# Author’s response to:
# RC#1 from Raphaela Vogel
# https://doi.org/10.5194/amt-2022-252-RC1

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Dear Raphaela Vogel,

Thank you for carefully reading the manuscript and pointing out several issues where the description needs to be improved for understanding. The requested clarifications and references to ambiguities contribute to the improvement of the manuscript.

In order to separate the reviewer’s comments and the author’s response, we printed the comments in black and the response in blue. Excerpts of the manuscript with marked changes are pinned directly to the appropriate responses, with the indicated text location (e.g., line number) referring to the manuscript in preprint.

Sincerely, on behalf of all authors

Heike Kalesse-Los

**Changes done to the manuscript:**

- The Virga-Sniffer code was updated (v0.3.4 -> v1.0.0), with mostly minor changes (e.g., more flexible plotting routines). Nevertheless, there are two considerable additions, listed below. In particular, the handling of situations in which precipitation falls into lower cloud layers was changed compared to the first submitted manuscript. We now focus on avoiding misclassifications and therefore set the newly introduced configuration *cbh_connect2top* to False (see below).

  1. Adding a configuration flag "*lcl_replace_cbh*". When additional LCL data is provided, this flag changes the behaviour of the *add LCL* module for CBH preprocessing. In the default setting (True), the LCL data completely replaces the lowest ceilometer CBH layer. If False, the LCL data is merged with the lowest ceilometer CBH layer by replacing only missing values.
  2. Adding a configuration flag "*cbh_connect2top*". This flag changes how situations where precipitation falls in lower CBH layers are handled. In the default setting (False), the lowest CBH is retained and higher CBH layers are omitted from processing because no distinction can be made between clouds and precipitation from higher layers if there is a continuous radar signal in the profile. Therefore, the default setting is most conservative to avoid false detection of virga. For True, the top CBH layer is retained and the lower CBH layer is omitted from processing. This approach results in more precipitation data points, but it is prone to misclassification of cloud droplets as precipitation.

  The up-to-date version of the Virga-Sniffer is hosted on GitHub, see also its Changelog (Witthuhn et al., 2022). All results and figures have been updated according to the new version.

- The technical description of the Virga Sniffer (Sect. 3) has been significantly revised. Care has been taken to name optional data and default configurations explicitly in order to avoid ambiguities. In the course of this, the flowchart (Figure 2) and the illustration (Figure 3) were adapted.

- A new appendix (B) has been added, where the sensitivity of precipitation and cloud detection on setting parameters and optional data are analysed and discussed.

- In section 4.1, "Comparison with Cloudnet target classification", we have added another performance evaluation of the *Virga-Sniffer*. Here we analyse how many data points were evaluated as precipitation by CloudnetPy but not by the *Virga-Sniffer*.

- Many text passages, figures and tables were revised in consideration of review comments, as can be seen in the detailed responses.

**Response to RC#1 of Referee Raphaela Vogel:**

**Major comment #1: Tool description**

1. *I think the tool description can be improved. I couldn't follow the explanation in Section 3.1 as I was missing some crucial information: at what temporal resolution are these analyses done? What is a CBH layer?*

* In order to clarify the operation of the Virga-Sniffer including its temporal and vertical resolution, as well as the term 'CBH layer', we added the following bits:

> **Sect. 3., 1st paragraph (L140ff.)**:
>
> The *Virga-Sniffer* is a profile-based detection scheme for virga events. It is a self-developed Python package (Witthuhn et al., 2022). The detection is based on a set of empirical thresholds, which are manually tuned on the EUREC$^4$A data set (Sect. 2) and summarized with their default values in Appendix A. This package provides a tool for detecting ~~virga from profiles~~ precipitation, virga and clouds from profile-by-profile observations of vertically-pointing cloud radar reflectivity and ceilometer observations of cloud base height (CBH), taking into account multilayer cloud situations. The radar data serve as a basis, as they define the temporal and vertical resolution for the *Virga-Sniffer*, which in the case of the EUREC$^4$A data set is 1.6–2.9 s and 22–42 m, respectively (see Sect. 2.1). The main result are Boolean masks, which mark clouds, virga and/or precipitation on the radar coordinates (range-gates and time-steps). It is highly configurable, modular and therefore usable for different measurement setups. In addition, virga detection can be refined by additionally considering radar mean Doppler velocity, LCL, and surface rain detection. Example cases presented in the following are based on the default settings of the *Virga-Sniffer* to process the EUREC$^4$A data set.

**Sect. 3.1, 1st paragraph (L150ff.)**:

The ~~input CBH layer data is~~ ceilometer provides the input values of the CBH. The variable CBH is a data product of the internal ceilometer processing. For multilayer cloud situations, multiple CBH are output, until the ceilometer signal is fully attenuated. Depending on the type of ceilometer and the underlying internal CBH determination algorithm, multilayer cloud situations can also be taken into account. In the *Virga-Sniffer* cloud layers are sorted within a processing interval, which depends on the given input data (here daily data). A cloud layer is identified in the *Virga-Sniffer* by its CBH, which on average differs from other layers over the processing interval by more than the set threshold of 500 m (*cbh_layer_thres*, see Appendix A). The term *layer* is used, if a variable is tied to a specific cloud layer, as the term CBH layer refers to the cloud-base height of one cloud layer.
The CBH input data from the ceilometer must be pre-processed ~~before it is~~ to achieve a sorted CBH layer data set before it can be used for virga and cloud detection (see Fig. 2 box 1). As the *Virga-Sniffer* is designed to work on the radar data coordinates, the CBH input data, on a temporal resolution of 30 s, is interpolated to the radar time-steps (1.6–2.9 s).

2. *L152: The module numbering in Sec 3.1 is a bit counter-intuitive: why not put the smoothing as module 1 (instead of 5) and thus start with module 1?*

* We agree, that the sorting of the modules is debatable, and it would make sense to put *smooth* either as module 1 or 5. In the current design of the Virga-Sniffer, an additional CBH smoothing step is applied before, but not as a part of, the pre-processing modules. The idea was to give the user the opportunity to alter the pre-processing but to also force smoothing beforehand, as it seems mandatory in order to have the pre-processing modules work correctly. Therefore, during 'pre-processing', the *smoothing* is actually only applied at the end. Following this logic, the modules are already sorted in order of occurrence, except *clean&sort* which is frequently applied after each individual pre-processing step. For clarification, we rephrased this paragraph (also see answers to #1.3. and #1.4.) as:

**L151ff**:

~~For this processing~~Prior to configurable pre-processing, CBH data is smoothed to avoid outliers in the input data that would complicate pre-processing. For the pre-processing, modular methods are applied to the CBH input data, which can be individually configured. In total~~five modules (described below) are available~~, five modules are available. These modules are named *clean & sort*, *split*, ~~used settings and thresholds~~ *merge*, *add LCL* and *smooth*. Flags and thresholds used to control in the modules, and their default values, are summarized in ~~Sect.~~Appendix A. ~~Prior to the configurable processing, the CBH data is smoothed, which corresponds to processing module five:~~

3. *L154: what does 5% mean here? 5% of a given time period? Or 5% of vertical extent?*

* Here, we refer to the number of data points of CBH in a cloud layer within the processing interval (see answer to #1.1.). For clarification, we have rephrased this description, also deleting "First,", as this might indicate, that this module is applied first, which it is not, see also the answer to the next remark.

> **L154ff**:
>
> 1. *clean & sort*: ~~First, CBH layers with less valid~~ The valid data-points of each CBH layers are counted and compared to the number of data-points for the total processing interval. If the number is lower than the given threshold of 5 % ~~are~~ by default, the data of this layer is removed (*clean*). ~~Then, for~~ After the cleaning, the remaining layers ~~, the mean height of each layer is calculated. The CBH dataset is then re-indexed, by sorting the layers~~ are sorted in ascending order by ~~mean height~~ comparing their mean height over the processing interval (*sort*). Note that cloud layers in the Virga sniffer are not sorted profile by profile, but by height for the processing interval. This results in gaps, for example in lower layers in broken cover, e.g., caused by trade wind cumulus clouds.

4. *L166-168: this is a very lengthy way of saying that 'two iterations of all 5 steps are made'*

* We agree, that the current phrasing is misleading. Actually, it is not two iterations of all five modules, but two iterations of [split, clean&sort, merge, clean&sort, add LCL, clean&sort] (config = [2, 1, 3, 1, 4, 2, 1, 3, 1, 4, 5], see also Appendix A), and these two iterations are followed by a final smoothing step. We have rephrased this paragraph as:

> **L166ff.**:
>
> ~~For the pre-processing of the EUREC⁴A RV *Meteor* CBH data~~ As default, two iterations of the combination *split*, *merge*, *add LCL* are considered~~, followed by an additional smoothing step~~. The module *clean & sort* is applied in between each step to continuously filter outliers. After these two iterations, a last smoothing step is applied.

5. *L168: I thought that LCL data is optional (Fig. 2), but here it seems to be necessary.*

* Yes, the LCL data is optional, but for the processing of EUREC4A data we provide all optional data to foster the full potential of the tool. We agree, that the phrasing in L168 is therefore misleading, and modified this paragraph as:

**L168ff.**:

Note ~~, that here additional data of LCL is required, which is~~ that the *add LCL* module is used here, which utilizes the optional LCL data. With the additional information about the LCL, the lowest potential cloud layer can be estimated. This supplements the CBH data of the lowest cloud layer, filling in gaps that may occur in the ceilometer data. This ultimately leads to a more complete virga and cloud mask in the *Virga-Sniffer* output. Nevertheless, the use of the module and LCL data is optional, since the main CBH information is provided by the ceilometer. To use the full potential of the Virga-Sniffer, the LCL is included here. The LCL is calculated from surface observations of ~~air~~ atmospheric pressure, temperature, and humidity from the meteorological observation station on the RV *Meteor* using the method of Romps (2017) ~~, which is build into the~~ built into the utilities of the *Virga-Sniffer* package~~utilities~~.

6. *L175: I don't remember a definition of 'valid radar reflectivity'.*

* We have added an explanation to the text accordingly.

**175ff.**:

After the pre-processing of CBH, the radar reflectivity values ~~, specifically the Boolean mask of valid reflectivity values, is~~ are used for the initial step of detecting precipitation, clouds and cloud-top heights (CTH) ~~. This is done by successively iterating~~ (see Fig. 2 box 2). A Boolean mask is created, which yields True if the radar reflectivity ~~mask~~value is not a nan-value, meaning any kind of particles are detected by the radar in the given time and altitude. This mask is successively iterated, starting from each cloud-base in both up- and downward direction. To do this, the values of the cloud base must be mapped to the radar range-gate resolution, each of which has a certain vertical extent. Precipitation events are generally detected from the range-gate containing the measured cloud base, whereas clouds are detected from the next higher range-gate. This step is referred to as range-gate mapping in Fig. 2.Figure 3 shows a demonstration example for precipitation, virga and cloud detection.

7. *L200ff: These clarifications are helpful, but e.g. the minimum virga length requirement is only mentioned in Sec 3.3, and comes as a surprise here. These examples could thus be moved after Sec 3.3. Furthermore, instead of just writing 'maximum allowed gap for virga', the chosen default threshold could be mentioned again (I actually thought that 700m is a typo, it seemed too large for me – so repeating it would clarify this choice).*

* We added the default threshold values as well as a reference to Sect. 3.3 and the Appendix. Except for *minimum_rangegate_number* the sketch refers to maximum allowed gaps of virgas and clouds, and therefore mainly refers to Sect. 3.2. We opt to keep the Figure in place but added another schematic sketch as panel (b). The changes in the text are summarized in answer to #1.8.

8. *L204: What is rg19 then? Did the ceilometer miss this second cloud layer due to the strong rain? This should be discussed.*

* Yes, if the clouds in the lower layer are optically too thick, the clouds in the upper layer might not be detected by the ceilometer. This statement is added as shown below.

**L199ff.**:

Virga and cloud detection is sketched in Fig. 3 to highlight special cases and usage of certain thresholds . Special cases demonstrate the usage of thresholds handling gaps in the radar reflectivity signal. The specific cases of Fig. 3 panel (a) are:

- *time-step* = *1*: The standard case, when precipitation and cloud are detected from the observed CBH. No further considerations have to be made.
- *time-step* = *2*: The gap (range-gate (rg) 7–8) is smaller than maximum allowed gap for virga (*precip_max_gap* = 700 m) to count rg 6 as virga, but rg 6 is filtered since the requirement of minimum virga length of 2 rg is not met. , which is a requirement of the virga mask refinement based on the threshold *minimum_rangegate_number* (see Sect. 3.4 and Appendix A).
- *time-step* = *3*: The gap (rg 7–8) is smaller than the threshold, therefore rg 3–6 are counted as virga.
- *time-step* = *4*: The In addition, the gap (rg 7–1117–18) is larger than the threshold, maximum allowed gap for clouds (*cloud_max_gap* = 150 m) therefore rg 3–6 are 19 is not counted as virga. In addition, the cloud. In this case, rg 19 could be a cloud, but since the *Virga-Sniffer* detection is tied to the CBH input data, rg 19 cannot be identified. Missing information about the second cloud layer can occur if the ceilometer signal is strongly attenuated by the clouds of the lower layer or by strong precipitation.
- *time-step* = *4*: The gap (rg 17–187–11) is larger than the maximum allowed gap for cloudsthreshold, therefore rg 19 is 1–6 are not counted as cloud. virga. Therefore, the rain flag at the surface has no effect, as the virga detected in rg 12–14 does not reach the first rg.
- *timetime-step* = *5*: Rain is observed Precipitation is detected from (rg 1–14) as the gap (rg 7–8) is smaller than the threshold. Due to the rain flag at the surface (either by the additional data of surface rain flag, or by exceeding the radar reflectivity threshold in the lowest rg)radar rg, therefore *ze_thres* = 0 dBz), no virga is assigned in this profile.
- *time-step* = *6*: Same as *time-step* = *5*. In addition, the gap (rg 17) is smaller than the maximum allowed gap for clouds, therefore rg 18–19 are counted as cloud. The surface rain flag doesn't lead to a reclassification of the detected virga towards rain, as the first rg has no data.
- *time-step* = *7*: Same as *time-step* = *6*. In addition, another CBH layer is observed right below rg 19. This CBH layer is not considered, as the gap at rg 17 is smaller than the maximum allowed gap for clouds, and it is not possible to distinguish between clouds and precipitation due to that. Therefore, the lowest CBH is assigned, as in time-step = 6 to initialize the detection of clouds and precipitation and the higher CBH is ignored per default (*cbh_connect2top* = False).

9. *L210: This step of virga mask refinement is thus not optional (as suggested in Fig. 2, part 3))?*

* Every step in the 'virga mask refinement' is entirely optional. This had not been made entirely clear previously and was now modified. We have separated step 3 into the mandatory virga detection using the radar-based rainflag given by the reflectivity in the lowest radar range gate and the optional virga mask refinement:

**L145ff.**:

The workflow of the virga detection is separated into three parts, as summarized in Fig. 2:

1. Preprocessing of CBH
2. Precipitation and cloud detection
3. Virga detection
   (a) Masking rain events
   (b) (Optional) ~~Virga detection~~ virga mask refinement

Note, all modules in the virga mask refinement are entirely optional (step 3b). In order to separate rain and virga events (step 3a) the *mask_rain_ze* module is used, which is based on the radar reflectivity values in the lowest range-gate. Potentially, the *Virga-Sniffer* can be used to mask both rain and virga by opt out of using the rain masks *mask_rain_ze* and *mask_rain*.

10. (Fig.) *4: what does 'filled cloud base' mean?*

* We added an explanation to the figure caption.

**Fig. 4 caption**:

LIMRAD94 reflectivity factor $Z_e$ (panels (a), (c), (e)) , and *Virga-Sniffer* output for different cloud situations during EUREC[4]4A based on RV *Meteor* observations ~~. The colorbar~~ (panels (b), (d), (f)). The colour bar on the right side panels ~~denote the maximumd~~ denotes the maximum number of cloud layers detected during the case study days (count starts at zero for the lowest layer). Panels (a) and (b) show ~~stratocumulus~~ stratiform cloud layers with virga and a warm precipitation system, panels (c) and (d) ~~altocumulus~~ stratiform cloud layers with virga, and panels (e) and (f) trade wind cumuli with virga. The dotted line labelled "filled cloud base" refers to either LCL values which fill in gaps during the CBH pre-processing or CBH gaps which are filled by interpolation (see Sect. 3.1 and Appendix A).

11. *L269: I don't see the multiple layers at 05:00 in Fig. 5. Is the 'filled cloud base' considered as a cloud? If so, I'd find this problematic, because there is obviously no cloud there.*

* You are correct, there are no multiple layers of clouds at 05:00 UTC, this might have sneaked in while preparing the manuscript, thank you for reading carefully and pointing this out. We have deleted 05:00 UTC from this sentence, as this

paragraph is dedicated to the 05:45 UTC time-step. No, the "filled cloud base" is not considered as a cloud, rather as a potential cloud base, from which the cloud and precipitation detection is initiated.

12. (Figures) *4&5: Zooming into the detected virga (e.g. Fig 5c, around 04:40 or 05:45), the sub-cloud layer virga is not continuously detected, potentially due to surface rain or (for stratiform inversion cloud) positive Doppler velocity. I find that a bit problematic, as physically these rainshafts should be considered as one object, and the on-off-virga detection is a bit arbitrary. See also my major comment #3.*

   * Yes, for some profiles, the radar reflectivity at the lowest level is larger than the threshold of 0 dBz, which is considered to have rain reaching the surface. We agree that the precipitation events recognized as "on-off Virga" and the intervening rain should be physically counted as one precipitation event from this cloud. The current version of the Virga-Sniffer does however not include temporal aggregation and segmentation of precipitation events. We focus here on the profile-by-profile evaluation of whether precipitation reaches the ground, or whether a particular time step can be considered virga. Therefore, the precipitation analysis is tied to time rather than a specific cloud or precipitation event (e.g., within an hour, there were 50% clear skies, 25% clouds with no precipitation, and 20% clouds with precipitation classified as virga, and 5% clouds with precipitation classified as rain). We agree that the identification of aggregated virga/precipitation events is very interesting and would allow for cloud/situation specific analysis of precipitation and could be implemented as an enhancement in the future.

13. *To clarify the reason why some sub-cloud layer rain is not classified as virga, it would be helpful if Fig. 4 & 5 could also show the surface rain flag.*

   * We agree and added the rain flag in both figures.

14. *The beginning of the summary section 5 mentions that profile-by-profile information is used. I think this information should come at the beginning of Sec. 3, together with information about the temporal resolution of the analyses (e.g., it is unclear what temporal resolution the ceilometer has), and reference to the appendix, which summarizes the configuration (I only realized after the summary that there is an appendix).*

   * We added this information to the beginning of Sec. 3 accordingly. The changes are summarized below the answer to #1.1.

15. *I also have some issues with Fig. 2, as (i) the gray thin lines in Fig. 2 are hard to see on my print out, and (ii) the figure claims some steps to be optional, which are discussed as necessary in the text (see above).*

   * (i) We increased the line width in Fig. 2. (ii) Indeed, all steps marked as optional in Fig. 2 are optional modules in the Virga-Sniffer algorithm. See answer to #1.9. Nevertheless, we have separated the obligatory virga detection based on the radar reflectivity value in the lowest radar range gate (Step 3a) from the optional virga mask refinements (Step 3b), although in principle it is up to the user whether to use it or not.

16. *For Figure 3, the coloring is ambiguous, because detected cloud and virga should also be partly green, because they have a valid Ze. So maybe make two masks (one input and one output), or hatch the boxes with valid Ze. It would also be nice to have an example of a multi-layered cloud situation here.*

  * We agree, and updated the figure to an unambiguous labelling. Note, we have also changed the colours for cloud and virga masks in related figures, and changed the label of "radar signal" to "unclassified".

**Major comment #2: Cloud type classification**

*I have some issues with the cloud type classification here. During EUREC4A, I don't remember any situations of stratocumulus or stratus clouds. However, deeper trade cumulus clouds with extensive stratiform cloud layers were very frequent. But these stratiform cloud layers were at some point detrained from a cumulus core rooting in the sub-cloud layer. I.e., the convection and cloud formation was surface-driven and not cloud-top driven as in stratocumulus. From a ground-based single-point perspective, this distinction is of course not easily made, because you might only capture the stratiform part of a cloud.*

*Although the classifications used here might be in line with the Stratocumulus Cumulogenitus (CL = 4) class of the WMO cloud atlas, I would encourage the authors to reconsider their cloud type classification. In the broader EUREC4A or trade cumulus community, we usually use different names for this 'cloudiness aloft' components, which are often called 'stratiform (cloud) layers', 'stratiform inversion cloud', 'shallow anvils', or sheared edges of deeper trade cumuli. Nuijens et al. (2014) or Vial et al. (2019, https://doi.org/10.1029/2019MS001746) are good references for how to deal with these naming issues.*

We acknowledge that in our initial manuscript version, the cloud classification terminology for stratiform clouds differs from the one generally used the trade wind community. When looking through the R/V Meteor sounding data, we saw cases where the radiosondes combined with radar and ceilometer measurements indicated the presence of stratocumulus clouds, given by an unstable layer or even elevated mixed layer aloft (i.e 21.01.2022 18:45 UTC or 24.01.2020 00:28UTC). In general, many moist layers below the trade inversion where rarely completely stable, but often showed at least some weak instability. As suggested by Vial et al. (2019), we decided to also follow the cloud classification nomenclature of the broader trade cumulus community and will call the Stratucumulus Cumulugenitus class of the WMO cloud atlas "stratiform cloud layers".:

**L17ff.**:

The most important virga-producing clouds were either anvils of convective cells or ~~stratocumulus clouds~~stratiform cloud layers.

**L29ff.**:

The other third consists of clouds bases above 1 km, mainly ~~stratocumulus, stratus~~ stratiform cloud layers or cloud edges near the trade wind inversion at 2–3 km (Nuijens et al., 2014, 2015).

**L32ff.**:

Therefore, precipitation generally occurs as light rain/drizzle from ~~stratocumulus and stratus~~ stratiform cloud layers or as showers from well-developed trade wind cumuli (Austin et al.,1995; Baker, 1993).

| **L319ff.**: |
|---|
| In these heights, mostly ~~stratocumulus~~ stratiform cloud layers are present, reaching up to the base of the trade inversion. |

| **L329ff.**: |
|---|
| Those are mostly ~~stratocumulus~~stratiform cloud layers, cloud edges and anvils of convective cells spreading under the trade inversion. Virga depths smaller than 0.3 km often occur from shallow ~~stratocumulus~~ stratiform cloud layers with depths below 0.5 km |

| **L334ff.**: |
|---|
| Those clouds are mainly thick ~~stratocumulus~~ stratiform cloud layers and anvils below the trade inversion, with a cloud base that is high enough to produce deep virga. |

| **L372ff.**: |
|---|
| Clouds with bases between 1 km and 4 km, which are either cloud edges of convective cells or ~~stratocumulus~~ stratiform cloud layers forming below the trade inversion, were identified as important virga producers. ~~Stratocumulus and stratus~~ Stratiform cloud layers with their base around 1.5 km and 2.5 km frequently produce either virga with small depths up to 200 m or virga reaching the lowest radar range gate. |

**Major comment #3: Virga vs. evaporation from rainshafts that reach the ground**

*I miss the motivation for focusing only on virga rather than all rainshafts. Although raining clouds are less frequent than clouds with virga (your Table 3), in terms of their contribution to total rain evaporation they are likely still very important. So when the main reason motivating this study is to (eventually) investigate rain evaporation, why focusing only on virga? In my eyes, the only physical reason that distinguish virga from other rainshafts is that total versus partial re-evaporation is relevant for the isotopic signal (Torri 2021, https://doi. org/10.1029/2020JD033139). But e.g. from a moisture or heat budget point of view, it doesn't matter whether rain reaches the surface or not. It would be great if the authors could discuss their reasons for their focus on virga more explicitly.*

The authors agree that from an atmospheric perspective, it is true that besides full rain evaporation (as in virga), partial rain evaporation that occurs when rainfall reaches the ground is important and also influences the atmospheric heat and moisture budget. To differentiate between both, we have made our wording more precise by adding "full vs partial rain evaporation" throughout the manuscript. However, for the hydrological cycle it does make a difference if rain evaporates fully or only partially. In marine settings, rain reaching the ground changes the surface water salinity and temperature. Rain reaching land surfaces is important for vegetation and can be stored in the soil. Since satellite precipitation products (like from CloudSat or GPM) have a blind-zone in the near-surface region, biases in total precipitation estimates occur. Knowing if rain reaches the ground or if it fully evaporates can thus also be important for evaluating satellite-based rain statistics. We have added this motivation in the introduction and the outlook:

| **L42f.**: |
| --- |
| While both - full subcloud evaporation of precipitation resulting in virga as well as partial precipitation evaporation in which rain still reaches the ground - are important, the focus of this manuscript is to introduce a tool that allows for identification of virga. Besides the need to distinguish partial vs. full evaporation due to their different implications for the biosphere, the tool could be used to evaluate satellite-based rain statistics which suffer from blind-zone effects in the near-surface region leading to biases in total precipitation estimates as shown e.g. by Valdivia et al. (2022). |

| **L387f.**: |
| --- |
| Our virga identification tool might help to evaluate satellite-based surface precipitation statistics suffering from blind-zone effects as indicated by Maahn et al. (2014) and Valdivia et al. (2022). |

## Minor comments

- *Review of earlier approaches of virga detection or rain evaporation retrievals: In the introduction, I missed a review of earlier work focusing on virga and rain evaporation in the trades. E.g. Sarkar et al. (2020, DOI: 10.1175/MWR-D-19-0235.1) is a study that comes to my mind, but there are for sure others.*
- We acknowledge that there is much more work on precipitation evaporation retrieval that we have not included in the introduction. The reason for this is that our work is mainly focused on a technical approach to virga detection and the study of trade wind cumulus clouds here serves as a case study. The EUREC$^4$A dataset was used as a basis for the development of the tool, and in the future we plan to use the *Virga-Sniffer* at other geographical locations. For this reason, we prefer not to expand the introduction with papers focusing on the trade wind zone. Instead, the introduction favours papers that use cloud radar Doppler spectra for precipitation evaporation studies, such as the cited references by Xie et al. (2016) and Tridon et al. (2017). We have expanded the literature review of studies on rain evaporation via radar observations. For details please see our response to Comment 43 of reviewer 3.
- *Results for single cloud layers: Sec. 3.5 showed that most challenges and limitations pertain to multi-layer cloud situations. To increase the robustness of the results, it would be great to see how the results (e.g. in Fig. 8 and 9) change if only single-layer clouds are considered. These results will likely be more trustworthy.*
- It is true that mainly in situations with multilayer cloud cover sources of error of the *Virga-Sniffer* appear. However, the main problem is when the cloud layers are not clearly distinguishable from each other, such as in big convective rain systems, where the measured CBH is influenced by updrafts and downdrafts. Therefore, we find no significant deviations from the figures shown if we exclude (clearly delineated) multilayer cloud cover, as illustrated in Fig 1 below.
- *Comparison with Cloudnet target classification: How often does Cloudnet detect drizzle / rain when the VirgaSniffer doesn't detect anything? I think the comparison in both directions is important.*

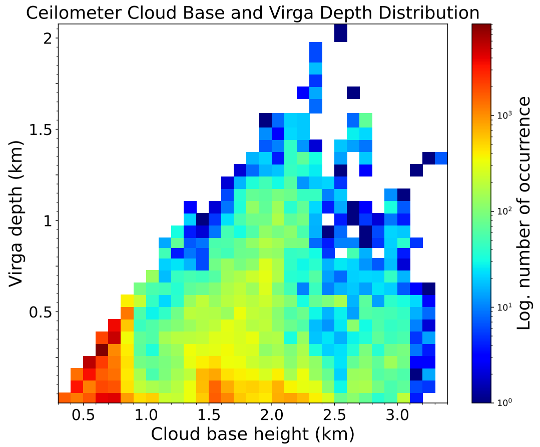


**Figure 1.** Single layer cases cloud base height and virga depth.

– We added an analysis according to your suggestions

> **L289f.**:
>
> It is also possible to assess the performance of the *Virga-Sniffer* by only taking into account situations without rain reaching the ground, no rain observed in the lowest radar range-gate and the virga classified by the *Virga-Sniffer*. During these situations the *Virga-Sniffer* misses 15 % of cloud and precipitation related Cloudnet targets (excluding clear sky, aerosols or insects targets). This is mainly due to the determination of the cloud base in the *Virga-Sniffer*. In certain situations, the cloud base used in the *Virga-Sniffer* is lower than the cloud base used in CloudnetPy. As a result, data points in between the cloud bases from CloudnetPy and the *Virga-Sniffer* are identified as the drizzle or rain Cloudnet class, but as cloud by the *Virga-Sniffer*. These situations include: (i) When precipitation connects multi layers of clouds, where the *Virga-Sniffer* retains the lowest CBH only (see Sect. 3.2); (ii) The LCL, which is usually lower than the observed CBH, replaces the lowest CBH layer of the *Virga-Sniffer* (see Sect. 3.1).

– *Commas: I'm not an expert on commas, but I feel that some additional commas would ease the reading. I made some suggestions in the annotated pdf.*

– Thank you, we have taken them into account.

### Technical corrections

*Please find some technical suggestions in the annotated pdf.*

Thank you, we have taken the suggestions into account, which definitely improves readability.

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