Statistical Study of Echoes from Wind Farms and Other Moving Clutter Targets

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1 Introduction

The weather radars of Environment Canada regularly see a significant number of wind farms, with more farms continuously being proposed. Although Doppler filtering can minimize the effect of the turbine towers, the moving blade evade those filters Other man-made moving targets, such as highways and railways provide some of the same issues, although their lesser vertical extent means they are generally less visible. Therefore there is a desire to quantify the impact of the moving targets on the weather radar data and to understand the origins of spatial structure. Apart from understanding the echoes, it is desirable to have metrics that highlight areas with these issues so they can get special treatment. In the past we have looked for the areas with moving clutter using statistical properties derived from the distributions of echoes values at a location, such as frequency of occurrence or mean reflectivity (Donaldson 2010). Those methods remove any information about the spatial and temporal relationships between observations. This presentation shows the results of a few metrics that describe the variability of the echo intensity, with comparison of moving targets such as wind farms and traffic on highways.

2 Temporal variation metrics

To compare the temporal variations of moving targets from categories such as wind turbines and traffic, two new metrics have been created: average scan-to-scan absolute temporal change, and a non-parametric comparison of change in a bin to change in a neighbouring bin (“Concord”). The changes of interest are expected to be multiplicative in nature so calculations are done in terms of dBZ. This leads to the well-known issue of how to quantitatively handle situations where Z ~= 0. Simple variables such as variance or correlation have the underlying assumptions about the mean being homogeneous and stationary, while the quality assessment process is often about exploring reasons that the mean fails to have those properties. Assumptions that statistics are normal can also lead to inconsistencies. The “Concord” variable attempts to sidestep those issues by looking at the sense of changes rather than attempting to do a correlation calculation.

The absolute temporal variation (ATV) is simply the average of scan-to-scan changes in dBZ. If a radar bin has valid observations at consecutive times, their absolute difference is calculated, if only one time has valid data the interval is ignored and if both are invalid a 0 is used. Values from all calculated intervals are averaged, giving a variation on mean absolute error, MAE.

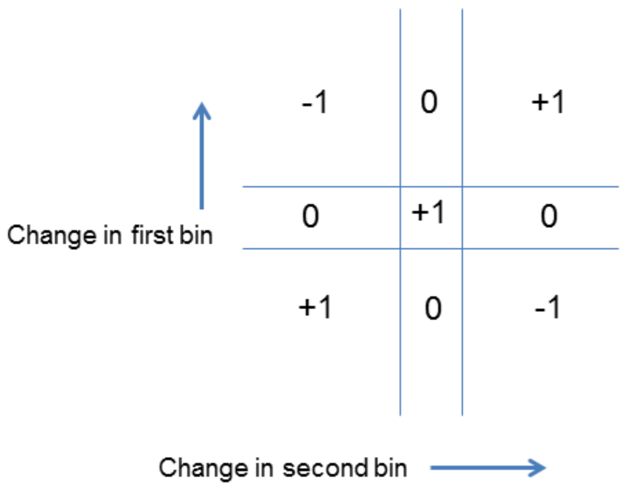

Figure 1: Calculation of "concord" based on relation of changes in two bins.

The "Concord" variable is designed to assess whether two neighbouring bins are changing together. For example it might be expected that a strong clutter target could appear in azimuths to one side of the azimuth directly to the target, due to the edges of the main beam or side-lobes ("side echoes"), and that if dBZ in the primary azimuth moves up/down then adjacent bins at the same range might also move up/down at the same time. Concord uses a simple change of sign variable, a bit like the "spin" variable of Steiner et al (2002). In each bin the change between consecutive times is categorized to be clearly positive, approximately zero or clearly negative. Together the changes in the two neighbouring bins are given a score. A score of 1 is given if the sense of change is the same, -1 if the sense is opposite, or 0 if in adjacent categories. See Figure 1. The average score is calculated for all pairs for which the changes can be calculated. For the study three Concord variables are calculated: comparison of each radar bin to the one on the adjacent azimuth clockwise ("Concord_A"), comparison to the next further bin on the same radial ("Concord_R1") and comparison to the second further bin on the same radial ("Concord_R2"). The reasoning was that Concord_A would give a sense of how often a bin contaminates its neighbours and the Concord_R*n* variables would give a sense of multi-path echoes due to nearby secondary reflectors.

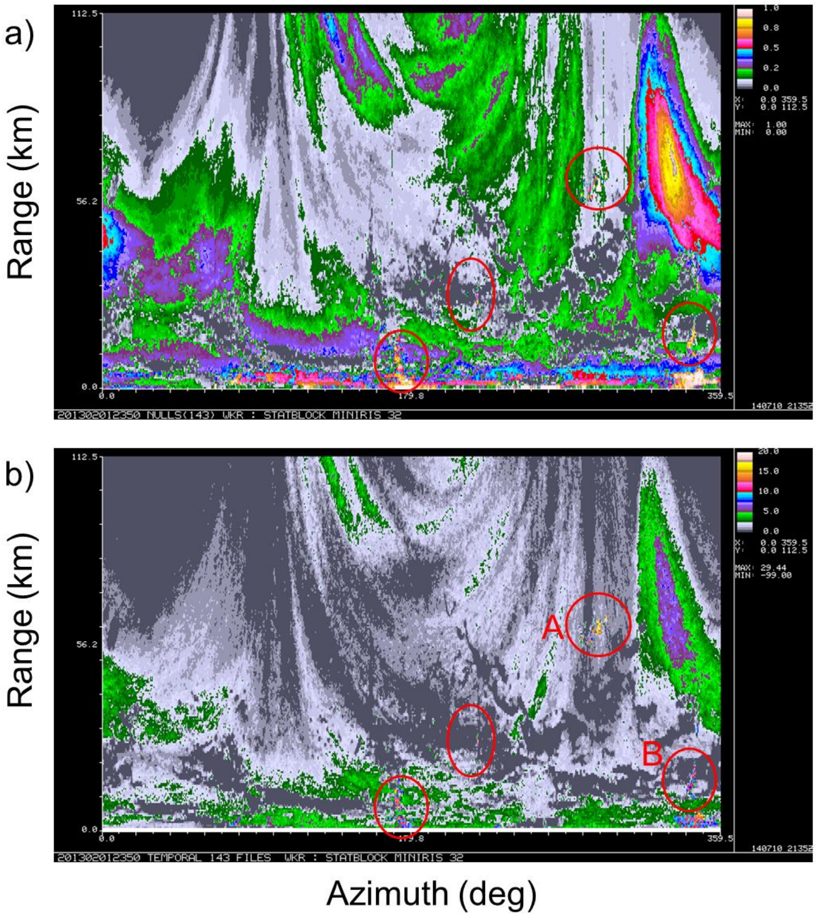

Figure 2: Statistics from 2013-02-01 for CWKR presented in B-Scan format. a) fraction of valid observations and b) absolute temporal variation. Circled areas in Frame b) contain frequently observed moving targets.

3 Observations

3.1 Radar characteristics and processing

The data was collected from Environment Canada's C-band Doppler weather radars (Joe and Lapczak 2002). These radars have either 0.6° or 1.1° beam widths, depending on the site. The EC radars are configured to include one very high quality low level scan, typically with elevations in the range 0.1° to 0.5° in each 10 minute long cycle. This Doppler data is collected with average sampled at resolutions of 0.5 km and 0.5° azimuth. Data from lower quality scans was also examined, but is not discussed here. The moments collect include both raw reflectivity and Doppler-corrected reflectivity, with FFT processing using fixed width filters. The system uses dual-PRF data collection for velocity meaning that the PRF alternates between the 0.5 degree azimuthal rays.

The data was analyzed on a daily basis, where the 144 possible files for each day were used to obtain the statistical properties discussed above. Data from five radars with known wind farms were examined for selected days, with about 30 case days in total.

In addition to the temporal statistics introduced above, other parameters were derived from the distributions of reflectivity observations seen in each range/azimuth pixel (Donaldson, 2010). Of those only "Fraction non-Null" will be shown here.

A "null" for this study means either a pixel where there was no signal above the SNR threshold or the signal was rejected by other quality control. The metric gives the fraction of the time a pixel is valid: a value of 0 means we never make a valid measurement while a value of 1 means something is always measured in the pixel.

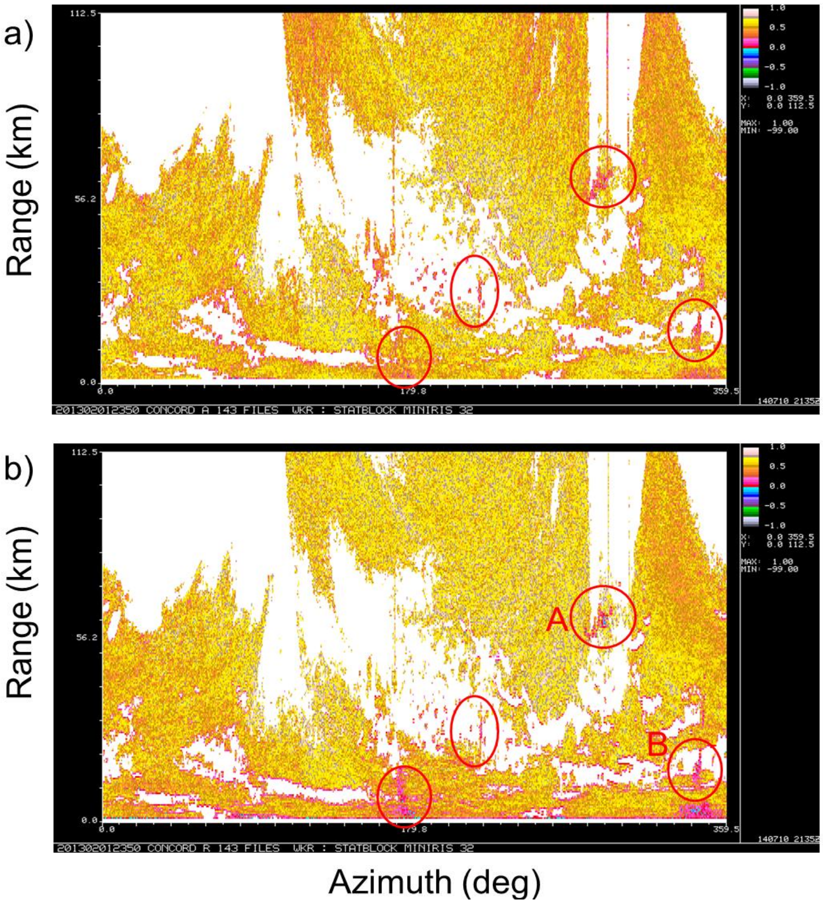

Figure 3: Statistics from 2013-02-01 for CWKR presented in B-Scan format. a) Concord_A and b) Concord_R1 . Circled areas in Frame b) contain frequently observed moving targets.

3.2 An illustrative day 2013-02-01

February 1, 2013 at the King City radar (CWKR) will be used to illustrate the results of the temporal measures. This was a day with winds from the northwest, giving persistent lake effect precipitation bands, especially to the northwest of the radar. Other precipitation bands appeared with less persistence. Because some artefacts and issues can manifest themselves in polar coordinates, data will be presented in "BScan" format, where the axes are the polar coordinates, azimuth and range.

Figure 2 and 3 show 2a) the fraction of non-Null (FNN), 2b) the absolute temporal variation (ATV), 3a) Concord_A and 3b) Concord_R1. Circles mark areas where there is clutter in Doppler corrected data due to moving man-made targets. Area A marked in Frames 2b) and 3b) is a wind farm at about 55-60 km from the radar and Area B is a highway going up a long hill to the north of the radar. The areas of moving target all show up as having a high FNN, but not more than the persistent precipitation band to the north west. This illustrates that FNN can be used by a human analyst to identify contaminated area but the human relies on patterns rather than expecting the raw values to fall outside a predetermined meteorologically valid range. This is in fact how we have been recognizing areas of moving contamination. Looking at the absolute temporal variation of the persistent moving clutter in Frame 2b) shows that those areas have higher values than the weather signals, but not spectacularly so. Wind turbines and traffic on highways vary a great deal due to the constantly changing nature of the targets. In reasonably uniform precipitation the ATV has moderate values. Looking at CONCORD_A (3a) and CONCORD_R1 (3b), the values in precipitation on this day are quite high (0.6+) indicating that when the value in a bin changes then the neighbouring bins will most probably change in the same sense. The areas of moving targets stand out as area of low Concord, although zooming in (shown later) one can occasionally see sub-area with high Concord. In places the precipitation areas are fringed with low Concord. Comparison of Concord_A and Concord_R1 , in precipitation indicates slightly higher values of the radial version.

Figure 4 is a zoomed view of the traffic area marked as Area B in Figures 2 and 3. The comments above continue to apply but it is interesting to look more closely at the Concord variables. Concord_R1 is uniformly low, indicating that changes in one bin are not connected to changes in other bins along the same radial. However Concord_A seems to have a core of high values at locations indicated with arrows. This synchronicity of changes in azimuth suggests that the radar is seeing strong individual echoes that continue to be seen in adjacent radial, presumably due to the target continuing to be seen at measurable levels in the sides of the main beam.

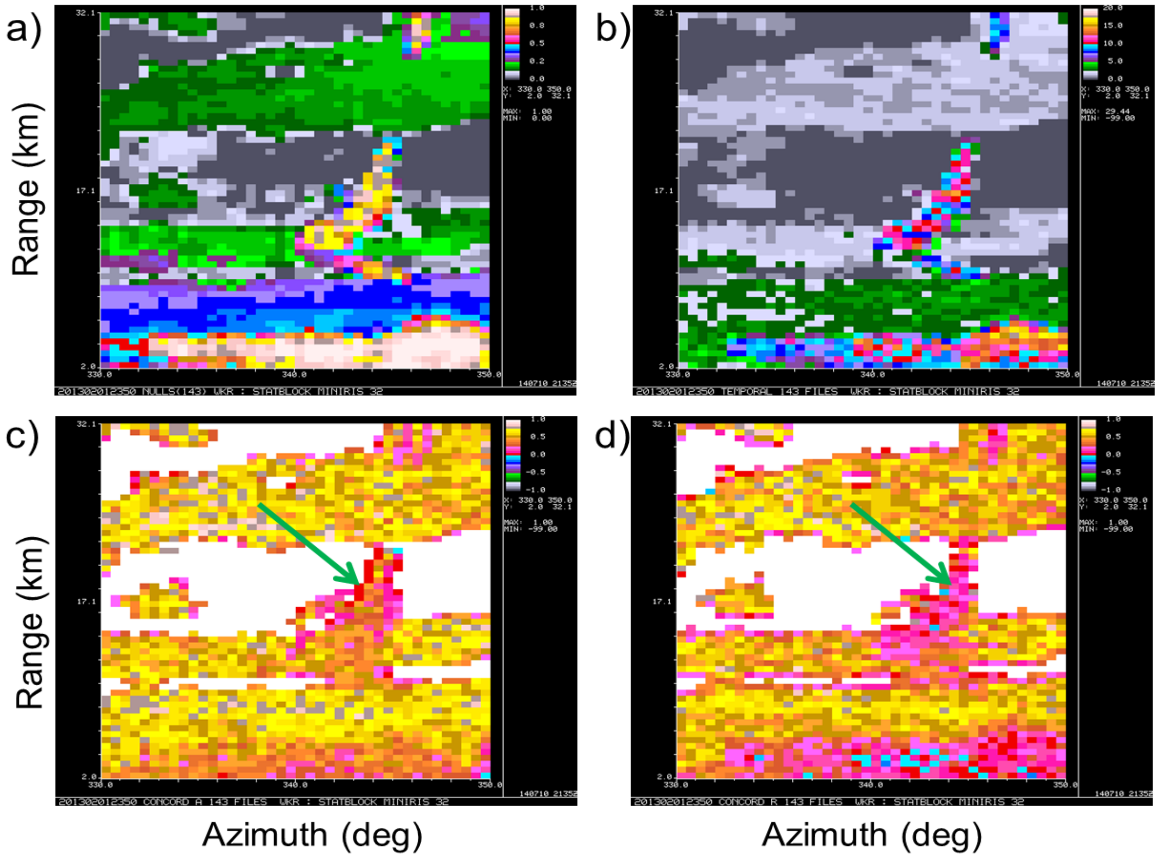

Figure 4. Zoomed views of Area B, with highway traffic, on 2013-02-01. a) Fraction non-Null, b) absolute temporal variation, c) Concord A, d) Concord_R1 . Arrows indicate a line along the highway where Concord_B is high.

3.3 A wind farm example: CXAM 2013-02-03

The Val D'Irène weather radar (CXAM) in eastern Québec is on a ridge with a wind farm ("Lac Alfred") centred about 20km to the west on a large hill that is higher than the radar. This means that the turbines are extremely well illuminated by the weather radar. Figure 5 shows the Concord variables for 2013-02-03, which was a day that was almost without precipitation. As with the moving targets seen in the CWKR highway example, the Concord variables are mainly low but there are embedded areas with high Concord, especially in azimuth. The arrows point to one area where Concord_A is high, but Concord_R1 is low. This is a bit of a counter-example to most other wind farms examined. In this case, the wind farm is so close that individual wind turbines may be particularly well illuminated and side-echoes may dominate in adjacent bins.

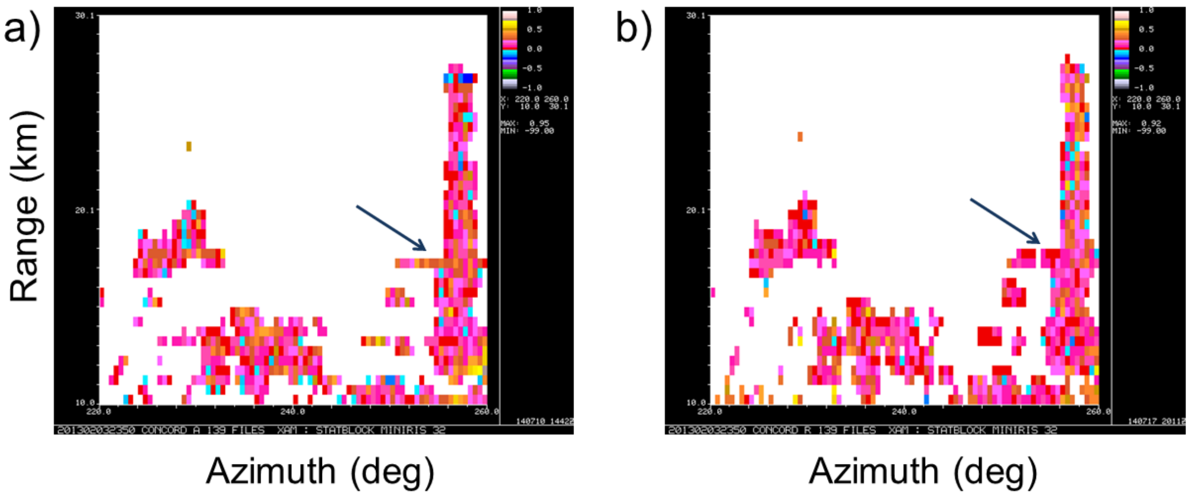

Figure 5: Concord variables for CXAM over wind farm 2013-02-30. a) Concord_A b) Concord_R1

3.4 Summary of observed behaviour of the Concord metric.

From the many cases and radars in the overall study a few patterns are observed in new metrics applied to the Doppler corrected reflectivities.

- Wide-spread precipitation has quite high values of Concord. Not enough convective days were examined to generalize about them.
- Wind farms and traffic mainly exhibit low values of Concord.
- Sea clutter was observed to have near zero Concord values.
- An examination of Concord in uncorrected (total) reflectivity showed that ground clutter areas showed low values of Concord.
- Summertime clear air echoes near the radar, probably due to insects, exhibited near zero values of Concord, with slightly positive values for Concord_A.

While Concord is predominantly low in wind farms, at least one wind farm showed high values of both Concord values embedded in the generally low values. This may be due to the effect of individual turbines that are especially well illuminated appearing as side echoes. Possibly for most of the wind farms that have been examined the wind turbines are sufficiently close together that there is azimuthal overlap of changes, but for more distant wind farms it is also possible that the side-echoes are too weak to be seen persistently. In the only case of a completely isolated wind turbine near Zurich Ontario, Concord had moderate values both for radial and azimuthal cases.

For the two highway sections in this study, when there is weak or no precipitation in the area there is often strong connection between the strongest central echoes and their neighbours, with these higher values being surrounded by weak Concord. This reverses in the presence of moderate precipitation, where one might expect the weaker side echoes to be submerged by precipitation echoes and hence changes in the central echoes would be unconnected to the weather signals on the adjacent radials.

3.5 A previously unnoticed source of moving clutter

The results from one radar in northern Alberta showed several large areas with low “Concord” values of Doppler corrected dBZ. Examination of satellite photographs of the area show a pattern that initially resembled huge wind farms, with a network of coarse roads connecting together pad areas. However this is an area with no known wind farms and there are none of the long shadows that one sees with wind turbines. The area is known to be an oil producing area, so it seems possible that the source of the echoes is “nodding” oil pumps.

4 Conclusions

A couple of new metrics were used to examine echoes from moving targets such as wind farms and traffic. Wind turbines and traffic show more temporal variation of Doppler corrected dBZ than weather targets. Looking at whether echoes in neighbouring bins are synchronized (by analogy to being temporally correlated), bins with turbines stand out in overall coverage of synchronization as having mainly low values of the “Concord” metric relative to weather signals. That is, neighbouring bins change together relatively tightly in weather, but that is not the usual case for wind farms. However there are cases where echoes on adjacent radials at the same range do seem to change together in wind farms. On highways there is a somewhat stronger azimuthal connection, suggesting that the variability is due to strong individual echoes (a single vehicle or cluster of vehicles?) that are also seen as side echoes. Looking at signals from adjacent range bins at times without precipitation present, there seems to be little synchronization in the wind farm data, suggesting that multi-trip echoes are not a large component of the observed signals close to turbines. However the radial tests are quite limited for determination of multi-trip echoes because they are restricted to cases where the secondary reflector is within the distance corresponding to one range bin.

The new metrics have shown a similarity of wind farms to visible highways, but the metrics have no strong signatures that make wind farms much more obvious than do more simply calculated metrics, such as the high degrees of persistence of turbine echoes relative to weather signals. Nonetheless, the Concord variable does augment the simpler metrics and does seem to highlight moving targets a bit more than the simple parameters in some situations. The absolute temporal variation does not seem to add much insight.

One unexpected thing to come from this exercise was the potential discovery of oil fields as a previous unrecognized source of moving clutter.

Acknowledgement

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