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

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1 Response to Anonymous Referee 2

This study proposes an approach to estimate the freezing level (FL) using vertical/quasi-vertical profiles (VP/QVP) achieved from polarimetric radar observations. The proposed approach was applied to some selected events, and the estimated FLs were evaluated using radiosonde observations. Based on the evaluation results, the authors concluded that the combinations of ZH, HV, and the gradient of the velocity V, and ZH, HV, and ZDR for each VP and QVP method are the best predictors for the FL estimation. I think that the study was well-designed, and the focus and experimental details and results of the study are clearly addressed in the manuscript. However, I have a basic question about the utility of this study for radar QPE and additional comments/suggestions for some other aspects presented in this study.

We thank the reviewer for the positive remarks and for the interesting feedback/discussion that surely will help to improve our work. We will modify the manuscript as outlined below, replying point by point in blue.

Major comments:

1. Utility of FL height. The authors discuss the necessity of FL information for radar-based applications (e.g., QPE) in Introduction. In my opinion, what is really useful for radar applications is to provide a range of the melting layer (ML), not just a single value of FL height itself (as this study mostly devoted to find the FL height) because mixed (liquid-solid) precipitation is usually located below the FL height, and this is a significant challenge e.g. for rainfall and attenuation estimation. I am wondering what specific applications require the estimated FL height. I think that a bottom height of the ML presented in Figures 10 and 13 is much more useful than the FL height itself because the majority of scattering and

propagation theories can be applied only to the region below this height (liquid precipitation or pure rain region).

(a) *We completely agree with the reviewer on the importance of accurate detection of the bottom of the Melting Layer as most of the QPE algorithms can only be applied in the rain region. Unfortunately, if the output of the algorithm is the bottom of the ML, it would be challenging to validate it using the radiosonde datasets or some other instrument. Hence, the proposed algorithm detects both the FL and the bottom of the ML based on the geometry of the profiles and the FL is validated using radiosonde data. Then, the ML bottom can be determined using a fixed ML thickness or by using the output of the algorithm.*

2. QVP. It is not clear if either time-averaged or instantaneous QVP is used in the proposed FL detection algorithm. I think that instantaneous QVP is not appropriate for the proposed algorithm because it could be affected by local storm structures (although it is derived from higher elevation angles) particularly for the ones near the radar. If the authors used time-averaged QVPs, they need to clarify it and define the averaging time window. It might be helpful for readers to understand the QVP method if the authors provide a brief description on the background and procedures to retrieve QVP from radar observations, rather than just referring to Ryzhkov et al. (2016).

   (a) *We are aware of the advantages of using time-averaged QVPs, and we did some tests using time-averaged QVPs. The algorithm considers this situation with the parameter k, which is helpful to deal with the smoothness caused by the time-averaging of the profiles, e.g. in figure 2, the profiles are averaged using a time-window of 30 minutes, and the parameter k is modified to allow lower values on the resulting profiles. The estimated FL do not vary that much. Hence, we decided to display examples in the instantaneous QVPs format at this is the most common format of QVPs. We'll expand this in the discussion section.*

3. FL spatial variability. I think that the proposed QVP method results in the average FL over the entire radar domain while the VP method yields limited FL to the radar site (if VP was obtained from a 90 degree elevation angle). I am wondering how the spatial variability of FL over the radar domain looks like, and the authors may compare the FL information retrieved from the NWP model with the one achieved from this study. It might be helpful to discuss this spatial variability issue in the discussion section as a limitation of this approach.

   (a) *A strong motivation for this work was to avoid relying on NWP products. One of the advantages of the algorithm is that it enables the*

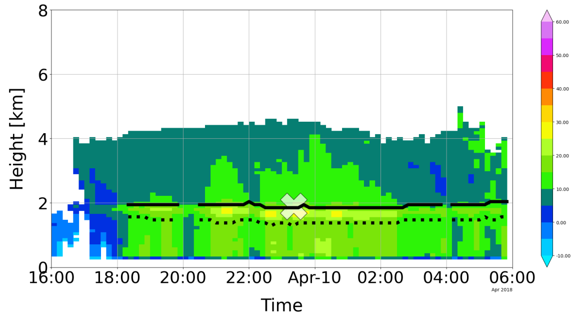

Figure 1: Instantaneous QVPs and FLe, related to a stratiform-type rain event.

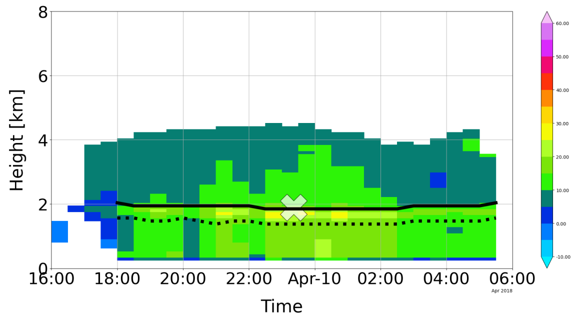

Figure 2: Time-averaged QVPs and FLe, related to a stratiform-type rain event.

estimation of the FL based entirely on the radar data; this is really helpful to implement corrections that depend on hydrometeor discrimination. We agree with the reviewer that there is a spatial variability of the FL over the radar domain. Still, after weighing the options, we considered that for the FL accuracy required in radar corrections, a straightforward algorithm and its validation using radiosonde surpass the complexity of data retrieved from numerical models and its computationally expensive runs, as showed by Hall et al. (2015) or Mittermaier and Illingworth (2003) . We'll discuss the spatial variability of the FL and the limitation of the algorithm in section 5.

4. Error analysis. Whereas the analyses presented in this study focused on finding the best predictors of the polarimetric radar observations, it is valuable to characterize the structure of errors resulted from the proposed methods. I think that it would be useful to demonstrate error distributions of each VP and QVP method (e.g., P14 and P26), rather than just reporting "the errors in the FL estimation using either VPs or QVPs are within 250m."

(a) *We'll add an error analysis in section 5, comparing the detected FL depending if QVPs or VPs were used as input of the algorithm.*

Minor comments:

1. Line 10 Maybe better to remove "extremely."

    (a) *Noted*

2. Line 24-26 It would be interesting to compare the FL heights computed from between this study and the NWP model.

    (a) *Please refer to the answer of major comment No. 3.*

3. Line 87 Please define "UKMO."

    (a) *Corrected, UKMO refers to the UK Met Office.*

4. Line 106 Please replace "twice daily" with "twice a day."

    (a) *Corrected*

5. Table 1 I think that the "Location" in Table 1 represents coordinates on a certain projected coordinate system. Geographic coordinates are more common and please provide latitude and longitude of the radar site.

    (a) *Corrected*

6. Figure 2 Please use consistent height (y-axis) and color scales for the same radar observables to enable easy comparisons between left and right panels for (a)–(h). Please also define "HTI" in the figure caption.

    (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.*

7. Line 144 Please clarify if QVPs shown in Figure 3 were time-averaged before they were normalized.

    (a) *Please check the answer provided above*

8. Line 181-182 How are "type of precipitation" and "phase of the hydrometeors" different?

    (a) *We agree with the reviewer, we'll rephrase as: "The correlation coefficient (ρ_{HV}) measures the correlation between Z_H and Z_V measurements and it is sensitive to the distribution of particle sizes and shapes, hence being sensitive the phase of the hydrometeors, becoming a valuable hydrometeor classifier helping to identify non-meteorological echoes (Islam and Rico-Ramirez, 2014). "*

9. Line 278 It turned out that "magnitude (k) of Ppeak" was a threshold (e.g., parameter) for peak magnitude (Line 287). Please clarify it here.

   (a) *We'll rephrase as: "An adequate choice of the magnitude of the parameter* (k) *is important to discard profiles with a* P_{peak} *that is not strong enough to be related to the ML.*

10. Line 291-294 Something is missing. Please rewrite.

    (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."*

11. Line 300 Why do the authors compare VPs and QVPs? Is this comparison performed because the authors used instantaneous QVPs for FL estimation? I think that they (VP and QVP) are not necessarily consistent, and QVP should be used with timeaveraging to avoid local storm effects and capture the consistent vertical structure with VP.

    (a) *This section is somewhat intended as a validation of the construction of the QVPs. We consider it necessary to assess the consistency between both types of representations as the FLe algorithm is based on the geometry of the profiles. But apart from* Z_H*, it is not possible to compare the figures of the polarimetric variables due to the azimuthal averaging on the construction of the QVPs.*

12. Section 5.2 This section does not describe the result of this study and should be moved to the "Methodology" section.

    (a) *We agree with the reviewer, we'll modify this section.*

13. Line 352 Please replace "better" with "best."

    (a) *Corrected*

14. Line 358 Why P16? Both ZH and [grad V] are the elements of P26. [grad V] was used for P16–P31, not just for P16.

(a) *The purpose of showing the performance of P_{16} in Figures 10c and 10d is to emphasise the value of the proposed variable $gradV$. If the reviewer consider that this part is not necessary or repetitive, we are willing to leave it out of the manuscript.*

15. Line 359 Figures 10a and 10b instead of "Figures 13a and 13b?"

    (a) *Corrected*

16. Line 361-362 The estimation procedure of the ML bottom was not described.

    (a) *Due the importance of the ML bottom, we'll elaborate on this in section 3.*

17. Line 383 Please replace "better" with "best."

    (a) *Noted*

18. Line 386 Why P10? P10 does not have to be mentioned here because the two factors shown in Figure 13 are also included in P14.

    (a) *We use the variable P_{10} to compare the different outputs of the algorithm, but we are willing to remove it if the reviewer considers it necessary.*

19. Line 404-407 I think that the ZDR calibration bias is not an issue in this study because relative ZDR values (e.g., normalized) are used to construct vertical profiles. ZH also contains the calibration issue.

    (a) *We agree with the reviewer, but we want to emphasize the necessity of the knowledge of the FL before the implementation of the Z_{DR} calibration procedure.*

References

Hall, W., Rico-Ramirez, M. A., and Krämer, S. (2015). Classification and correction of the bright band using an operational C-band polarimetric radar. *Journal of Hydrology*, 531:248–258.

Islam, T. and Rico-Ramirez, M. A. (2014). An overview of the remote sensing of precipitation with polarimetric radar. *Progress in Physical Geography*, 38(1):55–78.

Mittermaier, M. P. and Illingworth, A. J. (2003). Comparison of model-derived and radar-observed freezing-level heights: Implications for vertical reflectivity profile-correction schemes. *Quarterly Journal of the Royal Meteorological Society*, 129(587 PART A):83–95.