# Responses to referee 1

p. 1809/1810: I miss a general introduction about the various ways to derive precipitation with radars: e.g. Z-R relation, attenuation bases, via the Doppler spectrum, polarimetric, etc…

*As per referee's suggestion, we have added a paragraph on deriving precipitation from different techniques in the introduction section (Line 67 onwards)*

p. 1809/1810: Your introduction deals mainly with the MMCR, but the study is about the KAZR.

*Now we have revised the paragraph with a main focus on KAZR system (Line 109 onwards). Though we have applied this technique to KAZR systems, the future scope is to extend this analysis to the long-term MMCR observations where precipitation mode data is available. To consider the future scope into perspective, we have retained a brief introduction on MMCRs.*

p. 1810, l. 5: "Many phenomena" is to vague

*We agree with the referee. We have removed this sentence based on a suggestion from other referee.*

p. 1810, l. 12: In section 3.2.2 you say the dynamic range of the KAZR is better than the MMCR. Consequently, how can you apply the product to the MMCR?

*Though the MMCR general mode has lower dynamic range, MMCR systems operate in precipitation mode has comparable dynamic range to that of KAZR systems. In*

*principle, the proposed algorithm can be implemented to long-term MMCR precipitation mode. We have added these details into the revised version (Line 118).*

This sounds like just the acronym was replaced, but its a new instrument,
where is the introduction of the KAZR?

*We have added an introduction on KAZR systems (Line 106 onwards).*

p. 1811: What about describing your main instrument first, then the others? i.e. switch 2.1 and 2.2

*As per referee's suggestion, we have switched sections 2.1 and 2.2.*

p. 1816, l. 26: So your method works only if there is a co-located S-band? This is an important drawback you have to point out more clearly. Why should I use your method and not the S-Band data directly?

*S-band data is used here to identify the relative magnitudes of reflectivity change due to attenuation versus the change in reflectivity from microphysics. This identification is needed especially for rain rates (between 1-4 mm/h), where there is a transitional shift from effects due to evaporation versus attenuation. Out of total profiles (734) considered for retrieving precipitation using attenuation based (A-R) technique, 16 % (118) of the data are eliminated due to microphysical effects, which contributes (< 10 %) to the total rain amount. Hence, the dependence of Ka-band rain retrieval on S-Band radar is only for a short rain rate window,*

*For example, recent studies have shown that the retrieval of diabatic heating profiles (which requires rain-rate and convective-stratiform fraction) is sensitive to the convective-stratiform rain classification. The way in which the stratiform-convective regimes are defined from scanning (S-Pol) radars are different from the profiling (Ka-band vertically pointing) radars, and there hasn't been any independent consistency*

*check to examine the representativeness of the S-band retrievals. Ka-band profiling radar, with its high vertical resolution and unique ability to detect bright band (classical signature of stratiform rain) could be used as a consistency check to validate retrievals from other radars.*
*Similar to tuning the Z-R parameters from S-band for particular rain fall regime and geography, here also tuning and reference rainfall data is needed in order to apply the present technique to other locations and slightly different systems (KAZR versus MMCR precipitation mode).*

p. 1817, l. 1: What percentage of your dataset is affected by this?

*The microphysical effects accounts for ~16 % (118) of the total points considered for retrieving rain fall rates based on A-R technique.*

# Responses to referee 2

1. Page 1808, Abstract. Please introduce the term ARM when used - the abstract should be self contained.

   As per referee's suggestion, the abbreviation is included into the abstract (Line 29).

2. Page 1808, lines 9-13. The proposed... is implemented. Please check and correct the last part of the sentence.

   The sentence is rephrased in the revised version as per referee's remarks (Line 34).

3. Page 1809. Mather and Voyles 2012: is it 2013? Otherwise not found in ref section. 4. Page 1809, line 3. extreme rare -> extremely rare 5. Page 1809, line 18. Moran et al: not found in ref section 6. Page 1809, line 18. Kollias et al 2007a: not found in ref section. 2007?

   The references are revised as per referee's suggestion.

7. Page 1810, line 8. Typo: ka -> Ka

It is updated in the revised version of the manuscript.

8. Page 1810. As mentioned above, Mather and Voyles 2012: is it 2013? Otherwise not found in ref section.

Yes, The year for the reference is 2013. It is updated in the revised section.

9. Page 1810, last parag. The change of acronym KAZR instead of MMCR is rather odd and confusing as they refer to different instruments. Please look for an alternative way of introducing this.

As per referee's suggestion, we have added a new paragraph on KAZR.

10. Page 1811, line 13. Keeler et al: not found in ref section.

The reference (Keeler et al) is updated in the ref. section.

11. Page 1811, line 21. Feng et al 2013: not found in ref section. 2014? Please check.

We have updated the ref. section (Feng. et al., 2014).

12. Page 1811, line 25. Typo: offers -> offer (radars is plural)

It is corrected now

13. Page 1812, line 4. precipitation. (KAZR -> precipitation. KAZR [remove "("]

It is corrected now

14. Page 1812, line 9. Suggest: non-significant (non-hydrometeors) -> non-significant (non-hydrometeors) echoes

The referee's suggestions are incorporated in the revised version.

15. Page 1812, line 16 (if I understand correctly, please check and correct otherwise) episodes are seen -> episodes as seen

It is corrected now.

16. Page 1812, line 22. Typo: a automated -> an automated

It is corrected now

17. Page 1813, 2nd sentence. Please rewrite (missing verb).

18. Page 1813, after Eq.1. Ar and Ac are the attenuation by rain and cloud: not the opposite, aren't they? Please check.

We thank referee for correcting. It is corrected now.

19. Page 1813, last line. typo: show -> shown

It is now corrected.

20. Page 1814, please add a "." after Eq. 2.

It is now added into the revised version.

21. Page 1814, line 21. factor -> factor being [Check meaning]

The sentence is revised with referee's suggestions.

22. Page 1814, line 21. Matrosov et al 2004: not found in ref section.

The reference (Matrosov et al. 2004) is added in the ref. section.

23. Page 1815, line 6. Fig 6a quoted before Fig 5 - check and reorder fig if necessary.

24. Page 1815, lines 7-9. Please check and rewrite text.

The lines 7-9 is revised in the updated version (Line 234).

25. Page 1818, line 16. When giving the correlation coefficient, please also give the number of samples (either in the text, or in the figure, or figure caption).

The details on the number of profiles are added into the text (Line 348)

26. Page 1819, line 3. Geerts 2004: not found. Perhaps Geerts and Dawei?

The reference (Geerts and Dawei 2004) is updated in the revised version

27. Page 1819, line 7. Steiner -> Steiner et al? Otherwise not found in ref section.

The reference (Steiner et al) is added in to the reference section

28. Page 1819, line 15. Typo: method -> methods

It is now updated.

29. Page 1819, line 26. Typo: comparing -> compared

The typo is corrected now.

30. Page 1821, ref section. Deng et al under review: I suggest not to quote a manuscript under review.

As per referee's suggestion, we have removed the reference (Deng et al)

31. Page 1821, Feng et al 2014: check year cited in text (is it 2013 or 2014?). Moreover typo before DOI (double ":").

32. Page 1821, Kollias et al 2002: not quoted in text.

The reference (Kollias et al., 2002) is quoted in the revised text.

33. Page 1822, Lhermitte 1990: not quoted in text. 34. Page 1822. Mather & Voyles: check year (in text is cited 2014 but here is 2013?).

The references and years (Mather and Voyles 2013) are quoted in the revised version

35. Page 1822, Steiner et al: not quoted in text (instead Steiner alone). 36. Page 1823. Zhang 2013: not quoted in text. 37. Page 1824. Suggest: & sensitivity -> sensitivity

The above changes are updated in the revised version of the manuscript.

38. Page 1826, Fig. 2 and others . In each panel, I suggest to write the axis labels in the usual way, i.e. variable [units] - without ",". For example Height [km], KAZR Z [dBZ],Time [h], etc.

The axis labels in figures are revised as per referee's suggestions.

39. Page 1826, fig. 2 and elsewhere: the abbreviation of hour is h not hr [in rainfall rate units].

It is corrected now

40. Page 1827, fig 3. Suggest to include in fig caption the meaning of Nw and mu (which should be given as a Greek symbol, as in the text, to avoid possible confusions).

We have revised Fig 4 as per referee's suggestions

41. Page 1828, fig 4. I suggest to remove shadowing of text in the flowchart to improve readability. The connecting lines and arrows also should be improved.

The Fig. 4 is revised as per referee's suggestions.

42. Page 183, fig 6. The two panels should have the same axis limits to allow compar- ing them more easily.

As per referee's suggestion, we have revised the axes limits in Fig. 6.

# Responses to Referee 3

1. In the whole paper, you never mention a third effect on the reflectivity gradient which could be **called dynamics** effect: the wind shear can produce non-vertical fallstreak of precipitation and lead to strong negative or positive gradient of reflectivities which have nothing to see with a microphysics or attenuation effect. How would you correct for this effect? If no correction can be easily proposed, I would like to see this issue mentioned in the paper as well as the implications on the accuracy of the retrievals.

   We admit that we have missed the discussion on the dynamic effect. We also agree with the reviewer that the presence of wind shear leads to strong positive or negative reflectivity gradient artifacts. In the present study, visual inspection of all the rain events used for the analysis shows no significant wind drifts in the reflectivity data. The mean and standard deviation of wind

speed and mean wind shear (averaged over rain layer depth, which is 500 m) for all the events is ~ 6 +/- 1.8 $ms^{-1}$ and 5 +/- 2.1 $x10^{-3}$ $s^{-1}$ respectively. The wind-drift effects may not be significant for the rain rates retrieved for the fall velocities threshold (>5 $ms^{-1}$), it can significantly affect at lower rain rates where the size of raindrops is smaller. Given the wind speed and wind shear values observed for the rain events and also the rain layer depth of 500 m (close to surface) considered for the retrieval, the dynamic effect for the lower rain rates can be neglected, and hence no correction has been applied

The events with non-vertical fall streaks caused by wind shear can also be recognized from the measurement of vertical profiles of reflectivity at longer wavelength radars. Such measurements available, for example during RHI scan of C-band radars at the ARM sites. Those estimates of non-attenuated profiles can be used for example to either to reject strong reflectivity gradient cases or to account for actual non-attenuated reflectivity profiles in Ka-band retrievals after correction for frequency differences as was done, for example in Matrosov (2010). This has been discussed under newly added section ("Limitations and Uncertainties') in page 17 (Line 374 onwards).

2. The second major issue with this technique is the determination of the thresh- old on Doppler velocity to separate the two regimes of precipitation. Firstly, the threshold is defined in terms of fall velocity while radar measure the Doppler velocity, hence, a non-negligible vertical wind could lead to a wrong separation of the two regimes. Secondly, this threshold is certainly the best possible but the two regimes are not so well separated and a different threshold could lead to different retrievals. Some statistics on the variability of the retrieval using different thresholds could help to assess the accuracy of the retrieval.

We thank referee for raising several interesting comments. We agree that the presence of strong vertical wind during convective cases leads to wrong separation of the regimes. This could be addressed when there is simultaneous retrievals of precipitation and vertical velocity from Doppler radar spectra using VHF profiler as in Wakasugi et al. (1986). Since DYNAMO offers no such setup for combined retrievals of precipitation and vertical velocity, no treatment of vertical wind is considered in the present study. This is discussed under the newly added section "Limitations and Uncertainties" (Page 18: Line 401 onwards).

As per referee's suggestions, now, we have tested the sensitivity of Doppler velocity threshold on rain rate retrieval for different thresholds

(4, 5, 6, and 8 $ms^{-1}$). We found that the correlation coefficient marginally increase from 0.29 to 0.32 for increase in Doppler velocity threshold from 4 to 5 m/s, and then slightly decreases (0.28 and 0.26) for higher Doppler velocity threshold. This justifies the Doppler velocity threshold (5 $ms^{-1}$) chosen based on the 1D microphysical model. This is added into the revised version in Page 15 (Line 333 onwards).

**Specific comments**

1. P.1810, l.3-7: The whole paragraph needs to be re-written: you don't need to motivate the study of clouds in this paper, I don't understand the last sentence ("Deployments of multiple radars . . .")

   The last sentence ("Deployment…") is removed now. The whole paragraph has been rewritten as per referee's suggestions (Page 3: Line 59 onwards).

3. P.1810, l.8-11: Can you please describe explicitly why retrieving precipitation can help to characterize the microphysics and radiative effects of clouds?

   It is more on the applicability of rain rate to microphysics and radiation (e.g. Long wave fluxes, drop size distributions, etc.) rather than the explicitly for characterization. We have rephrased the sentence now.

4. P.1814, l.12: “The results are plotted as a function of the mean Doppler velocity”. This is wrong and is one of the biggest issues of this paper: the results of the microphysical model are function of fall velocity while Doppler velocity is the sum of fall velocity and vertical wind. You never mention the effect of vertical wind in the determination of the two regimes (dominated by attenuation or microphysics effects), while the vertical wind can be significant in convective cores, even at low levels.

We acknowledge that we missed the discussion on neglecting the vertical velocity here. As mentioned above, we have added a discussion on this under a newly added section “ Limitations and Uncertainties”.

5. P.1814 and 1816: 5 m/s is indeed the best fall velocity to separate the two regimes, however, around 5 m/s, the microphysics effects are still significant (gradient of 2dB/km) and can produce a non-negligible error on attenuation-based estimates. In this paper, this problem is resolved by using the non-attenuated reflectivity reference of S-Pol, but what happen if no Rayleigh reflectivity reference is available?

The fraction of profiles affected by the microphysical effects is 16 % (118) out of the total profiles (734) considered for

retrieving precipitation using attenuation based (A-R) technique, which accounts for < 10 % to the total rain amount. S-Pol (or any un-attenuated radar) dependence is needed to identify the relative influence of microphysical versus attenuation effects especially for rain rates (around 5 mm/hr), where there is a transitional shift from effects due to evaporation versus attenuation.

If there is no Rayleigh reflectivity reference available, KAZR rain retrievals may not be reasonable for the rain rate interval (between 0.5 to 3-4 mm/h), where the identification of microphysics effect is not possible.

6. P.1815, l.11: The effect of water vapour should be balanced compared to the other effects: "significant" may be too strong. However, you never mention how you take this effect into account in the attenuation-based retrieval of rain rate.

The KAZR ARSCL accounts for the water vapor attenuation. This has been added in the manuscript (Page 6: Line 123).

P.1816, l.3-6: The figure 6a shows indeed some correlation between the Doppler velocity and the Ze-R relationship, but I don't see two regimes clearly separated by a Doppler velocity threshold, which could be determined unequivocally. So this figure can at most confirm the existence of two somewhat separated regimes, but it cannot be used to

identify the Doppler velocity threshold.

We did choose the threshold based on 1D microphysical model used here, which shows that at Doppler velocity ~5 m/s, where the attenuation effects starts to dominate. This has been justified after performing the sensitivity test for different Doppler velocity thresholds, which shows that at DV=5 m/s threshold, the correlation coefficient of retrieved rain rates is marginally higher than the other thresholds. This is added in the discussion on Page 15 (Line 333 onwards).

7. P.1816-1817, section 3.2.1: The full section is obscure and needs to l rewritten: (a) Why do you use rain layers of varying depth? Which depth chosen at the end?

Initially, we examined the rain layers of varying depth to examine t sensitivity of rain rate retrieval for chosen rain layer depth. At the end, we ha chosen rain layer depth of 500 m, starting from the lowest location of t identified unsaturated layer below 1.5 km AGL. As per referee's suggestion, t whole paragraph is rewritten (Page 15, Line 271)

2.(b) It is clear that, in case of light rain, the reflectivity may not decrease with height, but it can also happen in case of non-vertical fallstreak of heavy precipitation for which we could observe positive gradients of reflectivity and Doppler velocities larger than 5 m/s. You say that, this allows determining the profiles suitable for the attenuation technique but how the rain rate estimation is done in such cases?

We thank reviewer for raising this interesting question. The treatment on non-vertical fall streak is not addressed here. It is because, visual inspection of reflectivity data shows no significant wind-drift effects and also the mean wind speed (5.1 +/- 1.8 $ms^{-1}$; mean and standard deviation) and wind shear (3.5 +/- 2.1 $x10^{-3}$ $s^{-1}$; mean and standard deviation) values observed for the rain cases analyzed being low. This is added under section: "Limitations and Uncertainties" (Page 17).

(c) You mentioned in section 2.1 that S-Pol vertical scans above the KAZR are available only every 15 min and your algorithm uses the Rayleigh reference profiles of the S-Pol radar to detect the cases where microphysics effects are not negligible. How do you detect them in the data between two S-Pol vertical scans?

We interpolated S-pol reflectivity field for 1 min time interval without altering its vertical resolution. Given the presence of coherency in the reflectivity field and non-significant fall-streak effects (based on visual inspection), we think interpolation would be reasonable.

3. (d) Finally, what is the rate of profiles that are kept for the attenuation based retrieval? How much rainfall do we miss by eliminating such profiles?

Out of total profiles (734) considered for retrieving precipitation after initial screening using attenuation bases (A-R) technique, about 16 % (118) of the cases has been eliminated due to microphysical effects. The amount of missing rain fall from these outliers is less than 10 %. This is added into the revised manuscript (Page 14: Line 290 onwards).

4. (e) " . . . this results in underestimation of the cloud-top heights from the KAZR for higher rain rates.": Since this is not the real cloud top height, I would not use the term "cloud top height" but rather something like "maximum height were the reflectivity is significant".

   We concur with the referee's remarks. As per his suggestion, we have replaced "cloud top height" with "maximum echo height" (Page 15, line 314).

5. (f) "A near-linear relationship between the gradient of reflectivity due to attenuation and the rain rate is clearly seen in Fig. 5d.": Matrosov (2005) found indeed a linear-relation between attenuation (i.e. gradient of reflectivity) and rain rate, but there is no way that Figure 5d can allow you to claim this.

   We admit that the statement made is a mistake. It is is removed now. The description of Fig. 5 is re written (Page 13, Line 290 onwards).

6. P. 1817, l.22: ". . . the mean and standard deviation of top 25% of the Doppler velocities . . . ": I guess that you mean the 25% most frequent Doppler velocities?

   I meant, for each reflectivity bin, the Doppler velocities have been sorted in ascending manner and considering only the mean and standard deviation of top 25 % of the Doppler velocities.

7. P. 1818, l.11:" The computed reflectivity values from DSDs are compared with the KAZR reflectivity values and corrections are applied to the Ze–R relation- ship.": How well do they compare? Such comparison should show some scatter

Due to the use of the Ze-R relation and also because of the volume mismatch between instruments. What corrections are applied to the Ze-R relationship? Don't you think that it be would more relevant to derive the relationship directly from the 2DVD calculations? It is well known that Z-R relationships are very variable and plenty of them have been proposed. Can you make some comments about your new relationship: how far is it from the other existing Ze-R relationships at Ka-band? What is the effect of the filtering from Doppler velocities? How representative is it for other rain data (other location, other seasons). Do you think that the relationship needs to be updated for each rain event, and that your technique always requires some disdrometer data?

The referee raised several interesting questions. For matching volumes, here only time averaging of 1 min is performed for the calculations. The Ze-R relationship based on KAZR reflectivity is compared with the computed reflectivity values using disdrometer data. Both the $Z_e$-R relations are fitted with power laws, and the difference in rain rates between these relations is expressed as a linear correction (of the form y=ax+b) as a function of KAZR reflectivity as shown in Fig. 7 (shown below). This proposed correction eliminates the requirement of a reference (e.g., disdrometer or non-attenuated radar) to correct for KAZR based $Z_e$-R relationship. However, given the variability in the Ze-R relationships for different rain events, geographical location, the representation of the relationships needs to be tested and refined for other locations and other seasons.

The exponent (1/b=1.18) in the proposed $Z_e$-R relation is slightly lower compared to previous proposed relations (with 1/b=1.3-1.6 for below 0.5 km) by tokay et al. (2009). The filtering of the Doppler velocities results in reduction of the data. This is documented in Table 2.

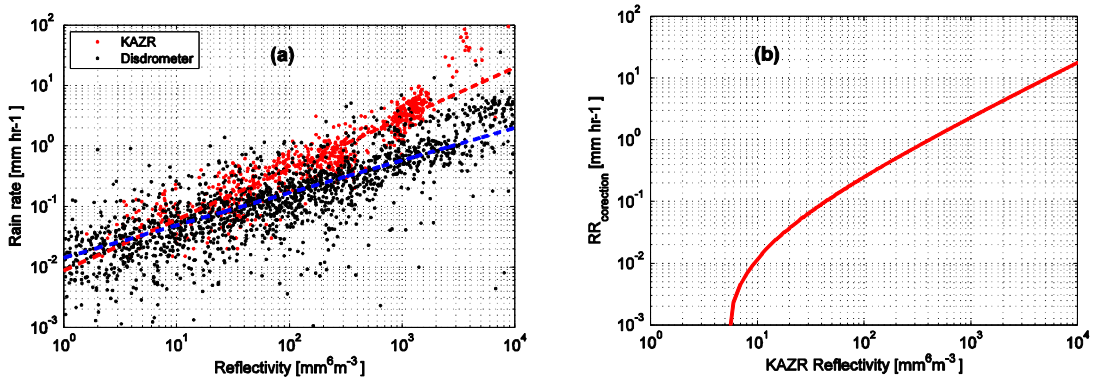


Figure 7: The Ze-R relationships based on both KAZR and Disdrometer (Left). The rain-rate correction as a function of KAZR reflectivity (Right).

8. P. 1818, l.18: "The comparison is shown for R > 5 mm h-1. . .": Why not showing the data below 5 mm/h? It is part of your algorithm and it should help to discuss its limitations. In particular, if the scatter is important, it would give you a good argument for the use of the attenuation based technique.

As per referee's suggestion, we have revised old figure (new figure 8) with extension below 5 mm/h.

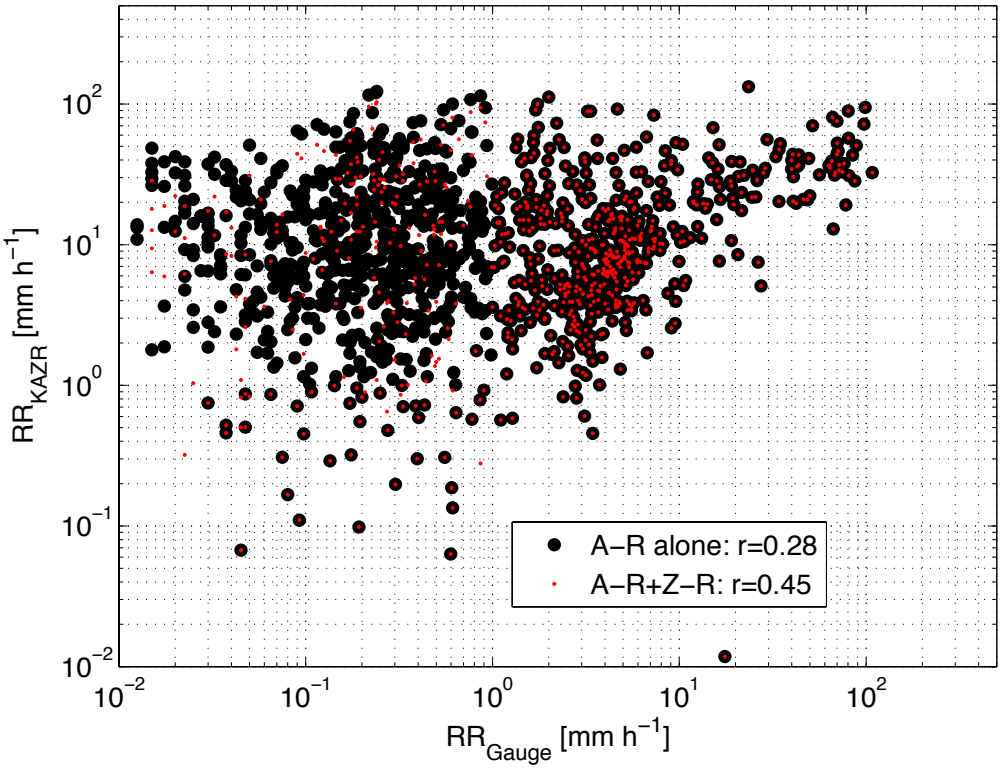


Figure 8: Scatter plot of observed rain rates from an optical gauge vs rain rates retrieved from the KAZR covering 15 days of rain events between October 08, 2011 and February 06, 2012. Black dots indicate rain retrievals using attenuation-based (A-R) technique. Red dots indicate rain retrievals using Ze-R relation up to 5 $ms^{-1}$ Doppler velocity threshold, and A-R relationship for Doppler velocities above 5 $ms^{-1}$.

9. P.1818, l.24-25: ". . . the comparison in terms of the time series and scatter plot agrees reasonably well." These are only qualitative observations of the quality of the retrieval. If you

pretend to be able to "derive robust statistics of rain rates" (from the abstract), I would like to see also some quantitative comparisons (like standard deviation and bias) of the rain rate retrieval with rain gage and disdrometers measurements.

We admit that the rain rate retrieval presented here is not robust given the rudimentary treatment of the uncertainties from different methods. That is why we have removed the sentence "derive robust statistics …" from the earlier version. The quantitative comparisons will be a future scope of the present study.

10. P.1818, 25-26: You need quickly introduce the other rain products that you are using to validate your retrievals or at least give some references.

We agree with the referee. Now, we have added this information in the dataset section (Page 6: Line 133 onwards).

**3 Selection of technical corrections**

I provide here a selection of the technical corrections because the manuscript need substantial correction overall. I will provide a more detailed list once I'll have an im- proved version of the manuscript in terms of science.

11. P.1808, l.13: "is implemented" seems unnecessary.

We have revised the sentence as per referee's suggestion.

12. Reference should be Mather and Voyles, 2013 (the year is correct in the references list). Same remark at p.1810, l.15.

    The correct year is updated in the revised version.

13. P.1809, l.18: Moran et al. is missing in the references list.

    It is added into the reference list

14. P.1809, l.18: There is only one article written by Kollias in 2007 in the reference list.

    We have revised the reference section with the quoted references from Kollias

15. P.1811, l.10: Two verbs in the sentence "The KAZR is a profiling Doppler radar operates at Ka-Band ...". However, I don't think that it is necessary to repeat these characteristics of the KAZR which are identic to the MMCR and already described in the introduction, and because the KAZR is the focus of the following section.

    As per referee's suggestion, we have removed common characteristics of KAZR compared to MMCR, and retained the specifics of KAZR (Page 5: Line 108 onwards).

16. P.1811, l.23: The reference should be Feng et al., 2014 (the year is correct in the references list).

We have revised the reference list.

17. P.1812, l.9: ". . . and non-significant ? (non-hydrometeors) are removed.": a word is missing.

We have added the missing word in the revised version.

18. P.1812, l.16: "The KAZR is heavily attenuated for high rain rate episodes are seen in the reflectivity field...": meaningless sentence, please proofread more carefully.

As per referee's suggestion, we have rephrased the sentence (Page 14; line 298 onwards).

19. P.1813, l.1-2: "Consequently, the DSD parameters, in particular the concentration parameter.": same as above.

We have rephrased the sentence in the revised version.

20. P.1814, l.19: "In Fig. 3, all calculations are done using the Mie theory (and only attenuation).": same as above.

As per referee's suggestion, we have rephrased the sentence

21. P1814, l.21: The reference Matrosov (2004) is not in the

references list.

It is now into the reference section

22. P1814, l.22: Matrosov (?): year missing

It is added in the revised section

23. P1814, l.27: “derivative”: gradient would be more explicit.

As per referee’s suggestion, we have replaced it with “gradient”.

24. P.1816, l.7:”...the drops are considerably small that the attenuation ...” word missing.

It is been updated in the revised section

25. P.1818, l.8:”... diameter bin form disdrometer ...”: I guess that you mean “... diameter bin of the disdrometer . . .”

Yes, It is the diameter bin of the disdrometer. We have revised this sentence.

26. P.1818, l.13: “Rain rates from the KAZR are continuously retrieved in two steps.”: From this sentence, we understand that you use two consecutives steps for the whole dataset. I would suggest replacing “in two steps” by “using two techniques for two categories of rain rate”.

As per referee’s suggestion, we have revised the sentence (Page

16: Line 341).

27. P.1819, l.1: The sentence would be more understandable If you replace ". . . are based.." by ". . . classified from . . ."

We have revised the sentence as per referee's suggestion, (Page 16; Line 359)

28. P1819, l.3: The reference should be "Geerts and Dawei (2004)"

It is added into the revised reference section

29. P1819, l.3 to 8: These sentences are very obscure, please rewrite.

As per referee's suggestion, we have rephrased the sentence.

30. P1819, l.7: The reference should be "(Steiner et al., 1995).

We concur with the referee. The reference has been revised now.

31. P1819, l9: The differences can also be due to the errors associated with the different techniques.

We concur with the referee. We have added the above sentence in the revised version.

32. References: Keeler et al. (2000) is missing from the list, while Kollias et al. (2002) and Zhang et al. (2013) do not appear in the text.

The references are updated in the revised version

33. Fig.2: What does mean "-ve" in the caption?

-ve means the "sign negative" to indicate the convention for Doppler velocity. It is revised in the caption now.

34. Fig.3: It is possible to deduce from the text but please mention to which process corresponds each group of lines in this figure.

As per referee's suggestion, we have added the description in the figure caption.

35. Fig.5: Subplot (a): what is the black line? What is the x axis? (c) and (d): the rain rate estimate comes from the disdrometer data?

The black line in Fig 5a indicate rain rates (RR/5 in mm/hr) from optical rain gauge. X-axis shows time in UTC (Coordinated Universal Time) in hours. These details are updated in the figure caption.

36. Fig.6: The points in subplot (b) are not easy to see. Please use larger markers like in (a).

We have revised Fig. 6b as per referee's suggestion.

37. Fig.9: From only the rain event of fig.5, I see that you have a lot of data. Why are you using only 5 bins in the histograms?

We have used 5 bins showing rain rate distribution covering small (0.01 mm/hr) to large rain rates (100 mm/hr). Since we are interested in only the qualitative comparison of rain rate distribution from different radars, we didn't use more bins.