Anonymous Referee #1

The manuscript entitled "Apparent discrepancy of Tibetan ice core $\delta^{18}O$ records may be attributed to misinterpretation of chronology" by Hou et al. presents a new high resolution $\delta^{18}O$ record from the Chongce ice core from the Tibetan Plateau (TP) on the basis of the previously published timescale (Hou et al., 2018). The record covers the middle and late Holocene (the past ~7 kyr). Although the Chongce ice core is very close to the Guliya ice core (~30 km away), the Holocene pattern in the Chongce $\delta^{18}O$ record is clearly different from the original Guliya $\delta^{18}O$ record (Thompson et al., 1997). As such, the authors attributed the observed discrepancy between the Holocene $\delta^{18}O$ records of the Guliya and the Chongce ice cores to a misinterpretation of the Guliya ice core chronology. Given the fact that the Guliya record (covering the past ~130 kyr based on its original timescale) has been widely used as an important climate reconstruction/benchmark (cited nearly 1000 times), even after its chronology was questioned by Cheng et al. (2012), the new observational data obtained near Guliya and the new insights about Guliya chronology are fascinating and thus deserve to be published. However, I have a few suggestions for improvement pending on which I recommend acceptance of this paper.

(1) The authors imply that they could not get the original dataset of the Guliya and other Tibetan ice core records that were used in several published papers. Please contact the authors of the original papers again to get the original datasets, instead of using digitizer software or other approximate approaches.

Response:

I sent an email on 3 April to the corresponding author of the original papers regarding the possibility of sharing the original datasets of the Guliya and other Tibetan ice core records, and got responses from Prof. Lonnie Thompson on 13 April, and Prof. Ellen Mosley-Thompson on 15 April. They said they would provide a web link for downloading the Dunde ice core $\delta^{18}O$ datasets. We are very grateful for their willingness to share the datasets, and will update the figures accordingly with the datasets. It is worth pointing out that, even without the original datasets, the general patterns of the Guliya and Dunde $\delta^{18}O$ profiles are sufficiently preserved in the summary data to support our conclusions.

(2) The interpretation of Tibetan ice core $\delta^{18}O$ data solely as a temperature proxy needs to be further validated. The apparent positive relation observed between ice core $\delta^{18}O$ and local temperature from instrumental records cannot be mechanically extrapolated to explain the relation on much longer timescales, for example, the Holocene (e.g., Liu et al., 2015; Shao et al., 2017). This claim is crucial to Tibetan ice core researches, including this paper, and should be more rigorously backed up with empirical data and/or model simulations.

Response:

Many studies have shown a significant positive correlation between local temperature and isotopic composition in precipitation in the northern Tibetan Plateau (e.g., Yao et al., 1996; Tian et al., 2003). This positive correlation is also observed between local temperature from instrumental records and isotopic composition in ice cores from Tibetan Plateau (e.g., Tian et al., 2006; Kang et al., 2007; An et al., 2016). Specifically, An et al (2016) established a statistically significant correlation between annual (not seasonal) $\delta^{18}O$ of Chongce ice core and annual temperature record at Shiquanhe (the nearest climate station). In addition, simulations by the LMDZ4 general circulation model indicate that this positive correlation between local temperature and precipitation isotope has persisted during the Holocene (Risi et al., 2010).

Although changes in moisture source (as indicated by Liu et al., 2015) or large-scale atmospheric circulation (as indicated by Shao et al., 2017) could influence precipitation isotopic composition in the Tibetan Plateau, such changes often lead to concurrent temperature change with the same effect on the precipitation isotopes. Therefore, we believe that the isotopic variability of Chongce ice core primarily reflects local temperature signals.

(3) In the past decade, more and more evidences demonstrate that the temporal pattern of the precipitation $\delta^{18}O$ changes on orbital-scale, including the Holocene, broadly follows Northern Hemisphere summer insolation (NHSI) inversely in the westerlies (e.g., Bar-Matthews et al., 2003; Cheng et al., 2012a, 2016a; Cai et al., 2017; Mehterian et al. 2017), Indian Monsoon (e.g., Zhang et al., 2011; Cheng et al., 2012b; Cai et al., 2015; Kathayat et al., 2016; Han et al., 2017), East Asian Monsoon (e.g., Cheng et al., 2016b) climatic regimes, as well as within the Tibetan Plateau (e.g., Cai et al., 2010, 2012; Zhang et al., 2011). Cheng et al. (2012) proposed two possibilities: (1) Both the Guliya and Kesang relationships (nearly opposite on orbital-scale) could be valid, with differences related to the different elevations and localities of the sites. (2) Alternately, differences could be reconciled if the low excursions in Guliya $\delta^{18}O$ were, instead, correlated to high excursions in CH_4 (or higher NHSI). Notably, all aforementioned precipitation $\delta^{18}O$ records show a consistent inverse $\delta^{18}O$–NHSI relationship on orbital (possibly millennial) timescale with rather similar amplitudes, in line with the latter possibility. As such, the authors should take the above observations into consideration. In other words, a detail comparison of the Guliya ice core record with the NHSI or a large number of precipitation $\delta^{18}O$ records remains one of valid (or better) approaches to establish a more reliable Guliya ice core chronology. Additionally, the new dates from the bottom of the Guliya ice cap indeed show some last glacial ages (Thompson et al., 2018; Zhang et al., 2018; as well as the data in Figure S2), which are consistent with the chronology of the 'Guliya-Cheng' (rather than

the 'Guliya-New') reconstructed on the basis of a comparison with other precipitation $\delta^{18}O$ records from both Westerlies and Asian Monsoon climatic domains.

Response:

We think that the Guliya-New chronology is more reasonable than Guliya-Cheng for several reasons. (1) The Guliya-Cheng chronology would put the high stands of $\delta^{18}O$ values of the Guliya profile from the depth 266 m to the ice core bottom (Fig. 4 in our manuscript) in the cold glacial period. This is very unlikely, given the significantly positive relationship between temperature and $\delta^{18}O$ in precipitation over the northwestern TP (see the response above). (2) The ages established in Zhang et al (2018) and Ritterbusch et al. (2018) only serve to provide upper constraints, and the actual bottom age of the ice cores is likely to be younger. Thompson et al. (2018) did not provide any new estimates of the bottom age of the Guliya ice cores (both 1992 and 2015 cores), as they wrote that "Future analyses will include ^{14}C on organic material trapped in the ice, and ^{36}Cl, beryllium-10 (^{10}Be), $\delta^{18}O$ of air in bubbles trapped in the ice, and argon isotopic ratios ($^{40}Ar/^{38}Ar$) on deep sections of 2015PC2 to determine more precisely the age of the ice cap." (3) The data in Fig. S2 in our manuscript is based on Zhong et al. (2018), who established the chronology of the 2015 Guliya summit ice core by matching its $\delta^{18}O$ values with those from the 1992 Guliya ice core (Thompson et al., 1997). There is still much inconsistency between the age ranges of the 2015 Guliya summit ice core and the1992 Guliya ice core despite the fact that the two age points of the 2015 Guliya summit ice core are deduced from the original chronology of the1992 Guliya ice core. This casts further doubt on the original 1992 Guliya chronology. Consequently, the chronology of the 2015 Guliya summit ice core might also suffer from this questionable original 1992 Guliya chronology. (4) Hou et al. (2018) provided convincing evidence that the bottom age of the Chongce ice cores is likely within the Holocene, consistent to the other Tibetan ice cores except the Guliya ice core. Given the similarity between the Guliya and Chongce depth $\delta^{18}O$ profiles (Fig. 5 in our manuscript), it is reasonable to suggest that the Guliya core covers a similar time span as the Chongce core, though a more detailed comparison (Fig. 4 in our manuscript) would be necessary when more evidence and the original datasets of the Tibetan ice cores become available in order to confirm the Guliya-New chronology.

Consistent with all other precipitation $\delta^{18}O$ records in the westerlies regime, the Chongce ice core $\delta^{18}O$ record also shows an inverse $\delta^{18}O$-NHSI relationship at the precession time scales. There are two possible explanations for this inverse $\delta^{18}O$–NHSI relationship. First, some studies suggest this inverse relationship is caused by the possible incursions of the Asian summer monsoon moisture (with low $\delta^{18}O$) into central Asia during the high NHSI summers. For example, the speleothem $\delta^{18}O$ record from Kesang Cave in northwestern China was much depleted at times of high NHSI (Cheng et al., 2012, 2016), a feature closely resembling speleothem records in Asian summer monsoon regime. The second explanation suggests that one would expect an inverse $\delta^{18}O$–NHSI relationship if winter precipitation (with low $\delta^{18}O$) in the westerlies region increased during the low Northern Hemisphere winter insolation (NHWI, which has a reverse phase with NHSI) (Tzedakis, 2007; Kutzbach et al., 2014). At present, there is no consensus on what caused the inverse $\delta^{18}O$-NHSI relationship, and additional studies are needed for unravelling the underlying mechanisms. Here, we compared the Chongce isotopic record with other records of precipitation $\delta^{18}O$ in the westerlies regime, including speleothem $\delta^{18}O$ records from the Kesang Cave in the northwestern China (Cheng et al., 2012), the Ton Cave in Uzbekistan (Cheng et al., 2016), the Kinderlinskaya Cave in the southern Ural Mountains (Baker et al., 2017), and the Soreq Cave from Central Israel (Bar-Matthews et al., 2003), and a record of the oxygen isotope composition of permafrost ice wedges from the Lena River Delta in the Siberian Arctic (Meyer et al., 2015) (Fig. 1). All of these records show a consistent rising trend during the middle to late Holocene, in contrast with decreasing trend observed in the isotopic record of the Guliya ice core during this period.

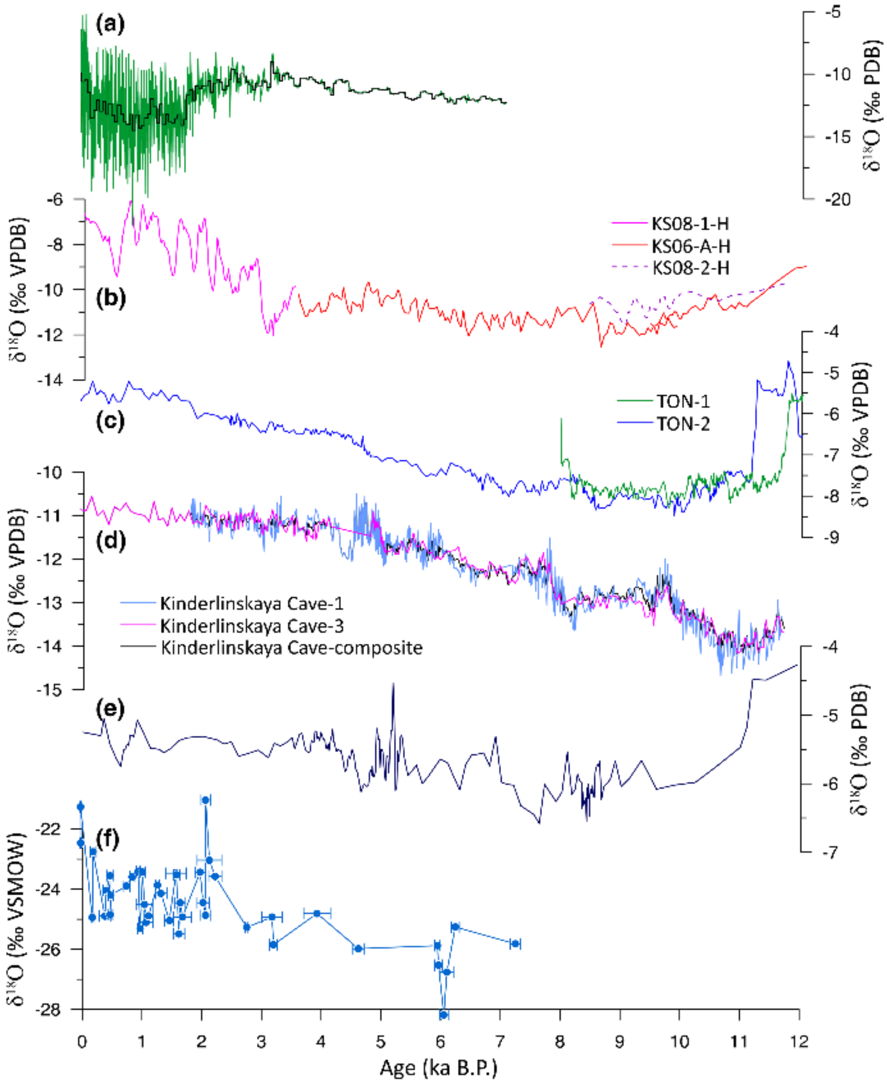

Fig. 1: Comparison of oxygen isotopic records during the Holocene from the Chongce ice core (a), the Kesang Cave (Cheng et al., 2012) (b), the Ton Cave in Uzbekistan (Cheng et al., 2016) (c), the Kinderlinskaya Cave in the southern Ural Mountains (Baker et al., 2017) (d), the Soreq Cave from Central Israel (e) and permafrost ice wedges from the Lena River Delta in the Siberian Arctic (Meyer et al., 2015) (f).

(4) Broadly, the amplitude of $\delta^{18}O$ variations on orbital (or glacial-interglacial) scale is about ~8 ‰ in the Westerlies (e.g., Bar-Matthews et al., 2003; Cheng et al., 2012a, 2016a; Mehterian et al., 2017) and Indian Monsoon (e.g., Cai et al., 2010, 2012, 2015; Kathayat et al., 2016) domains, and ~4 ‰ in the East Asian Monsoon domain (e.g., Cheng et al., 2016b). In addition, the climate during the interglacial time periods, including the Holocene, is fairly stable as inferred by a wide range of proxy records, including various precipitation $\delta^{18}O$ records. Provide the 'Guliya-New' chronology was factual, the prominent multi-millennial changes around the mid-Holocene as characterized by ~10 ‰ $\delta^{18}O$ change (larger than

the large regional glacial-interglacial amplitude) would be an unconceivable anomaly (Figure 4), which requires a proper explanation.

Response: Large amplitudes of $\delta^{18}O$ variations are often observed in the Tibetan core cores during the Holocene, such as ~8 ‰ for the Guliya ice core (Fig. 2 in the manuscript) (or ~6‰ based on its original chronology, Fig. 3 in the manuscript), ~6.5 ‰ for the Chongce ice core (Fig. 5 in the manuscript), and ~6 ‰ for the Puruogangri ice core (Fig. 3 in the manuscript). This is largely attributed to the elevation dependency of temperature change observed in many studies, i.e. high altitude regions experience larger temperature changes than low elevation regions (Beniston et al. 1997; Liu and Chen, 2000; Mountain Research Initiative EDW Working Group, 2015). In addition, prominent changes in water vapor sources associated with northward and southward shifts of the westerly circulation on longer timescale (e.g., from multi-millennial to orbital timescales) may also contribute to the large amplitude of $\delta^{18}O$ variation in core cores on the Tibetan Plateau.

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