climate-model simulations, and were further validated using independent proxy datasets. These regions spatially overlap with the core areas where historical rain-praying records are concentrated, making them highly relevant for comparison with the Rain-Praying Index.

In addition, we employed the precipitation reconstruction of Tan et al. (2011), which synthesizes speleothem records and historical drought/flood indices using principal component analysis to a high-resolution, independently validated precipitation series for north-central China over the last 1800 years.

Relevant descriptions of the proxy records, data sources have been added to the revised manuscript (Section 2.1.2, Line 118–136).

2.1.2 Precipitation Reconstruction Datasets

To provide independent precipitation proxies for evaluating drought variability, two precipitation reconstruction datasets were incorporated for comparison and cross-validation.

The first dataset was derived from Shi et al. (2021), who reconstructed summer precipitation variations across eight climatic regions of China over the past 22,000 years using an Optimal Information Extraction (OIE) data assimilation framework. The reconstruction integrates instrumental observations, proxy-based precipitation records, and outputs from multiple climate model simulations, including CESM-LME, LOVECLIM-LCE, and TraCE-21ka. In the present study, the precipitation series for North China (NC), Central China (CC), and East China (EC) were extracted for the period 200 BC–1910 AD. These regions correspond closely to the primary distribution areas of historical rain-praying rituals in eastern China.

The second dataset was obtained from Tan et al. (2011), who reconstructed a decadal-resolution precipitation series for north-central China spanning AD 190–1980. The reconstruction was developed using principal component analysis (PCA) of multiple independently dated hydroclimatic archives, including stalagmite $\delta^{18}O$ records from Wanxiang Cave and Huangye Cave, as well as historical drought/flood indices from the Longxi region and the Haihe River Basin. To match the temporal coverage of the documentary drought dataset, the segment covering AD 190–1910 was extracted and used in the present analysis.

3. Analytical methods are too simple to support complex historical interpretations; the core analytical methods of the paper are Spearman correlation and moving correlation analysis. However, the research questions involve complex issues such as political institutions, administrative capacity, social crises, and climate variability. Simple correlation analysis is insufficient to support the causal interpretations proposed in the manuscript. Many of the conclusions currently rely primarily on historical narrative rather than statistical testing. The manuscript repeatedly argues that increases in rain-praying frequency served functions such as demonstrating the Mandate of Heaven, stabilizing society, or responding to governance crises. However, these interpretations are

supported only by historical examples rather than quantitative indicators. The authors are encouraged to introduce multivariate regression models to statistically examine the relationship between explanatory variables and the response variable. In particular, previously quantified indicators of social activity, such as war frequency, rebellion events, or fiscal stress, could be incorporated to test whether rain-praying activities indeed increased during periods of political crisis. Without such tests, these interpretations remain historical narratives rather than empirically validated conclusions.

Response 3: Accepted and revised. We thank the reviewer for this valuable suggestion. We agree that the original version relied primarily on correlation analysis and historical interpretation, which was insufficient to quantitatively evaluate the relationships between rain-praying rituals and broader social, economic, and political conditions.

To address this concern, we incorporated several additional datasets that have been widely used to characterize social and economic variability in historical China. These include a peasant uprising series reconstructed by Fang et al. (2015)based on the History of Chinese Peasant Revolutionary Struggles and the General History of China, a fiscal balance series from Wei et al. (2014), and a grain harvest grade series from Yin et al. (2015). The peasant uprising record was selected because it reflects social instability driven primarily by livelihood pressures and differs from interstate wars, ethnic conflicts, or military rebellions.

The newly incorporated datasets are summarized in the revised manuscript as follows:

Name	Site	Proxy type	Resolution	Period (BCE/CE)	Reference
Precipitation	North China (NC), Central China (CC), and East China (EC)	CESM-LME, LOVECLIM-LCE, and TraCE-21ka	Decadal	200BCE–1910CE	Shi et al. (2021)
Precipitation	North China Plain (104°–121°E, 33–42°N)	Multi-proxies	Decadal	190CE–1980CE	Tan et al. (2011)
Peasant uprising	Whole China (23°–42°N, 80°–127°E)	Historical documents	Decadal	210BCE–1910CE	Fang et al. (2015)
Grain harvest grade	Whole China (23°–42°N, 80°–127°E)	Historical documents	Decadal	210(BCE)–1910	Yin et al. (2015)
Fiscal balance	Whole China	Historical documents	Decadal	210(BCE)–1910	Wei et al. (2014)
Economic	Whole China	Historical	Decadal	210(BCE)–	Wei et al.

level		documents		1910	(2015)

In addition, we incorporated independent precipitation reconstructions to further evaluate the climatic significance of the Official Rain-Praying Index. Correlation analyses were conducted between the Official Rain-Praying Index and reconstructed precipitation series. Although the full-length records do not exhibit significant correlations, analyses conducted for periods with relatively complete documentary evidence (200CE–1910 CE) reveal significant relationships during several dynastic periods. Specifically, the Rain-Praying Index shows significant negative correlations with the precipitation reconstructions of Shi et al. (2021)and significant positive correlations with the precipitation reconstruction of Tan et al. (2011), supporting the interpretation that rain-praying activities were associated with hydroclimatic.

Following the reviewer's suggestion, we also explored multivariate regression models incorporating fiscal balance, grain harvest grades, peasant uprisings, and hydroclimatic variables. The results indicate that simple linear relationships are generally weak and do not adequately explain variations in the Rain-Praying Index. Considering the possibility that rain-praying activities responded differently under varying levels of environmental and social stress, we further introduced threshold regression analysis to examine potential nonlinear relationships between the Rain-Praying Index and these explanatory variables.

Interpretations concerning political legitimacy, governance capacity, and social crisis are now discussed more cautiously and are supported by the additional statistical analyses where appropriate.

4. The manuscript defines each record as one rain-praying event. However, historical sources may record the same event multiple times. A single rain-praying activity may last for several days, and actions in different locations may originate from the same administrative order. Therefore, the statistical unit of events may not be consistent. The authors should clarify whether duplicate counting exists and whether the time series may contain structural biases due to the counting method.

Response 4: Accepted and revised. We highly appreciate the reviewer's insightful and discerning comment regarding the potential risk of duplicate counting and inconsistent statistical units.

To avoid any ambiguity, we would like to clarify that during our initial database construction, we did perform line-by-line cross-checking of all historical accounts to ensure the uniqueness of each recorded event. However, we admit that the description of this screening process in the original manuscript (previously around Line 205) was too brief and lacked sufficient detail.

In accordance with your valuable suggestion, we have substantially revised and expanded the description of our data processing protocol in the revised manuscript to make our methodology completely transparent. Specifically, "Step 3" of the data filtration workflow has been updated to explicitly detail our manual cross-verification and deduplication procedure as follows:

Step 3: Manual cross-verification and deduplication. (1) Institutional texts, rain-praying poems, and other non- “actual rain-praying actions” were removed. (2) Each entry was compared across the original texts (printed editions) to remove duplicate records arising from overlapping keywords or repeated mentions in different sections. This step ensures that each recorded rain-praying ritual represents a unique, verifiable event.

5. The authors propose that rain-praying activities exhibit a four-stage pattern (“low–high–low–high”). However, the division of stages appears to rely mainly on dynastic chronology rather than statistical testing. The stage classification should be based on time-series analysis and supported by statistical methods; otherwise, the segmentation may be subjective.

Response 5: Accepted and revised. We agree that stage division should be statistically supported rather than relying solely on dynastic chronology. Therefore, we applied ordered clustering analysis to both the frequency series and the Rain-Praying Index series to identify significant temporal regimes objectively. The results consistently identified four major stages and largely corresponded with, but were not predetermined by, dynastic boundaries. Prior to this analysis, we also tested the Mann–Kendall mutation detection method. However, due to the large number of zero values, discontinuities in the series, and the overall long-term increasing trend, no statistically significant intersections between UF and UB curves were detected at $\alpha = 0.05$.

The breakpoints detected were in the 900CE, 1730CE and 1830CE, revealing changes across four distinct phases.

Revised text as follow (Section 2.2.4, Line 304–327):

2.2.4 Ordered Cluster Analysis

Ordered clustering is a method used to identify change points or trend shifts in time series data. Its core principle is to cluster only adjacent years in the time series, ensuring temporal continuity in the clustering results. Based on these results, distinct phases are then delineated. This study employs the improved ordered clustering method proposed by Yuan et al. (2017) to segment the time series of official rain-praying frequency from the Western Han Dynasty to the Qing Dynasty (202 BC–1911 AD). The specific calculation procedure is as follows:

（1）Let the rain-praying frequency time series of length n be $\{x_1, x_2, \dots x_n\}$, Adjacent years in the series are considered as candidate breakpoints α, with $2 \leqslant \alpha \leqslant n-1$.

（2）Calculate the mean of the two sequence segments before and after the breakpoint α.

$$\bar{x}_{\alpha} = \frac{1}{\alpha}\sum_{i=1}^{\alpha} x_i \quad (1)$$

$$\bar{x}_{n-\alpha} = \frac{1}{n-\alpha}\sum_{i=\alpha+1}^{n} x_i \quad (2)$$

（3）Calculate the intra-class standard deviation for the two segments of the sequence.

$$\sigma_{\alpha} = \sqrt{\frac{1}{\alpha}\sum_{i=1}^{\alpha}(x_i - \bar{x}_{\alpha})^2} \quad (3)$$

$$\sigma_{n-\alpha} = \sqrt{\frac{1}{n-\alpha}\sum_{i=\alpha+1}^{n}(x_i - \bar{x}_{n-\alpha})^2} \quad (4)$$

（4）Calculate the inter-class deviation between the two sequence segments.

$$d = |\bar{x}_{\alpha} - \bar{x}_{n-\alpha}| \quad (5)$$

（5）Define the improved objective function.

$$S_1(\alpha) = \sigma_{\alpha} + \sigma_{n-\alpha} - d \quad (6)$$

（6）Iterate through all candidate breakpoints α, compute the corresponding $S_1(\alpha)$values, and identify the αthat minimizes $S_1(\alpha)$as the optimal change point.

References

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