

Interactive comment on “Evaluation of gridded Scanning ARM Cloud Radar reflectivity observations and vertical Doppler velocity retrievals” by K. Lamer et al.

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The authors would like to thank the reviewer for his comments that will definitely help improve this manuscript.

Answer to specific major comments:

Page 6, line 18, how are cloud bases “detected” or determined? It has not been mentioned before. And why 5°C? Are you assuming no insects exist below 5°C? And, can you provide more details about how is the linear depolarization ratio used to distinguish insects from clouds, such that a feature mask is truly hydrometeors only?

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The details of the insect-filtering algorithm were recently published at the Journal of Atmospheric and Oceanic Technology. The reviewer is kindly asked to see the following paper and its early, online view for more details: Kollias P., I. Jo P. Borque P., A. Tatarevic, K. Lamer, N. Bharadwaj, K., Widener, K., Johnson and E. Clothiaux 2013: Scanning ARM Cloud Radars – Part II: Data Quality Control and Processing. Online release, Journal of Atmospheric and Oceanic Technology 2013; e-View doi: <http://dx.doi.org/10.1175/JTECH-D-13-00045.1>. Below is a summary of the insect-filtering algorithm described in Kollias et al., 2013: The insect-filtering algorithm is applied only to Ka-SACR returns at heights with temperatures higher than 5 °C. According to Luke et al., 2008, insects are rarely found in temperatures colder than 10 °C. If there are significant radar detections at temperatures warmer than 5 °C, the next step is to use the ceilometer cloud base height detections within a one-hour window around the time of interest. If there are no cloud base height detections in the lowest 3 km within the one-hour window (this situation is frequently encountered during the summertime over the SGP site), then all low-level SACR detections are flagged as insects. If the ceilometer detects cloud bases in the lowest 3 km within the one-hour window the average cloud base height is used to constrain the maximum height to which the insect-filtering algorithm is applied. A LDR threshold value of -15 dB is initially used to conservatively distinguish insect (LDR > -15) and hydrometeor returns (LDR ≤ -15). A two-dimensional filtering mask similar to the one applied for the FM is then applied to remove remaining insect-contaminated radar returns. Our ability to distinguish clouds from insects is limited near the cloud edges. In the future, the algorithm will be continuously evaluated and improved using coincident DWR and LDR measurements at 35- and 94-GHz frequencies when available.

To better orient the reader we will modify p. 9584 line 26-28 to: A detailed methodology of the quality-control processing of the SACR observations (feature mask, insect filter and Doppler velocity unfolding) can be found in Kollias et al. (2013b, in review).

Figure 2, the lines are confusing to read due to lack of contrast, why not just plot the

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standard deviations as error bars, or use different colors for cloud vs. drizzle?

We agree with the reviewer. Below is a revised figure.

Figure 8d, the interpolated vs. polar coordinate reflectivity during certain time seem to have significant differences (e.g. between 1-2 min, 3.5-4.5 min, 10.5-11.5 min), where the polar coordinate data are consistently lower than the interpolated one. Why is that? If the times between two actual observing points (both cloudy) are simply just interpolated in between, shouldn't we expect that at the time that is not interpolated, the gridded data should be the same with the original data? Similarly such difference is seen in Doppler velocities in Fig. 9d too.

The reviewer raises a valid point. To clarify, the gridding is a two-step process. First, the SACR coordinate system radar data (range, elevation) are mapped in a 2-D x-z grid (using cressman, barnes, maximum or mean value). Subsequently, the data are interpolated/extrapolated along the time dimension. What is plotted in the figure is not the interpolated x-z grid data, but rather the raw SACR observations at the radar native coordinate system. It is conceivable that the none-linear interpolation in x-z in areas of large reflectivity gradient can contribute to the observed differences. Moreover, the range resolution in polar coordinates is 30 meters, while the interpolated data has a range resolution of 25 meters. It is thus impossible to select the same heights to compare the polar coordinates and interpolated times series. The displayed time series are taken about 10m apart in height, which might also contribute the slight differences. We believe that those figures still carry the key message that the gridded Ka-SACR data captures the major eddies responsible for mass and momentum transport through the cloud.

Section 4.1, Since the projection of horizontal wind onto the radar line-of-sight is critical to decomposing horizontal and vertical velocity, and a fundamental assumption is that the radar is scanning perpendicular to the mean wind direction, which is based on 4/day sounding, can you discuss how these prerequisites would impact the result of

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your vertical velocity retrieval? For example, what if the mean wind direction changes by 30° and thus there is additional horizontal velocity projected on the CW-RHI scans? How much error would it introduce to your proposed retrieval method?

We agree with the reviewer that the possibility of wind direction changes within a 6-hr period can create a projection of the horizontal wind in the CW-RHI scan plane. This is particularly true in the presented cases since the SACR currently uses a wind direction based on climatological analysis of horizontal wind data over the ARM site.

The proposed technique presented in this manuscript doesn't assume that the radar is scanning perfectly perpendicular to the mean wind direction. The proposed technique assumes that there is always a projected horizontal wind in the scan plane. In fact, the magnitude of the projected horizontal wind velocity on the radar scan plane will increase the scan departs from the cross-wind position. Thus, the proposed technique estimates and removes the projected wind using the actual radial Doppler velocity measurements.

Below is a relevant excerpt from the document:

Page 17, line 25: The input to the VD,V retrieval technique are the 2-D CW-gridded RHI planes. The retrievals are performed at each gridded height with hydrometeor detections and for all the 2-D gridded planes that compose a 19 min set (380 for $\Delta t = 3$ s). First, at each constant height all VD, θ observations at elevations 75° – 105° are averaged to produce a first estimate of the average value of $\langle VF \rangle$.

Subsequently, all VD, θ observations at elevations lower than 75° or higher than 105° are used to produce estimates of VH, RHI at each elevation using the following formula:

Rather than estimating the mean and the standard deviation of the $VH, RHI(_)$, a linear model of $VH, RHI(x)$ is fitted to the dataset $(x, VH, RHI(x = z \tan(\theta) - 1))$:

The intercept (β , ms^{-1}) represents the bulk of VH, RHI and the slope (α , s^{-1}) is introduced to quantify small linear trends.

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On that related note, such CW-RHI scans can only focus on one particular cloud type at one time. If there is a significant vertical wind shear (e.g. between boundary layer and upper level, very common), how would that affect the other type of clouds that is not being “cross-wind scanned”? The authors need not provide any quantitative analysis, but discussions to these conditions should be provided so that potential users of the data will be aware of the limitations of the proposed method and data product.

We accept the reviewer comment. The following text was added in the summary section: “The CW-RHI scan strategy can only focus on a particular cloud layer/type since typically the wind direction changes with height. Thus, a prioritization based on the scientific objectives tied to the operation of the SACR at the ARM site is need to select a particular cloud type (e.g., boundary layer clouds, cirrus clouds) or atmospheric layer (e.g., middle or upper troposphere) that will be of interest. This information along with the profile of the horizontal wind will be available in the dataset to help potential data users”.

Page 17, line 22-24, what does “a large number of points” mean? How large? 80%, 90%? Please be more specific.

It is difficult to assess how many points are required to get an accurate retrieval. In theory, one point on each side of the radar should be sufficient to observe the sinusoidal behavior of the projection of the horizontal wind speed on the radar slant-path. However the addition of vertical air motion component and radar reflectivity-weighted particle fall velocity component add “noise” to the retrieval and can distort the sinusoidal curve. The higher the number of radial Doppler velocity measurements available at a particular height the higher the confidence we have in the retrieved projected horizontal wind component. One way to assess the number of points needed at each CW-RHI plane we estimate the mean and standard deviation of the projected wind component retrieved at each height from all scan planes. The standard deviation allows us to filter out outlier and bad estimates of projected wind. A sanity check is performed before the horizontal wind correction is performed. Only CW-RHI planes attaining an 85% fit

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of the sinusoidal wave at each level from cloud base to cloud top are corrected for horizontal wind contamination others are flagged. Also, the fact that we smooth the bulk wind velocity and its slope over the time of the set would allow us to remove outliers and increase our confidence. We propose to apply the technique in all situations and assess the quality of the retrievals by looking at the standard deviation of the vertical velocity retrievals and treat them as error bars.

Fig. 11b, the retrieved vertical velocity still shows some radial components, especially within ± 1 km range. There is no reason to believe the cloud vertical motion to behave this way (i.e. downdrafts across the cloud toward a single point at the ground), can you comment on why this is the case? Fig. 11d did not show such “feature”, although the choice of colorbar is a bit confusing as 0 vertical velocity shows up as red, so it is hard to visualize updraft vs. downdraft. Is it possible to adjust that (e.g. equal \pm values center at 0) if you have determined most of ice particles are falling (negativeVD) anyway?

The reviewer is correct to point out this issue. The issue is also visible in the “raw” radial Doppler velocity data (Fig. 11a). Thus, we are confident that these “titled” features are generated by the way the radar samples the cloud. We are currently investigating this issue with the ARM radar engineers. One possibility is the following: The Ka-SACR uses pulse compression to increase the radar sensitivity of the radar and thus compensate the loss of sensitivity due to the short signal dwell. It is possible that there is imperfect deconvolution of the received pulse and this “stretches” radial Doppler features. The large-eddies in boundary layer clouds are more pronged to this effect since their size (~ 300 - 400 m) is comparable to the length of the pulse compression pulse (~ 600 m). In cirrus clouds, the dynamical features are controlled by lower frequency phenomena (e.g., gravity waves) and thus are more tolerant to this effect.

Page 19, line 22-26, the standard deviation of VD,V greatly increases beyond just 2 km range, what does this mean in terms of the accuracy of the vertical velocity retrievals? Does it mean that they should not be trusted at all? Or does it mean it is still usable

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if the users are willing to accept a certain amount of uncertainty, and what would that uncertainty be? Simply pointing out the obvious that error is larger does not give users much useful information of what to do with it. Further, did you look at other stratocumulus cloud case? Is this a common feature in low clouds? What does it mean when implementing this algorithm to future retrievals in terms of the range/volume of usable vertical velocity retrievals?

Statistically, the variance of the VD,V should be independent of the SACR range. The low value observed near the radar at high elevation angles is indicative of the amount of turbulence at scales resolved by the SACR. The increase in the standard deviation of the VD,V with range is a direct result of noisiness in the retrieval due to the decreased contribution of VD,V to the observed radial Doppler velocity. The surplus in standard deviation is a measure of this uncertainty. Certainly these variance measurements can be used for turbulent studies and the retrieved VD,V should not be recommended for microphysical retrievals. One could still use these vertical velocity retrievals to make a confident statement about the location of updrafts and downdraft in clouds for example. We applied this technique across many stratocumulus cloud cases and the observed broadening of the standard deviation at elevation angles lower than 60 degrees and higher than 120 degrees is typical.

Page 22, line 10, have you actually shown in the results that max value interpolation method near cloud edges perform better than the other methods? How would you implement such hybrid interpolation method? What criteria are needed to define a volume that is at/near cloud edges (e.g., fraction of cloud mask)? Please provide more details.

It is well known that the quality of Doppler radar observations depends on two factors: the Signal-to-Noise Ratio (SNR) and the radar Doppler spectrum width that is an indicator of how uncorrelated the radar samples are. Near cloud edges the reflectivities are very low and close to the noise floor and thus the signal to noise ratio is low. As a result, all radar Doppler observables (reflectivity, mean Doppler velocity, spectrum

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width, LDR) will have high uncertainty. This is the reason we propose the use of the max value interpolation at these areas. One way to implement such a hybrid scheme is described below: For each grid point (x,z) the radius of influence help us to determine the fraction of cloudy vs non cloudy points. If more than 50% of the points are non-cloudy, then we use the max value interpolation scheme.

Answer to minor comments

Page 5, line 9, what does "land contamination" mean exactly? Contamination by aerosols? Clouds? It is unclear.

The sentence has been modified to: "The close proximity of this site to the ocean enabled observations of marine stratus because low-level winds often advect these clouds shoreward."

Page 8, line 10, what about sensitivity at 20 km? It should be provided since that is the maximum operating range according to the authors.

Following table 1, the sensitivity of the KaSACR at 20km is -24dBZ.

Figure 12, some caption seems missing, I assume the "fitted projected horizontal wind contribution (VH,RHI)" is the blue line?

The figure caption has been modified to:

Fig. 12. Nineteen min averaged Doppler velocities at the middle of: (a) a stratocumulus cloud layer and (b) a cirrus cloud case as a function of range from the radar. The 19 min average implies that all 3-D gridded CW-RHI planes at this height have been used to estimate the mean and variance of the retrieved Doppler velocities. The radial observed Doppler velocities (VD,θ) are shown in red, the fitted projected horizontal wind contribution (VH,RHI) are shown in blue and the retrieved vertical Doppler velocity (VD,V) in black. The standard deviation of the retrieved vertical Doppler velocity is in dashed grey.

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Technical corrections

Page 3, line 10, "... the lack of factual 3-D cloud structure ...", do you mean "actual"?

The sentence has been corrected.

Page 3, line 12, "... in cloud properties retrievals", should be just "cloud property retrievals".

The sentence has been corrected.

Page 3, line 25, "On the contrary, scanning cloud radars ... deploy innovative scanning strategies such as ...", radar cannot "deploy" scanning strategy by itself.

The sentence has been modified to: On the contrary, scanning cloud radars need to sample the part of the atmosphere near and above the ground-based facility, and thus, execute innovative scanning strategies such as the cross-wind scan strategy (Frisch, Fairall and Snider 1995) scan strategy.

Page 8, line 7-9, this sentence does not read right, I suggest separate the SGP and NSA sites into two sentences to be more clear.

The sentence has been modified to: For instance, at the ARM SGP, shallow cumuli represent an even more challenging target to detect. In contrast, at the ARN NSA site, the presence of highly reflecting ice particles for most of the year decreases the dependency to the radar sensitivity.

Page 21, line 25, "The suitability of a CW-RHI to addresses the need ...", should be "to address" the need.

The sentence has been corrected.

Page 21, line 26, "The Ka-SACR observations are initial post-processed ...", should be "are initially post-processed".

The sentence has been corrected.

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Page 23, line 5, "... are noisy for elevation angle lower than 60° ...", should be "lower than".

The sentence has been corrected.

Interactive comment on Atmos. Meas. Tech. Discuss., 6, 9579, 2013.

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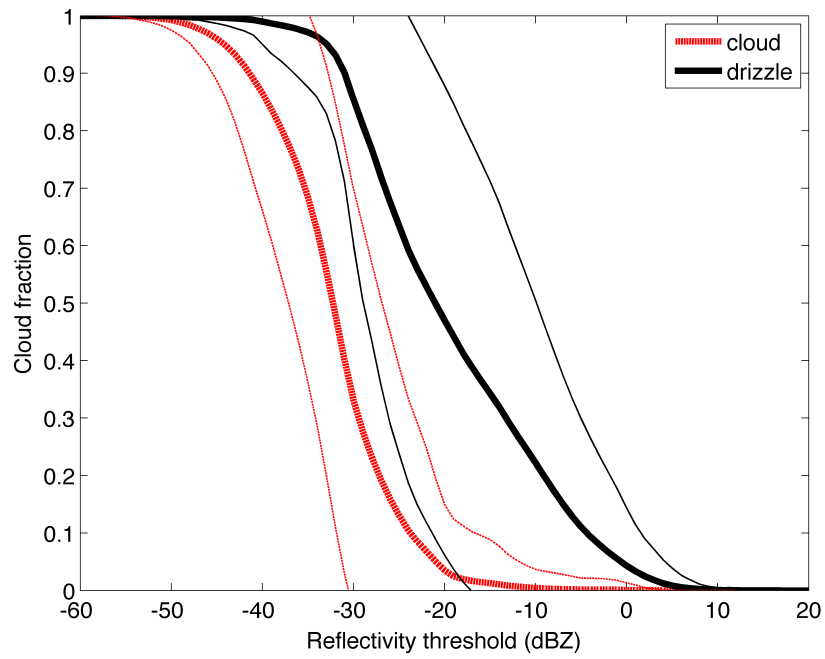


Fig. 1. Figure 2: The radar-detected cloud fraction (mean (thick lines) and standard deviation (thin lines)) for boundary layer clouds at the Azores during the CAP-MBL deployment as a function of the radar se