Interactive comment on “Detection of the freezing level with polarimetric weather radar”

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1 Response to Anonymous Referee 1

This paper describes a melting layer detection technique from vertical Profiles (VP) and quasi-vertical profiles (QVP) from polarimetric radar observations. Examples are given from a C-band operational weather radar in SE England. Apart from Zh, Zdr, phi_dp, and rho_hv, the technique includes mean Doppler velocity and the gradient of the vertical Doppler velocity. The paper can be published in AMT but it needs to be written in a more coherent manner. Sentences don't follow each other in some cases, and more clarification is needed in some cases.

We thank the reviewer for the insightful review of the manuscript. We will improve the revised manuscript through a careful review of the language. In the following, we address all their point-by-point comments in blue, outlining our response and how are we modifying the manuscript.

1. At the end of Intro, insert a paragraph outlining what this paper is trying to achieve and how the paper is structured

    (a) *We'll add a paragraph as: "The main objective of this work is to present an automated, operational and robust algorithm that can accurately estimate the FL based on the combination of QVPs or VPs of polarimetric measurements collected from operational dual-polarisation weather radars. The algorithm outputs are validated using FL heights from high-resolution radiosonde data. Note that the proposed algorithm is not intended to replace NWP-based FL estimation methods, but it is an alternative way to estimate the FL when only polarimetric weather radar measurements are available. The article is organized as follows: the next section will describe the datasets used for the design and validation of the algorithm. The aim of Section 3 is to examine the footprints of the melting layer* *on both QVPs and VPs of polarimetric variables. Section 4 provides a detailed explanation of the design of the algorithm. Results, implementation, validation and several examples of the outputs of the algorithm are presented in Section 5. Section 6 provides a discussion on the performance and implementation of the algorithm. Finally, Section 7 provides a summary of the conclusions from this work."*

2. Line 95: By Doppler velocity, do they mean the mean radial component?

   (a) *The reviewer is right: the sentence needs further explanation; we'll add a phrase as: "Mean radial velocity (V) measurements of the observed droplets is available"*

3. Line 115: What does 'visible signatures' mean? Can you quantify?

   (a) *We agree the sentence needs further explanation. We'll rephrase as follows: "A total of 94 rainfall events with visible signatures of the ML on Z_H or ρ_{HV} were selected, i.e. an enhancement up to 30 dBZ on Z_H or ρ_{HV} constantly decreasing below 0.90. Also, from the total events, only 25 rain events observed by the radar shown a suitable temporal matching with the data collected by the radiosondes, i.e. the difference in time between measurements do not exceed 3 hours."*

4. Line 128: The authors say "Based on the profiles of vertical velocity [V], we propose a new variable: [gradV].." - What about spectral width? Is this available from routine scans?

   (a) *The Spectral width variable was not available in the analysed radar datasets.*

5. Figure 2: For the VP plots on the left side, the y-axis should go from 0 to 8 km to be consistent with the QVP plots. What about panel (j)? Why is the 0 to 1 km omitted?

   (a) *As described on line 125, data collected at vertical incidence is contaminated by spurious echoes. Still, we'll modify the plot so the y-axis is consistent on both sides, enabling a straightforward comparison.*

6. Line 144: Define 'normalised' at this point.

   (a) *We'll rephrase as follows: "For comparison purposes, the VPs and QVPs of polarimetric variables are normalised (scaling each feature into the range [0, 1]) to intensify the features observed in the ML; each variable maximum is set to 1, whereas the minima are set to 0. Examples of normalised QVPs and VPs related to a stratiform event* *are shown in Figure 3 along with the closest-in-time radiosonde data where the temperature reaches 0 °C (FL_{RS})."*

7. Line 147: should 'estimate' be 'detect'?

    (a) *Agreed and corrected*

8. Line 148: What does 'enhancements that the ML bring-up into the variables' mean?

    (a) *We'll rephrase as follows: "Given that the main objective of this work is to detect the FL based on the geometric features of the polarimetric profiles, herein, we will try to explain the ML signatures and how it shapes the structure of the profiles."*

9. Line 154: By 'elevation' do they mean 'altitude a.g.l'?

    (a) *Indeed. This will be corrected in the revised version.*

10. Lines 156-159: Grammar needs to be improved, and also the text is ambiguous; the sentence doesn't make much sense.

    (a) *We'll rephrase as: "The reflectivity (Z_H) is represents the power backscattered by precipitation particles, thus providing information about the concentration, size, phase and water content of the hydrometeors (Gourley and Hong, 2014). In figures 2a and 2b it can be seen that the values of Z_H on both QVPs and VPs show similar intensities. These aspects will be analysed on the following sections."*

11. Lines 163: convective events are associated with different microphysical processes so ML doesn't apply.

    (a) *Agreed, we'll rephrase as follows: "Whilst for convective events, the profiles of Z_H do not show the BB feature, therefore the estimation of FL based only on this variable and for this type of events is not feasible."*

12. Line 168: Doesn't the radar perform 'bird-bath' scans routinely?

    (a) *Yes, the bird-bath scans are the VPs. Please note that in lines 169-170 we explained the need to know first the height of the FL to apply a bias-correction to Z_{DR}.*

13. Line 168: The sentence beginning 'Hence the Zdr ..' requires much more clarification.

(a) *We agree the sentence needs further explanation. We'll rephrase this sentence as follows: "From Figure 2c we can observe that Z_{DR} is not calibrated, as we expect near-to-zero values for Z_{DR} in rain region for vertically pointing measurements as raindrops are symmetrical on average when observed from underneath (Gorgucci et al., 1999). Non-zero Z_{DR} values in rain are a strong indicator of uncalibrated Z_{DR} measurements, and a subsequent analysis of 'birdbath' scans in light rain confirmed a negative offset. Hence, Z_{DR} measurements must be corrected if Z_{DR} is intended for radar QPE; this reaffirms the importance of the detection of the freezing level, as it helps to set the upper height for the implementation of a Z_{DR} calibration algorithm."*

14. Section 3 is verbose, not very technical and not well-written at all. Please rewrite. Also explain clearly why the peaks in Zh, Zdr and rho_hv are at different heights above ground level and explain the difference between BB and ML.

    (a) *We will revise this section to improve its readability.*

15. Line 237: Once again, explicitly say how the normalisation is performed.

    (a) *We'll rephrase as: "These two profiles are normalised and combined into a single profile (P_{comb}) as suggested by Wolfensberger et al. (2016), but using different thresholds that are related to drizzle, heavy rain, snow and ice (Kumjian, 2013; Fabry, 2015). The normalisation is carried out using the min-max normalisation procedure:*

$$X_n = \frac{X - min(X)}{max(X) - min(X)} \quad (1)$$

where X is the original value and X_n is the normalized value.
Here, the values of Z_H between 5 and 60 dBZ are normalised between 0 and 1, respectively: $[Z_H(dBZ)[5, 60] \rightarrow Z_H^*[0, 1]]$, whereas the values of ρ_{HV} between 0.85 and 1 are normalised between 0 and 1: $[\rho_{HV}(\,)[0.85, 1] \rightarrow \rho_{HV}^*[0, 1]]$. Values outside these intervals are fixed to 0 and 1, correspondingly. Note that (*) in the polarimetric variable indicates a normalised variable."

16. Explain how equations (2) and (3) were derived. If published elsewhere, then insert reference for the derivations.

    (a) *We'll rephrase as follows: "Once U_L is defined, the algorithm identifies the 0 °C height based on a profile that is the result of the combination of several polarimetric profiles as follows.*
    The profiles of the available polarimetric variables have an upper limit set by U_L to search for the FL. Every individual profile is normalised. Note that Z_H^* and ρ_{HV}^* were already normalised in step

1.a, whereas the rest of the variables are normalised using the minimum and maximum values of each variable. The variables were normalised based on the QVP/VP patterns observed in Section 3, i.e. variables where the peak related to the ML is orientated to the right, e.g. Z_H or Z_{DR} are normalised using the measured values. In contrast, variables where the ML cause a depression on the profile, are normalised using the complement of the variable, e.g. $gradV \rightarrow (1 - gradV)$. This is made to generate profiles with analogue ML peaks that enhance the footprints of the ML when combined. A new profile is computed following Equation 2 for VPs or Equation 3 for QVPs:"

17. Line 267: Explain/justify why the second derivative was chosen.

    (a) *Please note that this is discussed in lines 284-287 and illustrated in Figure 5.*

18. Line 293: "QVPs and VPs of Zh, as these variables measure similar properties of the raindrops" What does this mean?

    (a) *We'll rephrase as: "Both VPs and QVPs proved to be an efficient way to monitor the temporal evolution of the ML. But the elevation angle from where the QVPs were taken affects in different ways to each variable, as described in Section 3 and shown in Figures 2 and 3. As Z_H is the variable less prone to significant variations due to the elevation angle, we analysed the consistency between the Z_H profiles constructed from different elevation angles. To some extent, the consistency between these profiles increases the confidence of the QVPs utilisation as an input of the algorithm. For the rest of the variables is not possible to quantify the consistency as they represent different properties of the hydrometeors, depending on the elevation angle from they were taken."*

19. Line 303: What does "resides on relative low values of reflectivity" mean?

    (a) *We'll rephrase as: "Figure 6a shows that lower values of reflectivity are similarly depicted on both, VPs and QVPs. These values are related to light and moderate rain rates, expected on stratiform-type events."*

20. What is the purpose of Section 5.1 if only the Z comparisons are given? It's not clear how it is relevant to the rest of the paper.

    (a) *This section is intended as a validation of the reflectivity QVPs. We believe it is necessary to assess the consistency between VPs and QVPs as the FL algorithm is based on the geometry of the profiles. But apart from Z_H, it is not possible to compare the figures of the* *other polarimetric variables due to the azimuthal averaging on the construction of the QVPs.*

21. Regarding Fig. 9: What does 'FL estimated' represent exactly, that is in relation to the radar BB (peaks in all the variables), and the 0 deg C isotherm level?

    (a) *At this point, we compared the FL height measured by the radiosonde and the output of the algorithm (i.e. the BB top in the enhanced profile) described in step 2.d (lines 274-276).*

22. What about attenuation corrections needed for Zh and Zdr? Were these applied?

    (a) *We are aware that the attenuation is an error source for radar QPE. But the height of the FL is essential to implement attenuation correction algorithms as they can only be applied in the rain region. For the events analysed in this paper, we consider that the signal attenuation is negligible as we are using high-elevation scans to construct the QVPs and set a relatively short-range as a constraint for the algorithm's implementation. A glance to the generated* Φ_{DP} *profiles reveals that larger accumulations of* Φ_{DP} *are most likely related to the DGZ rather than to heavy rain.*

References

Fabry, F. (2015). *Radar Meteorology: Principles and Practice*. Cambridge University Press.

Gorgucci, E., Scarchilli, G., and Chandrasekar, V. (1999). A procedure to calibrate multiparameter weather radar using properties of the rain medium. *IEEE Transactions on Geoscience and Remote Sensing*, 37(1 PART 1):269–276.

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