Response to Anonymous Referee #1

General comments: Despite the moisture sources of the Tibetan Plateau (TP) have been basically revealed by several researches on the basis of different methods, the further study of the moisture sources over TP from various dataset is necessary. In this manuscript, the authors quantified the absolute and relative contributions of oceanic moisture sources over TP based on a moisture tracking model and the various atmospheric reanalysis products. The methods in the manuscript is generally effective, while the moisture tracking method in this study still have non-ignorable uncertainties and need proper evaluation. In science, the novel contribution of this study is not clear due to most of the conclusions have been revealed in previous studies. Therefore, I would recommend that the manuscript need major revision before accepted by HESS. Below are my specific comments.

Response: Thank you for your valuable comments and suggestions.

For the uncertainties of the moisture tacking method, in the revision, we will further explain (1) why we chose the WAM-2layer model and (2) how we dealt with the uncertainties of this model. The clarification will be added to the revised manuscript. Please see our detailed response to your specific comment #1.

For the novelty of this study, in the revision, we will more clearly point out the unique contributions of this paper by (1) summarizing knowledge gaps and (2) thoroughly comparing this study with existing moisture tracking studies in the TP (see Table AC1). Please see our detailed response to your specific comment #2.

Specific comments:

1. In this study, there are several approximation in the Eulerian moisture tracking method (Van der Ent et al., 2010; Van der Ent, 2014), which induce non-ignorable uncertainties of the moisture sources calculations. For example, it only can resolve two vertical layers in the model and does not consider all the water substances (water vapour, cloud droplets, cloud ice, rain, and snow) and all the physical processes that the moisture undergo in the model, eg. deep convection, shallow convection, cloud macrophysics, cloud microphysics, diffusion etc. It is not the best one. In fact, the detailed quantified moisture models have been developed. In the references in around line 70, I suggest the authors pertinently evaluate previous studies and properly evaluate Van der Ent' (2014) method in section 2.1. Also need indicate the uncertainties of this method in the manuscript.

Response: Thank you for the comment and suggestion. We would like to address your concern from the following two aspects.

(1) Why we chose to use the WAM-2layer model over the study area.

Firstly, the WAM (Water Accounting Model) has already been widely used in moisture tracking in the TP region, for example, in the central-western TP (*Zhang et al.*, 2017), in the Endorheic TP (*Li et al.*, 2019), between the southern and northern parts of the TP (*Zhang et al.*, 2019a), and in the entire TP (*Guo et al.*, 2019; *Zhang*, 2020). The quantified moisture tracking results with WAM are generally consistent with other commonly used models, such as FLEXPART, HYSPLIT, LAGRANTO, QIBT, and CAM (see Table AC1 for a detailed comparison). This cross-region, cross-model comparison showcases the reliability and robustness of WAM model for moisture tracking over the study area.

Table AC1. Studies of numerical moisture tracking in the TP region.

Reference	Study area	Time period	Model	Data	Main conclusions
Chen et al. (2012)	TP	2005–2009 (summer)	FLEXPART	NCEP/GFS	The ocean source could extend from the Arabian Sea to the Southern Hemisphere.
Sun and Wang (2014)	Grassland on eastern TP	2000–2009	FLEXPART	NCEP-CFSR	During the warm (cold) season, oceanic moisture is mainly from the Arabian Sea and Bay of Bengal (areas surrounding the Arabian Peninsula).
Zhang et al. (2017)	Central-western TP	1979–2013	WAM	ERA-I, NCEP-2	More than 21% of the moisture comes from oceans.
Huang et al. (2018)	Southeastern TP	1979–2016 (winter extreme precipitation)	LAGRANTO	ERA-I	About 18% of the moisture comes from oceans.
Pan et al. (2018)	Southern/northern TP	1982–2014	CAM	MERRA	During summer, the Indian Ocean supplies about 28.5% of the moisture to the southern TP.
Chen et al. (2019)	Four areas in TP	1980–2016 (May–August)	FLEXPART	ERA-I	The northwestern TP and northeastern TP are less affected by the Indian monsoon moisture.
Guo et al. (2019)	TP	1979–2015	WAM-2layers	ERA-I	Indian Ocean and Pacific Ocean account for 24% and 2% of the moisture contribution, respectively.
Li et al. (2019)	Endorheic TP	1979–2015	WAM-2layers	ERA-I, MERRA-2, JRA-55	24%–30% of the moisture comes from oceans.
Qiu et al. (2019)	Three areas in TP	1979–2016 (winter extreme precipitation)	LAGRANTO	ERA-I	Moisture contributions of the Arabian Sea to the intense precipitation in the western, south-central, and southeastern TP are 9.2%, 6.9%, and 1.1%, respectively.
Xu and Gao (2019)	Southeastern TP	1982–2011 (April–September)	QIBT	ERA-I	Only 2% of the moisture originates from the oceanic source.
Zhang et al. (2019a)	Southern/northern TP	1979–2016	WAM-2layers	ERA-I	Northwestern (southeastern) source contributes ~39% (~51%) of the moisture in the northern (southern) TP.
Zhang et al. (2019b)	Sanjiangyuan Region	1960–2017 (June–September)	HYSPLIT, HDBSCAN	NNR1	About 51% (54%) of the medium to heavy precipitation is influenced by the northwestern (southern) source.
Liu et al. (2020)	Western TP	1979–2018 (winter)	HYSPLIT	ERA-I	About 57% of the moisture comes from the Arabian Sea, Arabian Peninsula, and northern Indian Ocean.
Ma et al. (2020)	Seven areas in TP	1961–2015 (summer extreme event)	HYSPLIT	NCEP/NCAR	About 75% of the moisture for extreme precipitation in the southeastern TP comes from the Bay of Bengal.
Yang et al. (2020)	Southeastern TP	1980–2016 (June–September)	FLEXPART	ERA-I	30% of the moisture comes from oceans.

Zhang (2020)	TP	1998–2018	WAM-2layers	ERA-I, TRMM	The southeastern source from the TP to the western Indian Ocean accounts for 32% of the moisture contribution.
LI et al. (2022)	Seven basins in TP	1979–2015	WAM-2layers	ERA-I, MERRA-2, JRA-55	Oceanic moisture accounts for 24%–30% of the moisture in different basins of the TP.

Secondly, Lagrangian models (e.g., FLEXPART and HYSPLIT) concern the movement of ‘air particles’ in the atmosphere, thus, the identification of precipitation and evaporation events mainly relies on the dynamic humidity information of each air particle (*Tuinenburg and Staal*, 2020). The detailed methods have been introduced in *Sodemann et al.* (2008) (‘moisture source attribution’ method) and *Sun and Wang* (2014) (‘areal source–receptor attribution’ method). In comparison, Eulerian models (i.e., WAM-2layers) focus on the water balance of fixed grids, which enables us to track the precipitation and evaporation moisture separately based on the mass balance principle. This results in different computational costs for long-term studies. In Lagrangian models, researchers generally use a tracking period of about 10 days (the average residence time of moisture in the atmosphere) for a single release of air particles. For long-term experiments as in this work (1979–2020), Lagrangian methods can consume relatively higher computational resources if one continuous release particles from the target region during the period (or releasing a large amount of air particles from all potential source regions at once). Therefore, considering the need for long-term precipitation/evaporation moisture tracking, the WAM-2layer is more suitable in this study.

Thirdly, the model developers of the WAM-2layers have verified the availability of this model at both global and regional scales, by the comparisons with the ‘RCM-tag’ (MM5, the Fifth-Generation Mesoscale Model) model and the ‘3D-Trajectories’ (QIBT, quasi-isentropic back-trajectory) models (*Van der Ent et al.*, 2013). This comparison has suggested the reliability of WAM-2layers model in moisture tracking.

(2) How we dealt with the uncertainties of the model.

Firstly, as mentioned by the reviewer, the model contains only two layers. The two layers are set to adequately deal with the wind shear in the upper air, but this does not affect the accuracy in calculating the $\partial(S_k u))/\partial_x$ and $\partial(S_k u))/\partial_x$ in Equation (1) in the manuscript. In fact, a total of 17 layers of wind fields and specific humidity were used in the model to separate these two model layers. In addition, we also downloaded the total column moisture and vertically integrated moisture fluxes over all tracking areas to revise the calculations of moisture transport in the model.

Secondly, we have considered all possible phases of water in the atmosphere in ERA-Interim and MERRA-2, which contains water vapor, cloud liquid water, and cloud frozen water. One exception is JRA-55, for which we did not consider the cloud liquid/frozen water, as it is not available.

Thirdly, we totally agree with the reviewer that some physical processes, such as the deep convection, shallow convection, cloud macrophysics, cloud microphysics, and diffusions, are not considered in the model. However, the core function of the WAM-2layers is the dynamic reproduction of the moisture transport processes with the input datasets. An analysis at the original resolutions of the input datasets will largely limit uncertainties to input datasets themselves. We acknowledge that for analyses at a higher spatial-temporal resolution, more physically based models might be more accurate (e.g., WRF-WVT). In this work, all analyses were conducted at the original spatial resolution of the input datasets (1°×1°). To better capture the vertical exchanges due to convection, turbulence, and re-evaporation and minimize the water balance losses between different model layers in a higher temporal resolution in the WAM-2layers, the gross vertical flow is set to 4 times the vertical flow in the net flow direction and 3 times the vertical flow in the opposite direction according to the studies from *van der Ent et al.* (2014) and *Findell et al.* (2019).

Fourthly, to better demonstrate the reliability of our conclusions and potential uncertainties, we used three reanalysis products for moisture tracking over the study area. We have ensured that all relevant conclusions are supported by results using different reanalysis products.

In our revision, we will strengthen the relevant descriptions of the advantages/disadvantages of the WAM-2layers model, thoroughly evaluate previous studies in moisture tacking over the TP, and add discussion to address the uncertainties of the model.

2. In science, the novel contribution of this study is not clear. The absolute and relative contributions of moisture sources, including oceanic source over TP have been quantitatively revealed. I suggest the authors focus on the comparisons of moisture sources evaluation based on the various atmospheric reanalysis products. The relationship between model oceanic source and isotope δ18O is interesting.

Response: Thanks for your suggestions. To highlight the novelty of this study, we re-summarized the scientific significances from the following two aspects:

(1) The pressing need to study the oceanic moisture contribution to the TP.

Firstly, the TP has been considered as a thermal "air pump" that attracts low-latitude oceanic evaporation to the region, particularly under recently altered land-sea thermal gradient between the TP and global oceans (meteorological records revealed that the atmospheric warming rate over the TP was twice that of the global mean). A quantitative, spatial and temporal evaluation of the oceanic moisture contribution to the TP could help better understand the changing hydrological cycle over the TP and its underlying mechanisms.

Secondly, the interpretations of paleoclimate records in the TP, particularly the δ^{18}O and δD in the precipitation and ice-cores, largely rely on the understanding of different moisture sources for the TP. For example, the δ^{18}O and δD evaporated from oceans are relatively enriched in comparison with the other sources. Different oceanic contributions may link to different isotope values in different climate regions of the TP, which has not been thoroughly explored.

More specifically, we distinguished the moisture contribution of the Indian Ocean (IO) from that of the Western Oceans (WO) in our analyses. These two regions represent the source areas of the Indian summer monsoon and the mid-latitude westerlies (the two core circulation systems dominate the TP's climate), respectively. For example, by using numerous δ^{18}O measurements from precipitation and ice-core on the TP, Tian et al. (2007), Yao et al. (2013), and numerous isotope-related studies (Tian et al., 2001; Yu et al., 2008; Hren et al., 2009; Zhao et al., 2012; Joswiak et al., 2013; Ren et al., 2021) empirically identified a line around the 34°–35°N to represent the northward extension of the Indian summer monsoon. In this context, we intend to provide a quantitative view of the region influenced by the Indian monsoon, from the perspective of moisture contributions.

(2) The novelty of this study as compared with previous moisture tracking studies in the TP.

In comparison with the traditional synoptic and climatological analyses, the numerical moisture tracking method could quantitatively diagnose the moisture contribution to a target region. In Table AC1 above, we summarize existing studies using numerical moisture tracking in the TP published during the past two decades. Although these studies have quantified the oceanic moisture contribution to different parts of the TP in different seasons after the 1960s, nearly all of them only considered *regional averages* for specific target areas in the TP (‘Study area’ in Table AC1) with *backward* moisture tracking. The *spatial distribution* of oceanic moisture contribution to the vast TP, e.g., the transition gradient of the moisture transported from the Indian Ocean, is hitherto unclear. To fill this knowledge gap, in this study we leveraged a *forward* moisture tracking method and studied the *spatial distribution* of oceanic moisture contribution over the TP.

3. In line 147, I do not think the oceanic sources of the Mediterranean, the Red Sea, and the Persian Gulf, can compared to the Atlantic. They are too small. If say this, please give the quantitative tracking results.

Response: Thanks for pointing this out. Figure AC1 below shows the long-term mean contribution of moisture source to the TP precipitation in summer (Figure AC1a–c), in winter (Figure AC1d–f), and on an annual scale (Figure AC1 g–i). Although the spatial extent of the Mediterranean, the Red Sea, and the Persian Gulf is much smaller than that of the Atlantic, as pointed out by the reviewer, their relative contribution to TP precipitation is non-negligible. In fact, the summation of the contributions from these three regions can be greater than the contribution from the Atlantic (Table AC2 below summarizes the relative contributions of these four regions to summer, winter, and annual precipitation over the TP based on ERA-Interim dataset). We will add this table and justification in the revised manuscript.

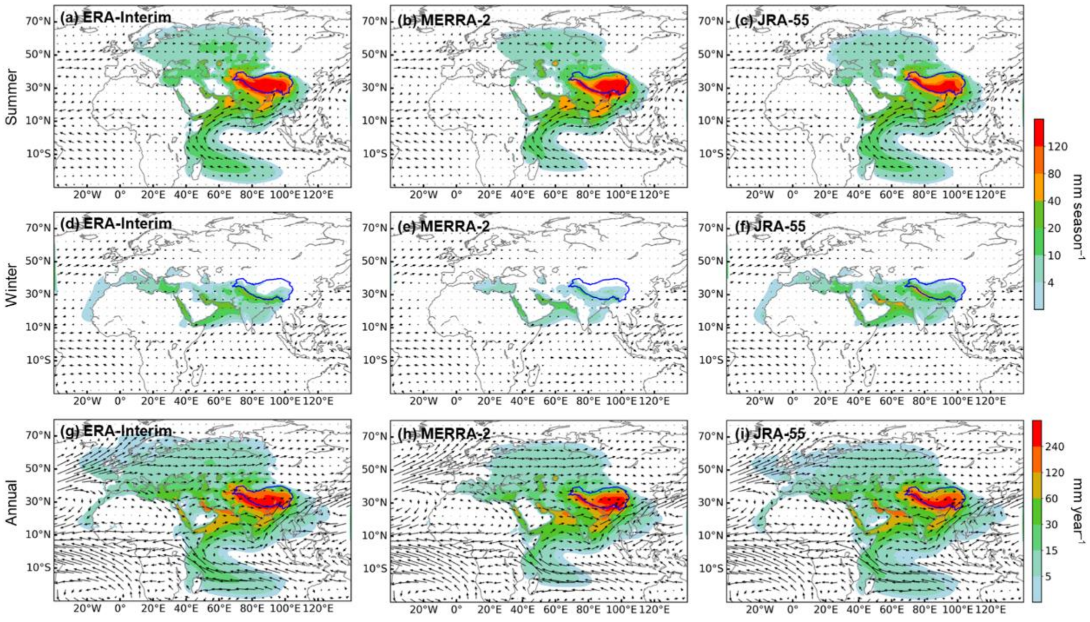

Figure AC1. Long-term mean moisture source of the TP precipitation in summer (a, b, and c), winter (d, e, and f), and on an annual scale (g, h, and i)**.**

Table AC2. Relative moisture contribution to the TP from different oceans.

	The Atlantic	**The Mediterranean**	**The Red Sea**	**The Persian Gulf**
Summer	1.88%	1.05%	0.35%	0.82%
Winter	13.76%	8.43%	5.39%	4.42%
Annual	4.49%	2.75%	1.36%	1.57%

4. Please indicate the sub-figures when describe in around line 239.

Response: Thanks for the suggestion and sorry for the confusion. We will cite sub-figures accordingly in the revised Lines 239-241: "Quantitatively, this geographical barrier of the monsoon system reflected in water isotope ratios closely aligns with the 10%–20% isoline of the relative contribution from IO (Figure 4h) and 20%–30% isoline of the relative oceanic moisture contribution in summer (Figure 1h)."

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