Answer to B.R. Pagán in the Interactive comment on "Evaluation of the Moisture Sources in two Extreme Landfalling Atmospheric River Events using an Eulerian WRF-Tracers tool" by Jorge Eiras-Barca et al.

Supplemenatary Material : One-to-one answer to technical comments

Page 1, Line 13: "mean water vapor transport (IVT) of" Mean integrated water vapor transport.

"Mean water vapor transport (IVT)" will be replaced by "Mean integrated water vapor transport (IVT)" in the final version of the manuscript.

Page 1, Line 17-18: "Between 3 and 5 ARs can be found per hemisphere at any given time," The 3-5 ARs in each hemisphere at any given time statistic is from Zhu and Newell 1998 not Guan and Waliser 2015.

The reviewer is correct in that the estimation of "between 3 and 5 ARs" was initially proposed by Zhu and Newell (1998), whereas Guan and Waliser (2015) provide a more up-to-date information about the total amount of meridional moisture transport by ARs per hemisphere. We will include both references in the final version of the manuscript:

Between 3 and 5 ARs can be found per hemisphere at any given time (Zhu and Newell, 1998), accounting for approximately 84% of the meridional IVT for the Northern Hemisphere and about 88% in the Southern Hemisphere (Guan and Waliser, 2015).

Page 2, Line 16: Tropical moisture exports acronym defined as TME, but not used again in the text.

The acronym will be removed in the final version of the manuscript.

Page 2, Line 21: "Ramos et al. (2016) used the FLEXible PARTicle dispersion model (FLEXPART) to show that both tropical and local sources of moisture are present in AR landfall events for different European latitudes." Can the authors provide a better distinction between the advantages/disadvantages of the Ramos et al 2016 Lagrangian tool versus the newly presented WRF-Tracer tool?

It was not our intent to present the WRF-Tracer tool in this paper, contrasting it with other methods. Our goal was to just use it to answer specific questions about the importance of tropical moisture sources in ARs. We will make this point more explicit, as we leave the in-depth details of the method and the discussions of advantanges/disadvanges with respect to other methods for another publication in review in this same ESD special issue:

Insua-Costa, D. and Miguez-Macho, G.: A new moisture tagging capability in the Weather Research and Forecasting Model: formulation, validation and application to the 2014 Great Lake-effect snowstorm, Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2017-80, in review, 2017

that we will now cite in the text. However, at the reviewer's request, we will also include a brief discussion about the key differences between lagrangian models and online eulerian models, as our WRF-Tracer tool. Lagrangian models are based on the spatio-temporal tracking of individual fluid particles. They give information about the Evaporation-Precipitation budget and as they rely on atmospheric analyses, they need to estimate subgrid vertical mixing occurring in the column. Online eulearian models like our WRF-Tracer tool, explicitly calculate the evolution of the moisture from a given source, as they are coupled to an atmospheric model. The main disadvantage is that their accuracy is tied to the skill of the atmospheric model. If simulations are not realistic, moisture pathways will not be either.

Page 3, Figure 1: "Source Era-In", use proper reference to ERA-Iterim. It is not intuitive which event is associated with the names "Great Coast Gale" and "Great Storm". I would stick with Pacific and Atlantic.

The final version of the manuscript will include this caption for Figure 1:

Figure 1. Integrated vapor transport (IVT, vectors, $kg \cdot m^{-1} \cdot s^{-1}$), sea level pressure (SLP, isobars, hPa) and integrated water vapor (IWV, background. $kg \cdot m^{-2}$) for both the Pacific "Great Coast Gale" (a-d) and the Atlantic "Great Storm" (e-h) avents throughout a four-days window time frame. Source: ERA-Interim (Barrisfor et al., 2009).

Page 3, Line 4: "This manuscript is organized as follows. Section 2 describes the applied data and methods, the results and discussion are presented in section 3 and we summarize our conclusions in section 4." Unnecessary description of paper outline.

Following the reviewer's suggestion, the description of the paper outline is going to be removed from the introduction section.

Page 3, Line 7: Interchangeably using United States and U.S.

The acronym "U.S." is going to be replaced by "United States" throughout the entire text in the final version of the paper.

Page 3, Line: 11: How does Figure 1.a. (a snapshot in time) demonstrate the rapid development?

Certainly, a snapshot in time would never demonstrate a rapid development. This is going to be replaced by Figure 1a-d in the final version of the manuscript.

Page 4, Figure 2: All panels of this figure are repeated elsewhere in the manuscript, it should be removed.

Following your advice, we have decided to remove all the repeated figures from the final version of the manuscript**.**

Page 4, Line 1: "Regarding the alleged role of the atmospheric river in the fast deepening of the cyclone -35 mb in 24 hours- (Figure 1, b), Shutts (1990) showed the key role played by the latent heat release in the storm formation." Sentence is hard to follow, try rewording.

For the sake of clarity, the sentence is going to be completely reworded as follows:
For this case, Shutts (1990) showed that two thirds of the central pressure falling could be ascribed to latent heat release, which suggest that the existent atmospheric river played a key role in the fast deepening of the cyclone 35 hPa of pressure drop in 24 hours- (Figure 1, b).

Page 4, Lines 7-9: "For the Pacific case, the WRF horizontal resolution is 15 km and the vertical column is divided into 40 levels. For the Atlantic simulation, grid spacing is 20 km in the horizontal and there are 50 vertical levels." Why use different resolutions?

This study is the result of collaboration between our groups at USC and UIUC. The simulation carried out for the Atlantic case is part of a series of analyses that we are developing for Europe at the Non-Linear Physics Group at USC. We performed the simulation for the US West Coast as part of a different set of analyses that are being carried out at the Department of Atmospheric Sciences at the UIUC. The spatial resolution of the experiments had been forehand selected by both departments some years ago and is slightly different, since the domain sizes are also different. The domain corresponding to the Atlantic case is much bigger than the Pacific one; thus, a slight reduction of the resolution is well justified in order to keep the computational requirements of the simulations relatively low. We do not think that these differences have any significant effect in the conclusions of the present study.

Page 4, Line 10: Water Vapor Tracer (WVT) tool defined with acronym, but not used again.

The acronym is going to be removed from the final version of the manuscript.

Page 4, Lines 11-19: YSU, WSMC6, RRTM, ECMWF and ERA all undefined acronyms.

The definitions of the acronyms are going to be included in the final version of the manuscript.

Page 4, Line 7, 14: "We use the Weather Research and Forecasting Model " "Spectral nudging has been applied" Make sure to use consistent verb tenses, present and past tense are used interchangeably.

The present tense is going to be used throughout the entire text.

Page 4, Line 21: "Water vapor is not nudged, and given that the subject of this study is moisture transport and precipitation, we focus validations on these two variables" This sentence dismisses the nudging of water vapor since moisture transport and precipitation are used for validation. The statement makes it seem as though precipitation and moisture transport are not functions of water vapor. This should be further clarified and supported.

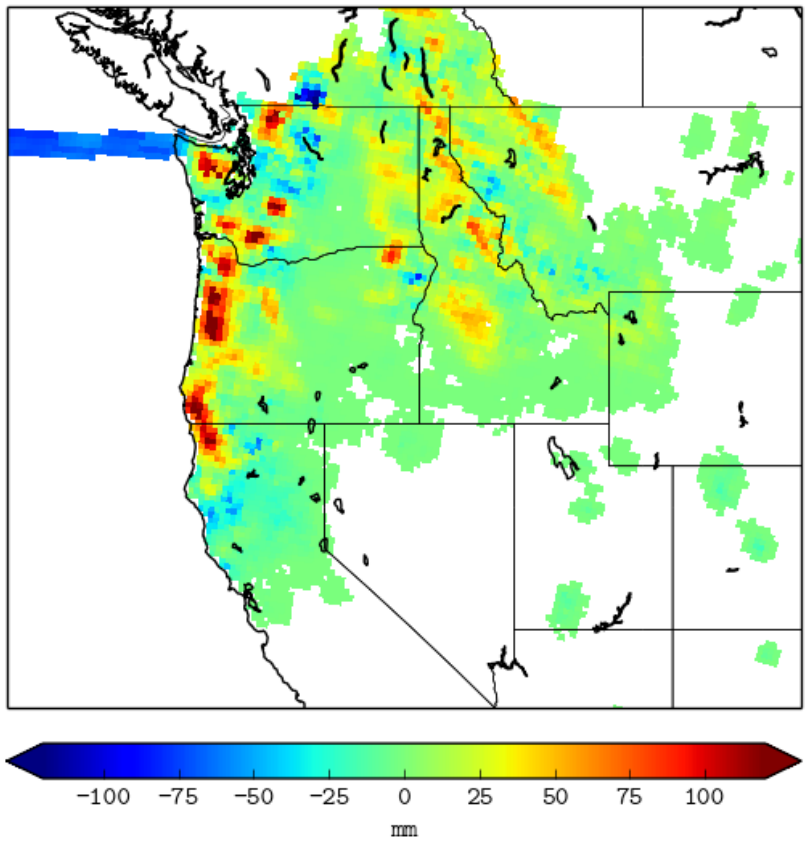
The reviewer is right in that including both statements in the same sentence may lead to confusion. Thus, in the new version of the manuscript, we propose to rephrase it as follows:

Water vapor is not nudged to ensure the mass conservation needed for the traceability of humidity from different sources. Given that the subject of this study is moisture transport and precipitation, we focus validations on these two variables.

Page 5, Figure 3: Can you provide a difference map between the WRF simulation and observations for both locations? Not required in the text, but for this review.

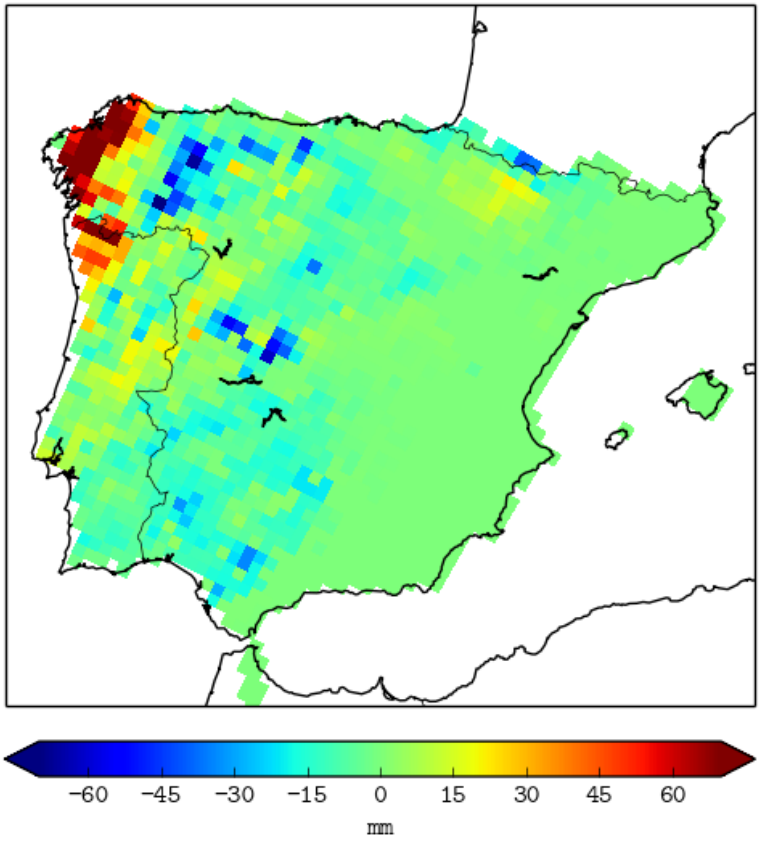
<u>Pacific:</u>

WRF Simulation of Precipitation – Livneh Precipitation :

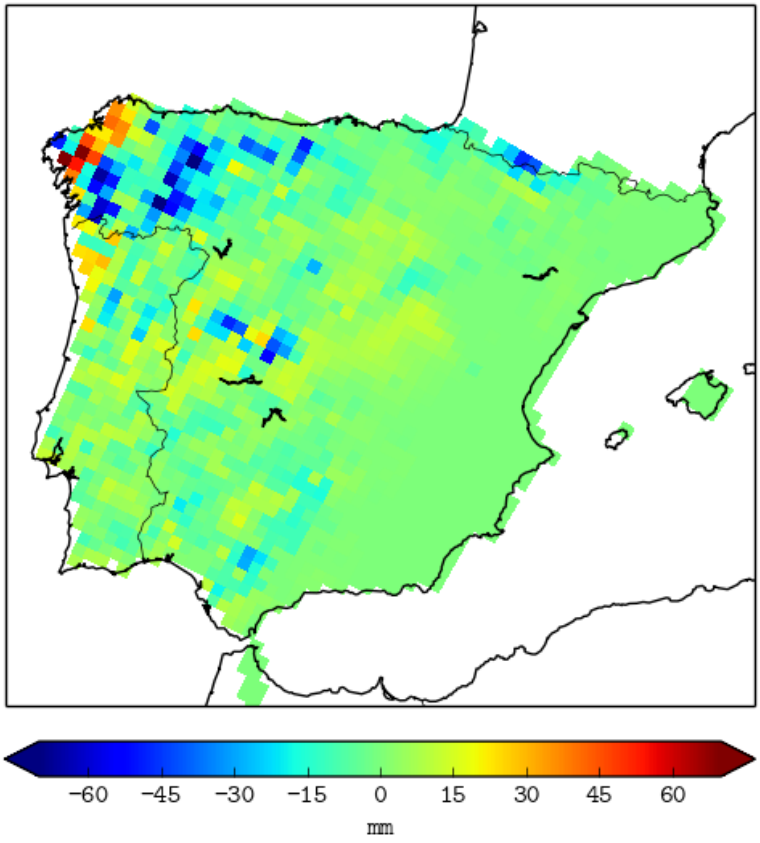


Atlantic:

WRF Simulation of Precipitation – IBERIA02 Precipitation : Figure 4.



Regarding the last map, certainly the observed differences are high. We have detected that this is due to the fact that IBERIA time range cover from 12PM to 12PM, and we were comparing with 0AM-0AM WRF. With this correction , the validation improves substantially. This is going to be fixed in the final version of the manuscript. (See Figure):



As mentioned in the text, the model tends to overestimate precipitation in the mountains, precisely where analyses tend to underestimate it, so the differences are largely magnified.

Page 5, Line 5: "[FigVALQ]," Figure 4?

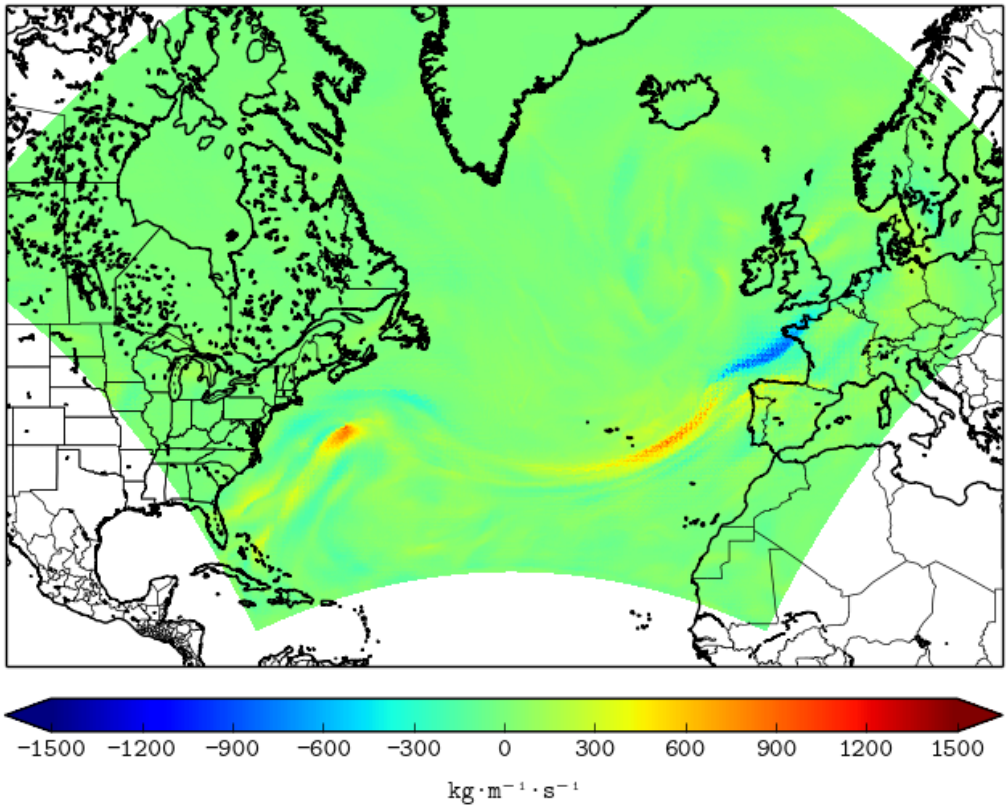
Certainly, this typo is going to be corrected in the final version of the manuscript.

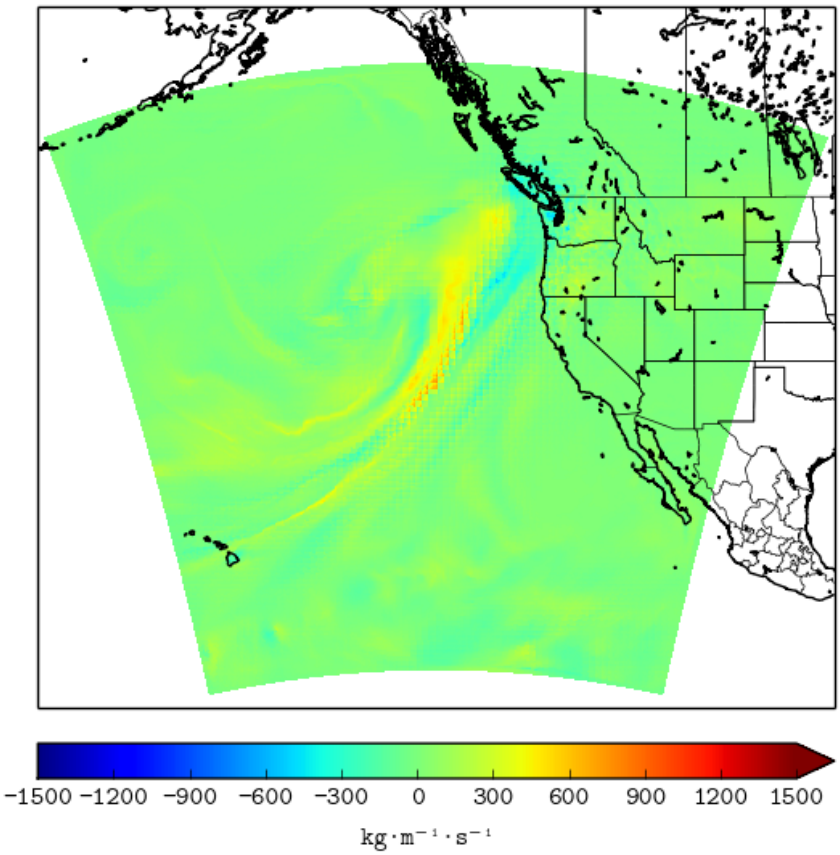
Page 5, line 8-9 and Figure 3: The overestimation of precipitation for the west coast event which is pronounced over high topography is concerning. Especially as the focus of this paper is moisture sources and differentiating between topic/subtropic and local origin. This is not to say that the observations are entirely accurate but do you have any supporting information to better clarify the amplified orographic enhancement? How will this potentially effect results?

Certainly, model simulations in areas where orographic amplification could play a key role, still require substantial improvements. This lack of accuracy in abrupt orography areas has its bases in a insufficient resolution (present in all the mesoscale models), wich is not the proper to depict the mountains. This essentially causes that the vertical fluxes are not well solved.

However, we think that the important point in here is the ratio of tropical precipitation out of the total. Even when the total amount of precipitation could not be well solved, we do not find any reason to think that the ratio could have the same problem.

Page 6, Figure 4: Same as Figure 3, provide a difference map.





Page 7, Figure 5: What do the labels of "Domain CS1"and "Domain CS2" mean? Again, avoid identifying the events by vague names of Great Coast Gale and Great Storm, use Pacific and Atlantic.

Following the advice of the reviewer, all those labels and vague names are going to be removed or renamed in the final version of the manuscript.

Page 7, Equation 1: Meridonial component of IVT? Incorrect formulation.

Actually, **u** is a vector magnitude representing **u**=(u,v). Since the template of the review forces us to use bold letters and not arrows to represent vectors, no changes can be made in the equation. The following equation has been added for clarity:
u = (u,v)

Page 7, Lines 8-9: "Figure 6 shows the three-dimensional distribution of water vapor mixing ratio (a), and tracer water vapor mixing ratio (b) for the event in the Pacific that made landfall along the U.S. West Coast on December 3, 2007." Date of landfall already mentioned in methods. Also West Coast alternates between being capitalized and not capitalized throughout the text.

The date is going to be removed and the use of capitalized words is going to be consistent throughout the text in the latest version of the manuscript.

Page 8, Line 12: "The main goal of Figures 6 and 7 is the visual depiction of the total and tracer moisture." Should not have to state this.

This statement is going to be removed from the final version of the manuscript.

Page 8, Lines 13-21: This paragraph explaining Figure 1 should be moved to the methodology section where the figure was originally introduced and detailed.

Following the instructions of the reviewer, the paragraph is going to be moved to the proper location.

Page 8, Line 22: The formatting of the names for the two events should be consistent, keeping it as the Pacific and Atlantic events is detailed enough. The inclusion of the dates is unnecessary.

The dates are going to be removed, and the names of the events are going to be consistently used in the final version of the manuscript.

Page 8, Line 30: "In the October 1987 Atlantic case, we also see a clear plume where tropical water vapor accounts for more than 80%. What is the explanation for the cause of rapid decrease?

At the time shown in Fig. 9, the center of the storm is just off the coast of Galicia (see Fig 2), which lies at the converging point between cold and warm front. Airflows are complex at that location within baroclinic systems, with air in the warm conveyor belt, loaded with tropical moisture in this case, lifted above air ahead of the warm front, with much less tropical content. In addition, enhanced convergence due to the explosive cyclogenesis taking place also feeds local moisture into the AR, decreasing the tropical moisture fraction in it. The presence of the high terrain of the Iberian Peninsula makes the situation harder to analyze.
. To address the reviewers concerns, we propose to reword the sentence as follows:

"In the October 1987 Atlantic case, we also see a clear plume where tropical water vapor accounts for more than 80% of precipitable water; however, the percentage decreases to around 70% closer to the center of the system and just before arriving on the Iberian coast (Figure 9). In this case, cyclogenesis occurs just off the coast of Galicia, on the northwest tip of the Iberian Peninsula, and thus, the enhanced convergence of existent local moisture feeds the AR and is involved in the heavy precipitation, which consequently is only between 60% and 80% of tropical origin.

Page 8, Line 34-35: ": : :there is evidence that the maximum of tropical moisture does not necessarily coincide with the low-level jet (LLJ), which is the maximum in wind speed at lower levels." Citation?

This is an evidence obtained from our results, so no citations are required. This is now going to be clarified in the text.

Page 9, Figure 6: The addition of lat/lon labels would make the figure and the point made on Page 8 line 5 more obvious. Also "d) Vertical cross sections of (d)." should be "sections of (b)"

The 3D plotting software is not specifically designed for earth sciences. The input data should be in x-y projection, so, adding lat/lon to labels is not yet an easy task in this version of the program. Instead, to address the reviewer's concern, we will add the lat/lon labels to the map box located below (c), indicating the area that is being plotted in 3D above. The typo "sections of (d)" is going to be replaced by "sections of (b)".

Page 9, Line 1: Where is Figure 8d? Perhaps you meant 10d.

Certainly, we meant 10d. This typo is going to be fixed in the next version of the manuscript.

Page 11: Consider combining Figures 8 and 9.

Following the reviewer's advice, Figures 8 and 9 are going to be combined in the next version of the manuscript.

Page 12, Figure 10: Define TCS. Axis labels of km cut off.

"TCS" is going to be replaced by "Transversal Cross Sections" and the axis labels will be fixed in the final version of the manuscript.

Page 12, Line 4: ""the Great Coast Gale of December, 2007"" Date not previously included in the quotes.

For consistency, quotes will only include "Great Coast Gale" anywhere in the text .

Page 13, Lines 5-7: "The Pacific event shows a more intense connection with tropical regions; therefore, the percentage of tropical precipitation for this event is higher and peaks at around 85These two main conclusions should be reworded.

Following the reviewer's advice, these conclusions are going to be reworded as follows:
The Pacific event shows a more intense connection with tropical regions than the Atlantic case. As a result, the percentage of tropical precipitation for this event over North America is higher and peaks at around 85%. Nevertheless, for the Atlantic event, still more than 60% of the resulting precipitation is of tropical origin

Page 13, Line 8: "in terms of heavy precipitation" In terms of? Or chosen because of the subsequent heavy precipitation.

"in terms of" is going to be replaced by *"chosen because of the subsequent"*

Page 14, Lines 7-9: "It is widely accepted in the literature that the bulk of moisture in ARs is primarily advected within the LLJ of extratropical cyclones but in light of our results we suggest that further discussion is necessary for this matter." This is not a very effective concluding sentence, should be reworded.

The sentence will be reworded as follows:

"It is widely accepted in the literature that the bulk of moisture in ARs is primarily advected within the LLJ of extratropical cyclones but our results suggest that this is not always the case, and that a revision with a more in-depth investigation is necessary for this matter."

Page 16, Figure A2: Labels of LLJ missing. European not capitalized, however this event was not previously described as the "European case".

The labels of the LLJ are going to be added, and "European case" is going to be replace by Atlantic case, as named elsewhere in the text,

Page 20, Line 4: Partial citation.

This typo is going to be fixed .