Responses to Reviewer 2

R 2.1: The manuscript titled "Climatic and Societal Impacts of Volcanic Eruptions in the Western Han Dynasty (206 BCE - 8 CE): A Comparative Study" provides a comprehensive case investigation of the potential climatic and societal impacts of volcanic eruptions on ancient China, employing both quantitative and qualitative analysis. The study is well designed, and the results help foster our understanding of the interplay between the nature-induced-disasters and human society beyond the common era. I therefore recommend publication of the study after addressing the following comments and issues raised by other reviewers.

A 2.1: We thank the reviewer for their supportive comments.

R 2.2: Section 2.2, in addition to list the data sources, please describe how the data (for example, the ones in Figure 1) are compiled. How are the frequencies accounted? How are the time series reconstructed, which data sources/chronicles have been included in different periods? Are they consistent, especially during the two periods of 180-150 BCE and 60-30 BCE?

A2.2: Thank you for these queries. The method for compiling data is provided in Sections 2.1 and 2.2. Each entry included in our frequency count is listed in the supplementary tables, with a column clarifying the source and reference for each record.

As outlined in section 2.1, our approach involved a thorough re-surveying of available historical sources and the integration of their content with established datasets including *A Compendium of Meteorological Records of China in the Last 3000 Years* by Zhang et al. (2004), *The General History of Natural Disasters in China-the Volume of Qin and Han* by Jiao et al. (2009), and the *Table of Natural and Human Disasters in Chinese Dynasties* by Chen et al. (1933), as well as two studies on Han climate that provide lists of relevant records (Chen, 2016; Chen, 2001).

Hanshu, the dynastic history, is ultimately our main historical source, along with *Shiji*. If the same event is documented in both sources, we counted it only once to avoid repeated counting. Thus, in terms of research method and source, our counting is consistent throughout the whole period under study — the Western Han Dynasty — including the case study years 180-150 BCE and 60-30 BCE. In addition, we compared our counts with all the existing datasets mentioned above. In rare cases, where there are slight differences, we re-examined the historical contexts and details of the relevant records to confirm our decision about whether the event in question should be counted. This has also been detailed in the notes of Table S1 and the additional "Notes for the Tables" document in supplementary materials.

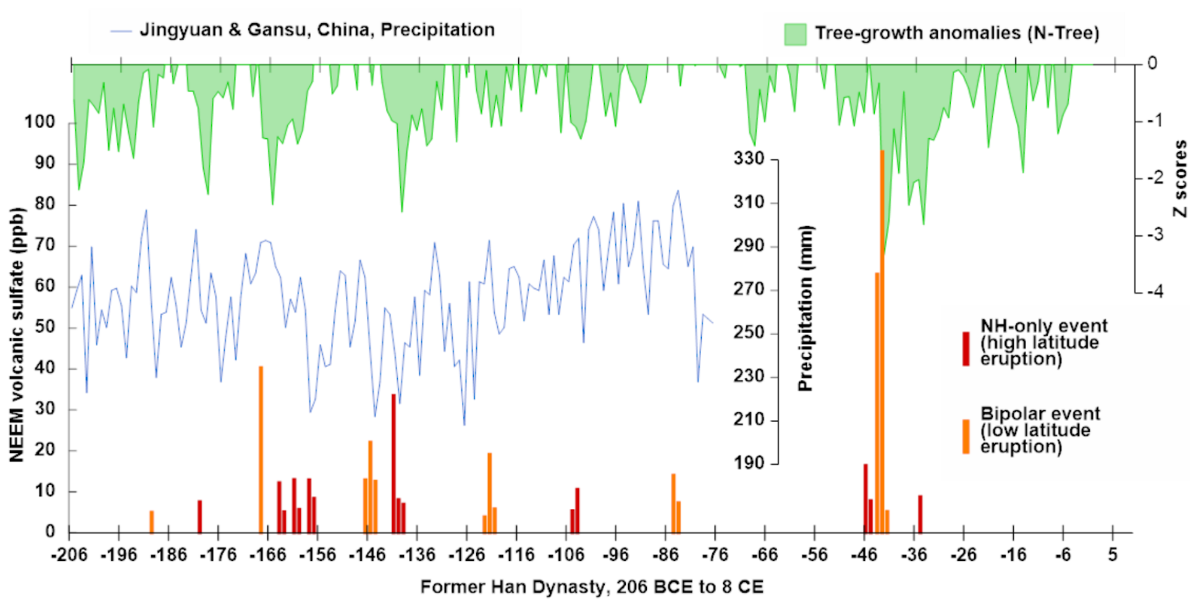
To improve clarity in the main article text, we have revised the relevant wording and added additional explanation to address this comment (as well as the related comment R1.3 of the first reviewer, in response to which we have added a table to the main text exemplifying the types of data extracted from our historical sources and the number of records for each disaster type).

R 2.3: Figure 1. It would be nice to see the information about the 11 eruptions, for example, the cumulative radiative forcing of the eruptions, in this figure. Please also state in the figure caption, where the data drawn can be found (tables in the Supplemental Information, etc).

A 2.3: We thank the reviewer for these suggestions.

We have now added a new figure to the manuscript. Ultimately all our volcanic dates and forcing data come from the study of Sigl et al. (2015), which provides the relevant data in its supplementary files. However, there are many ways by which to graph the number and forcing potential of the volcanic events under study for our period. Since the data originally come in the form of ice-core sulphate deposition measurements, we have plotted the annual chronology of sulphate deposition (in ppb) deemed of volcanic origin by Sigl et al. (2015). We also indicate the distinction made by these authors between "bipolar" volcanic signals (i.e., those found in ice-cores in both hemispheres and deemed to represent tropical or low-latitude eruptions) and those signals found only in Greenland ice (and deemed to represent extratropical Northern Hemispheric eruptions). Sigl et al. (2015) also provide an estimate of global radiative forcing (in terms of the cumulative annual reduction of solar energy reaching the Earth's surface, in watts per square meter) associated with the sulphate output from each eruption, and we now also cite these values in the main text.

Additionally, we plot negative growth values from the temperature-sensitive NH tree-ring chronology (N-Tree) employed by Sigl et al. (2015), which clearly shows the growing season temperature impacts of many of the eruptions experienced during the Western Han era (206 BCE - B CE). We further plot the precipitation data provided by the Qin et al. (2025) study highlighted by the reviewer below (where we further discuss this interesting record).



R 2.4: Figure 3 and the relevant text. Please provide brief description of how "vagrancy "and "planned migration" are identified. What criteria goes into the definition, the direction, distance, population scale, etc? And what implications do such difference have?

A 2.4: We thank the reviewer for these queries.

We have now explained these terms more explicitly in the main article text and are also happy to elaborate here. Thus, vagrancy refers to historical records where the word "vagrant" (流民) is directly used or where historical accounts clearly describe groups of people "abandoning their homes or land" (line 301 in our original submission; the location of the text may change after adjustments). Planned migration events, by contrast, refer to historical records that report people being relocated long-term (years or more) following edicts or administrative orders, etc. Escaping, fleeing, and surrender events during or due to war are not counted, because, based on a detailed examination of these records, their scale appears relatively small, and their impacts are temporary, unless historical sources clearly mention that the surrendered populations were arranged to be resettled in specific areas (e.g., the over 50,000 people led by Chanyu surrendered to the Han government in 55 BCE).The movement of populations for temporary labour needs is also not counted, as these populations were dismissed from their duties after a short period of time.

We also examined all the relevant records we found from historical sources with *The population and geography of Western Han (西汉人口地理)* (Ge, 2014), a major study which, although it does not directly provide a dataset, lists many records describing cases of population changes as mentioned in section 2.1.

For our SEA approach, we require only a chronology of the annual frequency of vagrancy and documented planned migrations. Thus, information regarding the direction, distance, and population scale does not play a part in our count. We have provided this information (if available from historical sources) in table S5 only for reference, because there is no scholarly compilation of population changes in the Western Han Dynasty currently available in Chinese or English. We believe that this can provide some convenience for researchers who study this topic in the future.

R 2.5: Section 3.2. The comparative case study could benefit from a more constructive and easy-to-follow structure, with a section summary highlighting the main conclusions from the comparison.

A2.5: See also our response A1.11. We have adjusted the discussion and conclusion sections addressing this comment and Reviewer 1's related comment R1.11.

R 2.6: Instead of being a stand along case investigation, the study could benefit from some parallel discussion on the climatic impacts of same eruptions in other society, such as Ptolemaic Egypt and the Ancient Near East (Line 185-188), or the climatic and social impacts of more recent eruptions in Imperial China.

A2.6: Reference to both suggested cases can be found in several parts of the main article text, with additional discussion now offered in the Discussion and Conclusion. For example, we highlight the case of Ptolemaic Egypt (using the studies of Manning et al., 2017, Ludlow and Manning, 2021, and Singh et al. 2013) with respect to the apparent link between explosive volcanism and internal revolt in Egypt (but also the cessation of inter-state warfare conducted by Egypt). We also cite Ludlow et al. (2023) in terms of motivations for state-planned migrations elsewhere in the ancient world, and newly now in terms of the apparent association between documented societal stresses (famine, conflict, etc.) and explosive volcanism between 750 and 650 BCE in the Ancient Near East. We also highlight the work of Gao et al. (2017) in examining the impact of the 1815 CE Tambora eruption on Qing dynasty China.

Gao, C., Gao, Y., Zhang, Q., and Shi, C.: Climatic aftermath of the 1815 Tambora eruption in China, Journal of Meteorological Research, 31, 28-38, 2017.

Ludlow, F. and Manning, J.: Volcanic eruptions, veiled suns, and Nile failure in Egyptian history: Integrating hydroclimate into understandings of historical change, in: Climate Change and Ancient Societies in Europe and the Near East: Diversity in Collapse and Resilience, Springer, 301-320, 2021.

Ludlow, F., Kostick, C., and Morris, C.: Climate, violence and ethnic conflict in the Ancient World, The Cambridge world history of genocide, 1, 2023.

Manning, J. G., Ludlow, F., Stine, A. R. Boos, W., Sigl, M. and Marlon, J: Volcanic Suppression of Nile Summer Flooding Triggers Revolt and Constrains Interstate Conflict in Ancient Egypt, Nature Communications, 8, Article 900, 2017.

Sigl, M., Winstrup, M., McConnell, J. R., Welten, K. C., Plunkett, G., Ludlow, F., Büntgen, U., Caffee, M., Chellman, N., and Dahl-Jensen, D.: Timing and climate forcing of volcanic eruptions for the past 2,500 years, Nature, 523, 543-549, 2015.

Singh, R., Tsigaridis, K., LeGrande, A. N., Ludlow, F., and Manning, J. G.: Investigating hydroclimatic impacts of the 168–158 BCE volcanic quartet and their relevance to the Nile River basin and Egyptian history, Climate of the Past, 19, 249-275, 2023. [Updating this from the previously cited Discussion paper].

R 2.7: In addition to the documentary data, the results and discussion could benefit (be more concrete and solid) from including proxy records such as tree-ring. For example, Qin et al (2025, copied below) provides annually resolved tree-ring records and process-based physiological modelling results of hydroclimate conditions of northern China during 270 to 77 BCE. It would be helpful to check out their results and compare them with results of this study.

Qin, B. Yang, A. Bräuning, etc, Persistent humid climate favored the Qin and Western Han Dynasties in China around 2,200 y ago, Proc. Natl. Acad. Sci. U.S.A. 122 (1) e2415294121, https://doi.org/10.1073/pnas.2415294121 (2025).

A 2.7: We thank the reviewer for highlighting this important study. We now cite it in the main article text and emphasize its finding of the beneficial effects of a more humid period (on average) on the fortunes of the Western Han dynasty. This also allows us to note that a society may still be vulnerable to sudden departures from a climatic norm, as can be induced by large explosive volcanic eruptions, such as those experienced by the Western Han.

We have also added the precipitation reconstruction offered by Qin et al. (2015) to the new figure described in A2.3 (above). This suggests a notable correspondence between drier years and several of these large eruptions. This is consistent with the finding in our SEA analysis that shows an association between documented droughts and eruptions. However, not all eruptions appear to coincide with drier conditions in the Qin et al. (2025) record. Understanding this requires further investigation, but we note that (1) it may partly arise from the seasonality of the human-documented droughts versus those identifiable in the tree-ring-based evidence, (2) the location of the tree-rings employed (from Jingyuan and Gansu) and how representative they may be of the regions of human-documented drought, and (3) the size and location of the volcanic eruptions in question (our sample during the Han period is too small to offer any conclusive study of whether tropical or NH extratropical or tropical eruptions are more clearly associated with drought (and for which regions across the vast landmass of China)). Moreover, the Qin et al. (2025) precipitation reconstruction currently ceases in 77 BCE, and so we cannot currently use it to examine the effect of the largest eruption of our period (in 43 BCE).

Nonetheless, even the brief consideration of the Qin et al. (2025) record usefully highlights remaining open questions about volcanic hydroclimatic impacts for China, and the potentially differing signals captured by human and natural climate proxies. We now note these issues in the main manuscript text.