Responses to Comments on the Manuscript:

Water vapor isotopes indicating rapid shift among multiple moisture sources for the 2018/2019 winter extreme precipitation events in Southeast China

(MS No.: hess-2021-269)

Many thanks for the reviewer's and editor's constructive comments. Below are our point-to-point responses to the comments. The comments are in black, and our responses are in blue.

Editor's comments:

Dear authors,

Thank you very much for your responses to the review comments, on which basis I would like invite you to submit a revision that fully addresses the review comments.

Please pay special attention to the comments by referee #3, in particular attention is needed to the issue 'Even slight precipitation can produce the lower $\delta^{18}O$ and d-excess in the observed near surface vapor. Therefore, to trace the vapor source, we usually remove the period apparently influenced by rainfall events. This have been found by previous publications in comparing the concurrent vapor and rainfall $\delta^{18}O$ and d-excess.'

It is not clear if you have excluded the isotope data impacted by rainfall events.

Referee #3 suggested that you compare the vapor isotopes data with parallel precipitation isotopes. This may resolve this issue, however if you do not have observation of parallel precipitation isotope, at least you need to make sure that your analyzed data are not contaminated by precipitation.

Response: We thank you for handling our paper and for summarizing issues raised by the reviewers. Considering reviewers' comments, we made considerable efforts to revise this manuscript thoroughly.

We agree with referee #3. Following the comments by referee #3, we analyzed the relationship between precipitation amount and water vapor isotopes. Overall, no significant correlations were observed for our winter precipitation events, indicating that precipitation amount is not the dominant factor affecting stable isotopes in water vapor. However, precipitation amount can affect the isotopic composition in water vapor during a certain stage of precipitation event (i.e., stage 4 of event a, stage 1 of event c and d, stage 2 of event e), which was analyzed in the revision.

Referee #1:

General comments:

Through isotope observation data and HYSPLIT model simulation, this study reveals the close relationship between isotope changes and different water vapor sources, and clearly shows the rapid movement of water vapor source area through d-excess, which provides a certain theoretical basis for in-depth analysis of water vapor source path and water vapor supply in extreme precipitation area. Although there are still some shortcomings in this paper, I suggest that this paper be revised and published on HESS.

Specific comments,

1) L.73 'above sea level' can be abbreviated as 'a.s.l.'.

Response: Change has been made accordingly in the revision.

2) L.78-80 How to define extreme precipitation in this paper? What standards are used?

Response: In this paper, the 2018/2019 winter extreme precipitation refers to extreme precipitation at climate scale, in difference with the definition of extreme precipitation event at weather scale. In the 2018/2019 winter, the regional average cumulative effective precipitation days in Southeast China exceeded 51 days, breaking the historical record since 1981 (Guo et al., 2019). In Nanjing, where our research site is located, the accumulated precipitation is 259 mm, more than double the seasonal average of 1981–2010 (the seasonal average precipitation is 126 mm). As a result, we defined the 2018/2019 winter as a typical long-term extreme precipitation period. Because some water vapor isotopic data at Nanjing were missing due to instrument repair or maintenance, five large-scale precipitation events were finally selected for analysis, including (a) December 4−11, (b) December 24−30, 2018, (c) January 7−11, (d) February 16−22, and (e) January 27−31, 2019. We added the definition of winter extreme precipitation in new **Section 2.5**.

3) There are six extreme precipitation indexes (WMO). Which indexes are studied in this study? The reviewers believe that the relationship between precipitation events, precipitation intensity and stable isotopes should be analyzed respectively;

Response: In the 2018/2019 winter, the regional average cumulative effective precipitation days in Southeast China exceeded 51 days, breaking the historical record since 1981 (Guo et al., 2019). In Nanjing, the accumulated precipitation is 259 mm, more than double the seasonal average of 1981–2010. As a result, we defined the 2018/2019 winter as a typical long-term extreme precipitation period.

We agree with the reviewer that the relationship between precipitation events, precipitation intensity, and stable isotopes should be analyzed respectively. In this study, we analyzed the relationship between five extreme precipitation events and stable isotopes in water vapor. Based on the large-scale atmospheric circulation patterns, we group these precipitation events into three classes: 1) the cold air mass dominated events, 2) the warm air mass dominated events, and 3) the alternating cold and warm air masses dominated events. Correspondingly, water vapor isotopes also show three kinds of variation characteristics. In the first class, the $\delta^{18}O_v$ value was generally high at the beginning, decreased significantly during the events, and gradually increased again toward the end of the events, whereas the d_v value showed the opposite trends. In the second class, the $\delta^{18}O_v$ value was generally high at the beginning, decreased significantly during the events, and gradually increased again toward the end of the events. Different from the first class, both $\delta^{18}O_v$ and d_v values in this class showed changes in the same direction throughout the event. In the third class, the $\delta^{18}O_v$ value remained constant in the early stage, and decreased rapidly in the later stage, while the d_v value fluctuated greatly. It is clear that the impacts of different atmospheric circulation systems on water vapor isotopes differ significantly.

According to the reviewer's suggestion, we analyzed the relationship between precipitation intensity and stable isotopes, as shown in Figure R1. Overall, no significant correlations were observed for all events. There are only weak negative correlations in some events (Figs. R1c, d, and e), indicating that precipitation intensity is not the dominant factor affecting stable isotopes in water vapor. However, precipitation amount can influence water vapor isotopes during some stages of precipitation events (i.e., stage 4 of event a, stage 1 of event c and d, stage 2 of event e), which was analyzed in new **Section 4.1** "Controlling factors for water vapor isotopic variations during precipitation events".

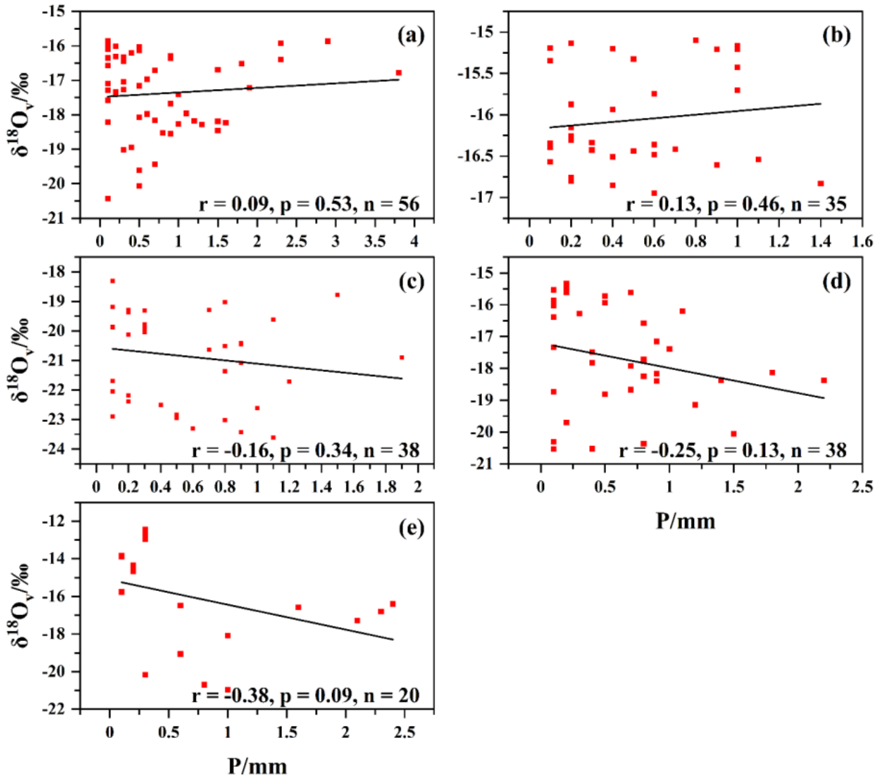

Figure R1. The bivariate plots between hourly $\delta^{18}O_v$ and precipitation amount (P) for the five extreme precipitation events. (a) Event December 4–11, 2018; (b) Event December 24–30, 2018; (c) Event January 7–11, 2019; (d) Event February 16–22, 2019; (e) Event January 27–31, 2019. Lines represent the linear regression relationship.

4) How long did the HYSPLIT backward trajectory mode simulation track?

Response: In this study, the backward trajectory was simulated for 192 hours (8 days) because the average residence time of water vapor in the atmosphere is about 8 to 10 days (van der Ent and Tuinenburg, 2017).

5) The typical reason for the formation of cold wave in winter is the complex weather in 2018/2019. In addition to sufficient water vapor conditions and circulation field, atmospheric stability is also a necessary condition for the formation of extreme precipitation events. The analysis of atmospheric stability is lack in this paper

Response: We agree with the reviewer. Hourly atmospheric stability has been calculated and added to **Figure 2** in the revised manuscript. We also analyzed the variations of atmospheric stability and their influence on water vapor stable isotopes in **Section 3** and new **Section 4.1**, respectively.

6) The variations in $\delta^{18}O_v$ and d_v values of water vapor have a good correspondence with wind direction, but what is the relationship with the vapor transport simulated by the HYSPLIT model?

Response: Thanks for the reviewer's comments. Figure R2 shows the comparison between the HYSPLIT backward trajectories 6 hours before the turning point of d_v (red) and the trajectories 6 hours after the turning point of d_v (blue) for the five precipitation events. In most cases, the trajectories before and after the turning point are significantly different, which further proves that the turning points of d_v correspond to the rapid shift of moisture source regions. We added these results in **Section 4.3**.

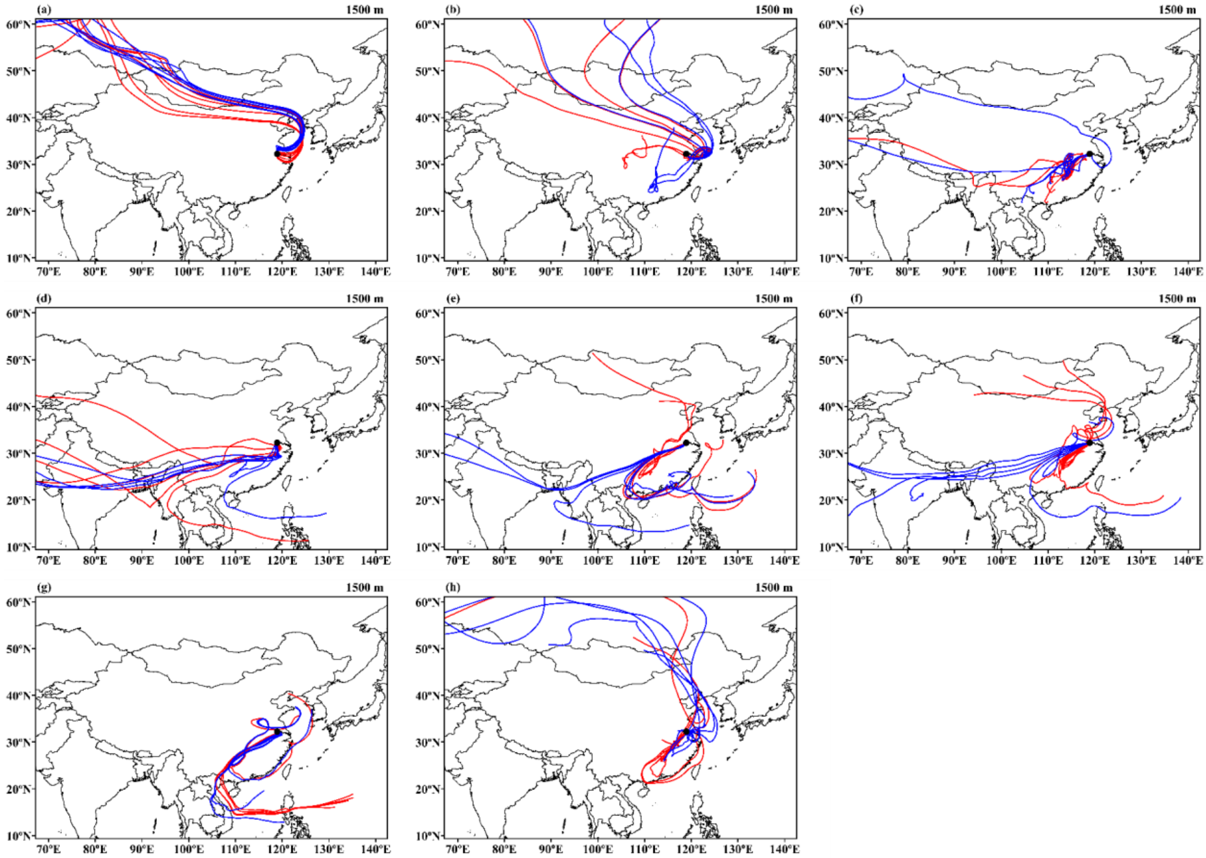

Figure R2. Spatial distribution of the selected 192 h HYSPLIT back trajectories for the five precipitation events. The red lines represent the trajectories 6 hours before the turning point of the d_v, and the blue lines represent the trajectories 6 hours after the turning point of the d_v: (a) and (b) for the d_v turning points of Event December 4−11, 2018; (c) for the d_v turning points of Event December 24−30, 2018; (d) and (e) for the d_v turning points of Event January 7−11, 2019; (f) and (g) for the d_v turning points of Event February 16−22, 2019; (h) for the d_v turning points of Event January 27−31, 2019. The black circle indicates the location of Nanjing.

7) L.118-119 '(c) January 7−11, (d) February 16−22, and (e) January 27−31, 2019'. should be '(c) January 7−11, (d) January 27−31, and (e) February 16−22, 2019'.

Response: The subplots were ordered by the three classifications, and hence not in chronological order.

Referee #2:

Extreme precipitation events can lead to great disasters to society. It is very essential to study the mechanism of extreme precipitation events with multiple approaches. With the development of continuous measurements of water vapor isotopes with high temporal resolution, tracing moisture source and water vapor transport through water vapor isotopes becomes an important tool for studying precipitation process (especially the extreme precipitation events). However, the complex variation patterns of water vapor isotopes and the atmospheric processes behind extreme precipitation events are unclear due to the lacking of observation studies. This study successfully reveals the complex variation patterns of water vapor isotopes and their controlling factors during the winter extreme precipitation events in Nanjing, which is important for further understanding the complex variation patterns of water vapor isotopes and the underlying mechanism. However, some issues listed below need to be addressed to improve the paper.

Lines 44-59: In this paragraph, I suggest adding some case studies on precipitation process (especially the extreme events) through water vapor isotopes observations, aiming to demonstrate the effectiveness of the water vapor isotope approach for studying the extreme precipitation.

Response: Following the reviewer's comment, we added additional literatures to cover case studies of using stable isotopes observations to study individual precipitation events in the revised manuscript.

Lines 99-100: What's the basis for choosing 8 days and 1500 m for the HYSPLIT simulations?

Response: In this study, the backward trajectory was simulated for 192 hours (8 days) because the average residence time of water vapor in the atmosphere is 8 to 10 days (van der Ent and Tuinenburg, 2017). The 1500 m simulation height is chosen because the water vapor transport mainly occurs in the lower troposphere (Breitenbach et al., 2010; Bedaso and Wu, 2020).

Lines 115-171: In the Results section, you combined the results of isotopic variations during precipitation events and the discussion of controlling factors for isotopic variations. It is difficult for readers to follow. I suggest separating the results and the discussion and adding a new subsection for discussing the influencing factors of isotopic variations.

Response: Thanks for the reviewer's constructive comments. As suggested, we moved the discussion of controlling factors for isotopic variations to the Discussion section as the new **Section 4.1** "Controlling factors for water vapor isotopic variations during precipitation events" in the revised manuscript.

Fig.2: Array the sub-figures in the same way as Figs. 3-5

Response: Change has been made according to the reviewer's suggestion.

Line 101: Why the resolution of the CWT field is 0.5°×0.5°? But the resolution of the GDAS dataset you used is 1°×1°.

Response: We have recalculated the CWT with a resolution of 1°×1° in order to keep the same resolution as the GDAS dataset.

Line 111: What kind of reanalysis data do you use? ERA5 or ERA-Interim?

Response: The ERA5 dataset was used in this study.

Referee #3:

The authors presented an continuous observation of near surface vapor isotope ($\delta^{18}O$ and d-excess) for 5 winter raining events in Nanjing, China. Although precipitation isotopes have been used to diagnose different moisture sources, the vapor isotopes are less observed and more rare for moisture source identification of winter precipitation. This manuscript presented the vapor isotopes abrupt shifts during the 5 raining events and related them to the moisture transportation and moisture shifts.

My concern about this work is that the measurement is the near surface vapor, not the free atmosphere vapor that formed the precipitation observed. In fact, the vapor isotope shifts are caused by the re-evaporation of precipitation, which is much lower than the normal vapor isotope without precipitation events. Even slight precipitation can produce the lower $\delta^{18}O$ and d-excess in the observed near surface vapor. Therefore, to trace the vapor source, we usually remove the period apparently influenced by rainfall events. This have been found by previous publications in comparing the concurrent vapor and rainfall $\delta^{18}O$ and d-excess.

I suggested the author to compare the vapor isotopes data with parallel precipitation isotopes and you can find the trick. I also suggest the authors to refer more references for similar observations.

Response: We highly appreciate the reviewer's comment. Limited by the existing conditions, free atmosphere vapor samples are difficult to collect. Therefore, observation of near-surface water vapor isotopes is the main means to achieve high-frequency and continuous isotopic data in water vapor. We agree with the reviewer that the raindrop re-evaporation could contribute to changes in stable isotopes in precipitation and surface water vapor.

As suggested, we compared the observed water vapor isotopic ratios ($\delta^{18}O_v$) with the theoretical isotopic composition of the water vapor in equilibrium with that of the precipitation at local temperature ($\delta^{18}O_e$) for the five typical precipitation events (Fig. R3). In most cases, the observed values are close to the equilibrium values, suggesting little raindrop re-evaporation. The $\delta^{18}O_e$ values are slightly larger than the observed $\delta^{18}O_v$ values in some days during precipitation events d and e, indicating the re-evaporation of falling raindrops. We found that the relatively large fluctuations of $\delta^{18}O_v$ and d_v (especially lower $\delta^{18}O_v$) in stages 2 and 3 of precipitation event d and in stage 1 of precipitation event e may be caused by the effect of re-evaporation of precipitation. These analyses, discussions, and a new figure (**Fig. 4**) have been added to the revised manuscript.

We also agree with the reviewer that precipitation can produce the lower $\delta^{18}O$ and d-excess in the observed near surface vapor. Therefore, we analyzed the relationship between precipitation amount and stable isotopes, as shown in Figure R1. Overall, no significant correlations were observed for all events, indicating that precipitation amount is not the dominant factor affecting stable isotopes in water vapor. There are only weak negative correlations in some events (Figs. R1c, d, and e), indicating that precipitation can influence water vapor isotopes during some stages of precipitation events (i.e., stage 4 of event a, stage 1 of event c and d, stage 2 of event e), which was analyzed in new **Section 4.1** "Controlling factors for water vapor isotopic variations during precipitation events".

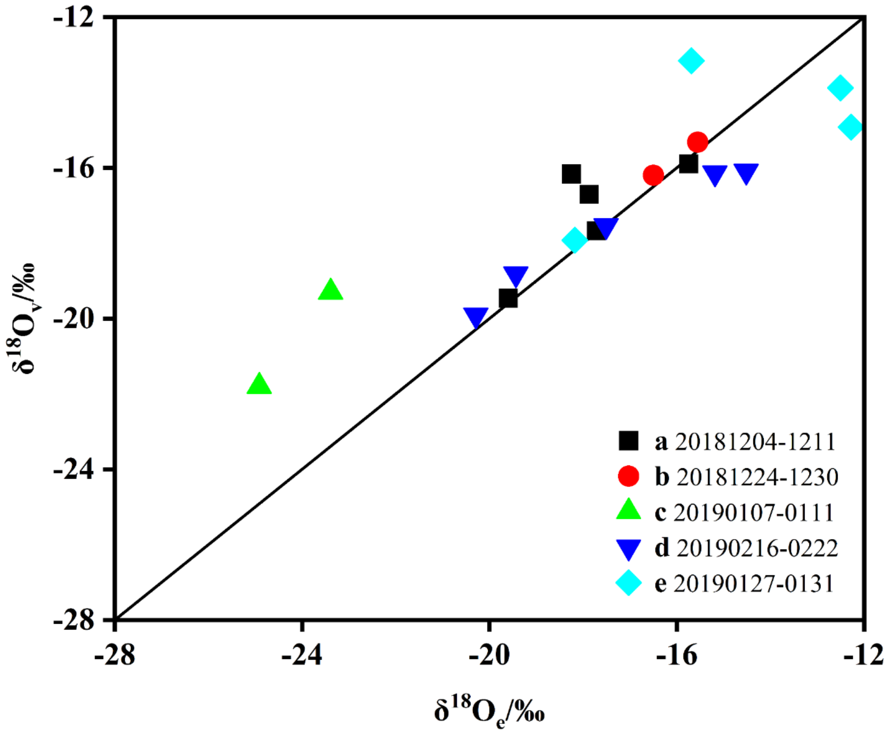

Figure R3. Relationship between observed ($\delta^{18}O_v$) and equilibrium ($\delta^{18}O_e$) vapor isotopic ratios in the five typical precipitation events. The isotopic composition of the water vapor theoretically in equilibrium with that of the precipitation ($\delta^{18}O_e$) is calculated by $\delta_e = (\delta_p - \varepsilon) / \alpha$, where ε is the equilibrium enrichment factor, and α is the liquid-to-vapor equilibrium fractionation factor (Mercer et al., 2020). The solid black line is the line of equilibrium.

References

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