Responses to Dr. A. M. Durán-Quesada (Referee comments)

General comments:

The study aims to provide a long term analysis of the sources of atmospheric water vapor for the NAM system and their relationship with synoptic scale rainfall events using a backward Lagrangian trajectories method based upon the FLEXPART mode. Considering moisture supply to the NAM has been mostly analyzed from an Eulerian perspective, the proposed approach provides a new insight to the problem analysis. Moreover, including a more detail analysis in terms of the synoptic rainfall events is regarded as a new and valuable contribution.

We thank the reviewer for the thoughtful comments that will improve the manuscript. Please find below the response to the specific comments.

Specific comments:

<u>Introduction</u>

1- The introduction condenses a vast amount of previous studies on the NAM, still something can be added to briefly explain why regardless of not fulfilling the wind reversal criteria, the system is considered as a monsoon.

The pioneering studies using the reversal in wind direction to identify a monsoon domain were designed to work for the Eastern Hemisphere (Ramage, 1971). Because the seasonal wind reversal is less significant over the Americas, this criterion was subsequently revised in order to consider the characteristics of the monsoonal precipitation.

Monsoonal precipitation is characterized by a concentration of yearly rainfall in the local summer and a dry period in the local winter. Using simple parameters based on precipitation, the global monsoon area have been more recently redefined (e.g. Wang and Ding, 2008; Wang et al., 2012; Huo-Po and Jia-Qi, 2013; Lee and Wang, 2014; Liu et al., 2016; Mohtadi et al., 2016; Wang et al., 2017; Wang et al., 2018). In this approach, both the North America Monsoon System (NAMS) and the South America Monsoon System (SAMS) are clearly found (figure R1):

However, the term “NAM” has also been extensively used to refer to the precipitation of Sinaloa Sonora and Southern Arizona (in northwestern Mexico and southwestern U.S.). We adopt the latter definition of the NAM, but in this manuscript, we pretend to briefly reflect on the suitability of using the same name in the existing scientific literature to refer to climatological features of different regions.

In the revised version we will explicitly include a discussion on this important comment.

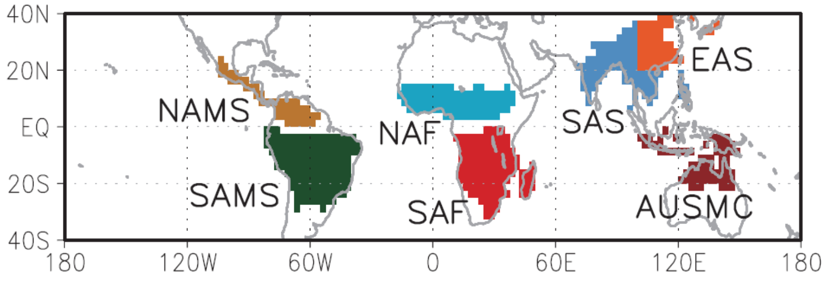

Figure R1. Regional land monsoon domain based on 26 CMIP5 multi-model mean precipitation with a common 2.5° × 2.5° grid in the present-day (1986-2005). For regional divisions, the equator separates the northern monsoon domains from the southern monsoon domains. All the regional domains are within 40°S to 40°N. Source: IPCC, 2013.

<u>Method</u>

Section 2.1

Page 3:

2- It is not clear which FLEXPART version was used to generate the trajectories dataset or whether the data was generated for this work at all. Version 9.0 is referred as Stohl et al., 1998 and Stohl and Thomson, 1999 but those correspond to much older versions of the model, version 9.0 was released in 2012. More detail on the dataset generation is needed or mention the correspondent reference of the work for which the data was originally computed that must have the full detail.

We have used FLEXPART v9. We will clarify this in the revised version including an update of the references.

Page 4:

3.- How does “the difference between simulated precipitation and CHIRPS data” represent a lifetime? Does this refer to a validation of the skills of the trajectories to capture rainy days compared to (I suppose daily) CHIRPS based on a threshold for daily accumulated precipitation and dq/qt?

The time period was calculated following this methodology:

1.- First the sources of moisture where calculated (using the backward mode) for the NAM region integrating E-P>0 values during 10 days.

2.- Next, from the complete sources of moisture, defined in point 1, we calculate E-P<0 (P-FLEX) using the backward mode for 1 day to 10 days, individually.
3.- Then, we calculate E-P<0 over each grid over NAM region for each integrated time. So, we have 10 P-FLEX values for each grid point.
4.- We calculated the best "integrated time" for each grid point as the difference between CHIRPS data and each P-FLEX.
5.- Finally, we obtain a "mean time" out of these "individual grid" values.

As a result, we detect that the best time to reproduce the precipitation with FLEXPART over the NAM region is 6 days.

This procedure will be clarified in the revised version of the paper.

4- I would suppose CHIRPS is a reasonably good dataset for the analysis domain as a larger amount of observations are included, I would like to recommend some briefing on the accuracy of FLEXPART to capture rainy days compared to CHIRPS to ensure reliability.

We will compute the precipitation modelled by FLEXPART during the last time step of the trajectories to assess how FLEXPART represents precipitation at this stage.

Section 2.2:

Page 4:

5- Though this section provides an explanation to previous question, the method for selecting events must be better explained.

We will explain with further detail.

6- The interpretation of synoptic events is confusing, it is certainly based on a spatial scale considerations which is a bit different to what is expected after reading the title and introduction. Following the title one may expect a full synoptic classification (such as Hochman et al., 2018) that identifies the large scale conditions associated with rainfall for which the (E-P)-n field is analyzed. Instead, the synoptic classification is used to provide a sort of measurement of the precipitation influence area identified following a dry/wet days criteria. A change in the title is suggested to avoid confusion in what to expect from the method and results.

We agree with the reviewer, a new title is proposed, something like "Climatological moisture sources for the North American Monsoon through a Lagrangian approach: their influence on precipitation intensity".

7- Caption of figure 3 is required to be self-explanatory. The cut in the figure looks weird, you can use a larger domain to show a more complete map and contour only the region of interest.

Thanks. We will improve figure 3 in the revised version.

<u>Results</u>

Section 3.1:

Page 5

8- There seems to be a misunderstanding on the interpretation of (E-P)-n (when using trajectories analysis) for it is known that the presence of a moisture source is valid interpretation for (E-P)-n > 0 over ocean, the accuracy of a similar interpretation for (E-P)-n > 0 over land is rather questionable (the bias of E estimation is high with this method so that interpretation of recycling ratios is restricted to an upper level, see full detail in Stohl and James, 2004). Further aspects are to be considered for recycling, namely a few: a) meaning of the "E" term and how does it reflector not recycling processes such as transpiration, b) the scale dependency of moisture recycling rations need to be taken into consideration (see e.g Van der Ent and Savenije, 2011), c) what does "recycling" actually mean in terms of the modeled scales?.

We understand the reviewer's concern. We roughly approximated (E-P)>0 over the NAM itself to the recycling ratio but as the referee points out, this is not exactly correct (see also our response to the other referee). We will change the term "recycling" by "inland evaporative sources".

9- The identification of the "five moisture sources" is then limited to the interpretation of the (E-P)-n estimates. Hence, strictly speaking, the results for sources identified as NAM, EAST and NORTH need a through review for the full manuscript. Same for every result related to inferred "recycling".

We will revise and further explain our interpretation of the NAM, EAST and NORTH sources. In particular, we will make this discussion consequent with the changes proposed in comment #8.

10- The GoC has been previously highlighted as a relevant source of moisture for the NAM development, however the results show that it is not the GoC but the region off the Pacific coast which acts as a moisture supplier. Does this present a contrasting result compared to previous work? How do you interpret the result in comparison with previous works?.

In fact, the main moisture source over the Pacific is the GoC area. We joined the entire Pacific coast as a moisture source region for simplicity because of the homogeneity of the mean seasonal flow at lower levels showed in figure R2. We performed some sensitive tests that proved that the GoC area is indeed the main moisture source and that the results for the complete region could be compared to previous works. However, we will separate the results for the GoC and the Eastern North Pacific coast in the revised manuscript.

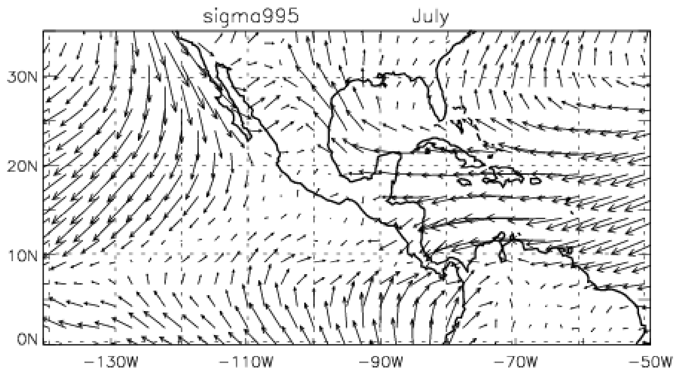

Figure R2. Average horizontal wind at sigma 995 for the period 2000-2010.

11- Figures 5 and 6 should be modified according to the considerations of the “precipitation recycling” interpretation. Previous comments on interpretation of precipitation recycling apply for this section as well the full document.

We will clarify this. Please, see our response to comment #8.

Page 6

12- [Considering the oceanic sources only] results for the difference among weak, moderate and extreme rainfall events (figure 9) show very little variations from one case to the other. How do you interpret this result in terms of moisture availability, transport and observed precipitation for the events? The use of other variables such as precipitable water vapor and a measure of atmospheric stability could provide support for analysis.

In figure 9 an apparent increase of moisture is seen over northeastern Mexico, that extends along part of the Gulf of Mexico and the Caribbean Sea. We interpret this result as the signature of larger moisture transport toward the NAM during the days leading to extreme precipitation events than those leading to low precipitation events. To add confidence to this result, we will compute the statistical significance associated to these differences for the revised version of this work.

We speculate that this moisture transport could be related to the development of low-level troughs or upper levels IVs that enhance precipitation over the northern NAM. Moisture from large-scale patterns can influence pre-surge air masses and thus surge generation. However, regarding the IVs we allowed ourselves to be a little bit more speculative, since the moisture processes related to the development of IVs are still an open question. This research will be carried out in the future but we consider that it is out of the scope of this paper. We concur with the referee in this point, and it is important to explicitly stablish that this interpretation is speculative and not fully developed in this paper.

One possible limitation of many numerically based climatological moisture source studies of precipitation is the lack of observational data for validating the results. We will compute composites of PWV during the days before of the weak, moderate and extreme precipitation events over the GOC and over the GOM-Caribbean Sea for supporting our result.

13- Vectors in figure 10 are not easy to ready, you can try plotting them every 5 or 10 gridpoints to improve the figure. The discussion regarding the interpretation of the Geopotential height and moisture transport anomalies in the analysis in page 7 needs improvement. Consider for example discussing the dynamics underlying the large scale patterns and the bin of event (weak, moderate, extreme).

We will improve figure 10 in the revised version. A deeper discussion in the interpretation of the Geopotential height and moisture transport anomalies will be included.

<u>Summary and concluding remarks</u>

Page 8

14- Summary and concluding remarks. Considering the authors have defined the recycling of precipitation in terms of local evaporation over the NAM domain, the analysis and this section need a revision. It is key to note that the time scale of the simulations does not necessarily fit the scale of processes that occur at local scales.

We absolutely concur with the referee at his point. Time scale of the simulations fits the <u>monsoonal scale</u> processes. We are not (in fact we cannot) evaluating processes that occur at local scale. In fact, this is the reason why the precipitation events are detected at a synoptic scale, being representative of a large area of the studied region. We will try to be sure that this essential fact is clear throughout the revised manuscript and particularly in the final conclusions.

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