Impact of upstream moisture structure on a back-building convective precipitation system in south-eastern France during HyMeX IOP13

By K. O. Lee et al.

Reply to the referees' comments

In the following, the comments made by the referees appear in black, while our replies are in red, and the proposed modified text in the typescript is in blue.

Referee #1 comments

General Comments

This piece of work investigates how the simulated accumulations, duration and extent of rainfall in an observed convective event respond to variations of the moisture content in the upstream air (in two different layers: the marine boundary layer below 1 km ASL; and the free atmosphere between 1 and 2 km ASL). The general finding is that higher moisture availability leads to increased rainfall (in terms of either duration or amount). Some subtle deviations to this general pattern are documented, but are not explained in great detail. This manuscript is written in good English and figures are very well made. The authors do a good job in justifying the design of the sensitivity study and in documenting the findings. However, they could do better in the interpretation and critical examination of the results. I have a feeling that there could be a bit more of physically- and dynamically-based reasoning in the explanation of the observed sensitivities (see for instance comment 1 below). Even if the study is well designed and there is no major flow in the arguments, I honestly have doubts about the degree of novelty and significance of the results. Here we have a sensitivity study that demonstrates that rainfall rates depend on the upstream moisture, mostly in fairly obvious ways. Is this really new enough to justify publication?

I recommend requesting major revisions before accepting the manuscript.

The authors are grateful for reviewer's interest in this study and the many helpful suggestions for improving this manuscript. Replies to each major comments and minor comments are listed below.

Major comment

1) While the sensitivity to moisture variations in the MBL seems rather obvious, that to moisture variation in the 1-2 km layer doesn't seem to be. Unfortunately, the authors don't do much to explain it. To clarify: Simulations show that moistening the 1-2 km layer enhances precipitation, in terms of duration and extent. Conversely, drying that layer reduces both precipitation duration and amount.

I found it hard to reconcile this finding with the ideas, suggested by the authors themselves, that: (1) the moisture supply for the convective system comes from the marine boundary layer, below 1 km ASL; (2) air in the cold-air-pool mostly descends from the 1-2 km layer; (3) the precipitation rate is mostly governed by the cold-air-pool dynamics.

Cold-air-pools are generated by the latent heat uptake due to evaporating precipitation in the convective downdraft. Evaporation should be enhanced if it occurs in a drier air mass, so the manuscript documents just the opposite, so this is not a good explanation. What is then the casual relationship between the moisture variations in the 1-2 km layer and the observed sensitivity? Can the authors clarify them?

Agreed. We have improved our analysis of the simulations with the moistened and dried air mass in the 1-2 km layer in the manuscript. We have done an additional analysis on rainfall intensity and cold-air pool in CNTL, FA×M and FA×P simulations (please also note that we have taken into account your suggestion to change the names of the simulations). Figure A indicates the hourly evolution of domain-averaged rainfall intensity (mm hr^{-1}) and virtual potential temperature (ϑ_v) at the first model level in a fixed area (5.5-7.5°E, 43-44.5°N) where most of precipitation

is produced. Figure Aa shows that the rainfall intensity in FA×M simulation (dashed lines) is reduced by about 0.1−0.5 mm hr^{-1} compared to CNTL (black line) between 1200 and 1430 UTC, and the rainfall intensity ≥ 0.1 mm hr^{-1} starts about 45 min later (1300 UTC, dashed line) than in CNTL (1215 UTC, black line). Under the weakened precipitation, evaporation rate is reduced. The corresponding values of ϑ_v in the FA×M simulations are increased by about 0.2−0.5 K with respect to CNTL (dashed line, Fig. Ab). While the dried air mass in the 1-2 km layer is advected toward upstream the convection, it mixes with the moist air below, reducing the total moisture below 2 km. With the reduced moisture in the lower troposphere, the triggered convection near the Var coast produces less intensive rainfall and the weakened cold pool. Figure Ba–c shows the reduced rainfall accumulations in FA×M compared to CNTL (blue shades) are highlighted near the Var coast.

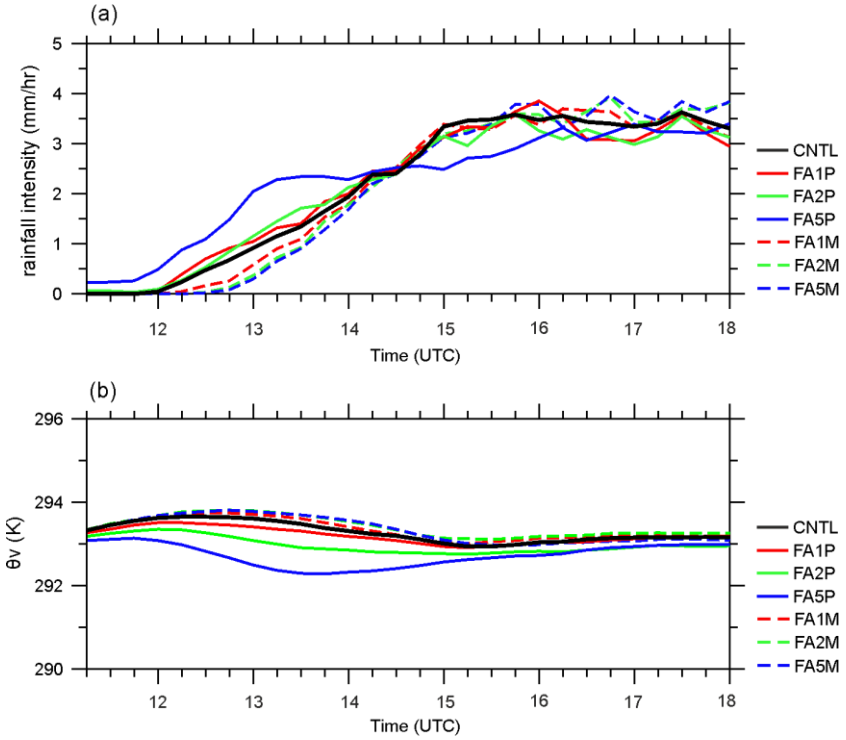

Figure A. Temporal evolution of domain-averaged rainfall intensity (mm hr^{-1}) and virtual potential temperature (ϑ_v) at the first model level in a fixed domain of 5.5−7.5°E, 43−44.5°N, simulated by CNTL (black line), FA×P (solid lines), and FA×M (dashed lines) from 1115 to 1800 UTC on 14 October 2012.

The enhanced rainfall intensities (about 0.2−2.5 mm hr^{-1}) are seen in FA×P simulations (colored solid lines, Fig. Aa) compared to CNTL (black line) between 1200 and 1430 UTC, especially FA5P produces the precipitation about 45 min earlier in time. Under the intensifying precipitation, the values of ϑ_v in FA×P simulations are about 0.2−1.7 K reduced, indicating the intensified cold pool formed by evaporative cooling than in CNTL (Fig. Ab). As the moistened air mass in the 1-2 km layer mixed with the moist air below during its advection towards the region of upstream convection, the total moisture below 2 km ASL increased. Thanks to the moistened lower troposphere, the convection triggered near the Var coast produces more intensive rainfall (red shades, Figure Bd–f) and correspondingly more intense cold pool. Also the moistened air masses in the lower troposphere initiate precipitation earlier while the precipitating area, particularly over the sea, is enlarged.

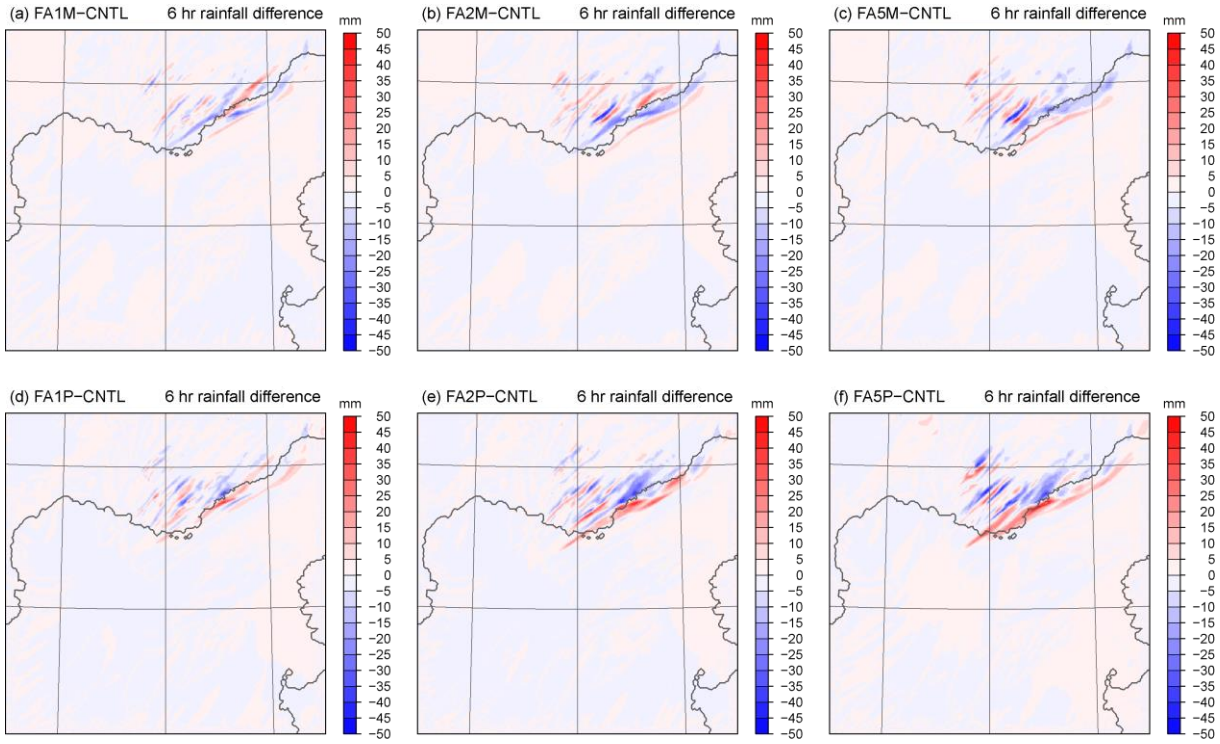

Figure B. Differences of 6 hour accumulated rainfall from 1200 to 1800 UTC on 14 October 2012 (a) FA1M minus CNTL, (b) FA2M minus CNTL, (c) FA5M minus CNTL, (d) FA1P minus CNTL, (e) FA2P minus CNTL, and (f) FA5P minus CNTL.

We have add Figure A (as Figure 16) and clarify the mechanism in the manuscript as:

♣ Page 13, from line 29

"Figure 16 shows that the rainfall intensity in FA×M simulation (dashed lines) is reduced by about 0.1–0.5 mm hr^{-1} compared to CNTL (black line) between 1200 and 1430 UTC, and the rainfall intensity ≥ 0.1 mm hr^{-1} starts about 45 min later (1300 UTC, dashed line) than in CNTL (1215 UTC, black line). Under the weakened precipitation, evaporation rate is reduced. The corresponding values of ϑ_v in the FA×M simulations are increased by about 0.2–0.5 K with respect to CNTL (dashed line, Fig. 16b). While the dried air mass in the 1-2 km layer is advected toward upstream the convection, it mixes with the moist air below, reducing the total moisture below 2 km. With the reduced moisture in the lower troposphere, the triggered convection near the Var coast produces less intensive rainfall and the weakened cold pool."

♣ Page 14, line 12-18

"In summary, decreasing the moisture content in the dry layer between 1 and 2 km ASL reduces the total amount of precipitation as well as the area affected by the precipitation and the duration of the precipitating episode. As the MABL is nearly saturated, the convection triggers easily along the coast but develops less intensively. The maximum of precipitation located along the eastern Var coast is reduced, corresponding to a weakened cold pool and weakened ascents at its southern boundary. This shows that around the coast, the dryness in the 1–2 km ASL layer is not a major ingredient for the convection development and the cold pool generation when the lowermost layer is nearly saturated."

♣ Page 15, line 15-24

"[…] Figure 16a shows the enhanced rainfall intensities (about 0.2–2.5 mm hr^{-1}) in FA×P simulations (colored solid lines) compared to CNTL (black line) between 1200 and 1430 UTC, especially FA5P produces the precipitation about

45 min earlier in time. Under the intensifying precipitation, the values of ϑ_v in FA×P simulations are about 0.2−1.7 K reduced, indicating the intensified cold pool formed by evaporative cooling than in CNTL (Fig. 16b). As the moistened air mass in the 1-2 km layer mixed with the moist air below during its advection towards the region of upstream convection, the total moisture below 2 km ASL increased. Thanks to the moistened lower troposphere, the convection triggered near the Var coast produces more intensive rainfall and correspondingly more intense cold pool. Also the moistened air masses in the lower troposphere initiate precipitation earlier while the precipitating area, particularly over the sea, is enlarged."

♣ Page 16, line 2-4
"[…] In the environment with similar instability but with further moistened conditions in the lower troposphere, the triggered convection further intensifies with enlarged horizontal extent of cold pool and strengthened ascents at its southern boundary."

♣ From Page 16, line 29
"Similarly, moistening the layer at 1−2 km ASL (see Fig. 17c), just above the MABL, increases the humidity in the lowermost 2 km ASL by mixing in the environment with a similar instability as in CNTL. With more moisture in lower troposphere, the triggered convection further intensifies which produces an enlargement of the horizontal extent of cold pools (dark blue area). […]"

♣ Page 17, line 14-16
"[…] The dryness in the 1−2 km ASL layer is not a major ingredient for the convection development and the cold pool generation when the lowermost layer is nearly saturated."

2) The initialization of the sensitivity runs with dry or moist bubbles, and the related consequences, could be described better. Even if they can be guessed by the reader, several aspects are not thoroughly explained. (A) How far do the bubbles travel, between the model initialization and the initiation of convection? (B) How is their shape deformed? (c) Most importantly, do bubbles follow exactly the same trajectories for all sensitivity runs? How much do the trajectories differ between runs? (D) Most of the initial profiles in Figure 5 differ by constant amounts in either the lower or upper layers, but this is not always the case. For instance, the *5P profiles deviate from this pattern. Why?
Agreed. The details regarding the initialization and evolution of the sensitivity bubbles and its deviation among the experiments have been revised in sections 2.2, 3 and 4, as discussed below (newly added part is marked in red).

We have added this bit of information in results as:

♣ Page 5, line 17-23
"[…] Then the convection (highlighted by reflectivity values exceeding 45 dBZ, Lee et al., 2012) initiates upstream (yellow star, Fig. 2b), about 25 km further south than observed at 1200 UTC and maximum 15-minute precipitation over 5 mm is simulated approximately 93 km from the initiation at 1230 UTC (Fig. 2b). It develops preferably towards Marseille, then around the Argens valley region and the east coastal Var region (Figs. 2b and 3a−b), similarly as observed. The intense precipitation (≥ 15 mm per 15 min, red circle in Fig. 2b) is first simulated at 1400 UTC north of Marseille (5.6°E, 43.5°N) in a location distant of about 95 km from the bubble initiation."

♣ Page 10, line 3-5
"The sensitivity bubbles of MBL experiments travels north-eastwards over the sea as in CNTL, and it keeps its ellipse shape but with a slightly reduced horizontal size due to lateral mixing with the ambient air mass during its advection."

♣ Page 10, line 10-13
"[…] The intense precipitation (≥ 15 mm per 15 min) starts 3 hour later in MBL5M than in CNTL, MBL1M, and

MBL2M. The convection at 1800 UTC is located at the eastern coast of Var, as in CNTL (square in Fig. 2b) and MBL×M (square in Fig. 8a–c), and then stays 2–3 additional hours in this region."

♣ Page 12, line 2-6
"[…] In MBL×P experiments (Fig. 8d–f), precipitation is initiated over the sea at 1200 UTC, and then the bubbles travel along similar pathways over the sea as in CNTL. However the inland precipitation starts later (e.g. 15, 45, and 90 min later in MBL1P, MBL2P, and MBL5P, respectively) than in CNTL. This late onset of inland precipitation is also consistent with more widespread precipitation over the sea in MBL2P and MBL5P (Fig. 7e, f)."

♣ Page 13, line 17-20
"[…] The sensitivity bubbles of FA experiments travel north-eastward over the sea as similar as seen in CNTL and MBL, but the horizontal extent is slightly reduced by mixing with the ambient air mass during the travel. The convection initiates about 20 km offshore of the Var coast (yellow star, Fig. 14a–c)."

♣ Page 15, line 9-12
"[…] The convection initiates near the Var coast, as in CNTL, however the horizontal extent of the convective region (reflectivity ≥ 45 dBZ) is relatively large compared to CNTL. The precipitation starts at 1200 UTC about 50 km offshore the southern Var coast, when the bubble reaches this region ~140 km distant from the location of initiation […]"

3) Naming the two experiment series MST* and DRY* is confusing, because runs 1-2-5M are dry in both series, while 1-2-5P are moist in both series. I suggest renaming to MBL*) for "marine boundary layer"; e.g. MBL5M) and FA* (for "free atmosphere" – or something similar).
Agreed. The name of the two experiments series has been changed from MST and DRY to MBL and FA, respectively, in the text and in the related tables and figures (1, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, and 16), as suggested.

Minor comments

4) Page 1, line 14: "intensive observation period". Please introduce the acronym IOP here.
The acronym IOP has been introduced (Page 1, line 14).

5) Page 1, lines 18-21: Sentence unclear. The response of what to what?
Corrected (Page 1, line 18-19) as:

"The sensitivity experiments are designed to investigate the response of the HPE to the variability of the water vapour content upstream […]"

6) Page 1, line 27-28: A lifetime can be "shortened", but the amount is "reduced".
Corrected (Page 1, line 27).

7) Page 2, line 3: "At the same time". At the same time of which event?
Deleted for the sake of clarity.

8) Page 2, line 6: "in lower troposphere" → "in the lower troposphere"
Corrected (Page 2, line 5).

9) Page 3, line 12-13: Please split this sentence. "…over the sea. These are difficult…"
Corrected (Page 3, line 15).

10) Page 3, line 21: “disturbances” → “disturbance”.
Corrected (Page 3, line 23).

11) Page 4, line 1: “moist structure” → “moisture structure”
Corrected (Page 4, line 4).

12) Page 4, line 18: In a bulk one-moment microphysical scheme, the number concentration of cloud concentration nuclei is prescribed. What value was used? Is it appropriate for maritime convection?
There is no prescribed concentration of cloud condensation nuclei in the ICE3 scheme (Caniaux et al., 1994; Pinty and Jabouille, 1998) used by Meso-NH: condensation of cloud water is the result of a saturation adjustment procedure while the conversion of cloud droplets into raindrops is based on a threshold of cloud water content.

13) Page 6, line 12: “French coasts” → “French coast”.
Corrected (Page 6, line 18).

14) Page 7, line 6: The meaning of “WVMR” can be easily guessed, but it is better to expand the acronym on its first occurrence.
The acronym of WVMR is stated in page 6, line 23.

15) Page 8, line 3-10: This is a very long sentence. Consider reformulating: “To investigate the WVMR impact on the location, intensity and duration of precipitation, we consider several indicators…”
Corrected as suggested in Page 8, line 18-19 as:

“To investigate the WVMR impact on the location, intensity and duration of precipitation, we consider several indicators, […]”

16) Page 8, line 10-19: Traditionally, figures are numbered in the same sequence as they are cited. Here, the order of citation is awkward: 6-10-7-13-8-14-9. Please fix.
As suggested, the order of citation has been revised. However for the sake of readability, we introduce Figures 6 and 12 in a same sentence (from Page 8, line 24).

17) Page 9, line 20: “in the mountainous region of close to Marseille”. Confusing. Consider deleting. “West of 6°E” is easier to understand.
Corrected (Page 10, line 10) as:

“[…] rainfall accumulations stay longer west of 6°E than in CNTL […]”

18) Page 9, line 22, Figure 9: How are the CAPE values computed? Are they spatially averaged? What is the initial height of the rising parcels?
The CAPE values are averaged within a “sensitivity bubble” every 15 min. The initial height of the rising parcels is around 20 m. The relevant explanation is added in manuscript in Page 10, line 15-16 as:

“[…] Figure 9 shows the domain-averaged CAPE values (using a rising air parcel having its initial height about 20 m) within the sensitivity bubble upstream […]”

19) Page 10, line 3: Does an air mass "weaken"? What you referring to, exactly? Virtual potential temperature? Extent of the cold-air pool?
Corrected (Page 10, line 25-27) as:

"[…] The extent of cold air mass (ϑ_v < 291 K at the first model level) formed along the foothill of the mountain by evaporation of the intense precipitation is also reduced in MBL×M (Figure 11a–c). […]"

20) Page 10, line 5: "This combination of decreased CAPE and weakened cold pool can explain the weakened precipitation." The casual link is unclear. Does the cold pool become weaker because of the weaker precipitation, or vice versa?
Corrected (Page 10, line 29) as:

"[…] of decreased CAPE and weakened cold pool which are induced by the weakened precipitation […]"

21) Page 10, line 21: "instead of CNTL of 435 min" → "instead of 435 min in CNTL"
Corrected (Page 11, line 18).

22) Page 11, line 1: "in the MST1P" → "in MST1P"
Corrected (Page 11, line 26).

23) Page 11, lines 24-25: "CAPE favours triggering". CAPE doesn't favour triggering. Roughly speaking, CAPE quantifies the "degree of instability". You can have high values of CAPE and no way to overcome convective inhibition. Conditional instability (steep mid-level lapse rate) is on ingredient of deep moist convection; triggering (uplift) is another one.
The interpretation about the high values of CAPE has been modified in Page 12, line 24-25 as:

"[…] (Figure 11f). CAPE values higher than 1500 J kg^{-1} lead to an increase of the degree of instability in the upstream environment […]"

24) Page 12, line 13: "the duration are" → "the duration is"
Corrected (Page 13, line 10-11).

25) Page 13, line 4: "increased over the time" → "increased over time"
Corrected (Page 14, line 10).

26) Page 13, line 12: "in lower troposphere" → "in the lower troposphere"
Corrected (Page 15, line 23).

27) Page 13, line 15-19: "However, the duration of precipitation over land (Dland) and the duration of more intense precipitation (DRR15, ≥ 15 mm in 15 min) are shortened (from 315 min in CNTL to 270 min, 240 min, and 240 min in DRY1P, DRY2P, and DRY5P, respectively for Dland, and from 120 min in CNTL to 105 min, 60 min and 30 min, in DRY1P, DRY2P, and DRY5P respectively for DRR15)". Such lengthy sequences of acronyms and numbers are hard to read and not very informative. What really matters is the sign of the deviation from CNTL – there is probably no need to mention more than that. If you want to include numerical values, you can put them in a table. There are other similar sentences in the manuscript. Removing them would make the paper much better readable.
As suggested, the relevant sentences have been shortened without numerical values (from Page 14, line 24 and from Page 9, line 11).

28) Page 14, lines 6-8: “and less stationary system” → “and a less stationary system”
For the sake of readability, we modify the sentence as:

♣ Page 15, line 25-26
“[…] It also appears that the precipitation is less stationary.”

29) Page 14, line 15: “topped by dry air mass” → “topped by a dry air mass”.
Corrected (Page 16, line 10).

30) Page 14, line 27-28: “A small increase of moisture content favours convection triggering”. If the authors are alluding to the effect of moisture in increasing CAPE, then this has nothing to do with triggering (see a previous comments). Incidentally, moisture can also make (orographic) triggering easier by reducing the static stability (buoyancy frequency) of the atmosphere. But I think this is not what authors mean here.
Agreed. The relevant interpretation to CAPE has been modified (Page 16, line 22-23) as:

“[…] A small increase of moisture content in the warm and moist MABL increases the degree of instability.”

31) Figure 2, caption: There’s an ellipsoid in panel a. Please explain what it is. Also, please make thicker, so as to make it visible.
The ellipsoid in panel (a) has been removed for the sake of clarity.

32) Figure 6: I am confused by the units of RR_{acc} and RR_{sum}. I am fine with RR_{acc} being in m^2, but, if RR_{sum} is a domain wide sum, shouldn’t it be expressed in liters? 1 mm = 1 liter/m^2. Sum up over all grid points accounting for the mesh size should give liters of water.
RR_{acc} is a maximum value of 6-hours accumulated precipitation amount, and it has been renamed by RR_{max} for better understanding. For better comparison among experiments, RR_{sum} is recalculated to domain-averaged total sum of the 6-hours accumulated precipitation amount for a fixed area bounded by 40.5−45°N and 3.5−9°E where the sensitivity bubble passed through. Now RR_{sum} has a unit of mm. Figures 6 and 12, and the relevant text have been modified.

33) Figure 7: Same as above. Please explain the meaning of the ellipsoids, and make them thicker.
Corrected.

34) Figure 9: Label and units are missing on the y axis.
Corrected.

35) Figure 10: Same as above. Please make the ellipsoids thicker.
Corrected.

Impact of upstream moisture structure on a back-building convective precipitation system in south-eastern France during HyMeX IOP13

By K. O. Lee et al.

Reply to the referees' comments

In the following, the comments made by the referees appear in black, while our replies are in red, and the proposed modified text in the typescript is in blue.

Referee #2 comments

General Comments

The sensitivity of HyMeX SOP1-IOP13 to low level moisture content is analyzed in a series of sensitivity experiments. The two layers 0-1 km and 1-2 km are analyzed separately in order to test whether an increase or decrease in moisture content would affect the rainfall location, amount, and duration. The main conclusion is that the moisture structure in the lower troposphere is a key for accurate prediction at short-term range of precipitation in the coastal mountainous region in southern France. Results are presented clearly and comprehensively, although some deepen investigation is suggested.

We appreciate the time and effort you put in this review as well your mindful comments on our paper. We have worked hard to comply with all of them. Replies to each major comment and minor comment are listed below.

Major comment

The reasons why an increase of humidity in the 1-2 km layer would increase the cold pool are not clear and should be investigated better. My interpretation is that a higher humidity content produces earlier precipitation (as discussed in Page 13, line 27-28), thus producing anticipated and stronger cold pool than in control run. I suppose the cold pool is mainly generated by the mid-level air, thus it is not affected directly by the changes of vapour content in the low troposphere. Anyway, this or any other justifications you have should be properly supported.

Agreed. When a low-level cold pool forms under a meso-scale convective system (MCS), and it can lift the ambient low-level flow at its leading edge (Ducrocq et al., 2008) or modify the low-level circulation locally and enhance convergence areas (Duffourg, et al., 2016). In this study, the origin of air parcel in the low-level cold pool that developed under a convective system is retrieved using a 3-D backward trajectory analysis. We found the air parcel feeding the cold pool development was relatively dry, with water vapour mixing ratios less than 6 g kg^{-1} in the 1-2 km ASL layer. We have done an additional analysis on rainfall intensity and cold-air pool in CNTL, FA×M and FA×P. The discussion of simulations with the moistened and dried air mass in the 1-2 km ASL layer are improved in the manuscript.

Figure Aa shows that the rainfall intensity in FA×M simulation (dashed lines) is reduced by about 0.1−0.5 mm hr^{-1} compared to CNTL (black line) between 1200 and 1430 UTC, and the rainfall intensity ≥ 0.1 mm hr^{-1} starts about 45 min later (1300 UTC, dashed line) than in CNTL (1215 UTC, black line). Under the weakened precipitation, evaporation rate is reduced. The corresponding values of ϑ_v in the FA×M simulations are increased by about 0.2−0.5 K with respect to CNTL (dashed line, Fig. Ab). While the dried air mass in the 1-2 km layer is advected toward upstream the convection, it mixes with the moist air below, reducing the total moisture below 2 km. With the reduced moisture in the lower troposphere, the triggered convection near the Var coast produces less intensive rainfall and the weakened cold pool.

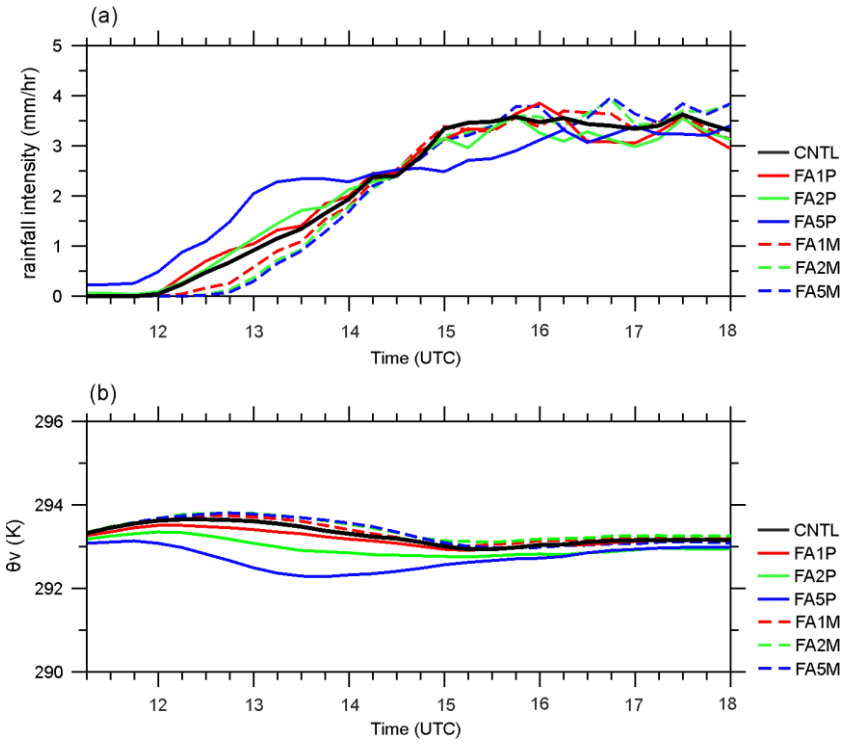

Figure A. Temporal evolution of domain-averaged rainfall intensity (mm hr^{-1}) and virtual potential temperature (ϑ_v) at the first model level in a fixed domain of 5.5−7.5°E, 43−44.5°N, simulated by CNTL (black line), FA×P (solid lines), and FA×M (dashed lines) from 1115 to 1800 UTC on 14 October 2012.

The enhanced rainfall intensities (about 0.2−2.5 mm hr^{-1}) are seen in FA×P simulations (colored solid lines, Fig. Aa) compared to CNTL (black line) between 1200 and 1430 UTC, especially FA5P produces the precipitation about 45 min earlier in time. Under the intensifying precipitation, the values of ϑ_v in FA×P simulations are about 0.2−1.7 K reduced, indicating the intensified cold pool formed by evaporative cooling than in CNTL (Fig. Ab). As the moistened air mass in the 1-2 km layer mixed with the moist air below during its advection towards the region of upstream convection, the total moisture below 2 km ASL increased. Thanks to the moistened lower troposphere, the convection triggered near the Var coast produces more intensive rainfall (red shades, Figure Bd–f) and correspondingly more intense cold pool. Also the moistened air masses in the lower troposphere initiate precipitation earlier while the precipitating area, particularly over the sea, is enlarged.

We have add Figure A (as Figure 16) and clarify the mechanism in the manuscript as:

♣ From Page 13, line 29

"Figure 16 shows that the rainfall intensity in FA×M simulation (dashed lines) is reduced by about 0.1−0.5 mm hr^{-1} compared to CNTL (black line) between 1200 and 1430 UTC, and the rainfall intensity ≥ 0.1 mm hr^{-1} starts about 45 min later (1300 UTC, dashed line) than in CNTL (1215 UTC, black line). Under the weakened precipitation, evaporation rate is reduced. The corresponding values of ϑ_v in the FA×M simulations are increased by about 0.2−0.5 K with respect to CNTL (dashed line, Fig. 16b). While the dried air mass in the 1-2 km layer is advected toward upstream the convection, it mixes with the moist air below, reducing the total moisture below 2 km. With the reduced moisture in the lower troposphere, the triggered convection near the Var coast produces less intensive rainfall and the weakened cold pool."

♣ Page 14, line 12-18

"In summary, decreasing the moisture content in the dry layer between 1 and 2 km ASL reduces the total amount of precipitation as well as the area affected by the precipitation and the duration of the precipitating episode. As the MABL is nearly saturated, the convection triggers easily along the coast but develops less intensively. The maximum of precipitation located along the eastern Var coast is reduced, corresponding to a weakened cold pool and weakened ascents at its southern boundary. This shows that around the coast, the dryness in the 1–2 km ASL layer is not a major ingredient for the convection development and the cold pool generation when the lowermost layer is nearly saturated."

♣ Page 15, line 15-24

"[…] Figure 16a shows the enhanced rainfall intensities (about 0.2–2.5 mm hr^{-1}) in FA×P simulations (colored solid lines) compared to CNTL (black line) between 1200 and 1430 UTC, especially FA5P produces the precipitation about 45 min earlier in time. Under the intensifying precipitation, the values of ϑ_v in FA×P simulations are about 0.2–1.7 K reduced, indicating the intensified cold pool formed by evaporative cooling than in CNTL (Fig. 16b). As the moistened air mass in the 1-2 km layer mixed with the moist air below during its advection towards the region of upstream convection, the total moisture below 2 km ASL increased. Thanks to the moistened lower troposphere, the convection triggered near the Var coast produces more intensive rainfall and correspondingly more intense cold pool. Also the moistened air masses in the lower troposphere initiate precipitation earlier while the precipitating area, particularly over the sea, is enlarged."

♣ Page 16, line 1-3

"[…] In the environment with similar instability but with further moistened conditions in the lower troposphere, the triggered convection further intensifies with enlarged horizontal extent of cold pool and strengthened ascents at its southern boundary."

♣ From Page 16, line 29

"Similarly, moistening the layer at 1–2 km ASL (see Fig. 17c), just above the MABL, increases the humidity in the lowermost 2 km ASL by mixing in the environment with a similar instability as in CNTL. With more moisture in lower troposphere, the triggered convection further intensifies which produces an enlargement of the horizontal extent of cold pools (dark blue area). […]"

♣ Page 17, line 14-16

"[…] The dryness in the 1–2 km ASL layer is not a major ingredient for the convection development and the cold pool generation when the lowermost layer is nearly saturated."

We have clarify 'low-level cold pool' in the Introduction (Page 3, line 3-5), as:

"[…] Furthermore, a low-level cold pool forming under a MCS can also lift the impinging ambient low-level flow at its leading edge (Durocq et al., 2008) or modify the low-level circulation locally and enhance convergence areas (Duffourg et al., 2016)."

Minor comments

Page 1, line 19: …the response to the variability…

Corrected (Page 1, line 19).

Page 2, lines 27: A simplified theory for the interaction of the low-level jet with a mountain range is provided in Miglietta, M. M., and Rotunno, R.: Numerical simulations of sheared conditionally unstable flows over a mountain ridge, J. Atmos. Sci., 71, 1747-1762, 2014

The reference paper has been cited (Page 3, line 3).

Page 3, line 6: … with respect to …
Corrected (Page 3, line 8).

Page 4, line 4: grid spacing is more appropriate than horizontal resolution.
Corrected (Page 4, line 20).

Section 2.2: Since the title of the section includes "validation", you should include an image of observations, e.g. the observed 6-h accumulated rainfall, for sake of comparison.
The objective of this section is to describe the results of the control simulation in order to compare them with the results of sensitivity simulations in the next sections. Thus, the title of section 2.2 has been modified to "Control simulation" (Page 5, line 9).

Page 5, line 14: "maximum 15-minute" instead of "6-hour"
Corrected (Page 5, line 18-19).

Page 5, line 16: … similarly as observed…
Corrected (Page 5, line 21).

Page 6, line 20: where are SSM/I data retrieved? in the same window considered for the analysis data?
Yes, SSM/I data over the north-western Mediterranean region was used, and this information is described in manuscript (Page 6, line 27-28) as:

"SSM/I over the north-western Mediterranean are in broad agreement, […]"

Page 6, line 25: since most of the IWV concentrates below 1 km ASL, one would expect that humidity is due to evaporation more than to advection: did you try any sensitivity experiment to test how the results change in the absence of surface fluxes?
By comparing control and sensitivity experiments, we investigate the impact of the advected air mass below 1 km ASL. We agree that the humidity can be increased by local evaporation over the sea. Indeed, additional sensitivity experiment would be needed to understand the impact of evaporation over the sea, hence we have not looked into this. However, the first author is currently leading a study based on stable water isotopologue data to see the influence of local surface flux and advected moisture on convection development on the same case study.

We have added the sentence from Page 17, line 29 as:
"[…] Another approach is to use stable water isotopologue data to disentangle the various moisture sources, i.e. evaporation over the sea, advected moisture upstream of the HPEs in the Mediterranean (Sodemann et al., 2017)."

Page 7, line 14: It is not clear how you impose under-saturation in case of increased moisture (MST5P experiment)
The relevant explanation has been improved. The expression "keeping the air under-saturated" has been changed for "up to the saturation limit"

We have added the sentence in Page 7, line 20-21 as:
"In other words, the water vapour value at saturation with respect to liquid water was calculated at each altitude and used as an upper threshold of the modified WVMR."

Page 9, line 20: stay instead of stays
Corrected (Page 10, line 10).

Page 10, line 21: rephrase as “instead of 435 min in CNTL”
Corrected (Page 11, line 18) as:

“instead of 435 min in CNTL, […]”

Page 12, line 23-24: which are the implications of the improved location of the simulated rainfall? Does it mean that the reference analysis is not accurate in the 1-2 km layer?
It is true that drying air mass even by 1 g kg^{-1} in the 1–2 km ASL layer leads to an onset of the precipitation at a more realistic location, about 25 km closer to Marseille. This evidences the importance of having precise observation-based water vapour profiles over the sea to improve the analysis and in turn the rainfall forecast in terms of location. This finding has been added in the conclusion.

Figure 6 caption: is the duration of precipitation above a threshold calculated in a fixed point and does it refer to any point in the domain?
Yes, a fixed point in the domain (north of 40.5°N, east of 3.5°E, i.e. to the northeast of the initiated bubbles) is used to calculate the duration of precipitation. The sentence has been corrected as suggested.

Figure 7 caption: what do the ellipses represent?
The meaning of the ellipses is given in the caption, as:

“Figure 7. […] Ellipsoid in (a)–(c) indicates the area with less precipitation than CNTL, while the ellipsoid in (d)–(e) shows the shifted precipitation area to the offshore region.”

Figure 10 caption: how is the “sensitivity bubble” shown in this figure related to that shown in Fig. 1?
The CAPE values in both CNTL and FA×M (previously named DRY×M but modified to comply with Referee’s #1 comments) slightly increased over time in the location of the sensitivity area as it mixed with the adjacent moister air.

We have added this information in manuscript in Page 10, line 3-5 as:
“The sensitivity bubbles of MBL experiments travels north-eastwards over the sea as in CNTL, and it keeps its ellipse shape but with a slightly reduced horizontal size due to lateral mixing with the ambient air mass during its advection.”

Impact of upstream moisture structure on a back-building convective precipitation system in south-eastern France during HyMeX IOP13

By K. O. Lee et al.

Reply to the referees' comments

In the following, the comments made by the referees appear in black, while our replies are in red, and the proposed modified text in the typescript is in blue.

Referee #3 comments

General Comments

This study investigate the impacts of upstream moisture structure of the HyMeX IOP13 case through two sets of sensitivity tests, one altering the moisture content below 1 km in the marine boundary layer (MBL) while the other altering that over 1-2 km above sea-level (ASL). The topic is interesting and quite important and I do not have a major issue with the method and basic conclusion. However, I think that this paper can be much improved with some additional work (some of which I think is necessary). Therefore, I recommend "major revision" before acceptance. Below, some major and minor comments are given.

We appreciate the time and effort you put in this review as well your mindful comments on our paper. We have worked hard to comply with all of them. Replies to each major comment and minor comment are listed below.

Major comment

1. I do not think that the authors have picked all the important (and relevant) parameters (related to rainfall or precipitation system) to be shown and examined/discussed in this paper, in order to look deeper into what is going on physically in their numerical tests (beyond just describing their results). Right now, much of the discussion is quite descriptive, and in my opinion it does not shed enough light on the physical mechanisms leading to the differences in results as seen in the figures. I would like to see the authors put in more efforts to discuss how the changes in moisture (in MBL or in 1-2 km ASL) affect the rainfall system's structure (organization mode) and perhaps the back-building (BB) behavior in particular. One of the issues that affects the interpretation is the variables RR_{acc} and RR_{sum}, which are not defined very clearly in the text or reflective of what they mean (p.8), and I recommend the authors go through them carefully and perhaps use a table to summarize all those chosen. Some other parameters (linked to convective triggering, stability, and cold pool) that they may consider include (but not limited to): total water production (in ton or m3) from event, the production over land versus over sea, level of free convection (LFC, beside CAPE) and/or CIN averaged over the source region, duration of linear organization and/or BB behavior, strength/ size/duration of cold pool, etc. Another thing that may also help is adding four more experiments of ±3 g/kg. Right now, jumping from 2 to 5 g/kg (which is quite a big change as shown in Fig. 5) seems too much.

The way the changes in moisture below 2 km ASL effect the rainfall system structure (mechanism) is now more detailed in the manuscript as highlighted below.

The definitions of RR_{acc} and RR_{sum} and the related explanations are now clearly stated in the manuscript. The differentiated rainfall structure and mechanism is better described by including various parameters, e.g., precipitation production over land and sea, rainfall intensity, CAPE, equivalent potential temperature, virtual potential temperature in order to give more details on the water production, atmospheric stability, and cold pools.

♣ We have added parameters RR_{land} and RR_{sea} that are summarized in Table 2. We re-calculated RR_{sum} to show the 6-hour accumulated precipitation amounts in a fixed domain (north of 40.5°N, east of 3.5°E, i.e. to the northeast of the initiated bubbles) for CNTL and the 12 sensitivity experiments. Figures 6 and 12 have also been improved (see below).

Table 2. Deviation of domain-averaged 6-hour total accumulated precipitation amount over land (RR_{land}) and over sea (RR_{sea}) for the MBL and FA experiments with respect to the CNTL (RR_{land} of 14.2 mm, RR_{sea} of 1.5 mm) within the fixed area (3.5–9°E, 40.5–45°N) from 1200 UTC on 14 October 2012.

(a) Exp.	MBL1M	MBL2M	MBL5M	MBL1P	MBL2P	MBL5P
RR_{land}	–0.5	–0.8	–3.4	–0.7	–1.9	–3.2
RR_{sea}	–0.1	–0.4	–0.6	+0.6	+1.3	+0.8

(b) Exp.	FA1M	FA2M	FA5M	FA1P	FA2P	FA5P
RR_{land}	–0.6	–0.5	–0.7	–0.7	–1.2	–1.5
RR_{sea}	+0.2	+0.2	+0.3	+0.6	+1.1	+1.4

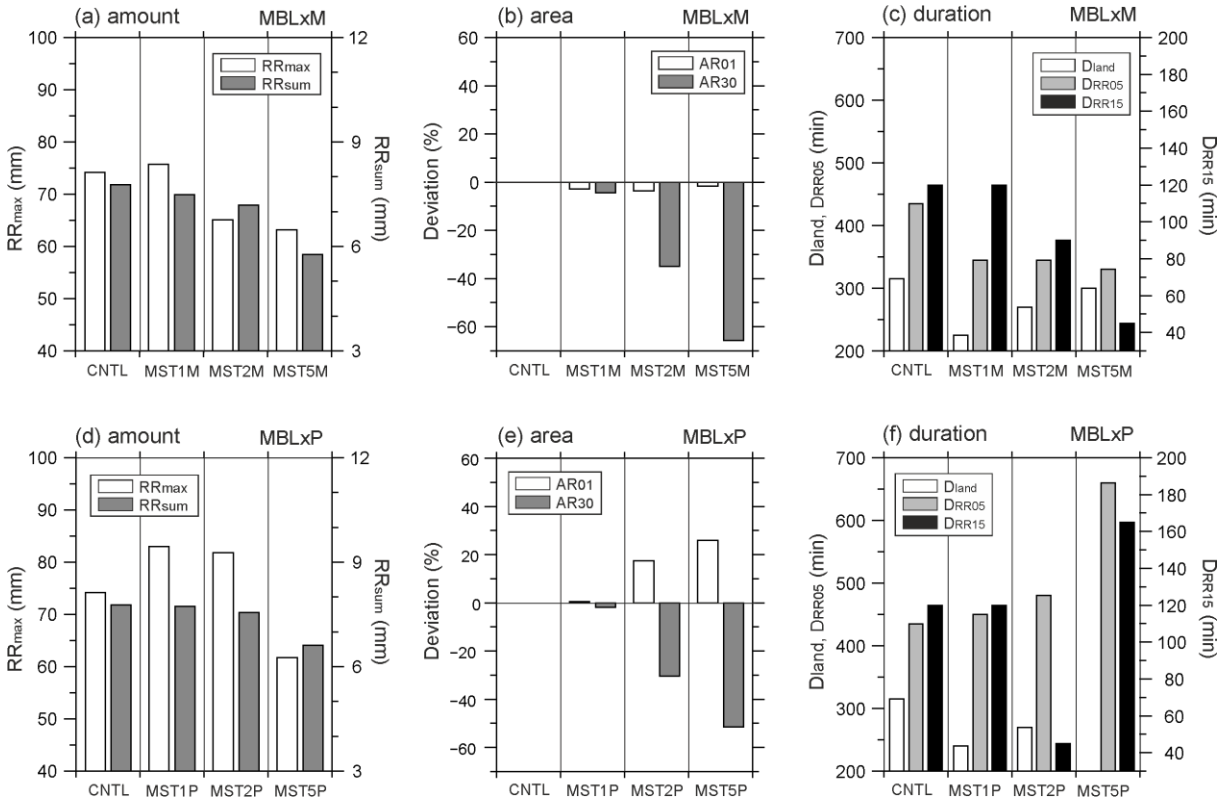

Figure 6. Results of CNTL, MBL×M (upper panel, a–c) and MBL×P (bottom panel, d–f) experiments: (a) and (d) maximum 6-hour accumulated precipitation amount (RR_{max}), and the domain-averaged total sum of the 6-h accumulated precipitation amount (RR_{sum}, mm) from 1200 UTC on 14 October 2012, (b) and (e) the deviation of areas (km^2) of $RR_{acc} \geq$ 1 mm (AR01) and $RR_{acc} \geq$ 30 mm (AR30) in MBL to ones in CNTL, and (c) and (f) duration of precipitation (≥ 5 mm) over the land (D_{land}), duration of precipitation ≥ than 5 mm per 15 min (D_{RR05}), duration of intense precipitation ≥ 15 mm per 15 min (D_{RR15}). The RR_{sum} and duration of precipitation were calculated at a fixed area of latitude of 40.5–45°N, longitude of 3.5–9°E where the sensitivity bubble passed though are used, respectively.

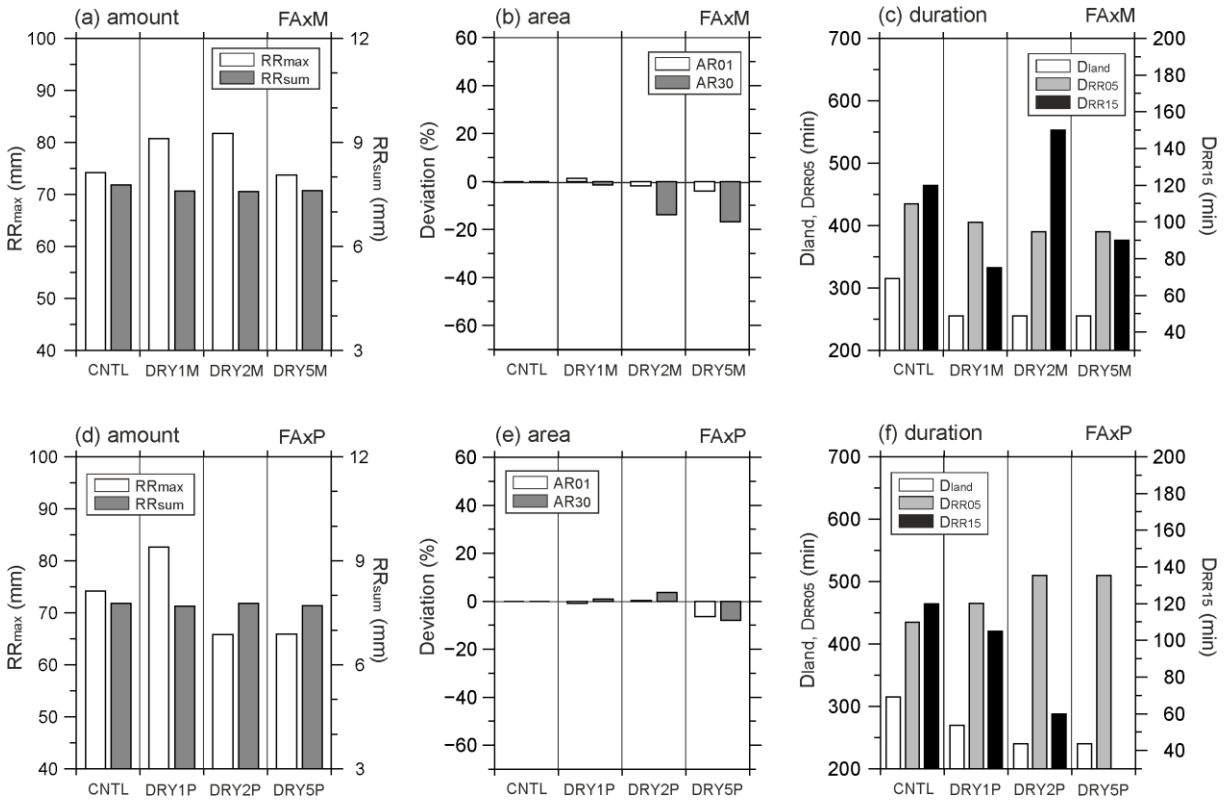

Figure 12. As Figure 6 but for CNTL, FA×M (upper panel, a–c) and FA×P (bottom panel, d–f) experiments.

We have added the information contained in the table and figures in the discussion of the results as:

♣ Page 9, line 13-15

"[…] The reduction of total precipitation seen over land (RR_{land}, between −0.5 and −3.4 mm) is more significant than that seen over the sea (RR_{sea}, between −0.1 to −0.6 mm) in MBL×M (Table 2a)."

♣ Page 11, line 15-17

"[…] For instance, excesses of 1.3 mm for RR_{land} and of 1.9 mm for RR_{land} are produced in MBL2P with respect to CNTL (RR_{land} of 14.2 mm, RR_{sea} of 1.5 mm) (Table 2a)."

♣ Page 13, line 10-12

"[…] The duration of precipitation (D_{RR05} and D_{land}) is also reduced (Fig. 12c). Correspondingly, RR_{land} is reduced to between −0.5 and −0.7 mm with respect to the value of 14.2 mm in CNTL (Table 2b)."

♣ Page 14, line 26-27

"[…] Table 2b shows the reduced RR_{land} values between −0.7 and −1.5 mm in FA×P, with respect to CNTL (1.5 mm), as well as the increased RR_{sea} values between +0.6 and +1.4 mm."

We have added Figure 16 to show the temporal evolution of rainfall intensity and virtual potential temperature (ϑ_v) upstream the convection to understand better the impact of moisture in 1-2 km ASL layer (FA×M and FA×P) on the cold pool intensification. We also examine the evaporation flux near the surface.

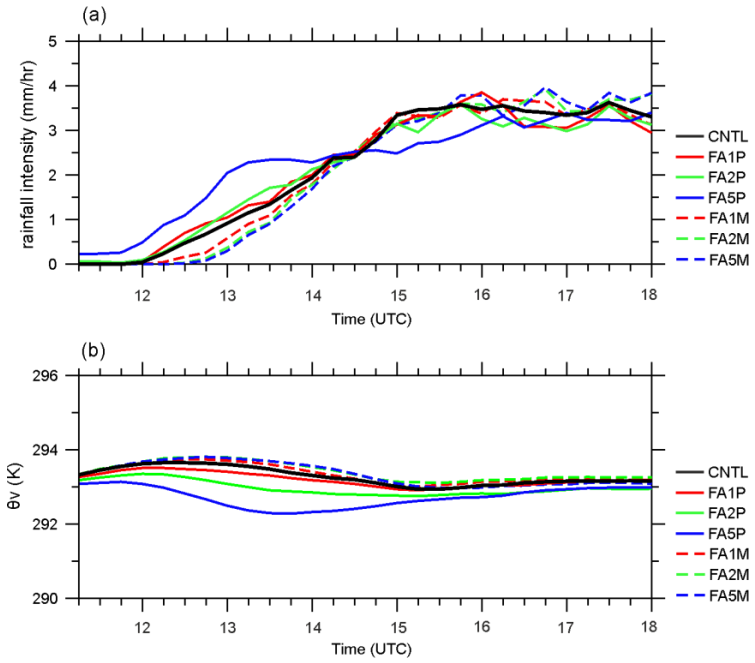

Figure 16. Temporal evolution of domain-averaged rainfall intensity (mm hr^{-1}) and virtual potential temperature (ϑ_v) at the first model level in a fixed domain of 5.5–7.5°E, 43–44.5°N, simulated by CNTL (black line), FA×P (solid lines), and FA×M (dashed lines) from 1115 to 1800 UTC on 14 October 2012.

We have add the information in result as:

♣ From Page 13, line 29

"Figure 16 shows that the rainfall intensity in FA×M simulation (dashed lines) is reduced by about 0.1–0.5 mm hr^{-1} compared to CNTL (black line) between 1200 and 1430 UTC, and the rainfall intensity ≥ 0.1 mm hr^{-1} starts about 45 min later (1300 UTC, dashed line) than in CNTL (1215 UTC, black line). Under the weakened precipitation, evaporation rate is reduced. The corresponding values of ϑ_v in the FA×M simulations are increased by about 0.2–0.5 K with respect to CNTL (dashed line, Fig. 16b). While the dried air mass in the 1-2 km layer is advected toward upstream the convection, it mixes with the moist air below, reducing the total moisture below 2 km. With the reduced moisture in the lower troposphere, the triggered convection near the Var coast produces less intensive rainfall and the weakened cold pool."

♣ Page 14, line 12-18

"In summary, decreasing the moisture content in the dry layer between 1 and 2 km ASL reduces the total amount of precipitation as well as the area affected by the precipitation and the duration of the precipitating episode. As the MABL is nearly saturated, the convection triggers easily along the coast but develops less intensively. The maximum of precipitation located along the eastern Var coast is reduced, corresponding to a weakened cold pool and weakened ascents at its southern boundary. This shows that around the coast, the dryness in the 1–2 km ASL layer is not a major ingredient for the convection development and the cold pool generation when the lowermost layer is nearly saturated."

♣ Page 15, line 15-24

"[…] Figure 16a shows the enhanced rainfall intensities (about 0.2–2.5 mm hr^{-1}) in FA×P simulations (colored solid lines) compared to CNTL (black line) between 1200 and 1430 UTC, especially FA5P produces the precipitation about 45 min earlier in time. Under the intensifying precipitation, the values of ϑ_v in FA×P simulations are about 0.2–1.7 K reduced, indicating the intensified cold pool formed by evaporative cooling than in CNTL (Fig. 16b). As the moistened air mass in the 1-2 km layer mixed with the moist air below during its advection towards the region of

upstream convection, the total moisture below 2 km ASL increased. Thanks to the moistened lower troposphere, the convection triggered near the Var coast produces more intensive rainfall and correspondingly more intense cold pool. Also the moistened air masses in the lower troposphere initiate precipitation earlier while the precipitating area, particularly over the sea, is enlarged."

In the revised version of the manuscript, we now investigate the location of convection initiation in CNTL and all the sensitivity experiments. This information has been added in the text and Figures 2b, 8, and 14, as also suggested in minor comment #26.

♣ Page 5, line 17-23
"[…] Then the convection (highlighted by reflectivity values exceeding 45 dBZ, Lee et al., 2012) initiates upstream (yellow star, Fig. 2b), about 25 km further south than observed at 1200 UTC and maximum 15-minute precipitation over 5 mm is simulated approximately 93 km from the initiation at 1230 UTC (Fig. 2b). It develops preferably towards Marseille, then around the Argens valley region and the east coastal Var region (Figs. 2b and 3a–b), similarly as observed. The intense precipitation (≥ 15 mm per 15 min, red circle in Fig. 2b) is first simulated at 1400 UTC north of Marseille (5.6°E, 43.5°N) in a location distant of about 95 km from the bubble initiation."

♣ Page 10, line 3-5
"The sensitivity bubbles of MBL experiments travels north-eastwards over the sea as in CNTL, and it keeps its ellipse shape but with a slightly reduced horizontal size due to lateral mixing with the ambient air mass during its advection."

♣ Page 10, line 10-13
"[…] The intense precipitation (≥ 15 mm per 15 min) starts 3 hour later in MBL5M than in CNTL, MBL1M, and MBL2M. The convection at 1800 UTC is located at the eastern coast of Var, as in CNTL (square in Fig. 2b) and MBL×M (square in Fig. 8a–c), and then stays 2–3 additional hours in this region."

♣ Page 12, line 2-6
"[…] In MBL×P experiments (Fig. 8d–f), precipitation is initiated over the sea at 1200 UTC, and then the bubbles travel along similar pathways over the sea as in CNTL. However the inland precipitation starts later (e.g. 15, 45, and 90 min later in MBL1P, MBL2P, and MBL5P, respectively) than in CNTL. This late onset of inland precipitation is also consistent with more widespread precipitation over the sea in MBL2P and MBL5P (Fig. 7e, f)."

♣ Page 13, line 17-20
"[…] The sensitivity bubbles of FA experiments travel north-eastward over the sea as similar as seen in CNTL and MBL, but the horizontal extent is slightly reduced by mixing with the ambient air mass during the travel. The convection initiates about 20 km offshore of the Var coast (yellow star, Fig. 14a–c)."

♣ Page 15, line 8-11
"[…] The convection initiates near the Var coast, as in CNTL, however the horizontal extent of the convective region (reflectivity ≥ 45 dBZ) is relatively large compared to CNTL. The precipitation starts at 1200 UTC about 50 km offshore the southern Var coast, when the bubble reaches this region ~140 km distant from the location of initiation […]"

In this study, the purpose of experiments with ± 1 and 2 g kg^{-1} is to understand the impact of water vapour uncertainty observed during the IOP 13 (Duffourg et al., 2018) (as described in p.8), while the purpose of experiments with ± 5 g kg^{-1} is to understand the behavior in an extreme environment. We expect that the behaviors of experiments with ± 3 g kg^{-1} would be bounded by the results with 2 and 5 g kg^{-1}. For the sake of concision, we have decided not to add a discussion in the revised manuscript on four additional experiments based on ± 3 g kg^{-1}

WVMR variations. Rather, we decided to put more emphasis on the existing 12 experiments.

We have added this information in the section 2.3. Initial conditions of sensitivity experiments (Page 8, line 14-17) as:
"In this study, experiments with ±1 and 2 g kg^{-1} were conducted to understand the impact of water vapour uncertainty in the vicinity of Balearic Island on precipitation downstream, while the experiments with ±5 g kg^{-1} are done to see such an impact in a more extreme environment."

2. From Figs. 6 and 12, it is clear that when the moisture is added (or removed) from the MBL (or 1-2 km ASL), some parameters change in a rather consistent fashion but others not (e.g., DRR15 in MST2P in Fig. 6f, or that in DRY1M in Fig. 12c). Also, some changes are easy to understand while others are trickier and not as straight forward (e.g., RRsum in MST5P in Fig. 6d), I suppose. While an understanding at the physical level is important (as stated in my major comment #1 above), before that, it is also important to clarify whether such an inconsistency is indeed a response to the change in the moisture in the model, or arises simply due to the nonlinearity of the processes. Right now, this possibility is not considered by the authors but I think they should. The authors should at least examine the trajectories in the ±5 g/kg tests to check whether the source region of the deep convection (and for the cold pool) remains the same in those runs as in CNTL (and they should also show those trajectories in the CNTL). If yes, runs an examination of what is going on physically would be more meaningful, but you would need a different interpretation if not.

We have examined the trajectories in the ±5 g kg^{-1} test. We compared the trajectories of FA5M and FA5P with CNTL because the convection activities in MBL5M and MBL5P are too weak to produce the cold pool. The horizontal and vertical projection of some of these backward trajectories for parcels at the top of the simulated convective ascent, and for parcels in the cold pool at 1600 UTC of the CNTL, FA5M, and FA5P experiments are displayed in Figure A, B, and C, respectively. In all figures, the locations of "sensitivity bubble" of the MBL experiments (previously named MST) and the FA experiments (previously named DRY) are superimposed. The comparison of three figures indicates that the origin of those air parcel affecting the convective system near the Var coast linearly comes from the area of the sensitivity bubbles. Also the initial altitude of the moisture supplying the precipitating system is below 1 km, and the initial altitude of air parcel feeding the cold pool is between 1 and 2 km.

We trust the model ability to respond to the change in the moisture of ±5 g kg^{-1}.In the few hours following the initial forcing, the model reaches an equilibrium state. In addition, the lateral boundary is forced every 3 hours to compute the rainfall system realistically.

We have added the sentence in page 8, lines 4-7 as:
"[…] Using backward trajectory analysis, we can assess that the origins of air parcels feeding the convective system and of air parcels feeding the cold pools are within the sensitivity bubbles of the FA and MBL experiments, respectively, (ellipsoids in Fig. 1) and that the trajectories do not deviate significantly from one experiment to the next, even though some differences exist."

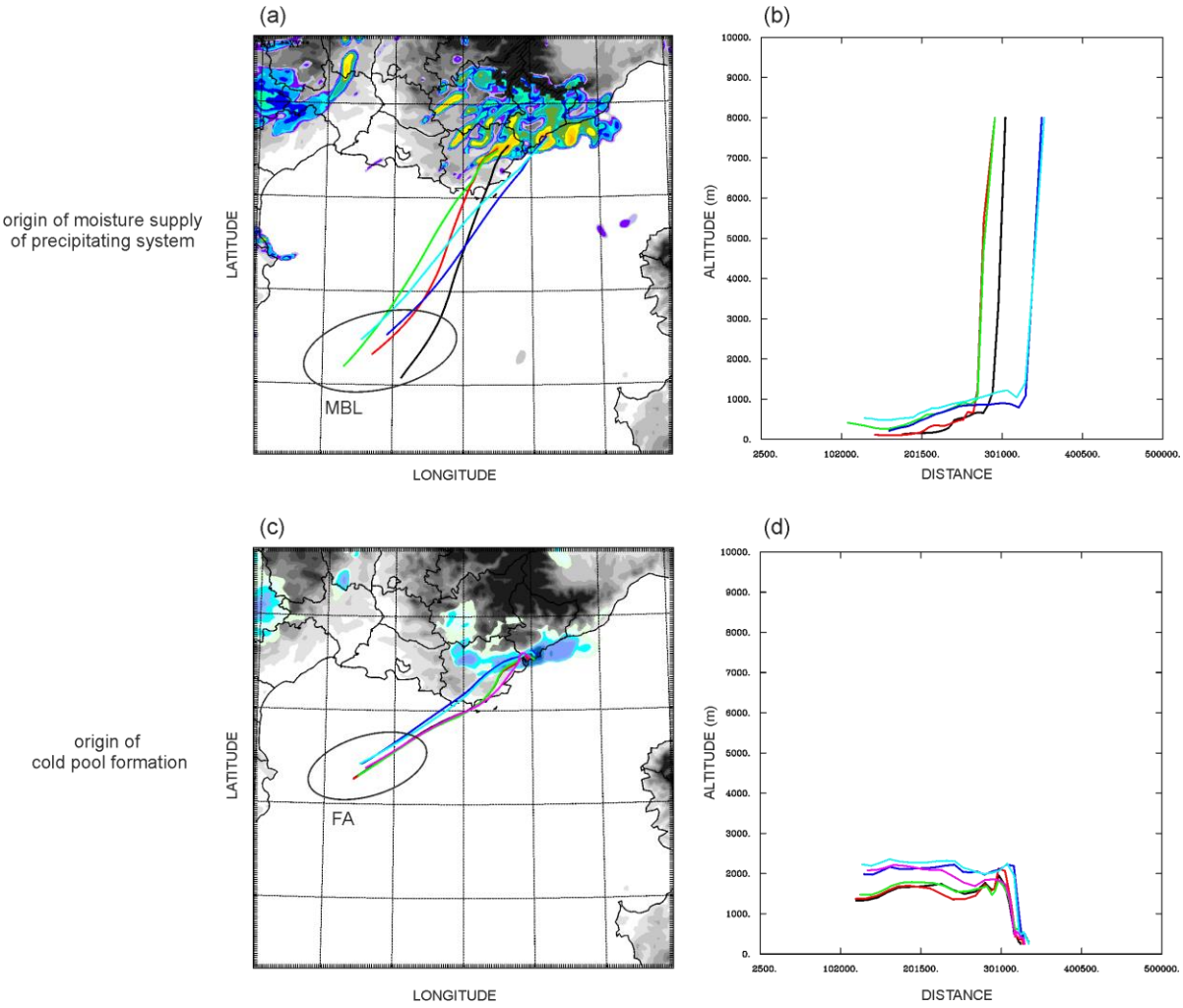

Figure A. CNTL: (a) and (b) backward trajectories of selected air parcels taken in the upper part of the convective system at 1600 UTC in horizontal and vertical projection, respectively., and (c) and (d) backward trajectories of selected air parcels taken in the cold pool at 1600 UTC in horizontal and vertical projection, respectively. The radar reflectivity at 2000 m is displayed in (a). The virtual potential temperature at the first model level is shown in (c). The location of sensitivity bubbles in the MBL and FA experiments are superimposed in (a) and (c).

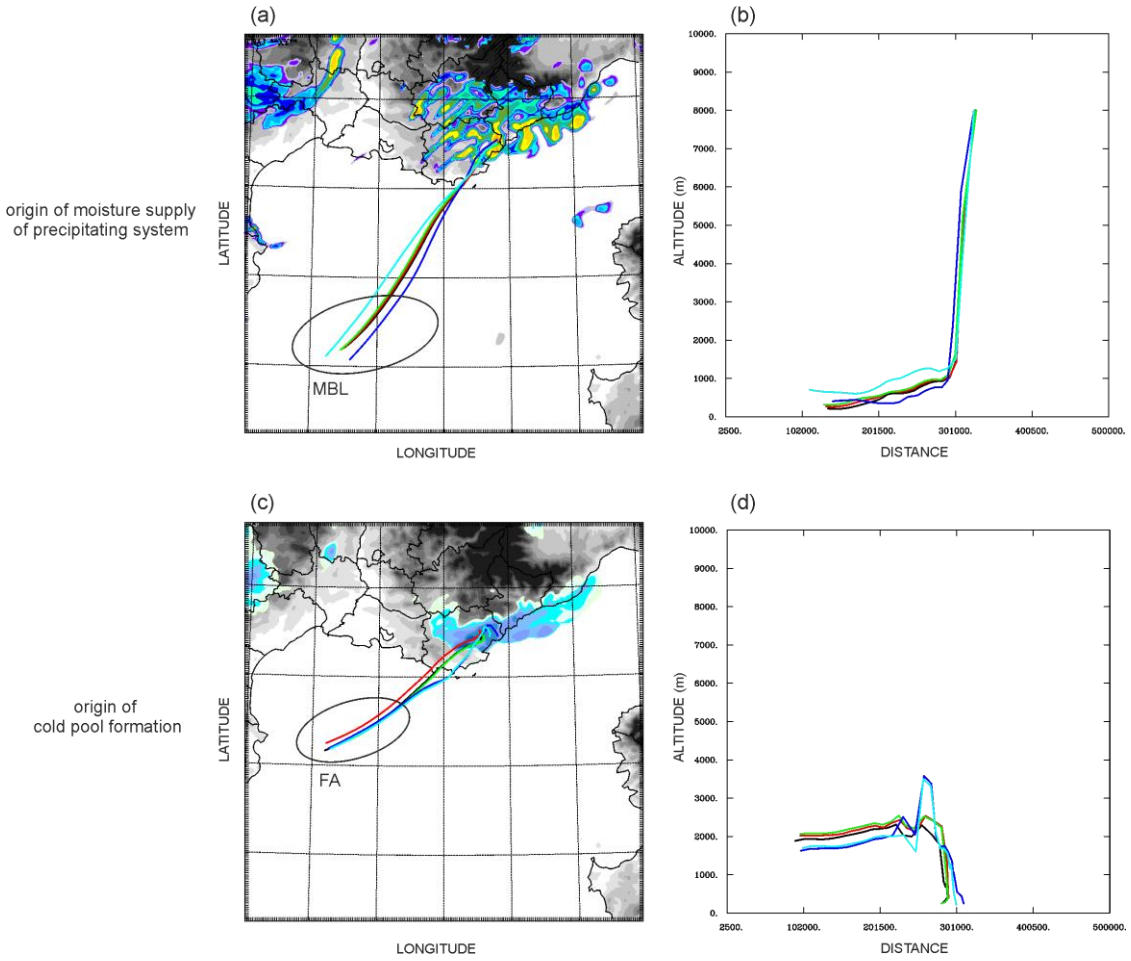

Figure B. Same as Figure A for FA5P.

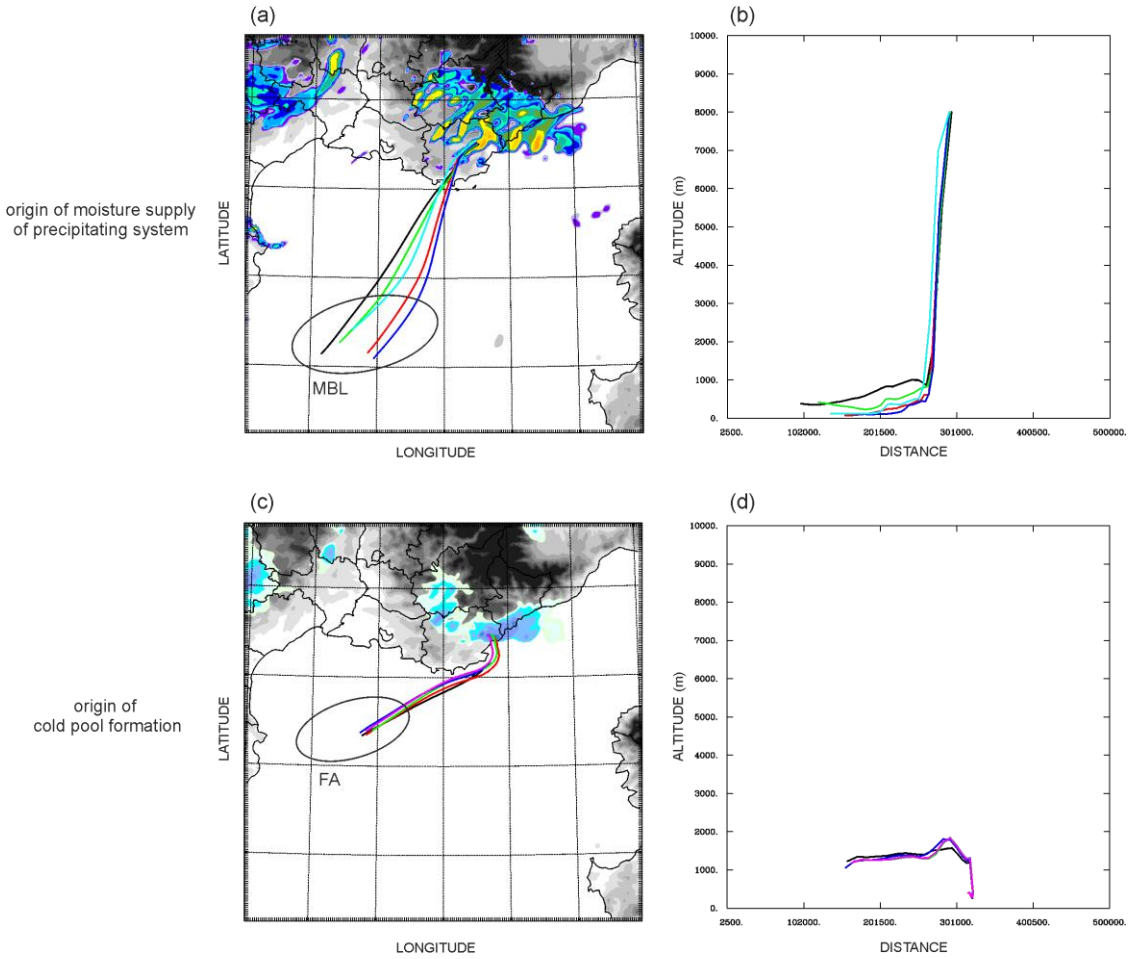

Figure C. Same as Figure A for FA5M.

3. This is related to my major comment #1 above. In the DRY×P runs, where the layer of 1-2 km ASL in the source region (for the cold pool) is moistened, the cold pool at 1500 UTC apparently enhances with more moisture (Figs. 15d-f vs Fig. 4c). The reason is not yet completely clear to me. The authors should elaborate on this too, if possible.

With the moistened air mass in the 1–2 km ASL layer, similar CAPE values (≥ 1050 J kg^{-1}) were calculated offshore of the Var coast in the FA×P experiments and in CNTL. In an environment with instability similar to that of CNTL, but with higher moisture content, the triggered convection in the FA×P experiments can produce larger precipitation than in CNTL. For this reason, the horizontal extent of the cold pool (delineated by ϑ_v < 291 K) is larger than the one seen in CNTL.

We have added the sentence from page 15, line 28 as:
"[…]With the moistened air mass in the 1–2 km ASL layer, similar CAPE values (≥ 1050 J kg^{-1}) were calculated offshore of the Var coast in the FA×P experiments and in CNTL. In the environment with similar instability but with further moistened conditions in the lower troposphere, the triggered convection further intensifies with enlarged horizontal extent of cold pool and strengthened ascents at its southern boundary."

4. The English and fluency of this paper can be improved. I recommend that some of the authors can be of more help in this aspect.

The English has been improved through careful.

Minor comments

1. P.2, ln 15-16 and other places: Unusually, the references would be given according to the year of publication.
Corrected in Page 2, line 15-16 as:

"[…] (*e.g.* Nuissier et al. 2008; Romero et al. 1999; Trapero et al. 2013a, 2013b; Barthlott and Davolio, 2015)."

2. P.2, ln 16: Is Romero et al (1999) or (2000)? It is not consistent here with the reference list. Similar issue for Ricard et al. (2011) or (2012) in ln. 20-21.
Corrected. Romero et al. (1999) and Ricard et al. (2012) are right (Page 2, line 16 and 20).

3. P.3, ln. 11: Bielli et al. (2012) is not listed at the end. Similar issue for Ricard (2005) and Seity et al. (2011).
Added. Please note that the reference to Ricard (2005) is now excluded (Page 18, line 16 and Page 22, line 27).

4. P.3, ln. 19 (also ln. 21) and many other places throughout the text: Here, a hyphen in south-eastern is not needed (just southeastern).
Corrected throughout the text.

5. P.4, ln. 4: Has the term "Meso-NH" been defined already?
The definition has been added (Page 4, line 14).

6. P.4, ln 23: A reference for RRTM should be given here.
Mlawer et al. (1997) is added now (Page 4, line 26).

7. P.5, ln. 3: The acronym "AROME" is already defined two lines above.
Corrected (Page 5, line 5).

8. P.5, ln. 22: Here, it says that the horizontal wind (u/v) is at 500 m ASL, but at 925 hPa in the caption (p.24, ln. 5). Please check and correct the wrong one.
Corrected to 925 hPa (Page 5, line 28).

9. P.6, ln 12-17: From Fig. 5, I suppose that the mixing ratio (BTW, few would use an acronym for it, just the symbol *r*) is bounded by 0 and the saturation value. While the lower bound of 0 g/kg is noted here, the upper bound is not (and should be).
Improved in Page 7, line 20-21 as:

"[…] In other words, the water vapour value at saturation with respect to liquid water was calculated at each altitude and used as an upper threshold of the modified WVMR."

10. P.7, description of Fig. 5b: The mixing ratios converge back to the observed value at 2.1 km instead of 2.0 km similar to the MST tests. It is a minor point but is there a reason for this?
This is caused by smoothing.

11. P.8, ln. 4-11: Some of these parameters are not clearly described, especially RRacc and RRsum (please also see major comment #1). I understand that RRacc is the peak 6-h accumulative amount but its name should reflect this (by comparison, RRmax would be better). For RRsum, I suppose it is an averaged amount, but for where and for what accumulation period?

RR_{acc} is the maximum of 6-hour accumulated precipitation amount. For the sake of clarity and in order to comply with the referee's comment, we have renamed it RR_{max}, as suggested. RR_{sum} is the sum of the 6-h accumulated precipitation amount within the domain bounded by 3.5−9°E and 40.5−45°N. It is a measure of the averaged total amount of produced precipitation. The unit is changed to mm (Page 8, line 18-22). The text has been modified as:

"To investigate the impact of WVMR variability on the location, intensity and duration of precipitation, we consider several indicators, such as: the maximum of the 6-hour accumulated precipitation amount (RR_{max}), the domain-averaged total sum of the 6-hour rainfall accumulation (RR_{sum}), and the RR_{sum} produced over land (RR_{land}) and over the sea (RR_{sea}) in the fixed domain bounded by 3.5−9°E and 40.5−45°N, from 1200 UTC on 14 October 2012, to understand the impact of WVMR variability on precipitation amount […]"

12. P.8, ln 12-20: Here, the authors do not need to go to such a detail and say which figure shows what later, but what will be shown (and for what purpose) should be enough.
To help guide the readers with the interpretation of the content of the section, we decided to keep these explanations.

13. P.9, ln. 1: The "x" in the experiment names (which represent 1, 2, or 5), at their first appearance in text, should be explained more clearly, if possible.
Corrected (from Page 8, line 29) as:

"[…] Figure 9 shows the temporal evolution of the maximum of CAPE in the "sensitivity bubble" every 15 min from 0930 to 1445 UTC in CNTL, MBL×M (i.e. MBL1M, MBL2M, and MBL5M), and MBL×P (i.e. MBL1P, MBL2P, and MBL5P)."

14. P.9, ln. 2: Shouldn't you use 0.67 and 0.4 for the factors here, instead of their reciprocals of 1.5 and 2.5?
Yes indeed, this is now corrected (Page 9, line 17).

15. P.9, ln. 3-4: …the time for precipitation ≥ 5 mm…
Corrected (Page 9, line 18-19).

16. P.9, ln. 20: …mountainous region close to…
For better understanding, the sentence has been simplified to "west of 6°E" by removing "mountainous region close to Marseille".

17. P.9, ln. 25-28: The description here is not clear.
Corrected in Page 10, lines 19-23, as:

"In MBL1M, MBL2M, and MBL5M, CAPE values increase gradually until 1445 UTC but remain lower than in CNTL. At 1400 UTC, the spatial distribution of CAPE values less than 1000 J kg^{-1} is highlighted offshore of the Var coast where the sensitivity bubble is located (i.e. 5.2−6°E, 42.4−43°N, dashed ellipsoid in Figure 10b) in MBL2M. It is worth noting that higher CAPE values (> 1400 J kg^{-1}) are displayed in the same region in CNTL (Figure 10a)."

18. P.9, ln. 29: Here, ϑ_e has already been defined, so why not just use it.
Corrected (Page 10, line 24).

19. P.10, ln. 4 (and other places): Please change vertical wind into vertical motion (or in this case, upward motion) for better clarify.
Corrected to vertical motion (Page 10, line 28 and Page 11, line 2).

20. P.10, ln. 5-6: The strength of cold pool and precipitation amount is a chicken and egg relationship in terms of the cause/effect, in my opinion.
Corrected (from Page 10, line 28) as:

"[…] This combination of decreased CAPE and weakened cold pool which are induced by the weakened precipitation (Figs. 7a–c) is found around the Argens valley region in particular."

21. P.10, ln. 20-23: The sentence here is not clear and should be improved.
Corrected (Page 11, line 14-17) as:

"[…] In MBL2P and MBL5P experiments, the increase of the moisture content in the MABL (0.1–1 km ASL) induces more precipitation over the sea than in CNTL. For instance, excesses of 1.3 mm for RR_{land} and of 1.9 mm for RR_{land} are produced in MBL2P with respect to CNTL (RR_{land} of 14.2 mm, RR_{sea} of 1.5 mm) (Table 2a)."

22. P.11, ln. 1-11: Some of the description here is quite repetitive.
Corrected in manuscript from Page 11, line 25 as:

"The 6-hour accumulated precipitation in MBL1P experiment displayed in Figure 7d confirms that in MBL1P, the largest accumulation on the eastern Var coast is increased (consistently with the increase of RR_{acc}, Fig. 6d) and slightly shifted offshore (consistently with the reduced D_{land}, Fig. 6f) (area enclosed by solid line, Fig. 7d). This is consistently seen in the temporal evolution of the location and amounts of the maximum of 15-min accumulated rainfall in Figure 8d which shows that this accumulation is due to a stationary system blocked over the Var coast, similarly as in CNTL."

23. P.11, ln. 23-26: This sentence needs to be revised for better clarity.
Improved in Page 12, line 21-25 as:

"The widespread and weaker precipitation over the sea seen more particularly in MBL5P is associated to a less organized precipitating system when the moisture content in the MABL is increased. The lesser degree of organization of the convective system in MBL5P is related to the absence of a cold pool (Figure 11f). CAPE values higher than 1500 J kg^{-1} lead to an increase of the degree of instability in the upstream environment (blue solid line in Figure 9)."

24. P.12, ln. 23: What does the part "a more realistic location" mean? Please clarify.
In CNTL, the overall precipitation distribution and the evolution of the target convective system occurring during IOP 13 were successfully produced by Meso-NH simulations. However, the convection is first observed over the land closer to Marseille than simulated in the CNTL run in which it is produced around the southern tip of Var coast (i.e. about 25 km from the observed convective initiation). The experiments with dry air mass in the 1-2 km ASL layer initiate precipitation over land at a more accurate location. We have clarify this information in manuscript as:

♣ Page 5, line 17-18
"[…] Then the convection (highlighted by reflectivity values exceeding 45 dBZ, Lee et al., 2012) initiates upstream (yellow star, Fig. 2b), about 25 km further south than observed at 1200 UTC […]"

♣ Page 17, line 12-13

"[…] Also it is true that dried air mass in the 1–2 km ASL initiates precipitation at a more accurate location, about 25 km closer to Marseille."

25. P.13, ln. 3-5: Can the authors elaborate on the reason why? Perhaps, it is related to the entrainment process (please see my major comment #1). Also, the authors use the term "bubble" too much, and it can be confusing.
The CAPE values in both CNTL and FA×M experiments (previously named DRY×M but modified to comply with Referee's #1 comments) slightly increased over time in the location of the sensitivity area as it mixed with the adjacent moister air (Page 10, line 3-5). For better understanding, we have decided to use the term of "sensitivity bubble" constantly throughout the text.

26. The authors may want to consider some plots showing the location of first convection initiation in different runs, if they can help to shed more light.
The location of first convection initiation is marked by a yellow star for the CNTL and all the sensitivity experiments in Figures 2b, 8, and 14.

27. P.15, ln. 24-27: Here, I suppose that the authors should broaden their scope and not focus on another single event.
Corrected (from Page 17, line 28) as:

"[…] By accumulating the event scale analysis in other regions of the Mediterranean basin, we can expand our knowledge what is the general impact of upstream water vapour on precipitation (e.g. categories of synoptic conditions). Another approach is to use stable water isotopologue data to disentangle the various moisture sources, i.e. evaporation over the sea, advected moisture upstream of the HPEs in the Mediterranean (Sodemann et al., 2017)."

28. P.23, Fig. 2b and other similar plots: The last point should be also labelled for better clarify, if possible. Also, if the color shades for topography can be lightened (since you already have Fig. 1), that may also help.
As suggested, the last point is marked by a square pointed by an arrow in Figures 2b, 8, and 14. As the precipitation develops over the topography, we have decided to keep the topography scale as it is to highlight this link.

29. P.26, caption of Fig. 6: The description here for RR_{acc} and RR_{sum} is not the same as that in the text (and not clear either). Please also see major comment #1 and minor comment #11.
Corrected as explained in minor comment #11.

30. P.27, Fig. 7: What are those ellipses in the panels (also in many other figures)? I suppose that they depict the area of interests, but they are never explained in the caption of any figures.
Corrected (Figures 7 and 13) as in following page:

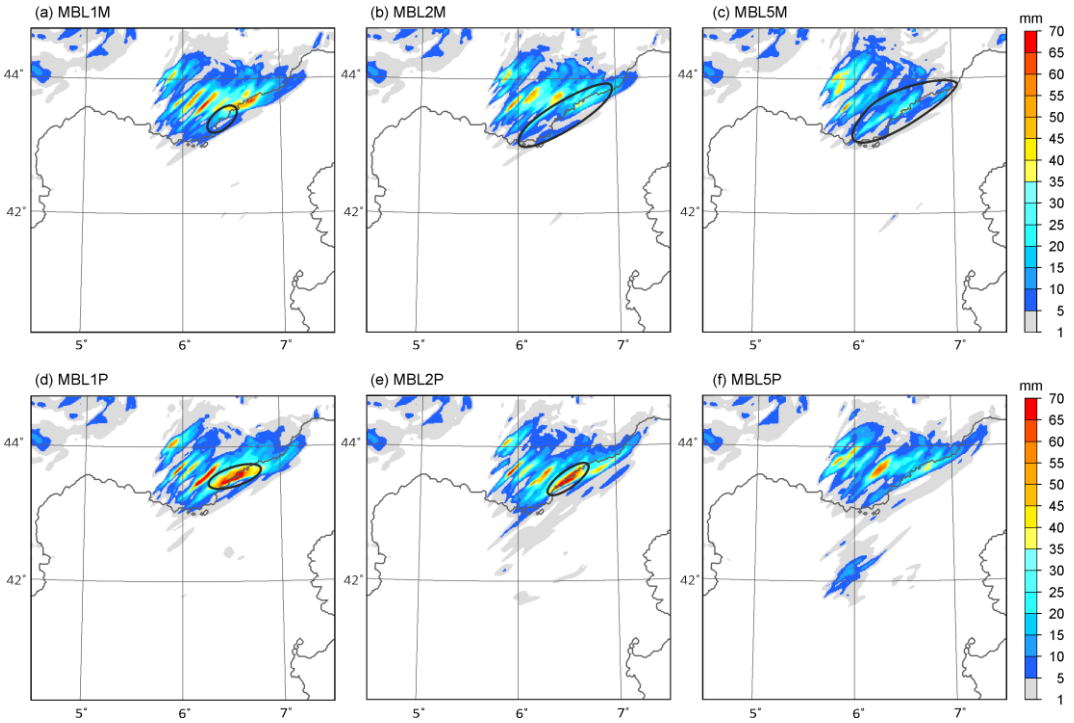

Figure 7. Distribution of the 6-hour accumulated precipitation simulated by (a) MBL1M, (b) MBL2M, (c) MBL5M, (d) MBL1P, (e) MBL2P, and (f) MBL5P at 18 UTC on 14 October 2012. Black contour line shows the coast of southern France. The ellipsoid in (a)–(c) indicates the area with less precipitation than CNTL, while the ellipsoid in (d)–(e) shows the shifted precipitation area.

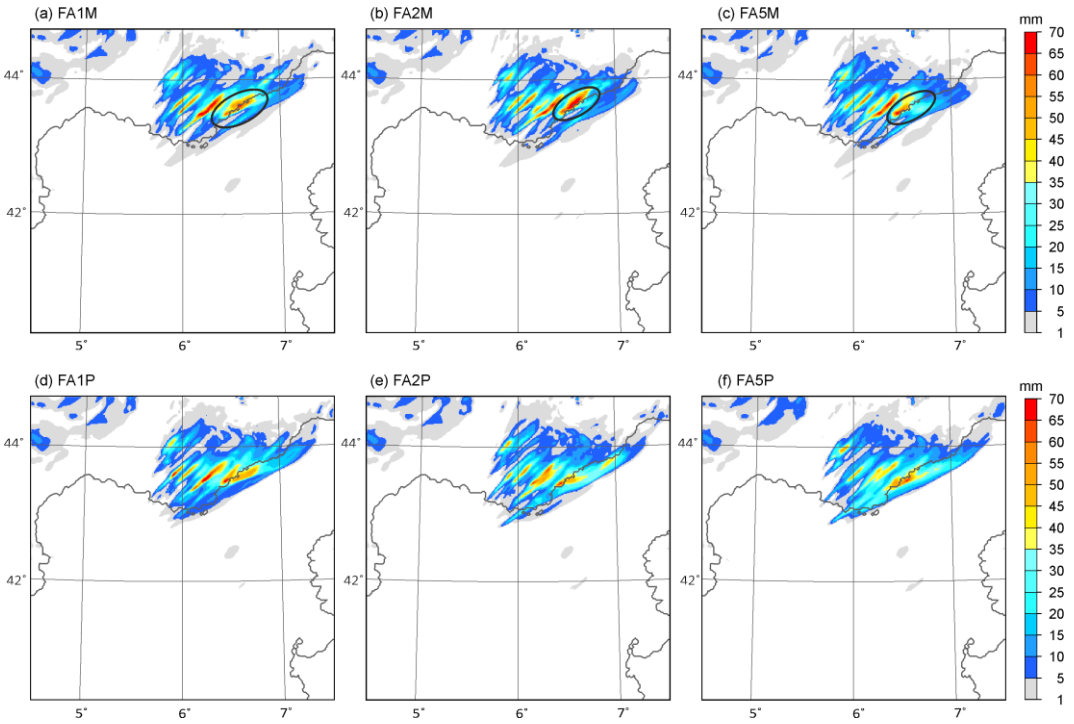

Figure 13. Same as Figure 7 for (a) FA1M, (b) FA2M, (c) FA5M, (d) FA1P, (e) FA2P, and (f) FA5P. In (a)–(c), the reduced precipitation around the coast is indicated by an ellipsoid closed with solid line.

31. P.28, Fig. 9: The y-axis is missing a title. And, is the CAPE calculated for surface parcels (same for Fig. 10)? Please clarify. Also, sensitivity area is better than sensitivity bubble…

As suggested, Figure 9 has been corrected. For better understanding, we now use the term of "sensitivity bubble" throughout the text as explained above.

We have added the information in manuscript in Page 10, line 15-16 as:
"[…] Figure 9 shows the domain-averaged CAPE values (using a rising air parcel having its initial height about 20 m) within the sensitivity bubble upstream of the precipitation area in CNTL […]"

For the sake of the readability, the Figure 9 has been improved with coloured lines as Figure 16.

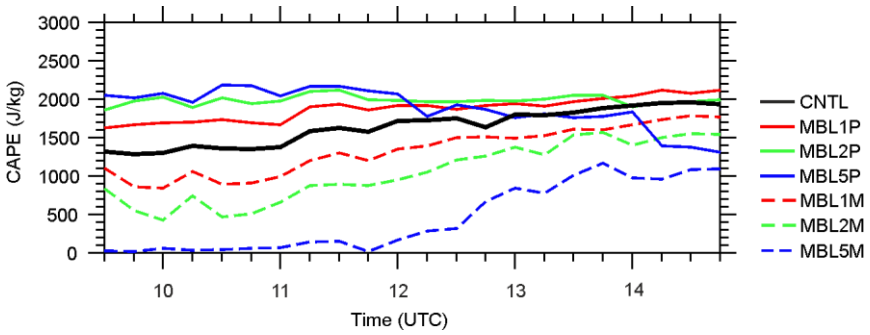

Figure 9. Temporal evolution of CAPE in the sensitivity bubble simulated in CNTL (black line), MBL×P (solid lines), and MBL×M (dashed line) from 0930 to 1445 UTC on 14 October 2012.