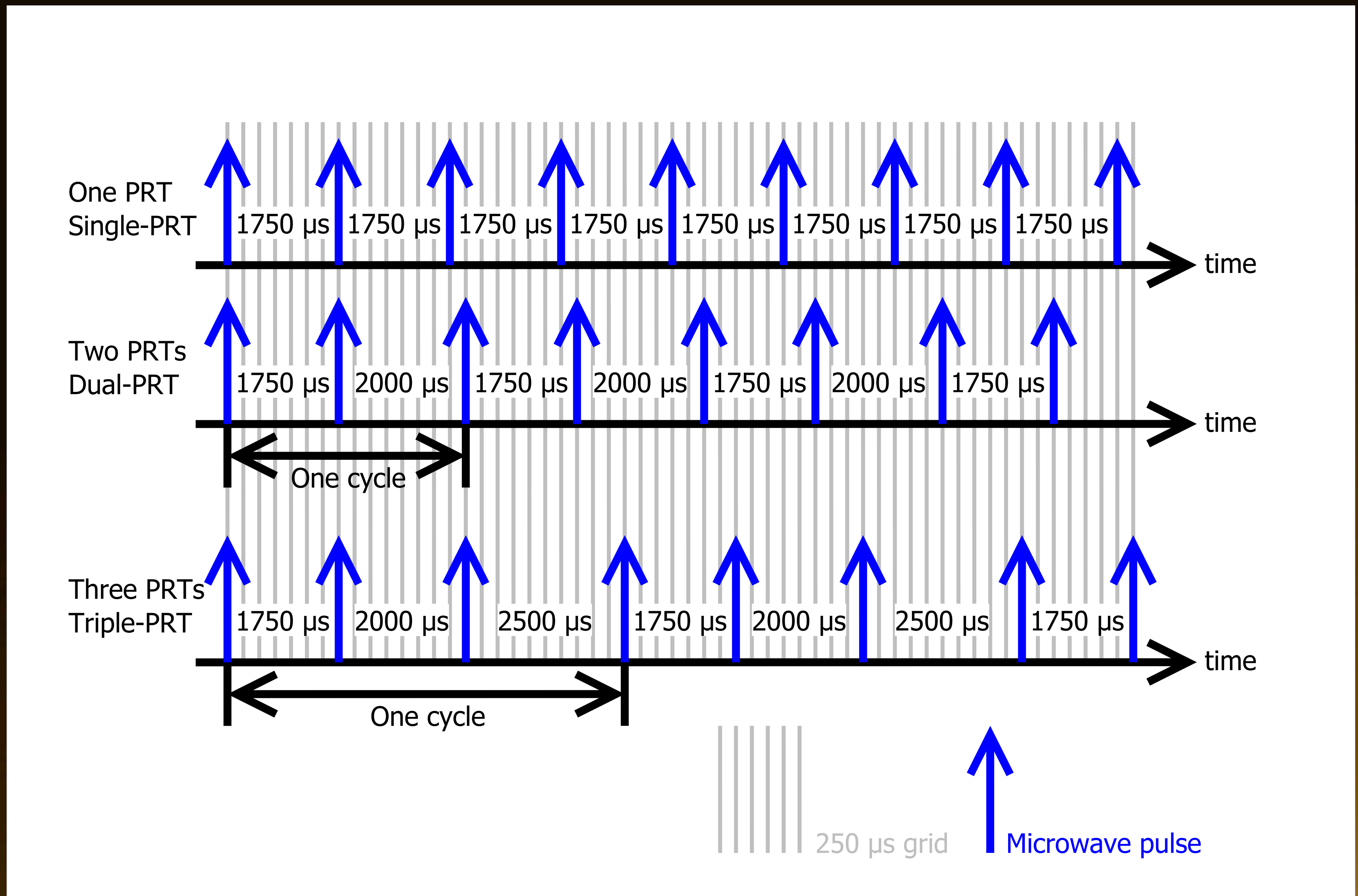
What is triple-PRT?

Ordinary weather radars send pulses with a fixed PRF, say 570 Hz. This sets the maximum unambiguous range to 260 km and the maximum unambiguous velocity to 6 m/s for C-band. We call this system with a fixed PRT of 1750 µs "single-PRT".

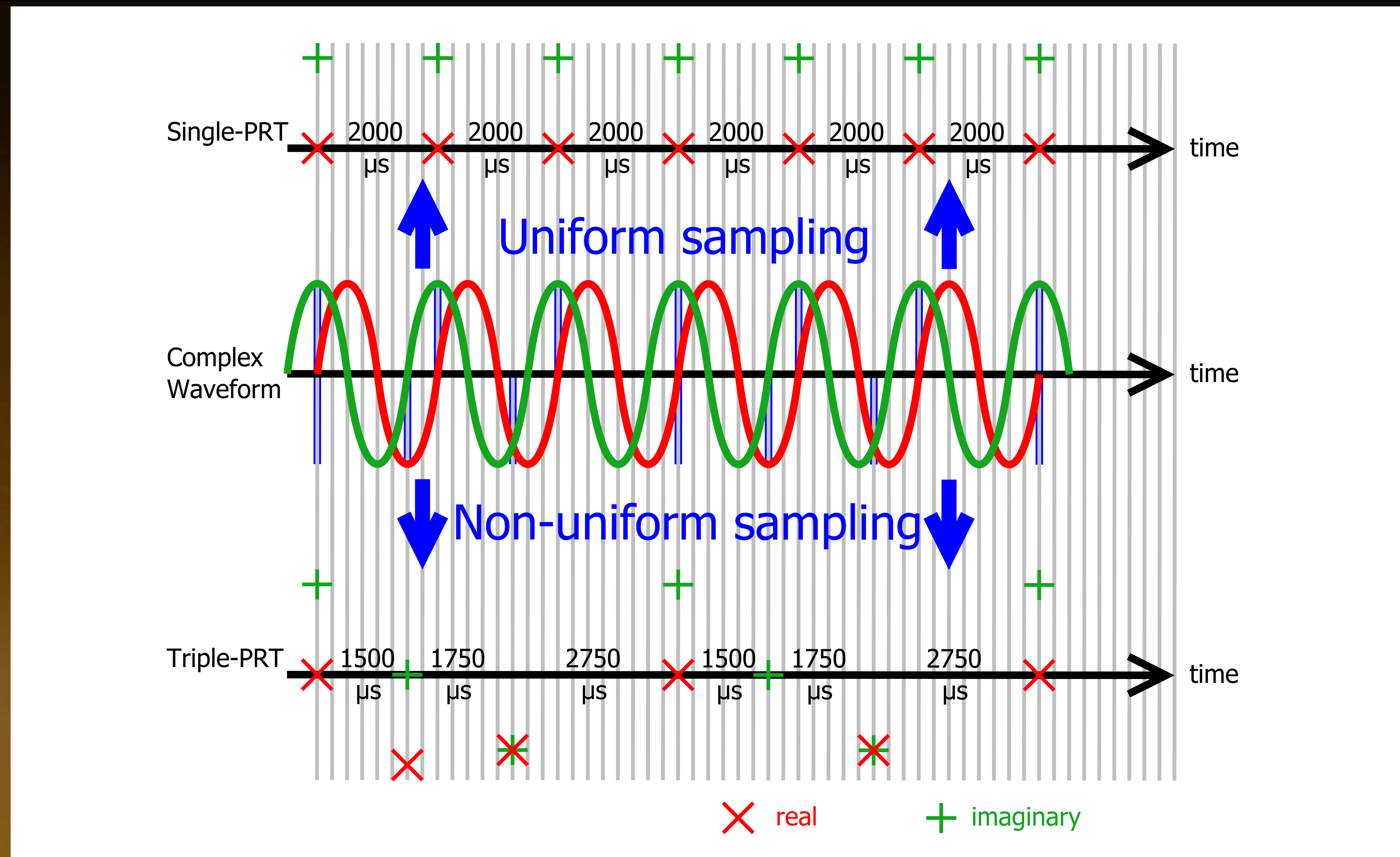


Multi-PRT has been in use for radar system for a long time, for instance in space debris measurement. Meteo France has been using it operationally in its weather radar network.

We have developed a real-time triple-PRT signal processing software, which includes fully functional ground clutter removal (compliant with WSR-88D specifications). Our solution takes I/Q time series data as input and outputs PPI data.

Using more than one interval can be done in several ways. For instance, a PRF of 570 Hz can be used during half a degree of antenna rotation and then a PRF of 456 Hz during another half a degree of antenna rotation. This is called dual-PRF.

Multi-PRT uses the intervals directly after another. Dual-PRT uses two intervals alternatingly, triple-PRT uses three intervals.



For the Doppler velocity calculation, this results in a signal which is non-uniformly sampled. The unambiguous velocity rises far beyond 6 m/s as the higher velocities remain distinguishable. The interval ratios are chosen so that normal winds and birds are measured correctly, for instance up to velocities of 50 m/s.

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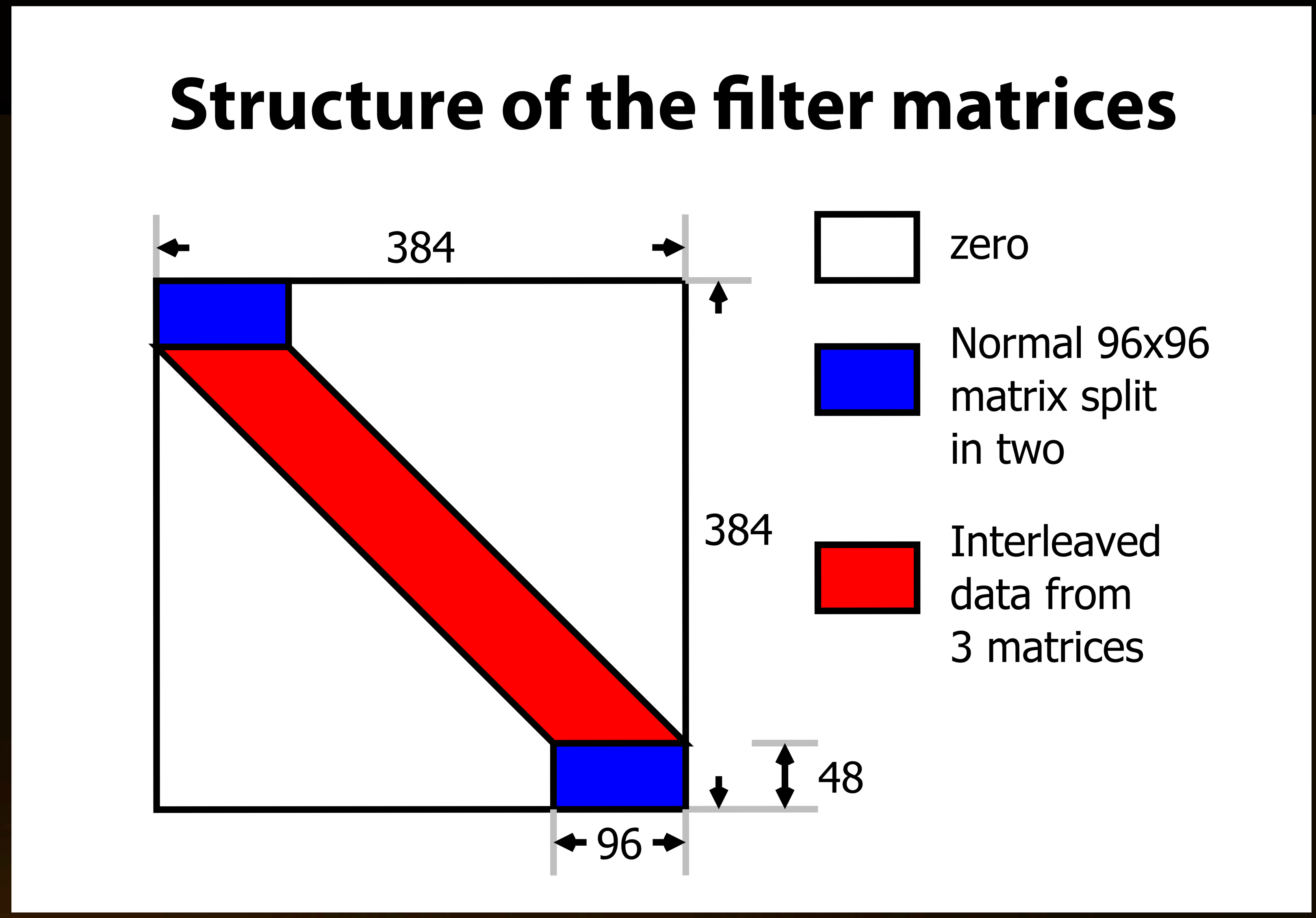
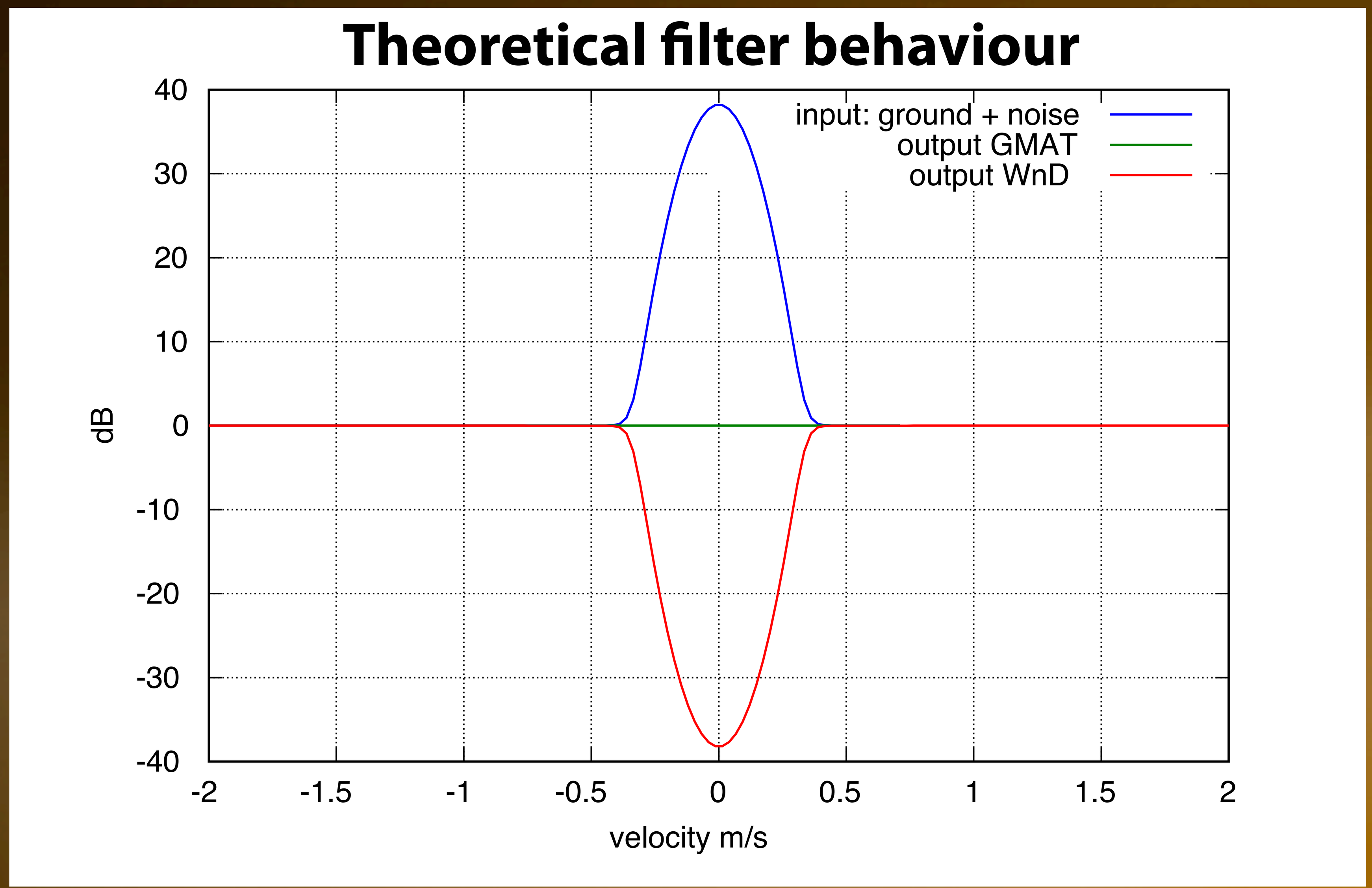
Ground clutter filter

We have chosen a system that uses several sparse matrix-vector multiplications to filter the input I/Q data. The ground clutter model is fixed, but several filters with different ground-clutter-to-precipitation power ratios are used. The adaptive algorithm then chooses the best results, either the unfiltered signal or one of the filtered signals.

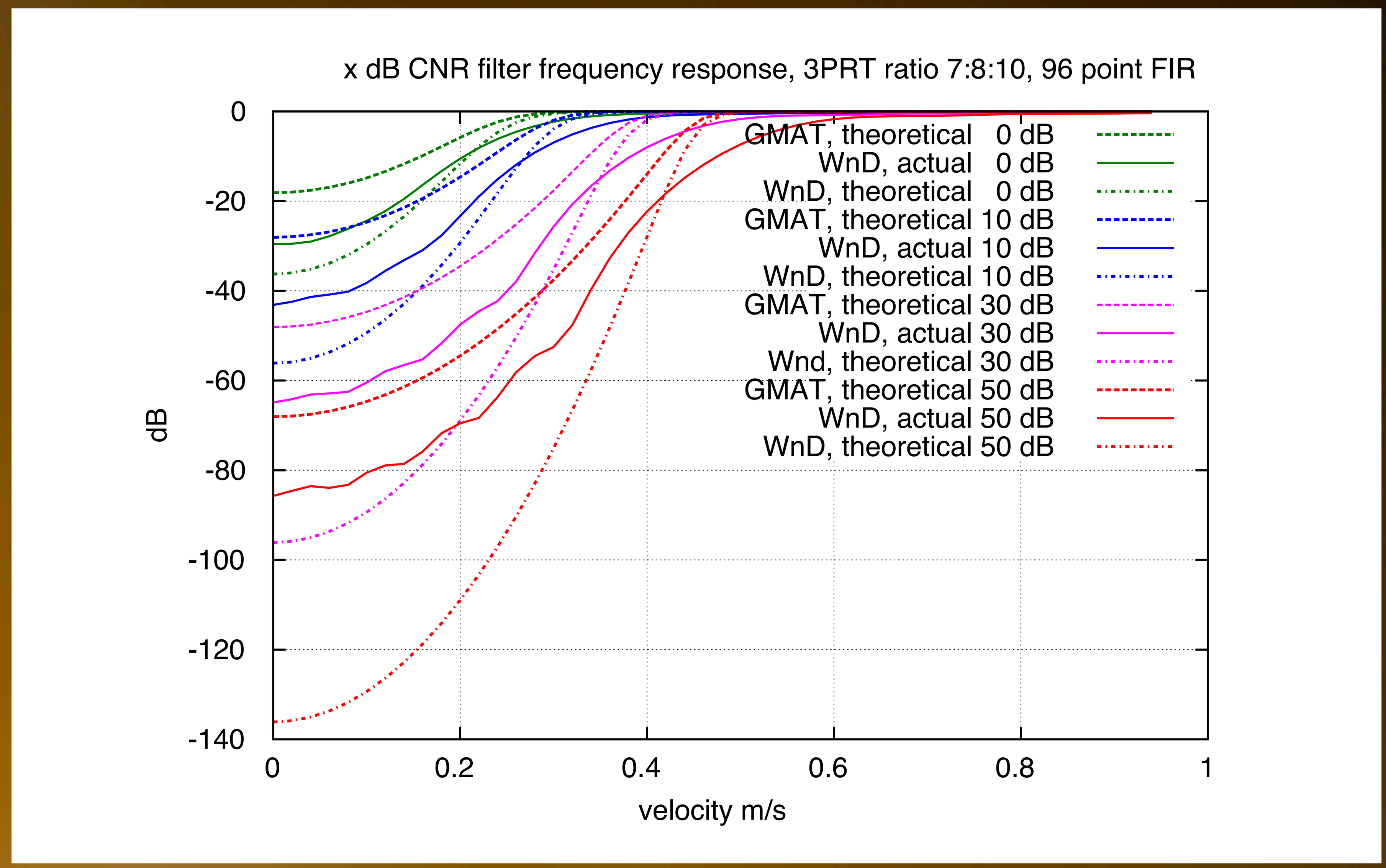
Our system typically processes eight beams of one degree of antenna rotation as one operation. Using a rotational speed of 10 degrees per second this results in a input vector of 384 samples. Vector is multiplied by the filter matrices.



Our filter tries to make the filtered signal as similar to the precipitation signal as possible (as in least square fit), unlike GMAT which uses a whitening filter.



Several filters with different ground-clutter-to-precipitation power ratios. We have found that it's enough to use four different power ratios.



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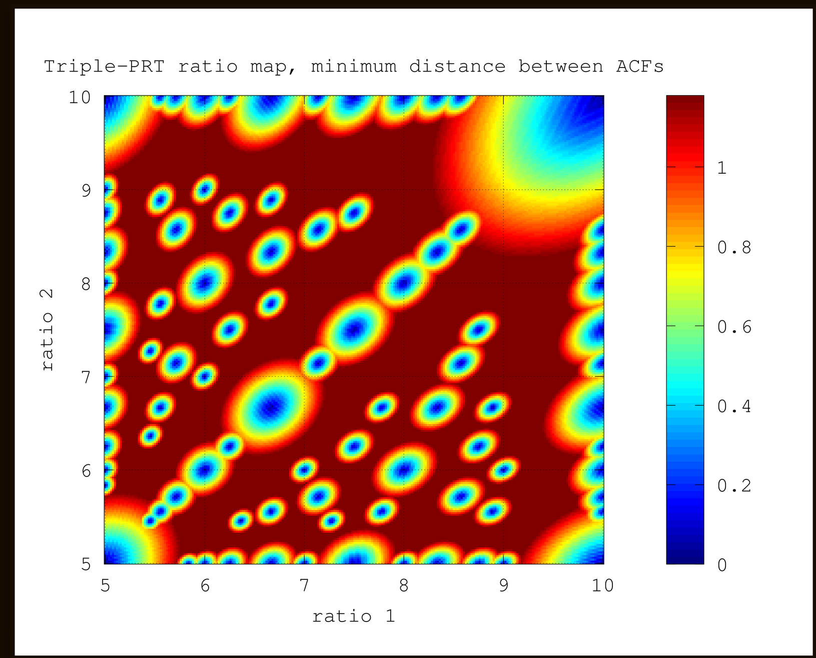
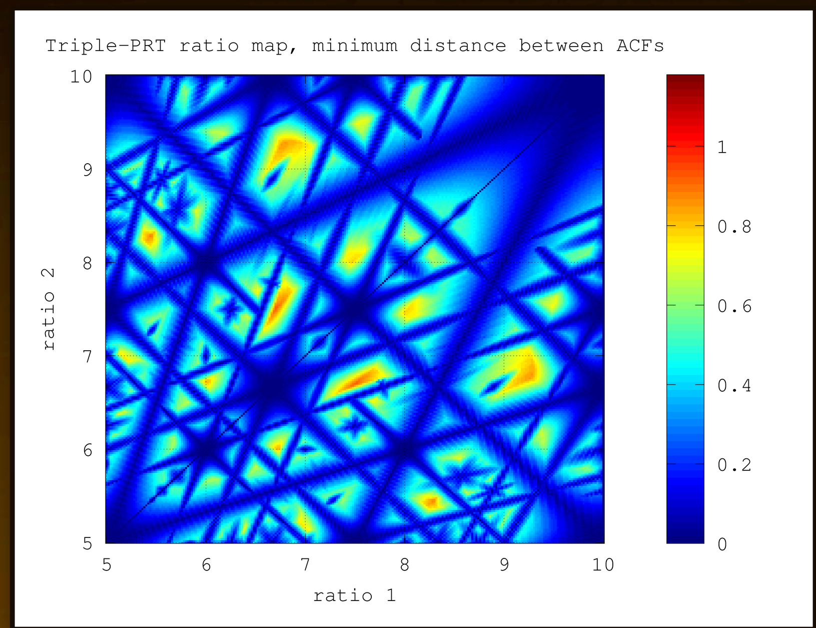
Comparison of triple-PRT ratios

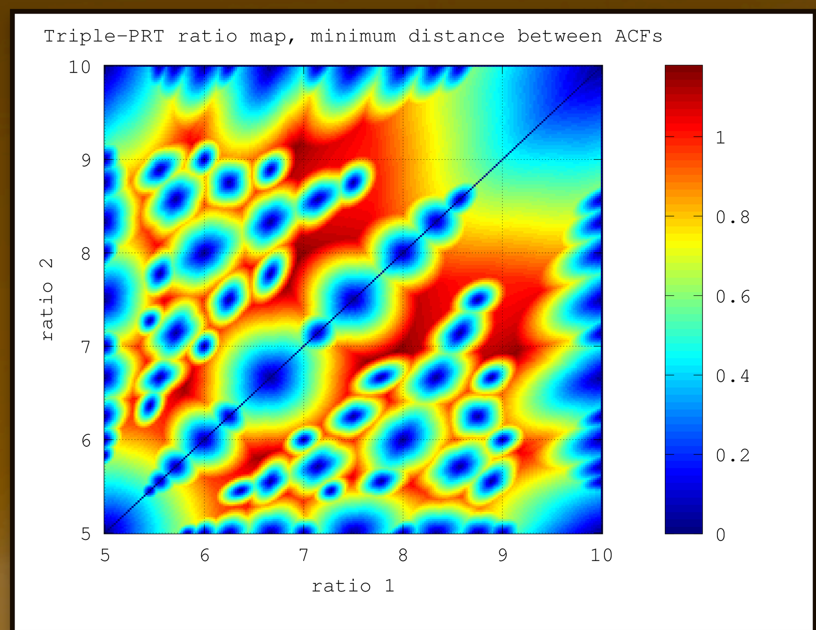
If ground clutter removal is not needed, the choice of a triple-PRT ratio is not very critical. This image shows how well the ACFs of the signal can be distinguished from each other if the input is limited to speeds from -50 to +50 m/s. Higher values are better. Calculations are for a C-band radar, the smallest PRT is always 1750 µs. The ratios are plotted as x:y:10. To look up the ratio 8:9:12 it has to be transformed to 6.66:7.5:10. Minimum distance zero (dark blue) indicates that the unambiguous velocity range is less than +/- 50 m/s. The ratio of 6:6:10 for instance only has an unambiguous speed range from -23 to +23 m/s.



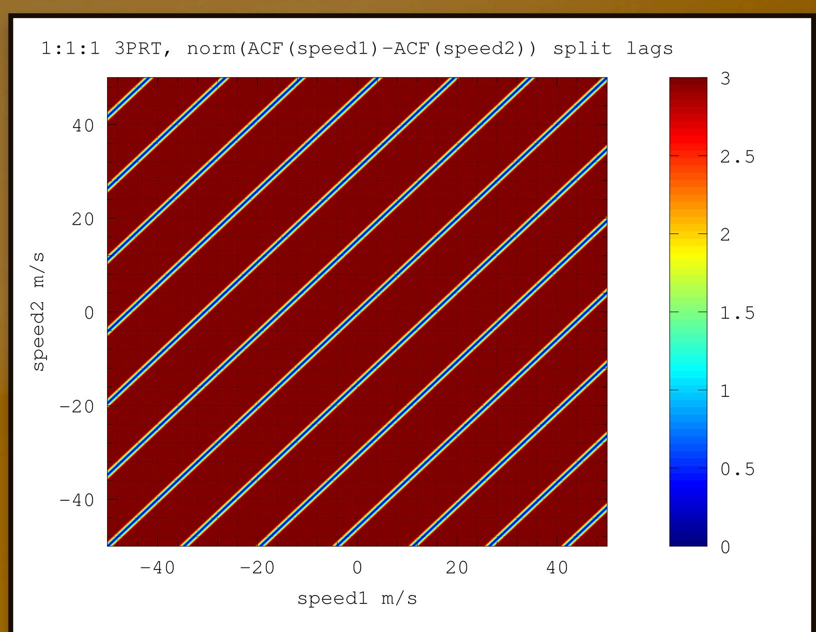
Adding ground clutter removal complicates the situation a lot. When appliying a high-pass FIR filter to the input data, the DC offsets characteristic of many speeds are removed and often several speeds are mapped to the same or very similar ACFs after ground clutter removal. In the right image, the ground clutter is removed before calculating the ACF. As an example, ratio 8:9:10 works well, if there is no need to remove ground clutter, but does have serious complications when ground clutter is present.



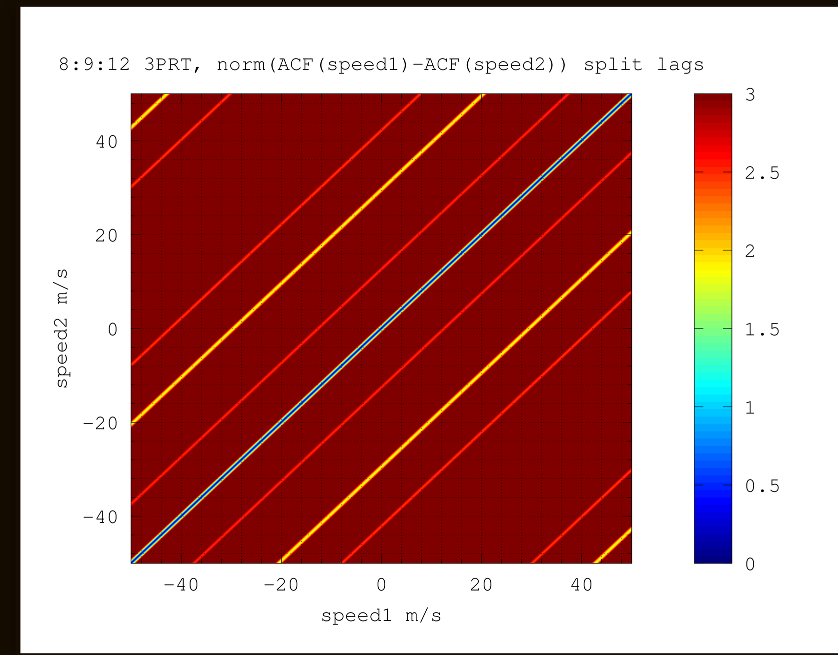
The image changes again if the input is a Gaussian distribution of velocities. This image shows the distances if the width is 1 m/s.



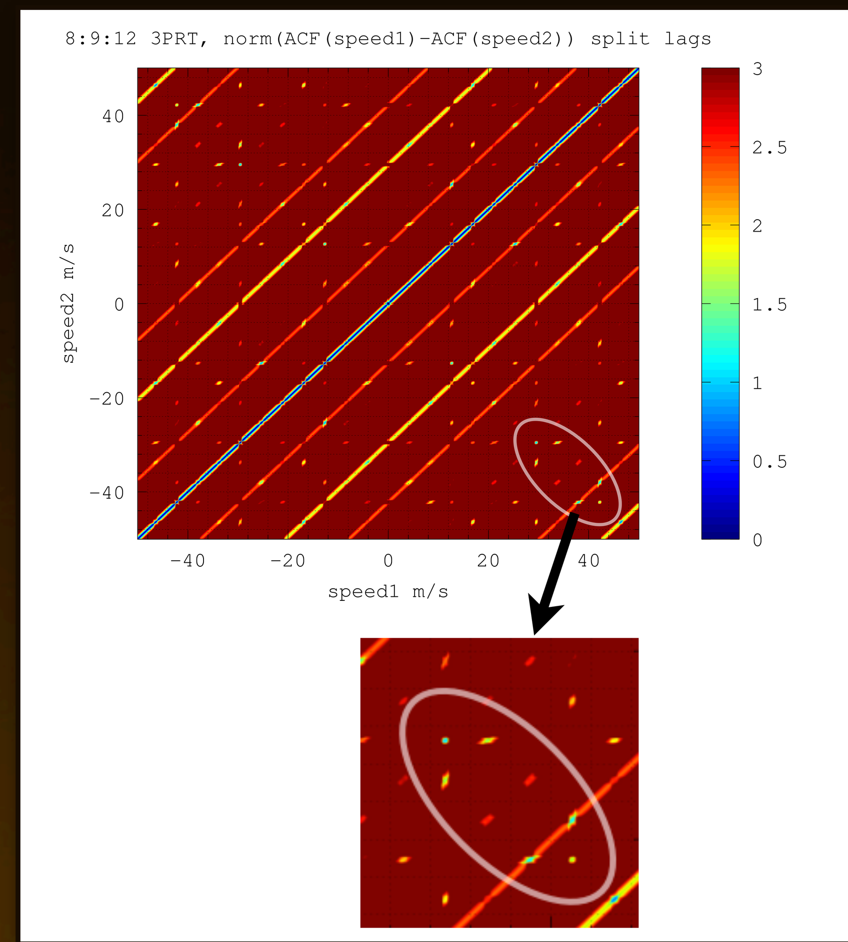
As we match ACFs with least-squares, we can generate images which show the norm of differences between any two complex ACFs. Here is such an image for an ordinary radar. In this case the pattern repeats every 15 m/s due to the unambiguous speed range (+/- 7,5 m/s).



For triple-PRT ratio of 8:9:12 the unambiguous speed range is so wide that the norm of distances is zero only on the diagonal (blue line is present only once). In the lower right and upper left corner you can see that the pattern begins to repeat.

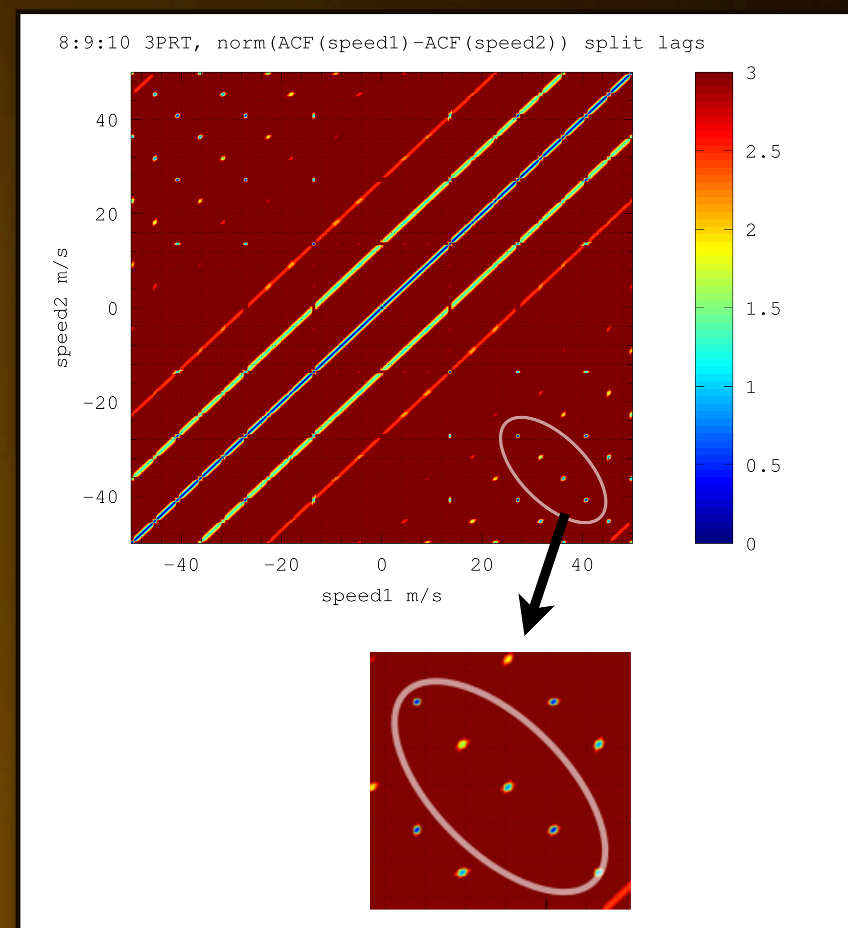


As evidenced by the dots on the image, the ground clutter removal does complicate speed separation, yet it can be done when a proper ratio is chosen. The value does not drop below 1.5. On this image we use 8:9:12.



As comparison, a badly chosen ratio (8:9:10) has speeds which are indistinguishable, marked as dots having a value of zero. (The small blue dots, for instance at (-40, 40))

After the speed and width have been measured, our algorithm is able to correct the reflectivity value which might have been reduced during filtering. If the precipitation is around zero, the correction is equivalent to the Gaussian fit done by GMAP.



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Adaptive filtering

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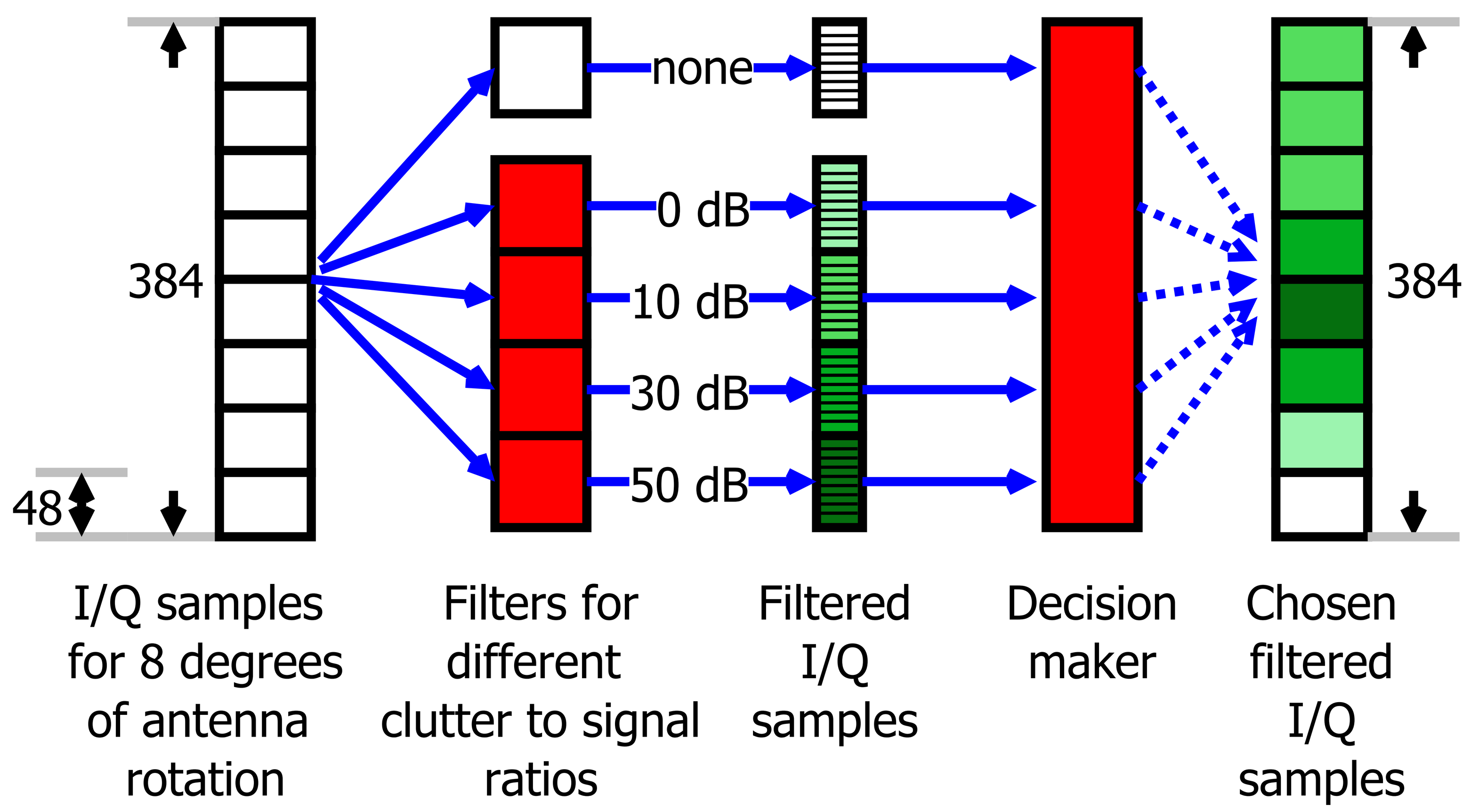
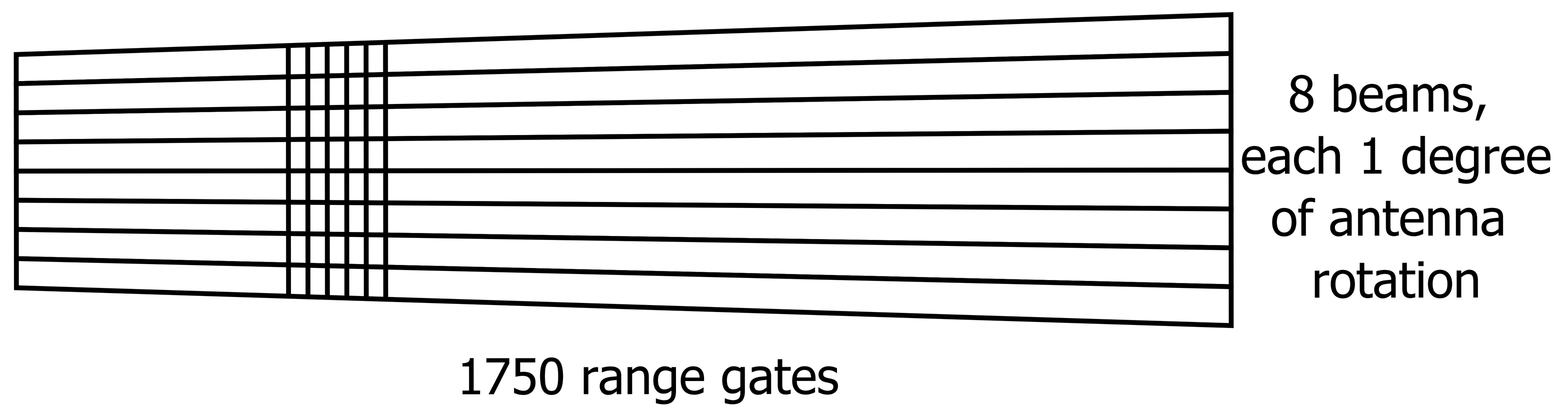
The input data is filtered with several filters and dual-polarization parameters are calculated for all of the output. The adaptive filter chooses one of the filtered signals.

This is significantly different from other systems which make the decision to filter first and then remove the ground clutter.

Adaptive filter flowchart

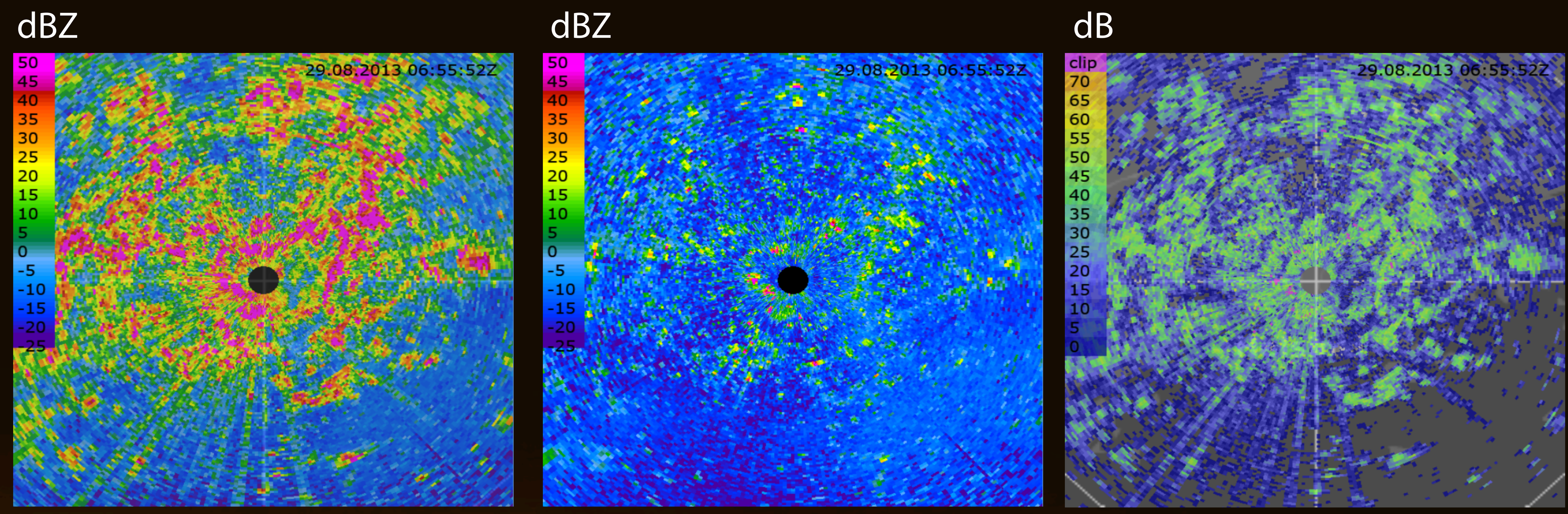


2D grid analysis



1750x8 = 14000 volumes are processed with all filters and dual-pol products are calculated for all output. For each volume the best filter output is chosen

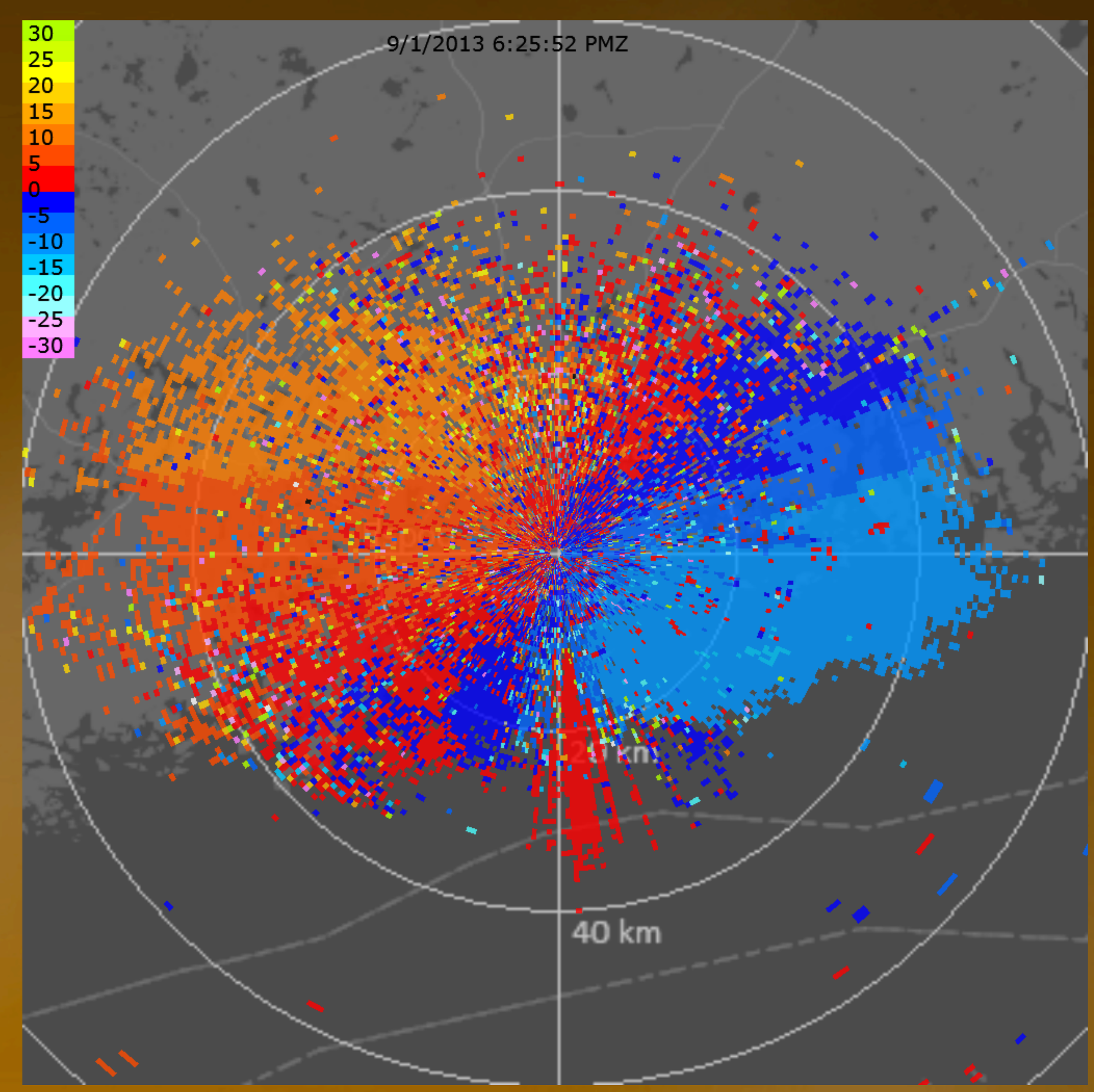
Power before filtering | Power after filtering | Difference in power



Elevation 0.5 degrees, background consists of insects and groundclutter

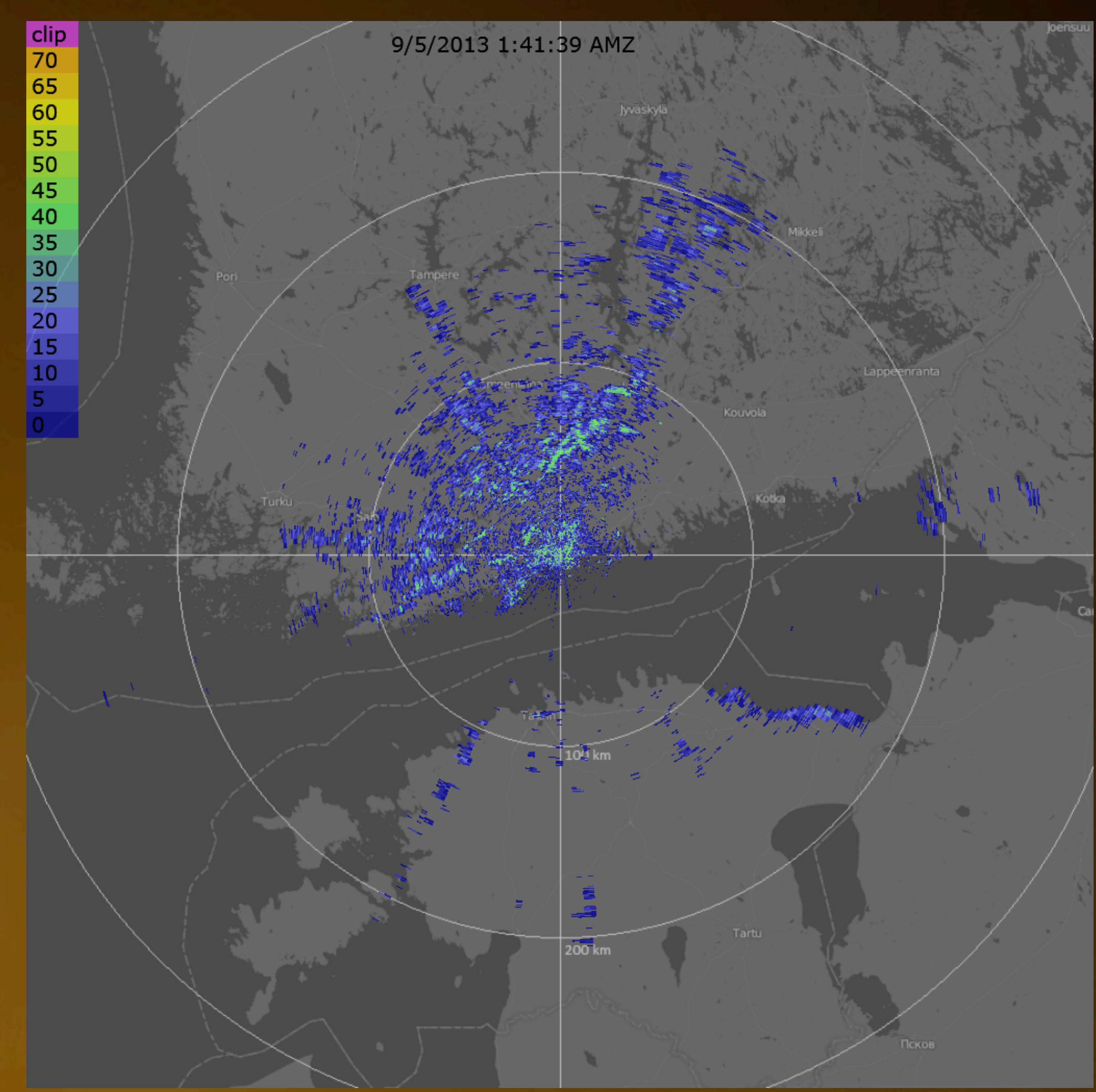
Insects, birds and sea clutter

Reflectivity -10 to 0 dBZ. Speed m/s



Anomalous propagation

Difference in power, dB



All images are using Vaisala's wide dynamic range update

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