Response to Referee 2

We thank the referee for taking the time to review our manuscript. Please, find below your comments (CX) and our answers (AX), the latter highlighted in red.

Update:

After checking carefully the ERA5 datasets used in the analysis we found an error when computing total precipitation. We therefore corrected the error and created new figures. No significant changes, compared to the submitted version of the paper are observed, except for Figure S8 which has now been removed and replaced with Figure S8_new. Please see the **Update** description in "Response to Referee 1" for more details.

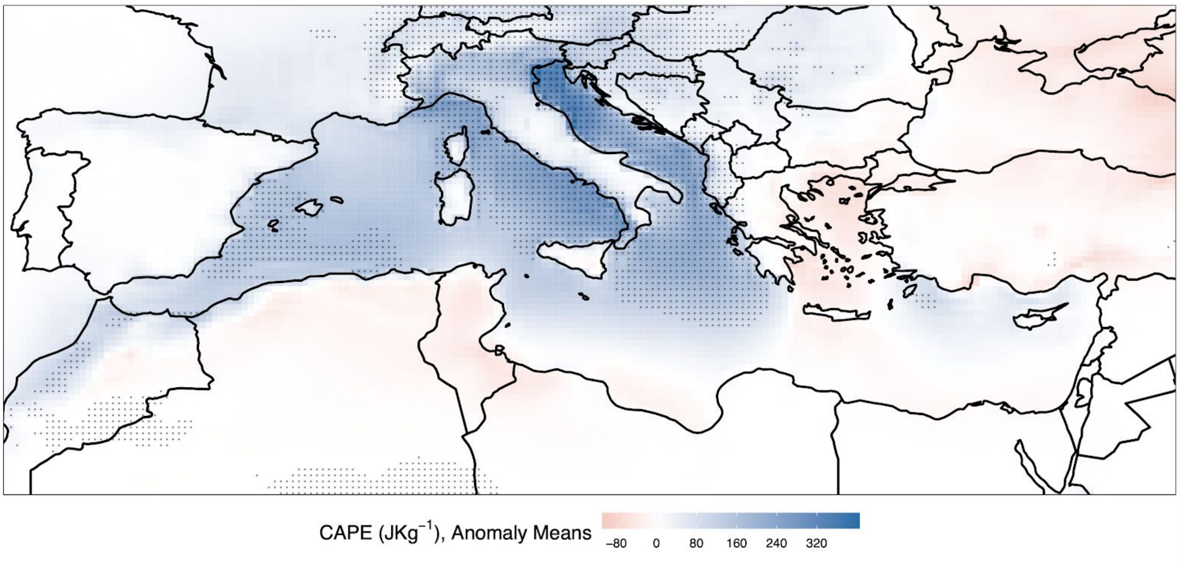

Figure S8_new - As Figure 4e but for daily anomaly means of convective available potential energy (CAPE, JKg^-1).

In this paper concurrent recurrence of temperature and precipitation patterns over the Mediterranean are quantified and changes over time highlighted. The paper is well written and the results are highly interesting and relevant. There are some methodological points that need further explanations for non-experts (explained in more detail under major points) and the colorbars of the map figures need to be improved. After these clarifications the paper is ready for publication. Olivia Martius

Thank you, please find our answers below.

Major points:

C1: 1) Consider adapting the title because the term "dynamical extremes" may not be widely known.

A1: Based also on comments from Referee 1, we amended the title to “Compound Warm-Dry and Cold-Wet Events Over the Mediterranean”.

2) I have some basic methodological questions that I did not yet fully understand and that might be confusing for other readers as well.

C2: a. Co-occurrence of dry and hot (cold and wet) conditions refers to the entire Mediterranean area. The dry conditions and the hot conditions must not necessarily happen at the same location in the Mediterranean area?

A2: Yes, warm-dry (cold-wet) conditions are computed singularly at grid-point-level (based on alpha extremes) and therefore if a grid-point in a given day is warm it does not necessarily imply that it is also dry. The *average* of these patterns are shown at grid-point levels in Figure 4c-f. We expanded a sentence in Section 2.2 specifying this.

C3: b. You state that you get an alpha and theta value for each time step of the data, but it is unclear how long the time period is that you use to determine these parameters, you only mention a “relatively long time period” in the beginning. Is it a moving window of a number of days? Are then successive alpha and theta values very similar?

A3: We computed alpha and theta for the entire 1979-2018 period at daily timesteps. We mentioned “relatively long time period” when providing the general description and derivation of the dynamical systems metrics. However in the revised paper we specified the 1979-2018 period within this sentence. Moreover, at the end of Sections 2.1 and 2.2 we also clearly stated that alpha and theta have been computed at daily timsteps for the full 1979-2018 period. Within this study we did not use a moving window nor aggregated data over *n* days.

C4: c. Is it correct that compound dynamical extremes are “extreme” in the coupling but not necessarily in p and T? Do these CDEs then point to weather situations that are dominated by the synoptic-scale flow rather than by local convective systems?

A4: Yes, the alpha metric reflects the strength of joint recurrences in the phase-space, which are defined with a high-quantile threshold (see updated Section 2.1 in the revised paper). Then, based on daily alpha values (1979-2018), we apply a further threshold (in our case >90th quantile) and define alpha observations > 90th quantile CDEs. For a test of the sensitivity of our results to this choice of threshold see our reply to C20 from Reviewer 1 above. So CDEs are indeed extremes in the coupling by definition. Lastly, we compute composite maps of SLP, Tmax (Tmin) and P based on CDE days and prove that CDEs correspond to warm-dry and cold-wet days over the MED, although these are not necessarily extremes. Such link naturally depends on the variables, seasons and region(s) under study.

In the submitted manuscript we computed composite maps of large-scale and convective P during CDEs in JJA (Figure S8) and found that large-scale P was having a significant effect compared to convective P. However, after updating Figure S8 with large-scale and convective P calculated correctly (see **Update** at the start of this file) we found that both fields show significant anomalies (Figure S8_rev). Therefore, we explored further the matter by making use of convective available potential energy (CAPE, JKg^-1) and found that its positive anomalies over the Alps during JJA are statistically significant (Figure S8_new). Therefore, we concluded that JJA wet anomalies during alpha extremes over the Alps are driven by localised convective P events.

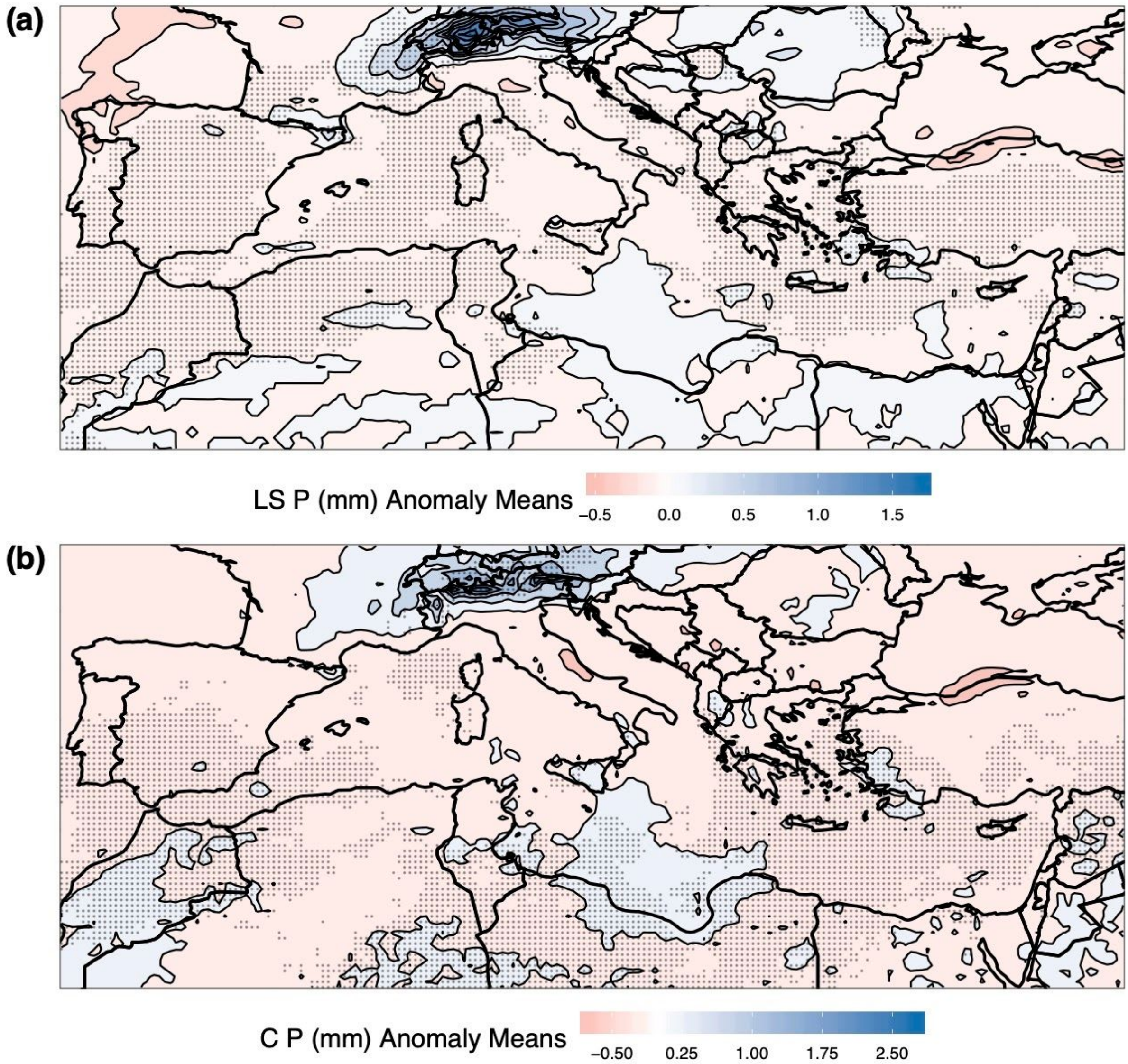

Figure S8_rev - As Figure 4e but for daily anomaly means of (a) large-scale total precipitation (mm) and (b) convective total precipitation (mm).

C5: 3) Please use colorbars with discrete colors for all map figures. For example, when I am interested in the SLP anomaly over Italy in Figure 4a it is very difficult to link the discrete colors on the map to the continuous colors in the colorbar.

A5: Thank you for your comment. In the next revision (after Editor's comments) we will try to re-do all the maps with discrete colorbars.

C6: 4) The interpretation of Figure 4 is difficult without a reference to the climatology. It would be good to indicate how the anomalies relate to the climatology (e.g. % of mean) and if feasible to the variability (e.g., STD, inter quartile range). For example, precipitation rates in the Alps are higher in the climatology. So maybe in Figure 4e the anomalies over the Alps are small from a climatological and variability perspective and the dry anomalies in other areas are large.

A6: Thank you for your comment. The statistical test performed in Figure 4 (one-tailed Mann-Whitney test) is an ordinal test which has been applied singularly to each grid-point. As such, it provides a statistical comparison of the values between the two sets of data regardless of their magnitude. With respect to the variability, we computed the standard deviations (SDs) of the anomaly means reported in Figure 4 (Figure R_1). From Figure R_1 one can see that: i) SLP SDs are larger over the northern and central MED; ii) temperature SDs are larger over land compared to the sea; and iii) precipitation SDs are larger where the higher anomaly values are reported (i.e. the Alps in JJA and south-eastern MED in DJF). See also answer A20 to Referee 1. A sentence describing the SD patterns has been added in Section 4.2 of the revised paper.

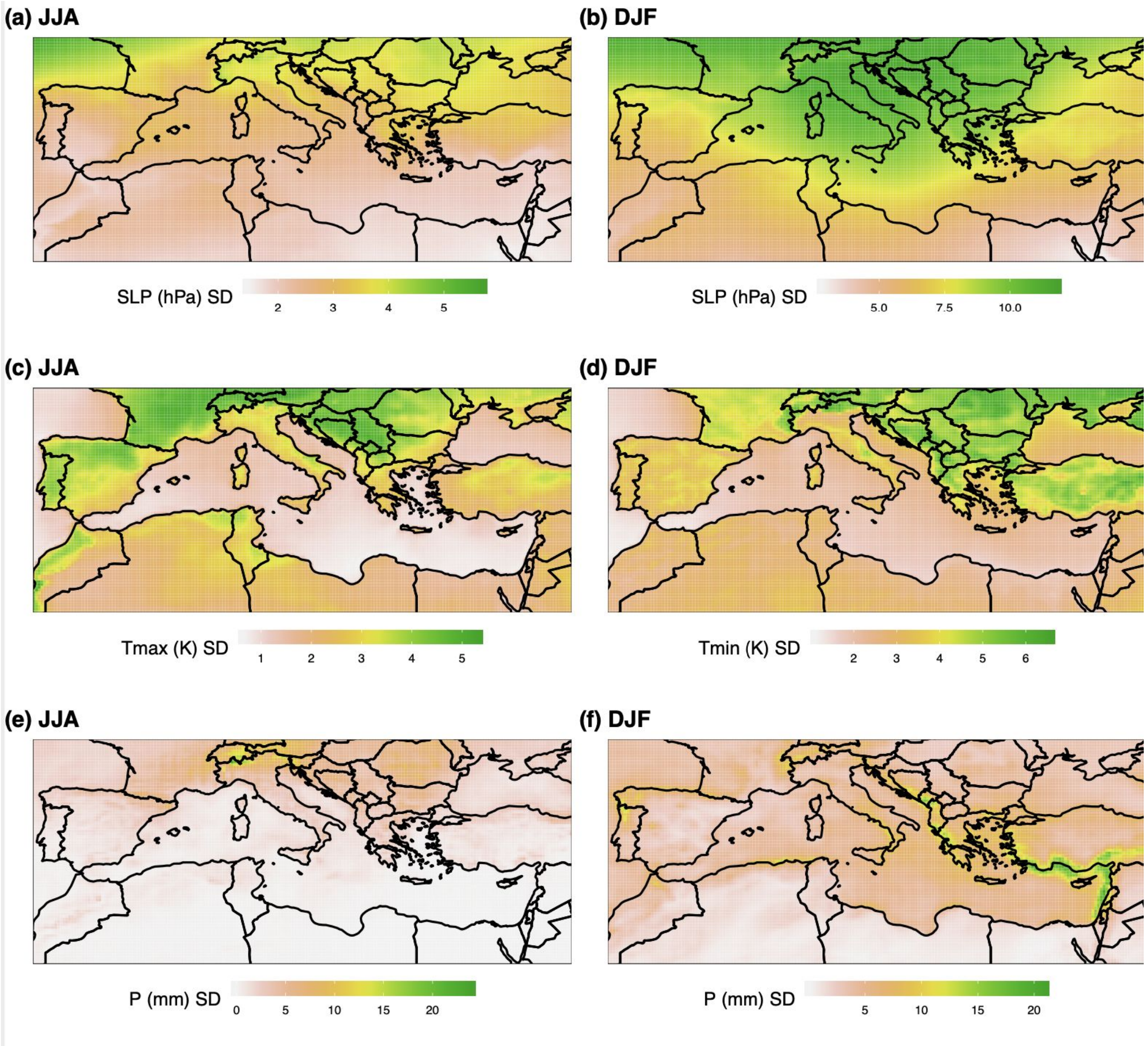

Figure R_1 - Standard deviations (SDs) computed for the anomaly means of Figure 4 in the main text.

C7: This would also clarify a follow up question namely can your method capture dry and wet extremes at the same time? The discussion of Figure 4d focuses on the wet anomaly over the Alps but the subsequent discussion of the histograms points to the prevalent dry signal. This is confusing for the reader.

A7: Yes, our method can also capture dry and wet extremes co-occurring in different parts of the geographical domain under study. Indeed, our method captures the dependence structure of two atmospheric variables, independently of their values (e.g. wet or dry) and spatial configuration. We then focus our analysis on a specific combination of anomalies based on their prevalence throughout the analysis domain. We clarified this in Section 2.1 of the revised paper.

Minor points:

C8: 1) L16: Could you provide an example for the dynamical changes.

A8: We added northward shift and intensification of the storm track as examples of atmospheric circulation changes as discussed in Hoerling et al. (2012).

C9: 2) L28: Clarify what you mean by similar changes.

A9: The sentence has been rephrased.

C10: 3) L44: Define large-scale precipitation, here I assume it is the model variable.

A10: Thanks. In this case “precipitation” was meant to be generic. The word “large-scale” has been removed.

C11: 4) L47: Suggest to shift a couple of sentences from the next section up here to briefly explain what dynamical systems are. A dynamical meteorologist might think of weather systems at this point of the paper rather than system dynamics.

A11: Two sentences have been added as suggested.

C12: 5) L92: How do you define anomalies? Are these to the 30-year (seasonally varying?) mean?

A12: Anomalies are defined based on the JJA (DJF) seasonal means. We specified this in Section 2.2 as also suggested by C8 of Referee 1.

C13: 6) L92: But you also use large-scale vs. convective precipitation? Could you add the information that the precipitation is a forecast field and not assimilated.

A13: Yes, in the first submitted file we also use large-scale and convective precipitation, please see **Update** at the start of this file. We added in Section 2.2 and supplementary material that precipitation is a forecasted field while temperature, sea-level pressure and CAPE are instantaneous fields.

C14: 7) L121: what do you mean exactly be “restricting the analysis. . .”?

A14: By “restricting the analysis” we meant that we computed the co-persistence trend by using only warm-dry days instead of the full dataset. Specifically, the persistence trends have been here computed *for each grid-point*, and then averaged, by considering only persistence daily values recorded during compound warm-dry events, instead of using the full time-series. The sentence has been amended.

C15: 8) L141: Please define how you calculate the anomalies, wrt to a seasonal mean?

A15: Yes, SLP anomalies have been computed with respect to JJA (DJF) means. We made this clear in Section 2.2 of the revised paper.

C16: 9) L141: Linking the precipitation anomalies with the SLP anomalies should be formulated in the form of a hypothesis.

A16: The sentence has been rephrased as suggested in the revised paper.

C17: 10) L147: Please add supporting references. For heavy precipitation along the western Alpine south-side the low pressure system is typically located over the Gulf of Genoa. Also these types of low pressure systems are associated with cold fronts and colder surface temperature. However, the temperature pattern shows high temperatures in this area. An alternative interpretation is that the low pressure system over the Balkans might correspond to a heat low. It is unclear for me which aspects of the SLP distribution are related to the precipitation field and which ones to the temperature field. Can you separate this? This might also link back to major point 4.

A17: We agree that for the western Alpine south-side heavy precipitations are mostly associated with Genoa Low pressure systems. Following the study by Trigo, Isabel F., Grant R. Bigg, and Trevor D. Davies. "Climatology of cyclogenesis mechanisms in the Mediterranean." *Monthly Weather Review* 130.3 (2002): 549-569, we note however that the large scale circulation pattern induced by Genoa Low has a less pronounced anomaly structure over the MED than the Cyprus low, as the main cyclonic structure in these events is still typically on the Northern side of the Alps. Moreover, we tend to disagree on the nature of cold fronts and colder SST associated with Genoa Low. They mostly produce occluded or warm fronts as the results of the advection of Scirocco (SE) or Libeccio (SW) winds from Africa. These winds, charged with the humidity of the Mediterranean sea and impacting with the Apennines and with the Southern Alpine mountain ranges, produce heavy precipitation with Stau effects (Faccini, F., et al. "Geohydrological hazards and urban development in the Mediterranean area: an example from Genoa (Liguria, Italy)." *Natural Hazards & Earth System Sciences* 15.12 (2015)). In the same paper and references therein it is well explained why Genoa lows extreme precipitations are rather associated with warm fronts than cold fronts.

However, in our specific case (see Figure R_2 below) we did not find the signature of the Genoa low during JJA and after checking JJA CAPE anomaly means observed during alpha extremes we conclude that wet P anomalies over the Alps in JJA are driven by local convective events. We therefore: i) removed from L148-149 of the submitted paper “and in particular to the advection of moist Mediterranean air masses inland towards the Alpine region.” ; and ii) we specified the link between wet P anomalies and convective events in Section 4.2 of the revised paper.

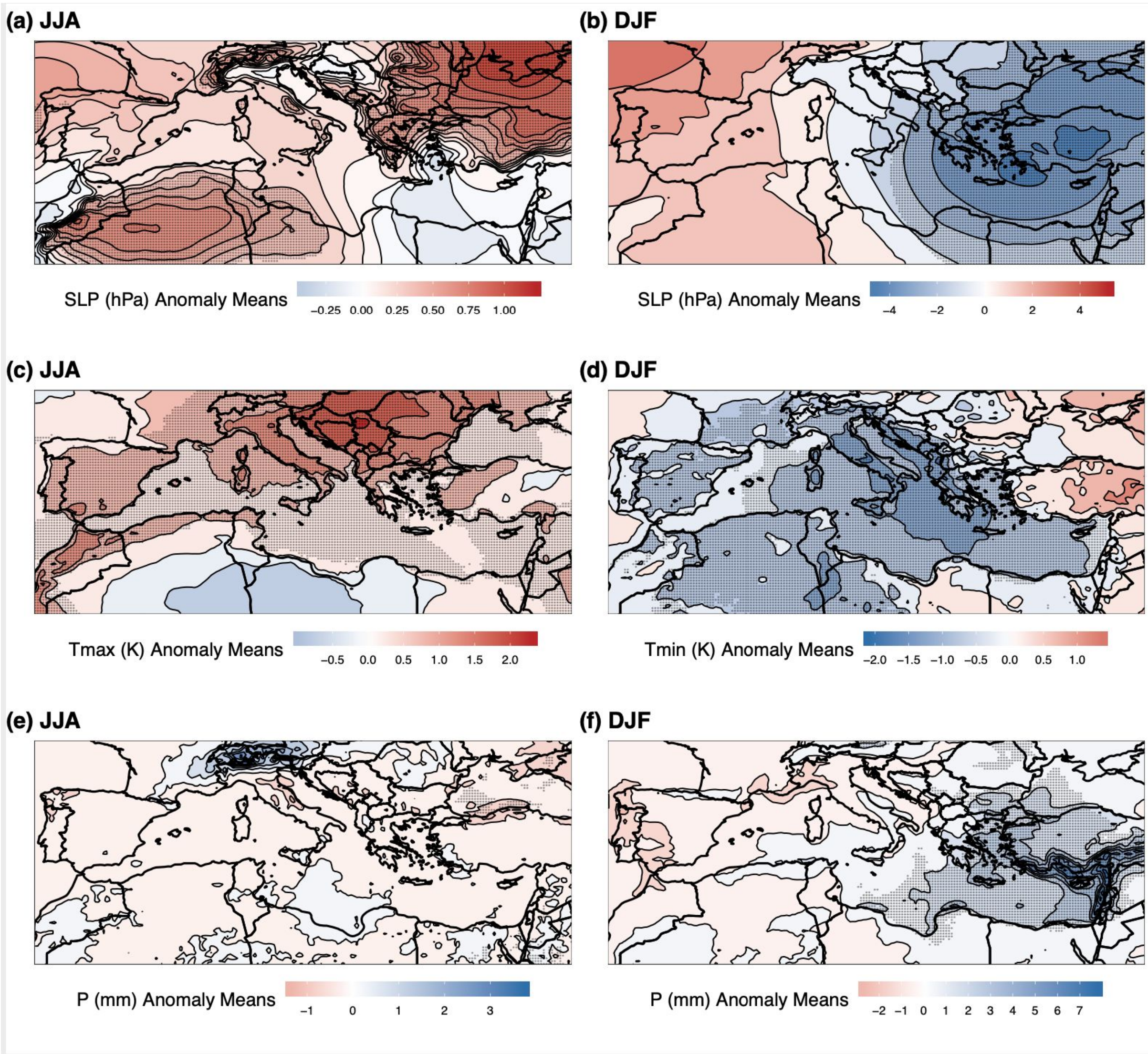

*Figure R_2 - New Figure 4 of the revised paper with total precipitation computed correctly (see **Update** at the start of this file).*

C18: 11) L151: How does the cold air from northern Europe cross the Alps into Italy? This statement does not have any supporting analyses in the paper. Please either refer to the literature, show the trajectories or remove the statement.

A18: In the revised paper we amended the sentence as follows: “In DJF we observe an east-west dipole in SLP over the MED, that favours cold-air advection from northern Europe to the the Balkans and the eastern MED, leading to significant negative Tmin anomalies in these regions. Negative and significant Tmin anomalies are also observed over the Italian peninsula, central and western MED.”

C19: 12) L162: how do you define dry?

A19: Dry anomalies are negative (<0mm) precipitation anomaly values computed relative to the seasonal JJA means. We improved the definition of anomalies in Section 2.2 of the revised paper.

C20: 13) Please add units to Figure 5.

A20: Done.

C21: 14) L175: It is unclear to me how you compute these maps since I understood the measures to be linked to one pattern over the entire Mediterranean. Please expand your explanations.

A21: Here we link the compound events for each gridpoint to CDEs (i.e. one pattern or time-series for the entire MED). The procedure to compute the maps is the following: i) for each grid-point in Figure 6 we identify the days (or dates) reporting compound events *and* CDEs, ii) we divide the total number of these days by the total number of CDEs and iii) we multiply the resulting number by 100 to obtain the % agreement value. A sentence has been added in the revised paper that clarifies the method.

C22: 15) L195: weaker anomalies -> can you be more specific?

A22: By ‘weaker anomalies’ we refer to the fact that P anomalies during JJA are mostly negative, yet not large enough to result in statistically significant values (see Figure 4e). We replaced ‘weaker’ with ‘not significant’ in the revised paper.