

We thank the editor's constructive advices through the manuscript. And we've revised the manuscript in accordance with the editor's and reviewers' suggestions point by point.

### **Detailed response to reviewer's comments:**

*The responses are in blue. The revisions are marked in red in the revised manuscript.*

*The comments were separated into several parts and responded to point by point.*

#### **Reviewer #1:**

Major comments:

1. The authors say the Jiayuguan is finally closed in 1539 AD and this is the end of the Ancient Silk Road on land (Line 213-215). However, Fig 2 b-c show the tribute trades through the Jiayuguan Pass still exist after 1539 AD. The authors should give more details and explanation on this contradiction.

Response: Thanks for the reviewer's constructive suggestion. Jiayuguan Pass was the primary routeway connecting the western region to the domestic territory during the study period. The closure of the Jiayuguan Pass in 1539 AD was essentially the official abandonment of territory outside the Jiayuguan Pass (including the Dunhuang area); it also intensified the tribute trade restriction. The twice closure of the Jiayuguan Pass contributed to a much stricter management system for tribute trades and also caused the obvious decline of trade frequency (Yang *et al.*, 1997; Yang *et al.*, 2014). On the other hand, a small number of trades still continued between the Ming government and several Western countries (Research Institute of History and Language of the Central Academy, 1962; Sheng, 1989; Tian, 1999). So, small number of tribute trades through the Jiayuguan Pass still exist after 1539 AD but the Silk Road lost prosperity.

#### **References:**

- Research Institute of History and Language of the Central Academy. *Ming Shilu, Ming Xiaozong Shilu, Taiwan, 1962.*
- Sheng, S. X., *Ming Hui Dian, China Publishing House, Beijing, 1989.*
- Tian, S. *Tributary trade between Gansu town and in western regions in Ming Dynasty. China's borderland history and geographic studies, 1999 (01):15-24.*
- Yang, F. X. *The Overland Silk Road and its Trade in Ming Dynasty. China's borderland history and geographic studies, 1997(02):12-20.*

Yang, L. K., *West wind miles of river road: Study on emissaries and business Trips on the Silk Road in the Western Regions of Ming Dynasty*, Lanzhou University Press, Lanzhou. 2014.

2. The Jiayuguan Pass was first closed in 1524 AD and finally closed in 1539 AD. In Fig 2 f-g, the tree-ring based precipitation and streamflow reconstructions show the drought climate condition is during 1450- 1510 AD and the hydroclimate returns to average since 1520s. This indicates that the rainfall is normal during 1524 to 1539. Moreover, the driest decade is around 1460s (Fig 2f-g) and 1490s (Fig 2f) and there are several trade teams in these intervals. This means that it is possible for people to reach Jiayuguan under the worst climate condition. Therefore, there must be other critical factors for the closure in 1539. More evidences are needed to prove which factor is the most important one.

Response: Thanks for the reviewer's constructive suggestion. We agree that the influence of the ~1450 AD arid event on the streamflow of the Qilian Mountain gradually decreased after 1520s. However, oasis formation and development are long-term processes (*Stamp, 1961; Zhang and Hu, 2002; Li et al., 2016*). The oasis ecological response would not be to disappear immediately (*Fan, 1993*), and in addition it takes at least 15-20 years for an oasis to recover after degradation within ~1-3 years (*Zhang and Hu, 2002*). Therefore, the degraded oasis was not as easily reversible as the streamflow does. In addition, once land desertification occurred, the recovery is a long process. We accept the reviewer's advice and have modified the text accordingly. Please sees **Line 388-398**.

On the other hand, the Silk Road on land "interrupted or not" refers to the flourishing or decline of commercial trade between the Ming government and Western countries operating in central Asia. The East-West tribute exchange existed during entire duration of the Ming dynasty (*Research Institute of History and Language of the Central Academy, 1962; Sheng, 1989; Tian, 1999*), and there were several trade teams operating around the 1460s (Fig 2f-g) and 1490s (Fig 2f). In addition, after 1450 AD, the pronounced decline in tribute exchange indicates that the prosperity of the Silk Road declined abruptly in the Ming dynasty after 1450 AD. Although the immediate cause of the closure in 1539 AD was government policy, we argue that the policy was a result of other factors (*Feng et al., 2019*). We propose that climatic deterioration and subsequent desertification event during the late 15<sup>th</sup> century triggered serial social problems such as the abandonment of farmlands in Dunhuang that was the major policy to maintain governance in western frontier areas, extensive human migrations eastward,

the increasing threaten of powers in adjacent areas, and then final closure of the Jiayuguan Pass. Please see **Line 399-409**.

### References:

- Fan, Z.L., *A study on the formation and evolution of Oases in Tarim Basin, Acta Geographica Sinica*, 1993, 48:421-427.
- Feng, Q., Yang, L., Deo, R. C., AghaKouchak, A., Adamowski, J. F., Stone, R., Yin, Z. L., Liu, W., Si, J. H., Wen, X. H., Zhu, M., Cao, S. X.: *Domino effect of climate change over two millennia in ancient China's Hexi Corridor, Nat. Sustain.*, 2, 957-961, 2019.
- Li, X., Yang, K., Zhou, Y., *Progress in the study of oasis-desert interactions. Agricultural and Forest Meteorology*, 2016, 230-231:1-7.
- Research Institute of History and Language of the Central Academy. Ming Shilu, Ming Xiaozong Shilu, Taiwan, 1962.*
- Sheng, S. X., *Ming Hui Dian, China Publishing House, Beijing, 1989.*
- Stamp, L.D., 1961. *A history of land use in arid regions. Literary Licensing, LLC.*
- Tian, S. *Tributary trade between Gansu town and in western regions in Ming Dynasty. China's borderland history and geographic studies*, 1999 (01):15-24.
- Zhang, Q., Hu, Y.Q., *The geographical features and climatic effects of oasis. Advance in Earth Sciences*, 2002,17(4).

3. The author should provide some quantitative evidences of the oasis fragile. For example, how many years continuous drought could destroy it and could the oasis recover when climate return to better condition. There are also many extreme drought years occurred before 1450s but the Silk Road is not interrupted.

Response: This is a very good question. It's quite difficult to quantitatively estimate how many years continuous drought can destroy oasis, and how soon it can recover when climate return to better condition, due to the difference in both local natural and social environments. When ancient human abandoned vast farmlands as was occurred in Dunhuang after ~1450 AD, it provided plenty of material sources to aggravate desertification. Zhang and Hu (2002) suggested that it takes at least 15-20 years for an oasis to recover that has been degraded within ~1-3 years. This means that once destroyed, it takes about ten times longer for an oasis to recover under manual intervention. Therefore, the ancient oasis is very difficult to recover even climate return to better condition. The two desertification events in Dunhuang during ~800-600 BC and post ~1450 AD was primarily triggered by severe climate deterioration that persisted for many decades with large amplitude (Fig. 3), according to the tree records in eastern Qilian mountains (Yang et al., 2014), the duration and drought degree during

the Little Ice Age was unparalleled during the past 2000 years, which can explain why the Silk Road was not interrupted by other droughts since Han Dynasty.

**References:**

Yang, B., Qin, C., Wang, J.L., He, M.H., Melvin, T.M., Osborn, T.J., Briffa, K.R. A 3500-year tree-ring record of annual precipitation on the northeastern Tibetan Plateau. *Proc Natl Acad Sci USA*, 2014, 111, 2903-2908.

Zhang, Q., Hu, Y.Q., *The geographical features and climatic effects of oasis. Advance in Earth Sciences*, 2002,17(4).

4. Which season do most the trade teams passed through the Hexi Corridor? Or do they move in all seasons? The authors say LOI and Rb/Sr profiles represent the spring and autumn period (Line 346). How about other proxies in Fig 2 and 3?

Response: The team mentioned in this study passed through the Taklamakan desert in the autumn (September-November) of 1993 (*Blackmore, 2000*). In addition, the explorer Sven Anders Hedin (1865-1952) preferred to cross the desert in winter (*Hedin, 1996*). The “Spring and Autumn period” that we mentioned is the period during the Zhou dynasty from approximately 771 to 476 BCE (from Wikipedia) but we do not emphasize the seasons. Please see **Line 299-300**. The dating result of 800-600 BC period corresponds to this historical period. All of paleoclimatic proxies in the XSW section show the same trend of variation.

**References:**

*Blackmore, C.: Crossing the Desert of Death: Through the Fearsome Taklamakan. John Murray press, London, 2000.*

*Hedin, S.A., My Life as an Explorer, Kodansha International, 1996.*

[https://en.wikipedia.org/wiki/Spring\\_and\\_Autumn\\_period](https://en.wikipedia.org/wiki/Spring_and_Autumn_period)

5. Line 140-146. The topic of the paper is the end of the Ancient Silk Road in Mid-Ming Dynasty while the main data is a sediment core that only has one dating sample since Ming Dynasty. More high resolution data should be included. Authors may be interested in recently published paper. Hao et al. (2019) Climatic changes during the past two millennia along the Ancient Silk Road. *Progress in Physical Geography*.

Response: Thanks for the reviewer’s constructive suggestion. The decline of the Ancient Silk Road is shown by closure of Jiayuguan. We found that the most available cause of this closure was desertification inducted by climate change, based on the evidence of the sedimentary profile at XSW, records of stream flow, tree-rings and temperature changes. This is also supported by historical records of the consequent effects in terms of the steep fall in trade, more wars, and eastward migration events in

the area. Your suggestion is very important as the more the evidence, the sounder our conclusion. However, we did search many sites for more sections and evidence during the field trip, as the reviewer suggests. Unfortunately, no other profiles were found in the surrounding areas other than the XSW site, as most of the area is covered by sandy desert. The wood sample, which can be precisely dated by advanced <sup>14</sup>C dating techniques, was the only wood sample that we found in the top sand layer. The dating result corresponds well with the ~1450 AD event. The coarse-grained quartz OSL signal was too dim to date in younger upper section of the XSW site. In the basal sand layer at 185-250 cm, no reliable radiocarbon dating material was found. However, the quartz OSL dating approach can be applied for this age range.

The reference of Hao et al. (2019) “Climatic changes during the past two millennia along the Ancient Silk Road. Progress in Physical Geography” was very supportive and enlightening for our research. Thank you for the reviewer’s kind reminder. We have cited this paper in the text. Please see **Line 41-42**.

6. Minor comments: 1. Line 146, 270 m should be 270 cm. 2. Line 340, Fig2 should be Fig3.

Response: Thanks for the reviewer’s kind reminder. We have modified the content correspondingly. Please see **Line 158 and Line 293**.

## REVIEWER #2

### Responds to reviewer's comments:

*The responses are in blue. The revisions are marked in red in the revised manuscript.*

*The comments were separated into several parts and responded to point by point.*

#### Reviewer #2:

1. In this paper, the authors tried to figure out the fundamental cause of the demise of the Ancient Silk Road trade was climate-triggered desertification. It is not easy to prove it. It seems that there is still room for improvement in this paper. I recommended that this paper can be accepted after a moderate revision. Some comments are as follow: 1) In this paper, two desertification events were founded during 800-600 BC and about 1450 AD, corresponding to sand layers in the XSW profile. But it is not clear that how far can desertification extend when the extreme drought events has been happened. It is more perfect if the author provided more profiles in this area to compare with XSW profile.

Response: Thanks for the reviewer's constructive suggestion. It is not easy to determine the exact extent of the desertification area. Previous results suggested that large-scale desertification affected ~1,700 km<sup>2</sup> during the Ming and Qing dynasty in the Shule River Basin which contains the Dunhuang-Guazhou area (Cheng, 2007). In addition, Dunhuang city and Guazhou city are all located in the central part of the eastern Gobi Desert. When the desertification event occurred at the XSW site (located in the middle of the Dunhuang and Guazhou oases, ~60 km on both sides), we assume that the desertification would affect these areas and cause the degradation of the oases. Li (2003) pointed out that during 15<sup>th</sup> and 16<sup>th</sup> centuries, drought events and locust plagues occurred frequently in the Hexi area. We agree that results from "more profiles in the area as comparison with XSW profile" would be more convincing, and we thank you for this kind suggestion. However, although we searched many sites for more sections and evidence during our field investigation, the only profile we found was the at the XSW site. Also, we are fortunate that the only age of ~1450 AD (0-10 cm) in the Ming dynasty was from wood and is therefore likely to be reliable. Importantly, the arid event is also recorded in the sediments of Sugan Lake (Qiang et al., 2005) and Tian' E

lake (Zhang *et al.*, 2018); these lakes were dried up during the modern interval of arid climate (Wünnemann *et al.*, 2010).

### Reference:

Cheng, H.Y.: Human impact on environment in historical time, a quantificational case in Hexi Corridor, NW China. *China Population, Resources and Environment*, 2011, 22(3): 360-363.

Li, B.C.: *Study on Desertification of Hexi Corridor in historical period, China*. Beijing: Science Press (in Chinese), 2003.

Wünnemann, B., Demske D., Tarasov, P., *et al.* Hydrological evolution during the last 15 kyr in the Tso Kar lake basin (Ladakh, India), derived from geomorphological, sedimentological and palynological records[J]. *Quaternary Science Reviews*, 2010, 29(9-10):1138-1155.

Qiang, M.R., Chen, F.H., Zhang, J.W., Gao, S.Y., and Zhou, A.F.: Climatic changes documented by stable isotopes of sedimentary carbonate in Lake Sugan, northeastern Tibetan Plateau of China, since 2 ka BP. *Chinese Sci. Bull.*, 50, 1930-1939, 2005.

Zhang, J., Huang, X., Wang, Z., Yan, T., and Zhang, E.: A late-Holocene pollen record from the western Qilian Mountains and its implications for climate change and human activity along the Silk Road, Northwestern China. *Holocene*, 28, 1141-1150, 2018.

2. In XSW profile, the upper sand layer is only 10 cm thick. Only one OSL sample was determined (see Figure 3). How did the author get the top age (1350 a) of this sand layer?

Response: Thanks for the reviewer's constructive comments. The 10cm-thick sand layer has one radiocarbon age (1440-1460 AD). And the wood sample that we applied on dating was collected from the depth of 10cm from the top of sampled profile. We didn't date the samples on top but instead using linear fitting method of two radiocarbon age in combination with comparing with tree ring records (Fig. 2f and 2g) to achieve the top age. It's not enough rigorous to give the top age without exact dates indeed. We accept the reviewer's advice and make relative modifications through the content.

3. There are some inconsistencies in this manuscript. For instance, tree-ring based precipitation record and stream flow record showed that the drought events happened during 1460 to 1510, recovered after 1510 (Figure 2 f and g). The authors should provide more evidences to explain it.

Response: Thanks for the reviewer's constructive suggestion. We agree that the influence of the arid event of ~1450 AD on the streamflow of the Qilian Mountains gradually decreased after the 1510s. However, oasis formation and development are long-term processes (Stamp, 1961; Zhang and Hu, 2002; Li *et al.*, 2016). For example, the decline of Loulan city was irreversible because of regional climate conditions and

possible human impact (Mischke et al., 2017). First, the oasis ecological response would not be to disappear immediately (Fan, 1993). Also, after 1-3 year's destruction, an oasis takes at least 15-20 years to recover (Zhang and Hu, 2002), and therefore a degraded oasis is not as easily reversible as streamflow. The ancient Silk Road was interrupted by the deteriorating ecological environment along the routeway. The obvious decline in tribute exchange (Fig. b and Fig. c) indicates that the prosperity of the Silk Road declined rapidly in the Ming dynasty. We accept the reviewer's advice and have modified the text accordingly. Please see **Lines 399-409**.

#### **References:**

- Fan, Z.L., *A study on the formation and evolution of Oases in Tarim Basin*, *Acta Geographica Sinica*, 1993, 48:421-427.
- Li, X., Yang, K., Zhou, Y., *Progress in the study of oasis-desert interactions*. *Agricultural and Forest Meteorology*, 2016, 230-231:1-7.
- Mischke, S., Liu, C., Zhang, J., Zhang, C., Zhang, H., Jiao, P., Plessen, B. *The world's earliest Aral-Sea type disaster: the decline of the Loulan Kingdom in the Tarim Basin*. *Sci. Rep.* 2017, 7, 43102.
- Stamp, L.D., 1961. *A history of land use in arid regions*. Literary Licensing, LLC.
- Zhang, Q., Hu, Y.Q., *The geographical features and climatic effects of oasis*. *Advance in Earth Sciences*, 2002,17(4).

## REVIEWER #3

### Responds to reviewer's comments:

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*The comments were separated into several parts and responded to point by point.*

### Reviewer #3:

The general argument of the paper is that cold and dry climate prevailing during the Ming dynasty in the region of Dunhuang around 1450 CE was the chief cause for the closure of the Silk Road (meaning by it the system of communication between the Chinese capital and Central Asia) – Evidence for this hypothesis is presented in the form of climate proxies from the site of Xishawo (XSW), consisting of paleosols and sediments, dated on the basis of 14C analysis of charcoal and wood samples from the same section of the site. The laboratory analysis showed a increase in desertification, attributed to especially dry and cold climate, between 1450 and 1530. – The authors also consulted historical sources and compared their results with written records. The main thesis of the study is that the closure of the trade route and abandonment of Dunhuang in the early 16th century was due to climatic change rather than two other causes considered here, namely, the “alternative” maritime route and warfare. In their analysis the authors argue against these two possibilities, and exclude them in favor of a climate change as the single cause for the closure of the Silk Road. In their view after 1450 transit through Dunhuang would have been impossible because of drought conditions.

### General comments

1. The archaeological context of the site from where the samples were collected is not discussed. This is a critical issue since other studies have attributed the decline of the oases to Ming government policies that reduced the inhabitants.

Response: Thanks for the reviewer's constructive suggestion. The Xishanwo site is an ancient city, recently detected by Integrated RS, GIS and GPS approaches (Luo et al., 2014). While few relics have been found at the site, several cultural layers have yielded plant remains such as crop seeds and charcoal (Li et al., 2017). According to the radiocarbon dates reported in Li et al. (2017), the ancient city of Xishawo was established and developed during the Five Dynasties and Ten Kingdoms (897-979 AD),

the Song Dynasty (960-1127 AD), and the Yuan Dynasty (1271-1361 AD). Your suggestion is helpful and we have added an introduction to the site in **Lines 146-154** and we have also cited the reference (Li et al., 2017).

To elaborate our argument more clearly, we accept the reviewer's advice and modified the title of the paper to "**Climate-driven desertification and its implications for the Ancient Silk Road trade**".

#### **References:**

Luo L, Wang X Y, Liu C S, Guo H D, Du X C. 2014. *Integrated RS, GIS and GPS approaches to archaeological prospecting in the Hexi Corridor, NW China: a case study of the royal road to ancient Dunhuang. Journal of Archaeological Science, 50: 178-190*

Li, H.M., Liu, F.W., Cui, Y.F., Ren, L.L., Storozum, M.J., Qin, Z., Wang, J., Dong, G.H., 2017. *Human settlement and its influencing factors during the historical period in an oasis-desert transition zone of Dunhuang, Hexi Corridor, northwest China. Quaternary International, 113-122.*

2. A reduction in population density is attributed uniquely to environmental factors, without considering other possibilities for the same phenomenon.

Response: We agree with the reviewer's reminder and modified throughout the text. We regard environmental factors as the trigger or the best explanation rather than the only determinant of the population decline in Dunhuang during the early Ming Dynasty in terms of what we discussed in this study. We suggest that environmental factors had a "domino effect" on the social system, via the shrinkage of the habitat and farmland necessary for human survival, resulting in the four waves of human migration into the eastern part of the Hexi Corridor, and the shift of frontier from Dunhuang to Jiayuguan (Feng et al. 2019). We appreciate your comments and we have tried to clarify the discussion accordingly. "Climatic perturbations and environmental degradation may not necessarily be a direct trigger of a societal crisis, but they may instead result in institutional failure caused by the lack of a centralized response to an environmental crisis (Feng et al. 2019). Social disturbance associated with migrations and chaos in the Ming dynasty (Fig. 2d) was most likely an indirect consequence of environmental changes. For example, the consequences of a deteriorating environment would include a shrinking of the habitat and farmland necessary for human survival, multiple waves of human migrations into the eastern part of the Hexi Corridor, and the shift of the frontier from Dunhuang to the Jiayuguan pass. Thus, the population decline in the

Dunhuang area during the early Ming Dynasty was most probably a “domino effect” (Feng et al. 2019).”

### References:

Feng, Q., Yang, L., Deo, R. C., AghaKouchak, A., Adamowski, J. F., Stone, R., Yin, Z. L., Liu, W., Si, J. H., Wen, X. H., Zhu, M., Cao, S. X.: Domino effect of climate change over two millennia in ancient China’s Hexi Corridor, *Nat. Sustain.*, 2, 957-961, 2019.

3. Social-political analysis is uniquely based on frequency of “agri-nomadic” conflict. The category of conflict is too vague to be accepted as a proxy for political processes, and statistical means are not normally accepted in historical analysis for inferring government policies. In other words, a historical analysis should focus on specific actions by the Ming government to protect Dunhuang, increase its productivity, regulate trade and manage its population. Therefore, specific references to such policies are needed.

Response: Thanks for the reviewer’s constructive suggestion. First, the frequency of warfare in the Dunhuang area in the Ming dynasty is discussed because of the previous hypotheses that frequent wars directly led to the abandonment of Dunhuang. “Agri-nomadic” conflict was distinguished from other types of conflict because it directly reflects the conflict between the central government and the nomadic peoples (Zhang et al., 2020). Furthermore, in this border area, it was a unique form of warfare which could have toppled the Ming regime. Second, it is not easy to quantify the social-political-economic environment because of the numerous factors involved (*Chen, 2010; Fang et al., 2015*). Warfare frequency was, to some extent a quantized index for social-political analysis. In addition to the complex range of factors that influenced the social-political-economic environment of the Dunhuang area under Ming rule, warfare was the final manifestation (*Zhang et al., 2007; Fang et al., 2015*). For example, economic turbulence, policy change, population pressure, and famine and disease were costly but gradual processes. In general, wars would not occur when the social environment was harmonious, but when a factor changed which sufficiently worsened social-political-economic conditions, then the probability of conflict would increase sharply. Finally, human social development was not sufficient to buffer the tensions caused by shrinking resources when wars became common consequences (Gleditsch, 1997; Zhang et al., 2007). Although conducting “a historical analysis about the Ming government to protect Dunhuang, increase its productivity, regulate trade and manage its population”

is not our main purpose in discussing the frequency of wars, we agree that it is important to analyze the political environment in depth. Therefore, we have added several historical references to strengthen the discussion (Research Institute of History and Language of the Central Academy in Taiwan, 1962, Zhang, 1974). Please see **Lines 75-76**.

**References:**

*Chen, G. W.: Research on the abandonment of the Dunhuang during Ming Dynasty. J. Dunhuang Stud., 60, 111-118, 2011 (In Chinese).*

*Fang, X.Q., Su, Y., Yin, J., Teng, J.C. Transmission of climate change impacts from temperature change to grain harvests, famines and peasant uprisings in the historical China. Science China: Earth Sciences, 2015, 58(8): 1427-1439 (In Chinese with English abstract).*

*Gleditsch, P.N. Conflict and the environment. Nato Asi, 1997.*

*Research Institute of History and Language of the Central Academy in Taiwan: Ming Yingzong Shilu. Taiwan, 1962.*

*Zhang, S.D., Zhang, D.D., Li, J.B., Pei, Q. Secular temperature variations and the spatial disparities of war in historical china. Climatic Change (2020) 159:545-564.*

*Zhang, T.Y.: History of Ming dynasty. China Publishing House, Beijing, 1974 (in Chinese).*

4. The authors assume that maritime trade could be in competition with the continental "Silk Road" trade, but in fact such trades were different and not in mutual competition. Therefore, debunking the notion that maritime trade might have led to the decline of the Silk Road in the 15th and early 16th century seems a "strawman" argument.

**Response: We agree with the review's suggestion and deleted the related discussion.**

5. Other studies have contended that desertification was caused by a decline in population. The authors acknowledge the fragility of the oasis environment, but in fact the economy of the oasis is fragile even in relatively favorable conditions, given that maintenance of irrigation system is labor-intensive and requires substantial investments and constant attention. Therefore, a decrease in population could lead to lack of maintenance and accelerate desertification. This is a possibility that the authors do not contemplate, and requires a more accurate investigation of both the historical and archaeological contexts.

**Response: This is a very helpful comment. We admit that both climate change and human activities (especially the abandonment of farmland) could induce or aggravate the process of desertification, especially in Dunhuang oasis. However, we argue that**

the onset of desertification in Dunhuang at ~1450 AD was induced by climatic deterioration because it was nearly synchronous with cold and dry events that are recorded in high-resolution paleoclimate archives. From Cheng et al. (2007)'s research, human factors start to play a primary role in desertification process from 300a (middle of Qing dynasty), natural factors were the main cause for the desertification process in Hexi corridor during the last 2000yrs before middle of Qing dynasty. Which means, natural environmental factor but not the humankind activities were still the primary cause for the desertification in Dunhuang area at ~1450 AD. Moreover, we have not found any historical documentary evidence indicating that human activities caused the desertification during this period. However, the superimposed effects of climatic deterioration and human abandonment of farmland in the ancient oasis contributed to the continuation of a desert landscape in the study area until today, even though the climate became wetter after ~1540 AD (Fig. 2). Farming activity in the Dunhuang area is also recorded in the archives (Research Institute of History and Language of the Central Academy in Taiwan, 1962, Zhang, 1974). Thank you very much for your constructive comments.

#### **References:**

- Cheng, H.Y., 2007. The Desertification of the Hexi Area in Historical Time. Lanzhou University, Doctoral Dissertation (In Chinese with English abstract).*
- Research Institute of History and Language of the Central Academy in Taiwan: Ming Yingzong Shilu. Taiwan, 1962.*
- Zhang, T.Y.: History of Ming dynasty. China Publishing House, Beijing, 1974 (in Chinese).*

6. The authors present as evidence of desertification the cessation of embassies and tribute missions from the kingdoms and principalities in the Western Regions (today's Xinjiang) as evidence of the collapse of the Jiayuguan transit route. While there was a decline around 1450, by no means there was a total collapse of trade missions. If we take the periods 1436-64, 1465-1509 and 1510-1539, the embassies from Turfan were respectively 5, 40, and 14, those from Hami 84, 56 and 14, and from Samarkand (further west) 14,15, and 14. Even after this time a few embassies continued to be sent from Hami and Samarkand. Unless the authors can show that there was an alternate route, the assumption that Hexi corridor was completely impassable after 1450 is not supported by the evidence.

Response: Thanks for the reviewer's kind reminder. We agree with the reviewer's opinion that the Hexi Corridor was not completely impassable after ~1450 AD. The

reasons for this may be first that both the desertification and oasis degradation were slow processes; and second, the Jiayuguan Pass was the primary routeway connecting the western region to the domestic territory. However, the closure of the Jiayuguan Pass in 1539 AD marked the abandonment of territory beyond the pass (including the Dunhuang area) as well as the strengthening of the restriction on the tribute trade. The twice closure of the Jiayuguan Pass contributed to a much stricter management system for the tribute trade and it also caused a pronounced reduction in trade frequency (Yang et al., 1997; Yang et al., 2014). On the other hand, trades still continued between the Ming government and several Western countries (Research Institute of History and Language of the Central Academy, 1962; Sheng, 1989; Tian, 1999). Based on our investigation of the published historical archives, the number of trades was sharply reduced after 1450 AD. And this decrease indicated that the prosperity of the ancient Silk Road was faded.

### **References:**

- Research Institute of History and Language of the Central Academy. *Ming Shilu, Ming Xiaozong Shilu*, Taiwan, 1962.
- Sheng, S. X., *Ming Hui Dian*, China Publishing House, Beijing, 1989.
- Tian, S. *Tributary trade between Gansu town and in western regions in Ming Dynasty*. *China's borderland history and geographic studies*, 1999 (01):15-24.
- Yang, F. X. *The Overland Silk Road and its Trade in Ming Dynasty*. *China's borderland history and geographic studies*, 1997(02):12-20.
- Yang, L. K., *West wind miles of river road: Study on emissaries and business Trips on the Silk Road in the Western Regions of Ming Dynasty*, Lanzhou University Press, Lanzhou. 2014.

7. The paper does not explain clearly why Dunhuang would be abandoned only seventy years after the drought event, and how the government reacted to it. In the meantime. Response: According to previous studies, human social resilience to climate change was relatively low during both the prehistoric and historical periods, especially in arid areas where human living environments are very susceptible to climatic deterioration. In these areas (such as Dunhuang), drought that persisted for many decades would have resulted in the decline of agriculture and animal husbandry, resulting in the population decrease and the collapse of ancient civilizations (e.g., the Maya, Angkor) (Buckley et al., 2010; Medina-Elizalde and Rohling, 2012). According to historical records, the government supply relief food and migrate the resident to Zhangye city (inside the Jiayuguan Pass) (Zhang, 1974). Which provide evidences for feedback of social environment to the environment deterioration.

## References:

- Buckley B M, Anchukaitis K J, Penny D, Fletcher R, Cook E R, Sano M, Canh Nam L, Wichienkeo A, That Minh T, Hong T M. 2010. Climate as a contributing factor in the demise of Angkor, Cambodia. Proc Natl Acad Sci USA, 107: 6748–6752*
- Medina-Elizalde M, Rohling E J. 2012. Collapse of classic Maya civilization related to modest reduction in precipitation. Science, 335: 956-959*
- Research Institute of History and Language of the Central Academy in Taiwan: Ming Yingzong Shilu. Taiwan, 1962a.*
- Zhang, T.Y.: History of Ming dynasty. China Publishing House, Beijing, 1974 (in Chinese).*

8. The conclusions presented in other studies that are especially relevant to the questions raised here should be discussed more explicitly, in particular Zhang, et al. "A late-Holocene pollen record from the western Qilian Mountains and its implications for climate change and human activity along the Silk Road, Northwestern China." *The Holocene*, 28(7) (2018), 1141-1150 (in the reference list), and Li, Haiming, et al. "Human settlement and its influencing factors during the historical period in an oasis-desert transition zone of Dunhuang, Hexi Corridor, northwest China." *Quaternary International* 458 (2017): 113-122 (not in the reference list).

Response: Thanks for your comments. Zhang et al. (2018) mainly reconstructed climate change since ~4,000 BP, based on the analysis of paleoclimate indices (especially pollen) from Tian'e Lake in the western Qilian Mountains. Although they also propose that drought may have contributed to the abandonment of Dunhuang, they only compare their paleoclimatic record with historical documents, without providing a detailed discussion of how the impact of climate deterioration was transmitted to the human living environment and social system, such as the via desertification and the shrinking of the ancient oasis. Also, Li et al. (2017) (Guanghai Dong is the corresponding author) focus on the transformation of human settlement intensity, plant exploitation strategies, and their relationship to geopolitics and climate change in the oasis-desert transition zone of Dunhuang during the historical period. The major topics of these two papers and our paper are different, although these other studies provide useful data and perspective. Therefore, we have added a citation to Li et al. (2017) in **Lines 152**.

## References:

- Li, H.M., Liu, F.W., Cui, Y.F., Ren, L.L., Storozum, M.J., Qin, Z., Wang, J., Dong, G.H., 2017. Human settlement and its influencing factors during the historical period in an oasis-desert*

*transition zone of Dunhuang, Hexi Corridor, northwest China. Quaternary International, 113-122.*

*Zhang, J., Huang, X., Wang, Z., Yan, T., and Zhang, E.: A late-Holocene pollen record from the western Qilian Mountains and its implications for climate change and human activity along the Silk Road, Northwestern China. Holocene, 28, 1141-1150, 2018.*

## Detailed comments

### Abstract

21 Demise is not synonymous with interruption: is it a demise or an interruption?

Response: Thanks for your comment. We changed “demise” to “decline” throughout the text.

22 Wala: the standard term is Oirat (or other spelling, such as Oyirad)

Response: Thanks for your comments. We have modified the term throughout.

24-26 Is it possible that there was more than one cause?

Response: Thanks for your constructive suggestion. We’ve modified the discussion into two causes as natural social aspects. Please see the manuscript.

27-32 The dates seem to indicate a long gap between the time of the drought (1440-60) and the closure of the trade route going through Dunhuang (1539)

Response: We agree with the reviewer’s opinion. As have argued throughout, the climatic factor was the primary trigger. The interactions between environmental deterioration and the government’s reactions (i.e. policy) were a slow process, like a “domino effect”, especially when the government was weak and incapable of governing the border area (Feng et al., 2019). The decline of the Silk Road is not only indicated by the official closure of the gate, but also by the steep fall in trade, which may closely follow the desertification and climate change.

### References:

*Feng, Q., Yang, L., Deo, R. C., AghaKouchak, A., Adamowski, J. F., Stone, R., Yin, Z. L., Liu, W., Si, J. H., Wen, X. H., Zhu, M., Cao, S. X.: Domino effect of climate change over two millennia in ancient China’s Hexi Corridor, Nat. Sustain., 2, 957-961, 2019.*

### 1. Introduction

43-47 Does this mean that there were no more contacts between China and central Asia, or between the Ming dynasty and the states in the Tarim Basin (today Xinjiang) after 1539?

Response: Thanks for the reviewer’s constructive suggestion. The Jiayuguan Pass was the only routeway connecting the western region to the domestic territory during the

study period. However, the closure of the Jiayuguan Pass in 1539 AD marked the official abandonment of territory beyond the pass (including the Dunhuang area), as well as the strengthening of the restriction on the tribute trade. The twice closure of the Jiayuguan Pass contributed to a much stricter management system for tribute trades and also caused an obvious decline in trade frequency (Yang et al., 1997; Yang et al., 2014). However, a few trades still continued between the Ming government and several Western countries (Research Institute of History and Language of the Central Academy, 1962; Sheng, 1989; Tian, 1999).

### References:

Research Institute of History and Language of the Central Academy. *Ming Shilu, Ming Xiaozong Shilu*, Taiwan, 1962.

Sheng, S. X., *Ming Hui Dian*, China Publishing House, Beijing, 1989.

Tian, S. *Tributary trade between Gansu town and in western regions in Ming Dynasty. China's borderland history and geographic studies*, 1999 (01):15-24.

Yang, F. X. *The Overland Silk Road and its Trade in Ming Dynasty. China's borderland history and geographic studies*, 1997(02):12-20.

Yang, L. K., *West wind miles of river road: Study on emissaries and business Trips on the Silk Road in the Western Regions of Ming Dynasty*, Lanzhou University Press, Lanzhou. 2014.

60-62 "The Ming : : : frontier": meaning unclear. Clarify especially "transfer of the leadership to Mongolia"

Response: Thanks for the reviewer's reminder. We have modified the sentence to "The Ming governor successively established seven garrisons, from the early Ming dynasty onwards, in the Jiayuguan-Dunhuang area and transferred the leadership to Mongolia which governed the seven garrisons in order to consolidate the frontier territory (Chen, 2000)." Please see **Line 63-66**.

63-87 The hypotheses presented here do not include archaeology-based hypothesis. Any discussion on the "closure" of the Silk Road should be documented by looking at arguments based on archaeological investigation.

Response: Thanks for the reviewer's suggestion. We've modified our discussion as the reviewer suggested and in the revised manuscript, we focused on the role that paleoenvironmental variations may have played on the ancient Silk Road in the Duanhuang-Jiayuguan area.

66-67 vague, not relevant

Response: Thanks for the reviewer's suggestion. Lines 66-67 are intended to explain the background which led to the frequent wars in the area.

67 unclear what "expand agri-nomadic wars" means: suggest to provide references to historical events

Response: Thanks for the reviewer's reminder. We accept the reviewer's advice and have added relevant references in this part. Please see **Line 75-76**.

69 Necessary to provide dates and other details and background of invasions by nomadic tribes

73-74 The reference to the rise of the maritime routes as an explanation for the decline of Silk Road in Western literature usually refer to the late 16th and especially 17<sup>th</sup> century but these are old theories that have since been criticized. The references cited here are to generic articles to which I have no access, but should be supplemented with references to a broader discussion. The ban on Dunhuang trade was irrelevant to the rise of international maritime trade, in South China which is due to Spanish and Portuguese commercial and diplomatic activities.

Response: Thanks for the reviewer's suggestion. We have deleted the discussion about maritime trade.

## 2. Study area

92-93 The statement about newly-discovered historical archives requires a reference

Response: Thanks for the reviewer's suggestion. We have modified the expression.

115-119 These lines can be deleted since they are vague and not relevant.

Response: Thanks for the reviewer's suggestion. We have deleted these lines.

130 Tulufan, normally known in English as Turfan

Response: Thanks for the reviewer's reminder. We have modified the term throughout the content. Please see **Line 135**.

135 Altun Mountains, normally known in English as Altyn-Tagh

Response: Thanks for the reviewer's kind reminder. We have modified the term throughout. Please see **Line 140**.

139-157 This is one of the most problematic, as well as critical, passages of the essay, since reference is made to a "newly-discovered site" but no information is given as to the nature of the site (settlement, village, city, palace, fortress: : :?), the conditions of the discoveries, the date of the discovery and archaeologists involved (if any). Since the evidence upon which the whole argument rests comes from this location, it is essential to provide the full picture of this site.

Thanks for the reviewer's suggestion. We have added relevant content and references (Li, 1990; Cheng, 2007). Please see Line **146-154**. "XSW site was previously an ancient oasis with cultural sites, ancient cities and beacon towers. Relict river channels are present at some locations, although most of them are buried by sand dunes (Li, 1990; Cheng, 2007). The modern annual mean precipitation and annual mean temperature of the area are 45.3 mm and 8.8°C, respectively (Li et al., 2017). Wind-eroded landforms are common in the region as a consequence of the arid climate, sparse vegetation and frequent sandstorms."

#### **References:**

- Cheng, H.Y., 2007. The Desertification of the Hexi Area in Historical Time. Lanzhou University, Doctoral Dissertation (In Chinese with English abstract).*
- Li, B.C. Investigation on the Ancient Ruins in the Western Sandy land of Minqin County. Journal of Desert Research, 1990 (in Chinese with an English abstract).*

#### **3. Methodology**

203-206 Unclear where these paleoclimatic records are located. References are required for published studies. See Below

207-210 References are not to the historical sources but to secondary studies or limited collections. No reference is made to actual historical sources, which were not consulted (Ming shi, Ming shilu, etc.). Unclear which "sociohistorical records" relative to Dunhuang and Jiayuguan were actually used (gazetteers, memoirs, standard histories, local archives etc.)

Response: Thanks for the reviewer's comments. The "sociohistorical records" we discuss are local archives, and what the reviewer mentions are gazetteers. Although it would be much better if we were able to investigate the source of each historical event, we are seeking a statistical trend. We believe that secondary data sources are useful in this type of quantitative analysis.

#### **4. Results and Discussion**

212-223 As mentioned before, the flourishing of maritime trade in the late 16th century cannot be simply attributed to a government decision (why was then ban lifted?)

Response: Thanks for the reviewer's recommendation. We've revised the content

deleted the related discussion. We agree with the reviewer's opinion that the flourishing of maritime trade in the late 16<sup>th</sup> century was affected by various factors. In fact, coastal inhabitants occasionally ventured out to sea to support themselves, even when maritime trade was banned at the beginning of the Ming dynasty (Chen, 1962). We would be interested in discussing this topic with the reviewer; however, a full investigation is beyond the scope of the present paper.

**Reference:**

*Chen, Z.L.: Ming Jing Shi Wen Bian, China Publishing House, 1962 (in Chinese).*

223 Zheng He's voyages have been amply investigated (see for instance Dreyer, Edward L. Zheng He: China and the oceans in the early Ming dynasty, 1405-1433. Pearson Longman, 2006.)

Response: Thanks for the reviewer's recommendation. We've deleted the related discussion.

224-239 The section of Zheng He's voyages is immaterial, and also historically inaccurate. I would be weary of statements that attribute to "national prestige" the reason for Zheng He's voyages.

Response: Thank you for the reminder. We've deleted the related discussion.

248 Few specialist historians would agree with the assumption mentioned here, especially if understood (as presented here) as a sharp break.

Response: Thanks for the comment. We've revised the structure of the manuscript and deleted the related discussion.

260 What is "frequent"?

Response: Thank you for the reviewer's reminder. Here we mean that there were many wars (19 wars in the period of 1360-1520 AD).

261-68. Presumably this refers to wars between Ming and Mongols in the early 16<sup>th</sup> century, but it is impossible to assess the actual impact of warfare on trade without details about when, where, and between whom the conflicts occurred.

Response: Thanks for the comment. Based on the timeline of occurrence of these wars and the timing of the closure, we reject the 'war hypothesis' because both of them are incompatible with the timeline. We assume that this type of time series does not

require us to assess the actual impact of each war.

274 Clarify what is meant by "nomadic peoples." Not all of them were at war with the Ming. Also, statistical data about "conflict" are basically irrelevant to historical analysis unless the category of "conflict" is explained. 282-283 The category of "agri-nomadic conflict" is not correct when discussing specific periods and cases (conflict occurs between polities, or otherwise defined groups of people, not between modes of production)

Response: Thanks for the reviewer's comments. "nomadic peoples" include the Mongols (nomadic) and the peoples who settled in the oasis area where animal husbandry and agriculture co-exist.

275 Reference to the source for data on frequency of tribute and trade is required.

Response: Thanks for the reviewer's reminder. We have added the reference. Please see **Line 242**.

303-4 Can the absence of a relationship demonstrate something? Possibly reconsider.

Response: Thanks for the reviewer's comments. We assume that absence of a relationship between the frequency of wars in the Dunhuang area and variations in the amount of tribute trade demonstrates that warfare was not the primary or the only cause of the collapse of trade along the Ancient Silk Road trade.

354-355 This seems to be a misunderstanding. The reference in Yang et al. is to lower precipitation during the 14-century period 900 BC- 500 AD. It does not indicate a specific desertification event from 900-550 BC, as is contended here. Therefore, there is no correlation with the XSW data. More generally, the significance of the "first desertification event" is difficult to place in terms of the main thrust of this article, which is about the collapse of the Silk Road from an environmental perspective.

Response: Thanks for the reviewer's comments. The evidence of a thick sand layer in the XSW section shows that desertification occurred during the period 800-600 BC., and Yang's work on tree-rings also indicates a decrease in precipitation during 900-550 BC. The difference in timing of 50-100 years may be caused by a lagged response

of desertification to the reduction in rainfall. In addition, there are possible measurement errors in the dating techniques. On the other hand, the precipitation decrease in Qilian Mountains consistent with the desertification process in 800~600 BC testified and provided more evidence for the relationship of the later ~1450 AD desertification event with tree ring records from the Qilian Mountains.

362-65 Gou et al. 2015a does not mention the period 1447-1567, but 1426–1555. Moreover, in Gou et al. 2015a and Gao et al. 2015b the climate data are based on scPSDI (self-calibrated Palmer Severity Drought Index) and SPEI (standardized precipitation and evapotranspiration index) values. It is unclear how these values match the data provided in this paper.

Response: Thanks for the reviewer's comments. We have modified the relevant data. - please see **Line 316**. These references are only supporting evidence and the trend of variation and our sedimentary profile are our principal pieces of evidence. Besides, the start and finish time was fitted.

387-402 Evidence for this region from the 4th to 1st millennium BCE is based uniquely on archaeological documentation and therefore it would be better to replace "documentary" in the subtitle with either "archaeological" or "material".

Response: Thanks for the reviewer's reminder. We have modified the text accordingly. Please see **Line 339**.

407-414 The migration of the Yugur requires context: when did it happen and how can we relate the difficulties mentioned in their oral history to the site of XSW at around 1450 CE?

Response: Thanks for the reviewer's comments. Unfortunately, we cannot provide the date of the folk song. However, the abandonment of Dunhuang led to the formation of the Yugur nationality which has been discussed in previous studies. Also, the content of the folk songs was directly related to migration from Dunhuang to Jiayuguan in the 15th century (Chen, 2011). Please see **Line 360-362**.

References:

*Chen, G. W.: Research on the enclosure of the Dunhuang during Ming Dynasty. J. Dunhuang study., 60, 111-118, 2011 (in Chinese).*

445-466 The contention that between 1450 and 1530 the oases of Dunhuang and Guazhou were not functioning is belied by the evidence of trade-tribute missions listed in Chinese sources for this period. Therefore, more research is required on communication routes. Moreover, the evidence presented in this article does not support the notion that no ground water was available through natural wells along the caravan route. In other words, evidence of drought conditions in one place does not mean that water disappeared for the limited use of watering camels en route.

Response: Thanks for the reviewer's comments. We accept the reviewer's opinion that although the desertification created major difficulties across the region, it would not have made it completely inaccessible. Even in the Qing dynasty, when the climate changed into wetter, foreign expeditions across the regions incurred substantial loss of people and animals. We have modified the text accordingly. Please see **Lines 435-438**.