

Final Author comments:

Review Alain Protat.

Comment 1:

There is a need for a better discussion in the introduction about the instrumental combinations that have been explored in the past (last paragraph of p. 2 and beginning of p. 3), not only the dual-frequency and radar-lidar : radar + IR radiometry (e.g., Mace et al. 1998), radar reflectivity and air temperature (Hogan et al. 2006; Protat et al. 2007), radar reflectivity+ Doppler (Matrosov et al. 2002; Delanoe et al. 2007; Deng et al. 2006). The list of papers about radar-lidar should also be expanded (Tinel et al. 2005; Wang and Sassen 2002). There is also a new type of algorithms that treats both the radar-only, lidar-only and radar-lidar parts of the clouds under study (Delanoe and Hogan 2008; Deng and Mace 2008) that need to be mentioned to be exhaustive.

Answer:

The list of paper mentioned in the comment will be added in the introduction.

Comment 2:

The description of the radar processing (section 2.2) needs to be improved. The Nyquist velocity of the radar should be mentioned. In section 2.2.4, I don't understand why additional steps are needed when the SNR is high (line 21, page 7), which should be easiest to process. Also regarding the additional clipping (end of p. 7), there is a suggestion that the threshold should be -15 dB for sLdr. But we have no indication that this threshold works in all conditions. Is there any evidence that you could show to make the case stronger?

Answer:

It is of great importance to note that two distinct types of radar processing are performed on the TARA data. The first processing steps are considered as the standard ones and are based on the work of Unal and Moisseev, 2004 and Unal, 2009. On the one hand, this first standard processing guarantees an optimum trade-off which is meant to keep the maximum atmospheric echoes while removing as much as possible the noise for any atmospheric situations.

On the other hand, the additional processing ensures a total noise and spectral fluctuation removal in order to use spectral polarimetry for cloud microphysical retrievals where high correlation between spectra in height and time is required. This additional processing is still in an experimental phase and is therefore first tested on high SNR only. However, even at high SNR, additional processing needs to be carried out in order to discard echoes which do not satisfy the current retrieval technique based on second order polynomial approximation. This second processing step is even more required in ice cloud regions where spectral clutters remain much more present than within precipitation regions after the standard processing is being applied.

In order to clarify this two radar processing steps, the sub-section of the additional processing will be shifted to Section 3, related to the application of spectral polarimetry on ice cloud microphysical retrieval. Figure 3 will be also improved by adding information on the unwanted echoes to be removed in the sZdr spectra.

Finally, a Table showing the main characteristic of TARA (such as the Nyquist velocity of about 3 cm.s^{-1} , radar elevation, range resolution, transmitted power) will be added (Figure 1 might be removed on demand if the reduction of the number of figures is required within the overall paper)

Comment 3:

In section 3.4.2, p. 16, first paragraph. I would show the Doppler and Zdr in the zoom of Fig. 10 because you have only one case to show and because I am not convinced by the arguments presented in the text. This would allow a better discussion to be made with all the pieces of information at hand. For instance, from what I see, I don't trust the physical interpretation of the change in microphysics observed between 16.30 and 16.32. It looks more like an instrumental problem than a switch to dominant pristine habit in a region of high reflectivity that does not look so different from the surrounding profiles. This particular point deserves more study of the observed radar variables (and maybe transmitted power if you measure it).

Answer:

Because of the experimental approach of this new technique, great care has been taken in order to avoid any instrumental problems which would lead to misinterpretation of the microphysical results. The processing has been performed directly on raw data which have been stored for this purpose. Furthermore, no discontinuities throughout the all column of atmosphere, which would indicate an instrumental failure, could be noticed in either the reflectivity profile or the Mean Doppler velocity profile. Finally, a disturbance within the transmitted power (not monitored during the measurement) would not have any impact on the retrieval result of Figure 10b which is based on sZdr categorization algorithm, and therefore not affected by the absolute value of the reflectivity.

However the reviewer is right to point out the weakness of the arguments which is provided in the text in Section 3.4.2. The argument was built upon the interpretation of the Mean Doppler velocity and Doppler width profiles measured by the TARA radar. For this particular day, the horizontal wind direction was found to be orthogonal to the TARA line of sight (as observed from the ECMWF deterministic forecast model). For that reason, the Mean Doppler velocity value could be interpreted as representing the mean vertical Doppler velocity. During this day, the mean Doppler velocity profile show some evidences of strong updraft occurring around 16.30 UTC within the inner part of the cloud. Evidences of this updraft were also supported from aircraft and radiosondes measurements as well as the topography (strong possibilities of orographical effect at the mountain ridge where TARA was located). This updraft was also linked with a sudden increase of the Doppler width measurement. As mentioned in Section 3.2, first paragraph, such strong updraft may act upon the airflow's orientation, changing the particle orientation.

The personal interpretation provided in Section 3.4.2 shall be clarified at the end of the paragraph and complemented with other figures (Doppler velocity and Doppler width) in order to document and allow a better discussion on such observed transition. Nevertheless, Z_{DR} won't be provided as it does not add any useful information when integrated over the whole Doppler spectra, especially within ice clouds where high amplitude fluctuations can dominate the spectrum.

Comment 4:

Figure 4: very difficult to understand where the signal is and the effect of clipping and other processing when you don't have the original spectra. Could you find a way to show the different steps in a more illustrative way. For instance, in Fig 4b and 4c, I can't see where the signal you want to extract is and where the artefacts are !

Answer:

Figure 4 will be fully re-arranged in order to clarify and correctly illustrate the processing steps performed on the measurement. Thresholds shall be displayed on the figure to correctly apprehend what was discarded from the original spectra. A new figure with an example of $sZDR$ spectra before and after additional clipping will also be added in the paper.

Minor edits:

p. 3, l. 27 : "extremely noisy". Just a question : is it really instrumental noise of the complex microphysical processes at very short time scale ?

Answer:

Because of the very low Nyquist velocity (about 3 cm.s-1), small variations of particle motion and change in orientation produced by micro turbulence can indeed largely affect the amplitude per velocity bins of the Doppler spectral. At this short time scale I don't expect any instrumental noise to influence the results.

p. 4, l. 5: define "FM-CW", and maybe in a sentence the difference between a pulsed radar and an FM-CW radar.

Answer:

TARA is based on the FM-CW principle (Frequency Modulated Continuous Wave). This technology brings the advantage of using a low transmitted power while possessing sensitivity comparable, or even higher, than pulse radar. It also provides better flexibility in terms of frequency modulation and sweep time (period of the frequency modulation), making the radar tunable for different spatial and time resolution.

This will be added in the text.

Eq. 2.2 : define v

Answer:

v represents each Doppler velocity bins.

This will be added in the text.

p. 5, l. 9-13 : At 45 degrees, the horizontal wind dominates largely the vertical component (fall speed + vertical wind). I would not say that you would be able to extract the fall velocity in any of these 45 measurements.

Answer:

The radial velocity can be seen as a combination of the radial wind speed coupled with the intrinsic cloud particle fall velocity. The particle fall velocities contain a wealth of information regarding Particle Size Distribution. The more off vertical is the measurement, the more the Doppler spectrum is affected by the horizontal component of the wind which often has a higher order of magnitude than the vertical wind velocity and particle fall velocity combined. The fall velocity information is therefore optimally retrieved when performing vertically pointing measurements, the horizontal wind component being orthogonal to the radar line of sight and therefore considered negligible.

On the other hand, polarization diversity measurements (polarimetric measurements) which benefit from the non-spherical shape of falling oriented hydrometeors are most effective when performed close to the horizontal plane.

Doppler and polarimetric measurements are therefore not optimal at the same elevation angle. However, as mentioned in page 532, line 15, a trade-off at 45 degrees elevation is actually taken to optimize the combination of both.

At 45 degree elevation, fall velocity could be retrieved by convoluting and fitting measured polarimetric spectra with spectra obtained from a spectral bin resolved microphysical cloud model. However, it is indeed worth noting that the retrieval of the fall velocity spectrum is not trivial and goes beyond the scope of this paper.

p. 6, l. 24 : please give the Nyquist interval of the radar.

Answer:

The TARA radar achieves an Nyquist velocity of about 3 cm.s^{-1} .

See answer of Comment 2.

p. 7, l. 21-22 (see also general comment) : I don't understand this statement : for high Z the signal to noise ratio is always high, so why would you need any additional clipping in that case ?

Answer:

See answer of Comment 2.

p. 8, l. 22 : there is a word missing in “where meteorological . . . are present”. Also, l. 26, I would not call the variations “statistical”. Maybe “higher-order” ? Also, l. 30-31 you don’t filter out the second order fluctuations but the higher-order fluctuations, isn’t it ?

Answer:

The single use of an additional Doppler velocity clipping doesn’t fully remove the statistical variations occurring in the remaining sZDR spectral interval where only meteorological echoes are considered.

This comment will be taken into account.

p. 12, l. 8: same thing as previously, with a second-order fit you filter out the orders higher than the second ? l. 11 and l. 143, I think it is Figure 8, not Figure 7.

Answer:

The reviewer is right for both remarks.

This comment will be taken into account in the new version.

p. 13, l. 13 : I suggest the following change : “heavily rimed crystals (graupel and hail)” instead of “graupel and hail). Also, l. 24, “tilted” instead of “titled”.

Answer:

This comment will be taken into account.