Manuscript amtd-8-9241-2015 "Multi-sensor analysis of convective activity in Central Italy during the HyMeX SOP 1.1"
By N. Roberto et al.

Reply to Reviewer #3 comments

The authors are grateful to the Reviewer#3 for having analyzed in depth our manuscript. Reviewer's work has resulted in numerous valuable comments that we have appreciated for being helpful to improve our manuscript. In the following paragraphs, we reply item-by-item to the Reviewer's comments enumerated and copied in blue color.

Major issues:

1 **Comment:**
Parameters used in the T-matrix simulations, section 3.1.1: The authors mention that for spheroidal shapes axis ratios vary between 0.9 and 1 but no reference is cited (page 9, lines 13-14). Some parameters described in this section and in table 1 are known for being a function of size as is the case of the axis ratio (ex.: Ryzhkov et al, 2011) and particle oscillations (ex.: List and Schemenauer, 1971). The authors should discuss why they chose a random variation of these quantities, and the impact of this choice in the simulated parameters. The intervals chosen for D0 and N0 should be discussed or backed up by a reference. The reference cited for the ranges of axis ratios in the case of conical graupel doesn't mention graupel anywhere.

Roland List and Robert S. Schemenauer, 1971: Free-Fall Behavior of Planar Snow Crystals, Conical Graupel and Small Hail.Â ˘aJ. Atmos. Sci.,Â ˘a28, 110–115.

A. Ryzhkov, M. Pinsky, A. Pokrovsky, and A. Khain, 2011: Polarimetric Radar Observation Operator for a Cloud Model with Spectral Microphysics.J. Appl. Meteor. Climatol.,Â ˘a50, 873–894.

Reply
We are grateful to the Reviewer for having highlighted some lacks in our references as far as electromagnetic simulations of graupel are concerned. About the variability of the input parameters of T-matrix simulation, the goal of our choice was to create a high variability in the population of samples in order to include the heterogeneous characteristics of the different types of graupel. This procedure was followed in the past to derive rain algorithms with synthetic DSD datasets. We started our study by simulating two different sets of graupel (namely low-density graupel and high-density graupel) defining, for each set, proper input parameters such as size, density and fall behavior. Analyzing the results obtained, we noticed that there were no substantial differences in terms of C-band radar measurements, or, at least, differences that a HCA can discriminate (a major goal of graupel simulations was to tune the MBFs of the HCA). Therefore, we choose to use a wide, single set to take into account the different types of graupel including low-density graupel to small hail. The wide ranges from which microphysical parameters are randomly chosen take into account mechanisms that involved graupel formation and accretion during cloud development. Actually, literature reports both classifiers with graupel indistinguishable from small and dense ice hydrometeors, such as small hail (Straka et al., 2000), and other classifiers considering two classes

of graupel, with low and high density, respectively (Dolan et al., 2009). However, based on results of our C-band simulations, we decided to use a single class of graupel that includes small hail.
Concerning the choice of N_0 and D_0, Chandrasekar et al. (2003) and Dolan and Rutledge (2009) are the references that justify our choice in exponential PSD and N_0 and D_0 intervals.
Regarding the last point of the Reviewer's comment, we are sorry for the wrong citation in relation to the ranges of axis ratios in the case of conical graupel. The right citation is Heymsfield (1978).

Action

This sentence will be inserted at page 8 line 20 "*All these quantities were set to be randomly varied in the interval defined in order to obtain a high variability of samples to include heterogeneous characteristics of different types of graupel*."
We will include the following corrections in the revised manuscript.

- page 9, lines 13-14 in relation to spherical axis ratio we will add the following citations: Prupaccher and Klett 1978 (p.343-346); Aydin and Seliga, 1984; Straka et al. 2000, Bringi et al. 1986.
- The citation Heymsfield (1972) will be removed and substituted with Heymsfield (1978).
- The citations Chandrasekar et al. (2003) and Dolan and Rutledge (2009) will be inserted in the revised manuscript at page 8 line 13.

2 **Comment:**

Deriving a relation for graupel IWC, section 3.1.3: The derivation of relation (2) needs to be clarified. The authors should describe in detail how this was done. Was this done by finding the best fit through the points? I suggest showing a figure to illustrate.

Reply

This comment is similar to the comment 4 of Reviewer #1. The reply to his comment discusses how the coefficients "a" e "b" were derived, i.e. from non-linear regression applied to the T-matrix simulations of the IWC for graupel and the radar reflectivity factor for the two shapes of graupel (conical and spheroidal) as listed in Table 1. In order to clarify this process, the outputs of T-matrix simulations are shown as scatter plots between IWC_g and Z_h for the two shapes of graupel (Figure II in the reply to the Reviewer E. Ruzanski, http://www.atmos-meas-tech-discuss.net/8/C3631/2015/amtd-8-C3631-2015-supplement.pdf). The scatter plots were fitted with power laws (Eq 2) and the coefficients "a" e "b" are provided in the manuscript (lines 22-23 page 10).

Action

In the revised manuscript we will add a new figure showing the two scatter plots IWC-Z_h. This figure will be labeled as Figure 2 and the other figures will be renumbered accordingly.

3 **Comment:**

The problem of TAG at great distances from the radar: This problem could be minimized if instead of using the TAG the authors used average ice water path (columnar) for graupel or just average IWCg. Even for atmospheric charging purposes, the same amount of graupel mass should have different effects if the graupel is very concentrated in a small volume or if it is more widespread.

Reply

TAG is obtained integrating in radar polar coordinates all the columnar IWC_g (in the units of mass per unit area), i.e. by summing all the columnar IWC_gs , each one multiplied by the area of the base of each column in order to account for radar beam broadening. Using the average of columnar IWC_g would not mitigate the effects of radar observation geometry mentioned in the manuscript

(page 18 lines 7-16). In fact, reflectivity measurements used to estimate IWC_g results from the power backscattered by the hydrometeors in the radar sample volume that becomes greater as distance from radar increases. If the space filled with graupel becomes smaller than the radar resolution volume, the peak of IWC_g will be underestimated. However, in order to follow the reviewer suggestion, we have calculated the columnar IWCg (computed every 5 min) dividing the TAG by the mean total area covered by graupel (in km^2). This quantity was related to the flash number density (number of flashes/km^2 registered in 5 min) and the result is shown in *Figure I* below. The LINET strokes were grouped into flashes following the methodology of Yair et al (2014) (see Answer to Reviewer #2). In *Figure I* the minimum threshold linear function found by Formenton et al (2013) (black dashed line) and the linear function found by Petersen et al (2005) over land (green dashed line) are also plotted. The data of the 15 October case (and their best fit) are in agreement with the Petersen et al. (2005) linear relation and are (for the most part) above the threshold found by Formenton et al (2013).

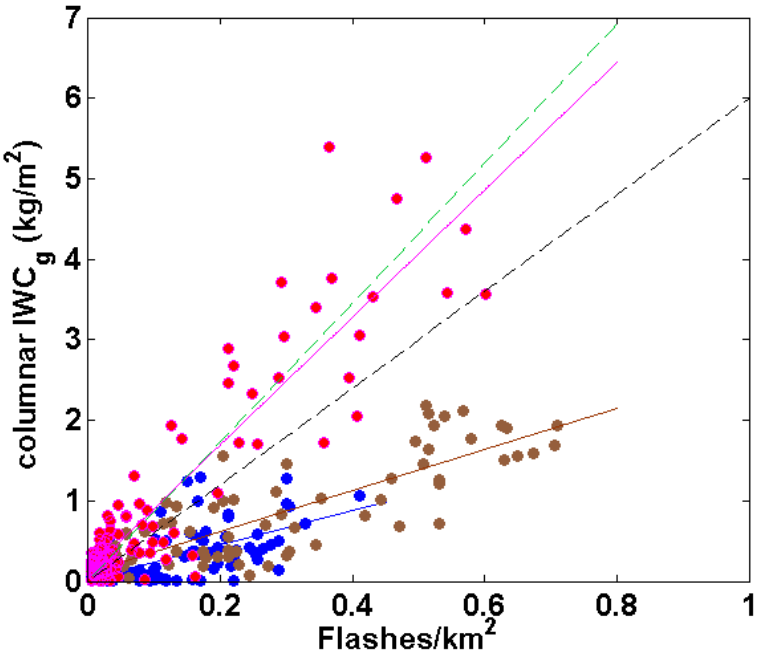

Figure I Flash density versus columnar IWC for the three case studies: 13 September 2012 (blue), 12 October 2012 (brown) and 15 October 2012 (magenta). Black dashed line is the threshold found by Formenton et al (2013) and green dashed line is the linear relation found by Petereson et al (2005) over land.

Action

In the revised manuscript the text on the top of page 12 explaining the computation of TAG will be changed into: "*by summing all the columnar IWC_gs , each one multiplied by the area of the base of each column*". We have decided to modify the Figure 7 (of the original manuscript) following the suggestion from Reviever #2 (*Figure II* in the reply to Reviewer #2). Furthermore we are considering to replace TAG with columnar IWC_g and number of flashes with flash number density (flashes/km^2) as shown in *Figure I*.

Minor issues

1 **Comment**

The terminology generally used for "columnar IWCg" is graupel ice water path, consider changing this, check for all occurrences. The terminology TAG, referring to the total amount of graupel in mass, needs do be consistent. For example Figures 7 and 8 are labeled "Total amount of IWCg" both in the vertical axis and in the figure legend.

Reply

We found that both terms in the literature to express the same physical quantity. *Graupel ice water path* implicitly assumes a propagation path that includes a graupel-filled medium. Therefore, it is more popular for satellite measurements that use quasi-vertical observations. In the case of scanning ground-based radar, the term "path" could be misleading, since propagation paths are typically quasi-horizontal. Other works making use of radar measurements prefer the term *Vertical Integrate Ice* (VII; Moiser et al., 2011). We have preferred *columnar* IWC_g because it expresses the concept of vertical integrated quantity although obtained from measurements collected using the typical weather radar observation geometry, i.e., using quasi-horizontal elevation angles.

Action

In the revised manuscript, labels of Figure 7 and 8 will be substituted with "TAG".

2 **Comment**

Abstract, page 2, line 16: "Parameters of the gamma raindrop size distribution (...) and where related." This sentence is not clear, what do the authors mean by "where related"?.

Reply

We agree. The sentence is not clear.

Action

In the revised manuscript, the sentence will be rewritten as: "*Parameters of the gamma raindrop size distribution measured by a 2D video disdrometer revealed the transition from convective to stratiform regime during the event.*"

3 **Comment**

Section 1, page 6 line 2: "can be found in" instead of "can be founded in".

Reply

Agreed

Action

The revised manuscript will be corrected accordingly.

4 **Comment**

section 3.1, page 7, line 21: "sensitive to cloud properties", should be changed to "precipitation properties". At the wavelengths considered the radar cannot see cloud particles. Check for more occurrences throughout the paper.

Reply

Agreed

Action

The revised manuscript will be corrected accordingly.

5 **Comment**

Page 9, line 17: "While Zdr was between 0 and 1 for spheroidal shapes, and it covered ...", substitute with: "While Zdr was between 0 and 1 for spheroidal shapes, it covered ...".

Reply

Agreed

Action

The revised manuscript will be corrected accordingly.

6 **Comment**

section 3.1.4, page 11, line 10: LIRE acronym?

Reply

LIRE is not an acronym. It is the ICAO code of the Pratica di Mare airport, 20 km south of Rome, where radio soundings are routinely collected. This will be specified in the revised manuscript.

Action

In the revised manuscript the sentence at line 3 page 10 will be modified as follows: "*The height of the top of ML is considered to be the 0°C level from vertical temperature soundings collected at the nearby (20 km south of Rome) Pratica di Mare airport (which ICAO code is LIRE and where radio soundings are routinely collected).*"

7 **Comment**

Section 3.2, page 12, lines 25-27: Insert reference here. It is only mentioned much later in the legend of figure 9. Also, be consistent, both equations are slightly different. Assign a number to the equation so it can be referred to later (section 5.2).

Reply

The reference related to lines 25-27 page 12 is Bringi el al. (2009) that is cited at line 15 of the same page and also reported in the caption of Figure 9 in order to identify that methodology of classification.

We agree with your suggestion to assign a number to that equation.

Action

In the revised manuscript the equation number (Eq.3) will be assign to equation at line 27 page 12.

8 **Comment**

Section 4, page 13, line 14: Substitute "described in details" with "describe in detail".

Reply

Agreed

Action

The revised manuscript will be corrected accordingly.

9 **Comment**

Section 4.1, page 14, line 4: Suggest substituting "At 20:00 UTC at 80 km South the Polar 55C..." with "At 2000UTC, 80 km to the South of the Polar 55C..." UTC times do not usually have ":". Check for other occurrences.

Reply

The use of the format "hh:mm " for the UTC time is standard for AMT.

10 **Comment**

Section 4.2, page 14, lines 26-27 Replace "... was located southwesterly respect to the radar" with "... was located southwesterly with respect to the radar".

Reply

Agreed

Action

The revised manuscript will be corrected accordingly.

11 **Comment**

Section 4.2, pages 14 (line 27) and page 15 (line1): Consider rephrasing this sentence, it is not clear what you mean by "(that was the third of the event)".

Reply

Agreed

Action

In the revised manuscript the sentence "(that was the third of the event)" will be removed because is not necessary for the comprehension of the case study.

12 **Comment**

Section 4.3, page 15, line 25: "costly co-located", do you mean: "closely colocated"?

Reply

Agreed

Action

The revised manuscript will be corrected accordingly.

13 **Comment**

Section 5.1, page 16, line 8: It is mentioned the RHI at 17:55UTC (delete ":"), should include the date of the event too.

Reply

Agreed

Action

The revised manuscript will be corrected accordingly.

14 **Comment**

Section 5.1, page 16, line 10: Substitute "... and hydrometeor classes..." with "...and the hydrometeor classes...".

Reply

Agreed

Action

The revised manuscript will be corrected accordingly.

15 **Comment**

Section 5.1, page 17, line 23: Typo: "higer" is spelled "higher".

Reply

Right.

Action
The revised manuscript will be corrected accordingly.

16 **Comment**
Section 5.1, page 17, line 27: Replace "...around the 70%" with "... around 70 %".
Reply
Agreed
Action
The revised manuscript will be corrected accordingly.

17 **Comment**
Section 5.1, page 17, line 28: Formenton et al. (2014) is incorrect, should be Formenton et al. (2013).
Reply
Agreed
Action
In the revised manuscript, Formenton et al. (2013) will be shortened as FO13.

18 **Comment**
Section 5.1, page 18, line 1 typo in "estension"
Reply
Right.
Action
The revised manuscript will be corrected accordingly.

19 **Comment**
Section 5.1, page 18, line 10 suggestion of replacing "farther 80km" with "farther than 80 km".
Reply
Right.
Action
The revised manuscript will be corrected accordingly.

20 **Comment**
Section 5.1, page 18, line 23-14 replace "In order to quantify this reducing" with "In order to quantify this reduction"
Reply
Right.
Action
The revised manuscript will be corrected accordingly.

21 **Comment**
Section 5.1, page 18, line 26 suggest replacing "... for a height of 3.9km respect to 2.9km..." with "... for a height of 3.9km with respect to 2.9km..."
Reply
Right.

Action
The revised manuscript will be corrected accordingly.

22 **Comment**
Section 5.1, page 18, line 28-29 suggest replacing "Concerning the causes (ii)" with "Concerning cause (ii)"
Reply
Right.
Action
The revised manuscript will be corrected accordingly.

23 **Comment**
Section 5.1, page 19, line 25 replace "...the rather good linear fit provide a quantitative means..." with "...the rather good linear fit provide quantitative means..."
Reply
Right.
Action
The revised manuscript will be corrected accordingly.

24 **Comment**
Section 5.1, page 19, line 26 consider replacing "...based upon the cloud ice mass due to graupel..." with "... .based upon graupel ice mass..."
Reply
Agreed.
Action
The revised manuscript will be corrected accordingly.

25 **Comment**
Section 5.1, page 19, line 29 replace "conditions respect to the radar geometry" with "conditions with respect to the radar geometry"
Reply
Agreed.
Action
The revised manuscript will be corrected accordingly.

26 **Comment**
Section 5.1, page 20, line 28 You mention a threshold on the graupel amount here, and say it is confirmed by the radar observations, but you never mention a threshold while describing the results. Please discuss and show how your observations confirm this.
Reply
The threshold is the one obtained by Formenton et al. (2013) and showed in dashed black line in Figure 7. Since the sentence in line 27-28 page 20 "*the modelling results of Formenton et al. (2013) , in which there exists a minimum threshold of columnar IWC required to produce lightning and this threshold increases with the enhancement of electrical activity, is confirmed by radar*

observations of 15 October." does not make sense (as also reported by Reviewer #2) will be changed.

Action

The sentence will be modified in "*The relation between the mass of graupel and number of strokes found using radar observations are in agreements with other results (Petersen et al, 2005; Lopez and Aubagnac, 1997). Moreover, for the October 15 case study the linear relation found grouping strokes into flashes is in agreement with the model results obtained by Formenton et al. (2013).* "

27 **Comment**

Section 5.2, page 21, line 4 delete double RSDs

Reply

Right.

Action

The revised manuscript will be corrected accordingly.

28 **Comment**

Section 5.2, page 21, line 14 Correct "It worth noting" with "It is worth noting"

Reply

Right.

Action

The revised manuscript will be corrected accordingly.

29 **Comment**

Section 5.2, page 21, lines 17-18 Consider revising last sentence. Suggestion: "Results confirm that the radar classification of convective vs stratiform from Baldini and Gorgucci (2006) is in fairly good agreement with the C/S threshold from Z-Zdr (number of the equation in section 3.2)".

Reply

Agreed.

Action

In the revised manuscript that sentence will be rewritten accordingly.

30 **Comment**

Section 5.2, page 22, line 24 "different phases of precipitation" (not cloud).

Reply

Agreed.

Action

The revised manuscript will be corrected accordingly.

31 **Comment**

Section 5.2, pages 22-23 Suggest including these scores POD, ETS and FAR in table 6, to make it clearer to the reader.

Reply

Agreed.

Action

In the revised manuscript statistical scores will be included in table 6.

32 **Comment**

Section 6, page 23, line 6 replace “Convective event occurred...” with “Convective events that occurred...”

Reply

Agreed.

Action

The revised manuscript will be corrected accordingly.

33 **Comment**

Section 6, page 23, line 25 Suggest replacing “Among three important case studies were selected...” with “Among the three important case studies that were selected...”

Reply

This part will be changed following also suggestions from Reviewer#1

34 **Comment**

Section 6, page 24, line 6 replace “more farther than 80 km” with “further than 80 km”, then delete “also”.

Reply

Agreed.

Action

The revised manuscript will be corrected accordingly.

35 **Comment**

Section 6, page 24, line 7 suggest changing “While the flux hypothesis suggest that there were differences in the updraft...” with “ Moreover, the flux hypothesis from (reference) suggest that there might be differences in the updraft...”

Reply

This part will be changed following also suggestions from Reviewer#1.

36 **Comment**

Section 6, page 24, line 18-19 Suggest deleting the times here.

Reply

Agreed.

Action

The revised manuscript will be corrected accordingly.

37 **Comment**

Table 4, page 34 Legend says Figure 9, but should be related to figure 7. Also, misspelling of “obtained” twice in this legend.

Reply

Right.

Action

The revised manuscript will be corrected accordingly.

38 **Comment**

Figure 7, page 43 Formenton et al. (2013) (not 2014) This threshold should be discussed in the text together with the discussion of this image.

Reply

The threshold will be discussed following the changes suggested by Reviewer #2.

Action

The comment about the threshold will be modified in the revised manuscript, both in the text and in the caption of Figure 7.

39 **Comment**

Figure 9, page 45 In the image, transition is misspelled. The transition points were never defined at this point. Please do so in the text, alongside with the discussion of this figure.

Reply

Agreed. "Transition" class is referred to Bringi el al. (2009) classification.

Action

The follow sentence will be insert in section 3.2 at line 15 page 9252.

"In this study, the technique of Bringi et al. (2009) which classified rain minutes in convective, stratiform and transition, was reformulated to apply it to both radar measurements and disdrometer data."

References

Heymsfield A. J.: The characteristics of graupel particles in northeastern Colorado cumulus congestus clouds. J. Atmos. Sci., 35, 284–295, 1978.

Chandrasekar, V., Fukatsu ,H., and Mubarak, K. :Global mapping of attenuation at Ku- and Ka-band," IEEE Transactions on Geoscience and Remote Sensing ,vol. 41, pp. 2166 – 2176, 2003.

Bringi, V.N., Rasmussen, R.M. and Vivekanandan, J.: Multiparameter radar measurements in Colorado convective storms. Part I. Graupel melting studies. J. Atmos. Sci., **43**, 2545-2563, 1986.

Mosier, R. M., Schumacher, C., Orville, R. E., and Carey., L. D: Radar nowcasting of cloud-to-ground lightning over Houston, Texas. Wea. Forecasting, 26, 199–212, 2011: