Answer to Oreste Reale (R2) in the Interactive comment on "Local and remote moisture sources for extreme precipitation: a study of the two famous 1982 Western Mediterranean episodes" by **Damián Insua-Costa et al.**

This is an excellent piece of research that brings a substantial advance to the complex issue of moisture sources related to flood-producing precipitation events over the Mediterranean region. While the writing could be improved, the results are very convincing. I find the methodology particularly praiseworthy. As such, I recommend the article to be accepted after some minor revision.

We would like to thank very much the referee for his kind remarks and positive review. Please, find below the responses to your comments.

General comment: expand the focus.

I agree with the other reviewer that the Authors should consider changing the title. Aside from defining as 'famous' events that may not be known outside the hydrology, engineering, and meteorology communities in Spain, I would rather use the term 'infamous' to describe catastrophic events that have caused death and destruction. Even better, I would avoid 'fame' entirely and perhaps refer to the events as 'catastrophic'. The term 'famous' also appears in page 17, second par.

We agree with the reviewer so the word "famous" is going to be replaced by "catastrophic" in the title. "Famous" will be replaced by "infamous" in the text.

Most important, I suggest to modify the introduction, in order to provide a broader motivation that can make the article relevant to a much larger community. The description of general mechanisms as it is cannot provide objective, generic, absolute 'causes'. Furthermore, the Authors themselves acknowledge that the 2 events are very different one from the other. Therefore, I suggest to broaden the focus of this article, by connecting this work with other research. Conditions for the development of these events surely are strong instability, presence of some circulation that organizes the flow, exploiting orographic contribution. However, the puzzling aspect is that most of these conditions, for example Mediterranean baroclinic cyclones, are often present but are rarely associated with extreme precipitation.

It is only a very small subset of Mediterranean cyclones that cause catastrophic events. Furthermore, in some instance the Mediterranean cyclone could be less relevant than the large-scale southerly flow associated with larger cyclonic circulations outside the Mediterranean. So, the Authors may consider starting with the statement that the presence (or absence) of intense moisture transport anomalies on a very large scale could be the critical, discriminating factor between many situations apparently similar but in which only one produces an extreme precipitation event.

Another suggestion is to think in a more 'global' scale. The Authors' experiments, unlike previous work, are both at very high resolution and encompass a very large domain. As such, they have the possibility of linking Mediterranean floods with the global scale. If this is done, the article will attract a much larger set of readers interested in the subject of tropical-extratropical connections.

As a starting work, consider the final part of Wu et al. (2013). In that work, we linked 2 cases of flood-producing precipitation over Europe with the so-called 6-9 day African Easterly Waves (for the part of the article relevant to your work, please see Section 3d, from page 6765 onwards). The 6-9 waves are different from the well-known 3-6 day waves, because they form to the north of the African Easterly Jet, at the jet level (about 600 hPa) and they travel northward. They can be conceived as a 'relaxation' in the subtropical high pressure that bridges mid latitude low pressure systems with the Inter Tropical Convergence Zone (ITCZ).

From this article's perspective, 6-9 day waves are relevant because they represent a way of connecting tropical moisture generated within the ITCZ with midlatitude systems. If one of such waves acts in phase with a deep midlatitude cyclone, a stream of moisture can leave the ITCZ, travel in a relatively stable area associated with the relaxed subtropical high (and thus without loosing moisture) and 'connect' with the warm advection ahead of a frontal system in the midlatitudes. Then, any mechanism able to concentrate and release this enormous amount of moisture over a small area, can cause a flood-producing precipitation event. Figures 14, 15, and 16 from Wu et al. (2013) illustrate this aspect for extreme precipitation events occurred in 2000 and 2002, respectively. It seems that the plume of moisture associated with Fig.3b, Fig. 5d, in this work, bears remarkable similarities.

Most relevant for this work are also the papers by Knippertz (2003), Knippertz et al. (2003) which connect episodes of extreme precipitation over northwest Africa with anomalous advection from the tropics, and place these into the context of a tropical-extratropical interaction.

Schepanksi and Knippertz (2011) further expand in this direction and finds in the Soudano-Saharan depression a key element connecting tropics with midlatides. We think that all these results are very consistent with each other, and simply focus on different aspects of the moisture transport.

It is important to notice that anomalous moisture advection from the tropical Atlantic has been noted also outside the Mediterranean region: the study of Stohl et al. (2008) identifies a very similar moisture path for precipitation events in Norway, connecting these with the tropical Atlantic.

We fully agree with the general comments provided by the reviewer, and we think it very appropriate to include his recommendations in the text. In order to address these suggestions, we are going to rewrite and expand paragraph one and two of the introduction as follows:

"The Western Mediterranean Region (WMR) is characterized by a high frequency in the occurrence of torrential rainfall episodes and floods that cause severe damages, with a very high social and economic impact (Llasat et al., 2010). The main mechanism generating these heavy precipitation events (HPEs) is the strong instability induced by the warm and moist air that for most of the year sits over the mild Mediterranean waters, along with the presence of a low pressure system (usually produced by a Mediterranean cyclogenesis event) that can trigger convection and organize the flow (Llasat, 2009). Other factors such as the complex orography of the region, often take also a very important role (e.g. Buzzi et al., 1998; Rotunno and Ferretti, 2003). Most cases occur in autumn, when the combination of a still warm sea surface temperature (after a peak in late summer), and a southward displacement of the jet stream, which usually favours the appearance of Atlantic lows or cut-off-lows (COLs; e.g. Nieto et al., 2005, 2008) affecting the WMR, make this season the most favourable for the development of these extreme events (see Dayan et al., 2015, for a detailed review of the most frequent atmospheric conditions resulting in Mediterranean HPEs).

While factors such as strong instability or the presence of a Mediterranean low in the vicinity are commonly associated with HPEs (Jansa et al., 2001, 2014), the concurrence of these weather features does not ensure the development of extreme precipitation. For example, in autumn, and other seasons too, the presence of Mediterranean cyclones is certainly much more frequent (Campins et al.,2011) than the occurrence of catastrophic flooding episodes (Llasat et al., 2013). Thus, an important question arises: what is the discriminating factor among many apparently similar weather situations where only one produces an HPE? The starting hypothesis of this work is that the factor setting extreme precipitation situations apart is the existence of a very large moisture supply from remote regions outside the Mediterranean. This very humid external influx, when added to local moisture, would yield the enormous amounts of total precipitable water (TPW) needed to produce the rain accumulations commonly recorded in these episodes, which often remind of the values associated with tropical systems. Once sufficient TPW is present, any mechanism able to concentrate and release this moisture over a small area can cause a flood-producing precipitation event. Under this hypothesis, the configuration of the large-scale circulation would therefore be also critical, since it determines whether an intense moisture transport from remote regions can be established or not.

Different studies support the aforementioned idea, especially those that point to the interaction with tropical regions as being key in the development of mid-latitude HPEs. The argument is that when extra-tropical baroclinic low pressure systems descend enough in latitude, they have the chance to capture large amounts of moisture generated in the tropics and advect them into the mid-latitudes and beyond. Thus, a high risk of severe rainfall would be induced if that high moisture content is forced upward by some mechanism, such as orographic lift. The phase of the baroclinic wave should be such allowing this moisture to enter the circulation on the eastern side of the cyclone, often funneled along the cold front, and then be transported poleward resulting in well-known structures such as tropical plumes or atmospheric rivers. Tropical moisture exports have been shown to be important contributors to precipitation in mid-latitude regions in both hemispheres, especially relevant for extreme precipitation (Knippertz and Wernli, 2010; Knippertz et al., 2013). Case studies of HPEs in different parts of the planet, such as the west coast of the United States and Europe, conclude that moisture from tropical and subtropical regions can be essential, comprising most of the TPW feeding these severe episodes (e.g. Stohl et al., 2005; Eiras-Barca et al., 2017). The tropical-extratropical connection in the aforementioned cases occurred through an atmospheric river, advecting highly humid air from lower latitudes to the affected areas. In the WMR, studies for different events also evidence the important role that tropical moisture exports can play in the development of HPEs (e.g. Winschall et al., 2014; Krichak et al., 2015). Some even go further and claim that tropical systems, such as Atlantic hurricanes and their extratropical remnants, can be instrumental, by injecting large amounts of moisture into the Mediterranean Basin (e.g. Pinto et al., 2001; Reale et al., 2001). In the Eastern Mediterranean, different research have also shown the importance for heavy precipitation of moisture transport from the tropics, sometimes reflected in the formation of tropical plumes (e.g. Ziv, 2001; Rubin et al., 2007). Another example of how tropical-extratropical interactions can trigger Mediterranean severe rains come from Wu et al. (2013), who found that the interaction of the (6-9 days) African easterly wave with mid-latitude low pressure systems resulted in large moisture exports from the tropics that were fundamental in producing the precipitation inducing floods in 2000 and 2002. All these studies reinforce the need to look at the problem of extreme precipitation in the Mediterranean region from a more global perspective and discard a local or regional view, particularly in the case of moisture origin.

However, in the ample literature analyzing the different contributors to the genesis of HPEs in the Western Mediterranean, moisture as a key factor is sometimes undervalued or not considered in depth, often assuming that the high values of TPW involved in these events originate locally at low levels from sea evaporation. But, where does such large amount of water vapour really come from? Is it evaporation in the Mediterranean the main source or, on the contrary, does most of the moisture in precipitation originate remotely?"

Nieto, R., Gimeno, L., de La Torre, L., Ribera, P., Gallego, D., García-Herrera, R., ... & Lorente, J. (2005). Climatological features of cutoff low systems in the Northern Hemisphere. Journal of Climate, 18(16), 3085-3103.

Nieto, R., Sprenger, M., Wernli, H., Trigo, R. M., & Gimeno, L. (2008). Identification and Climatology of Cut-off Lows near the Tropopause. Annals of the New York Academy of Sciences, 1146(1), 256-290.

Dayan, U., Nissen, K., & Ulbrich, U. (2015). Atmospheric conditions inducing extreme precipitation over the eastern and western Mediterranean. Natural Hazards & Earth System Sciences Discussions, 3(11).

Jansa, A., Genoves, A., Picornell, M. A., Campins, J., Riosalido, R., & Carretero, O. (2001). Western Mediterranean cyclones and heavy rain. Part 2: Statistical approach. Meteorological Applications, 8(1), 43-56.

Jansa, A., Alpert, P., Arbogast, P., Buzzi, A., Ivancan-Picek, B., Kotroni, V., ... & Speranza, A. (2014). MEDEX: a general overview. Natural Hazards and Earth System Sciences, 14(8), 1965-1984.

Campins, J., Genovés, A., Picornell, M. A., & Jansà, A. (2011). Climatology of Mediterranean cyclones using the ERA-40 dataset. International Journal of Climatology, 31(11), 1596-1614.

Llasat, M. C., Llasat-Botija, M., Petrucci, O., Pasqua, A. A., Rosselló, J., Vinet, F., & Boissier, L. (2013). Towards a database on societal impact of Mediterranean floods within the framework of the HYMEX project. Natural Hazards and Earth System Sciences, 13(5), 1337-1350.

Knippertz, P., & Wernli, H. (2010). A Lagrangian climatology of tropical moisture exports to the Northern Hemispheric extratropics. Journal of Climate, 23(4), 987-1003.

Knippertz, P., Wernli, H., & Gläser, G. (2013). A global climatology of tropical moisture exports. Journal of Climate, 26(10), 3031-3045.

Stohl, A., Forster, C., & Sodemann, H. (2008). Remote sources of water vapor forming precipitation on the Norwegian west coast at 60 N–a tale of hurricanes and an atmospheric river. Journal of Geophysical Research: Atmospheres, 113(D5).

Eiras-Barca, J., Dominguez, F., Hu, H., Garaboa-Paz, D., & Miguez-Macho, G. (2017). Evaluation of the moisture sources in two extreme landfalling atmospheric river events using an Eulerian WRF tracers tool. Earth System Dynamics, 8(4), 1247.

Winschall, A., Sodemann, H., Pfahl, S., & Wernli, H. (2014). How important is intensified evaporation for Mediterranean precipitation extremes?. Journal of Geophysical Research: Atmospheres, 119(9), 5240-5256.

Krichak, S. O., Barkan, J., Breitgand, J. S., Gualdi, S., & Feldstein, S. B. (2015). The role of the export of tropical moisture into midlatitudes for extreme precipitation events in the Mediterranean region. Theoretical and applied climatology, 121(3-4), 499-515.

Pinto, J. G., Klawa, M., Ulbrich, U., Rudari, R., & Speth, P. (2001, October). Extreme precipitation events over northwest Italy and their relationship with tropical–extratropical interactions over the Atlantic. In Proceedings of the third EGS Plinius Conf. on Mediterranean Storms, Baja Sardinia, Italy, GNDCI Publication (No. 2560, pp. 321-332).

Reale, O., Feudale, L., & Turato, B. (2001). Evaporative moisture sources during a sequence of floods in the Mediterranean region. Geophysical research letters, 28(10), 2085-2088.

Ziv, B. (2001). A subtropical rainstorm associated with a tropical plume overAfrica and the Middle-East. Theoretical and Applied Climatology, 69(1-2), 91-102.

Rubin, S., Ziv, B., & Paldor, N. (2007). Tropical plumes over eastern North Africa as a source of rain in the Middle East. Monthly Weather Review, 135(12), 4135-4148.

Wu, M. L. C., Reale, O., & Schubert, S. D. (2013). A characterization of African easterly waves on 2.5–6-day and 6–9-day time scales. Journal of Climate, 26(18), 6750-6774.

Minor comments:

The WVT could become a formidable tool, particularly because is coupled with the WRF, which is very well known and used worldwide. The Authors should consider distributing it, either through their own portal, or in collaboration with an WRF development team. It would gather widespread attention if it became an easily accessible methodology. I find particularly important, compared to earlier studies, the ability of investigating sources on a 3D scale.

Thank you for your suggestion. As we have also commented to the other reviewer, we are currently considering making the code open access.

Figures. The clarity of the figures illustrating the synoptic situation could be improved. Even coastlines and geographic features are barely detectable. In Figure 3a, I suggest blanking out the temperatures around 0C (such as -2 2) so as to have a white strip between cold and warmer air, and use less intense colors. If done in GrADS, the Authors could consider the use of transparencies which is now an option and allows more readable plots. Otherwise, just use lighter colors.

In figure 3b, I suggest to blank out completely the values of tpw less than 10mm. These are not relevant to this work, indicate simply drier air, and by eliminating them the emphasis would be given to the huge moisture plume stretching from the subtropical Atlantic towards the Iberian peninusula.

Similar suggestions for Figure 8.

We have modified Figure 3 and Figure 8 following the reviewer's suggestions:

Figure 3

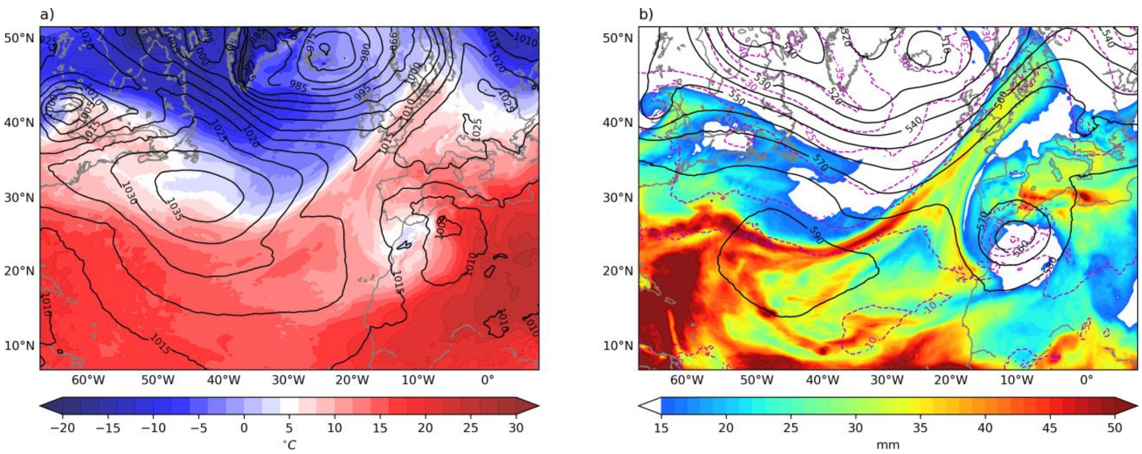
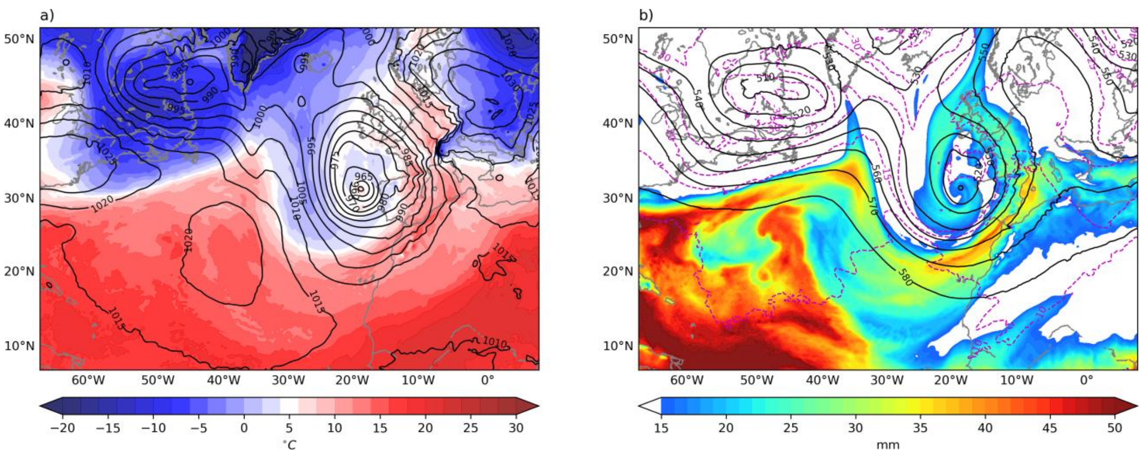


Figure 8



In the text, there are some sentences whose clarity could be improved. See for example page 4, lines 7-8, d

The sentence will be clarified.

Page 18, line 14.. a semantic issue.. Instead of 'verify the hypothesis' .. . Consider something like 'corroborate the idea that remote sources of moisture from the tropics contribute to an important fraction of extreme precipitaiton events in the midlatitudes..'

The sentence will be corrected as suggested.

In summary, aside from these relatively minor suggestions, I believe that the article is a great contribution to precipitation research, and I recommend acceptance after minor revision. However, I believe that the article would benefit by placing the results into the broader context of tropical-extratropical interactions and large scale advection of tropical moisture.

Thank you again for your positive comments.