Correction for clipping of Doppler spectra from clouds and other atmospheric targets

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Computing a Doppler spectrum usually increases the signal to noise ratio (SNR) considerably. The noise is distributed over all Doppler cells and the signal from atmospheric targets is concentrated in a limited interval. Storing the entire Doppler spectrum is often not done to reduce data storage, instead the moments of the Doppler spectrum are computed: total power, average velocity and Doppler width.

One way to prevent the signal to be drowned in noise again, when calculating the moments, is to apply clipping or thresholding. Clipping simply means ignoring Doppler cells that have a power close to the noise level per Doppler cell. A picture showing the idea of clipping is shown at the bottom of this page, fig. 1.

Clipping is very effective in removing noise, however a drawback is that also some signal is removed: the hatched area in fig. 1. If the clip level is close to the peak power in some Doppler cell, most of the signal power will even be removed. The width of the Doppler spectra is even stronger affected. If the distribution is not symmetrical, also the average velocity will change due to clipping.

The effect of clipping is studied on radar cloud measurements made with the Delft Atmospheric Research Radar, Darr. This is a sensitive 9-cm radar with a high Doppler resolution of 3.5 cm/s. Normally 256 Doppler cells make up one Doppler spectrum. This spectrum is clipped at 7 dB above the noise per Doppler cell. The Doppler width (standard deviation) for the clouds in this study is between 18 and 30 cm/s, i.e. between 3 and 8 Doppler cells. This means that 95 percent of the power is distributed over 5 to 13 percent of the spectrum (4 times the standard deviation of a Gaussian distribution).

When an accurate quantitative value for the signal power is needed the calculated average power must be corrected for the effect of clipping. To derive a function for the correction of the measured total power, the data processing of a Doppler radar has been simulated using a known signal. Without correction for clipping, cloud measurements with Darr below a SNR of 0 dB should not be used. Using the clip correction function from this paper, signals down to -6 dB can be reliably measured; a gain of about 6 dB.

As the correction for clipping depends on the target and the Doppler processing, a generally applicable correction function cannot be given. Instead, this paper gives a recipe to derive a clipping correction for a specific situation.

DOPPLER PROCESSING OF CLOUDS

For each range cell a Doppler spectrum is computed. To reduce the variance of the signal and the noise, the spectrum is smoothed before clipping. The shape of the smoother should be matched to the target. For cloud measurements with Darr, a Gaussian smoother with width 0.14 cm/s is used. Note, that the smoothing will increase the measured width, especially for spectra with a small width.

The clip level is normally chosen to be a few times the noise level per Doppler cell. If the level is too low a lot of noise and other system disturbances will still pollute the measurement, but if the clip level is too high a lot of signal will be removed. The optimal solution will depend on the properties of the target, especially its Doppler width.

Clipping removes the noise in the Doppler cells in which the power is below the clip level. In order to remove the noise from Doppler cells with power above the noise level as well, the average noise level should be subtracted. This was not done in the processing for the results shown.
in this paper. The clipping correction, also has to correct for this effect.

Clouds have a non-zero natural width of the Doppler spectrum, see fig. 2. This natural width is determined from this scatterplot as the minimum width at high SNR, in this case it is 18 cm/s. Based on case studies of two stratocumulus and two ice clouds this measured width is estimated to vary between 18 and 30 cm/s.

**RECIPE FOR CORRECTION**

In this section a recipe will be given to derive a clipping correction function for the measured SNR. This clipping correction function will be different for every radar set-up and target.

**Step 1: Determine original Doppler spectrum.** The clipping is corrected by calculation what the radar processing does to a known signal. So a good knowledge of the Doppler spectrum is paramount. It could be obtained from theoretical considerations or from special measurements with a high SNR.

**Step 2: Build Doppler processing simulator.** Next a simulator of the radar Doppler processing has to be build. The noise floor and clip level used in the data processing should be used in the simulation of the dataprocessing. A small error in measured power is not very important for a low SNR, when using a cliplevel of more than 5 dB.

**Step 3: Simulate signals with various SNR’s.** The algorithm for the calculation of the clipping correction is very simple, though calculation intensive. Signals having SNR’s between -20 and 10 dB should be used as input. To this signal noise has to be added and it should be put through the normal processing steps, including the calculation of the moments.

**Step 4: Derive clipping corrections from simulations.** The scatterplot of input and output SNR can then be fitted to a polynomial function. Care must be taken not to use this function outside the fitting limits. For high SNR’s the measured value should not be corrected. It is probably best to ignore values requiring a correction of more than 10 dB.

**RESULTS**

The main interest of this study is stratocumulus water clouds, which have a low SNR. The Doppler spectrum for these clouds is mainly determined by the turbulent motion of the atmosphere. So a Gaussian distribution should be a good approximation. The clipping correction functions for Doppler widths 3 through 8 cells are plotted in fig. 3. It can be seen that the width of the spectrum influences the minimal detectable signal, the spread is about 2 dB. The error in the clipping correction because of the unknown nature of the real signal may be much larger.

Determining the Doppler width for every (part of a) cloud is sometimes not practical. So a clipping correction function was calculated using as input signal a uniform distribution of widths between 3 and 8 cells. The computed function is shown in fig. 4. In fig. 4 one can see that because of clipping only cloud signals with a SNR of -6 dB or higher could be measured. The lowest SNR’s using the usual settings for Darr are -17 dB. (The Doppler gain is 24 dB (for 256 Doppler cells), from this the cliplevel of 7 dB should be subtracted). Thus Darr is 11 dB less sensitive for clouds than for a target with one constant radial velocity.

As an example, the measured radar reflections from a stratocumulus cloud are shown in figure 5. And a histogram of the measured and the corrected values in fig. 6a (using the correction function from fig. 4). The reflections from this stratocumulus cloud are just above the detection level, as they often are. So the reflection values have to be corrected considerably (fig. 6b). The clipping corrections are around 4 dB in the middle of the cloud, up to 10 dB at the

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**Fig. 2.** Scatter plot of reflection and Doppler width for strato-cumulus cloud. Clipping reduces the measured width for weak signal. At the same time signal is removed from the tails of the distribution.

**Fig. 3.** This graph shows the clipping correction function for the Darr processing using a Gaussian signal with a width of 3, 4, 5, 6, 7 and 8 Doppler cells. The lowest line is the one for the smallest width, etc.

**Fig. 4.** This graph shows the clipping correction function for the Darr processing using a Gaussian signal with a uniform distribution of width between 3 and 8 Doppler cells.

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edges. There is a clear cut-off to be seen in the corrected radar reflection (figure 6a), at the minimum SNR of -6 dB. This indicates that the radar in this case does not see the entire cloud. This was also found in lidar radar synergy studies of cumulus clouds. These studies showed that a large part of the bottom of these clouds are not detected by radar, but can be seen with lidar, [1].

The clipping correction seems to work fine. The corrected data looks reliable. But it should be remembered that corrected values can be up to 10 dB higher than the measured values, this means that just 10 percent of the power was measured. So the correction has to be very accurate to obtain reasonable values. Given the shape of the correction function other factors like noise are much less important, e.g. if the noise would increase the measured SNR from -16 to -10 dB, the corrected SNR would still be about -6 dB.

CONCLUSIONS

Clipping can have a strong influence on signals with a low SNR and a relatively high Doppler width. It is possible to correct for the effect of clipping if the shape of the original signal is known. The result for a stratocumulus cloud shows a sharp cut-off, this indicates that only part of these clouds are measured.

More work is needed to make a good error estimate. What errors are made if the width of the Doppler spectrum which is taken is wrong, or if the spectrum has a different shape?

IMPROVING THE CLIPPING

The Doppler spectrum gives information on clutter, disturbances in the system, bimodal or multimodal spectra and more using coherent averaging using relative phase between Doppler spectra calculated on odd and even sweeps [2], could improve the SNR for atmospheric targets that do not change quickly in time. Having a Doppler spectrum with a 10 dB better SNR than the spectra from which the moments were calculated would allow a very good clipping correction. Such a Doppler spectrum could be stored at a lower rate than the moments, to reduce data storage requirements.

There may be some other ways to improve the clipping process, which should be studied. Using a smoother with a width that is adaptively matched to the signal, may make it possible to chose a lower cliplevel. Also other criteria for clipping could complement SNR, e.g. the standard deviation of a time series or the cross correlation with another polarization state.

Using information in the number of clipped cells could be useful to improve the clipping correction. The correction could then become a function of SNR and the number of clipped cells. A simulation study would be interesting to estimate how much the clipping correction could be improved by using the measure.

LITERATURE